# ASSESSMENT OF ECOSYSTEM SERVICES AND BENEFITS OF ROOFTOP GARDENING FOR ECO-FRIENDLY CITY DEVELOPMENT USING GEOSPATIAL TECHNOLOGY

**A THESIS**

**BY**

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**DHAKA-1207**

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A Thesis
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## *CERTIFICATE*

*This is to certify that the thesis entitled "**ASSESSMENT OF ECOSYSTEM SERVICES AND BENEFITS OF ROOFTOP GARDENING FOR ECO-FRIENDLY CITY DEVELOPMENT USING GEOSPATIAL TECHNOLOGY**" submitted to the **Faculty of Agriculture,** Sher-e-Bangla Agricultural University (SAU), Dhaka in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (MS) IN AGROFORESTRY AND ENVIRONMENTAL SCIENCE**, embodies the results of a piece of bona fide research work carried out by **IFFAT JAHAN NUR, Registration no. 09-03357** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

*I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.*

**Dated: June, 2015**
**Place: Dhaka, Bangladesh**


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# ASSESSMENT OF ECOSYSTEM SERVICES AND BENEFITS OF ROOFTOP GARDENING FOR ECO-FRIENDLY CITY DEVELOPMENT USING GEOSPATIAL TECHNOLOGY


## ABSTRACT

Humanity is increasingly urban, but continues to depend on nature for its survival. Cities are dependent on the ecosystems beyond the city limits, but also benefit from internal urban ecosystems. The aim of this study is to identify the ecosystem services generated by ecosystems within the Rooftop Gardens and to examine the biotic and abiotic components that contribute to overall ecosystem services. The experimental survey was conducted from June, 2014 to March, 2015. A questionnaire survey was conducted by face to face interviewing of forty respondent garden owners among four different Thana (Mohammadpur, Adabor, Dhanmondi and Kalabagan) within Dhaka city. Data were collected both qualitatively and wherever possible quantitatively. Thermal performance of Roof gardening was measured using Thermo-hygrograph at the warmest week of the year. The experimental analysis of thermal performance resulted that average roof air temperature is reduced by 5.2°C with roof garden during sunshine hours while average room temperature is reduced by 1.7°C with roof garden compared to bare roof. 'Ecosystem services' found in the research were provisioning services (Fruits and Vegetable production), supporting services (plant species diversity conservation and economic support), regulating services (thermal and disease regulation) and cultural services (aesthetic value, recreation, education and learning). The overall ecosystem services provided by the roof gardens were mostly found medium. Among these the most prominent and remarkable services were plant species diversity conservation (diversity index 4.51), thermal regulation and mental satisfaction.

# LIST OF CONTENTS

## LIST OF TABLES

# LIST OF FIGURES

## LIST OF PLATE



## LIST OF APPENDICES

# ACRONYMS

| FULL WORD | ABBREVIATION |
|---|---|
| And others (at elli) | et al |
| Bangladesh Agricultural Research Institute | BARI |
| Bangladesh Bureau of Statistics | BBS |
| Bangladesh Forest Department | BFD |
| Degree Celcius | ˚C |
| Department of Agricultural Extension | DAE |
| Dhaka City Corporation | DCC |
| Dhaka North City Corporation | DNCC |
| Dhaka South City corporation | DSCC |
| Ecosystem Services | ES |
| ed est (means That is ) | i.e. |
| Exempli gratia (by way of example) | e.g. |
| Geographical Information System | GIS |
| Green House Effect | GHE |
| Global Positioning System | GPS |
| Kilogram | Kg |
| Millennium Ecosystem Assessment | MA |
| Millimeter | mm |
| Percentage | % |
| Rajdhani Unnayan Kartripakkha | RAJUK |
| Rooftop Gardens | RTGs |
| Relative Prevalence | RP |
| Shannon-Weiner Diversity Index | SWDI |
| Species Diversity Index | SDI |
| Standard Deviation | SD |
| Statistical Package for Social Science | SPSS |
| The Economics of Ecosystem Services and Biodiversity | TEEB |
| United Nations Development Program | UNDP |
| United Nations | UN |
| Urban Heat Island | UHI |

`CHAPTER I

# INTRODUCTION

## 1.1 General Background

Cities are continuously in transition of urbanization process due to accommodate increasing number of population, industrialization, economic and social changes. Dhaka, the capital of Bangladesh and one of the fastest growing cities in the world is not an exception of this trend. Bangladesh's urban population has been growing at a yearly average rate of 6 percent since independence, As a result, urban population has grown six-fold, compared with a 70 percent increase in rural population (World Bank, 2007). As per recent UN data, approximately 25 percent of Bangladesh's current population currently lives in urban areas. Of this urban population, more than half lives in the four largest cities: Dhaka, Chittagong, Khulna and Rajshahi, 58% of which live in Dhaka. With a population of almost 12 million, it is the 11th largest city in the world. At the same time, it is consistently ranked as one of the world's least livable city. In the process of urbanization, Dhaka, with an area of 140 sq mi has caused significant decline of green spaces, agricultural lands, wet lands and water bodies due to discriminated land use transformation. Over last few decades, this trend is leading to loss of natural resources and habitat fragmentation (Hafiz, 2004). Due to this rapid development, green areas and soft surfaces of cities, suburbs and communities are rapidly being grabbed by structures, roads, driveways, parking lots and other hard and impervious surfaces resulting from pressure of rapid and unplanned urbanization. However, due to destruction of green spaces, balance of thermal comfort and environmentalism is being disturbed through high temperature, high humidity, air pollution, heat waves, rising sea level, water log off, floods, noise pollution, heat island effect etc (Hafiz, 2004). So the necessity of recovering vanishing green spaces is becoming increasingly critical to maintain environmental quality. In this situation "Rooftop Gardens" and "Green Roofs" (roofs with a vegetated surface and substrate) can be a potential alternative remedy to reverse the problem through applying this green technology on contemporary houses in Dhaka city. Rooftop gardens (RTG) are man-made green spaces on the topmost levels of industrial, commercial, and residential structures. They may be designed to grow produce, provide play space, give shade and shelter, or simply be there as a living, green area. Plants are grown for a variety of utilitarian and non-utilitarian purposes (Sajjaduzzaman *et al.*, 2005). In environmental sector, green roofs and Rooftop Gardens proved its innovativeness to solve multiple environmental hazards by increasing aesthetic value, ensuring nutrition and recreation, reducing Urban Heat Island Effect, $CO_2$ and Green House Effect, air and noise pollution, run-off impacts, increasing thermal comfort among building occupants by increasing summer cooling and lengthening roof life two to three times, increasing urban biodiversity and many more ecosystem services.

## 1.2 Rationale of the study

Major environmental issues like GHE (green house effect), Global warming, climate change etc. resulted from human activities over the past 20 years are caused mainly due to land use change and deforestation and the effects of these issues are most prominent in urban areas. In the process of rapid urbanization of Dhaka city, it is found that about 20 percent vegetation coverage that was present in 1989 has gradually decreased to 15.5 percent and 7.3 percent in the year 2002 and 2010, respectively (BBS, 2011). Vegetation was found in the Dhaka metropolitan area is only 1.87 percent (BBS, 2015). In this critical situation, Rooftop gardening can be one of the best solutions against this situation.

Rooftop gardens can be effective stimulators of urban ecosystem. Rooftop gardens and Green roofs (roofs with a vegetated surface and substrate) provide a number of ecosystem services in urban areas, including improved storm-water management, better regulation of building temperatures, reduced urban heat-island effects, and increased urban wildlife habitat. This study reviews the evidence for these benefits and examines the biotic and abiotic components that contribute to overall ecosystem services. The aim of this study is to identify and analyze the major ecosystem services generated by ecosystems within the Roof garden area. The potential of rooftop gardens in providing urban ecosystem services was explored with the use of

Geographical Information System (GIS) to visualize the spatial relationships with a view to improving resilience and quality of life in cities.

## 1.3 Statement of the problems

In view of the importance of roof top gardening in providing ecosystem services the investigators of this survey were highly interested to find out the major ecosystem services and benefits of roof top gardening in Dhaka city entitled "Assessment of Ecosystem Services and Benefits of Rooftop Gardening for Eco-friendly City Development using Geo-spatial Technology''

This study attempted to find out the answer of the following research questions:

1. What are the respondents selected characteristics?
2. What is the purpose of rooftop gardening?
3. What are the suitable species for practicing rooftop gardening?
4. What is the level of potential of the roof top gardening in providing ecosystem services?

## 1.4 The Objectives of the Study was

**i.** To identify the species diversity grown in the rooftops of the study area.

**ii.** To assess the role of Rooftop garden in providing thermal comfort.

**iii.** To identify and analyze the major ecosystem services of Rooftop gardens.

## 1.5 Justification of the study

There are many studies that have been conducted on Ecosystem Services of various aspects of agriculture. However, within urban development research, little attention has been paid to the ecosystem services provided by rooftop farming and no research has been reported in home and abroad to determine the Ecosystem services of roof top gardening.

Rooftop gardening although being practiced in the cities in many forms for years in the past, there have been hardly any concerted effort on part of the government, community organization and as well the general citizens to integrate it to urban agriculture, which is beyond necessary to combat the present challenging environmental situation. Increasing knowledge in this regard is required to design sustainable rooftop gardens and give tools to urban planners in order to implement such green infrastructures. Proper understanding of the problems and prospects associated with the adoption of this green saving practice will contribute, to a great extent, to build a sustainable, energy saving, comfortable and healthy environment in the city. The proposed study is an effort in this direction. The aim of this study was to evaluate the benefits and ecosystem services of roof gardens in a large context using Geospatial Technology for better understanding so that the existence of this landscape can be beneficial to the environment and contribute towards sustainable urban development in Dhaka city.

## 1.6 Assumption of the study

An assumption is the supposition that an apparent fact or principal is true in the light of the available evidence (Good and Hatt, 1983). Following assumption were in the mind of the researcher during conducting the study:

1. The study respondents were competent enough to furnish proper responses to the questions contained in the interview schedule.
2. The researcher who acted as interviewer feels comfortable with study areas social and environmental conditions. Hence, the data collected by her from the respondents were free from bias.
3. Respondents view and opinions were the representative’s views and opinions of the whole population of the study area.
4. The responses furnished by the respondents were valid and reliable.
5. As there is no major typical variation of roof garden in our country, it was assumed that all the roof gardens are of same type (extensive).
6. The findings might have general application to other parts of the country where similar socio-economic and cultural condition are in view.

## 1.7 Limitations of the study

In order to conduct the research in a meaningful and manageable way, it becomes necessary to impose some limitations in certain aspects of the study. Considering the time, money, labor and other necessary resources to the researcher, the following limitations have been observed throughout the study:

1. The study was conducted only two metropolitan areas under Dhaka city.
2. Characteristics of the garden owners were many and varied but only ten characteristics were sleeted for investigation in this study.
3. The field measurements of Two thermal comfort parameters (temperature and Relative humidity) at the roof garden should be recorded simultaneously. However, this was not possible due to the limited number of equipments available. The readings were therefore recorded alternately each day for the same roof garden. In order to alleviate this problem, the frequency of data recording was increased (10 minutes interval) and that the average reading was used for analysis.
4. Another drawback from the study is that it was only based on recordings between 8 am to 7 pm daily due to limitations related to the operating hours of the building.
5. The most limited factor was accessibility to the households with roof garden without any reference.

# CHAPTER II

# REVIEW OF LITERATURE

The literature Review chapter consists of three sections. The first section illustrates the recent knowledge of the major focus of this research, the previous studies related to this topic is represented in the second section followed by a conceptual structure of the research in the third section. Literatures related to the ecosystem services of rooftop gardens which were collected through reviewing of journals, thesis, internet browsing, reports, newspapers, periodicals and other form of publications are presented in this chapter under the following headings-

## 2.1 Ecology of vs. Ecology in cities

Cities are interconnected globally through political, economic, and technical systems, and also through the Earth's biophysical life-support systems (Jansson 2013). Cities also have disproportionate environmental impacts at the local, regional, and global scales well beyond their borders (Grimm et al. 2000), yet they provide critical leadership in the global sustainability agenda (Folke et al. 2011 ). Although urbanized areas cover only a small portion of the surface of the planet, they account for a vast share of anthropogenic impacts on the biosphere. Still, the impacts of urbanization on biodiversity and ecosystems as well as the potential benefits from ecosystem restoration in urban areas remain poorly understood (see e.g., McDonald and Marcotullio 2011). Most of the ecosystem services consumed in cities are generated by ecosystems located outside of the cities themselves, often half a world away (Rees and Wackernagel 1996 ; Deutsch and Folke 2005). Thus, our analysis needs to go beyond what is sometimes referred to as "the ecology *in* cities" (Niemelä et al. 2011), which often focuses on single scales and on designing energy- efficient buildings, sustainable logistics, and providing inhabitants with functioning green urban environments, to put more focus on "the ecology *of* cities" characterized by interdisciplinary and multi scale studies with a social-ecological systems approach (Grimm et al. 2000 ; Pickett et al. 2001).

## 2.2 Urban Ecosystem

Definitions of urban areas and their boundaries vary between countries and regions. The urban ecosystems, defined here as those areas where the built infrastructure covers a large proportion of the land surface, or as those in which people live at high densities (Pickett et al. 2001). In the context of urban planning, urban ecosystems are often portrayed as embedding both the built infrastructure and the ecological infrastructure. The concept of ecological infrastructure captures the role that water and vegetation in or near the built environment play in delivering ecosystem services at different spatial scales (building, street, neighborhood, and region). It includes all 'green and blue spaces' that may be found in urban and peri-urban areas, including parks, cemeteries, gardens and yards, urban allotments, urban forests, single trees, green roofs, wetlands, streams, rivers, lakes, and ponds (EEA 2011)

## 2.3 Urban Heat Island Effect

An urban heat island, or UHI, is a metropolitan area that's a lot warmer than the rural and sub-urban areas surrounding it. Heat is created by energy from all the people, cars, buses, and trains in big cities. Urban heat islands are created in areas that have lots of activity and lots of people. Paved areas, streets and buildings overall reflect less solar radiation than natural surfaces such as grass and trees (Oke, 1987). The additional absorbed radiation on these hard and dry surfaces is transferred into energy and leads to an increase in surface temperature, which in turn increases the ambient temperature. Some energy may be used for evaporation if water is available on the surface. Anthropogenic processes such as waste heat from industries, air conditioners and the heating of buildings can add further warming to the city. This effect is called an urban heat island and it has become a major problem in many low- and mid-latitude metropolitan areas (Taha, 1997; Bretz *et al.*, 1998).

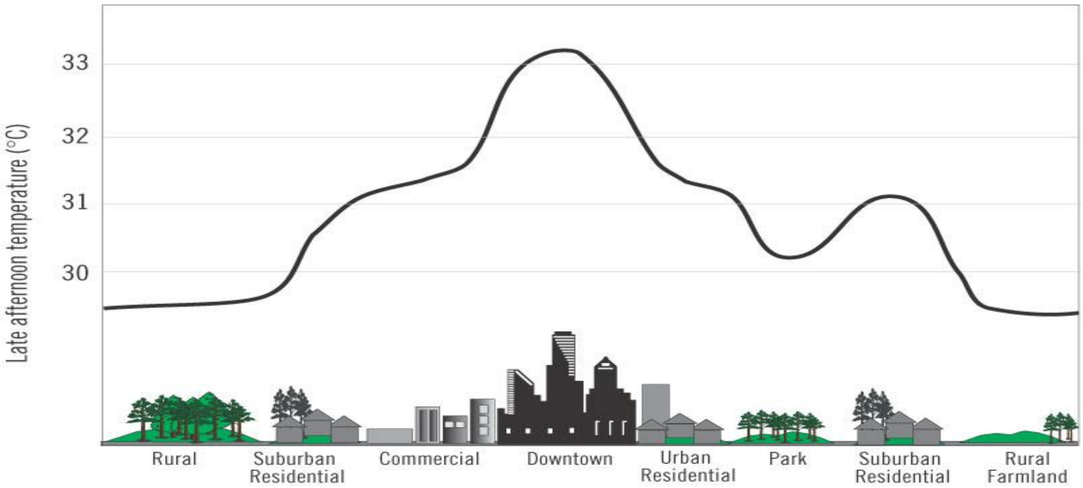



**Fig 2.1 Urban Heat Island (The x-axis represents a line through the city and the shows that the highest temperatures are found in the city centre. Source: Wong & Yu, 2005).**

Dhaka is a densely populated megacity. Rapid and unplanned urbanization made it an Urban Heat Island. This effect can be reduced by increasing albedo (the reflection of incoming radiation away from a surface) or by increasing vegetation cover with sufficient soil moisture for evapotranspiration

## 2.4 Classifying Urban Ecosystem Services

The term Ecosystem Services (ES) refers to "the benefits people obtain from ecosystems" (Millennium Ecosystem Assessment, 2005). Ecosystem services are defined as ''the benefits human populations derive, directly or indirectly, from ecosystem functions'' by Costanza et al. (1997). This section aims at classifying and describing ecosystem services provided in urban areas and how these may contribute to increase quality of life in cities.

Building on previous categorizations of ecosystem services (Daily 1997; de Groot et al. 2002 ), the Millennium Ecosystem Assessment (MA 2005 ) and The Economics of Ecosystem Services and Biodiversity (TEEB 2010 ) grouped ecosystem services in four major categories: provisioning, regulating, habitat, and cultural and amenity services (TEEB 2010 ) (Fig. 11.1 ).

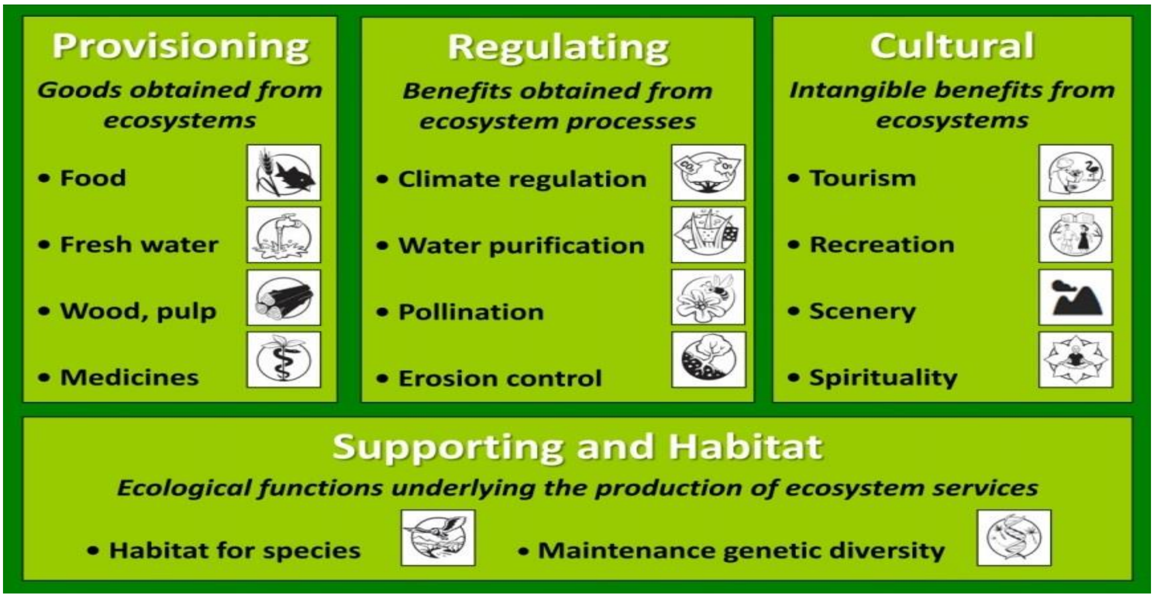



**Figure 2.2 Classification of ecosystem services by the TEEB initiative. (Sources: Millennium Ecosystem Assessment 2005; TEEB for Local and Regional Policy 2010; Icons by Jan Sasse, TEEB)**

Provisioning services include all the material products obtained from ecosystems, including genetic resources, food and fiber, and fresh water. Regulating services include all the benefits obtained from the regulation by ecosystem processes, including the regulation of climate, water and some human diseases. Cultural services are the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience as well as their role in supporting knowledge systems, social relations, and aesthetic values. Finally, supporting habitat services are those that are necessary for the production of all other ecosystem services. Examples include biomass production, nutrient cycling, water cycling, provisioning of habitat for species, and maintenance of genetic pools and evolutionary processes (Gómez-Baggethun E., & Barton, D.N., 2013)

## 2.5 Rooftop gardens and green roofs

Rooftop greening is a particular form of urban greening that uses the rooftops of buildings for growing plants. There are two main forms, green roofs and rooftop gardens, as described below. While both are of interest to urban areas, this research focuses on the latter. A roof garden is actually very different from a green roof, although the two terms are often and incorrectly used interchangeably. A **roof garden** is an area that is generally used for recreation, entertaining, and as an additional outdoor living space for the building's resident(s). It may include planters, plants, dining and lounging furniture, outdoor structures such as pergolas and sheds, and automated irrigation and lighting systems. A **green roof** or living roof is a roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane. It may also include additional layers such as a root barrier and drainage and irrigation systems. Green roof is less common in our country as it requires a high initial cost of production and maintenance compared to rooftop gardens.

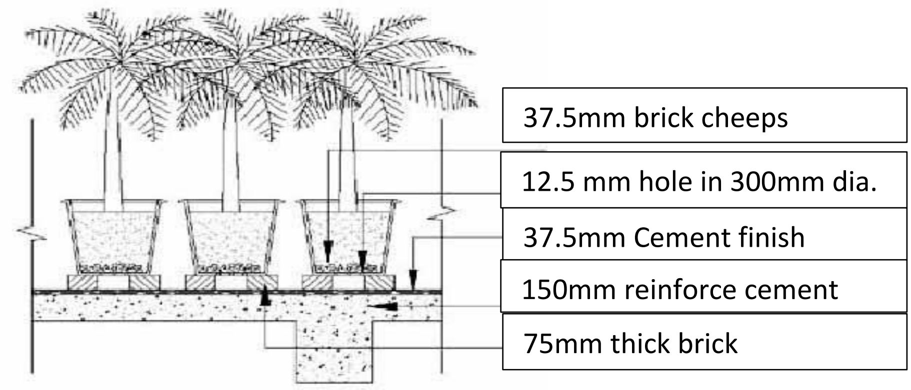



**Figure 2.3 A Typical Rooftop Garden with Pot Plants (R.Rasid, 2009)**

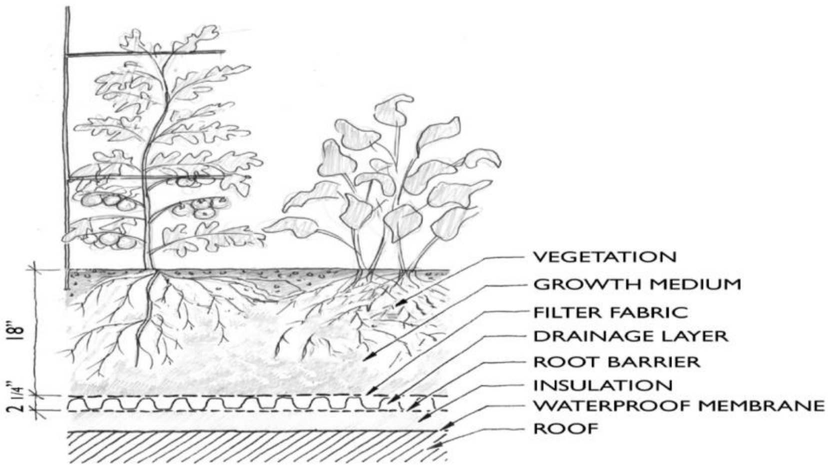



**Fig 2.4 A Green Roof with Permanent Structure**

**2.5.1 History of Roof Gardens:** Roof gardens, the precursors of contemporary green roofs, have ancient roots. The earliest documented roof gardens were the hanging gardens of Semiramis or Hanging garden of

Babylon, what is now in Syria, considered one of the seven wonders of the ancient world. The ziggurats of ancient Mesopotamia (4th millennium BC–600 BC) had plantings of trees and shrubs on aboveground terraces. An example in Roman times was the Villa of the Mysteries in Pompeii, which had an elevated terrace where plants were grown. A roof garden has also been discovered around an audience hall in Roman-Byzantine Caesarea.

**Plate-1 The Hanging Gardens of Babylon**

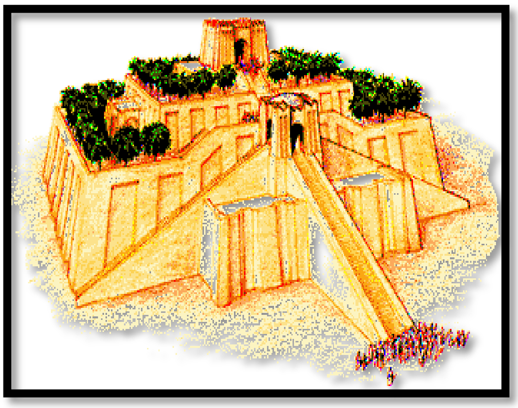


**Plate-2 The Ziggurats of Ancient Mesopotamia**

Traditionally sod (also called turf) roofs have been used in Scandinavia as an anti-fire protective measure by covering the roof with fire resistant soil. Grass develops over time to create a sod roof. Modern green roofs were first used in Switzerland in the 1960s as stormwater management and spread to Germany in the late 1970s. Today they are broadly used and are, in some parts, required by law as a means to preserve a certain degree of green space (www.gnla.ca). Green roofs are most widely used in Germany, where approximately 14% of all flat roofs are green (VanWoert *et al*., 2005). The first modern green roofs in Sweden arrived in the early 1990s and have only become commonly used in occasional projects or as part of new housing areas with an environmental profile, such as the West harbor (Västra hamnen) in Malmö in 2001. (Wikipedia, 2009).

## 2.5.2 Roof gardens as Ecosystem

Living ecosystems are recognized as a key to well-being. Green roofs and roof gardens represent an opportunity to increase the coverage of living ecosystems in cities. However, the extent on which roof gardens can be justified to compensate for the ground-level ecosystems and the extent on which roof gardens serve as a complementary solution needs to be studied, as their structure and many functions differ profoundly from ground-level ecosystems. both the green roofs and rooftop gardens represent a class of technology that can be considered bioengineering or bio mimicry: the ecosystem created by a roof garden's interacting components mimics several key properties of ground-level vegetation that are absent from a conventional roof. Green roofs and Rooftop gardens, like other constructed ecosystems (e.g., sewage treatment wetlands, bio swales for storm-water management, or living walls), mimic natural ecosystems to provide ecosystem services.

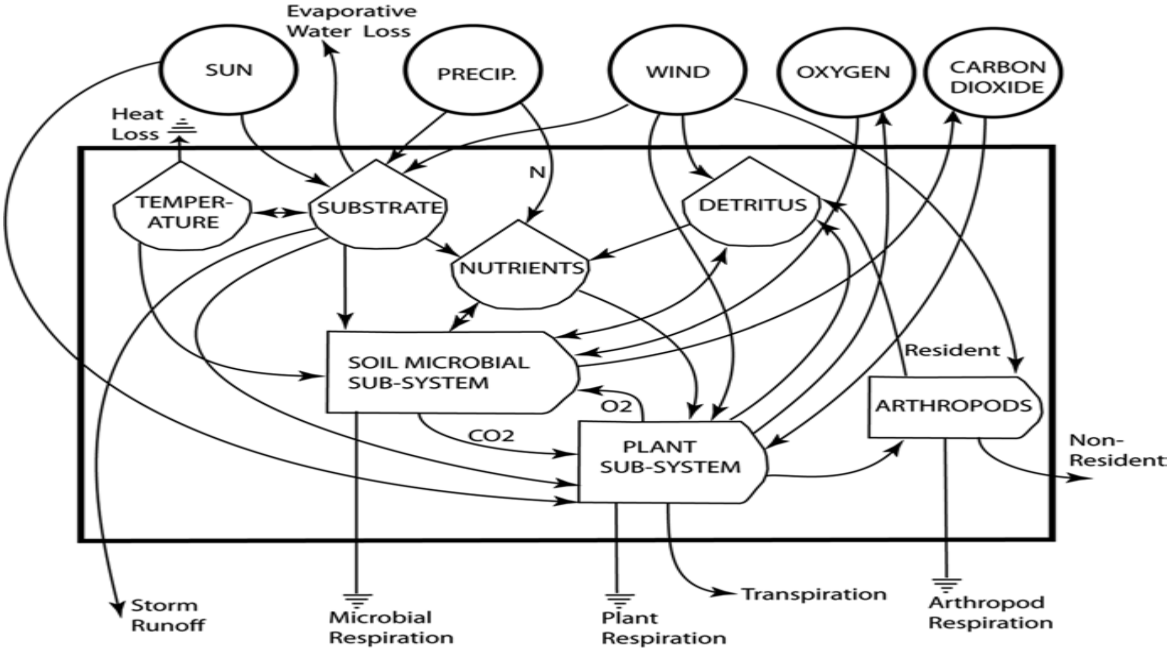



**Fig 2.5 A green roof ecosystem showing flows of energy, water, nutrients, and organisms**

Ecosystem diagrams use symbols to describe flows of energy, materials and information to, from and within an ecosystem.

## 2.5.3 Ecosystem services of Roof Gardens

Rooftop Gardens may reduce a city's Ecological Footprint (EF) by reduction of pollution and noise, the absorption of $CO_2$ emissions and the control of the Urban Heat Island (UHI) effect by shading. (Wackernagel and Rees 1996). Thus, RTGs can reduce the expense of heating and cooling and at the same time improve urban air quality (Peck et al. 1999). Furthermore, RTGs, while being aesthetically appealing, can contribute to biodiversity in the urban environment, achieve more sustainable conditions, including those necessary for the production of food and improve the overall quality of urban life (Bennett 2003; Maas *et al*., 2006., Khandaker 2004). The possible Ecosystem Services provided by RTGs based on previous research are listed below:

**Table 2.1 Possible Ecosystem Services of RTGs**

| Provisioning Services | Regulating Services | Cultural Services | Supporting Services |
|---|---|---|---|
| • **Food and fiber Production**<br>• **Raw material production** | • **Reducing storm water run-off**<br>• **Reducing Urban Heat Island Effect**<br>• **Air purification**<br>• **Noise reduction**<br>• **Providing thermal comfort**<br>• **Disease regulation**<br>• **Pollination** | • **Recreation**<br>• **Aesthetics**<br>• **Education & learning**<br>• **Social and Psychological improvement** | • **Lengthening roof life**<br>• **Reducing building energy use**<br>• **Local employment**<br>• **Carbon sequestration**<br>• **Nutrient cycling**<br>• **Biodiversity and Habitat preservation** |

## 2.5.4 Roof Gardening overview in Bangladesh

Although rooftop gardening is a new practice in Bangladesh, This concept has spreaded during 1990s with the pioneer works of Urban Agriculture Network supported by the UNDP

• The direct or indirect stakeholder departments which are responsible of Urban Greening and Roof Top Gardening are- City Corporations (Dhaka North, Dhaka South, Gazipur, Narayangonj) and the Rajdhani Unnayan artripakkha (RAJUK)

• With DCC and RAJUK, a number of state bodies, autonomous bodies, private organizations, NGOs, different societies are involved with greening activities in and around Dhaka city.

