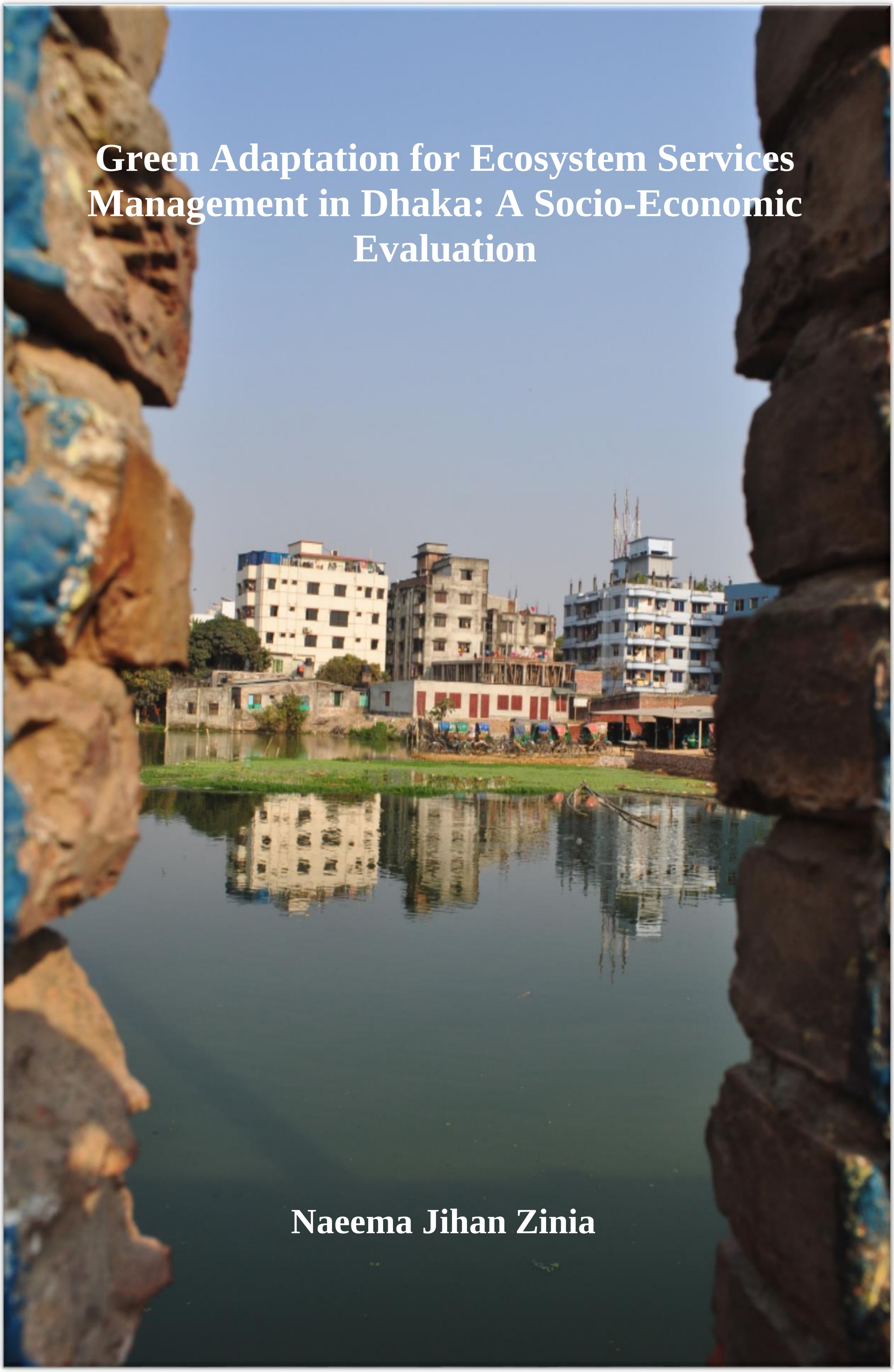
Green Adaptation for Ecosystem Services Management in Dhaka: A Socio-Economic Evaluation



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Green Adaptation for Ecosystem Services Management in Dhaka: A Socio-economic Evaluation

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MSc. MSS. BSS.

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ABSTRACT

Bangladesh faces multi-dimensional challenges related to, among others, population growth, rapid urbanization, land use change and natural hazards. The severity of these challenges is more intense given likely climate change. Dhaka, the capital, is the hub of socio-economic and cultural activities of the country. It is one of the world's fastest growing megacities. Continuous urban expansion is degrading and drastically reducing natural green and blue spaces and associated ecosystem services affecting residents' wellbeing. This interdisciplinary research addresses urban ecosystem services assessment, valuation, governance, and management. I identify socially acceptable and economically feasible green strategies for managing ecosystem services in an urban setting. My study is novel in that it integrates environmental, economic, and social aspects of urban ecosystem services management through quantitative and qualitative evaluations.

My study area was the Mirpur-Pallabi Zone of Dhaka North City Corporation. I undertook field-level observations, surveys, in-depth interviews with experts, and collected secondary data from literatures. Approaches to analysis included satellite image analysis, ecosystem services analysis, direct and indirect market valuation methods, and policy analysis.

The ecosystems I identified in the study area were diverse and included various vegetation and waterbodies. I produced an inventory of current ecosystem services for each ecosystem under four categories: provisioning (food, fodder), regulating (carbon sequestration, influence on air quality, natural drainage), cultural (recreation, religious use), and habitat (refugia for resident and migratory birds) ecosystem services.

I evaluated and compared the economic importance of selected marketed and non-marketed ecosystem services. Gross values were estimated to be BDT 5.3 million (USD 68,465) for provisioning services, BDT 3,257 million (USD 42 million) for regulating services and BDT 92.8 million (USD 1.19 million) for cultural services in 2016.

I assessed ecosystem related policies/activities of the government, non-governmental organizations (NGOs), and private sector organizations. Agricultural lands, rivers, wetlands, *and mangrove forests in rural and coastal areas were governance priorities in Bangladesh. Urban ecosystems received much less attention in all three governance regimes. The government emphasized regulating and habitat ecosystem services. The NGOs and private sector organizations highlighted provisioning and regulating ecosystem services. Ecosystem conservation and restoration got higher priorities than new ecosystem/ecosystem services generation.*

I evaluated green adaptation strategies implemented worldwide at city levels (parks, gardens, green roof, rainwater harvest, green façades/wall, porous pavement). I assessed their social acceptance and economic feasibility for implementation in Dhaka. Rooftop garden/agriculture had very high social acceptance (85%) and economic feasibility and was commonly practiced in Dhaka particularly among house owners. Pocket park, green roof, rainwater harvest, green façades/wall, porous pavement, and community garden were all considered highly feasible for implementation with collective efforts but had lower social acceptance.

My study is a first step, which could serve as a basis for in-depth analysis for sustainable urban environmental management in Dhaka. Such continuing research would be valuable for other cities in Bangladesh and in other developing countries similarly exposed to climate change and urban population growth.

DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

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Praise be to Allah, the Most Merciful and the Most Compassionate.

When I was a schoolchild, Bapi (my father) once told me to think about pursuing a PhD degree in future. I did not have any clear idea of what PhD was at that time, but a seed was planted in my brain! I completed the school, college, and university degrees and when it came to choose a career, I did not know exactly what I wanted to do, but I did know what I did not want to do! Elimination method always works fine for me. I discovered my immense passion for research while studying at Wageningen University in the Netherlands. After that, I never hesitated, never questioned my aim, and started developing my career in environmental research with confidence. This doctoral degree is the germination of that seed of aspiration planted by Bapi in my childhood.

I was searching for a suitable PhD position to further develop my knowledge and skills. By ‘suitable’, I meant- a supervisor willing to guide me on the research idea that I had in mind, full funding, and a university with a good reputation in a country within a half-day travel from Dhaka! This was no less challenging than a marriage match making! I received two or three rejection letters. One rejection letter was from Monash University. It was upsetting. One day I told Aammu (my mother) that if she prayed to Allah for me from her heart I would definitely get the opportunity I was looking for. A few weeks later, a miracle happened! I received a letter from Monash University; they had amended their decision and awarded me a scholarship to pursue a doctoral degree. That day I realized the strength of a mother’s prayer. I came to Melbourne and commenced the PhD program on December 16, 2014, the Victory Day of Bangladesh and Aammu’s birthday! What a great day to start a new phase of my life!

With the publication of this PhD thesis, a journey has come to an end during which I asked a lot of my supervisors, colleagues, friends, family, and myself. I am forever grateful to a number of organizations and people for their support and encouragement. My research was funded through a Monash Graduate Scholarship (MGS), Monash University with the Monash Sustainable Development Institute (MSDI). I would like to express my heartfelt gratitude and appreciation to Dr Paul McShane, my main supervisor, for his continuous encouragement and support right from the beginning. No matter in which country he was travelling, he always found time to respond to my queries. I never had to worry much about arranging funds for bearing the field expenses and attending international conferences/seminars. Paul made my PhD journey smooth. The last month before my thesis submission, Paul flew all the way from Tasmania to Melbourne every week to supervise my work in person. I felt much loved and taken care of. I would not have been able to complete the economic analysis part of my thesis without my associate supervisor Professor Michael Ward. He taught me to calculate complex things in simpler ways, think from different angles, and turn weaknesses into strengths. Any questions were welcomed by him no matter how silly. Michael made me realize that calculations could be enjoyable too! I am equally thankful to Dr Megan Farrelly for her academic stimulation and advice that guided my work on governance. She showed me how to analyze critically. I greatly benefited from the comments and suggestions of the respected panelists for my yearly progress review seminars: Professor Emeritus Marika Vicziany, Professor Nigel Tapper, Dr Annette Bos, and Dr Anke Leroux. I would like to acknowledge the contributions of the experts that I met in the international conferences and seminars that I attended in Dhaka, Rome, Jakarta, Southampton, Manila, Batangas City, and Melbourne. My thanks go to my PhD thesis examiners Dr Saleemul Huq and Dr Douglas Hill for their kind and encouraging words.

My fieldwork in Dhaka was eventful. It was extremely challenging to access respondents for the household surveys. Shofiul, Kumkum, Tashmiah, Manik, Tahmid, and Nur Islam made it possible ignoring high humidity, ~40° Celsius temperatures, Nor'westers, rains, even the cyclone Roanu. I cannot thank them enough for the hard work that they did for me. I thank Habib, Shahabul, and Arthi for helping me with observation activities, Swarna and Faysal for being supportive while measuring trees in the park and on the roadsides. My heartfelt thanks go to Faheem who was always there when I needed someone to accompany me for an interview session. I also thank him for the video clips of roads that he recorded for me. I could not have completed GIS mapping without the help of Opu. The survey data entry was a lengthy process. I am grateful to Rafiquzzaman who developed a dedicated data entry and digitization software to make my life easy. I would like to extend my thanks to Dr Niaz, Dr Saleh, Dr Shuvo, Mr Faruk, Mr Mofiz, Ms Rimy, Ms Lithi, Ms Tahmina, and colleagues from ICCCAD and MSDI for their advice. Overall, I am very much obliged to the interviewees and the surveyed respondents.

I have enjoyed every moment of my PhD journey: working until morning, waking up at noon, eating instant noodles late at night while watching movies or TV, talking over the telephone for hours, exploring the beauty of Australia, travelling to new countries, and the list goes on… Some people made those moments more cherish-able. I appreciated being able to share ideas and moments of doubts and happiness with Afentina, my PhD companion. Our small celebrations with delicious desserts and chai latte and shopping when stressed were motivational. Tasvir, Sonia, and Rehab fuelled my energy with lively conversations and laughter. My childhood friends Rita, Josephine, and Nayeema always believed in me and inspired me to keep going. Last but not the least; my heartiest gratitude goes to my current and previous housemates Joyce, Kathy, Natesha, Eliza, and Tanmeet for being amazingly supportive. They complied with my irregular timetable and demand for quietness, did grocery shopping for me, and cleaned up my unwashed utensils piling up in the kitchen! The time that we spent together in our home in 'The Rise' was peaceful and memorable.

The last three years away from home could have been difficult without the constant support and encouragement from my family. My loving parents, siblings Tania aapu and Tansim bhaia, in-laws Tinni bhabi and Mamun dulabhai, our little bundles of joy nephew Ishaat and nieces Triya and Zahreen were sources of moral strength throughout this whole time. Whenever I felt down or wanted to share happiness, they were just a call away! I am sincerely grateful for the internet and the video call apps! I am indebted to Munni auntie, Sharif khalu, and cousins Aupi and Aurnab who did not let me feel homesick in Melbourne. The kindness and love they showered on me were unparalleled. I would like to express my gratitude to my extended relatives in Bangladesh who have showed constant affection to me. They always made me feel special!