• Of them, the key state and autonomous authorities are Department of Environment (DOE), Local Government and Engineering Department (LGED), Bangladesh Forest Department (BFD), Dhaka Urban Transport

Project (DUTP), and Dhaka Transport Coordination Board (DTCB), Department of Archeology, etc.

• Apart from these, some NGOs like ASHA, PROSIKA, different financial organization, donor agencies such as ADB, World Bank are also taking part in greening activities in Dhaka city

• Some social organizations like Society of Arboriculture, Bangladesh National Nursery Consortium (NNC) are 'GREEN SAVERS' also contributing their efforts for promoting greening activities.

Recently, The mayors of DNCC and DSCC have been declared that, 10% building tax reduction will be granted for the resident buildings with RTGs to inspire and increase the number of RTGs in Dhaka city. Moreover Mayor Anisul Haque has been launched a project named "Green Dhaka Project" aimed for increasing greeneries in Dhaka city by utilizing free space such as over bridges, bare rooftops and so on.

## 2.6 Importance of GIS

Geographic Information Systems (GIS) have been developed to store, organize, edit, visualize, and analyze spatial and even non-spatial data. GIS is a powerful tool and is ultimately used to help understand spatial relationships and gain new information from spatial data. Displaying data in the form of maps can be useful as this type of visualization can reveal patterns and relationships that might not be apparent by traditional methods of data analysis (Piana and Carlisle, 2014). Visualizing spatial data can also be useful for communication and collaboration in scientific research (Jensen and Jensen, 2013).

Geographic Information Systems (GIS) has been a technical tool for urban planning over the past couple of decades. Geographic Information Systems not only provided the ability to visualize important spatial relationships but it also contributed significantly to the data analysis and ultimately to an increased understanding of the dynamic nature of the green roof system. GIS application can esure-

- Visualization of spatial data, particularly the distribution of agricultural open spaces in a city.

- Simple analytical functions such as calculation of the sizes of agricultural areas. Potential for updating digital maps in the future, and extension to a greater range of topics and layers.
- Possibility to print hardcopies of maps showing any desired selection of topics and areas in any scale, for discussions with stakeholders.

- Linkage of vector data in maps with attribute data such as type of crops grown or number of farmers.

- High flexibility: According to the respective local contexts and available data sources, a wide variety of spatial data can be integrated and combined for optimal outcome: Satellite imagery, aerial photography (digital or analogue), topographic or thematic maps of all scales, cadastral maps, GPS measurements etc.

It has become present that GIS is used as a valuable tool when identifying, analyzing, and portraying urban agriculture for the above reasons. Numerous GIS studies have been completed with a particular type of urban agriculture known as community gardens although no studies have been conducted using GIS in our country in this regard.

## 2.7 Related works

A range of studies have addressed the role played by rooftop gardens and related issues in improving human well-being through the provision of ecosystem services. Some of them are given under the following topics:

### 2.7.1 National:

Kamrujjaman (2015), Bangladesh Agricultural Research Institute, wrote a Book name “Green Banking” regarding the Rooftop Gardening. The book contains 7 chapters describing the thermal benefits of roof gardens and the overall techniques and farming procedures of vegetables, fruits, flowers/ornamental plants and multipurpose use of Roof garden.

Mostafa (2013) found in his study of present status of rooftop gardening in Sylhet City Corporation of Bangladesh that each gardener was interested in rising of rooftop garden because they think that home gardens could help them to income and save money 29.8% respondents were involved in gardening for economic purpose, 54.9% respondents for environmental amelioration, 95.3% was in favor of mental satisfaction, aesthetic value (82.5%) and leisure time activity (87.8%).

Mannan (2013) in his research on Plant Biodiversity in the Hoar Homesteads of Bangladesh, reported that 84 useful plant species were identified during study. Among them 33.33% fruits (28 spp), 28.57% (24 spp) timber, 22.62% (19 spp) summer vegetables and 15.48% (13 spp) were winter vegetable. Coconut, Mahagani, brinjal and bottle gourd were found most prevalent in their respective category. Inter species diversity was highest (0.799) in the fruit species and lowest in summer vegetable.

R. Rashid *et.al.,* (2010), experimented the thermal performance of rooftop garden in a six storied building established in 2003. She found that the temperature of this building is 3°C lower than other surrounding buildings and this Green application can reduce the indoor air temperature 6.8°C from outdoor during the hottest summer Period.

Kamron (2006) in her research in Mirpur area, reported that the selected characteristics of the respondents, family size, roof gardening experience, use of information sources, attitude towards roof gardening and knowledge of roof gardening had positive significance of relationship with their adoption of roof gardening.

Islam (2001) in his study identified the potential for and barriers to urban agriculture with reference to roof top gardening and to explored the strategies to promote food security in Dhaka.

F.K. Shuvo (2000) proposed for a conceptual framework based on an obligatory on-site adaptation to ‘long-term greening’ and discussed how this framework should enable a sustainable mainstreaming of the violated constructions ensuring fiscal benefits for RAJUK, building owner and the 'green industry' alike.

### 2.7.2 International:

**1. Review of Ecosystem Services analysis of RTGs**

J. Lundholm (2007) demonstrated that easily measured plant traits (height, individual leaf area, specific leaf area, and leaf dry matter content) can be used to select species to optimize green roof performance across multiple key services.

M.P. Zari (2012) in his research primarily investigated one area of human knowledge (ecology and biology) for its transferable applicability to another (the urban built environment). Finally, the research determines how such theory could be practically applied to urban and architectural design and tested this through conducting a case study of an existing urban environment.

Carter C. & Butler C. (2008) evaluated how stormwater retention, building energy and temperature, and rooftop habitat are influenced by the use of green roofs using test plots in Georgia and Massachusetts. Green roofs were shown to recreate part of the predevelopment hydrology through increasing interception, stormwater storage, evaporation, and transpiration on the rooftop and worked extremely well for small storm events. Temperature reductions were found on the green rooftop as compared to an asphalt surface.

Bennett (2003); Miller (2005); Maas et al. (2006) reported that RTGs, while being aesthetically appealing, can contribute to biodiversity in the urban environment, achieve more sustainable conditions, including those necessary for the production of food and improve the overall quality of urban life

**a) Provisioning service review**

N. Reese (2014) found that The small Business Mix Zone in West Oakland, California has over one million square feet of untapped rooftop space available for urban rooftop farming. Revenue of up to $4 million can be earned from the sale of produce grown on this space which will assist the City of Oakland meet its 30% locally sourced food goal and will provide the food desert of West Oakland with fresh fruits and vegetables currently unavailable to this area.

Andersson *et.al*., (2007) ; Barthel et al. (2010) reported that Urban food production takes place in peri-urban farm fields, on rooftops, in backyards, and in community gardens.

Grewal and Grewal (2012) in Cleveland (Ohio, USA), stated through a study comparing different systems for producing food in urban areas showed that hydroponic RTGs can produce an average of 19.5 kg m−2 year−1 against 1.3 kg m−2 year−1 found in conventional urban gardens .

Moustier (2007) provides an extensive summary of the importance of urban agriculture in 14 African and Asian cities. Among the results they found that 90 % of all vegetables consumed in Dar es Salaam (Jacobi et al. 2000 ) and 60 % of vegetables consumed in Dakar (Mbaye and Moustier 2000 ) originate from urban agriculture

Peck (2003) found that from 650,000 $m^2$ of "greened" rooftops growing vegetable crops, a yield of 4.7 million kg of produce per year could be generated In Toronto (Canada).

Yi-Zhang and Zhangen (2000) found that, a municipal programme promoting urban agriculture enabled cereal supplies of about 2,000,000 tyear−1 in Shanghai

Altieri *et.al*., ( 1999 ) estimated that in 1996 food production in urban gardens of Havana included 8,500 t of agricultural products, 7.5 million eggs and 3,650 t of meat.

Ratta and Nasr (1996) found that urban agriculture provides the city with about 100,000 t year−1 of fresh food in Dares Salaam (Tanzania)

**b) Regulating Service Review**

**I. Thermal regulation**

D. Morau *et.al*., (2012) in his theoretical survey of the green roof thermal behavior, showed that in diurnal period, the green roof concrete support top face temperature is lower than that of the concrete watertight roof top face, whereas in night-period the opposite occurs. These results highlight the energy benefit of the green roof.

E.J. Saeid (2011) in his research on effect of green roof in thermal performance of the building, showed that green roof reduce the internal solar gain and heat transfer, the U-value of green roof is lower that U-value of the conventional roof which means is better and the same time by having the green roof can maximize the insulation on the roof, evaporation from the green roof can have reduced the cooling and minimized the internal solar radiation and finally by choosing the best thickness of the soil, vegetation and plants can achieve the best result for hot and humid climate such as Dubai.

N. Taib *et. al*., (2010) in his field measurements of all four thermal comfort parameters at the three landscape gardens sky court garden, Balcony garden, Rooftop garden showed significant difference between the mean air temperature ($F = 899.47$, $p<.01$). The average air temperature is lowest at the Sky Court Garden (29.03 °C), followed by the Balcony Garden (30.42°C) and the Rooftop Garden (33.43°C).

R. Rashid *et. al*., (2009) showed that green roof reduces the ceiling surface temperature by a maximum of 3.0°C and on average 1.7°C, in comparison to bare roof. The average indoor air temperature is reduced by 2.4°C with roof during sunshine hours. The amount of solar heat energy entering into the indoors through green roof in comparison with the bare roof is decreased by more than 3 times. Daily average indoor air temperature is 33.0°C with bare roof. This is reduced by 3.0°C with green roof, thereby reducing the average indoor air temperature to 30.0°C.

Saiz *et. al*., (2006) in his study showed that a green roof reduced the cooling load on an eight-story residential building by 6% during the summer. In a peak demand simulation, the cooling load was reduced by 10% for the entire building and by 25%, 9%, 2%, and 1% for the four floors immediately below the green roof.

Gaffin and Colleagues (2005, 2006) showed that in the summer, green roofs reduce heat flux through the roof by promoting evapotranspiration, physically shading the roof, and increasing the insulation and thermal mass. They applied energy-balance models to determine how effectively green roofs evaporate and transpire water vapor compared with other vegetated surfaces.

J. Levallius (2005) found green roof would increase from 42% to 55%. Runoff reduction for July and August were 22% and 58%, respectively. Daytime roof surface temperatures decreased 9° C on average. The increase in latent heat, also called evaporative cooling, and reduced surface temperatures brought a decrease in sensible heat and thus a potential mitigation of the urban heat island effect.

In Ottawa, Canada, Liu (2002) found that an unvegetated reference roof reached temperatures higher than 70 degrees Celsius (°C) in summer, while the surface temperature of the green roof only reached 30°C.The membrane on the reference roof reached 30°C on 342 of the 660 days of the study, whereas the membrane underneath the green roof only reached that temperature on 18 days.

Wong and colleagues (2003) found that the heat transfer through a green roof in Singapore over a typical day was less than 10% of that of a reference roof.

Theodosiou (2009) reported that during warm weather, green roofs reduce the amount of heat transferred through the roof, thereby lowering the energy demands of the building's cooling system.

Bass *et. al.,* (2002) used a regional simulation model using 50% green-roof coverage distributed evenly throughout Toronto showed temperature reductions as great as 2°C in some areas.

Onmura *et. al.,* (2001) found reductions in heat flux on the order of 50% per year, and work in Ottawa (Liu 2004) found a 95% reduction in annual heat gain.

### II. Disease regulation

The gardening-related benefits in reducing psychological disorders e.g. against dementia (Simons et al. 2006), enabling stress recovery (Kingsley et al. 2009), or fostering cardiac rehabilitation (Wichrowski et al. 2005) are well known.

## c) Supporting service review

### I. Carbon Storage

Davies et al. (2011) estimated that domestic gardens would enable storage of about 0.76 kg C m−2. Based on these figures, it was possible to estimate that turning Bologna's flat roof surfaces into RTGs would enable the capture of 624.42 t CO2

Zhao et al. (2007) reported that One service that is an increasingly important feature for mitigation of climate change is the biological carbon storage associated with urban Green Infrastructures.

### II. Biodiversity conservation

Brenneisen (2006), Kadas (2006) reported that species richness in spider and beetle populations on green roofs is positively correlated with plant species richness and topographic variability.

Kadas (2006) reported that species richness in spider and beetle populations on green roofs is positively corrected with plant species richness and topographic variability.

Baumann (2006) reported that green roofs have also been used by nesting birds and native avian communities.

Brenneisen and Köhler (2006) reported that rare plants and lichens often establish spontaneously on older roofs as well.

Coffman and Davis (2005) reports that Green roofs are commonly inhabited by various insects, including beetles, ants, bugs, flies, bees, spiders, and leafhoppers

S. Sunwar (2003) found species diversity in Bharsa 4.03, Baikunthapur 4.25, Terai overall 4.25 and Gulmi 4.418 in Home gardens in western Nepal: Opportunities and challenges for on farm management of agrobiodiversity.

**III. Lengthening rooflife**

Porsche and Köhler (2003) found that temperature stabilization of waterproofing membranes by green-roof coverage may extend their useful life by more than 20 years (USEPA 2000); some green roofs in Berlin have lasted 90 years without needing major repairs.

**IV. Economic support**

Nurmi *et. al.*, (2013) in his research on the cost-benefit analysis of green roofs hint that with a higher rate of implementation and realization of public benefits, the green roofs would be a good investment.

**d) Cultural service review**

Dunnett and Kingsbury (2004) Living roofs also reduce sound pollution by absorbing sound waves outside buildings and preventing inward transmission

Matsuo and Relf (1995); Brown et al. (2004) found that working with plants and in the outdoors benefits are the mental health, mental outlook, and personal wellness of individuals in having roof top gardening.

Hynes (1996); Patel (1996); Hanna (1999); Von Hassell (2002); Saldivar-Tanaka (2002) found that sharing food with friends, families, neighbors, and/or needy members of their community in need are one of the important reasons that they grow produce. This also supported by various researchers in the world.

Towle (1996) was found in favor of mental satisfaction (10%), aesthetic value (12.5%) and leisure time activity (5%) in the role of ecological restoration in biodiversity conservation: basic issues and guidelines

Hartig et al. (1991) stated that even when green roofs are only accessible as visual relief, the benefits may include relaxation and restoration, which can improve human health.

Noss (1987) found that RTGs may play an important role in offering aesthetic enjoyment and increased property values.

**e) Review of GIS-based research**

Incorporation of spatial and GIS-based analysis in scientific research is becoming commonplace and it is one of the most popular growing fields in the study of ecology (Jensen and Jensen, 2013). A number of recent studies are showing the usefulness and sheer power of spatial and GIS-based analysis.

M. Buckland (2015) conducted a GIS-based Analysis to Understand the Effects of Environmental Variability on the Growth and Success of Native Plants on Green Roofs where 69 *Sibbaldiopsis tridentata* plants and 72 *Solidago bicolor* plants were monitored across an extensive green roof .Both species achieved faster growth, but had a greater risk of mortality. There were also species differences in responses to environmental conditions.

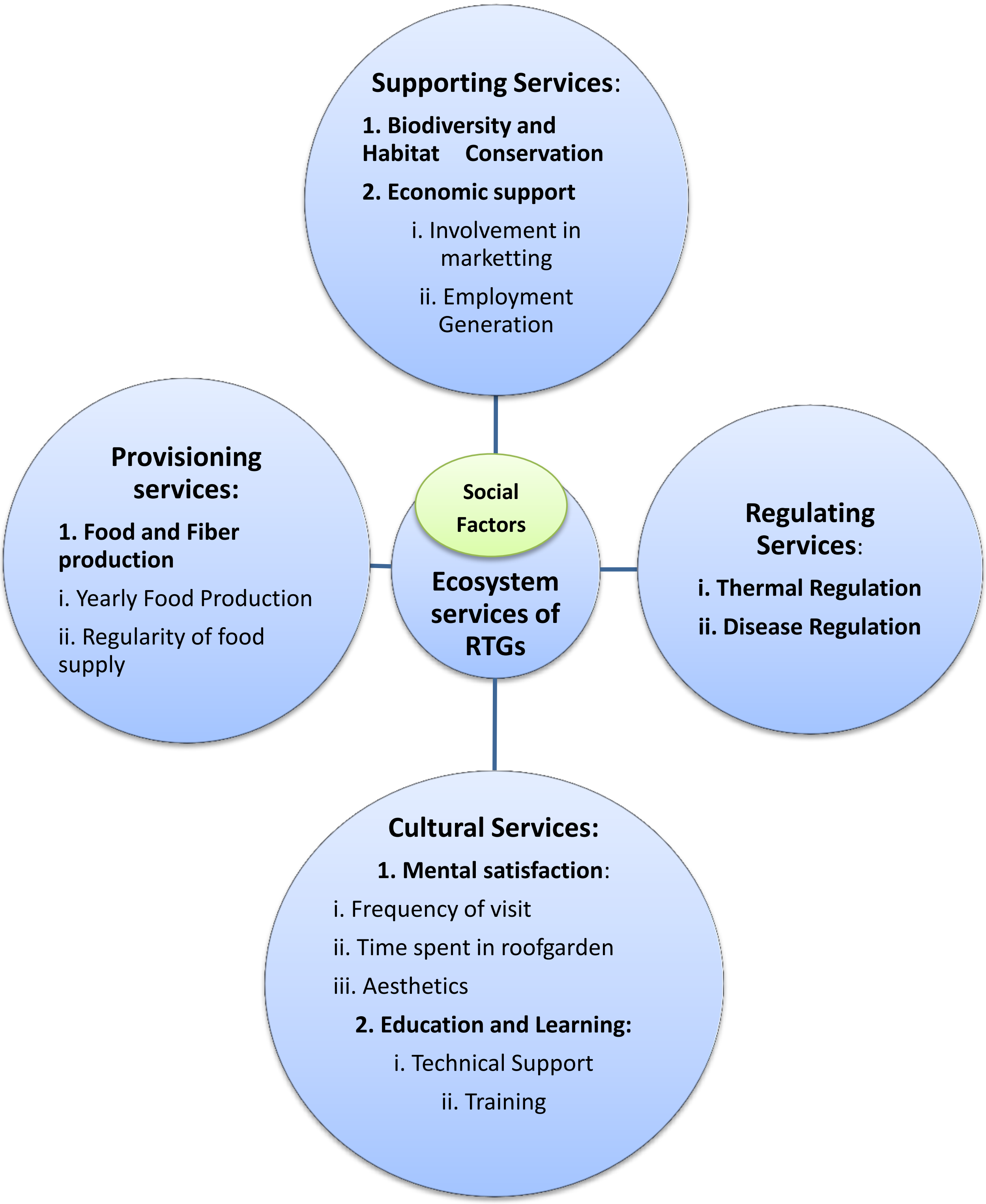
Deksissa, T., (2014) conducted a research using an ArcGIS based modeling tool where the results showed that constructing green roofs on the rooftops of 2% of the impervious areas or building can reduce up to 166% and 32% storm water runoff in Rock Creek and Anacostia River sub-watersheds in Washington DC, respectively. This can save up to $21.4 million in building storage tanks to store total runoff volume.

F. Orsini *et.al.*,(2014) in his GIS based research on production capacity of rooftop gardens, found that RTGs could provide more than 12,000 t year−1 vegetables to Bologna, satisfying 77 % of the inhabitants' requirements.

Berger (2013) conducted a GIS Suitability Analysis of The Potential for Rooftop Agriculture in New York City The model focuses on the North Brooklyn Industrial Business Zone on the south side of Newtown Creek and has identified over 50 acres of suitable roof space for agricultural projects.

M. Lamsal (2012) in his research on A GIS-Integrated Cost-benefit Analysis where Geographic Information System (GIS) is used to spatially identify the privately and socially optimal roof type for each building. The research also explores the effect of a positive externality (ambient air cooling from green roof adoption) on the optimal roof type.

## 2.8 The Structure of the Research:



# CHAPTER III
# METHODOLOGY

This experimental survey was conducted to find out the potential of rooftop gardens in providing major ecosystem services. In this chapter the materials used, the methodologies followed and the related works done during experimental period are presented. The methods and procedures followed in conducting this study have been described in the following sections.

## 3.1 Description of the Study Area

### 3.1.1 Dhaka city

Dhaka is the capital and largest city of Bangladesh. With its colorful history and rich cultural traditions, Dhaka is known over the world as the city of mosques and muslin. Its fame attracted travelers from far and near throughout the ages. Dhaka has been expanding spatially as its population has increased. Over the past decade, the core municipality, Dhaka, increased its population 45 percent. Dhaka may be the worst situated urban area in the world. Dhaka is located in wetlands and virtually surrounded by rivers.

### 3.1.2 Climate of Dhaka city

23°42′0″N 90°22′30″E Dhaka experiences a hot, wet and humid tropical climate. Dhaka has a tropical wet and dry climate. The city has a distinct monsoonal season, with an annual average temperature of 25 °C (77 °F) and monthly means varying between 18 °C (64 °F) in January and 29 °C (84 °F) in August. Nearly 80 percent of the annual average rainfall of 1,854 millimeters occurs during the monsoon season which lasts from May until the end of September. Increasing air and water pollution emanating from traffic congestion and industrial waste are serious problems affecting public health and the quality of life in the city. Water bodies and wetlands around Dhaka are facing destruction as these are being filled up to construct multi-storied buildings and other real estate developments. Coupled with pollution, such erosion of natural habitats threatens to destroy much of the regional biodiversity.

### 3.1.3 Demography of roof top gardening in Dhaka city

Rooftop gardening becomes growingly popular in the Dhaka city as the land for gardening shrinks every day with construction of more and more new buildings. City's gardeners and agriculturists, however, cite yet another reason why more house owners getting keen on having a patch of greenery on their roofs, which is, they want vegetables and fruits fresh and free from poisonous chemicals. The government Department of Agricultural Extension said around 6,000 rooftop gardens are in the Dhaka city. The DAE has divided the Dhaka city in three areas supervised by its three offices called Metropolitan Tejgaon, Metropolitan Gulshan and Metropolitan Mohammadpur. It has found 3082 rooftop gardens in the neighbourhoods overseen by its Gulshan office, 2000 have been spotted in areas under its Tejgaon office and 600 in the Mohammadpur neighbourhoods. These gardens have been providing a number of ecosystem services to the city dwellers and thus helping in uniting the urban ecosystem with the social and economic system.

### 3.1.4 Population and Sampling Procedure

The survey was conducted within the area of Dhaka city. Two metropolitan areas namely Dhanmondi and Mohammadpur were selected as study area through consultation with relevant organizations e.g., DAE, Botanical Garden, Horticulture, Rajuk. These two areas were preferred due to having successful, effective and higher number of roof gardens. Mohammadpur metropolitan includes adabor thana and Mohammadpur thana and Dhanmondi metropolitan includes Dhanmondi thana and Kalabagan thana. Survey was conducted in several sub areas of each ward of the corresponding thana where Individual households represented the sampling units. The population are randomly selected as the sample of the study by using random number table (Table 3.1). Thus, sample size of the study was 40 rooftop buildings.

**Table 3.1 Distribution of population and sample size in two selected metropolitan areas (Dhanmondi and Mohammadpur)**

**3.1.1: Dhaka North City Corporation**

| | **Thana** | **Ward** | **Sub areas under Thana** | **No. of roof gardeners finally selected for data collection** |
|---|---|---|---|---|
| **Mohammadpur metropolitan area** | **Mohammadpur** | Ward 42 | Chinumia Road Area | 1 |
| | | | Tajmahal Road Area | 1 |
| | | | Madrasa Road | 1 |
| | | Ward 44 | Zakir Hossain Road Area | 1 |
| | | | Salimullah Road Area | 1 |
| | | Ward 45 | Lalmatia Housing Society | 1 |
| | | | Iqbal Road Area | 1 |
| | | Ward 46 (Part) | Mohammadia Housing Society | 2 |
| | | | Mohammadia Housing Ltd. | 1 |
| | | | Nobodoy Housing | 2 |
| | | | Chanmia Housing | 1 |
| | | Ward 47 (Part) | Jafrabad | 1 |
| | | | West Dhanmondi | 1 |
| | | | Shangkar | 1 |
| | **Adabor** | Ward 43 | Uttor Adabor | 1 |
| | | | Baitul Aman Society | 1 |
| | | | Monsurabad Housing | 2 |
| | | Ward 46 (part) | Pisciculture Housing | 1 |
| | | | Shekhertek | 2 |
| **Total** | | | | **23** |

**3.1.2: Dhaka South City Corporation**

| | Thana | Ward | Sub areas under Thana | No. of roof gardeners finally selected for data collection |
|---|---|---|---|---|
| **Dhanmondi metropolitan area** | **Dhanmondi** | Ward 49 | Dhanmondi Lake area | 3 |
| | | | Dhanmondi | 3 |
| | **Kalabagan** | Ward 50 | Kalabagan Area | 1 |
| | | | Panthapath Area | 1 |
| | | | North Road Area | 1 |
| | | | Central Road Area | 1 |
| | | | Hatir pool | 1 |
| | | Ward51 (Part) | Kalabagan Lake circus Area | 2 |
| | | | Green Road Area | 1 |
| | | | Sobhanbagh | 2 |
| | | | Sukrabad | 1 |
| | **Total** | | | **17** |
| **Grand Total (23+17)= 40** | | | | |

## 3.1.5 Collection of necessary GIS information:

For collecting spatial information about the study area, base maps of each wards under Dhanmondi metropolitan were collected from Dhaka South City Corporation office and base maps of each wards under Mohammadpur metropolitan were collected from Dhaka North City Corporation Office. Geo-referencing was done of those maps using ArcGIS software to generate the final map of the study area. The results obtained from analysis have been shown spatially through maps. The collected base maps of the corresponding wards have been given in Appendix IV. The GPS reading of each roof garden building location was taken during the survey. The collected coordinates of each location has been given in Appendix III.

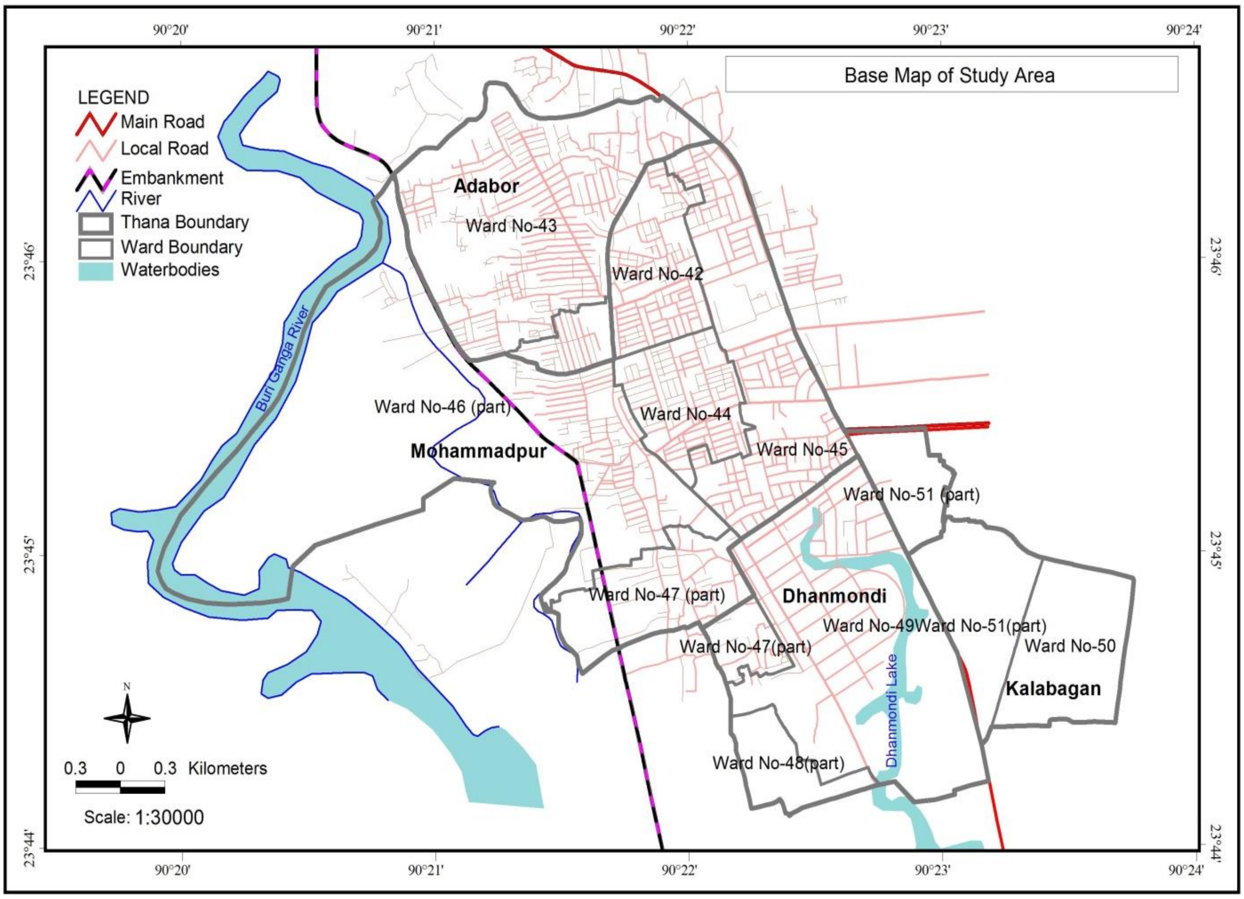



**Figure 3.1: Base map of the study area**

## 3.2 **Developing questionnaire** :

The questionnaire was developed according to the possible major ecosystem services provided by rooftop gardens in the city included provisioning, supporting, regulating, and aesthetic/cultural services (Table 2). These ecosystem services were selected based on the field observations of all authors in 2015 and our previous knowledge. Besides ecosystem services that were obviously important in local communities, e.g., food and fiber, ecosystem services that in our perception were used less intensively by local communities,. Responses to open questions were collected on a variety of demographic and socioeconomic indicators: roof garden species, choice of species, consumption access of roof garden products, expenditure, production and so forth. On each topic, the garden owners were free to express their views. Survey instruments were collected on two parts, species information on one parts and the demographic information on the other parts. Enumerators were oriented in participatory way. Finalization of the questionnaire was made after pre-testing in adjacent roof gardeners of the research site. Direct observation of roof garden was also carried out simultaneously. For quality control, the surveyed questionnaires were passed through edition, revision in different tiers first by enumerator herself, then peer review and editing among enumerators and final editing by the researcher on the same date.

## 3.3 Data Collection

### 3.3.1 Primary data collection

Reconnaissance survey was carried out before conducting the detailed data collection. After getting the general information about the study area, primary data were collected by using following methods:

#### 3.3.1.1 Direct observation of roof top garden observation with garden owners

Forty roof top gardens were visited with the help of Sub Assistant Agricultural Officer of metropolitan area and garden owners for obtaining the accurate information about the garden plants and their services. The geographical location of each Building was recorded accordingly using GPS. Total tree species and their numbers were counted species-wise with the help of garden owners in their garden using checklist. The main emphasis was given on the counting and identification of plant species (biodiversity), provisioning services (food and fiber production) and cultural services (aesthetics and recreation).

#### 3.3.1.2 Questionnaire Survey with schedule:

The feasibility of RTG was explored through a questionnaire survey of selected public and commercial buildings. The detail of the questionnaire is given in Appendix-1. After modifying questionnaire, randomly chosen 40 garden owners were selected as a sample, which represent male female respondents. Head of family and elderly individuals were interviewed. Data were collected by face to face interviewing of the respondents' during period from November 22, 2014 to March 23, 2016.

**Plate 3 Direct Observation of various roof top gardens by researcher**

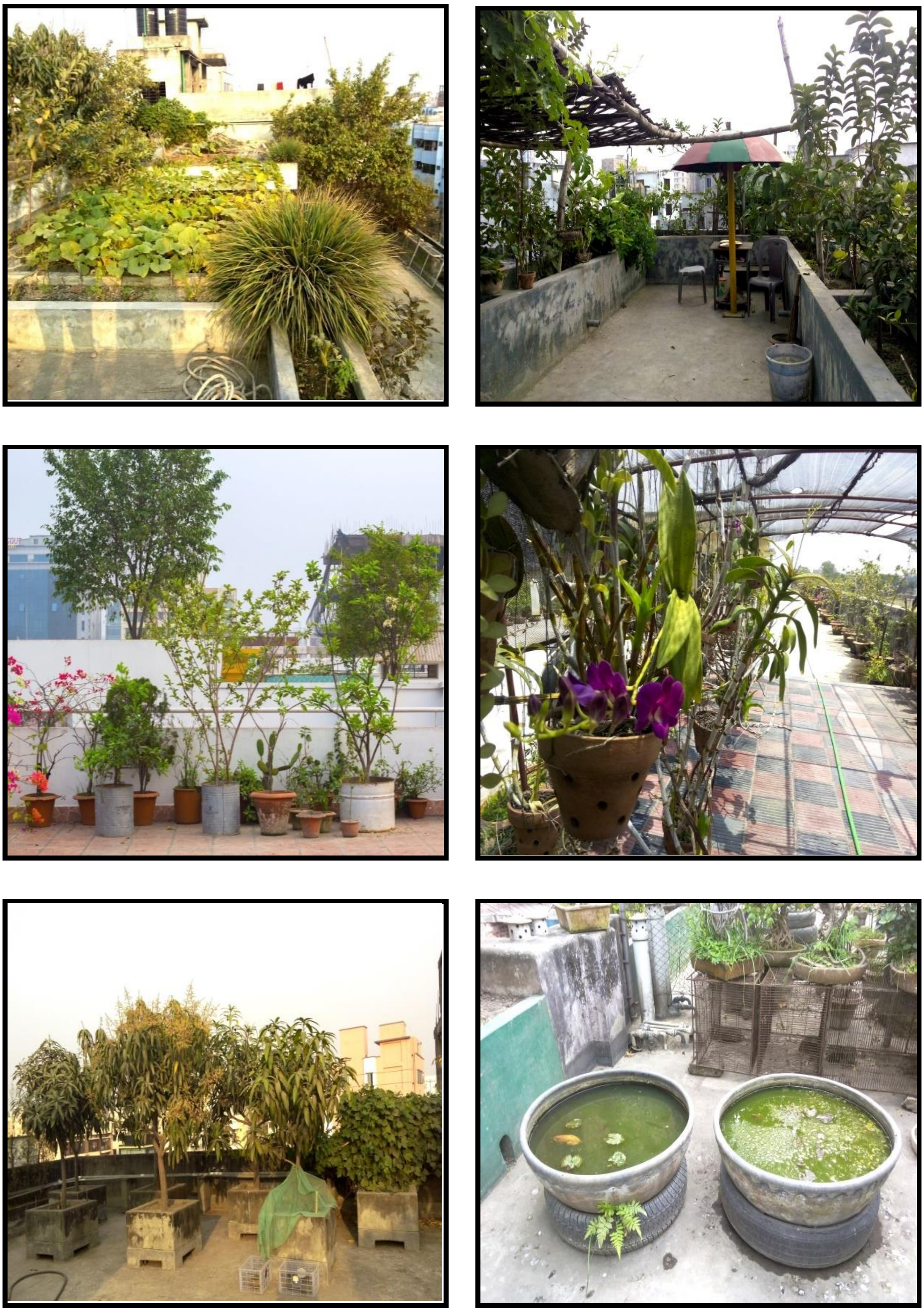


**Plate 4 Photograph shows the plant species and planting materials**

### 3.3.2 Thermal Data Collection:

- For collecting thermal data for the evaluation of thermal performance of roofgarden, the two most important thermal parameter, namely, Air Temperature and Relative Humidity reading were taken. The physical measurement was carried out by using the instrument "Thermo-hygrograph". A Thermo-hygrograph records air temperature and relative humidity on a continuous basis for every hour for seven days.
- The data were taken at the warmest week of the year from 25$^{th}$ April to 30$^{th}$ April.
- The data were recorded from 6 am to 6 pm in the roof garden over the four storied academic Building of Sher-e-Bangla Agricultural University. The garden was an extensive one, which was organized by plants to cover the hard surface; where plants were arranged densely.
- Outdoor temperature and RH were recorded both under plant shade area of the roof garden and under the sun in the bare roof alternatively for 6 consecutive days.
- Indoor temperature and RH were taken in the top floor rooms both under the roof garden and under the bare roof alternatively for 6 consecutive days.
- The collected temperature and RH reading were averaged to generate the final data. A scanned copy of the Thermo-hygrograph reading has been given in appendix V.

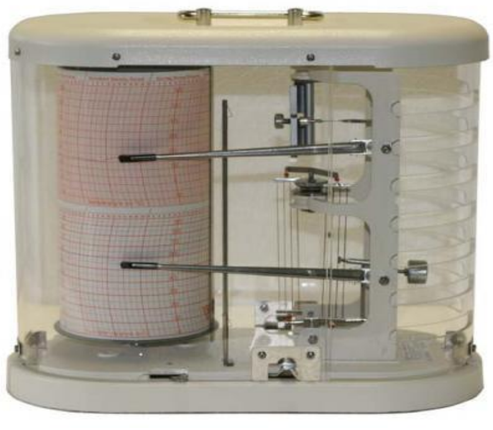


**Plate 5: A Thermo-Hygrograph**

**Plate 5 Taking thermal data using Thermo-hygrograph on rooftop garden and bare roof**

### 3.3.3 Secondary Data Collection

Secondary data were collected from the various sources and records like-reports published by related project, Department of Agricultural Extension, Metropolitan office. Maps, journals, publications, reports of other line agencies, published or unpublished and relevant literature were also consulted in the library and the relevant websites to make better understanding.

## 3.4 Measurement of Diversity

### 3.4.1 Shannon's Diversity Index

Shannon's diversity index is simply the ecologist's name for the communication entropy introduced by Claude Shannon:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Where pi is the fraction of individuals belonging to the i-th species. This is by far the most widely used diversity index. The intuitive significance of this index can be described as follows. Binary code words for each species in our ecosystem are supposed to be devised, with short code word used for the most abundant species, and longer code word for rare species. As individual organisms are observed by us, the corresponding code word is called out giving this a binary sequence. If we have used an efficient code, we will be able to save some breath by calling out a shorter sequence than would otherwise be the case. If so, the average code word length we call out as we wander around will be close to the Shannon diversity index. It is possible to write down estimators which attempt to correct for bias in finite sample sizes, but this would be misleading since communication entropy does not really fit expectations based upon parametric statistics. Differences arising from using two different estimators are likely to be overwhelmed by errors arising from other sources. Current best practice tends to use bootstrapping procedures to estimate communication entropy.

Shannon himself showed that his communication entropy enjoys some powerful formal properties, and furthermore, it is the unique quantity which does so. These observations are the foundation of its interpretation as a measure of statistical diversity.

### 3.4.2 Species richness

Species richness is the number of different species in a given area. Species richness is the fundamental unit to assess the homogeneity of an environment.

Typically, species richness is used in conservation studies to determine the sensitivity of ecosystems and their resident species. The actual number of species calculated alone is largely an arbitrary number. These studies, therefore, often develop a rubric, measure for valuing the species richness number, or adopt one from previous studies on similar ecosystems.

The species richness is simply the number of species present in an ecosystem. This index makes no use of relative abundances. In practice, measuring the total species richness in an ecosystem is impossible, except in very depauperate systems. The observed number of species in the system is a biased estimator of the true species richness in the system, and the observed species number increases non-linearly with sampling effort.

Species richness measures the number of species within an area. Roof top garden plants of the five locations were grouped into five categories namely fruits, flowers, vegetables, ornamental and medicinal.

### 3.4.3 Inter species diversity

The most commonly used formula of calculating inter species diversity "Simpson index (D)" suggested by Simpson (1949) was used in this study which was as follows -

$D = 1 – Pi^2$

Where, Pi is the proportional abundance of the ith species such that

Pi = Ni/N

Ni = Plant population of ith species and

N = N1+N2+N3+…+Nn where n is the number of species

### 3.4.4 Relative prevalence (RP) of species

Relative abundances must add to unity (save perhaps for some rounding error). Note that relative abundance has no units (it is dimensionless). Alternatively, relative abundances can be expressed as a percentage.

Relative prevalence (RP) of species was calculated by using the following formula:

RP = Population of the species per roof garden × % roof gardens with the species.

These relative prevalence values were used to rank the species in different regions according to Millat-e-Mustafa (1997).

## 3.5 Measurement of Independent Variables

In this study selected personal, economic, social and psychological characteristics of the garden owners were considered as independent variables. These characteristics are as follows:

1. **Age:** Age of a respondent was measured in terms of years from birth to the time of interview which was found on the basis of response. It was located in the Question no. 2 of interview schedule.

2. **Marital Status**: Marital status was measured in terms of weather the respondent is married or single/unmarried or divorced. It was located in the Question no. 3 of interview schedule.

3. **Education:** Education was measured in terms of one's year of schooling. One score was given for passing each level in an educational institution. For example, if a respondent passed the SSC examination, educational score would be given as 10. If a respondent did not know how to read and write, his educational score would be given as '0'. It was located in the Question no.4 of interview schedule.

4. **Family size:** The family size was measured by the total number of members in the family of a respondent. The family members included family head and other dependent members like husband/wife, children, etc. who live and eat together. It was located in the Question no.6 of interview schedule.

5. **Occupation:** Occupation was measured according to the respondent's profession or walks of life. The general occupations included are serviceholder, Businss and retired/housewife. It was located in the Question no. 5 of interview schedule.

6. **Family Annual Income:** Family annual income of the respondents was measured in terms of lack taka. Income from all sources by all the earning family members were added together to obtain family annual income. It was located in the Question no. 6 of interview schedule.

7. **House Ownership:** House ownership was measured by asking whether the respondent was building owner or tenant or lives in government quarter. It was located in the Question no. 7 of interview schedule.

8. **Surface area of roof garden:** The surface area of roof (sq. ft.) garden refer to the total area of roof on which his family carried out roof garden operation, the area being in terms of full benefit to the family. It was located in the Question no. 8 of interview schedule.

9. **Vegetation coverage**: Measuring the vegetation coverage of the RTG was done through visual observation of the roof garden and the roof

gardens were grouped under the following categories for qualitative analysis. It was located in the Question no. 9 of interview schedule.

| Extent of vegetation coverage | Weighting system |
|---|---|
| High (60-80% of the roof area) | 3 |
| Medium (40-50% of the roof area) | 2 |
| Low (20-30% of the roof area) | 1 |

10. **Yearly food/fiber Production**: Yearly food/fiber production was measured by asking the respondent and grouped in the following categories for qualitative analysis. . It was located in the Question no. 10 of interview schedule.

| Extent of yearly production | Weighting system |
|---|---|
| High ( >30 kg) | 3 |
| Medium (15-30 kg) | 2 |
| Low (upto 15 kg) | 1 |

11. **Meeting food demand**: The potential of RTG in meeting food demand was measured on daily, weekly and monthly basis. . It was located in the Question no. 11 of interview schedule.

12. **Spending time for gardening (hour):** Spending time for gardening (Hour) of a respondent was measured in terms of 1 hour, 2 hour and above 2 hours options on daily, weekly and monthly basis which was found on the basis of response. It was located in the Question no. 14 of interview schedule

13. **Mental Satisfaction:** Yearly food/fiber production was measured by asking the respondent and grouped in the following categories for qualitative analysis. . It was located in the Question no. 15 of interview schedule.

| Extent of mental satisfaction | Weighting system |
|---|---|
| High | 3 |
| Medium | 2 |
| Low | 1 |

14. **Thermal comfort**: Thermal comfort of the RTG was measured through observation of the garden and by asking the respondent's personal feelings about thermal comfort and grouped in the following categories for qualitative analysis. It was located in the Question no. 14 of interview schedule

| Extent of thermal comfort | Weighting system |
|---|---|
| High | 3 |
| Medium | 2 |
| Low | 1 |

15. **Yearly Expenditure**: For measuring yearly spent money for the RTG each garden owner was asked about their yearly expenditure and grouped in the following categories for qualitative analysis. It was located in the Question no. 15 of interview schedule.

| Extent of yearly expenditure | Weighting system |
|---|---|
| High (>15000 Tk) | 3 |
| Medium (5001-15000 Tk) | 2 |
| Low (upto 5000 Tk) | 1 |

16. **Nursing:** To measure the nursing characteristic of RTG, each respondent was asked whether the garden is nursed/maintained by the family members or family paid member or a well-paid gardener. It was located in the Question no. 16 of interview schedule.

17. **Technical Support:** Technical support of the garden owners were measured by asking the respondents with given choices. It was located in the Question no. 17 of interview schedule.

18. **Training:** Technical support of the garden owners was measured by asking the respondents with given choices according to DAE training. It was located in the Question no. 18 of interview schedule.

| Extent of thermal comfort | Weighting system |
|---|---|
| High (4-5 days) | 3 |
| Medium (2-3 days) | 2 |
| Low (1 day) | 1 |
| No training | 0 |

## 3.6 Measurement of Dependent Variables

**Floral Diversity**

Shannon's Diversity Index was used for measuring the plant species diversity of individual garden owner. For measuring the diversity, it was categorized into three groups such as low diversity, medium diversity and high diversity. Scores were assigned for all extension media in the following manner:

| Extent of Diversity | Diversity Range |
|---|---|
| Low | 0-2.4 |
| Medium | 2.5-3.5 |
| High | >3.5 |

Diversity of the plants could range from 0 to above 3.5, where 0 indicating no diversity of RTG and above 3.1indicating high diversity of RTG.

**Thermal performance**

The temperature and RH reading of diurnal period (6am to 6pm) from the experiment was averaged to get the final data. Graphical analysis was done in MS Excel to visualize the actual change of temperature and RH both indoor and outdoor.

**Purpose of gardening**

Purpose of rooftop gardening was assessed using a semi-structured open questionnaire which was calculated as percentage in MS Excel in garden owners opinion. It was located in the Q no. 11 of interview schedule.

## 3.7 Compilation of Data

After completion of field survey all the data of the interview schedule were compiled. Local units were converted into standard unit. Appropriate coding and scoring technique was followed to convert the qualitative data into quantitative forms. The responses of the individual respondent contained in the interview schedules were transferred to a master sheet for entering the data in the computer. As soon as the data entered into the computer, it was then analyzed in accordance with the objectives of the study.

## 3.8 Data Analysis

The data were coded, categorized and fed in computer and analyzed using computer software packages MS Excel and SPSS (Statistical Package for Social Science) 22 versions. Quantitative data were analyzed by simple statistical tools such as frequency, mean, percentage and standard deviation and qualitative data were analyzed by ordering, ranking with descriptive manner. The impacts of various socio-economic factors such as education status, Occupation, surface area of roof garden, annual income of garden owners and the diversification of plant species with comparison of percent of plants present in roof garden and diversification present in roof top garden were analyzed by using SPSS. The results are presented through text, Tables, Graphical Figures and spatial distribution with interpretation accordingly.

## 3.9 The Overall Methodology:

- **Collection of the base map of the wards**
- **Geo-referencing of maps using ArcGIS software for generating the final study area**

↓

**Developing questionnaire on the basis of Possible Ecosystem services of RTGs**

↓

**Reconnaissance visit in the study areas and testing the questionnaire.**

↓

**Taking GPS reading of each resident building**

↓

**Thermal data collection : Taking indoor and outdoor air Temperature and RH reading from 6 am to 6pm in both roof garden and bare roof using Thermo-hygrograph in the warmest week of the year.**

↓

**Processing of data**

a) **Processing of GPS/GIS data by using ArcGIS software**
b) **Processing of attribute/questionnaire data through SPSS**
c) **Analysis of Biodiversity using Shannon Weiner's Biodiversity Index in MS excel**

↓

**Drawing of result and displaying the outcomes in tables, Graphs and in GIS with maps**

# CHAPTER IV

# RESULTS AND DISCUSSION

The experimental survey results obtained from the present study on assessment of ecosystem services and benefits of rooftop gardening in Dhaka city were discussed in the results and discussion chapter. The first section deals with the four basic ecosystem services (provisioning, supporting, regulating and cultural) obtained from the qualitative and quantitative analysis while the second section deals with the selected individual characteristics of the garden owners. The third section deals with the relationships between the garden owners selected characteristics with ecosystem services provided by the roof top gardens.

## 4.1. Provisioning services

Provisional services provided by rooftop gardens in the study area are food and fiber production particularly production of fruits and vegetables.

### 4.1.1 Provision of Food (Fruits and Vegetable)

The study result showed that seasonal fruits and vegetables were the major food produced from roof gardening. According to the survey, total 8 garden owners (20%) grow high food production which is more than 40kg/year and 21 of them (52.5%) grow 21-40 kg/year (medium) and 11 garden owners (27.5%) grow low production which is less than 20kg/year.

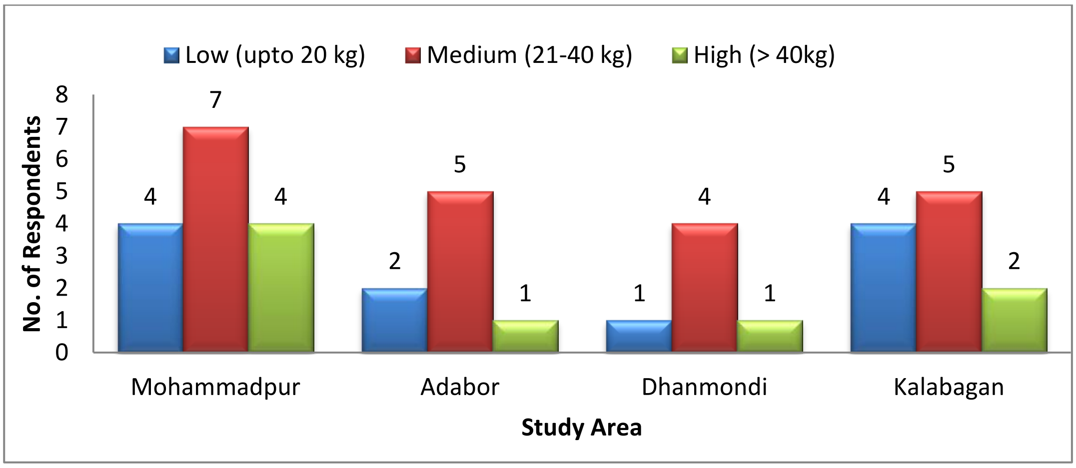



**Figure 4.1 Yearly food production in the study area**

High yearly food production (above 40kg) was mostly observed in Mohammadpur area which was found in 4 roof gardens followed by 2 roof gardens in Kalabagan and 1 in each of Adabor and Dhanmondi. Medium food production (21-40kg) was found in 7 roof gardens of Mohammadpur, 5 roof gardens of both Adabor and Kalabagan and 4 roofgardens of Dhanmondi. Yearly food production was found low (upto 20 kg) in 4 gardens of both Mohammadpur and Kalabagan followed by 2 gardens in Adabor and 1 in Dhanmondi. This distribution has been spatially shown in Figure 4.2.

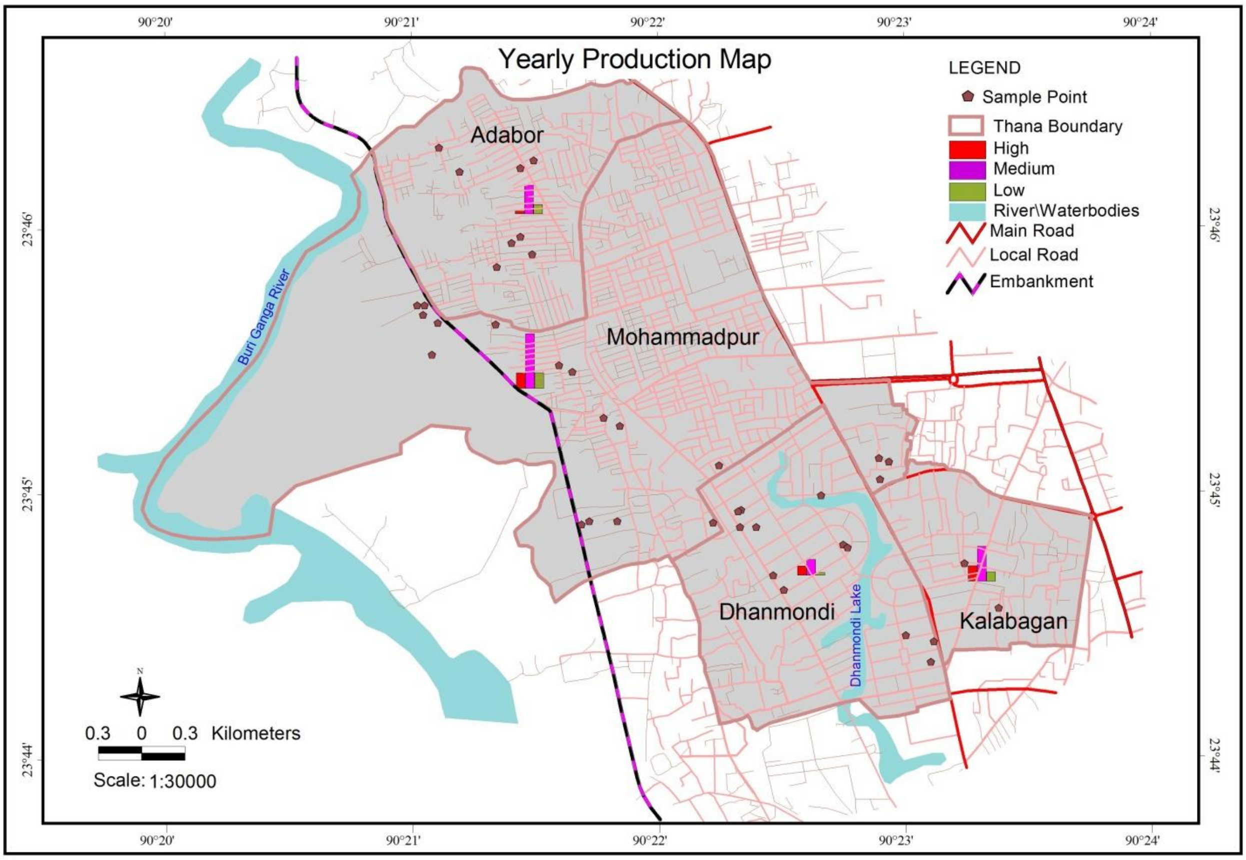



**Figure 4.2 Spatial distribution of yearly food production across the study area**

Spatial distribution shows that medium food production (21-40kg/year) was mostly found in all the four areas.

### 4.1.2. Regularity of food supply

The result revealed that most of the roof gardens in the study areas can meet up the food demand of the families in daily to weekly basis. 40% of the garden owners get daily food supply from their roof gardens, 45% get weekly food supply and only 15% get the food supply monthly.

**Table 4.1 Distribution of garden owners according to regularity of food supply**

| Areas | Food Supply | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | High (Daily) | | Medium (Weekly) | | Low (Monthly) | | Total | |
| | N | P(%) | N | P(%) | N | P(%) | N | P(%) |
| **Mohammad pur** | 7 | 17.5 | 6 | 15 | 2 | 5 | **15** | **37.5** |
| **Adabor** | 2 | 5 | 5 | 12.5 | 1 | 2.5 | **8** | **20** |
| **Dhanmondi** | 1 | 2.5 | 4 | 10 | 1 | 2.5 | **6** | **15** |
| **Kalabagan** | 6 | 15 | 3 | 7.5 | 2 | 5 | **11** | **27.5** |
| **Total** | **16** | **40** | **18** | **45** | **7** | **15** | **40** | **100** |

## 4.2 Supporting service

### 4.2.1 Biodiversity and habitat conservation

#### 4.2.1.1. Shannon diversity index

Shannon's index accounts for both abundance and evenness of the species present.

**Table 4.2 Shannon diversity index in the study area**:

| Categoriees of Species | Grand total of each category | Relative abundance (Pi) | LN (Pi) | Pi*LN(Pi) |
|---|---|---|---|---|
| Fruit | 1238 | 0.23 | -1.46 | -0.33 |
| Vegetable | 1695 | 0.32 | -1.13 | -0.36 |
| Flower | 791 | 0.15 | -1.89 | -0.28 |
| Ornamental | 963 | 0.18 | -1.71 | -0.308 |
| Medicinal | 564 | 0.108 | -2.21 | -0.23 |
| Grand total | 5251 | 1 | **ΣPiLn(Pi)** | -1.51 |
| | | | | **H'= -ΣPiIn(Pi) 1.51** |
| | | | | **e H' 4.51** |

The result revealed that Shannon-Weaver diversity index was very high in the study area which was 4.51. Shannon's Diversity Index ranges from 0 to 5. Typically the value of the index ranges from 1.5 (low diversity) to 3.5 (high species diversity) in natural ecosystems, though values beyond these limits may be encountered (www.wikipedia.org). Each rooftop garden acts as an urban ecosystem unit where plants don't grow naturally rather the plant species are grown according to the gardener's choice. That is the reason behind the higher diversity index resulted in the study.

#### 4.2.1.2. Species Richness

**Table 4.3 Species Richness found in the study area**

| Categories of Species | Types of plants |
|---|---|
| Fruits | 38 |
| Vegetable | 25 |
| Flowers | 40 |
| Ornamental | 32 |
| Medicinal | 15 |
| **Total** | **150** |

Almost all the roof top gardens had mixed vegetation with various annual and perennial trees and seasonal vegetables where 150 useful species were identified (Table 4.5, 4.6, 4.7, 4.8 and 4.9). Among them 38 species were fruits, 40 species were flowers, 25 species were vegetables, 32 species were ornamental and 15 species were medicinal which is shown in Table 4.3.

#### 4.2.1.3. Inter-species Diversity

Species diversity index is a measure, which renders considerable ecological insight (Amin, 1997). Simpson index of species diversity (D) varied among the different groups of plant species. Inter-species diversity was found higher for Flowering plant species (0.988) in the roof garden of the study area followed by vegetable species (0.977), ornamental species (0.966), fruit species (0.944) and medicinal species (0.895).

**Table 4.4 Interspecies diversity in the study area**

| Study areas | Fruits | Vegetables | Flowers | Ornamental | Medicinal | Average |
|---|---|---|---|---|---|---|
| **Mohammadpur** | 0.885 | 0.887 | 0.883 | 0.904 | 0.812 | 0.874 |
| **Adabor** | 0.953 | 0.966 | 0.948 | 0.958 | 0.956 | 0.956 |
| **Dhanmondi** | 0.977 | 0.982 | 0.988 | 0.978 | 0.989 | 0.984 |
| **Kalabagan** | 0.912 | 0.879 | 0.896 | 0.883 | 0.933 | 0.901 |
| **Average** | 0.932 | 0.928 | 0.928 | 0.931 | 0.923 | 0.928 |
| **All** | **0.944** | **0.977** | **0.988** | **0.966** | **.895** | |

The result showed that diversity index varied with different plant species in different Thana area. The highest average inter-species diversity (0.984) was found in Dhanmondi area followed by Adabor (0.956) and Kalabagan (0.901) area. The lowest inter-species diversity was found in Mohammadpur area (0.874) where study area showed the moderate to higher inter-species diversity. This distribution has been spatially shown in Figure 4.3.

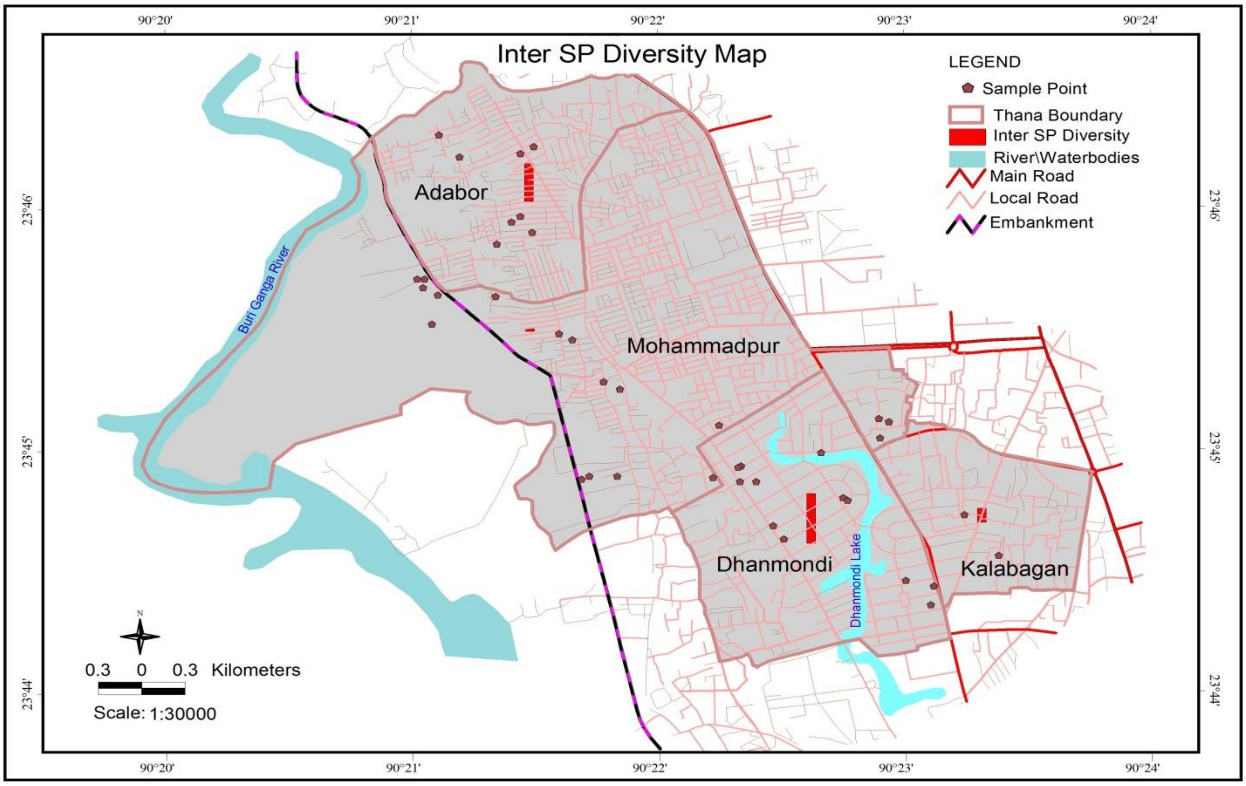



**Figure 4.3 Spatial Distribution of inter species diversity across the study area**

The spatial distribution shows that inter species diversity is found the highet in Dhanmondi, followed by Adabor, Kalabagan and Mohammadpur.