Praise be to the Almighty Allah for making my every step a success and letting me complete this doctoral degree. My faith and prayers strengthened my confidence to explore new windows of knowledge that I hope will be continuing. I am grateful for getting the opportunity to materialize my dream of pursuing the highest academic degree and to contribute somehow to the magical city of Dhaka- the place where I belong. I hope that I have made my family proud. With that note, I would like to dedicate this thesis to my beloved parents Kamrun Nahar Shelly and Abu Bakar Siddique. Aammu Bapi, I love you to the moon and back. আম্মু বাপী, তোমাদের ভালোবাসি।

Naeema Jihan Zinia | নাঈমা জিহান জিনিয়া

Melbourne, 2018

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ABBREVIATIONS AND ACRONYMS

°C	Degree Celsius
ACCCRN	Asian Cities Climate Change Resilience Network
ADB	Asian Development Bank
AGB	Above Ground Biomass
BBS	Bangladesh Bureau of Statistics
BCAS	Bangladesh Centre for Advanced Studies
BCCSAP	Bangladesh Climate Change Strategy and Action Plan
BDP	Bangladesh Delta Plan
BDT	Bangladeshi Taka (local currency)
BELA	Bangladesh Environmental Lawyers Association
BNAAQS	Bangladesh National Ambient Air Quality Standards
BRAC	Bangladesh Rural Advancement Committee
BUET	Bangladesh University of Engineering and Technology
C	Carbon
CAMS	Continuous Air Monitoring Station
CASE	Clean Air and Sustainable Environment
CEGIS	Center for Environmental and Geographic Information Services
CES	Cultural Ecosystem Service
cm	Centimeter
CO_2	Carbon Dioxide
dB	Decibel
DBH	Diameter at Breast Height
DEFRA	Department for Environment, Food and Rural Affairs, UK
DESCO	Dhaka Electric Supply Authority
DMCH	Dhaka Medical College and Hospital
DMDP	Dhaka Metropolitan Development Plan
DNCC	Dhaka North City Corporation
DoE	Department of Environment
DSCC	Dhaka South City Corporation
DUV	Direct Use Value
DWASA	Dhaka Water Supply and Sewerage Authority
ECA	Ecologically Critical Area

EIA	Environmental Impact Assessment
ENGO	Environmental Non-Governmental Organization
equ	Equivalent
ES	Ecosystem Service
ESA	Ecosystem Services Analysis
EUR	Euro
FVC	Fractional Vegetation Coverage
GA	Green Adaptation
GBH	Girth at Breast Height
GBM	The Ganges, the Brahmaputra and the Meghna
GDP	Gross Domestic Product
GIS	Geographic Information System
GNP	Gross National Product
GoB	Government of Bangladesh
GPS	Global Positioning System
Ha	Hectare
HES	Habitat Ecosystem Service
ICC	International Cricket Council
ICCCAD	International Center for Climate Change and Development
ICDDR,B	International Centre for Diarrhoeal Disease Research, Bangladesh
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
IUV	Indirect Use Value
JICA	Japan International Cooperation Agency
Kg	Kilogram
kJ	Kilojoules
km	Kilometer
kWh	Kilowatt hour
LDC	Least Developed Country
LGED	Local Government Engineering Department
LST	Land Surface Temperature
m	Meter
m^3	Cubic meter
MA	Millennium Ecosystem Assessment
Mg	Megagram
MLD	Megaliter per Day

MoEF	Ministry of Environment and Forests
MWh	Megawatt hour
NAPA	National Adaptation Programmes of Actions
NGO	Non-Governmental Organization
NUV	Non-Use Value
O&M	Operating and Maintenance
OR	Odds Ratio
OV	Option Value
PES	Provisioning Ecosystem Service
PM	Particulate Matter
POP	Persistent Organic Pollutant
PPP	Purchasing Power Parity
PROSHIKA	Proshika Manobik Unnayan Kendro
RAJUK	Rajdhani Unnayan Kartripakkha
RES	Regulating Ecosystem Service
RMB	Renminbi, Chinese currency
RQ	Research Questions
T_{air}	Air Temperature
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total Economic Value
TIB	Transparency International Bangladesh
UHI	Urban Heat Island
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
USD	US Dollar
WB	World Bank
WTP	Willingness to Pay
µg	Microgram

CHAPTER 1: GENERAL INTRODUCTION

1.1 BACKGROUND

Urbanization is a global phenomenon today, which once was simply "*sporadic and localized*" (Tisdale, 1942). People increasingly tend to reside in urban areas instead of rural. More than half of the world's population live in urban areas at present (United Nations, 2014). Unplanned and rapid urbanization, climate change (e.g., increased extreme weather events), and land use change (increased built-up areas) are often considered as key drivers that directly affect ecosystems and ecosystem services: loss of green and blue spaces, diminished ecosystem services and resilience, and aggravated pollution (air, water, soil) (Adger *et al.*, 2003; Escobedo, Kroeger, & Wagner, 2011; Foresman, Pickett, & Zipperer, 1997; Hossain *et al.*, 2015a; Lyytimäki & Sipilä, 2009; MA, 2005b; TEEB, 2010a; van Oudenhoven *et al.*, 2012). Urban areas and urban populations are vulnerable to the acute impacts of these drivers (Grimm *et al.*, 2008; Lyytimäki & Sipilä, 2009; Niemelä *et al.*, 2010; Tratalos *et al.*, 2007; Zinia & Kroeze, 2015). This is particularly the case for Dhaka, the capital of Bangladesh, one of the world's most densely populated cities. Being the socio-economic and cultural center of the country, Dhaka city induces displacement of population through rural to urban migration (Ishtiaque & Mahmud, 2017; Jahan, 2012; Rabbani, Rahman, & Islam, 2011; Zinia & McShane, 2018b). To meet the demand for the increasing population, formal and informal housing and associated infrastructure development is taking place at the expense of ecosystems (Alam & Mullick, 2014; Shubho *et al.*, 2015) and threatening or reducing crucial ecosystem services. Apart from demographic pressure, Dhaka residents also face climate change impacts including extreme heat and extreme weather events (Zinia & McShane, 2018a). No study has been completed for Dhaka addressing urban ecosystem and ecosystem services assessment and their nexus with the socio-economic systems integrating quantitative and qualitative evaluations. As a resident of Dhaka, I have been motivated to undertake this research to increase our understanding of urban ecosystems and ecosystem services in Dhaka, the ecosystem governance mechanism, and the strategies that citizens can adopt to manage those ecosystem services that contribute to human wellbeing.

In the following (Sub-sections 1.1.1-1.1.3), I give an overview of current knowledge of urban ecosystems and ecosystem services, the nexus of ecosystems and ecosystem services with the social and economic systems, and urban ecosystems and ecosystem services in the context of Bangladesh based on rigorous literature review. I then present my research purpose (Section 1.2) with a specific aim and research questions. In Section 1.3, I describe the overarching methodology comprising a description of the study area, scope of this research, research design and conceptual framework, and data collection, management and analysis tools and approaches applied for this research. I present the thesis outline in Section 1.4 with brief descriptions of each chapter.

1.1.1 Current Understandings on Urban Ecosystems and Ecosystem Services

The term ‘Ecosystem’ has had a long history, though it gained the attention of the scientific community as a field for research and management approach only in the last century (MA, 2003; Willis, 1997). Ecosystem was first mentioned in print media in 1935 by A. G. Tansley (Braat & de Groot, 2012; Willis, 1997). According to Tansley (1935), ecosystems are the “*basic units of nature*” within which there exists continuous interactions between organisms and between organic and inorganic factors. Ecosystems are of different types: marine or terrestrial, coastal or inland, urban or rural with varying spatial scales including local to global (DEFRA, 2007). Hence, an ocean and a coral reef both are ecosystems. Definition of an ecosystem has remained more or less the same until now. The Millennium Ecosystem Assessment (MA) described an ecosystem as “*a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit*” of which humans are an integral part (MA, 2003).

The concept ‘ecosystem function’ has been subject to several interpretations due to its different meanings in various disciplines. Barkmann *et al.* (2008) interpreted ecosystem functions normatively as values or sources of benefits from a social science perspective. From an ecological view point, OECD (2010), Zandersen, Bråten, and Lindhjem (2009), and Costanza *et al.* (1997) regard ecosystem functions as the processes or attributes of ecosystems, such as chemical, physical, and biological features that play roles in maintaining ecosystems. Researchers (e.g., Boyd & Banzhaf, 2007; de Groot, Wilson, & Boumans, 2002) sometimes considered ecosystem function as a part of biophysical processes or structures and as intermediate to the final production of an ecosystem. For instance, if a coral reef is an ecosystem then one of its functions is prevention of disturbance or of natural hazards. de Groot (1992), explicitly defined ecosystem function as the capability of an ecosystem to supply goods and services directly and/or indirectly satisfying people’s needs. Similarly, Potschin and Haines-Young (2011), TEEB (2010c), and Boyd and Banzhaf (2007) used similar notions regarding ecosystem function.

The modern history of 'ecosystem services' originated between 1970s to 1980s when an increasing number of researchers examined this concept in more depth (see detailed historical analyses in Braat & de Groot, 2012; Gómez-Baggethun *et al.*, 2010) and since then ecosystem service has entered the mainstream literature (Daily, 1997; Fisher, Turner, & Morling, 2009; Perrings, Folke, & Mäler, 1992). Existing journals have widened their coverage to provide for such research outputs and new journals have emerged, for example, *International Journal of Biodiversity Science*, *Ecosystem Services & Management*[1] (ISSN: 2151-3740) and *Ecosystem Services* (ISSN: 2212-0416). Definitions of ecosystem services are available in various publications with varying foci on economic and ecological aspects. In accordance with the commonly cited definitions, ecosystem services are the direct or indirect goods and services, i.e., benefits derived from ecosystem functions, which contribute to human well-being (Costanza *et al.*, 1997; Daily, 1997; de Groot, Wilson, & Boumans, 2002; MA, 2005a; TEEB, 2010a). There is no agreed single method of classifying ecosystem services. However, the classifications mentioned in the MA framework are commonly accepted (DEFRA, 2007). According to the MA (2005a), all ecosystem services can be categorized under four broad classes namely, provisioning, regulating, supporting/habitat, and cultural services. Provisioning services are the goods/products that humans obtain from ecosystems (e.g., food, water, ornaments, and medicines). Regulating services include shoreline protection, water purification, and climate regulation among other controls on ecological functions. Supporting/habitat services are necessary for the production of other ecosystem services (e.g., nursery services, gene pool control, production of oxygen). The non-material benefits derived from an ecosystem are regarded as cultural services (e.g., tourism, spiritual experience). Boundaries between ecosystem functions and ecosystem services are sometimes difficult to identify as two or more distinct ecosystem functions may generate a single ecosystem service and vice-versa (Costanza *et al.*, 1997; Potschin & Haines-Young, 2011). Nonetheless, the MA framework, The Economics of Ecosystems and Biodiversity (TEEB) and the UK government's Department for Environment, Food and Rural Affairs (DEFRA) approaches are exclusively focused on ecosystem services.

As mentioned above, ecosystems are of different types (see Costanza *et al.*, 1997; de Groot, Wilson, & Boumans, 2002; MA, 2005a for details on ecosystem typology) that also include

[1] Formerly known as: *International Journal of Biodiversity Science & Management* (2005-2009).

urban and rural ecosystems. Many studies of urban areas treat urban systems as separate ecosystems, such as Bolund and Hunhammar (1999), Grimm and Redman (2004), Mcintyre, Knowles-Yánez, and Hope (2000), Niemelä *et al.* (2010), and Foresman, Pickett, and Zipperer (1997). Definitions of 'urban' differ among nations and comparative assessments generally use national definitions (Seto, Parnell, & Elmqvist, 2013). Urban systems, as stated in MA (2005a), are linked to specific spatial settings, diversified landscapes comprising varied ecosystems, urban settlements, and people living in urban areas. Foresman, Pickett, and Zipperer (1997) asserted that 'urban ecosystems' imply a complex mixture of land cover and land use of any settings. Gómez-Baggethun *et al.* (2013) referred to urban ecosystems as areas with built-up zones encompassing significant percentages of land covers. Bolund and Hunhammar (1999) defined urban ecosystems as all available natural green and blue places within an urban area. These natural spaces supply crucial ecosystem services for urban residents (Ahern, Cilliers, & Niemelä, 2014). Bolund and Hunhammar (1999) identified seven distinct site-specific urban ecosystems: street trees, lawns/parks, urban forests, cultivated land, wetlands, lakes/sea, and streams. Some common services provided by urban ecosystems are production of fruits, grains and seeds; carbon sequestration; micro climate regulation; noise reduction; air, water and pollutant filtration; pollination; recreation (e.g., parks, boating, fishing, picnic) (Bastian, Haase, & Grunewald, 2012; Bolund & Hunhammar, 1999; Costanza *et al.*, 2006; Escobedo, Kroeger, & Wagner, 2011; Haase, 2015). No specific set of ecosystem services available in all urban areas have been identified; rather they vary with the physical and demographic characteristics of cities.

'Drivers' or 'driving forces' are natural or human-induced factors that directly or indirectly influence ecosystems and services therein (MA, 2003; van Oudenhoven *et al.*, 2012). As stated in MA (2003), there are direct drivers (those that unequivocally influence ecosystem services) as well as indirect drivers (those that influence ecosystem services by altering direct drivers) ranging from global, regional to local scales. They can be endogenous (controlled by decision makers) or exogenous (independent of decision makers). Nevertheless, direct drivers include physical and biological factors (e.g., climate change, land use, water use, energy) whereas indirect drivers involve demographic (e.g., population growth), economic (e.g., Gross Domestic Product), cultural and socio-political (e.g., lifestyle, environmental policies), and science and technological influences (e.g., research and development) (Hauck, Winkler, & Priess, 2015; TEEB, 2010c). Drivers can be interconnected and can influence simultaneously (MA, 2003).

Climate change is often considered to be a key driver that directly affects ecosystem services (Hossain *et al.*, 2015a; Lyytimäki & Sipilä, 2009; MA, 2005b; TEEB, 2010a). According to the Intergovernmental Panel on Climate Change (IPCC), "*warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia*" (Ding & Nunes, 2014). The IPCC (2013) further stated that "*the atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased*". Hunt and Watkiss (2011) summarized the findings from the IPCC reports from a city perspective and identified the most important climate change effects on cities namely, among others, effects of sea level rise (on coastal cities), effects of extreme events (wind storm, storm surges, floods from excessive rainfall, droughts), effects on health due to higher temperature, effects on water resources and supply. Cities across the globe are already responding to the challenges associated with changes in climatic factors (Brown, Dayal, & Del Rio, 2012). Hunt and Watkiss (2011) presented an inventory of cities where climate resilience practices were applied. However, there is less information on how climate change will impact inland cities ecosystem services even though it is evident that climate change will considerably modify or permanently destroy quantity, quality, and spatial distribution of ecosystem services in the coming decades (Hunt & Watkiss, 2011; Shaw *et al.*, 2011). Grimm *et al.* (2008) indicated that urban heat island (UHI), i.e., the effect of urban development on changing heat fluxes and surface energy balance, is an increasing problem in major cities particularly those situated in tropical regions. Extreme weather events induced by climate change damage urban forests and therefore ecosystem services including storm water reduction, soil infiltration, carbon sequestration and nutrient retention (Escobedo, Kroeger, & Wagner, 2011). Pollution (air, water, soil) is also increased through increasing emissions from industrial activity (Escobedo, Kroeger, & Wagner, 2011; Yang *et al.*, 2015). In addition, biodiversity in urban areas is under threat due to deterioration of water bodies particularly the flushing of storm effluent from drainage systems (Wilby & Perry, 2006), which also impacts urban dwellers through exposure to water-borne diseases.

Land use change is another driver that plays a vital role in changing ecosystem services (Foresman, Pickett, & Zipperer, 1997; van Oudenhoven *et al.*, 2012). Land use refers to the human actions that make use of biophysical characteristics (topography, soil, climate) of the Earth's land cover (i.e., the surface) and thus alter processes of ecosystems functioning (Dewan, Yamaguchi, & Rahman, 2012; Veldkamp & Fresco, 1996). Human activities convert ecosystems from their original states to different types of land use including habitation, cultivation, and transportation (de Groot, 2006). The extent of land use largely depends on land zoning policies, management practices and more importantly land ownership (Foresman, Pickett, & Zipperer, 1997). Increased built-up area and diverse land use practices alter landscape structure, resource flows, species composition, and ecosystem services from green and blue spaces, and diminish ecosystem resilience and aggravate pollution, which is obvious in many urban areas (Grimm *et al.*, 2008; Lyytimäki & Sipilä, 2009; Niemelä *et al.*, 2010; Tratalos *et al.*, 2007).