#### 4.2.1.4. Relative prevalence and Density

**Relative prevalence**

The local name, scientific name, family name, habit and relative prevalence of 38 fruit species, 40 flower species, 25 vegetable species, 32 ornamental species and 15 medicinal species were found in forty rooftop gardens of the study.

**a) Fruit Species**

Garden owners had different types of fruit species. Among them 35 fruit species were available in their garden where mango (127.1%) was found most prevalent and Dragon fruit (10.2%) was found the lowest prevalent. On the basis of relative prevalence, Mango, Guava, Papaya, Lemon and Jamrul were ranked in top position (Table 4.5). The result revealed that 38 fruit species were recorded under 33 genera and 23 families while 32 species were trees, 2 shrubs and 4 herbs in nature.

**Table 4.5 Fruit species with their local name, family name, genus, species, habit and relative prevalence**

| Sl. No. | Local name | Family | Genus | Species | Habit | Relative prevalence |
|---|---|---|---|---|---|---|
| 1 | Mango | Anacardiaceae | *Mangifera* | *indica* | Tree | 127.1 |
| 2 | Guava | Moraceae | *Psidium* | *guajava* | Tree | 114.6 |
| 3 | Papaya | Caricaceae | *Carica* | *papaya* | Herb | 113.5 |
| 4 | Lemon | Rutaceae | *Citrus* | *grandis* | Shrub | 103.5 |
| 5 | Jamrul | Myrtaceae | *Eugenia* | *javanica* | Tree | 99.67 |
| 6 | Kamrangha | Averrhoaceae | *Averrhoa* | *carambola* | Tree | 76.44 |
| 9 | Amloki | Euphorbiaceae | *Phyllanthus* | *embelica* | Tree | 44.6 |
| 10 | Billimbi | Averrhoaceae | *Averrhoa* | *bilimbi* | Tree | 44.5 |
| 12 | Lotkon | Phyllanthaceae | *Baccaurea* | *sapida* | Tree | 40.11 |
| 13 | Bael | Rutaceae | *Aegle* | *marmelos* | Tree | 38.44 |
| 14 | Malta | Rutaceae | *Citrus* | *sinensis* | Tree | 34.1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 15 | Jalpai | Elaeocarpaceae | *Elaeocarpus* | *floribundus* | Tree | 33.4 |
| 16 | Lichu | Sapindaceae | *Litchi* | *chinensis* | Tree | 30.1 |
| 17 | Sofeda | Sapotaceae | *Achros* | *sapota* | Tree | 28.88 |
| 18 | Sarifa | Sapotaceae | *Chrysophyllum* | *cainito* | Tree | 23.8 |
| 19 | Kamala | Rutaceae | *Citrus* | *reticulata* | Tree | 23.5 |
| 20 | Ata | Annonaceae | *Annona* | *reticulata* | Tree | 22.8 |
| 21 | Khejur | Palmae | *Phoenix* | *sylvestris* | Tree | 22.3 |
| 22 | Rambutan | Sapindaceae | *Nephelium* | *lappaceum* | Tree | 21.1 |
| 23 | Banana | Musaceae | *Musa* | *sapientum* | Tree | 21.0 |
| 24 | koromcha | Apocynaceae | *Carissa* | *carandas* | Tree | 19.6 |
| 25 | Amra | Anacardiaceae | *Spondias* | *pinnata* | Tree | 17.9 |
| 26 | Kul | Rhamnaceae | *Zizyphus* | *mauritiana* | Tree | 17.8 |
| 27 | Naspati | Rosaceae | *Pyrus* | *communis* | Tree | 17.7 |
| 28 | Jambura | Rutaceae | *Citrus* | *grandis* | Tree | 16.77 |
| 29 | Dalim | Punicaceae | *Punica* | *granatum* | Shrub | 15.99 |
| 30 | Cherry | Rosaceae | *Prunus* | *avium* | Tree | 13.8 |
| 31 | Tentul | Caesalpiniaceae | *Tamarindus* | *indica* | Tree | 13.3 |
| 32 | Arboroi | Euphorbiaceae | *Phyllanthus* | *acidus* | Tree | 13.1 |
| 33 | Kothbel | Rutaceae | *Feronia* | *limonia* | Tree | 12.44 |
| 34 | Straw berry | Rosaceae | *Fragaria* | *ananassa* | Herb | 12.05 |
| 35 | Panifol | Lythraceae | *Trapa* | *bicornis* | Herb | 11.23 |
| 36 | Kanthal | Moraceae | *Artocarpus* | *heterophyllus* | Tree | 10.2 |
| 37 | Passion fruit | Passifloraceae | *Passiflora* | *edulis* | Tree | 9.02 |
| 38 | Dragan Fruit | Cacteceae | *Hylocereus* | *undatus* | Herb | 9.73 |
| Total=38 | | Family=23 | Genus=33 | | | |

### b) Flower Species

Various flower species were found in the study area. Among 40 flower species, Beli (115.7%) was found the most prevalent and Bottle Brush (24.1%) was found the lowest prevalent. On the basis of relative prevalence, Beli, Baganbilash, Rangan, Musanda and Nayantara were ranked in top position (Table 4.7). The result indicated that 40 flower plants species were recorded under 37 genera and 22 families while 8, 15, 15 and 2 species were found as trees, shrubs, herbs and climbers, respectively.

**Table 4.6 Flower plant species with their Local name, family name, genus, species, habit and relative prevalence**

| Sl. No. | Local name | Family | Genus | Species | Habit | Relative prevalence |
|---|---|---|---|---|---|---|
| 1 | Beli | Oleaceae | *Jasminum* | *sambac* | Shrub | 115.7 |
| 2 | Baganbilash | Nyctaginacea | *Bougainvillea* | *grabra* | Climber | 114.8 |
| 3 | Rangan | Rubiaceae | *lxora* | *singaporensis* | Shrub | 113.6 |
| 4 | Musanda | Apocynaceae | *Musanda* | *sp.* | Tree | 112.4 |
| 5 | Nayantara | Apocynaceae | *Vinca* | *rosea* | Herb | 111.1 |
| 6 | Allamonda | Apocynaceae | *Allamanda* | *cathartica* | Shrub | 109.3 |
| 7 | Joba | Malvaceae | *Hibiscus* | *rosa sinensis* | Shrub | 109.1 |
| 8 | Rose | Rosaceae | *Rosa* | *sp.* | Shrub | 101.2 |
| 9 | Orchid | Orchidaceae | *Orchis* | *Sp.* | Herb | 100.6 |
| 10 | Malotilota | Combretaceae | *Combretum* | *indicum* | Vine | 100.2 |
| 11 | Chondro mollika | Oleaceae | *Jasminum* | *angustifolium* | Tree | 98.2 |
| 12 | Togor | Apocynaceae | *Tubernaemontana* | *divaricata* | Shrub | 98.1 |
| 13 | Hasnahenna | Solanaceae | *Cestrum* | *nocturnum* | Shrub | 95.6 |
| 14 | Petunia | Solanaceae | *Petunia* | *hybrida* | Herb | 92.4 |
| 15 | Gerbera | Asteraceae | *Gerbera* | *Sp.* | Herb | 90.7 |
| 16 | Kolaboti | Cannaceae | *Canna* | *indica* | Herb | 88.1 |
| 17 | Lily | Liliaceae | *Lilium* | *lanciflorum* | Herb | 81.8 |
| 18 | Ganda | Asteraceae | *Asteroideae* | *Sp.* | Herb | 79.7 |
| 19 | Dahlia | Asteraceae | *Dahlia* | *pinnata* | Shrub | 77.5 |
| 20 | Oporajita | Fabaceae | *Clitoria* | *ternatea* | Vine | 68.1 |
| 21 | Dolonchapa | Zingiberaceae | *Hedychium* | *coronarium* | Shrub | 67.3 |
| 22 | Euphorbia | Euphorbiaceae | *Euphorbia* | *Sp.* | Herb | 66.6 |
| 23 | Shondhamaloti | Nyctaginaceae | *Mirabilis* | *jalapa* | Climber | 63.7 |
| 24 | Radhachura | Fabaceae | *Caesalpinia* | *pulcherrima* | Tree | 62.7 |
| 25 | Krishnacura | Fabaceae | *Delonyx* | *rejia* | Tree | 56.1 |
| 26 | Kamini | Rutaceae | *Murraya* | *exotica* | Shrub | 55.7 |
| 27 | Sheuli | Oleaceae | *Nyctanthes* | *Arbor-tristis* | Tree | 50.9 |
| 28 | Bakul | Sapotaceae | *Mimosops* | *elengi* | Tree | 48.7 |
| 29 | Chrysanthemum | Asteraceae | *Crysanthemum* | *indicum* | Herb | 45.6 |
| 30 | Lojjaboti | Fabaceae | *Mimosa* | *pudica* | Bush | 44.7 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 31 | Gondhoraj | Rubiaceae | *Neolamarckia* | *cadamba* | Shrub | 41.2 |
| 32 | Kanur | Nymphaeaceae | *Nerium* | *indicum* | Herb | 40.8 |
| 33 | Gladiolous | Iridaceae | *Gladiolous* | *communis* | Herb | 38.7 |
| 34 | Sonalu | Fabaceae | *Cassia* | *fistula* | Tree | 37.4 |
| 35 | Kolke | Apocynaceae | *Cascabela* | *peruviana* | Shrub | 36.5 |
| 36 | Shapla | Nymphaeaceae | *Nymphaea* | *Nouchali* | Herb | 35.2 |
| 37 | Nilpoddo | Nymphaeaceae | *Nymphaea* | *Sp.* | Herb | 35.1 |
| 38 | Hydranjea | Hydrangiaceae | *Hydrangea* | *arborescens* | Shrub | 33.4 |
| 39 | Nightqueen | Solaneceae | *Cestrum* | *nocturnum* | Shrub | 25.3 |
| 40 | Bottle Brush | Myrtaceae | *Callistemon* | *Sp.* | Tree | 24.1 |
| Total=40 | | Family=22 | Genus=37 | | | |

**c) Vegetable Species**

All the garden owners grow seasonal vegetables for their daily consumption. Out of 25 vegetable species, Begun (132.6%) was found in the most prevalent and Sharisha shak (31.1%) was found the lowest prevalent. On the basis of relative prevalence, Begun, Lau, Tomato, Korolla and Dherosh were ranked in top position (Table 4.6). The result revealed that 25 vegetable plant species were recorded under 21 genera and 11 families with 1, 1, 14 and 9 species were found as trees, shrubs, herbs and climbers, respectively.

**Table 4.7 Vegetable species with their local name, family name, genus, species, habit and relative prevalence**

| Sl. No. | Local name | Family | Genus | Species | Habit | Relative prevalence |
|---|---|---|---|---|---|---|
| 1 | Begun | Solanaceae | *Solanum* | *melongena* | Shrub | 132.6 |
| 2 | Lau/kadhu | Cucurbitaceae | *Lagenaria* | *siceraria* | Climber | 130.8 |
| 3 | Tomato | Solanaceae | *Lycopersicon* | *esculentum* | Herb | 125.7 |
| 4 | Korolla | Cucurbitaceae | *Momordica* | *acutangula* | Climber | 116.5 |
| 5 | Dherosh | Malvaceae | *Abelmoschus* | *esculentus* | Shrub | 115.8 |
| 6 | morich | Solanaceae | *Capsicum* | *annum* | Herb | 115.2 |
| 7 | Puishak | Basellaceae | *Basella* | *alba* | Herb | 114.9 |
| 8 | Lettuce | Compositae | *Lactuca* | *sativa* | Herb | 102.3 |
| 9 | Sheem | Fabaceae | *Lablab* | *purpureus* | Climber | 101.7 |
| 10 | Mistikumra | Cucurbitaceae | *Luffa* | *charantia* | Climber | 88.5 |
| 11 | Kakrol | Cucurbitaceae | *Momordica* | *dioica* | Climber | 79.4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 12 | Shajna | Moringaceae | *Moringa* | *oleifera* | Tree | 78.3 |
| 13 | Dhundul | Cucurbitaceae | *Luffa* | *cylindrica* | Climber | 77.9 |
| 14 | Naga morich | Solanaceae | *Capsicum* | *chinense* | Herb | 75.8 |
| 15 | Borboti | Fabaceae | *Vigna* | *unguiculata* | Climber | 74.4 |
| 16 | Chalkumra | Cucurbitaceae | *Benincasa* | *hispida* | Climber | 72.1 |
| 17 | MukhiKachu | Araceae | *Colocasia* | *esculenta* | Herb | 70.3 |
| | Dudh Kachu | Araceae | *Xanthosoma* | *violaceum* | Herb | 68.3 |
| 18 | Potol | Cucurbitaceae | *Trichossanthes* | *dioica* | Climber | 67.9 |
| 19 | Lalshak | Amaranthaceae | *Amaranthus* | *tricolor* | Herb | 66.3 |
| 20 | Danta shak | Amaranthaceae | *Amaranthus* | *lividus* | Herb | 63.7 |
| 21 | Capsicum | Solanaceae | *Capsicum* | *sp.* | Herb | 60.1 |
| 22 | Shosha | Cucurbitaceae | *Cucumis* | *sativus* | Herb | 44.8 |
| 23 | Fulkopi | Brassicaceae | *Brassica* | *Campestris* | Herb | 33.4 |
| 24 | Badhakopi | Brassicaceae | *Brassica* | *oleracea* | Herb | 33.3 |
| 25 | Sarisha shak | Brassicaceae | *Brassica* | *Sp.* | Herb | 31.1 |
| Total=25 | | Family=11 | Genus=21 | | | |

**d) Ornamental Species**

Out of 32 ornamental species, Croton (110.1%) was found the most prevalent and King Sago Palm (41.3%) was found the lowest prevalent. On the basis of relative prevalence, Croton, Pathos( Money plant), Cactus and Spider plant were ranked in top position (Table 4.7). The result indicated that 32 ornamental plant species were recorded under 31 genera and 22 families with 7 were trees, 15 shrubs, 9 herbs and 1 climber in nature.

### Table 4.8 Ornamental species with their local name, family name, genus, species, habit and relative prevalence

| Sl. No. | Local name | Family | Genus | Species | Habit | Relative prevalence |
|---|---|---|---|---|---|---|
| 1 | Croton | Euphorbiaceae | *Croton* | *Sp.* | Shrub | 110.1 |
| 2 | Pathos | Araceae | *Epipremnum* | *aureum* | Climber | 109.7 |
| 3 | Cactus | Cactae | *Cactus* | *sp* | Herb | 105.6 |
| 4 | Spider | Liliacea | *Cholophytum* | *comosum* | Herb | 100.7 |
| 5 | Areca Palm | Arecaceae | *Dypsis* | *lutescens.* | Shrub | 99.8 |
| 6 | Arrowhead | Alismataceae | *Sagittaria* | *Latifolia* | Herb | 99.7 |
| 7 | Snake plant | Asparagaceae | *Sansevieria* | *trifasciata* | Shrub | 99.0 |
| 8 | Dracaena | Liliacea | *Dracaena* | *merginata* | Shrub | 97.5 |
| 9 | Fern | Polypodiaceae | *Pteris* | *sp.* | Herb | 97.3 |
| 10 | Phylodendron | Araceae | *Phylodendron* | *Sp.* | Shrub | 98.3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 11 | Duranta | Verbenaceae | *Duranta* | *repens* | Shrub | 98.1 |
| 12 | Christmas tree | Araucariaceae | *Araucaria* | *excelsa* | Tree | 97.6 |
| 13 | Thuja | Pinaceae | *Thuja* | *orientalis* | Shrub | 96.7 |
| 14 | Blood leaf | Amaranthaceae | *lindenii* | *Iresine* | Shrub | 95.4 |
| 15 | Ribbon plant | Liliaceae | *Dracaena* | *sanderiana* | Shrub | 94.6 |
| 16 | Cycus | Cycadaceae | *Cycus* | *circunalis* | Shrub | 92.8 |
| 17 | Lantana | Verbenaceae | *Lantana* | *camara* | Shrub | 91.7 |
| 18 | Purple heart | Commelinaceae | *Tradescantia* | *pallida* | Herb | 91.2 |
| 19 | Chinese Evergreen | Araceae | *Aglaonema* | *Sp.* | Shrub | 90.7 |
| 20 | Aralia | Araliaceae | *Aralia* | *Sp.* | Shrub | 88.3 |
| 21 | Cyperus | Cyperaceae | *Cyperus* | *rotundus* | Herb | 81.4 |
| 22 | Cast iron | Asparagaceae | *Aspidistra* | *elatir* | Herb | 80.3 |
| 23 | Garnet robe | Lamiaceae | *Solenostemon* | *scutellarioides* | Herb | 78.5 |
| 24 | Ficus | Moraceae | *Ficus* | *benjamina* | Tree | 77.4 |
| 25 | Peace Lily | Araceae | *Spathiphyllum* | *wallisii* | Herb | 75.1 |
| 26 | Monstera | Araceae | *Monstera* | *deliciosa* | Tree | 67.3 |
| 27 | Soft Succulents | Crassulaceae | *Echeveria* | *Sp.* | Herb | 61.9 |
| 28 | Jade plant | Crassulaceae | *Crassula* | *Sp.* | Herb | 54.3 |
| 29 | Rhapis palm | Arecaceae | *Rhapis* | *excelsa* | Shrub | |
| 30 | Chinese Bamboo | Poaceae | *Bambusa* | *Sp.* | Herb | 50.3 |
| 31 | Cardboard palm | Zamiaceae | *Zamia* | *furfuracea* | Tree | 46.7 |
| 32 | King Sago Palm | Cycadaceae | *Cycas* | *Revolute* | Tree | 41.3 |
| Total=32 | | Family=22 | Genus=31 | | | |

**e) Medicinal Species**

Out of 15 medicinal species, Henna (113.4) was found the most prevalent and Clove (23.4) was found the lowest prevalent. On the basis of relative prevalence, Henna, Pudina, Dhonia, Tulsi and Aloevera were ranked in top position (Table 4.8). The result showed that 10 medicinal plant species were recorded under 13 genera and 13 families with 1 were climber, 5 were herbs, 4 was shrub and 5 were trees in nature.

**Table 4.9 Medicinal species with their local name, family name, genus, species, habit and relative prevalence**

| Sl. No. | Local name | Family | Genus | Species | Habit | Relative prevalence |
|---|---|---|---|---|---|---|
| 1 | Henna | Lythraceae | *Lawsonia* | *inermis* | Tree | 113.4 |
| 2 | Pudina | Labiatae | *Mentha* | *spicata* | Herb | 112.9 |
| 3 | Dhonia | Apiaceae | *Coriandum* | *sativum* | Herb | 110.2 |
| 4 | Tulsi | Labiatae | *Ocimum* | *sactum* | Shrub | 107.3 |
| 5 | Alovera | Liliacieae | *Aloe* | *barbadensis* | Herb | 106.6 |
| 6 | Neem | Meliaceae | *Azadirachta* | *indica* | Tree | 99.5 |
| 7 | Gainura | Asteraceae | *Gainura* | *procimbens* | Climber | 95.8 |
| 8 | Thankuni | Umbelliferae | *Centella* | *asiatica* | Herb | 88.2 |
| 9 | Patharcuchi | Crassulaceae | *Kalanchae* | *pinnata* | Herb | 85.6 |
| 10 | Basok | Acanthaceae | *Adhtoda* | *vasica* | Shrub | 63.7 |
| 11 | Tejpata | Lauraceae | *Cinnamomum* | *tamala* | Tree | 59.8 |
| 12 | Long pepper | Piperaceae | *Piper* | *longum* | Tree | 42.7 |
| 13 | Cinnamon | Lauraceae | *Cinnamomum* | *verum* | Tree | 32.6 |
| 14 | Tokma seed | Lamiaceae | *Ocimum* | *basilicum* | Shrub | 28.8 |
| 15 | Clove | Myrtaceae | *Syzygium* | *aromaticum* | Shrub | 23.4 |
| Total=15 | | Family=13 | Genus=13 | | | |

**Species Density**

**Table 4.10 Density of plants with frequency and percentage found in the survey**

| No. of Plants | Fruits | | Vegetables | | Flowers | | Ornamental Plants | | Medicinal Plants | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | P(%) | N | P(%) | N | P(%) | N | P(%) | N | P(%) |
| **Low (1-20)** | 8 | 20 | 9 | 22.5 | 15 | 37.5 | 22 | 55 | 30 | 75 |
| **Medium (21-50)** | 26 | 65 | 17 | 42.5 | 18 | 45 | 11 | 27.5 | 9 | 22.5 |
| **High (51-100)** | 5 | 12.5 | 9 | 22.5 | 5 | 12.5 | 5 | 12.5 | 1 | 2.5 |
| **Very high (>100)** | 1 | 2.5 | 5 | 12.5 | 2 | 5 | 2 | 5 | 0 | 0 |
| **Total** | **40** | **100** | **40** | **100** | **40** | **100** | **40** | **100** | **40** | **100** |

Plant density is important factor to supply ecosystem services. Higher density of fruits and vegetable plants will give higher provision of food. Higher density of flowering and ornamental plants will provide higher aesthetic value. Similarly, higher medicinal medicinal plants density indicates higher disease regulation.

According to the survey, very high density (above 100) fruits, vegetables, flowers and ornamental plants were found in 2.5%, 12.5%, 5% and 5% roof gardens respectively while medicinal plants over 100 was not found. 51 to 100 plants of fruits, vegetables, flowers, ornamentals and medicinal were found in 12.5%, 22.5%, 12.5%, 12.5% and 2.5% roof gardens, respectively. 21 to 50 plants of fruits, vegetables, flowers, ornamentals and medicinal were found in 65%, 42.5%, 45%, 27.5% and 22.5% roof gardens respectively. Low density (1-20) plants of fruits, vegetables, flowers, ornamentals and medicinal species were found in 20%, 22.5%, 37.5%, 55% and 75% roof garden respectively.

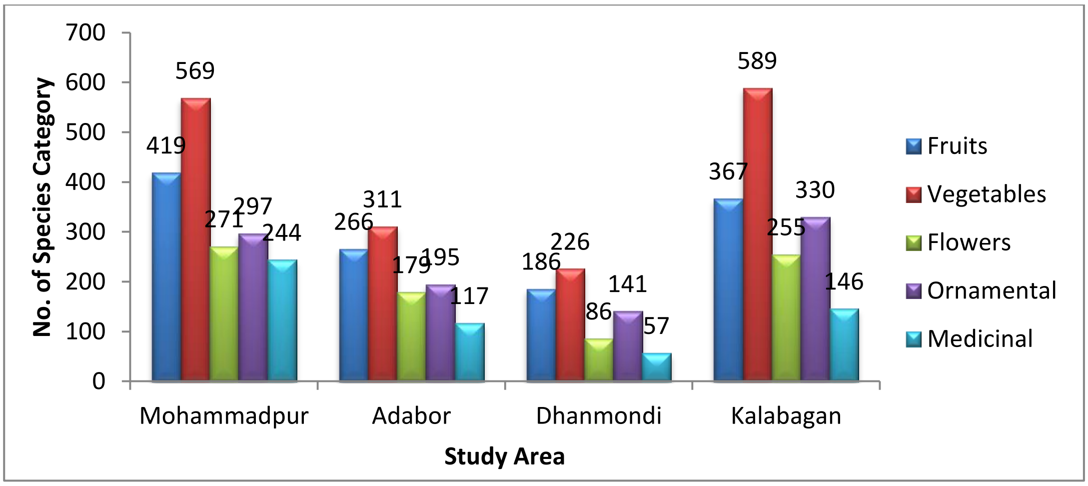



**Figure 4.4 Total no. of plants of each category found in the study area**

The higherst number of fruits were found in Mohammadpur (419) followed by Kalabagan (367), Adabor (266) and Dhanmondi (186). Highest number of vegetables were found in Kalabagan (589), followed by Mohammadpurr (569), Adabor (311) and Dhanmondi (226). The highest number of flowering plants (271) were found in Mohammadpur, followed by Kalabagan (255), Adabor (179) and Dhanmondi (86). The highest number of ornamental plants (330) were found in Kalabagan followed by Mohammadpur (297), Adabor (195) and Dhanmondi(141). The highest number of medicinal plants were found in Mohammadpur (244), followed by Kalabagan (146), Adabor (117) and Dhanmondi (57). This distribution has been spatially shown in Figure 4.5.

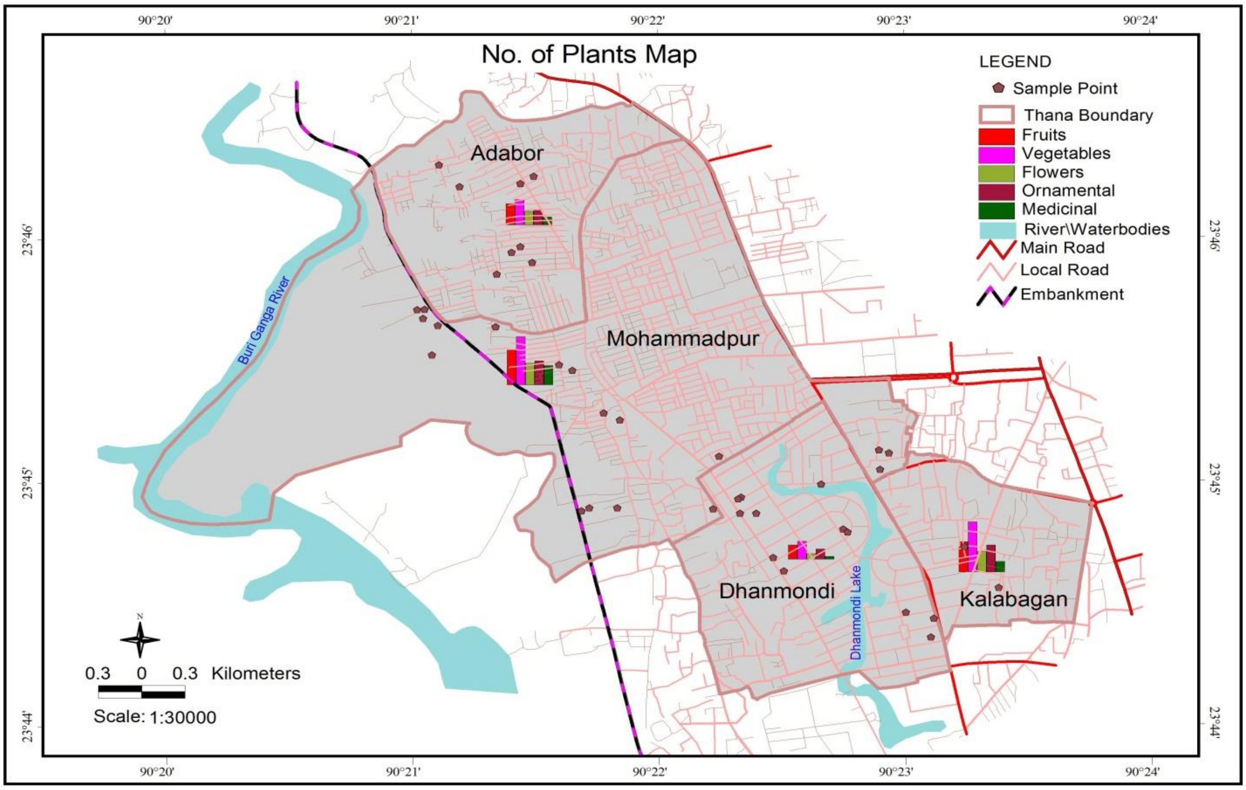



**Figure 4.5 Spatial distribution of total no. of plant species of each category across the study area**

According to spatial distribution it can be seen that vegetables are mostly grown (1695) in all the four thanas, followed by fruits (1238), Ornamental (963), flowering (791) and medicinal plants (564).

### 4.2.1.5. Plant species diversity across the study area

Plant species diversity of the garden owners in the study area were ranged from 0 to above 5 which was shown in Table 4.12.

Shannon's index accounts for both abundance and evenness of the species present. The proportion of species *i* relative to the total number of species (*pi*) is calculated, and then multiplied by the natural logarithm of this proportion (ln *pi*). The resulting product is summed across species, and multiplied by -1.

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

***H'*** = the Shannon-Weaver Diversity Index

But the S-W index is usually expressed as ***eH'***

**Table 4.11 Distribution of the garden owners according to their plant species diversity**

| Areas | Floral species diversity | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Low (0-2) | | Medium (2.1-3.5) | | High (>3.5) | | Total | |
| | N | P(%) | N | P(%) | N | P(%) | N | P(%) |
| **Mohammadpur** | 0 | 0 | 3 | 7.5 | 12 | 30 | **15** | **37.5** |
| **Adabor** | 0 | 0 | 2 | 5 | 6 | 15 | **8** | **20** |
| **Dhanmondi** | 0 | 0 | 2 | 5 | 4 | 10 | **6** | **15** |
| **Kalabagan** | 1 | 2.5 | 2 | 5 | 8 | 20 | **11** | **27.5** |
| **Total** | **1** | **2.5** | **9** | **22.5** | **30** | **75** | **40** | **100** |

The result showed that 75% percent garden owners had high plant species diversity while 22.5% percent garden owners had medium plant species diversity and only 2.5% roof garden was found to have low diversity.

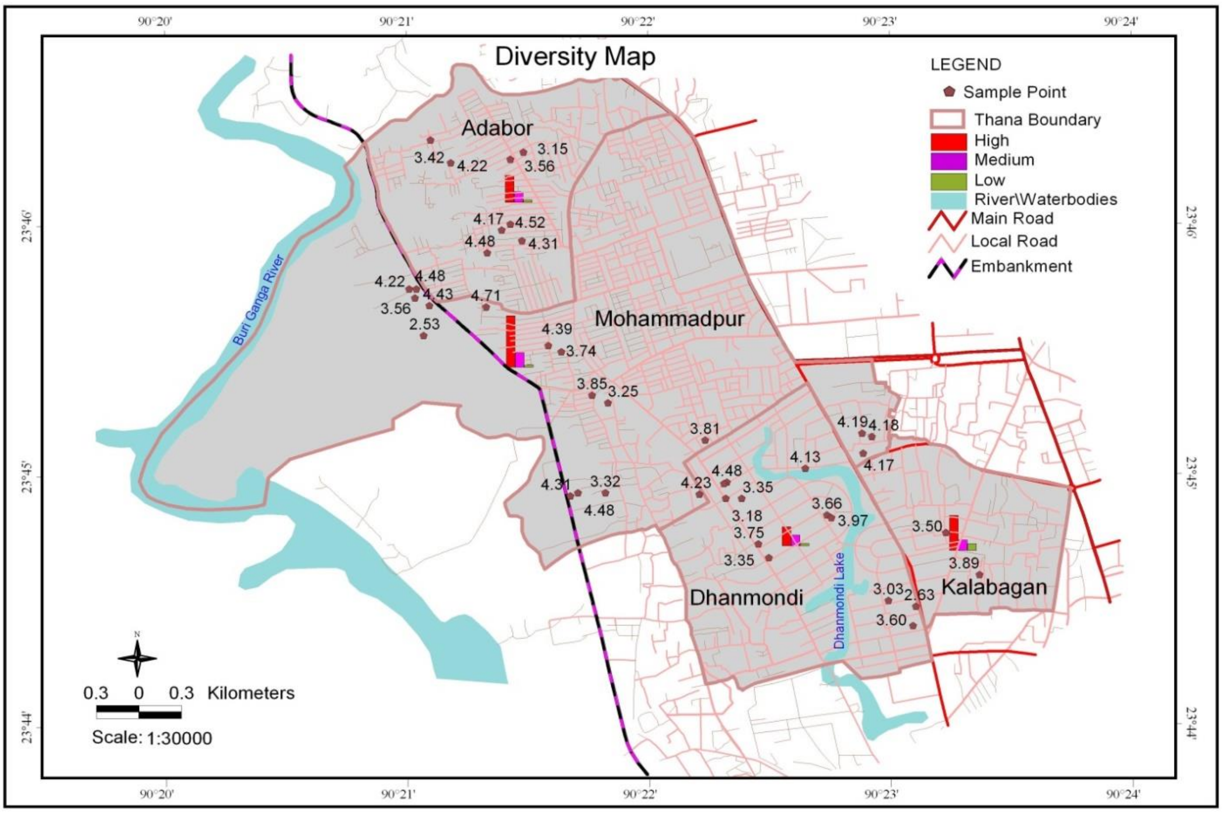



**Figure 4.6 Spatial distribution of floral diversity of the roof gardens across the study area**

According to spatial distribution the highest diversity was found in Mohammadpur, followed by Kalabagan, Adabor and Dhanmondi. The survey revealed that high plant species diversity ( above 3.5) was found in 30% roof garden in Mohammadpur area followed by Kalabagan (20%), Adabor (15%) and Dhanmondi (10%). Medium species diversity (2.1-3.5) was found in 7.5% roof garden in Mohammadpur area 5% of roof garden in the rest of the study areas. Only 1 roof gaden (2.5%) was found to have low diversity (0-2) in Kalabagan area.

## 4.2.2. Economic Support

### 4.2.2.1. Marketing of the produce

**Table 4.12 Distribution of garden owners according to their involvement in marketing**

| Areas | Involvement in marketing | | | | Total | |
|---|---|---|---|---|---|---|
| | Involved | | Not involved | | | |
| | N | P(%) | N | P(%) | N | P(%) |
| **Mohammadpur** | 1 | 2.5 | 14 | 35 | 15 | 37.5 |
| **Adabor** | 1 | 2.5 | 7 | 17.5 | 8 | 20 |
| **Dhanmondi** | 0 | 0 | 6 | 15 | 6 | 15 |
| **Kalabagan** | 1 | 2.5 | 10 | 25 | 11 | 27.5 |
| **Total** | **3** | **7.5** | 37 | 92.5 | 40 | 100 |

Survey revealed that generally very few people consider rooftop gardening commercially to get profit. Among 40 respondents, only 3 of them from Mohammadpur, Adabor and Kalabagan were found to be involved in marketing of their produce. Gardeners sell their surplus products sporadically in different local markets, directly or through intermediaries, with no uniform pricing for system.

#### 4.2.2.1.1. Relation between yearly expenditure and yearly food production

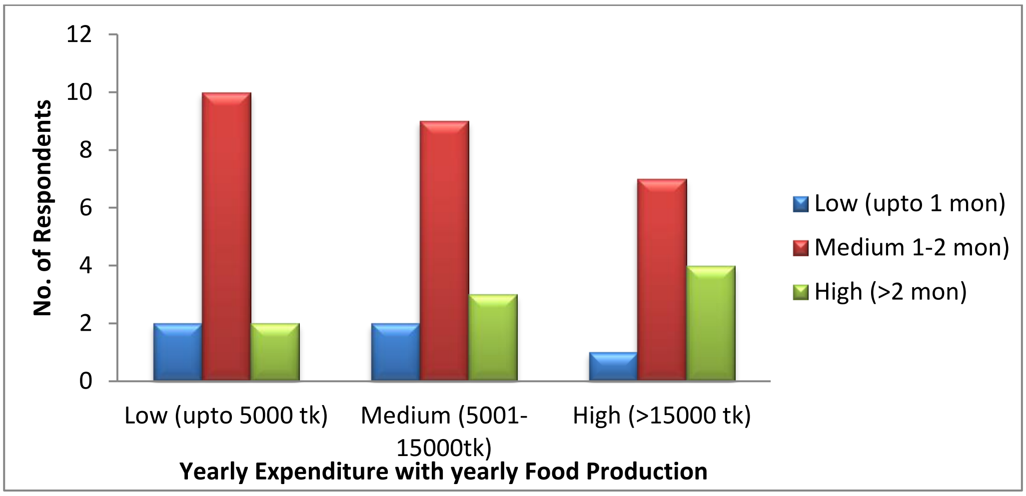



**Figure 4.7 Yearly Expenditure with Yearly Food Production**

Comparing yearly expenditure with yearly production it was found that with low investment 2 garden owners could yield low production/year, 10 of them could yield medium production while 2 of them could yield high production/year. With medium expenditure 2 garden owners grew low production, 9 grew medium production and 3 of them had high production/year. With high expenditure, 8 garden owners grew medium production and 4 of them grew high production/year. This comparison indicates that the garden owners can yield medium to high production even with low to medium expenditure.

#### 4.2.2.2. Employment opportunities

Survey revealed that Rooftop gardening practice can generate employment in society to a satisfactory level. The result showed that 50% garden owner recruited well paid gardener for nursing their garden and 25% garden owner had family paid personnel or extra paid made servant while 20% roof gardens were nursed by the family members of the garden owners

**Table 4.13 Distribution of garden owners according to nursing**

| Areas | Nursing | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Family members | | Family paid personnel | | Gardener | | Total | |
| | N | P(%) | N | P(%) | N | P(%) | N | P(%) |
| **Mohammad pur** | 5 | 12.5 | 3 | 7.5 | 7 | 17.5 | **15** | **37.5** |
| **Adabor** | 2 | 5 | 2 | 5 | 4 | 12.5 | **8** | **20** |
| **Dhanmondi** | 0 | 0 | 2 | 5 | 4 | 7.5 | **6** | **15** |
| **Kalabagan** | 3 | 7.5 | 3 | 7.5 | 5 | 10 | **11** | **27.5** |
| **Total** | **10** | **20** | **10** | **25** | **20** | **50** | **40** | **100** |

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Among the four study areas, nursing by well paid gardener was found in 7 roof garden in Mohammadpur, 5 roof garden in Kalabagan and 4 roof garden in Adabor and Dhanmondi. Nursing by family paid personnel was found in 3 roof gardens of Mohammadpur and Kalabagan and 2 roof gardens in Adabor and Dhanmondi. This distribution has been spatially shown in Figure 4.7.

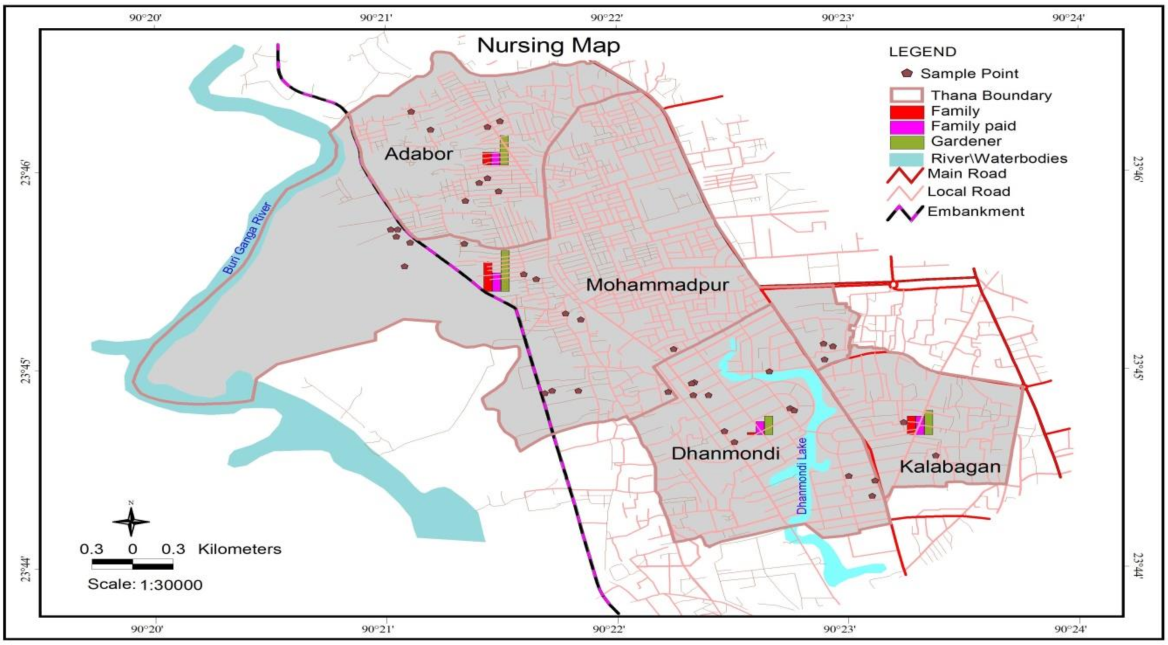


**Figure 4.8 Spatial distribution of nursing categories across the study area**

The spatial distribution shows that nursing by gardeners and family paid personnel is a common phenomenon in all the four areas. Nursing by family members were found the lowest in Dhanmondi than the other areas.

## 4.3 Regulating Service

### 4.3.1 Thermal regulation

#### 4.3.1.1 Quantitative analysis of thermal regulation

There are four parameters of thermal performance:

**1)** Temperature

**2)** Humidity

**3)** Wind velocity and

**4)** Solar radiation.

The most commonly used indicator of thermal comfort is air temperature and relative humidity. It is easy to use and most people can relate to it. The thermal performance of roof top greenery and bare roof was compared to identify the ability of the green roof in reducing the indoor and outdoor air temperature of the high-rise building and the surrounding environmental effects on micro climate of the ambient environment. The result is analyzed by comparing the ambient air temperature and relative humidity. A scanned copy of the Thermo-hygrograph reading containing indoor and outdoor temperature and RH has been given in Appendix V.

**a) Outdoor Thermal performance**

**i) Temperature:**

The thermal performance result of the environment on this research concludes that greenery contributes thermal benefit to both micro climates of the roof environment and surrounding outdoor ambient environment of the building. It was found that the average roof air temperature was reduced by 5.2°C with green roof during sunshine hours.

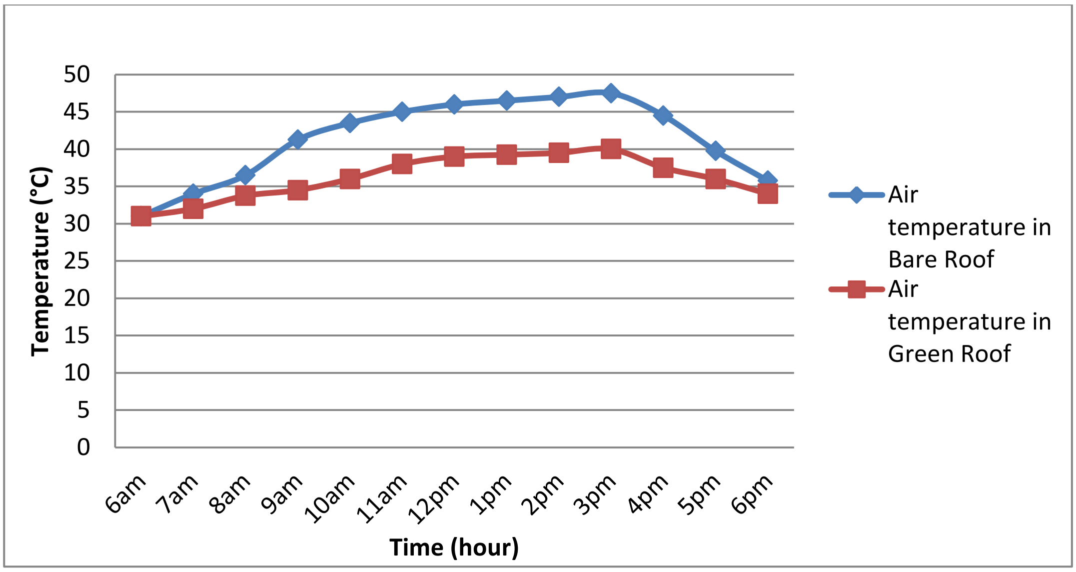


**Figure 4.9 Air Temperature with Roof Garden and Without Roof Garden**

However the reduction of air temperature followed a pattern. A maximum reduction of temperature was observed during peak heating period of 2pm to 3:30pm and minimum reduction occured during in off sunshine period.

## ii) Relative Humidity

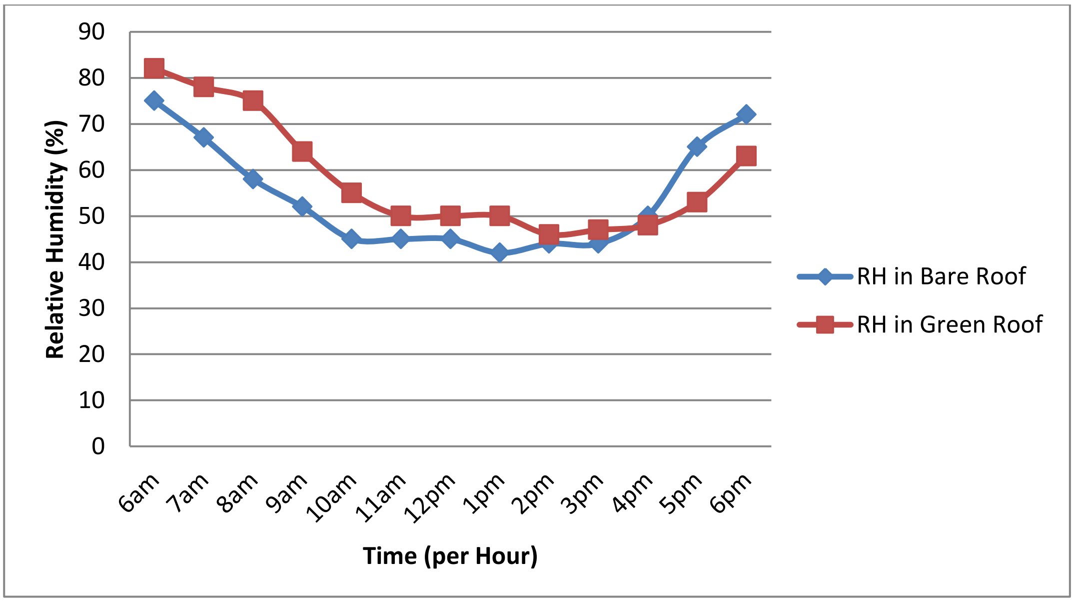


**Figure 4.10 Relative Humidity with Roof garden and Without Roof Garden**

It was found that the RH reading in bare roof was lower than the RH reading in roof garden for most of the time in a day. The RH reading was more or less similar from 2pm to 4pm in both roof garden and bare roof.

### b) Indoor thermal performance

#### i) Temperature:

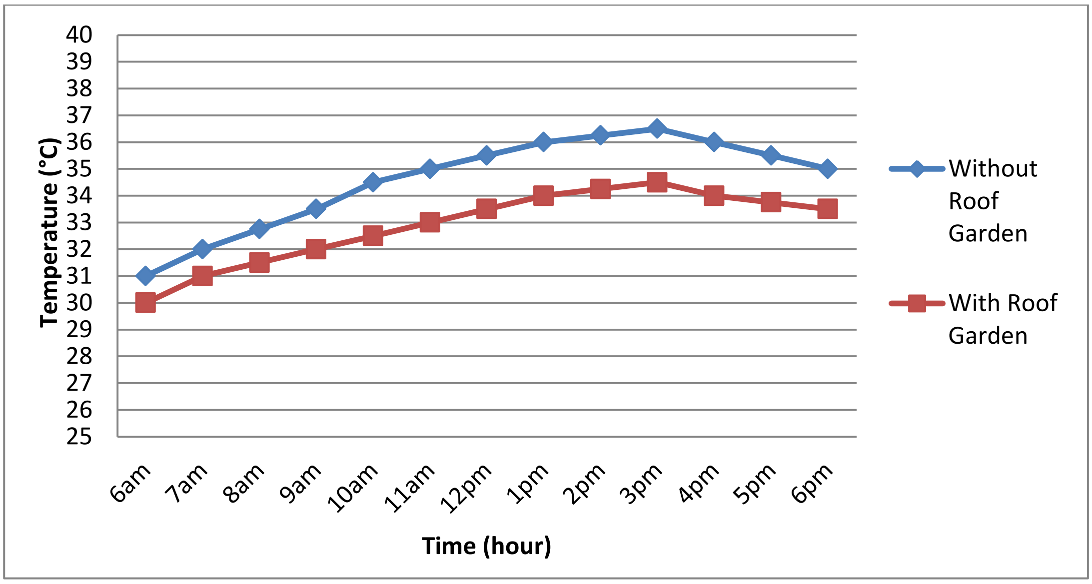


**Figure 4.11 Indoor Temperature with Roof Garden and Without Roof Garden**

It was found that the average indoor air temperature was reduced by 1.7°C with an extensive roof garden from 6am to 6pm. Daily average indoor air temperature is 34.6°C with bare roof. This is reduced by 1.7°C with roof garden, thereby reducing the average indoor air temperature to 32.8°C

#### ii) Relative Humidity:

It was found that the average indoor RH was more or less similar in both rooms under roof garden and bare roof until 11 am. The RH of the room under bare roof started to fall from 12 pm to 3pm from 60% to 45% while the RH of the room under roof garden were 55% at 1 pm. Moreover, the RH fluctuation was higher in the room under bare roof.

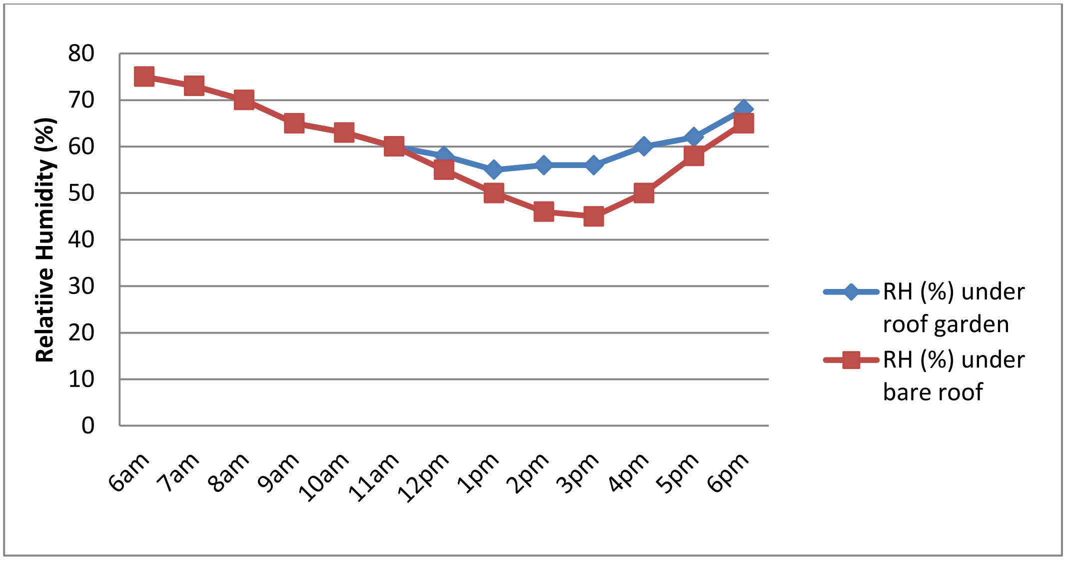


**Figure 4.12 Indoor RH (%) with Roof Garden and Without Roof Garden**

comfort zone analysis for Bangladesh according to Sharma, Ali and Mallick (1995) during the summer season, the comfort temperature range is between 24 ºC to 32 ºC while relative humidity range is fixed in 50% (lower limit) to 90% (upper limit). According to the graph profile the indoor temperature of the residence shows that maximum hour of the day is stay within comfort temperature range. It is a desirable condition for the resident.

#### 4.3.1.2 Qualitative analysis of thermal regulation

**Table 4.14 Distribution of garden owners according to thermal comfort**

| Areas | Thermal comfort | | | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | High | | Medium | | Low | | Not at all | | | |
| | N | P (%) | N | P (%) | N | P (%) | N | P (%) | N | P (%) |
| **Mohammad pur** | 4 | 10 | 6 | 15 | 5 | 12.5 | 0 | 0 | **15** | **37.5** |
| **Adabor** | 1 | 2.5 | 4 | 10 | 2 | 5 | 1 | 2.5 | **8** | **20** |
| **Dhanmondi** | 1 | 2.5 | 4 | 10 | 1 | 2.5 | 0 | 0 | **6** | **15** |
| **Kalabagan** | 6 | 15 | 3 | 7.5 | 1 | 2.5 | 1 | 2.5 | **11** | **27.5** |
| **Total** | **12** | **30** | **17** | **42.5** | **9** | **22.5** | **2** | **5** | **40** | **100** |

Qualitative analysis of thermal comfort was assessed using a semi-structured open questionnaire. Each respondent were asked about their personal thermal comfort with given choices. The result revealed that 30% roof garden provide high thermal comfort while 42.5% roof garden provide medium thermal comfort followed by 22.5% low thermal comfort and 5% provide no thermal comfort at all.

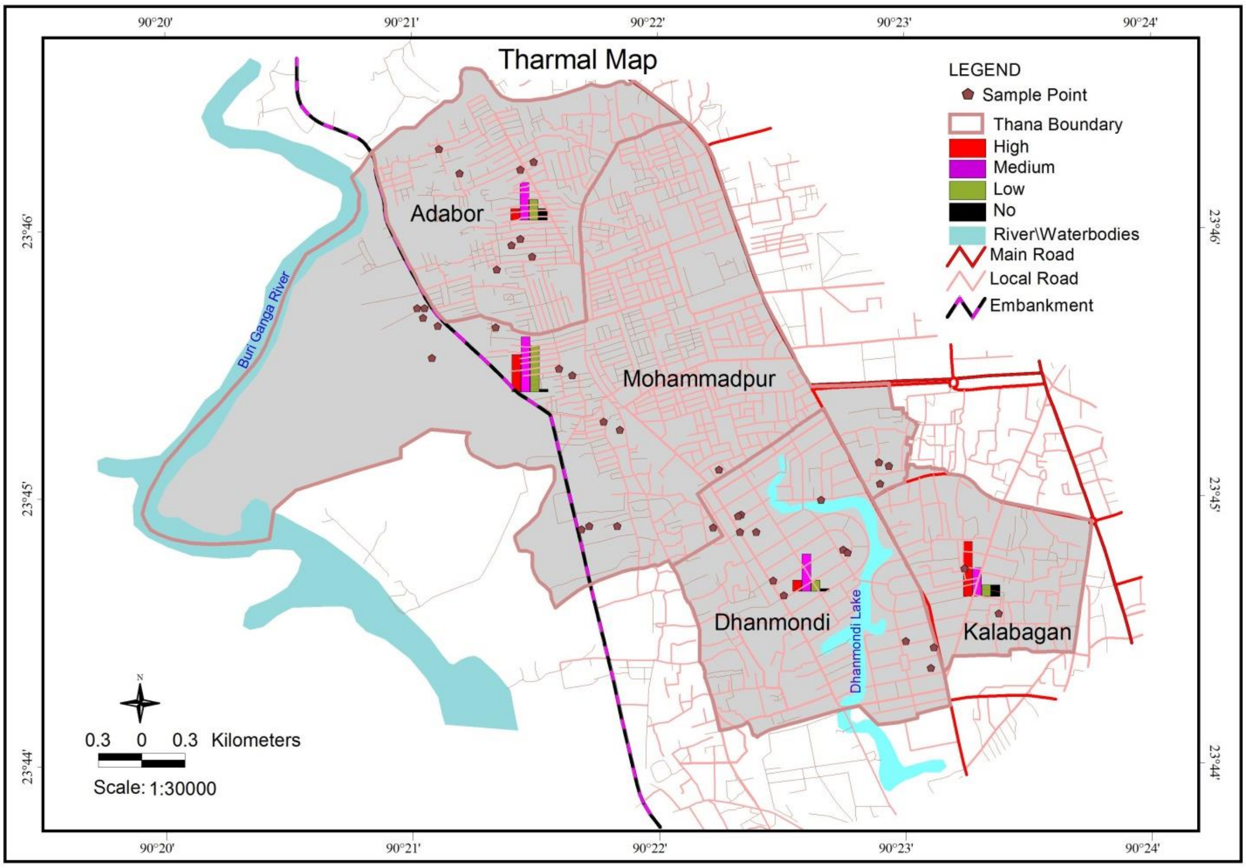


**Figure 4.13 Spatial Distribution of Thermal Comfort of Across the Study Area**

Among the four study areas, high thermal comfort was found in 15 roof garden in Kalabagan, followed by 10 roof garden in Mohammadpur and 1 roof garden in Adabor and Dhanmondi. Medium thermal comfort was found in 6 roof garden in Mohammadpur, followed by 4 roof garden in Adabor and Dhanmondi and 3 roof garden in Kalabagan. Low thermal comfort was found in 5 roof garden in Mohammadpur, followed by 2 roof garden in Adabor and 1 roof garden in Dhanmondi and Kalabagan. No thermal comfort was found in 1 roof garden of Adabor and 1 of Kalabagan. This distribution has been spatially shown in Figure 4.12.

#### 4.3.1.3 Thermal comfort with vegetation coverage

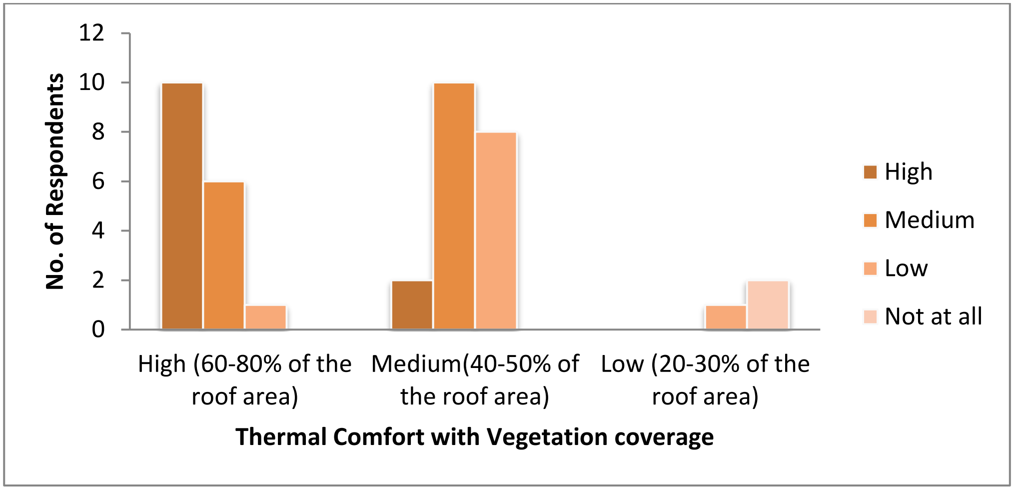


**Figure 4.14 Relationship between thermal comfort and vegetation coverage**

Figure shows the relationship between vegetation coverage and thermal comfort, where the findings showed that Thermal comfort is proportional to vegetation coverage. Higher thermal comfort were mostly found in the roof gardens with high vegetation coverage.

#### 4.3.1.4 Thermal comfort with Species diversity

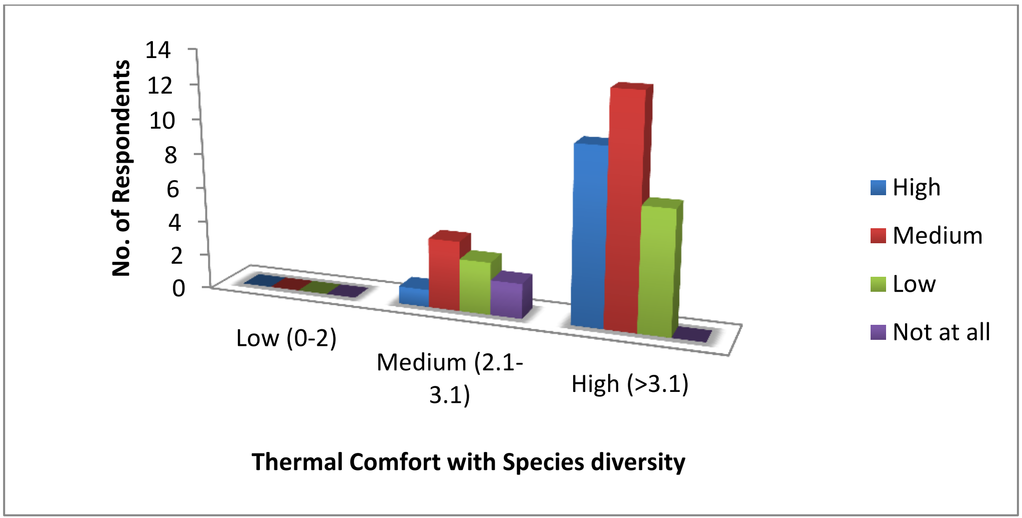


**Figure 4.15 Relationship between thermal comfort and species diversity**

Figure shows the relationship between plant species diversity and thermal comfort, where the findings showed that Thermal comfort is proportional to the plant species diversity. The higher the plant species diversity the higher the thermal comfort.

### 4.3.2. Disease Regulation

According to the survey the gardeners grew 564 number of 15 different species of medicinal plants (Table 4.11) which provide the gardeners' families with necessary health support and help in common disease regulation periodically.

## 4.4 Cultural Service

### 4.4.1 Aesthetics

According to the survey the 40 different flower species (Table 4.7) and 32 different ornamental plant species (Table 4.9) were found which contribute to the aesthetics of the roof area of the growers and create a platform for recreation and leisure time activity, improve psychological health and spiritual strength.

### 4.4.2 Frequency of Visit

The frequency of visiting the roof garden by the gardener and his family members is an indicator of recreation or leisure time activity which is an important factor of psychological health and thus considered as cultural service of RTG.

**Table 4.15 Distribution of garden owners according to their frequency of visiting the roof garden**

| Category | Areas | | | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mohammadpur | | Adabor | | Dhanmondi | | Kalabagan | | | |
| | N | P(%) | N | P(%) | N | P(%) | N | P(%) | N | P(%) |
| Daily | 12 | 30 | 7 | 17.5 | 6 | 15 | 7 | 17.5 | **32** | **80** |
| Weekly | 2 | 5 | 1 | 2.5 | 0 | 0 | 4 | 10 | **7** | **17.5** |
| Monthly | 1 | 2.5 | 0 | 0 | 0 | 0 | 0 | 0 | **2** | **2.5** |
| **Total** | **15** | **37.5** | **8** | **20** | **6** | **15** | **11** | **27.5** | **40** | **100** |

The survey revealed that 32 (80%) roof gardens are visited daily while 7 (17.5%) roof gardens are visited weekly and only 1 (2.5%) roof garden is visited monthly.

### 4.4.3 Time spent

The time spent by the gardener and his family members is an indicator recreation or leisure time activity which is an important factor of psychological health and thus considered as cultural service of RTG. The result showed that 22.5% garden owners spend upto 1 hour for gardening activities while 50% garden owners spend 1 to 2 hours and 27.5% garden owner's spend more than 2 hours for gardening activities.