1.1.2 Economic and Social Outlooks for Urban Ecosystem Services

People, in general, are less familiar with the scientific implications of ecosystem functions, but realize their importance to human wellbeing and to society as a whole if any value is attached to the services that ecosystems supply (Barkmann *et al.*, 2008). Valuation works as a mechanism that makes people rethink about the roles that nature plays in forming personal and social identities and consequences of their actions on environment (Clayton & Opotow, 2003; Zavestoski, 2004). Valuation expresses nature's value in such a way that influences major political and economic views worldwide (TEEB, 2010a). In addition, valuation helps decision making on intervention options for environmental management and assessing damages/ benefits associated with such interventions (DEFRA, 2007). Thus there has been increasing interest on valuing benefits of ecosystem services provided to human societies which is reflected in the noticeable growth of related publications (de Groot, Wilson, & Boumans, 2002). Such research outputs have received widespread attention by decision makers. In particular, the MA was influential in promoting ecosystem services on policy agendas across the world (Costanza *et al.*, 1997; Costanza & Daly, 1992; Fisher, Turner, & Morling, 2009; Perrings, Folke, & Mäler, 1992; TEEB, 2010c).

Valuation is defined in many ways across disciplines and there are debates on methods of valuation (Bingham et al., 1995; Costanza et al., 1997). Farber, Costanza, and Wilson (2002) defined valuation as "the *process*" of presenting a value- "*the contribution of an action or object to user-specified goals, objectives or conditions*" for a specific "*action or object*". The MA agrees on this notion and predominantly uses a valuation approach for assessing the impacts (benefits/losses) of alternative ecosystem management options (de Groot *et al.*, 2006; MA, 2003). Boyd and Banzhaf (2007) proposed to take into account the 'final' ecosystem services, i.e., "*the last contribution of the ecosystems*" and "*the components of nature, directly enjoyed, consumed, or used to yield human well-being*" to avoid double counting in valuation. These authors emphasized that final ecosystem services and final economic goods and services (directly consumed or enjoyed by households) are different. According to Fisher and Turner (2008), final services often depend on the beneficiaries' perspectives. The authors stated that no linear relationship existed between ecosystems. Furthermore, a single ecosystem service may generate diversified benefits and values of those benefits can be added together. Wallace (2007) proposed a new classification of ecosystem services for valuation. This claimed to avoid double counting but that classification has been criticized by others (see Fisher & Turner, 2008). Fisher and Turner (2008) stressed the need for further research to clarify the ambiguity between final and intermediate ecosystem services especially for economic valuation. More generally, urban ecosystem services in terms of valuation attract relatively little research attention (Zinia & McShane, 2018b). Milestone studies including Costanza et al. (1997), Costanza et al. (2014) and TEEB database[2] by Van der Ploeg, De Groot, and Wang (2010) have very limited information on values of urban ecosystems.

Methods of ecosystem services valuation involve conventional economic valuation including direct market valuation approaches (market price, factor income-based approach, cost based methods: avoided cost, replacement cost, mitigation and restoration cost), revealed preference approaches (travel cost method, hedonic pricing), stated preference approaches (contingent valuation, choice modelling, group valuation), and benefit transfer method. For details on valuation methods see de Groot *et al.* (2006); DEFRA (2007); Farber, Costanza, and Wilson (2002); MA (2003); Richardson *et al.* (2015); TEEB (2010b). Some researchers, such as Busch *et al.* (2012) compared qualitative versus quantitative assessment and valuation of ecosystem services and concluded that both are essential. Valuation methods are case specific and depend on data availability, investigation scale, and strength of development goals. The research cited above generally emphasizes both quantitative and qualitative approaches as this allows cross checking the directions of assessments using two different methodologies and identifying inconsistencies.

Assessment and valuation of ecosystem services provide a strong basis for selecting, modifying and formulating policy instruments, and scenarios for ecosystem services management

[2] http://doc.teebweb.org/wp-content/uploads/2017/03/teeb_database_teebweb.xlsx

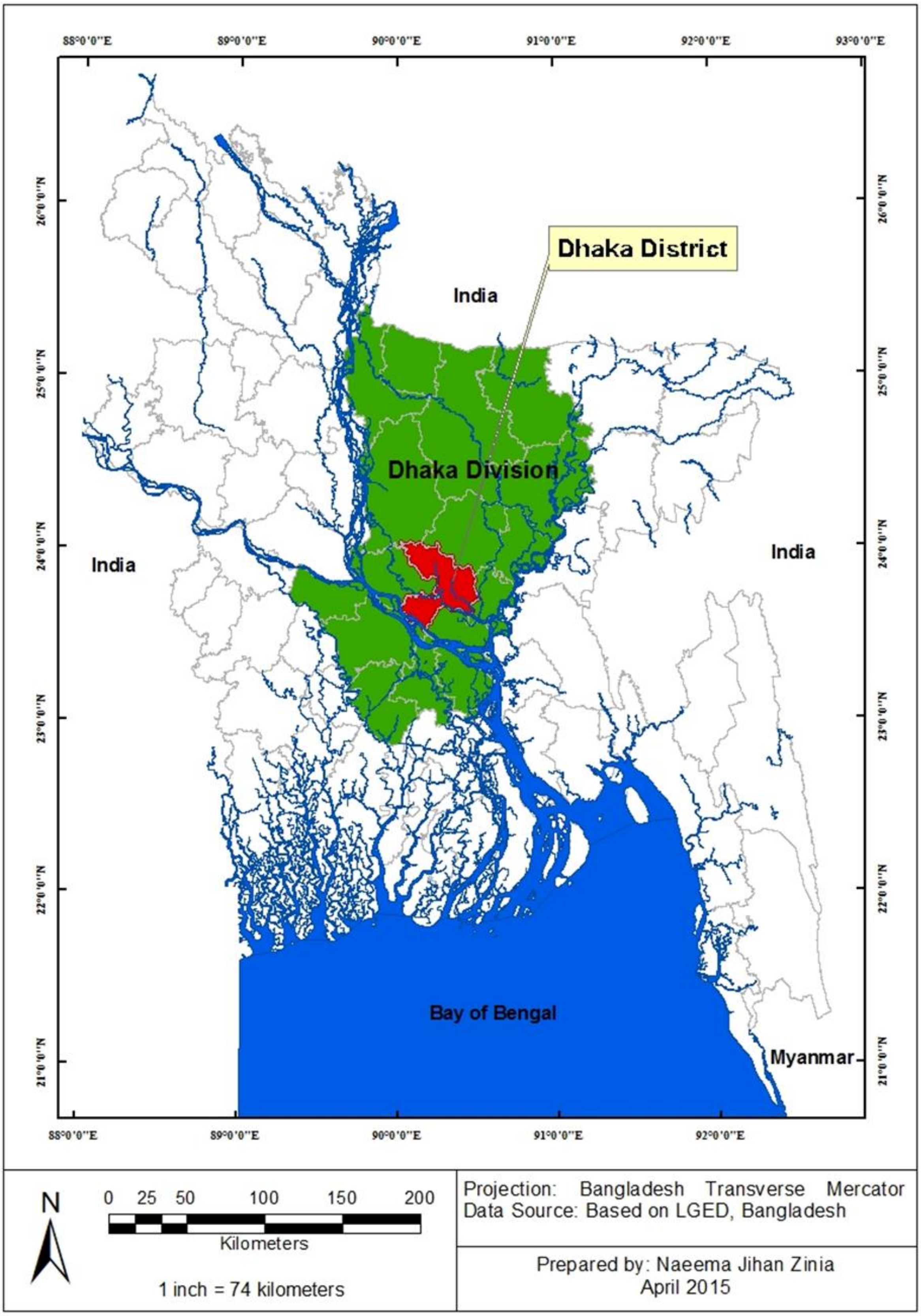
(Costanza *et al.*, 2014) and overall ecosystem governance. 'Governance' is a commonly talked about concept but its definition is rather vague (Davies, 2002; Rhodes, 1996). The notable literature refers to governance as a set of rules which involves government and non-government actors where the actors interact with each other for a common goal (Rhodes, 1996; Stoker, 1998; Weiss, 2000). The governance concept is applied in different sectors of a society (see Rhodes, 1996 for details) including the environment sector and thus its definition is modified accordingly. Environmental governance includes planning, policymaking, management, other governing processes (Ansell & Gash, 2008; Pahl-Wostl, 2009) targeting common welfare and comprising spatial scales and themes (environment as a whole and/or environmental components, such as water resources) (Bulkeley, 2005; Lemos & Agrawal, 2006; Wiek & Larson, 2012). Some widely acknowledged scholars (e.g., Paavola, Gouldson, & Kluvánková-Oravská, 2009; Pahl-Wostl, 2009) prefer 'governance regime' as an all-inclusive term rather than 'management' or simply 'governance'. 'Governance regime' embraces a set of principles, rules, norms and prevailing practices for formulating and implementing collective choices (i.e., decision-making procedures) with involvement of government, non-government, and private sector stakeholders of a society (Krasner, 1982; Paavola, Gouldson, & Kluvánková-Oravská, 2009; Pahl-Wostl, 2009; van de Meene, Brown, & Farrelly, 2011; Wiek & Larson, 2012).

As part of the governance process, many countries have successfully undertaken exemplary adaptation approaches for urban ecosystem services management given unprecedented rate of urbanization coupled with climate change and land use change impacts. For instance, in Stuttgart (Germany) extensive greening actions have been implemented one of which was planting grasses in tram tracks to reduce UHI and improve air quality; in Augustenborg (Malmö, Sweden) about 90% of storm water from roofs and other impermeable surfaces links to an open storm-water system (separate from the combined sewer) in residential areas which decreases the risk of urban flooding by half and enhances the image of the area; in Seattle (Washington State, USA) landslide risks (ground instability) are reduced in landslide-prone areas by creating provisions for, and restoration of, vegetation (Kazmierczak & Carter, 2010). Other successful urban adaptation measures include, among others, installing green roofs, establishing green belts around the city, community gardening, creating artificial urban wetlands and pocket parks (see Chiesura, 2004; Kabisch, 2015; Tzoulas et al., 2007; Voskamp & Van de Ven, 2015; Young et al., 2014). Such measures improve the quality of human lives, through generating diverse ecosystem services, e.g., providing recreation facilities, attracting tourism, creating habitats for different species, recharging aquifers, controlling UHI via evapotranspiration, and producing food (Kabisch, 2015; Voskamp & Van de Ven, 2015; Young et al., 2014). Urban ecosystem users are found to have greater longevity, better health, more physical activity, relaxation, and improved recovery from stress and mental fatigue (Tzoulas et al., 2007).

Regulatory agencies are concerned about ecosystem services and implement necessary measures at global, regional, and national levels. The United Nations Framework Convention on Climate Change (UNFCCC) is an environmental treaty with 196 countries that aims at stabilizing global warming. Consequences of climate change in the most vulnerable developing countries have got less attention than developed nations (Ayers & Huq, 2009). Nevertheless, many least developed countries (LDCs) have prepared National Adaptation Programmes of Actions (NAPAs) as part of the UNFCCC's adaptation activities prioritizing community-based ecosystem services management, such as afforestation/reforestation in Bangladesh and Myanmar for climate resilient ecosystems, and reducing natural hazards and rainwater harvesting in Bhutan[3]. The European Environment Agency recommends people having access to green space within 15 minutes distance by walk and it has been found that all citizens in Paris, Copenhagen, Brussels, Madrid, Milan, Gothenburg have such access (Barbosa *et al.*, 2007). China has national standards on national garden city and ecological garden city that incorporate green coverage and per capita park space for integrating greenery into development of cities (Zhao, 2011). Singapore is a successful example of urban greening with strong government commitment and allocation of land and financial resources where the residents have high levels of satisfaction regarding the greenery in their environment (Tan, Wang, & Sia, 2013). In Quy Nhon, a coastal city in central Vietnam, a mangrove forest restoration project for a 150 hectare zone has been undertaken under a co-management arrangements between the local communities including the local government departments, local research centers, and the Asian Cities Climate Change Resilience Network (ACCCRN) authorities which is expected to protect around 60,000 residents who are at high risks of coastal erosion and floods (Brown, Dayal, & Del Rio, 2012). A watershed approach in Hiware Bazaar under the 'Ideal Village Scheme' of the state government of Maharashtra, India, addressed ecosystem services management that contributes significantly to poverty alleviation by improving forest cover, water use efficiency, land degradation, and agricultural productivity (Avishek, Liu, & Yu, 2012). Decentralized measures have been taken to build resilience against water scarcity caused

[3] http://unfccc.int/adaptation/workstreams/national_adaptation_programmes_of_action/items/4583.php

by urban development through approaches including rainwater harvesting in Semarang, Indonesia (Brown, Dayal, & Del Rio, 2012). The governance of ecosystems and ecosystem services thus essentially requires cooperation among government agencies, development organizations, NGOs, other private sector organizations, and local communities.



Map 1.1 Location of Dhaka, Bangladesh.

1.1.3 Urban Ecosystem Services in the Context of Bangladesh

The People's Republic of Bangladesh is located in the South East part of the South Asian sub-continent. The country is bordered by India on three sides - the west, the north and the east, by Myanmar (former Burma) on the south-east, and by the Bay of Bengal on the south (Map 1.1). Bangladesh is one of the largest deltas in the world with a total area of 147,570 km^2 of which agricultural lands occupy 65%, forest land accounts for almost 17%, river networks and other land use comprise 10%, and urban areas make up the remaining 10% (BBS, 2014). Currently the real GDP (Gross Domestic Product) growth rate of Bangladesh is around 6% and about 50% of GDP comes from the services sector (BBS, 2014; MoF, 2014). The literacy rate is 58% at national level (BBS, 2014). Almost 88% of Bangladeshi people have access to safe drinking water but only about 67% people use improved sanitation facilities (MoF, 2014). About 23% of Bangladesh's total population lives in urban areas and more than 60% of this urban population is concentrated in four major cities: Dhaka, Chittagong, Khulna and Rajshahi (BBS, 2012; Rana, 2011). Migration from rural climate-stricken areas to the capital city Dhaka is common (Ishtiaque & Mahmud, 2017; Jahan, 2012; Rabbani, Rahman, & Islam, 2011).