**Table 4.16 Distribution of garden owners according to time spent on roofgarden**

| Time (hour) | Areas | | | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mohammad pur | | Adabor | | Dhanmondi | | Kalabagan | | | |
| | N | P(%) | N | P(%) | N | P(%) | N | P(%) | N | P(%) |
| **0-1** | 4 | 10 | 1 | 2.5 | 3 | 7.5 | 1 | 2.5 | **9** | **22.5** |
| **1-2** | 8 | 20 | 4 | 10 | 2 | 5 | 6 | 15 | **20** | **50** |
| **>2** | 3 | 7.5 | 3 | 7.5 | 1 | 2.5 | 4 | 10 | **11** | **27.5** |
| **Total** | **15** | **37.5** | **8** | **20** | **6** | **15** | **11** | **27.5** | **40** | **100** |

### 4.4.4. Mental satisfaction

Mental satisfaction or spiritual improvement was assessed using a semi-structured open questionnaire. Gardeners' choice was given as high, medium and low. The result showed that High mental satisfaction was mostly found in Mohammadpur and Kalabagan than the other two areas. Mental satisfaction was found high in 7 garden owners in Mohammadpur and Kalabagan, followed by 3 in Adabor and 2 in Dhanmondi.

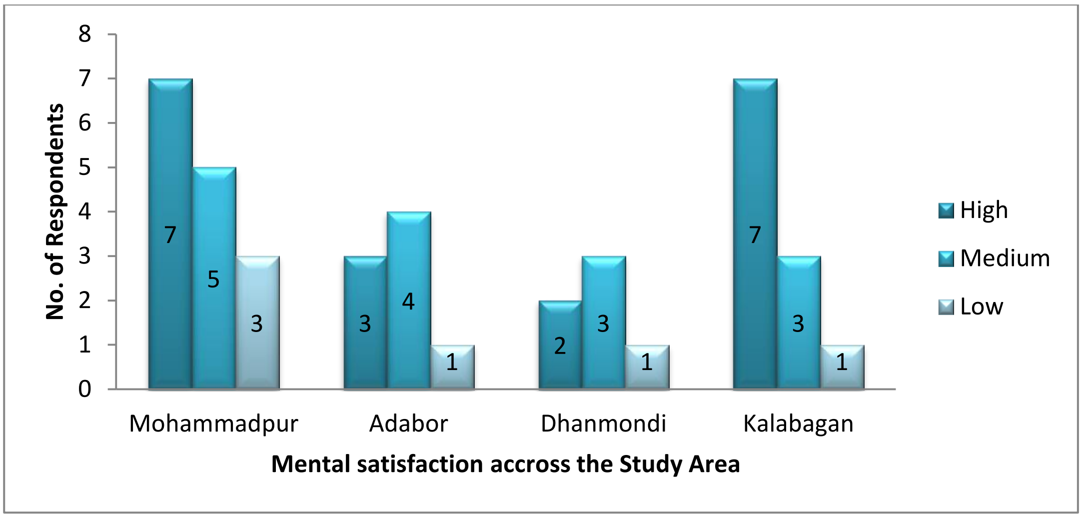


**Figure 4.16 distribution of garden owners according to mental satisfaction**

Mental satisfaction was found medium in 5 garden owners in Mohammadpur, followed by 4 in Adabor and 3 in both Dhanmondi and kalabagan. Mental satisfaction was found low in 3 garden owners in Mohammadpur and only one garden owner of Adabor, Dhanmondi and Kalabagan. This distribution has been shown spatially in Figure 4.16.

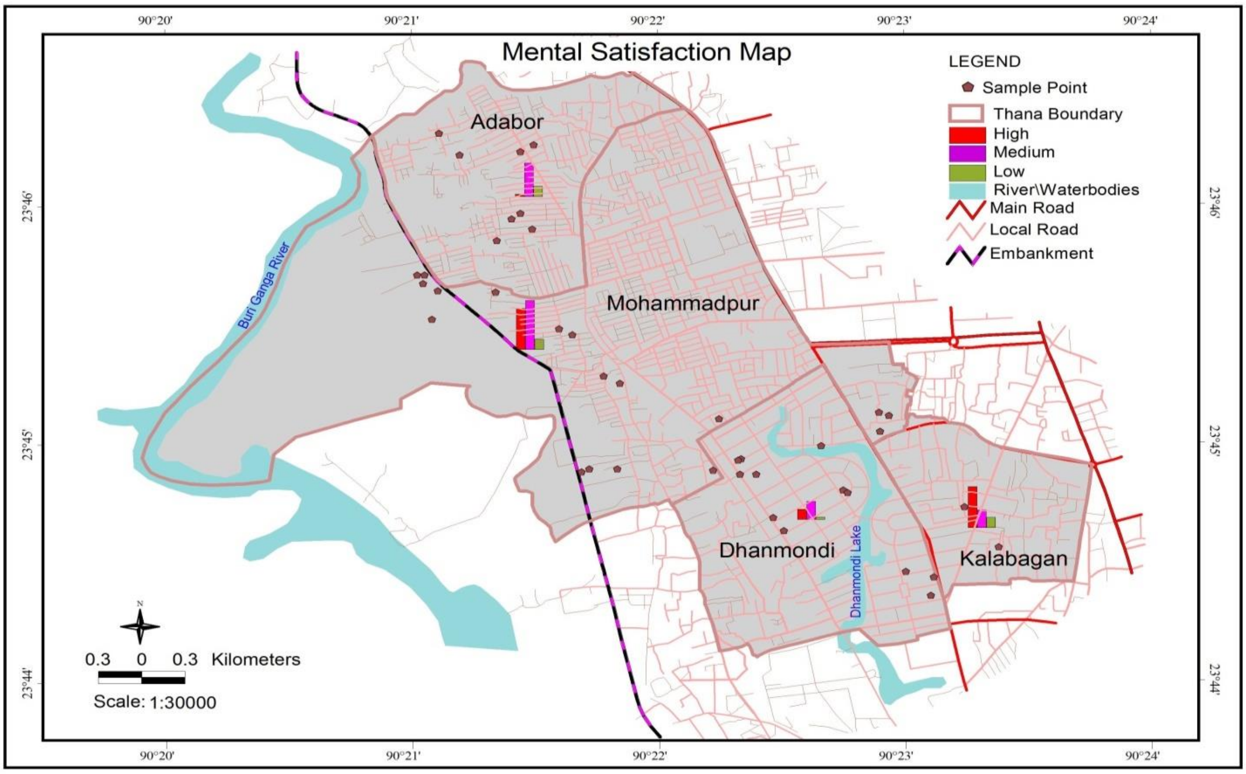


**Figure 4.17 Spatial Distribution of Mental Satisfaction Across the Study Area**

### 4.4.4.1. Mental satisfaction with species diversity

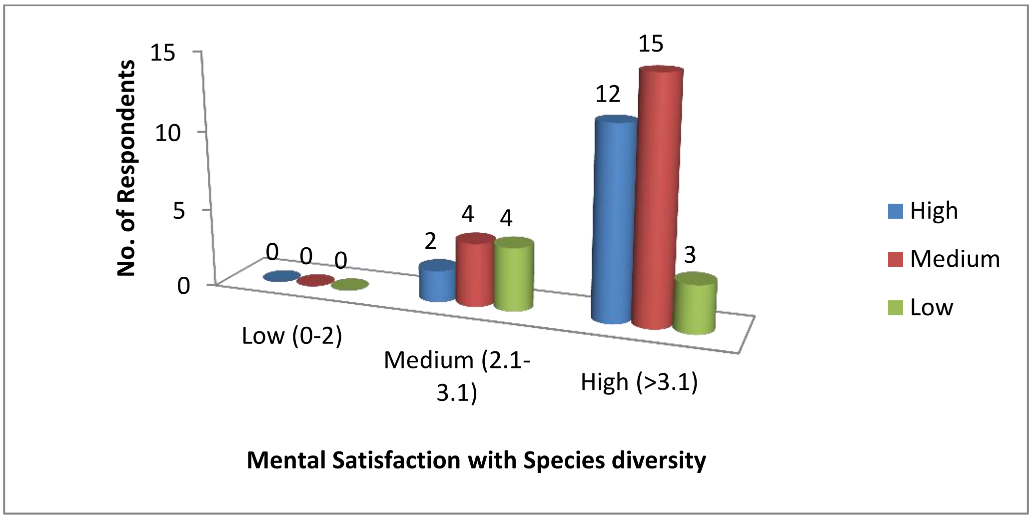


**Figure 4.18 Relationship between mental satisfaction and plant species diversity**

A qualitative analysis was done by analyzing the relationship between mental satisfaction and plant species diversity, where the findings showed that mental satisfaction is proportional to plant species diversity. Mental satisfaction increases with species diversity.

### 4.4.4.2. Mental satisfaction with yearly food production

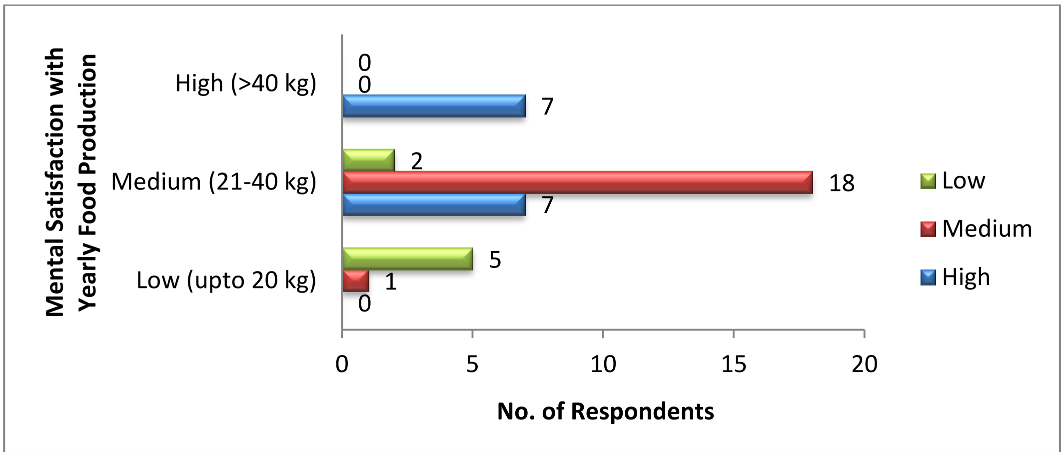


**Figure 4.19 Relationship between mental satisfaction and yearly food production**

A qualitative analysis was done by analyzing the relationship between mental satisfaction and yearly food production, where the findings showed that mental satisfaction is proportional to yearly food production. Mental satisfaction increases with food production.

### 4.4.5. Education and learning

Through experimentation with gardening practices, the garden owners get the opportunity to improve their education and learning on various aspects regarding gardening. Moreover, they face various problems going through this practice for which they periodically contact with relevant personnel or organizations for necessary technical support or go for training and gathering knowledge. All these activities enhance their learning and experience.

#### 4.4.5.1. Technical Support of the garden owners

According to the survey, 17 garden owners get technical support from Agricultural offices, while 10 garden owners from Nearby nurseries, 5 frm media and 8 of them get no technical support.

**Table 4.17 Distribution of garden owners according to technical support:**

| Area | Technical Knowledge | | | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Agricultural office | | Nearby Nursery | | Media | | No technical support | | | |
| | N | P(%) | N | P(%) | N | P(%) | N | P(%) | N | P(%) |
| **Mohammadpur** | 7 | 17.5 | 4 | 10 | 1 | 2.5 | 3 | 7.5 | **15** | **37.5** |
| **Adabor** | 3 | 7.5 | 2 | 5 | 2 | 5 | 1 | 2.5 | **8** | **20** |
| **Dhanmondi** | 1 | 2.5 | 3 | 7.5 | 1 | 2.5 | 1 | 2.5 | **6** | **15** |
| **Kalabagan** | 5 | 12.5 | 1 | 2.5 | 1 | 2.5 | 4 | 10 | **11** | **17.5** |
| **Total** | **17** | **40** | **10** | **25** | **5** | **12.5** | **8** | **22.5** | **40** | **100** |

According to the survey, 17 garden owners get technical support from Agricultural offices, while 10 garden owners from nearby nurseries, 5 from media and 8 of them get no technical support.

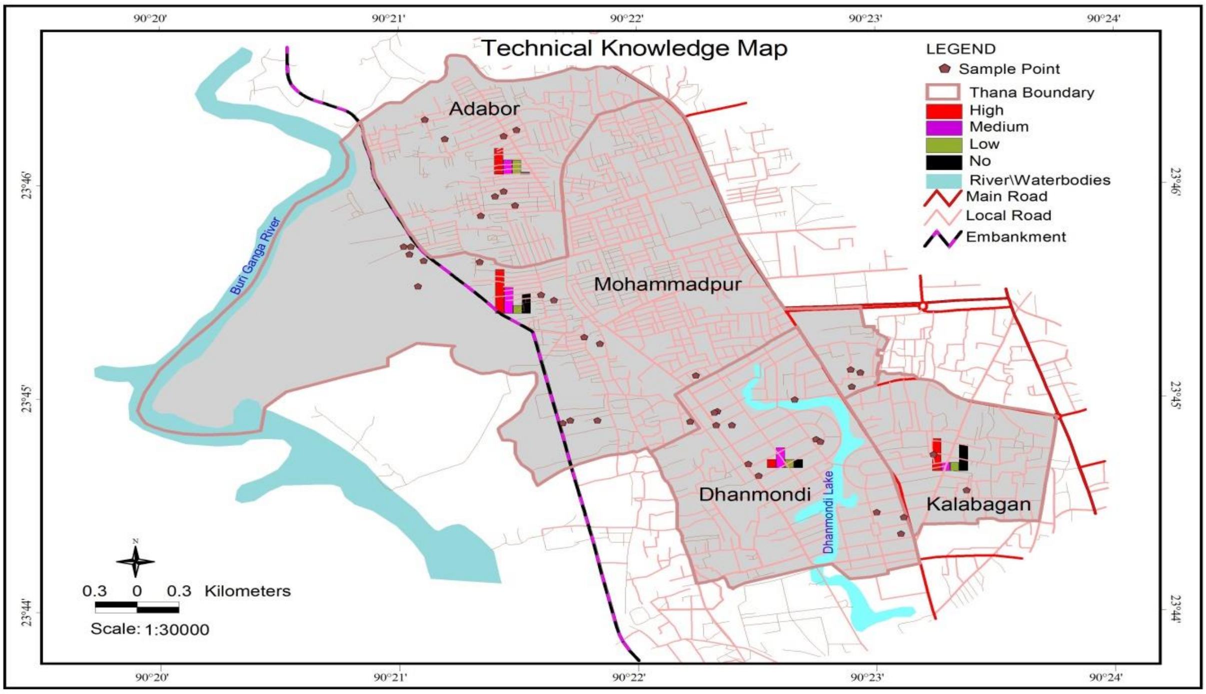


**Figure 4.20 Spatial distribution of technical knowledge of the garden owners**

Spatial distribution shows that garden owners receive their technical support from agricultural offices were found in higher number in Mohammadpur (17.5%) and Kalabagan (12.5%). Garden owners with no technical support were mostly found in Kalabagan (10%) and Mohammadpur (7.5%).

#### 4.4.5.2.Training of the garden owners

**Table 4.18 Distribution of garden owners according to their training**

| Area | Categories (days) | | | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No training | | Low (1 day) | | Medium (2-3 days) | | High (4-5 days) | | | |
| | N | P(%) | N | P(%) | N | P(%) | N | P(%) | N | P(%) |
| **Mohammadpur** | 6 | 15 | 3 | 7.5 | 3 | 7.5 | 3 | 7.5 | 15 | 37.5 |
| **Adabor** | 0 | 0 | 3 | 7.5 | 3 | 7.5 | 2 | 5 | 8 | 20 |
| **Dhanmondi** | 2 | 5 | 2 | 5 | 2 | 5 | 0 | 0 | 6 | 15 |
| **Kalabagan** | 0 | 0 | 2 | 5 | 5 | 12.5 | 4 | 10 | 11 | 17.5 |
| **Total** | **8** | **20** | **10** | **25** | **13** | **32.5** | **9** | **22.5** | **40** | **100** |

Garden owners received training (days) from DAE project training program for gardening which was categorized into five (0 to 5 days) groups where 0 day indicated no training received for gardening and 5 days indicated better training received for gardening.

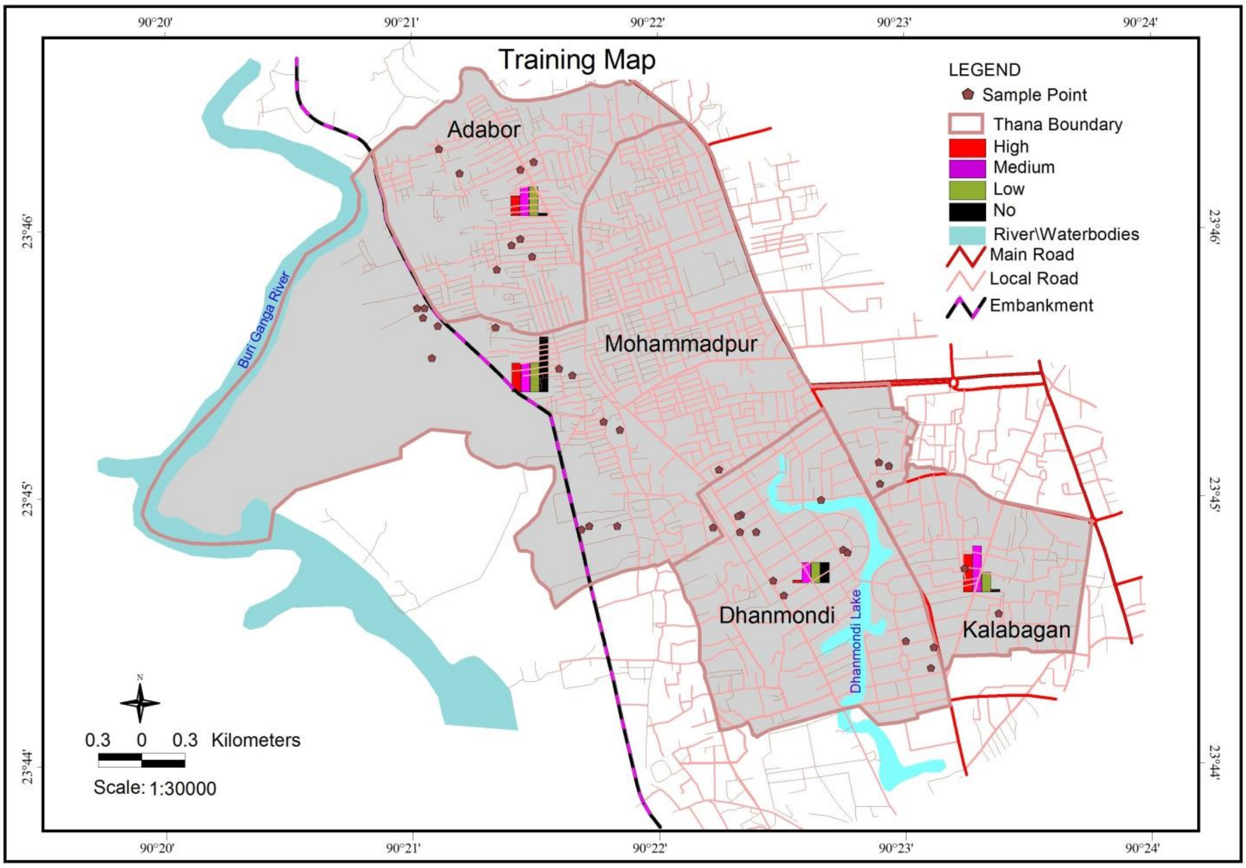


**Figure 4.21 Spatial distribution of training facilities of the garden owners across the study area**

According to the survey, 3 garden owners received 5 days training, while 6 of them received 4 days training, 6 of them received 3 days training, 7 of them received 2 days training, 10 garden owners received 1 day training and 8 garden owners received no training at all. This distribution has been spatially shown in Figure 4.20.

## 4.5. Individual characteristics of the garden owners

In this section the findings of the garden owner's individual characteristics have been discussed. Descriptive statistics of twenty Two characteristics of the garden owners have been presented in Appendix-II.

### 4.5.1. Gender, age and marital status of the garden owners

Survey result showed 55% garden owners were male and 45% of them were female, where most of them are middle aged.

**Table 4.19 Distribution of garden owners according to their gender, age and marital status**

| Age Categories | Gender | | | | Marital Status | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Male | | Female | | Married | | Unmarried | | Divorced | |
| | N | P(%) | N | P(%) | N | P(%) | N | P(%) | N | P(%) |
| **Young (upto 30)** | 3 | 7.5 | 2 | 5 | 3 | 7.5 | 2 | 5 | 0 | 0 |
| **Middle age (31-50)** | 9 | 22.5 | 9 | 22.5 | 16 | 40 | 0 | 0 | 2 | 5 |
| **Old (above 50)** | 10 | 25 | 7 | 17.5 | 17 | 42.5 | 0 | 0 | 0 | 0 |
| **Total** | **22** | **55** | **18** | **45** | **36** | **90** | **2** | **5** | **2** | **5** |

According to the survey, 12.5% garden owners are upto 30 years old while 45% garden owners age ranges between 31 to 50 and 42.5% garden owners are above 50 years old. The marital status showed that 90% respondents are married while only 5% are unmarried and 5% are divorced.

### 4.5.2. Education of the garden owners

According to the survey, 25% respondents were found being post graduate, 45% respondents were found being graduate, 25% were found educated to secondary/higher secondary level while only 5% were found educated to primary level.

**Table 4.20 Distribution of garden owners according to their Education**

| Area | Education | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Primary | | Secondary/ Higher Secondary | | Graduate | | Post Graduate | | Total | |
| | N | P(%) | N | P(%) | N | P(%) | N | P(%) | N | P(%) |
| **Mohammad pur** | 0 | 0 | 4 | 10 | 5 | 12.5 | 6 | 15 | **15** | **37.5** |
| **Adabor** | 0 | 0 | 1 | 2.5 | 5 | 12.5 | 2 | 5 | **8** | **20** |
| **Dhanmondi** | 0 | 0 | 1 | 2.5 | 4 | 10 | 1 | 2.5 | **6** | **15** |
| **Kalabagan** | 2 | 5 | 4 | 10 | 4 | 10 | 1 | 2.5 | **11** | **17.5** |
| **Total** | **3** | **5** | **10** | **25** | **19** | **45** | **8** | **25** | **40** | **100** |

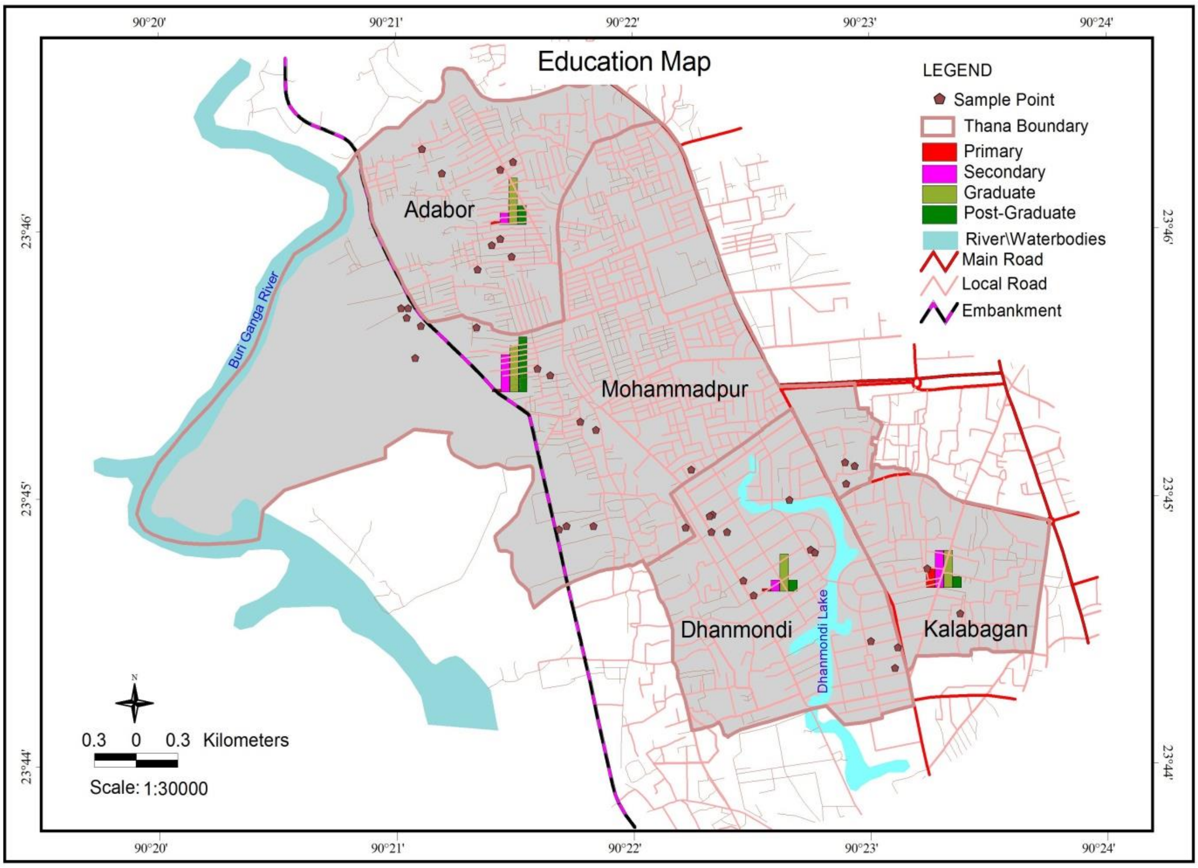


**Figure 4.22 Spatial distribution of education of the garden owners across the study area**

In Mohammapur area, 4 garden owners of secondary/higher secondary level, 5 graduate and 6 post graduate were found. In Adabor area, 1 garden owner of secondary/higher secondary level, 5 graduate and 4 post graduate were found. In Dhanmondi area, 1 garden owner of secondary/higher secondary level, 4 graduate and 1 post graduate were found. In Kalabagan area 4 garden owners of secondary/higher secondary level, 4 graduate and 1 post graduate were found. This distribution has been spatially shown in Figure 4.21.

#### 4.5.3. Occupation of the garden owners

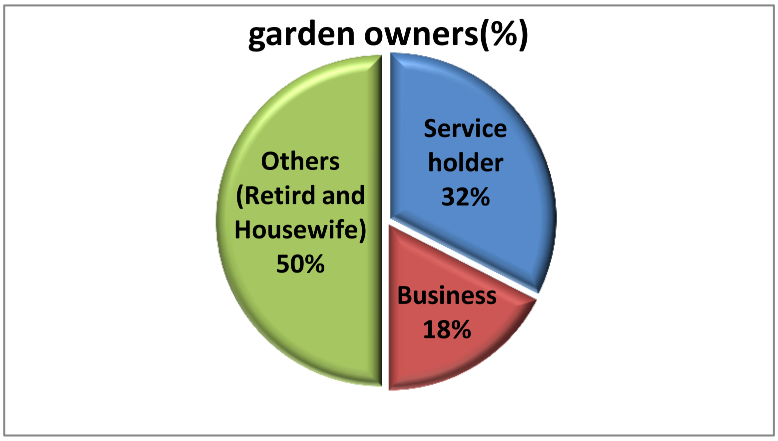


**Figure 4.23 Distribution of garden owners according to their occupation**

According to the survey, 32% garden owners were service holder, while 18% were businessmen and 50% (20 respondents) were retired and housewife.

#### 4.5.4. House ownership of the garden owners

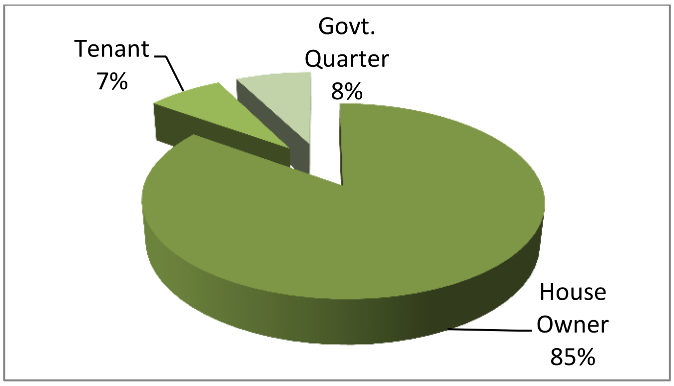


**Figure 4.24 Distribution of garden owners according to house ownership**

According to the survey, 85% garden owners were owner of their house buildings, while only 7% garden owners were tenant and only 8% roof gardens were found in Government quarters.

#### 4.5.5. Family size of the garden owners

According to the survey, most of the families of the garden owners belong to small to medium families. 17 garden owners (42.5%) had small family size and 16 garden owners (40%) had medium family size while only 7 of them (17.5%) had large family size.

**Table 4.21 Distribution of garden owners according to their family size**

| Family size | Frequency | Percentage (%) |
|---|---|---|
| **Small (2-4)** | 17 | 42.5 |
| **Medium(5-7)** | 16 | 40 |
| **Large (>7)** | 7 | 17.5 |
| **Total** | **40** | **100** |

### 4.5.6. Annual income of the garden owners

According to the survey, rooftop gardening practice was mostly observed in the higher class people of the society. Among 40 respondents, 18 respondents had higher annual income, 15 respondents had middle annual income while only 1 respondent were found to have lower annual income.

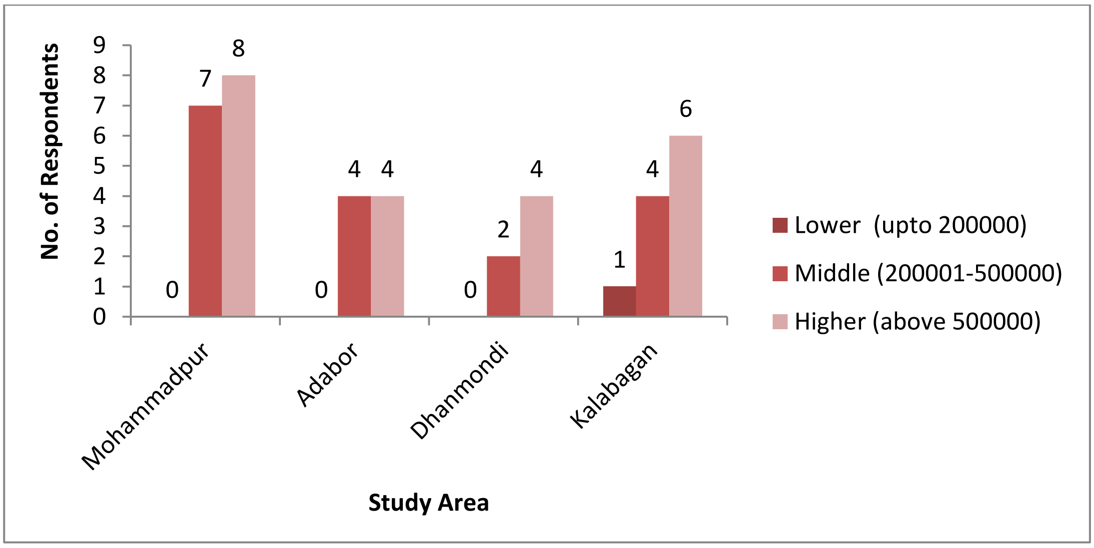


**Figure 4.25 Distribution of garden owners according to their annual income**

In Mohammadur Thana area, 8 garden owners had higher annual income while 7 had middle annual income. In Adabor thana area, both higher and middle annual income was found among 4 garden owners. In Dhanmondi Thana area, 4 higher and 2 middle annual income was found among the respondents. In

Kalabagan Thana area, 6 higher, 4 middle and only 1 lower annual income were found among the respondents.