Bangladesh is low-lying country with a complex network of 310 rivers of which 57 are transboundary rivers (BBS, 2013b). Monsoonal rains in the catchment of the transboundary rivers increase the risk of floods in Bangladesh (Mirza, Warrick, & Ericksen, 2003). Bangladesh is considered to be one of the most climate vulnerable countries in the world (MoEF, 2009a). According to ADB (2011), climate change, rising sea levels, and salinity intrusion will have devastating impacts on Bangladesh not only because of its low-lying topography but also because of its huge population size and density, inadequate physical infrastructure, lack of institutional capacity, low level of social development, and comparatively higher dependence on its natural resources. Susceptibility is extreme in major cities, such as Dhaka.

Dhaka, the capital city of Bangladesh, is located on the bank of the River Buriganga and its total area is 1,463.6 km^2 (BBS, 2013a). Geographically Dhaka is in the central part of the Bangladesh delta (Map 1.1) formed by three major rivers, the Ganges, the Brahmaputra, and the Meghna (GBM). Dhaka district includes six upazilas (sub-districts) namely, Dhaka Metropolitan, Dhamrai, Dohar, Keraniganj, Nawabganj and Savar (BBS, 2013a). More than 77% of Dhaka has been urbanized (BBS, 2012). The annual population growth rate of this district is 3.5% and, of the 12 million (approx.) people that live in the district, 62% live in urban areas (*ibid*, 2012). Dhaka is one of the world's fastest growing megacities (Ahmed, Nahiduzzaman, & Bramley, 2014; Rana, 2011; Roy, 2009b). As the capital, Dhaka is important to the national economy as well as socio-cultural developments. Further urban expansion is expected to occur in the peri-urban (fringe) areas of this city since the core is already developed (Roy, 2009b).

Byomkesh, Nakagoshi, and Dewan (2012) exclusively defined urban green spaces/ecosystems for Bangladesh. According to the authors, these include "*land surfaces that are comprised of both cultivated lands (agricultural areas, crop fields, fallow lands) and vegetation cover (deciduous forest, mixed forest lands, palms, conifers, shrubs, and others)*". Blue spaces/ecosystems comprise "*all visible surface waters*" (Völker & Kistemann, 2011). For Bangladesh this includes ponds, lakes, permanent open water, wetlands (permanent and seasonal wetlands, low-lying areas, marshy land, rills and gully, swamps), rivers, and reservoirs (Dewan & Yamaguchi, 2009a). Continuous urban expansion poses severe threats to Dhaka's ecosystems and ecosystem services (food provision, air/water quality, water logging frequency, microclimate (UHI), aesthetic value, and recreational use) that are inevitably affecting the wellbeing of residents (Byomkesh, Nakagoshi, & Dewan, 2012; Rana, 2011; Zinia & McShane, 2018a, 2018b).

Ecosystem services assessment, valuation, and management is a new arena of research in the context of Bangladesh. A few publications are available but these mostly focus on coastal or mangrove ecosystems. For instance, Hossain *et al.* (2015a) analyzed recent changes in ecosystem services and human well-being in the coastal zone, Hossain *et al.* (2015b) integrated ecosystem services with climate change for coastal wetlands, Uddin *et al.* (2013) valued provisioning and cultural services of the Sundarbans mangrove forest located in the coastal area, Ahammad, Nandy, and Husnain (2013) and Nandy *et al.* (2013) assessed ecosystem-based adaptations in coastal Bangladesh. There are some other studies that considered ecosystem services discretely rather than as a complete ecosystem services assessment. For example, Haque *et al.* (2013) utilized innovative approaches to assess the quality of major parks in Dhaka and Islam *et al.* (2004b) studied aquaculture as a source of food in urban and peri-urban areas of Dhaka. In-depth research has been undertaken on Dhaka's land use/ land cover change, climate change, land surface temperature, and other socio-economic and demographic issues (for details see the book titled "*Dhaka Megacity: Geospatial Perspectives* *on Urbanisation, Environment and Health*", published in 2014 by Springer[4]). However, until now, no study has been undertaken that focuses on Dhaka's urban ecosystems and on ecosystem services assessment, valuation, and management.

Ecosystem governance in Bangladesh mainly follows the government legal guidelines (Bahauddin, 2014). The government of Bangladesh (GoB) acknowledged the necessity for environmental protection and development at national level for the first time in the *National Environmental Policy, 1992*. This policy provides legal and institutional frameworks for improvement, protection and conservation of the environment (Legislative and Parliamentary Affairs Division, ND). Some significant environmental legal guidelines are the *Bangladesh Environment Conservation Act, 1995*; the *Environment Conservation Rules, 1997*; the *Land Use Policy, 2001*; the *Environment Court Act, 2010*; and the *Water Act, 2013*. Together, these legal guidelines introduced Environmental Impact Assessment (EIA) for industrial activities; presented conditions required for declaring Ecologically Critical Area (ECA) and imposed penalties for non-compliance; set standards for air, water, soil, noise, odor, sewage discharge and emission of waste; and put restrictions on filling out waterbody, hill cutting and or razing, ship breaking, and hazardous waste disposal (Bahauddin, 2014; Department of Environment, ND; Ministry of Environment and Forests, ND; Momtaz & Kabir, 2014). The GoB changes emphasis and/or includes new governance issues (e.g., setting the allowable usage of polythene bags, and specification of penalties) through amendments where necessary. The GoB has formulated legislations to give attention to the protection and conservation of specific ecosystems and ecosystem services: conserve haor ecosystem and optimize resource utilization and poverty reduction (Haor Master Plan, 2012); ensure sustainable integrated and socially-just water resources management for current and future generations (*National Water Policy, 1999* and *Water Act, 2013*); and prevent continuous decline in the rate of cultivated land to ensure crop production and to control unplanned urbanization (*Land Use Policy, 2001*) (Directorate of Bangladesh Haor and Wetland Development, ND; Legislative and Parliamentary Affairs Division, ND; Ministry of Water Resources, ND). Bangladesh also realizes the severity of climate change and its impact on ecosystems and ecosystem services and thus has adopted actions, plans, and programs for mainstreaming adaptations into national policies (Ayers & Huq, 2009; Ayers *et al.*, 2014). Such initiatives include National Adaptation Programmes of Action (NAPA), 2009; Bangladesh Climate Change Strategy and Action Plan

[4] ISBN 978-94-007-6735-5; http://www.springer.com/gp/book/9789400767348

(BCCSAP), 2009; and Bangladesh Delta Plan 2100. These initiatives are expected to develop resilience of ecosystems and disaster preparedness in short, medium, and long terms (Ayers *et al.*, 2014; GED, 2014; MoEF, 2009a, 2009b).

The environmental government agencies in Bangladesh often work in cooperation with international donor organizations, national and international NGOs, ENGOs, and civil society organizations (e.g., professional associations, community-based organizations, research groups, think tanks, and environmentalists), and local communities for ecosystem governance (Ahmed & Roy, 2015; Gauri & Galef, 2005; Haque, 2002; Zafarullah & Rahman, 2002). The governance activities include: providing policy inputs and assistance with international negotiations, performing research, working on project implementation, supporting environmental movements, ensuring rule of law and justice, and raising environmental awareness (Ahmed & Roy, 2015; Zafarullah & Rahman, 2002). Some research indicates that ecosystem-related policy formulation and implementation lack representation and input from potentially the most vulnerable groups, i.e., local communities (Bahauddin, 2014; Islam & Walkerden, 2017). Very limited research has been conducted on ecosystem governance or on the governance regime in context of Bangladesh. Some related research includes Mittal, Petrarulo, and Perera (2015) (urban environments at macro, meso, and micro levels), Ahammad, Hossain, and Husnain (2014) (co-management of forest conservation, Shamsuzzaman and Islam (2018) (legal frameworks for coastal and marine fisheries), Bahauddin (2014) and Morshed and Asami (2015) (roles of government, market, and NGOs in environmental governance), and Momtaz and Kabir (2014) (environmental problems and governance). Only a few of these studies have examined urban areas, more specifically, Dhaka city.

1.2 PURPOSE OF THE RESEARCH

1.2.1 Research Aim

My research is aimed at contributing to urban ecosystem services management in Dhaka by (i) identifying and valuing urban ecosystems and ecosystem services, (ii) assessing ecosystem governance, and (iii) recommending socially acceptable and economically feasible green adaptation strategies.

1.2.2 Research Questions

Relating to the research aim, the following research questions (RQ) were addressed;

RQ1. What ecosystems and ecosystem services are available in the study area?

RQ2. What are the economic values of the identified ecosystem services?

RQ3. How does the governance regime address ecosystems and ecosystem services?

RQ4. What green adaptation strategies are applied worldwide for urban ecosystem services management?

RQ5. Which green adaptation strategies are economically feasible and socially acceptable in the study area?

1.3 METHODOLOGY

1.3.1 Study area

Dhaka district was established in 1772. It is crisscrossed by many rivers. The Padma, the Buriganga, the Dhaleswari and the Shitalakshya are navigable almost all year round (BBS, 2013a). There are some small rivers flowing through Dhaka including the Turag, the Bangshi, and the Balu. The average annual temperature and rainfall of Dhaka are 34.5°C (maximum), 11.5°C (minimum) and 1,931 mm, respectively (BBS, 2012). Section 1.1.1 briefly presents Dhaka's demographic information. Agro-based activities dominate in rural areas of Dhaka whereas activities in urban areas are service and industry based.

Dhaka district has two city corporations, Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC) (Map A.1.1, Appendix I). The DNCC was established in 2011 by the *Local Government (City Corporation) (Amended) Act 2011*. The total area of DNCC is 82.64 km^2 and it lies between 90º20' to 90º28' east longitudes and 23º44' to 23º54' north latitudes (DNCC, 2017). The DNCC comprises 36 wards[5] (the smallest administrative urban geographic unit) which are distributed among five zones (Table 1.1). The Zone 2 (Mirpur-Pallabi) of the DNCC is the study area of my research that represents more than 25% of the total DNCC area.

[5] The smallest administrative urban geographic unit comprising mahallas (the lowest urban geographic unit having identifiable boundaries) and having ward council institution.

Table 1.1 Zone-wise DNCC Ward Numbers and Ward Areas (km^2).

Zone Number and Name	**Ward Number**	**Area (km^2)**
Zone-1 (Uttara)	Ward-01	6.095
	Ward-17	5.475
Zone-2 (Mirpur-Pallabi)	Ward-02	3.048
	Ward-03	1.101
	Ward-04	1.338
	Ward-05	1.3444
	Ward-06	3.029
	Ward-07	1.875
	Ward-08	3.776
	Ward-15	5.806
Zone-3 (Gulshan)	Ward-18	1.749
	Ward-19	5.186
	Ward-20	1.729
	Ward-21	1.449
	Ward-22	1.808
	Ward-23	0.855
	Ward-24	3.075
	Ward-25	1.218
	Ward-35	1.149
	Ward-36	0.769
Zone-4 (Mirpur-Kazi Para, Gabtoli)	Ward-09	1.615
	Ward-10	1.669
	Ward-11	1.133
	Ward-12	1.697
	Ward-13	1.814
	Ward-14	1.946
	Ward-16	2.088
Zone-5 (Kawranbazar)	Ward-26	1.374
	Ward-27	3.661
	Ward-28	1.528
	Ward-29	0.712
	Ward-30	2.383
	Ward-31	0.629
	Ward-32	1.561
	Ward-33	5.592
	Ward-34	1.362

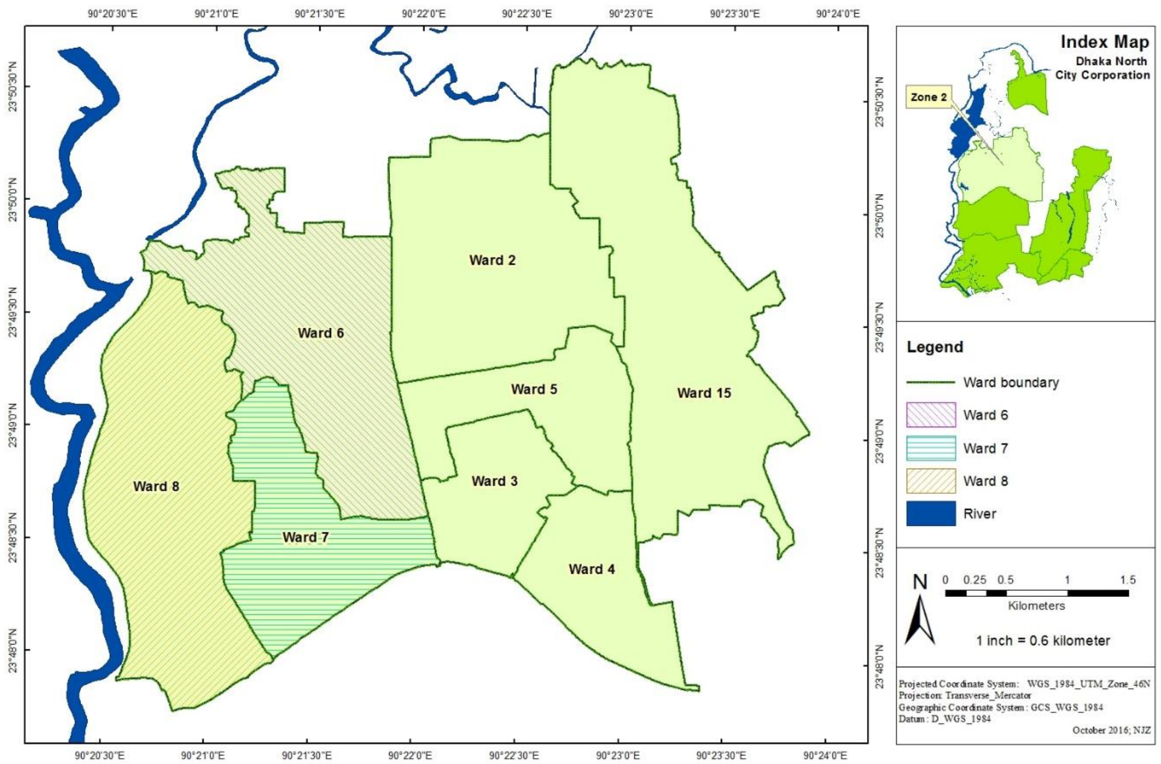
Source: DNCC (2017)

1.3.2 System Boundaries and Scope of the Study

1.3.2.1. Spatial Boundary

The Zone 2 (Mirpur-Pallabi), DNCC is the broad study area of my research, which consists of eight wards (Map 1.2). For the survey, I did in-depth research on three wards under this Zone. I selected wards 6, 7, and 8 based on field level observations, expert judgements, and literature review. These three wards cover 41% of the Zone-2 (DNCC, 2017). The demographic (population, income level, literacy rate, gender ratio) conditions and land use patterns across the wards under DNCC are similar (BBS, 2013a; DNCC, 2017). Furthermore, the presence of a wide range of ecosystems in these wards, access to them and to households within wards for surveys, were taken into consideration.

The total area of the Zone 2 is 21.32 km^2 with 24,488 holdings (DNCC, 2017). Among the wards, ward-15 is the largest in area followed by ward 8, ward 2, and ward 6. Ward 2 contains the greatest number of holdings/households (20%) and ward 4 the least (6%) (Figure A.1.1, Appendix I). The population in Zone 2 is about one million and the literacy rate ranges between 55% to 85% (BBS, 2013a).



Map 1.2 The DNCC Zone 2 and its Wards.

1.3.2.2. Temporal Scale

My research is essentially a baseline study and therefore takes into account the current time only: years 2015, 2016, and 2017.

1.3.2.3. Scoping of Related Concepts

The following concepts apply in my research.

Urban area

The definition of urban area adopted was given in BBS (2012): an urban area "*corresponds with area developed around a central place having such amenities as metaled roads, improved communication, electricity, gas, water supply, sewerage, sanitation and also having comparatively higher density of population with majority population in non-agricultural occupations*".

Ecosystem services

The commonly cited definition of ecosystem services was adopted: ecosystem services are the benefits (goods and services) that are derived from ecosystem functions which contribute to human well-being directly or indirectly (Costanza *et al.*, 1997; Daily, 1997; de Groot, Wilson, & Boumans, 2002; MA, 2005a; TEEB, 2010a).

Scoping of ecosystem services types

There is a risk of double counting ecosystem services in relation to supporting and some regulating services in valuation (Fisher, Turner, & Morling, 2009). Values of supporting services are embedded in other types of ecosystem services. Hein (2010) stated that it is not clear whether these services should be included or excluded from valuation. Some regulating services support the supply of other services. For example, pollination (regulating service) helps trees to produce fruits (provisioning service) inside the same ecosystem or to adjacent ecosystems. Considering the former in valuation leads to a double counting problem (Hein, 2010; Lele *et al.*, 2013). It would be difficult to identify if pollination occurs by insects from within the ecosystem or from outside. Therefore, only those regulating services that provide direct benefits to people were considered. To avoid the double counting problem, all supporting services and some regulating services that act like supporting services were excluded from ecosystem services valuation.

Scoping of economic values

Direct use and *indirect use values* associated with provisioning, regulating, and cultural ecosystem services at current time were evaluated. Any future value and consequently, *option value* were excluded from my research. Hence, no discounting was performed. In addition, *non-use values* of ecosystems/ecosystem services were not considered for valuation.

Governance regime

Governance regime is the set of principles, rules, norms and prevailing practices for formulating and implementing collective choices (i.e., decision-making procedures) with involvement of government, non-government, and private sector stakeholders (Krasner, 1982; Paavola, Gouldson, & Kluvánková-Oravská, 2009; Pahl-Wostl, 2009; van de Meene, Brown, & Farrelly, 2011; Wiek & Larson, 2012).

Green adaptations

Green adaptation strategies present affordable options, utilize ecosystems for multifunctional purposes, and involve multiple stakeholders (Goodess *et al.*, 2013; Hulsman, Van der Meulen, & Van Wesenbeeck, 2011). Green adaptations that were possible to implement individually and/or collectively with minimum direct government intervention were taken into consideration. 'Green adaptations' and 'green adaptation strategies' were used interchangeably in my research.

Social acceptance

An individual's or a group of local residents' support(s) (high to low) reflected in their preferences for adoption of green adaptation strategies (Chin et al., 2014; Schweizer-Ries, 2008; Wüstenhagen, Wolsink, & Bürer, 2007; Zhao et al., 2015; Jung et al., 2016; Zhao et al., 2015).

Economic feasibility

Individual and collective affordability, i.e., the purchasing power for implementing green adaptation strategies (Halil et al., 2016; Jana et al., 2016; Liang & van Dijk, 2010).

1.3.3 Research Design and Conceptual Framework

This is a 'mixed methods' research that incorporates both quantitative and qualitative approaches. Use of mixed methods enables including a wider range of data collection and analysis tools and approaches (Creswell, 2009) which strengthens the overall research. I collected both qualitative and quantitative data. I utilized these two types of datasets simultaneously to assess different aspects of the same issue to provide an overall composite evaluation. Sometimes, I compared the datasets in order to determine whether there was convergence, divergence, or some mixture/combination of data. Methods and approaches that I applied for data collection and analysis are available in Sub-sections 1.3.4 and 1.3.6, respectively. Following Creswell (2009), I adopted triangulation strategy for data validation. I triangulated different data sources: primary data- observation, interviews, and survey and secondary data- literature and map review.

The framework in Figure 1.1 conceptualizes my research scheme. Step 1 of this framework contains key data collection (literature review, interviews, observations, and surveys) and data analysis (economic valuation, policy, ecosystem services, and satellite images) approaches, and tools. Some other approaches and tools have also been applied. These are described in the relevant Chapters. Step 2 presents the process flows (e.g., identify green adaptation strategies, analysis of economic feasibility and social acceptance, evaluation of current conditions or ecosystem services, and analysis of governance regimes) that generated the research outcomes (targeted to address the research questions) shown in Step 3 and eventually achieved my research objectives.

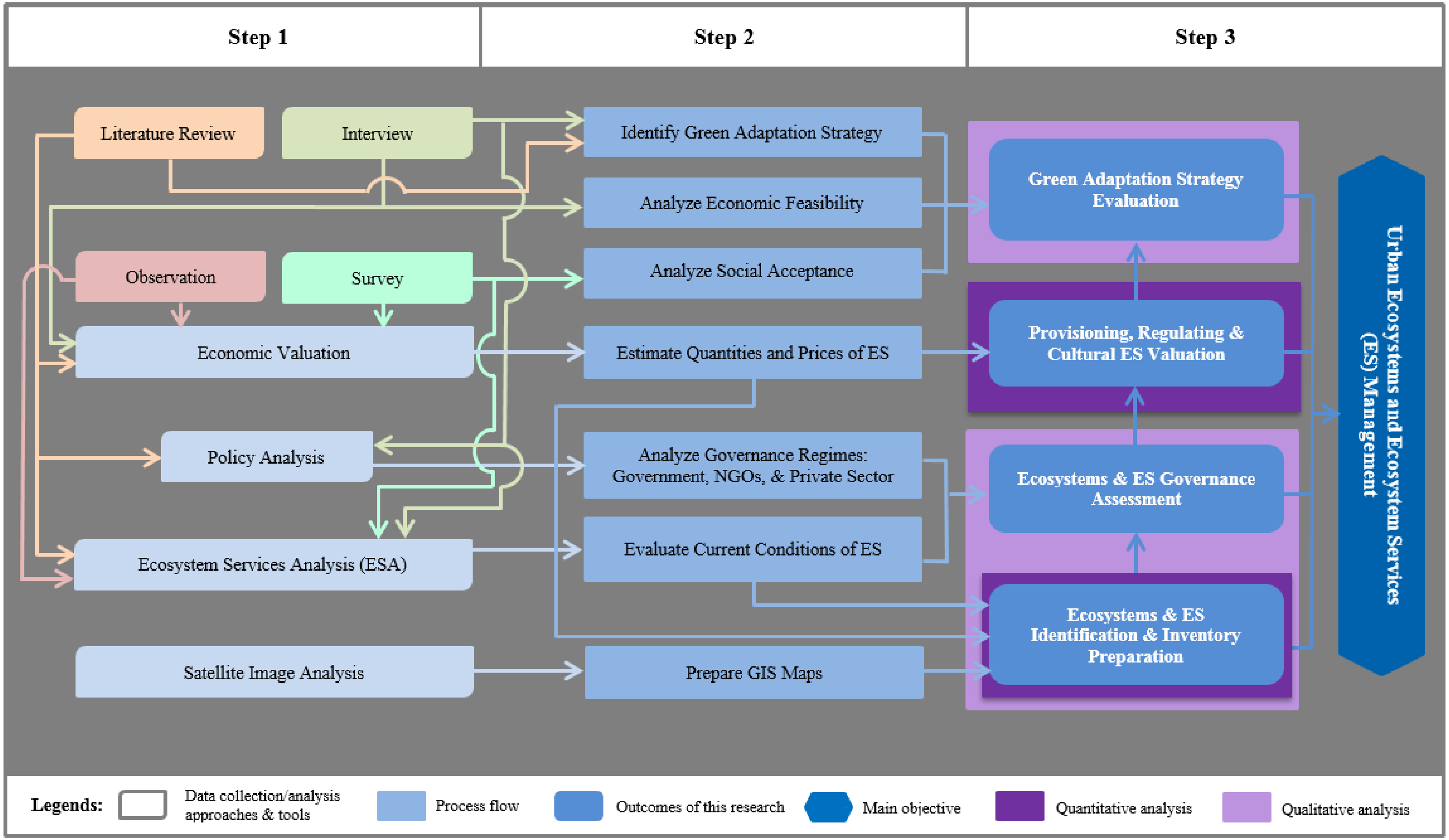


Figure 1.1 Conceptual Framework.

1.3.4 Data collection methods

The means for primary data collection include observations, surveys, interviews (individual or group), schedules, textual or visual analysis, and other content analysis (Gill *et al.*, 2008; Kothari, 2004; Overton & Van Diermen, 2014). Selection of these methods depend on the type of data to be collected, i.e., qualitative or quantitative, study area, access to perform research, time, human and financial resources. Table 1.2 presents the data collection methods used for my research together with brief descriptions. Secondary data were collected from reviews of journal articles, books, reports, maps, and information available on the internet. I collected primary data through observation, interviews with experts, and household surveys and tree surveys. Details on the primary data collection methods and rationale for selecting them are presented in the subsequent paragraphs and the method sections of Chpaters 2, 3, and 4. Appendix V includes the data collection formats and some images of my field activities.

Table 1.2 Data Collection Methods.

Data Type	**Data Collection Method**	**Description**
Secondary data	Review	- Collected freely available journal articles, books, reports, information from library, internet and personal contacts; - Purchased data, reports, and maps.
Primary data	Observations	- Prepared an observation framework for data collection; - Performed observation without hampering any activities in the field; - Verified information found from literature review; - Took GPS coordinates and photographs and did video recording. - Recorded noise levels, relative humidity, and temperature.
Primary data	Interviews	- Selected experts for interview based on their expertise using personal contacts and snowballing approach; - Conducted interview sessions using a check list; - Recorded conversations with a recording device, translated into English from Bangla, and transcribed.

Primary data	Household surveys	- Prepared a semi-structured questionnaire which was easy to understand and less time consuming to fill out; - Prepared the questionnaire in such a way so that it could collect both qualitative and quantitative data; - Pre-tested the questionnaire beforehand and made necessary changes; - Determined the statistically significant sample size for the survey; - Hired and trained some research assistants for the survey; - Explained the respondents as clearly as possible and made them comfortable with the survey process; - Entered the survey data systematically in data management software.
Primary data	Tree surveys	- Selected a park and three roads for surveying trees; - Counted trees in the park and on roadsides; - Measured tree diameter.

1.3.4.1. Observation

Observation method is used for both qualitative and quantitative data collection. It often involves techniques such as, counting number, measuring area, perceiving social and physical environments, and analysis of human behavior (Overton & Van Diermen, 2014; Raudenbush & Sampson, 1999). Observations eliminate subjective bias as information are directly collected without asking any respondents, obtain information on current conditions, and does not depend on respondents' willingness to respond like interview and survey methods (Kothari, 2004). One key disadvantage of observation method is that it fails to capture the theoretical constructs that require residents' perspectives, which can be attained by survey method (Raudenbush & Sampson, 1999). Relying only on observation may result in misinterpretation, however, if used in conjunction with surveys, it can be a strong and independent source of data (*ibid*, 1999).

Observation activities on of ecosystems and ecosystem services were performed for a week in February 2016 in the entire study area (eight wards, Zone 2). I used an observation framework (Appendix V) to identify ecosystem services supplied by those ecosystems identified. I utilized satellite image (Image 1.1) and prepared GIS maps for identifying the study area boundary and for observing ecosystem services. I verified and classified the ecosystems through observation. Observations were performed in 80 locations in all eight wards out of which about 20 locations had full or limited (entry fees or occasionally open) public access. I took GPS coordinates using a hand-held GPS device and photographs/videos during observations.

Additionally, I measured noise levels, relative humidity, and temperature twice daily (morning and afternoon) making a loop (built up area-ecosystem-built up area) for three consecutive days in January 2017 using a handheld 4 in 1 digital multi-function environment meter. The specification of the meter is available in Table A.1.1 (Appendix I). Mean values of three days' measurements were considered for analysis.

1.3.4.2. Interview

The interview method of qualitative data collection involves face-to-face or telephone-based communications with participants and focus group discussion intended to extract peoples' views and opinions (Creswell, 2009). The types of research interviews are: structured, semi-structured, and unstructured. Structured interviews with a checklist of predetermined questions are relatively quick and easy to administer, however, fail to capture in-depth information (Gill *et al.*, 2008). Unstructured interviews are time consuming and difficult to manage and to interpret. Semi-structured interviews, on the other hand, contain a few key questions that help to guide the discussion topics and also allow the interviewer to gather information in more detail (*ibid*, 2008). The interview sessions should not be too long, the interviewer's approach must be cordial and unbiased, and must record the responses accurately (Kothari, 2004).

I prepared a list of experts for in-depth interview using my personal contacts or applying snowballing approach (e.g., recommendations of the interviewees). The experts were emailed or contacted by telephone to establish mutually convenient meeting schedules. Selection of the experts was done considering their expertise. Experts included researchers (non-academic), academicians, government officials, economists, civil engineers, architects, urban planners, doctors, and local senior citizens. About 60% of the interviewees were environment and development related experts. The experts were from International Center for Climate Change and Development (ICCCAD); International Union for Conservation of Nature (IUCN) Bangladesh; BanDuDeltAS; World Bank; Climate Change and Health Initiative, International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR,B); Climate Finance Governance, Transparency International Bangladesh (TIB); Dhaka North City Corporation (DNCC); Center for Environmental and Geographic Information Service (CEGIS); Bangladesh Centre for Advanced Studies (BCAS); Department of Urban and Regional Planning, Bangladesh University of Engineering and Technology (BUET); Department of Economics, East West University; Department of Development Studies, University of Dhaka; Centre for

Climate Change and Environmental Research, BRAC University, Dhaka Medical College and Hospital (DMCH), and Latitude-23, Dhaka. Table 1.3 depicts organization type-wise number of experts interviewed in my research.