### 4.5.7. Surface area of the roof gardens

According to the survey the surface area was found large ( above 2100 sq.ft.) in 32.5% roof gardens while 55% roof gardens had medium surface area (1601-2100 sq.ft.) and small surface area (1000-1600 sq.ft.) were found in 12.5% roofgardens

**Table 4.22 Distribution of garden owners according to roof surface area**

| Surface area | Areas | | | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mohammadpur | | Adabor | | Dhanmondi | | Kalabagan | | | |
| | N | P(%) | N | P(%) | N | P(%) | N | P(%) | N | P(%) |
| **Small (1000-1600 sq.ft.)** | 2 | 5 | 1 | 2.5 | 0 | 0 | 2 | 5 | **5** | **12.5** |
| **Medium (1601-2100 sq.ft.)** | 9 | 22.5 | 5 | 12.5 | 3 | 7.5 | 5 | 12.5 | **22** | **55** |
| **Large (>2100 sq.ft.)** | 4 | 10 | 2 | 5 | 3 | 7.5 | 4 | 10 | **13** | **32.5** |
| **Total** | **15** | **37.5** | **8** | **20** | **6** | **15** | **11** | **17.5** | **40** | **100** |

In Mohammadpur, 10% roof gardens were found with large surface area, 22.5% were medium and 5% were found small. In Adabor thana, 5% roof surface were found large while 12.5% were medium and 2.5% small. In Dhanmondi, 7.5% roof surface area were found large, 7.5% medium and no small roof surface area were found there. In Kalabagan, 10% roof garden were found with large surface area, 12.5% medium and 5% were found with small surface area.

### 4.5.8. Pupose of gardening

Purpose of rooftop gardening was assessed using a semi-structured open questionnaire.

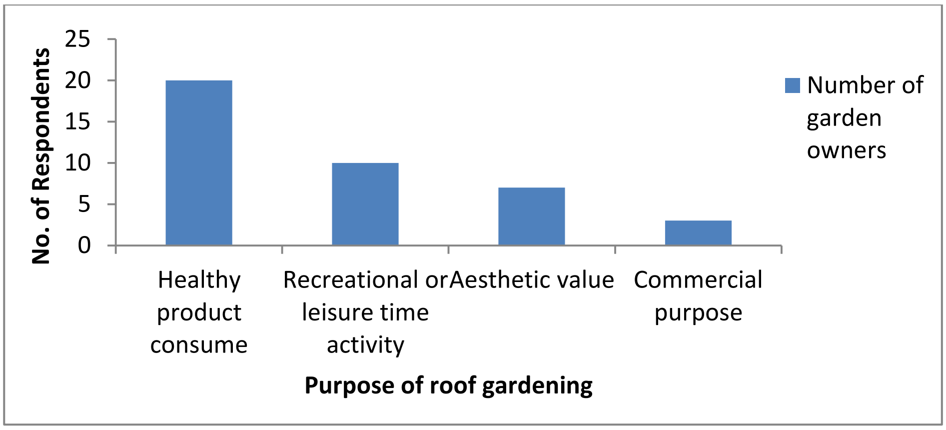


**Figure 4.26 Distribution of garden owners according to purpose of gardening**

The result showed that 20 garden owners were interested for rooftop gardening because they thought that gardening products were healthy for consumption (50%), 10 garden owners were interested for rooftop gardening as leisure time activity or recreational activity (25%), 7 garden owners practiced gardening for aesthetic value (17.5%) while only 3 garden owners had roof gardens for commercial purpose (7.5%).

### 4.6. Overall Ecosystem Services through qualitative analysis in the Survey:

The overall ecosystem services from the 40 rooftop gardens of the study area has been presented in this section. The results are derived from the previous qualitative analytical tables and categorized as high, medium, low and not at all. The percentage of garden owners receiving major ecosystem services are listed in table 4.23.

The provisioning services include fruits and vegetable production which was evaluated as regularity of food supply from Table 4.1. Supporting services were evaluated according to plant species diversity across the study area from Table 4.6. Regulating services include thermal regulation and disease regulation. Thermal regulation was evaluated according to qualitative analytical Table 4.9 and disease regulation was evaluated according to medicinal plants density in Table 4.1. Among the cultural services mental satisfaction was evaluated according to Graphical Figure 4.9 and education and learning from Table 4.12 and 4.13.

**Table 4.23 Overall Ecosystem Services Provided by RTGs in the Study**

| Ecosystem Services | | Categories | | | |
|---|---|---|---|---|---|
| | | **High** | **Medium** | **Low** | **Not at all** |
| **Provisioning** | **Food Production** | 27.5% | 52.5% | 20% | -- |
| | **Food supply** | 40% | 45% | 15% | -- |
| **Supporting** | **Plant Species Diversity** | 75% | 22.5% | 2.5% | -- |
| | **Economic** | 7.5% | 57.5% | 32.5% | 2.5% |
| **Regulating** | **Thermal Regulation** | 27.5% | 42.5% | 22.5% | 5% |
| | **Disease Regulation** | 2.5% | 22.5% | 75% | -- |
| **Cultural** | **Mental Satisfaction** | 47.5% | 37.5% | 15% | -- |
| | **Education & Learning** | 22.5% | 32.5% | 25% | 20% |

The overall findings showed that the ecosystem services provided by the rooftop gardens are mostly medium. Provisioning services provided by RTGs are mostly medium, Supporting services include high plant species diversity conservation and medium economic support. Regulating services are mostly medium as RTGs provide medium thermal and disease regulation. Cultural services of RTGs are mostly high. So, It is clear from the above Table 4.19 that the potential of RTGs in providing ecosystem services is high and it can improve the overall wellbeing of city dwellers if practiced in large context.

# CHAPTER V

# SUMMARY, CONCLUSION AND RECOMMENDATION

## a. Summary

According to the survey, the major ecosystem services being received by the garden owners of the study area and their selected characteristics are as follows:

Fruits and vegetable production was the main provisioning service provided by RTGs. 40% of the garden owner get daily food supply from their roof gardens, 45% get weekly food supply and only 15% get the food supply monthly. Yearly food production was found mostly medium (21-40 kg/year) in 65% roof gardens while high food production (above 40 kg) was found in 22.5% garden and low (upto 20 kg) was found in 12.5% roof garden. Moreover, fruit species was found in high density (51-100 or more) in 15% roof gardens, medium (21-50) in 65% gardens and low (1-20) in 20% gardens. Vegetable species were found in high density (51-100 or more) in 35% gardens, medium (21-50) in 42.5% garden and low (1-20) in 22.5% gardens.

Supporting Services include plant species diversity and economic support. In case of plant species diversity Conservation: The result revealed that the rooftop gardens of Dhaka city possess high plant species diversity where Shannon-Weaver diversity index were 4.51. In case of species richness, total 150 types of species were found among which 38 types were fruit, 25 types were vegetable, 40 types were flower, 32 types were ornamental and 15 types were medicinal species. Inter-species diversity was found higher for Flowering plant species (0.988) in the roof garden of the study area followed by vegetable species (0.977), ornamental species (0.966), fruit species (0.944) and medicinal species (0.895).Among 38 species of fruits, Mango (127.1%) was found the highest prevalent and Dragon fruit (10.2%) was found the lowest prevalent. Moreover, mango, guava, Papaya, lebu and Jamrul were ranked in top position. Among 40 species of flowers, Beli (115.7%) was found the highest prevalent and Bottle Brush (24.1%) was found the lowest prevalent. On the basis of relative prevalence, beli, Baganbilash, Rangan, Musanda and Nayantara were ranked in top position. Out of 25 vegetable species, Begun (132.6%) was found the highest prevalent and Sharisha shak (31.1%) was found the lowest prevalent. On the basis of relative prevalence, Begun, Lau, Tomato, Korolla and Dherosh were ranked in top position. Out of 32 ornamental species, Croton (110.1%) was found the most prevalent and King Sago Palm (41.3%) was found the lowest prevalent. On the basis of relative prevalence, Croton, Pathos (Money plant), Cactus and Spider plant were ranked in top position. Out of 15 medicinal species, Henna (113.4) was found the most prevalent and Clove (23.4) was found the lowest prevalent. On the basis of relative prevalence, Henna, Pudina, Dhonia, Tulsi and Aloevera were ranked in top position.

In case of economic support**,** among 40 respondents, only 3 of them each from Mohammadpur, Adabor and Kalabagan were found to be involved in marketing of their produce. Gardeners sell their surplus products sporadically in different local markets, directly or through intermediaries, with no uniform pricing for system. Sufficient employment opportunity was found as 50% garden owners recruited well paid gardener and 25% of them nursed their gardens by family paid personnel or extra paid servant.

According to the graph profile of the quantitative analysis of thermal regulation the indoor temperature of the residence showed that maximum hour of the day is stay within comfort temperature and RH range which is 24 to 32°C and 50-90% RH. It is a desirable condition for the resident.The experimental analysis resulted that roof air temperature is reduced by 5.2°C with green roof during sunshine hours while A maximum reduction of temperature is observed during peak heating period of 2pm to 3:30pm and minimum reduction occurs during in off sunshine period. The average reduction of RH was 4.4% in bare roof while the reading was more or less similar from 2pm to 4pm.Daily average indoor air temperature is 34.6°C with bare roof. This is reduced by 1.7°C with roof garden, thereby reducing the average indoor air temperature to 32.8°C. It was found that the average reduction of RH was 3.2% in the room under bare roof. The average indoor RH was more or less similar in both rooms except from 12 pm to 3pm.

The qualitative analysis resulted that high thermal comfort was found in 30% roof gardens, while medium and low thermal comfort was found in 42.5% and 22.5% roof gardens respectively. In 5% garden no thermal comfort was found. Morever thermal comfort is proportional to vegetation coverage and species diversity.

In case of disease regulation**,** Total 564 plants of 15 different medicinal species under 13 genera and 13 families were found in the study area which contribute to reduce common diseases of the garden owners' families periodically.

The cultural Services include aesthetic value, mental satisfaction, education and learning. Total 791 plants of 40 different flower species and 963 plants of 32 different ornamental plant species were found in the study area, which contribute to the aesthetic value of the Roof and create a platform for recreation.

Mental satisfaction was found high in 47.5% garden owners while medium and low mental satisfaction was found in 37.5% and 15% garden owners. Moreover, mental satisfaction is proportional to species diversity and yearly food production. In case of frequency of visit 80% roof gardens are visited daily while 17.5% roof gardens are visited weekly and only 2.5% roof garden is visited monthly. In case of time spent 22.5% garden owners spend up to 1 hour for gardening activities while 50% garden owners spend 1 to 2 hours and 27.5% garden owner's spend more than 2 hours for gardening activities.

Education and learning was measured through technical knowledge and training facilities. In case of technical knowledge, 42.5% garden owners get technical support from Agricultural offices, while 25% garden owners from nearby nurseries, 12.5% from media/printed matters and 20% of them get no technical support. In case of training, 32.5% gardeners got high training facilities(4-5 days), while medium (2-3) and low (1 day) categories of training was found in 22.5% and 25% gardeners respectively. 20% gardener had no training experience in their life.

In case of Selected Social Factors the survey result showed 55% male respondent and 45% female respondent, where most of them are middle aged (31 to 50). Most of the garden owners (70%) were highly educated (graduate/post-graduate). 32% garden owners were service holder, while 18% were businessmen and 50% (20 respondents) were retired and housewife. 85% garden owners were owner of their house buildings, while only 7% garden owners were tenant and only 8% roof gardens were found in Government quarters. Among 40 respondents, 45% respondents had higher annual income, 37.5% had middle annual income while only 2.5% were found to have lower annual income. Most of the roof gardens (55%) had medium surface area (1601-2100 sq.ft.). Purpose of gardening of 50% garden owners were healthy product consume while purpose of leisure time activity or recreational activity for 25%, aesthetic value (17.5%) while commercial purpose (7.5%) was found.

## b. Conclusion

Roof top gardening plays a significant role in urban landscape planning and management. For higher conservation of diversity with better aesthetic, environmental, and economic perspectives, plantation in the roof top is desirable. In this study, following conclusions were drawn on the basis of findings:

1. The prevailing RTGs in Dhaka city have been providing a number of ecosystem services (Provisioning, Supporting, Regulating, Cultural).
2. Different ecosystem services identified in the study were provision of food (fruits and vegetables), plant species diversity conservation, economic support (marketing, employment opportunity), thermal comfort, disease regulation (medicinal plants), aesthetics, recreation, education & learning.
3. The overall ecosystem services provided by the roof gardens were mostly found medium. Among these, the floral diversity conservation (Diversity Index 4.51), thermal regulation and mental satisfaction were found to be the most remarkable.
4. The experimental analysis of thermal performance resulted that average roof air temperature is reduced by 5.2°C with roof garden during sunshine hours while average room temperature is reduced by 1.7°C with roof garden compared to bare roof.
5. Incorporating GIS into research on green roofs were very useful for visualizing and analyzing spatial relationships in both environmental data and vegetation data across the areas, and these methods can certainly be applied to other areas with green roofs.
6. An understanding of the importance of ecosystem services could also mean that unexploited urban areas and prevailing infrastructures can be utilized by practicing this green technology for the development of an ecologically sustainable city.
7. Hopefully, an increased awareness of the ecosystem services could contribute to a more resource-efficient city structure and design. The urban ecosystems could then be fully appreciated for their contribution to urban life and valued accordingly when the land is claimed for exploitation.

## c. Recommendations

On the basis of results and conclusion of the study, recommendations are made as follows:

1. Different roof top gardening practices should be installed in the prevailing bare roofs for the fulfillment of the demand of urban garden owners, and environmental amelioration. But only few garden owners are involved in roof top gardening activities. It should be extended to all house owners, city dwellers and multistoried building owners under the city area.
2. As cities are expected to grow at a rapid rate in the coming decades, it is important that the ecosystem services in urban areas and the ecosystems that provide them are understood and valued by city planners and political decision makers and take necessary measures.
3. Adequate training, motivation and sustainable management are required to encourage the city people in practicing roof top garden to improve plant species diversity elsewhere in Bangladesh based on residential and rental houses.
4. The research had only included the roof top garden but not the garden in “Balcony’’, “Kitchen’’, “Container’’ and “Hydroponics” and “Aeroponics’’ or “Air-dynaponics” farming. At the time of data collection there was found that a large number of respondents had garden in balconies and kitchen. Based on this subject a further research would be done.
5. This research had only represented the ecosystem services through GIS maps across the study area. But due to severely expensive price of satellite images, remote sensing could not be done. Further research regarding ecosystem services of RTGs with the use of remote sensing and GIS model should be conducted for better understanding and decision making.
6. The present study was conducted in only four metropolitan areas of Dhaka city. Such studies are required to conduct in other areas of the country.

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# APPENDICES

## Appendix 1

AN ENGLISH VERSION OF THE INTERVIEW SCHEDULE

**Department of Agroforestry and Environmental Science**
**Sher-e-Bangla Agricultural University**
**Dhaka, Bangladesh**

*An interview schedule for a research study entitled*

**Assessment of Ecosystem services and Benefits of Rooftop Gardening for Eco-friendly City Development in Dhaka City using Geospatial Technology**

**Serial No.** ……………………….

**Date:** ……………………………..

**Name of the Survey Collector:** Iffat Jahan Nur

**Name of the garden owners:**

| Address of the Respondent | House no. | Road no. | Area | GPS reading |
|---|---|---|---|---|
| | | | | |

**Q:1. Gender:** Male………… female…………

**Q:2. How old are you?** …………………………Years

**Q:3. Marital Status:** Married/Unmarried/Divorced

**Q:4. Education of the garden owners:** ………………………………………..

| Q:5. | Give information about your annual income: | |
|---|---|---|
| | **Sources of income** | **Amount of annual income (Taka)** |
| | 1. Service holder | |
| | 2. Business | |
| | 3.Others | |

**Q:6. Family size:**

Male ……………….. Female ……………..…. Total ……………..……..

**Q:7. House Ownership**:

1. Owner……… 2. Rent……… 3. Government Quarter…………

| | | |
|---|---|---|
| **Q:8.** | **a) What is the approximate surface area of your roof garden?** | **square feet** |
| **Q:9.** | **b) What is the approximate surface area of your roof covered by vegetation?** | |

**Q:10. What is your purpose of practicing rooftop gardening?**

1. Recreation ☐ 2. Economic ☐ 3. Nutritional ☐ 4. Aesthetic ☐

| **Q:11.** | **What kind of species would you have in your roof garden which indicates diversification of plant species?** | | |
|---|---|---|---|
| | **i. Fruit species** | | |
| **Sl. No.** | **Plants name** | **Plants Number** | **Habit, family, genus and species** |
| 1. | | | |
| 2. | | | |
| 3. | | | |
| 4. | | | |
| 5. | | | |
| 6. | | | |
| 7. | | | |
| 8. | | | |
| 9. | | | |
| 10. | | | |
| 11. | | | |
| 12. | | | |
| 13. | | | |
| 14. | | | |
| 15. | | | |
| 16. | | | |
| 17. | | | |
| 18. | | | |
| 19. | | | |
| 20. | | | |

| ii. Vegetable species | | | |
|---|---|---|---|
| **Sl. No.** | **Plants name** | **Plants Number** | **Habit, family, genus and species** |
| 1. | | | |
| 2. | | | |
| 3. | | | |
| 4. | | | |
| 5. | | | |
| 6. | | | |
| 7. | | | |
| 8. | | | |
| 9. | | | |
| 10. | | | |
| 11. | | | |
| 12. | | | |
| 13. | | | |
| 14. | | | |
| 15. | | | |
| 16. | | | |
| 17. | | | |
| 18. | | | |
| 19. | | | |
| 20. | | | |

| iii. Flower species | | | |
|---|---|---|---|
| **Sl. No.** | **Plants name** | **Plants Number** | **Habit, family, genus and species** |
| 1. | | | |
| 2. | | | |
| 3. | | | |
| 4. | | | |
| 5. | | | |
| 6. | | | |
| 7. | | | |
| 8. | | | |
| 9. | | | |
| 10. | | | |
| 11. | | | |
| 12. | | | |
| 13. | | | |
| 14. | | | |
| 15. | | | |
| 16. | | | |

| | | | |
|---|---|---|---|
| 17. | | | |
| 18. | | | |
| 19. | | | |
| 20. | | | |

| **iv. Ornamental species** | | | |
|---|---|---|---|
| **Sl No.** | **Plants name** | **Plants Number** | **Habit, family, genus and species** |
| 1. | | | |
| 2. | | | |
| 3. | | | |
| 4. | | | |
| 5. | | | |
| 6. | | | |
| 7. | | | |
| 8. | | | |
| 9. | | | |
| 10. | | | |
| 11. | | | |
| 12. | | | |
| 13. | | | |
| 14. | | | |
| 15. | | | |
| 16. | | | |
| 17. | | | |
| 18. | | | |
| 19. | | | |
| 20. | | | |

| **v. Medicinal species** | | | |
|---|---|---|---|
| **Sl. No.** | **Plants name** | **Plants Number** | **Habit, family, genus and species** |
| 1. | | | |
| 2. | | | |
| 3. | | | |
| 4. | | | |
| 5. | | | |
| 6. | | | |
| 7. | | | |
| 8. | | | |
| 9. | | | |
| 10. | | | |

**Q:12. What is the approximate yearly food production from your roof garden? ……………………kg/year**

| Q: 13 . | How does your garden help you to meet your domestic food demand? | Daily | weekly | yearly |
|---|---|---|---|---|
| | | | | |

| Q:14. | How much daily time do you like to spend in your roof garden ?: | Extent of Informations | | |
|---|---|---|---|---|
| | | Daily | Weekly | Monthly |
| | 1. Below 1 hr | | | |
| | 2. Below 2 hr | | | |
| | 3. Above 2 hr | | | |

| Q:15. | What is the level of your mental satisfaction? | High | Medium | Low |
|---|---|---|---|---|
| | | | | |

| Q:16. Do you feel cooler environment in your garden and in adjacent rooms near the garden? | Extent of Informations | | |
|---|---|---|---|
| | Roof Temperature ($C^o$) | Room temperature ($C^o$) | Temperature outside ($C^o$) |
| 1. High ☐ 2. Medium ☐ | | | |
| 3. Low ☐ 4. Not at all ☐ | | | |
| | | | |

**Q:17. What is the approximate yearly expenditure for your garden?**

**......................taka**

**Q:18. Who nurses your garden ?** :

1. Family member ☐
2. Family paid personel ☐
3. Gardener ☐

| | |
|---|---|
| **Q:19.** | **From where you get technical support ? :**<br>Agricultural office ☐ Nearby Nurseries ☐<br>Media/Book and printed matters ☐ No technical support ☐ |

**Q:20. Did you receive any training on roof top gardening?**

1. YES 0. NO

**If YES, how many days (mention):** ……………

# Appendix II

## Descriptive Statistics

| Sl. No. | Variable | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|---|
| 1 | Gender | 40 | 1 | 2 | 1.4500 | .50383 |
| 2 | Age | 40 | 26.00 | 67.00 | 46.0500 | 11.60007 |
| 3 | Marital status | 40 | 1 | 3 | 1.1500 | .48305 |
| 4 | Education | 40 | 3.00 | 20.00 | 14.0500 | 3.88257 |
| 5 | Occupation | 40 | 1 | 3 | 2.1750 | .90263 |
| 6 | Family size | 40 | 2.00 | 12.00 | 5.5000 | 2.60177 |
| 7 | Annual income | 40 | 200000.00 | 1200000.00 | 589250.0000 | 220470.21428 |
| 8 | House ownership | 40 | 1 | 3 | 1.2250 | .57679 |
| 9 | Surface area | 40 | 950.00 | 3500.00 | 2070.0000 | 539.91927 |
| 10 | Vegetation coverage | 40 | 1.00 | 3.00 | 2.3500 | .62224 |
| 12 | Yearly food production | 40 | 10.00 | 60.00 | 26.9500 | 12.01271 |
| 13 | Regularity of Food supply | 40 | 1.00 | 3.00 | 2.2250 | .61966 |
| 14 | Species diversity | 40 | 2.53 | 4.71 | 3.8965 | .57645 |
| 15 | Thermal comfort | 40 | .00 | 3.00 | 1.9750 | .83166 |
| 16 | Yearly expenditure | 40 | 1200.00 | 70000.00 | 12302.5000 | 15122.36394 |
| 17 | Nursing | 40 | 1.00 | 3.00 | 2.2250 | .83166 |
| 18 | Frequency of visit | 40 | 1.00 | 3.00 | 1.2250 | .47972 |
| 19 | Spending time | 40 | 1.00 | 3.00 | 2.0750 | .72986 |
| 20 | Mental atisfaction | 40 | 1.00 | 3.00 | 2.3000 | .68687 |
| 21 | Technical support | 40 | 1.00 | 4.00 | 2.1000 | 1.17233 |
| 22 | Training | 40 | .00 | 3.00 | 1.7250 | 1.17642 |

# Appendix III

## Coordinates of the roof garden locations of the study area

<table>
<tr><th>Thana</th><th>Ward</th><th>Sub areas under thana</th><th colspan="2">Coordinates of the roof garden location</th></tr>
<tr><td rowspan="12">Mohammadpur</td><td rowspan="2">42</td><td>Chinumia Road Area (2)</td><td>23.7682<br>90.3596</td><td>23.7686<br>90.3602</td></tr>
<tr><td>Tajmahal Road Area (1)</td><td colspan="2">23.7667<br>90.3586</td></tr>
<tr><td rowspan="2">44</td><td>Zakir HossainRoad Area (1)</td><td colspan="2">23.7572<br>90.3658</td></tr>
<tr><td>Salimullah Road Area (1)</td><td colspan="2">23.7601<br>90.3637</td></tr>
<tr><td rowspan="2">45</td><td>Lalmatia Housing Society (1)</td><td colspan="2">23.7567<br>90.3669</td></tr>
<tr><td>Iqbal Road Area (1)</td><td colspan="2">23.7605<br>90.3628</td></tr>
<tr><td rowspan="3">46 (part)</td><td>Mohammadia Housing Society (2)</td><td>23.7631<br>90.3585</td><td>23.7632<br>90.3546</td></tr>
<tr><td>Mohammadia Housing Ltd.(1)</td><td colspan="2">23.7612<br>90.3542</td></tr>
<tr><td>Nobodoy Housing (2)</td><td>23.7643<br>90.3537</td><td>23.7637<br>90.3536</td></tr>
<tr><td rowspan="2">47</td><td>Jafrabad (2)</td><td>23.7507<br>90.3667</td><td>23.7505<br>90.3643</td></tr>
<tr><td>Shangkar (1)</td><td colspan="2">23.7507<br>90.3648</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="2"></td><td colspan="3">Total=15</td></tr>
</table>

<table>
<tr><th>Thana</th><th>Ward</th><th>Subareas under thana</th><th colspan="2">Coordinates of the roof garden locations</th></tr>
<tr><td rowspan="5">Adabor</td><td rowspan="3">Ward 43</td><td>Adabor<br>(1)</td><td colspan="2">23.7729<br>90.3602</td></tr>
<tr><td>Baitul Aman Society<br>(1)</td><td colspan="2">23.7727<br>90.3561</td></tr>
<tr><td>Monsurabad Housing<br>(3)</td><td>23.7734<br>90.3611</td><td>23.7734<br>90.3611</td></tr>
<tr><td rowspan="2">Ward 46 (part)</td><td>Pisciculture Housing<br>(1)</td><td colspan="2">23.7675<br>90.3611</td></tr>
<tr><td>Shekhertek (2)</td><td>23.7668<br>90.3632</td><td>23.7678<br>90.3627</td></tr>
<tr><td colspan="2"></td><td colspan="3">Total=8</td></tr>
</table>

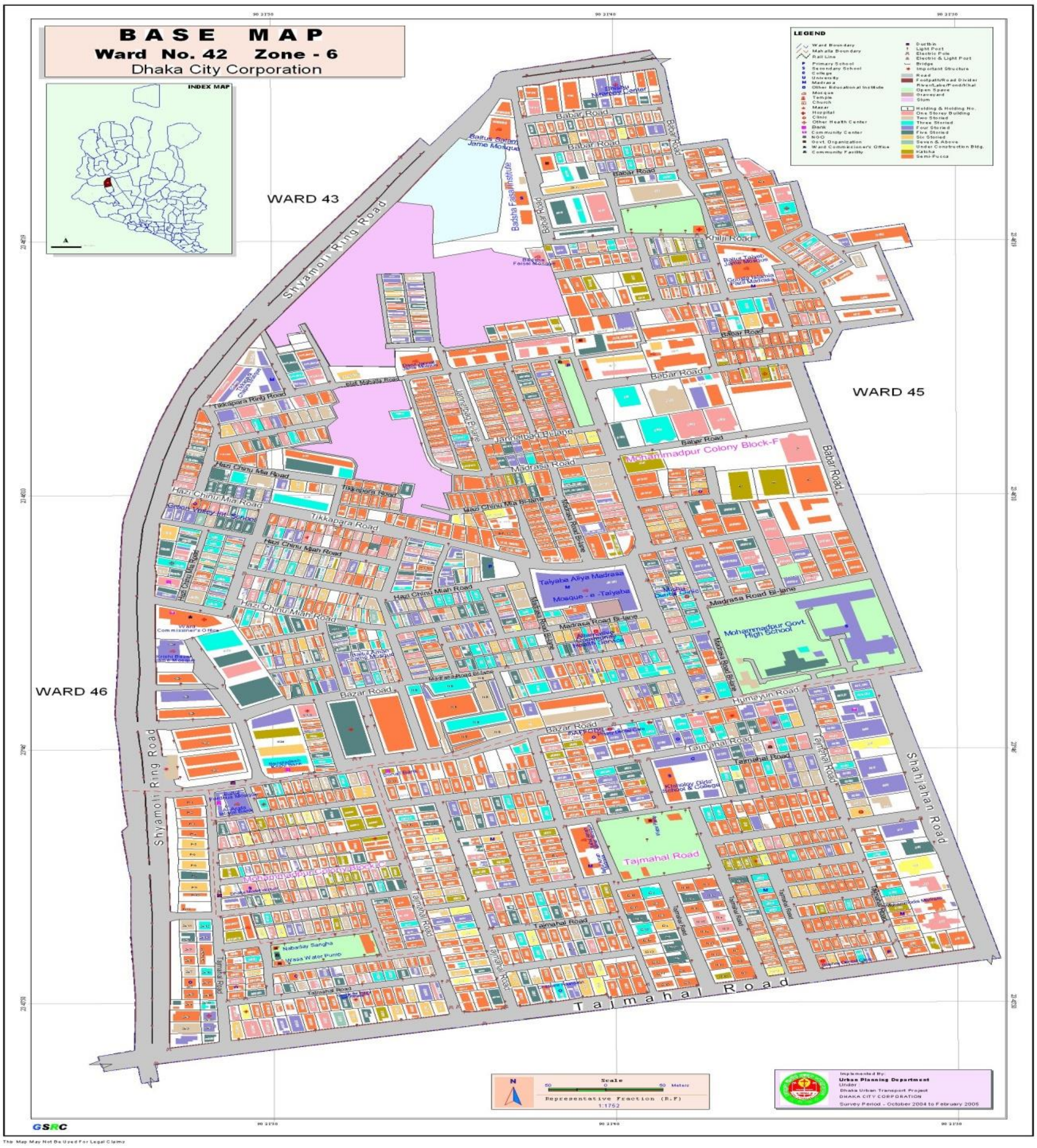
<table>
<tr><th>Thana</th><th>Ward</th><th colspan="2">Subareas under thana</th><th colspan="2">Coordinates of the roof garden locations</th></tr>
<tr><td rowspan="7">Kalabagan</td><td rowspan="5">Ward 50</td><td colspan="2">Kathalbagan Area (1)</td><td colspan="2">23.748<br>90.3902</td></tr>
<tr><td colspan="2">Panthapath Area (2)</td><td>23.7533<br>90.3845</td><td>23.7533<br>90.3845</td></tr>
<tr><td colspan="2">North Road Area(1)</td><td colspan="2">23.7435<br>90.3862</td></tr>
<tr><td colspan="2">Central Road Area (1)</td><td colspan="2">23.7418<br>90.3879</td></tr>
<tr><td>Hatir pool<br>(1)</td><td>Voter goli<br>(1)</td><td>23.7452<br>90.3925</td><td>23.7431<br>90.3881</td></tr>
<tr><td rowspan="2">Ward 51<br>(part)</td><td colspan="2">Kalabagan Lake circus<br>Area (2)</td><td>23.7492<br>90.3820</td><td>23.7492<br>90.3820</td></tr>
<tr><td colspan="2">Sobhanbagh (2)</td><td>23.7468<br>90.3731</td><td>23.7478<br>90.3737</td></tr>
<tr><td colspan="2"></td><td colspan="4">Total=11</td></tr>
</table>

| Thana | Ward | Subareas under thana | Coordinates of the roof garden locations | | |
|---|---|---|---|---|---|
| **Dhanmondi** | Ward 49 | Dhanmondi area | **23.7514 90.3751** | **23.7513 90.3749** | **23.7514 90.3751** |
| | | Dhanmondi lake area | **23.7542 90.3736** | **23.7506 90.3732** | **23.7542 90.3736** |
| | | **Total=6** | | | |