Table 1.3 Organization Type-wise Number of Interviewees.

Type of organization	No. of interviewees (n=33)
Academic institution	7
National environmental research organization	6
Government agencies	4
Local civil society organization	4
Individuals (local residents)	3
International development organization	3
Architecture farm	1
International civil society organization	1
International environmental NGO	1
International health research organization	1
National environmental NGO	1
National social research organization	1
Total	**33**

A semi-structured format for perspective mapping and a checklist of open-ended questions (see Appendix V) were used during the interview sessions. Written consent was provided by all interviewees. Some of the interviews were audio recorded with a recording device while also taking written notes. Recorded conversations were then translated into English from Bangla and transcribed. As promised to the interviewees, I did not disclose identities of individuals interviewed, rather I referred to them according to an assigned number.

1.3.4.3. Survey

Household survey

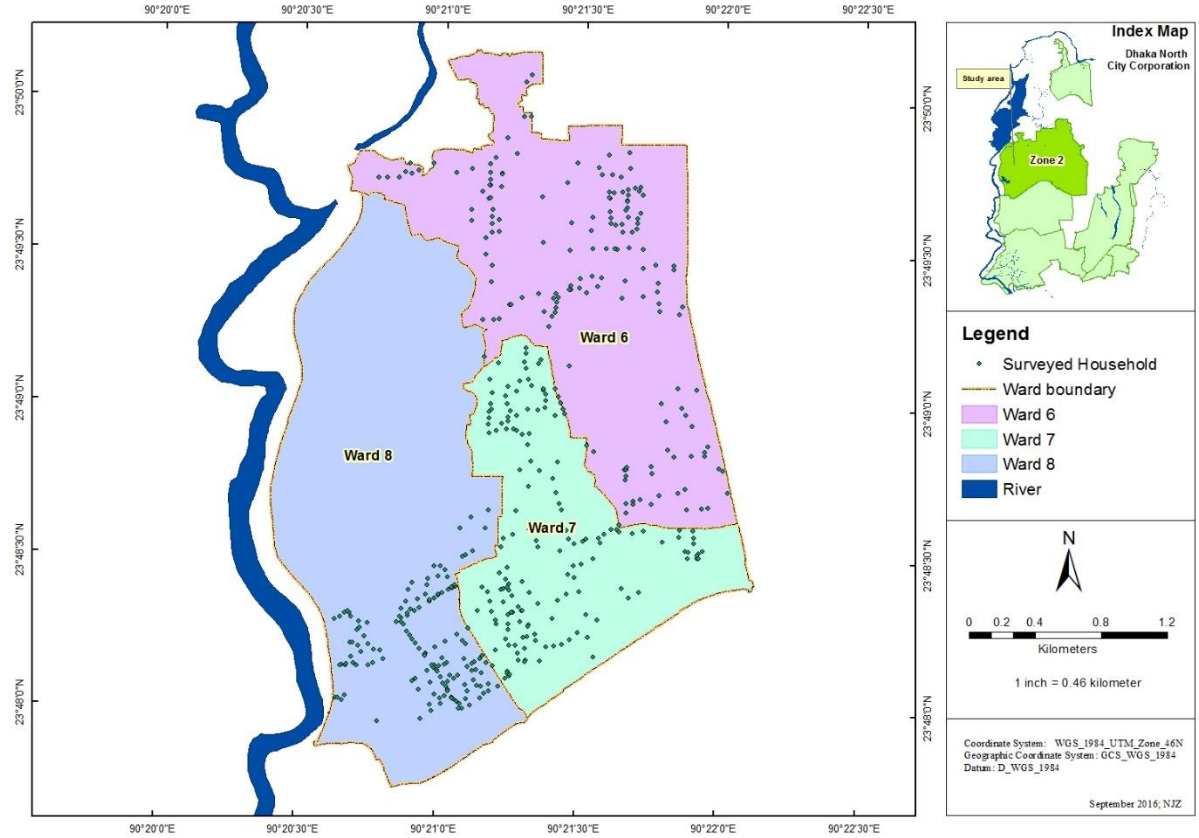
Questionnaire-based surveys are common quantitative data collection technique, which is particularly popular in case of big enquiries and widely used in social science and ecological research (Kothari, 2004; Overton & Van Diermen, 2014; Raudenbush & Sampson, 1999). A queationnaire consists of a number of questions beginning with some basic questions and progressing to the more complex and sensitive questions (Overton & Van Diermen, 2014). A questionnaire could be internet- or paper-based and the questions may be multiple choices, dichotomous (yes or no answers), or open ended (Kothari, 2004). Questionnaire-based surveys are inexpensive ways to obtain data from potentially a large number of respondents (de Groot *et al.*, 2006). However, designing and interpreting a questionnaire efficiently is time consuming. One difficulty may arise while collecting data that is the respondent may not reveal true preferences or situations Surveys are often conducted on a representative sample of a population to understand trends, attitudes, or opinions and then generalized to the whole population (Creswell, 2009). Conducting a pilot survey is essential before the main survey in order to pre-test the questionnaire and determine the sample size (Cochran, 1953; Kothari, 2004).

I conducted a survey on 510 households from April to June 2016 in three wards 6, 7, and 8 of Mirpur-Pallabi Zone, DNCC. I did a pilot survey beforehand for pre-testing the questionnaire and determining the sample size for the main survey. Dichotomous questions with answers of 'yes' or 'no' were assessed and the random sampling formula (Equation 1.1) from Cochran (1953) was applied to determine the sample size. I ensured that the randomly selected households covered as broad a geographic area as possible within the selected wards.

$$n = 1.96^2(P(1-P)/0.05^2)1.2 \qquad (1.1)$$

Where, *n* = sample size, *P* = Proportion of beneficiaries selected, i.e., percentage of preferred variable from 'yes' or 'no', 1.96 is the value of normal distribution at 5% level of significance implying that 95% of the area of a normal distribution is within 1.96 standard deviation of the mean, assuming 5% admissible error and 20% non-response rate (i.e., 20% more samples will be required).

Map 1.3 shows the surveyed area and locations of the surveyed households. The randomly-selected respondents were asked structured questions (see Questionnaire in Appendix V). Hand-held GPS devices were used to record the GPS coordinates of the households. There were 175 (34.3%), 174 (34.1%) and 161 (31.6%) respondents from ward 6, ward 7 and ward 8, respectively. About 63% respondents were male. Proportion of the females surveyed ranged from 31-44% across wards. Most respondents (42%) were aged between 35-45 years, held bachelor degrees (36%), and were married (91%). Average monthly household income was greater than 50 thousand BDT (Bangladeshi Taka; 78 BDT = 1 USD). Most respondents (66%) did not own their own houses paying 5-10 thousand BDT rent per month.



Map 1.3 The surveyed area and locations of the surveyed households.

Tree surveys

It is crucial to gather information on, for example, number of trees, tree height, diameter at breast height (DBH), leaf area, and species type in order to estimate carbon stock and equivalent carbon dioxide (CO_2) quantity in vegetation (Brown, Gillespie, & Lugo, 1989; Chave *et al.*, 2005). Sampling of trees is usually performed as it is not possible to measure each and every tree in a study area due to resource constraints (Pearson, Walker, & Brown, 2005). Pearson, Walker, and Brown (2005) prepared plot-size rules for simplicity that reasonably balance effort and precision, which is widely accepted and appreciated by IPCC. Although, choice of the size and shape of the sample plots depend mostly on time, cost, demand for accuracy and precision. Same applies to the number of plots and sub-plots.

I selected three major roads and a park (the National Botanical Garden) in the study area for tree counts and tree diameter measurement. These roads included Zoo road (Mirpur 1 Sony cinema hall to Zoo- 1.63 km), Mirpur road (Mirpur 10 to Mirpur 1 Sony cinema hall- 1.59 km), and Begum Rokeya Saroni (Mirpur 12 bus depot to Mirpur 10 circle- 2.51 km) (Image A.1.1, Appendix I). The total area of road considered was 17.2 ha (length: 5.7 km and width: 0.03

km) and vegetation coverage was assumed to be 50% for each road totaling 8.6 ha. Overall, 13 sub-plots each of 30 x 30 meter were randomly selected in the roads, and 10 random sub-plots each of 20 x 20 meter were examined inside the park. The GPS coordinates of the sub-plots were recorded. I measured Girth at breast height (GBH), i.e., circumference of trees (in cm) at 1.5 meter height from ground using a measuring tape. Diameter at breast height (DBH) was calculated by dividing GBH with the value of pi. Trees were classified as mature trees (DBH > 20 cm), poles (DBH 10-20 cm), and saplings (DBH < 10 cm). Saplings (DBH < 5cm), seedlings, shrubs, and any tree less than 1.5 meter in height and trees situated on private properties were excluded from my analysis.

1.3.5 Data management

A paperless data management application was developed for data entry and monitoring. Screenshots of this application are available in Appendix V. It was a desktop-based application that used MS Access database in a Windows platform. Maximum validation rules were set in the system to prevent errors during data entry. Rules included logical and range checks, uniqueness check, and skipping rules for avoiding collection of undesired information. Features of the developed application are as follows:

- Design application into a frequently updatable format;
- Include auto skips according to the questionnaire;
- Set up validation rules to prevent incorrect data entry;
- Notify the user while entering wrong data;
- Do detailed labeling to avoid confusion;
- Minimize manual typing by setting choice list.

The following technologies were used for development and data management of this application:

Tools	Technology
Database	MS Access
Development frameworks and languages	C#. Windows Forms
Data analysis tools	Stata, MS Excel

1.3.6 Data analysis approaches and tools

Four main approaches were undertaken for data analysis of my research: satellite image analysis, ecosystem services analysis, economic valuation (estimating prices and quantities of ecosystem services), and policy analysis. MS-Excel, SPSS, and ArcGIS 10.3 were some tools that I used for statistical analyses (e.g., regression, correlation) and preparing maps. Brief descriptions of the data analysis approaches and justifications for using them are presented below;

1.3.6.1. Satellite image analysis

Remotely-sensed satellite images are important tools to assess linkages between environmental and social systems, identifying, mapping and managing ecosystems and their services (de Araujo Barbosa, Atkinson, & Dearing, 2015; Taylor & Lovell, 2012; Weng, 2012). This technique has been applied to, amongst others, estimating impervious surfaces in urban areas (Weng, 2012), land use and land cover mapping and planning (Jacqueminet *et al.*, 2013), collecting spatial information for data poor regions (Dewan & Yamaguchi, 2009b; Sedano, Gong, & Ferrão, 2005), measuring quality of public open spaces (Taylor *et al.*, 2011), and investigating morphological characteristics (Goudie, 2013). Retrieving satellite images are sometimes costly and inaccessible. However, many scientific studies have been conducted based on open source images such as Google Earth (Goudie, 2013; Taylor *et al.*, 2011; Taylor & Lovell, 2012). Google Earth satellite images make data collection inexpensive, convenient and less time consuming. This approach provides an opportunity to extract information on inaccessible and data poor areas, helps to verify and classify documented and undocumented information, allows visualization of the study area, and offers wide geographic area coverage (Sedano, Gong, & Ferrão, 2005; Taylor *et al.*, 2011; Taylor & Lovell, 2012).

In order to identify the study area boundary, I used satellite images and GIS maps. The study area's administrative boundary information (GIS shapefiles) was provided by the DNCC town planner's office. The boundary was superimposed on high-resolution aerial images collected from Google Earth (Image 1.1). The satellite images were analyzed for initial identification of ecosystems. The GIS shapefiles were converted into kml/kmz format on ArcGIS 10.3 for preparing preliminary maps for my fieldworks.

Source: Google Earth, February 2016.

Image 1.1 Satellite image of the Zone 2 (Mirpur-Pallabi), DNCC.

1.3.6.2. Ecosystem services analysis (ESA)

Ecosystem Services Analysis (ESA) (analogous to 'function analysis') is one of the environmental systems analysis tools that is applied to identify and quantify provisioning, regulating, supporting, and cultural services provided by ecosystems (de Groot, Wilson, & Boumans, 2002). It has both qualitative and quantitative aspects. de Groot *et al.* (2006) considered this analysis to be the first step of ecosystem valuation as it helps to establish an inventory of ecosystem services within the ecosystem that is to be valued.

After identifying the provisioning, regulating, supporting, and cultural services provided by the ecosystems in my study area, I applied the ESA approach to evaluate the current condition of the ecosystem services and their contribution to human wellbeing. Afterwards, an inventory of ecosystem services was prepared (Section 2.4, Chapter 2). This analysis also contributed to the assessment of ecosystem and ecosystem services governance (Chapter 3). The ESA was performed based on observations, surveys, and expert interviews. An evaluation of relevant peer-reviewed literature supplemented this analysis. There was a lack of data on quantities of urban ecosystem services. Accordingly, the ESA was undertaken mostly in a descriptive manner.

1.3.6.3. Economic valuation

For economic valuation, a common unit (e.g., money) for valuing utility derived from actual or potential use (values) of ecosystem services is considered. Figure A.1.2 (Appendix I) presents a typology of economic values of ecosystem services to human societies. In the following, I present brief descriptions of economic values based on findings from mainstream literature, for example, de Groot *et al.* (2006); DEFRA (2007); MA (2003); TEEB (2010b).

Use values relate to private or quasi-private goods which generally attract market prices. Use values can be attached to actual or future use of an ecosystem service. Actual value is divided into two categories, *direct use value* (DUV) and *indirect use value* (IUV). DUV is obtained from direct use of ecosystem services, which can be consumptive (e.g., crops, fisheries, livestock, water, raw material) or non-consumptive (e.g., recreation, landscape amenity). These uses can be extracted, consumed, or enjoyed directly. IUV is non-extractive in nature and associated with regulating services considered as public services. The values of these uses are not usually reflected in markets (e.g., soil fertility, pollination, water purification). *Option value* (OV) (sometimes referred to as quasi-option value) is related to the possibility of future value from an ecosystem service (e.g., bioprospecting activities for discovering medicinal uses of plants). *Non-use value* (NUV) is passively derived from the knowledge that the natural environment is maintained. These values are neither directly nor indirectly involved in the uses of a particular ecosystem service. *Existence value* originates from the knowledge that an ecosystem service exists even though people may or may not have any actual or planned use of it (e.g., donating to panda or blue whale preservation even if there is no chance to see these animals in an individual’s lifetime). *Bequest value* relates to inter-generational equity, i.e., value of a resource that will be passed on to generations to come. Lastly, *altruist value* is linked to intra-generational equity, i.e., value associated with the availability of an ecosystem service to the current generation. Non-use values are challenging to derive as these are related to religious, moral, or aesthetic reasons for which markets do not usually exist. The same difficulty presents for measuring IUV. In the absence of direct and indirect price information on ecosystem services hypothetical markets are created to obtain values.

In principle, the total economic value (TEV) of an ecosystem is calculated according to Equation 1.2 where the values are considered to be mutually exclusive (Hein, 2010; Pearce & Turner, 1990). This approach enables measurements of the contributions of marketed and non-marketed benefits originating from ecosystems to social and economic well-being and helps to guide policy/decision making. Nonetheless, estimating the TEV of an ecosystem is complex. Some commonly-used methods of valuation of ecosystem services include direct market valuation approaches, revealed preference approaches, stated preference approaches, and benefit transfer method (see Table A.1.2, Appendix I for details).

$$TEV = DUV + IUV + OV + NUV \quad \ldots\ldots(1.2)$$

I evaluated a number of urban ecosystems and ecosystem services in the study area. Valuing each and every ecosystem service was not feasible. I estimated the gross economic values of some selected ecosystem services (Section 2.5, Chapter 2) following the TEV equation but I did not claim it to be a TEV analysis. Rather, I calculated quantities and prices of some selected ecosystem services. Quantities were estimated through the ESA (Sub-section 2.2.5, Chapter 2) and prices were estimated applying market prices, avoided cost methods, and benefit transfer methods (Sub-section 2.2.6, Chapter 2).

1.3.6.4. Policy analysis

Policy analysis gives insight into existing legal provisions and institutional contexts regarding relevant matters. According to Vignola, McDaniels, and Scholz (2013), for ecosystem services governance, the policy analysis provides a practical basis for recognizing "*information flows and influence in governance networks*" and thus it helps to analyze how much importance is given to this particular issue, identify key stakeholders, governance objectives, priorities and strategies, and detect possible shortcomings. Policy documents analysis, interviews, institutional analysis, and stakeholder analysis are some common methods for policy analysis.

In my research, the policy analysis was performed to get an overview of ecosystem and ecosystem services governance in Bangladesh, with a focus on urban areas and Dhaka city, by the government, NGOs, and private sector organizations. I evaluated government legal guidelines (see Appendix III: The Government Legal Guidelines A.3.1-A.3.17) passed after the Liberation War of Bangladesh in 1971 until 2016 from the Legislative and Parliamentary Affairs Division[6], the Ministry of Law, Justice and Parliamentary Affairs, the Department of Environment[7], the Ministry of Environment and Forests[8] and other ministries/departments of the Bangladesh government. Additionally, I assessed the environmental agendas of international development organizations and ENGOs, and private sector organizations (e.g., national NGOs, research organizations, civil society organizations). Information from in-depth interviews with experts (e.g., direct quotes, translated transcriptions), literature review (reports, websites, and journal articles), and household surveys were utilized for this analysis. Results from the ESA supplemented the policy analysis. Details of the policy analysis and the selected organizations are available in Sub-section 3.2.2, Chapter 3.

1.4 THESIS CONTOUR

Chapter 1 of my thesis includes a general introduction. It provides an overview of current understanding of urban ecosystems and ecosystem services, the nexus of ecosystems and ecosystem services with the social and economic systems, and urban ecosystems and ecosystem services in the context of Bangladesh based on a literature review. Furthermore, this Chapter contains the purpose of my research and the overall methodology that I followed for data collection and analysis. Some parts of Chapter 1, particularly background and methodology sections are necessarily repeated in other Chapters. Nevertheless, to avoid repetition, I have referred to relevant section or sub-section number(s) in the text throughout this thesis.

In order to attain my research aim, I have formulated five research questions. Chapters 2, 3, and 4 include the results of my research addressing these questions. All three Chapters are self-contained having separate introductions, methods, results, and conclusions/discussions.

Chapter 2 provides content, which identifies, classifies, quantifies, and values ecosystem services in Dhaka city (my study area). It provides a comprehensive examination of the current state of ecosystem services. In addition, it includes an inventory of currently-available ecosystem services and their gross economic values.

[6] http://bdlaws.minlaw.gov.bd/chro_index_update.php
[7] http://www.doe.gov.bd/site/page/9dbecce5-8da8-41e8-8142-ea143ef9942a/Acts
[8] http://moef.portal.gov.bd/site/page/9835327b-6954-4e0d-9f1d-71562fd6c452

Chapter 3 presents a description of the current ecosystem governance system in Bangladesh, or more specifically urban areas and Dhaka city, under three governance regimes: government, non-government, and private sector organizations. I particularly emphasize the involvement of local communities/citizens in governing ecosystems and ecosystem services.

Chapter 4 presents a review of green adaptation strategies already in practice worldwide at city scales for managing urban green and blue ecosystems and their associated ecosystem services. This chapter also includes the analyses of my empirical research on citizens' acceptance of green adaptation strategies and affordability for implementation in Dhaka city.

Finally, Chapter 5 synthesizes the main research findings. It is followed by a reference section and five appendices. Appendices I, II, III, and IV contain additional materials for Chapter 1, 2, 3, and 4, respectively. Appendix V includes the data collection (observation framework, interview questions, survey questionnaire) and management (data entry application) instruments, some snapshots taken during the fieldwork in Dhaka, a list of courses I attended at Monash University, and a list of relevant events that I participated in, and other activities that I performed during my study.

Table 1.4 shows the relationships between the results Chapters, research questions, publications, and my research aim. Research questions 1 and 2 are addressed in Chapter 2. Chapter 3 addresses research question 3. Chapter 4 deals with research questions 4 and 5. Chapter 2 is partially based on, and Chapter 4 is mostly based on, two of my publications.

Table 1.4 Relationships between the thesis chapters, research questions, publications, and research aim.

Chapter	Research question	Publication	Research aim
Chapter 2	RQ1. What ecosystems and ecosystem services are available in the study area? RQ2. What are the economic values of the identified ecosystem services?	Zinia, & McShane. (2018). Significance of urban green and blue spaces: Identifying and valuing provisioning ecosystem services in Dhaka city. *European Journal of Sustainable Development*, 7(1), 349-362. doi: 10.14207/ejsd.2018.v7n1p349	Identify and value urban ecosystems and ecosystem services
Chapter 3	RQ3. How does the governance regime address ecosystem and ecosystem services?	N/A	Assess ecosystem governance
Chapter 4	RQ4. What green adaptation strategies are applied worldwide for urban ecosystem services management? RQ5. Which green adaptation strategies are economically feasible and socially acceptable in the study area?	Zinia, & McShane. (2018). Ecosystem services management: An evaluation of green adaptations for urban development in Dhaka, Bangladesh. *Landscape and Urban Planning*, 173, 23-32. doi: https://doi.org/10.1016/j.landurbplan.2018.01.008	Recommend socially acceptable and economically feasible green adaptation strategies

CHAPTER 2: TYPOLOGY, INVENTORY, AND VALUES

2.1 INTRODUCTION

Urban systems are often treated as separate ecosystems (Costanza *et al.*, 1997; de Groot, Wilson, & Boumans, 2002; Grimm & Redman, 2004; Mcintyre, Knowles-Yánez, & Hope, 2000; Niemelä *et al.*, 2010). Urban systems, as stated in MA (2005a), are linked to specific spatial settings (cities, urban centers, peri-urban areas), diversified landscapes comprising varied ecosystems, urban settlements, and people living in urban areas. Urban ecosystems signify "*the most complex*" mixture of land cover and land use (Foresman, Pickett, & Zipperer, 1997) and thus comprise all available green and blue places within an urban setting (Bolund & Hunhammar, 1999). These ecosystems generate services that are crucial for urban residents (Ahern, Cilliers, & Niemelä, 2014). Ecosystem services are the direct or indirect goods and services i.e. benefits derived from ecosystem functions contributing to human well-being (Costanza *et al.*, 1997; Daily, 1997; de Groot, Wilson, & Boumans, 2002; MA, 2005a; TEEB, 2010a). There is no agreed single method of classifying ecosystem services. However, the classifications mentioned in the Millennium Ecosystem Assessment (MA) framework are commonly accepted (DEFRA, 2007): provisioning, regulating, supporting/habitat and cultural services (MA, 2005a). Provisioning services are the goods humans obtain from the ecosystems (food, water, raw materials and medicines). Regulating services include flood prevention, pollution control, and microclimate regulation among other controls on ecological functions. Supporting services are necessary for the production of other ecosystem services such as nursery services, gene pool control, and production of oxygen. The non-material benefits derived from an ecosystem are regarded as cultural services (tourism, religious value). Ecosystem services are location specific. Thus, no specific set of ecosystem services apply to urban areas; they vary with the physical and demographic characteristics of cities.

Valuation influences perceptions of the importance of ecosystem services to human well-being and causes people to rethink about the consequences of their own actions on the environment (Barkmann *et al.*, 2008; Clayton & Opotow, 2003; Zavestoski, 2004). Valuation helps to express nature's value in with a common way, aligned to major political and economic views all over the world (TEEB, 2010a). Additionally, valuation aids in deciding on intervention options for environmental management and assessing damages/benefits associated with such interventions (DEFRA, 2007). According to Farber, Costanza, and Wilson (2002) valuation is defined as "*the process*" of presenting a value that is "*the contribution of an action or object to user-specified goals, objectives or conditions*" for a specific "*action or object*". Methods of valuation for ecosystem services involve conventional economic valuation including direct market valuation approaches (market price, factor income based approach, cost-based methods such as avoided cost, replacement cost, mitigation and restoration cost), revealed preference approaches (travel cost method, hedonic pricing), stated preference approaches (contingent valuation, choice modelling, group valuation), and benefit transfer method (de Groot *et al.*, 2006; DEFRA, 2007; Farber, Costanza, & Wilson, 2002; Richardson *et al.*, 2015; TEEB, 2010b; Van der Ploeg, De Groot, & Wang, 2010).

Ecosystems and ecosystem services assessment and valuation is a new arena of research in Bangladesh. Some studies have been conducted recently on ecosystem services and human wellbeing in the coastal zone (Hossain *et al.*, 2015a), climate change and coastal wetlands (Hossain *et al.*, 2015b), values of provisioning and cultural ecosystem services of the Sundarbans mangrove forest (Uddin *et al.*, 2013), ecosystem-based adaptations in coastal Bangladesh (Ahammad, Nandy, & Husnain, 2013; Nandy *et al.*, 2013), the quality of major parks in Dhaka (Haque *et al.*, 2013), and aquaculture as a source of food in urban and peri-urban areas of Dhaka (Islam *et al.*, 2004a). Until now, no integrated study has been undertaken focusing on quantification and valuation of urban ecosystem and ecosystem services for Bangladeshi cities.

Dhaka, the capital city of Bangladesh, has a total area of 1,464 km^2 (BBS, 2013a). More than 77% of Dhaka has been urbanized and the annual population growth rate is 3.5% (BBS, 2012). Further expansion is expected to occur in the peri-urban areas of the city (Roy, 2009b). About 62% of 12 million inhabitants live in urban areas of Dhaka (BBS, 2012). Dhaka is the socio-economic and cultural center of the country. Migration from rural climate-stricken areas (northern and southern parts of Bangladesh) to Dhaka is common. Apart from economic factors, public facilities, and climatic events including flood, cyclone, river bank erosion and *monga* (drought) also drive migration to Dhaka (Ishtiaque & Mahmud, 2017; Jahan, 2012; Rabbani, Rahman, & Islam, 2011). Most migrants settle in slums: 3.4 million people currently live in slums of Dhaka (Ishtiaque & Mahmud, 2017). Informal settlements, housing development projects, and associated infrastructure construction, occur at the cost of loss (or degradation) of wetlands and vegetation (Alam & Mullick, 2014; Shubho *et al.*, 2015) thus threatening or reducing crucial ecosystem services. Accordingly, there is an urgent need to assess the states and values of urban ecosystems and their services in Dhaka, to develop strategies for preventing further degradation, and to maintain or improve the contributions of ecosystem services to residents' wellbeing.

The objectives of this Chapter are to construct a typology of ecosystems for the study area through identification and classification of ecosystems; to prepare an inventory of currently-available ecosystem services for each ecosystem category and finally, to estimate the economic value of major ecosystem services. Data collection and analyses methods comprise observations, household surveys, in-depth interviews with experts, literature review, satellite image analysis, GIS mapping, ecosystem services analysis, and direct and indirect market valuation. Both qualitative and quantitative approaches are used. This is the first interdisciplinary assessment of urban ecosystem services for the highly built-up city Dhaka with potential consequences for the entire South Asia region.

2.2 METHODS

2.2.1 Satellite Image Analysis and GIS Map Preparation

Recent and high-resolution aerial images from Google Earth were analyzed to identify ecosystems in the study area. Ecosystems were identified within the administrative boundary of Zone 2 (Mirpur-Pallabi), Dhaka North City Corporation (DNCC) comprising eight wards. This was done by superimposing the study area's GIS files on Google Earth. GIS shapefiles were collected from the DNCC office and converted into kml/kmz format in ArcGIS 10.3. Areas of the ecosystems were measured in hectares separately for each ward. After field-level validation and classification of the ecosystems, I prepared GIS maps as outputs. Sub-section 1.3.6.1, Chapter 1 has more information on satellite image analysis.

2.2.2 Observation

Observation activities were performed in 2016 to validate ecosystems in the entire Zone-2 (eight wards). I identified ecosystem services using an observation framework. GPS coordinates and photographs/videos were taken during observations. Observations were performed in 80 locations in all eight wards out of which about 20 locations had full or limited (entry fees or occasionally open) public access. I recorded noise levels in the built-up areas and inside/near ecosystems in 2017 with a handheld digital multi-function environment meter.

Mean values of three days' measurement were calculated in the analysis. For details of observation activities please see Sub-section 1.3.4.1, Chapter 1.

2.2.3 Household Survey and In-depth Interview

I utilized household survey data to analyze states of ecosystems and ecosystem services in the study area. The questionnaire-based survey of 510 households was conducted in wards 6, 7, and 8 of Mirpur-Pallabi Zone, Dhaka North City Corporation (DNCC) in 2016. Details of the study area and survey are described in Sub-sections 1.3.2.1 and 1.3.4.3 (Chapter 1), respectively. The randomly-selected respondents were asked structured questions on, amongst others, visits to preferred ecosystems, frequency and purpose of visits, travel cost, willingness to pay for an additional increase in existing entry fee or a newly imposed entry fee, and perceptions on the states of the ecosystems (air quality, surface water quality, noise level).