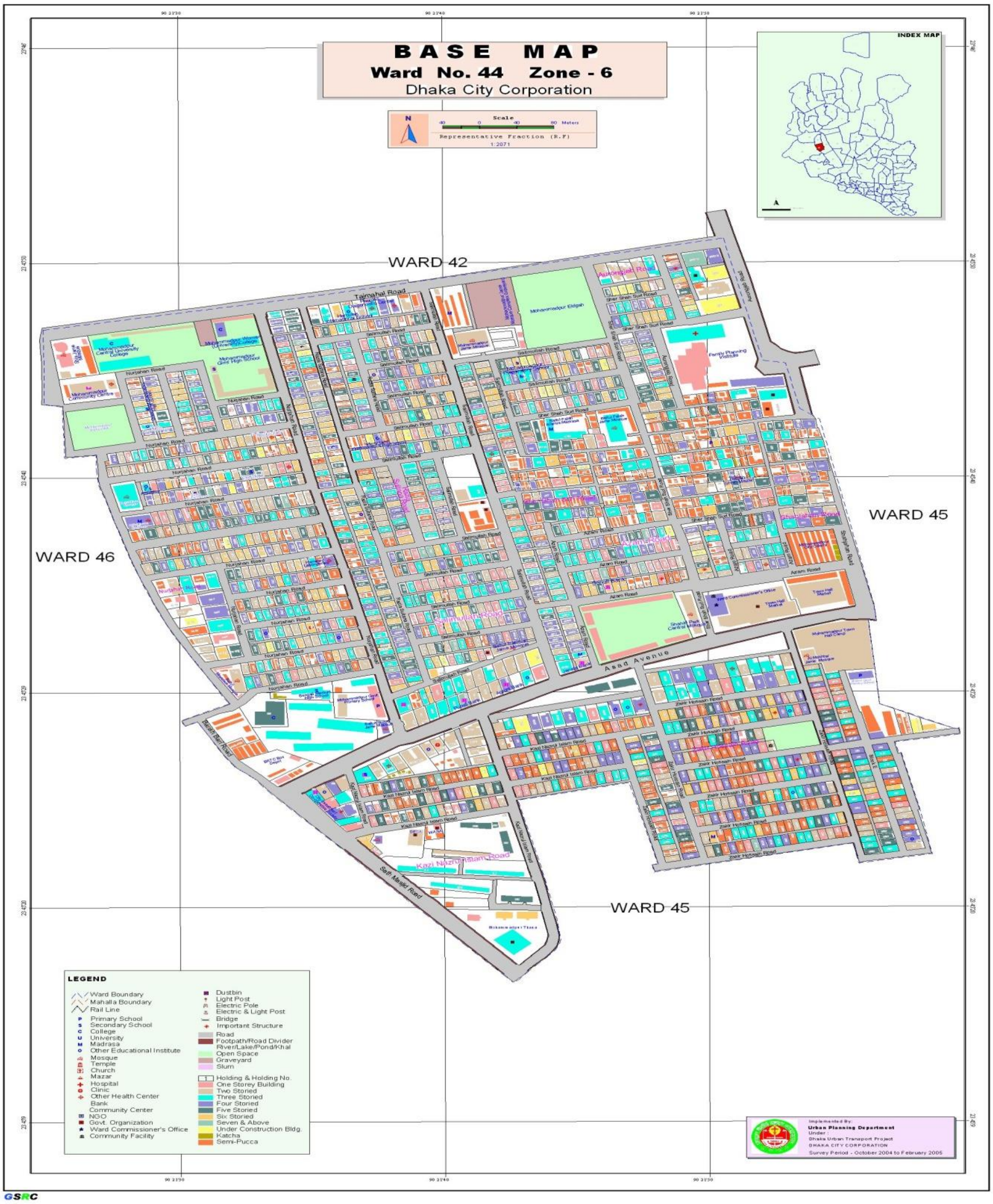
# Appendix IV

## Base maps of ward maps

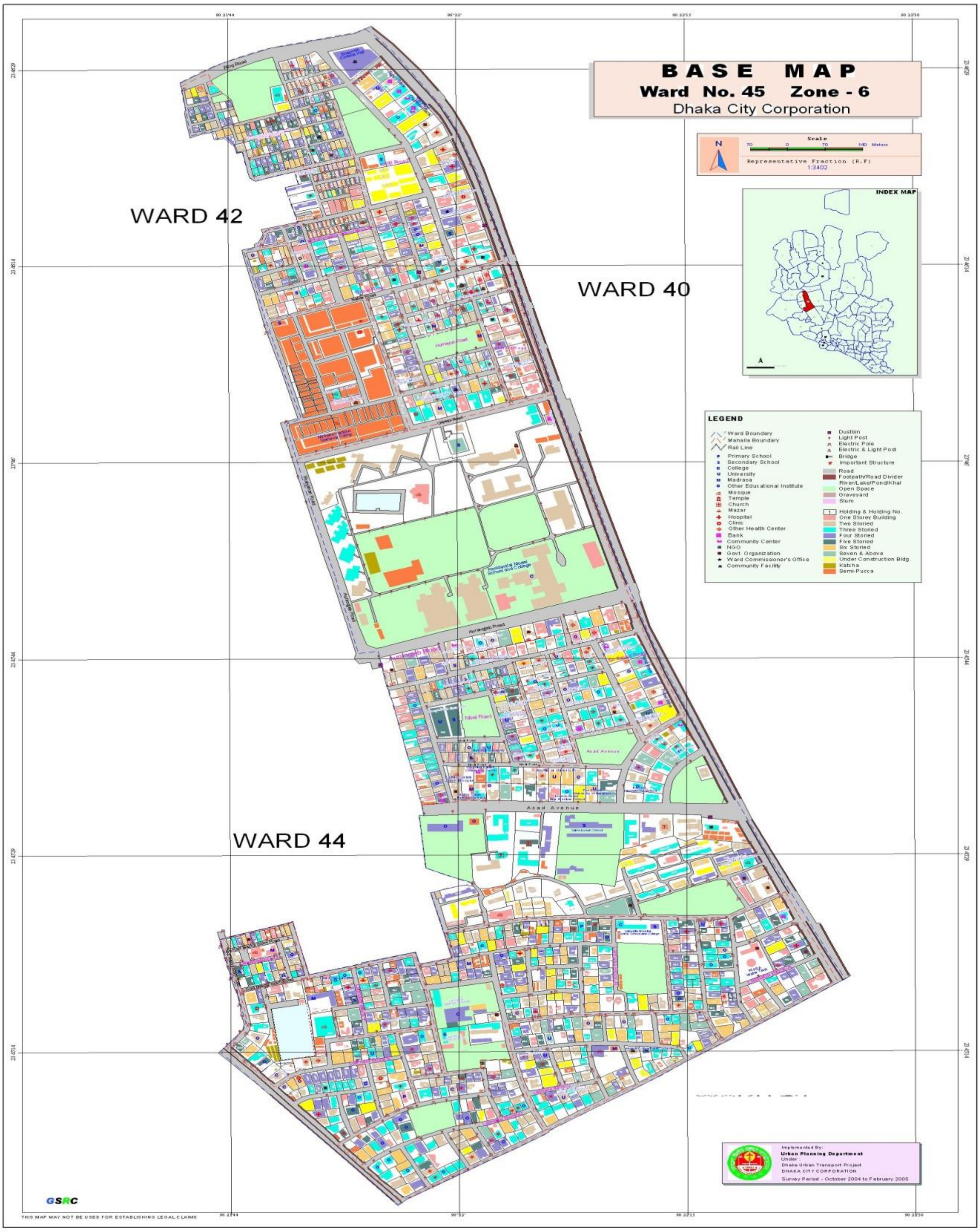
### Ward maps of Mohammadpur Thana (ward 42, 44, 45, 46-part, 47)



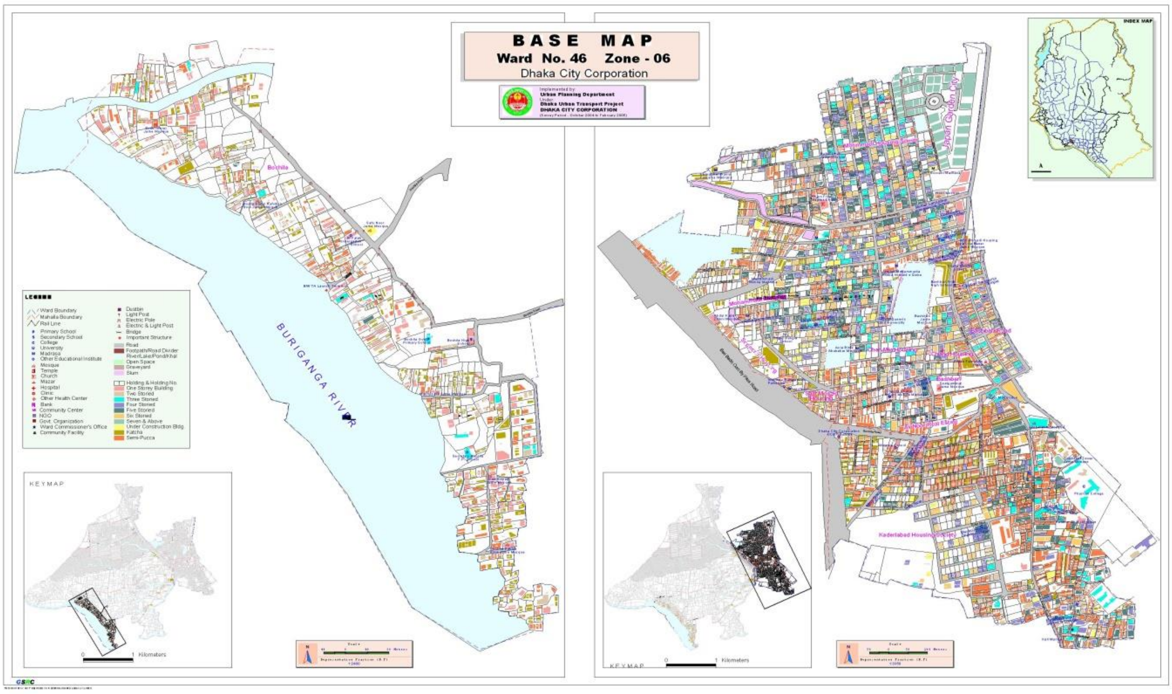

Ward 42


BASE MAP
Ward No. 44 Zone - 6
Dhaka City Corporation
INDEX MAP
WARD 42
WARD 45
WARD 46
WARD 45
Asad Avenue
Kazi Nazrul Islam Road
LEGEND
Ward Boundary
Mahalla Boundary
Rail Line
Primary School
Secondary School
College
University
Madrasa
Other Educational Institute
Mosque
Temple
Church
Mazar
Hospital
Clinic
Other Health Center
Bank
Community Center
NGO
Govt. Organization
Ward Commissioner's Office
Community Facility
Dustbin
Light Post
Electric Pole
Electric & Light Post
Bridge
Important Structure
Road
Footpath/Road Divider
River/Lake/Pond/Khal
Open Space
Graveyard
Slum
Holding & Holding No.
One Storey Building
Two Storied
Three Storied
Four Storied
Five Storied
Six Storied
Seven & Above
Under Construction Bldg.
Katcha
Semi-Pucca

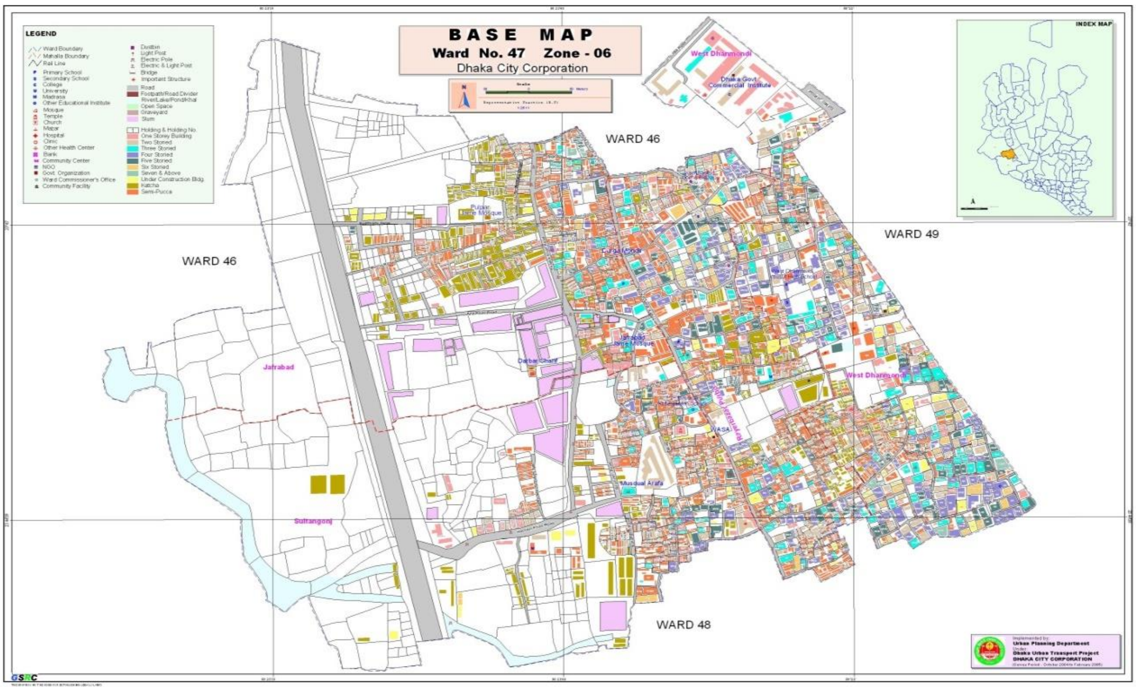
**Ward 44**


BASE MAP
Ward No. 45 Zone - 6
Dhaka City Corporation
WARD 42
WARD 40
WARD 44
INDEX MAP
LEGEND
Asad Avenue
GSRC
THIS MAP MAY NOT BE USED FOR ESTABLISHING LEGAL CLAIMS

**Ward 45**

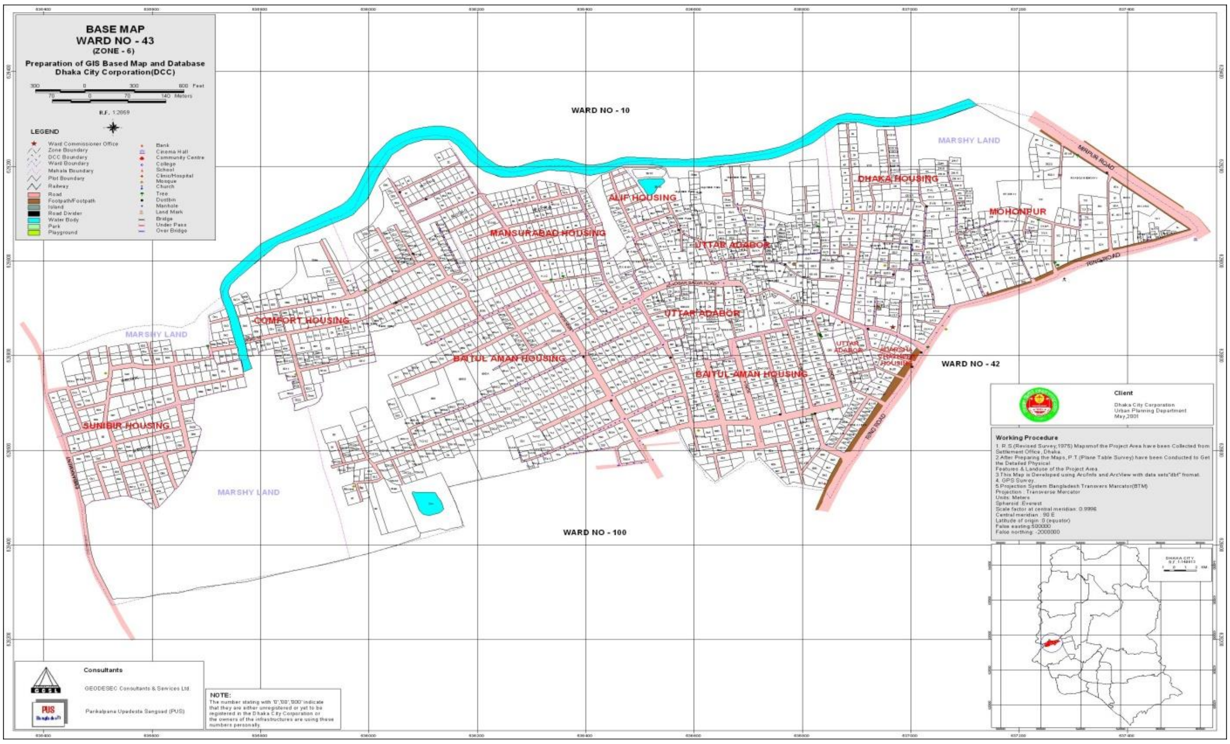



**Ward 46 (part-2)**

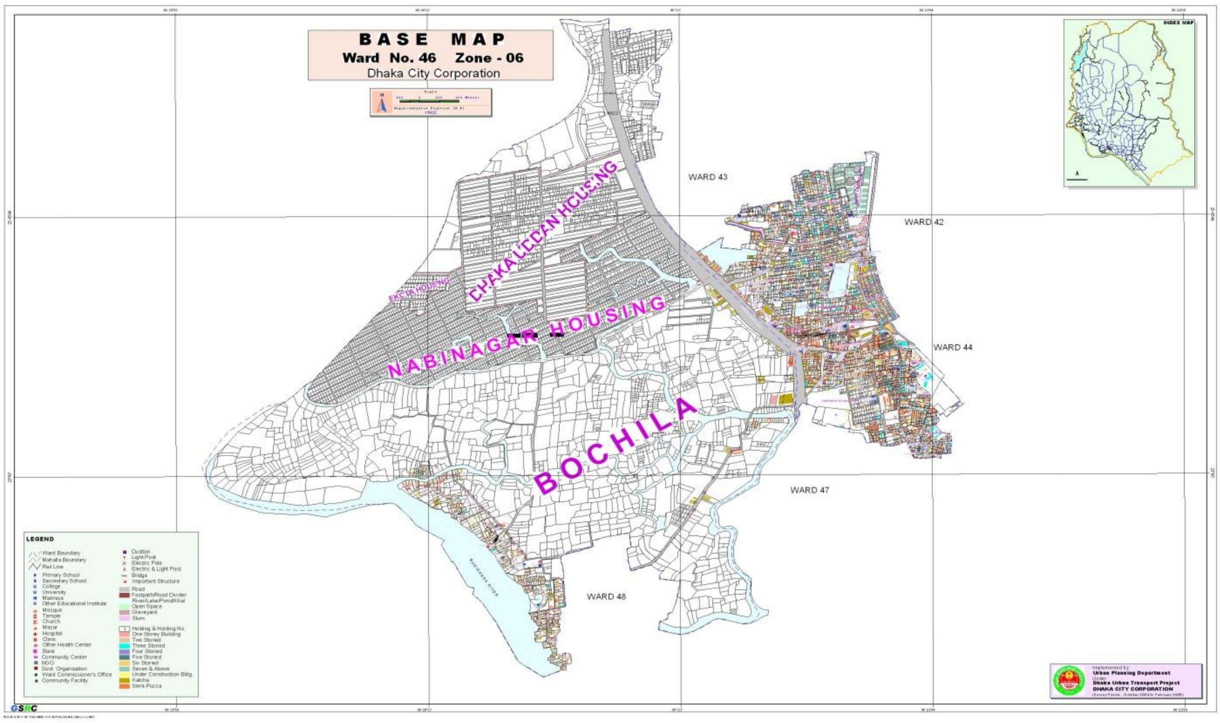



**Ward 47**

## Ward map of Adabor Thana (ward 43, 46-part)

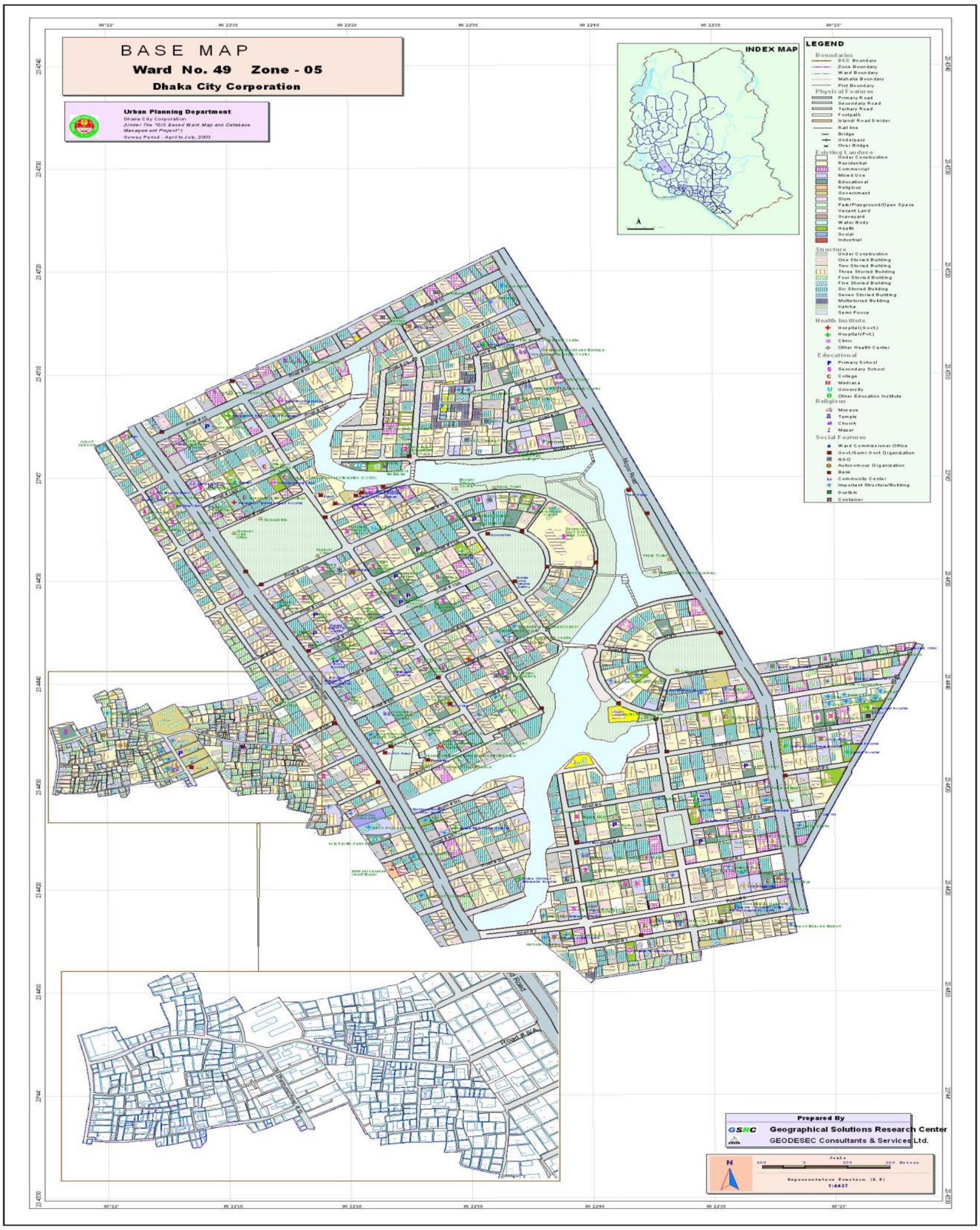



**Ward 43**



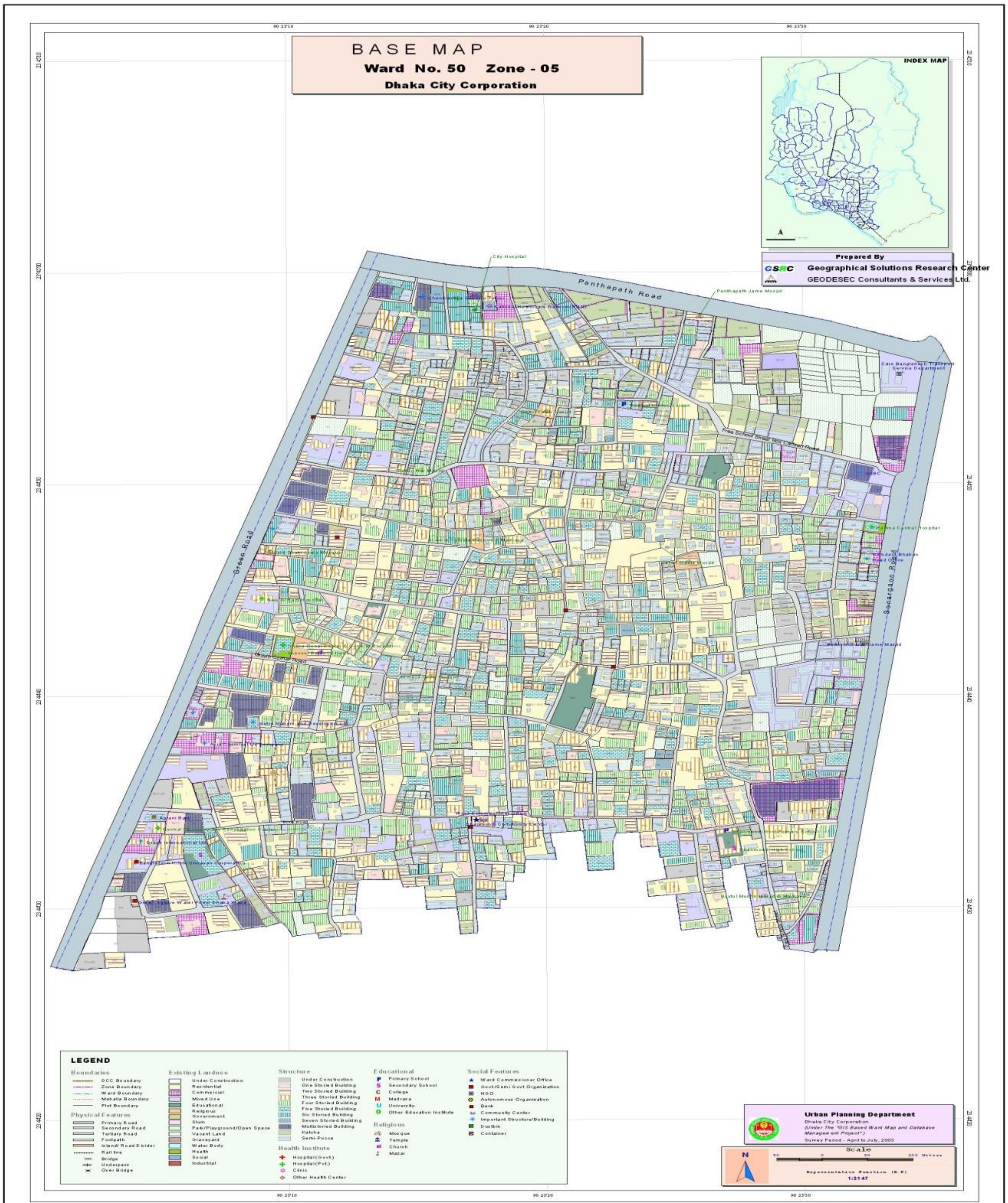

**Ward 46 (part-1)**

## Ward map of Dhanmondi Thana (ward 49)

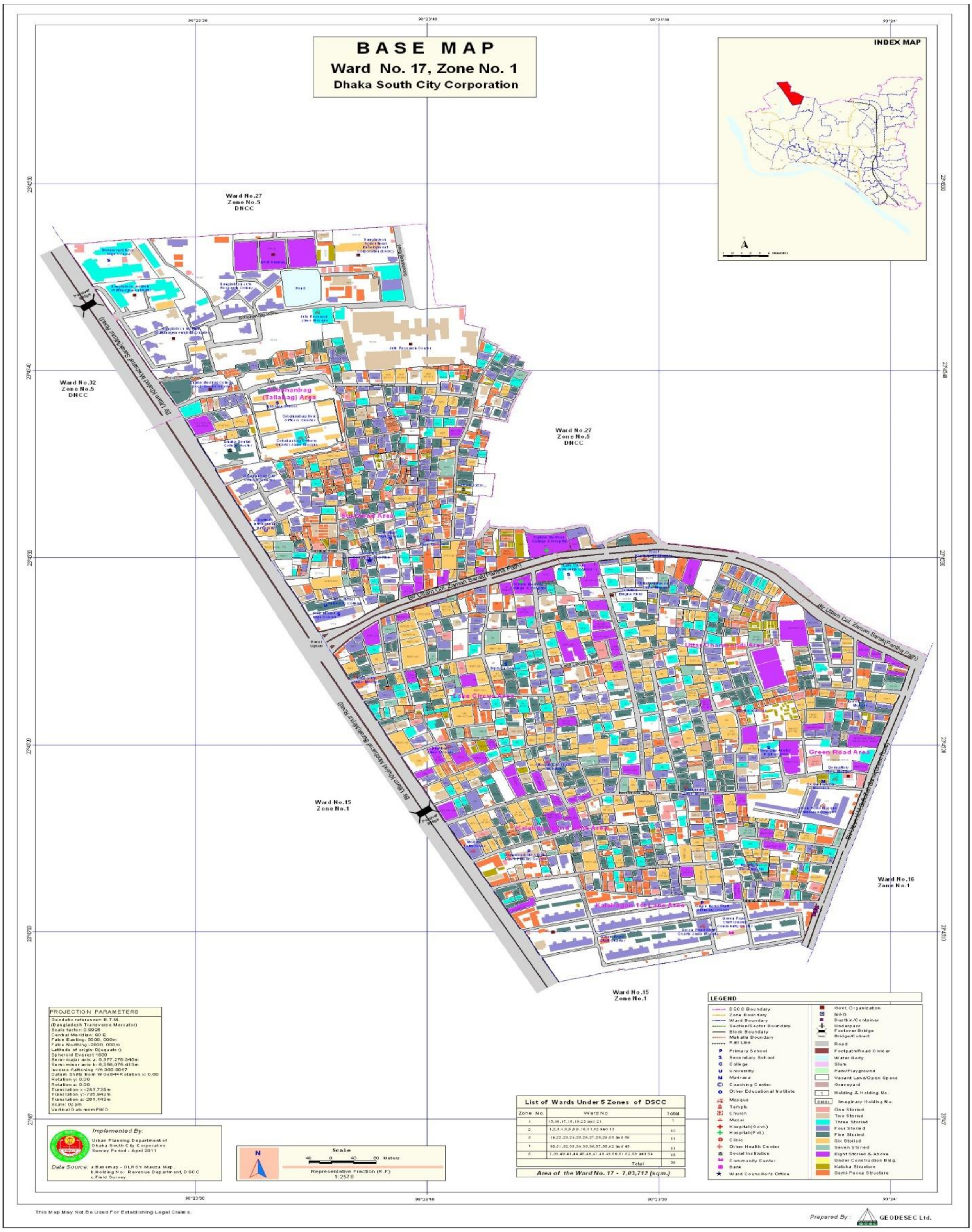



**Ward 49**

## Ward map of Kalabagan Thana: (ward 50, 17)




**Ward 50**




Ward 17 (previous 51)