In-depth interviews of 33 experts provided an overview on the abundance and state of Dhaka's ecosystems and ecosystem services, and contributions of ecosystem services to human wellbeing. I used a semi-structured format to obtain individual perspectives and a checklist of some open-ended questions. The interviewees included researchers, academicians, government officials, economists, architects, civil engineers, urban planners, doctors, and local senior citizens. For details on the organizational affiliations of the interviewees (Table 1.3) and interview procedure, please see Sub-section 1.3.4.2 (Chapter 1).

2.2.4 Ecosystem Services Analysis

I applied the Ecosystem Services Analysis (ESA) to get insights into provisioning, regulating, supporting, and cultural services currently provided by the ecosystems in the study area and to assess their contribution to the citizens wellbeing. An inventory of urban ecosystem services, i.e., a list of those services offered by each category of ecosystem was compiled using ESA. The typology of ecosystem services was adapted from Van der Ploeg, De Groot, and Wang (2010) and de Groot *et al.* (2012) (Table A.2.1, Appendix II). The ESA was evaluated mostly in a descriptive manner based on observations, surveys, and expert interviews. Information from secondary sources was incorporated in this analysis.

2.2.5 Ecosystem Services Quantification Methods

Selected provisioning and cultural ecosystem services and regulating ecosystem services generated by parks (National Botanical Garden and Bangladesh National Zoo; ward 8), rooftop gardens (ward 6, 7 and 8), cultivated lands (area extracted from satellite images and GIS maps; ward 6, 7 and 8), two khals (Rupnagar and Arambag; ward 6 and 7), one playground/field (Arambag; ward 6), trees in three major roads (ward 6, 7 and 8), two lakes inside the Bangladesh National Zoo (ward 8), one jheel (Pallabi jheel; ward 6) were quantified for economic valuation. Table A.2.2 (Appendix II) summarizes descriptions of quantitative data and their collection methods and the following sub-sections describe the quantification procedures.

2.2.5.1. Provisioning ecosystem services

Results of observations, surveys, and interviews (e.g., local residents, National Botanical Garden, and Bangladesh National Zoo authorities) were used to quantify provisioning ecosystem services (e.g., fruits, vegetables, fodder). An evaluation of relevant peer-reviewed literature complemented this assessment.

Rooftop gardens were identified in 35% of surveyed holdings. Extrapolation of the gross value of rooftop provisioning services for all holdings in the study area was calculated following Equation 2.1 from Lannas and Turpie (2009).

$$Value\ of\ rooftop\ garden = \sum_{PES} \%hh_{PES} \times HH \times V_{PES} \qquad (2.1)$$

Here, *PES* represents provisioning ecosystem services (i.e., fruits and vegetables from rooftop gardens), *%hh* is the percentage of surveyed households that used a particular species of fruit or vegetable, *HH* represents the total number of holdings in the study area, and *V* is the average income earned per user household from the rooftop.

2.2.5.2. Regulating ecosystem services

<u>A. Tree measurement</u>

Three major roads and a park (National Botanical Garden) were selected in the study area for tree count and tree diameter measurement. These roads included segments of Zoo road, Mirpur road, and Begum Rokeya totaling an area of 17.2 ha (length: 5.7 km and width: 0.03 km). The vegetation coverage was assumed to be 50% for each road totaling 8.6 ha (see Sub-section 1.3.4.3, Chapter 1 for roads information). I randomly selected 13 sub-plots each of 30 x 30 meter in the roads, and 10 random sub-plots each of 20 x 20 meter inside the park. GPS coordinates of the sub-plots were recorded. I measured circumference of trees (in cm) at 1.5 meter from ground using a measuring tape and calculated diameter at breast height (DBH). I classified the trees as mature trees (DBH > 20 cm), poles (DBH 10-20 cm), and saplings (DBH < 10 cm). Saplings (DBH < 5cm), seedlings, shrubs and any tree less than 1.5 m in height and trees situated on private properties were excluded from the analysis. Table 2.2 presents the number of trees counted and measured inside the park. See Table 2.3 for information on roadside trees.

B. Particulate matter capture

There are no official statistics available for quantities of particulate matter (PM) removal by urban ecosystems in Dhaka or anywhere else in Bangladesh. My research quantified PM capture by park and roadside trees. It was done by measuring their DBH first. Monthly average concentration of pollutants ($PM_{2.5}$ and PM_{10}) data for the year 2016 (Table A.2.3, Appendix II) were collected for the continuous air monitoring station (CAMS-3) located in the study area (Darus-Salam, Mirpur) from the monthly air quality monitoring reports of Clean Air and Sustainable Environment (CASE) Project, Department of Environment (DoE)[9]. The quantity of pollutant removal was estimated following Lovett (1994), Nowak (1994) and Jim and Chen (2008) (Equations 2.2 and 2.3).

$$PR = PF \times A \times T \qquad (2.2)$$

$$PF = DV \times C \qquad (2.3)$$

Here, *PR* = Pollutant Removal (g/sec), *PF* = Pollutant Flux (g/cm2/sec), *A* = Area i.e. tree cover (cm^2), *T* = Time period (sec), *DV* = Deposition Velocity (cm/sec) and *C* = Concentration of air

[9] http://case.doe.gov.bd/index.php?option=com_content&view=article&id=5&Itemid=9

pollutant (g/cm3). Deposition velocity rates (average: 0.64 cm/sec, range: 0.5-2 cm/sec) were adapted from Jim and Chen (2008).

C. Carbon sequestration

Carbon sequestration data for Bangladesh are scarce. I estimated above-ground carbon stock and equivalent carbon dioxide (CO_2) quantity in park and roadside trees. Only DBH of trees were measured. The allometric equation of Pearson, Walker, and Brown (2005) and Yuen, Fung, and Ziegler (2016) was used for quantifying above ground biomass (Equation 2.4). Equations 2.5 and 2.6 following Alamgir *et al.* (2016) were also applied to estimate carbon stock and CO_2 equivalent.

$$\ln(AGB) = -2.289 + 2.649\ln(DBH) - 0.021\ln(DBH)^2 \quad (2.4)$$

$$Carbon\ Stock = AGB \times 0.47 \quad (2.5)$$

$$CO2\ equivalent = Carbon\ Stock \times 3.67 \quad (2.6)$$

Where, *AGB*= above ground biomass (kg) and *DBH* = diameter at breast height (cm). Carbon stock (kg) was assumed to be 47% of a tree's *AGB*. CO_2 equivalent (kg) was assumed to be 3.67 times higher than carbon stock. Furthermore, it was assumed that tree species were homogeneous in the study area and their numbers, DBH, and other features remained constant throughout the year 2016.

2.2.5.3. Cultural Ecosystem Services

Most cultural services were non-consumptive in nature (e.g., religious and cultural use of playgrounds/fields) and therefore quantification was not possible. In such cases, valuation was performed directly (see Sub-section 2.2.6 for details). Other measures, such as the number of people visiting each ecosystem, and their purposes of visit, were determined from the surveys and from interviews.

2.2.6 Valuation Methods

Direct use values (DUV) and *indirect use value* (IUV) of ecosystem services were estimated for the selected ecosystem services mentioned under Sub-section 2.2.5. Consumptive use values included provisioning ecosystem services (crops, fish, water) and non-consumptive use values included the cultural ecosystem services (recreation, religious use). In contrast, IUVs were non-extractive in nature and associated with regulating services considered as public services prices and which are not usually reflected in markets (e.g., carbon sequestration). Gross economic values were expressed in terms of BDT (Bangladesh currency- Taka) and USD for the year 2016. The exchange rate considered was 78 BDT = 1 USD. Table A.2.2 (Appendix II) shows valuation methods applied for estimating DUV and IUV.

Direct use values of provisioning ecosystem services (Sub-sections 2.5.1.1 and 2.5.1.2) were estimated through market price based approach, i.e., multiplying prices and quantities. Market prices were collected from three kitchen markets in the study area (Mirpur 1, Ward 8; Rupnagar Bazar, Ward 7 and Mirpur 12 Bazar, Ward 6) in June 2016, interviews, and secondary sources (govt. reports, newspapers and websites). Direct use values of cultural ecosystem services (Sections 2.5.1.3 and 2.5.1.4) were estimated using a market price based approach and contingent valuation method (willingness to pay). For some services, revenue from entry fees (e.g., park recreation value), or the cost of arrangement (e.g., religious value of playground/field) information was collected from surveys, interviews and personal experiences were considered as their values.

Indirect use values of three regulating services were estimated: Particulate matter (PM) capture/removal, carbon sequestration, and drainage services. The first two services were estimated applying the avoided cost method and a benefit transfer method was applied to the latter;

- Abatement costs of PM_{10} by dry and wet sweeping with hand brooms were considered as the prices of PM removal. This was adapted from an experimental study conducted by the DoE under its CASE project in Dhaka's arterial roads, commercial-residential roads and highways some of which belong to the study area (see Rahman, Begum, & Ahmed, 2016 for details). Costs of dry and wet sweeping were estimated to be BDT 816,418 per ha (USD 10,467 per ha) and BDT 3,167,401 per ha (USD 40,608 per ha), respectively (Rahman, Begum, & Ahmed, 2016). The authors did not consider $PM_{2.5}$ abatement costs and I also excluded these. The abatement costs were multiplied with quantities of PM_{10} (Sub-section 2.4.2.1) captured by the ecosystems to determine gross values (see Sub-section 2.5.2.1).

- Carbon taxes and carbon credit prices are often considered as prices for carbon (see Elmqvist *et al.*, 2015). Bangladesh does not currently have a carbon tax. Shin, Miah, and Lee (2007) suggested that the prices of carbon credits would range between USD 15 and USD 20 per Mg carbon. I used these values as carbon prices and multiplied them with the quantities of carbon stock (Sub-section 2.4.2.2) in roadside trees and in the park to estimate their gross values under Sub-section 2.5.2.1.

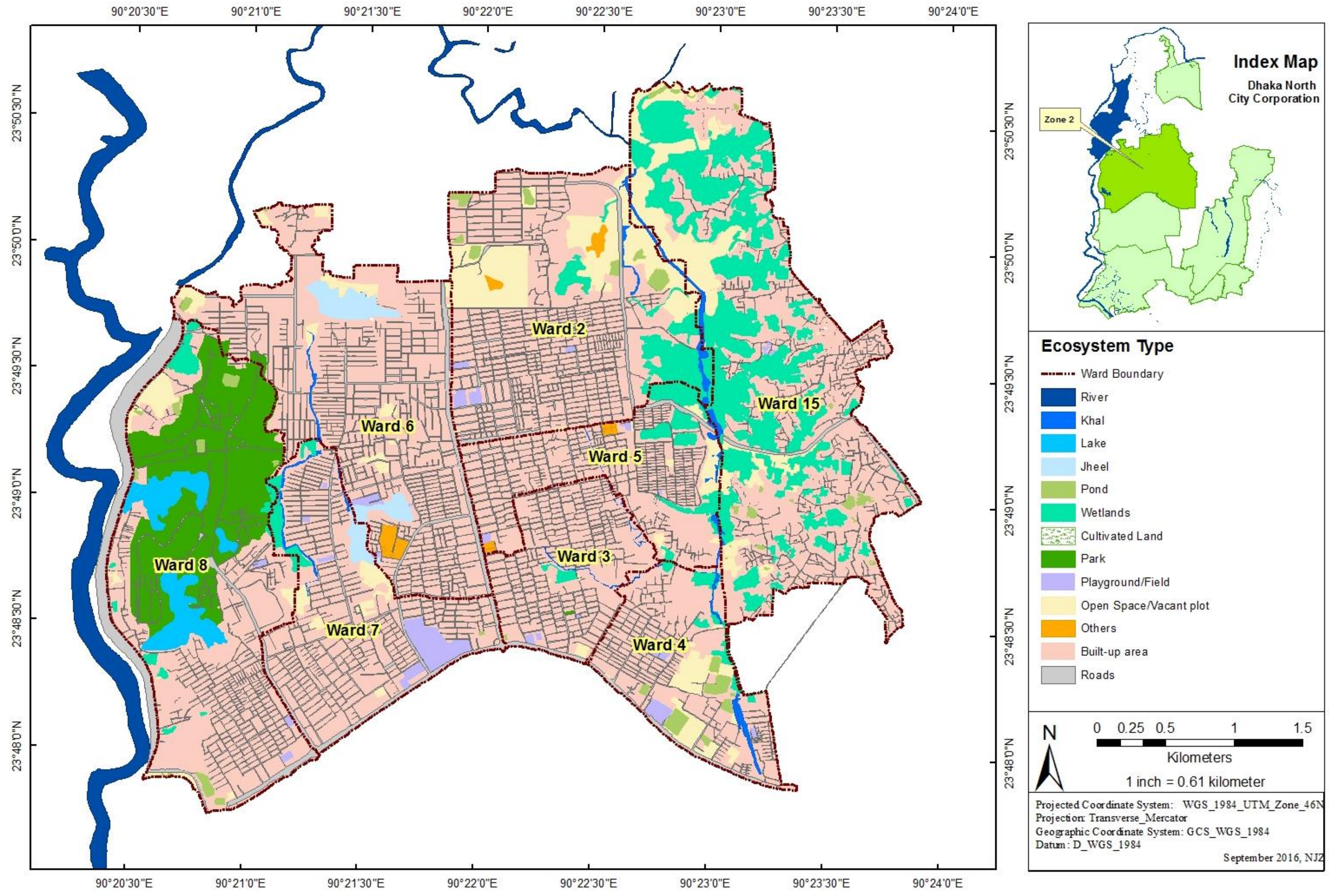
- Valuation of drainage service provided by khals in the study area was difficult as measurements of area, volume, and discharge were complex and time consuming. Moreover, flood damage information was unavailable. A benefit transfer method using information from WB (2016) and WB (2017) was applied to estimate drainage service value (Sub-section 2.5.2.2).

2.3 TYPOLOGY OF URBAN ECOSYSTEMS

2.3.1 Identification and Classification

Several satellite images from Google Earth similar to Image 1.1 (Sub-section 1.3.6.1, Chapter 1) were analyzed to identify ecosystems in the study area. Initially, ecosystems were categorized following Bolund and Hunhammar (1999); Byomkesh, Nakagoshi, and Dewan (2012); Völker and Kistemann (2011) and Dewan and Yamaguchi (2009a). These categories included street trees (stand-alone trees with/without paved base), park (highly managed areas including play grounds, golf courses), forest (less managed areas with density of trees higher than parks), agricultural land (cultivated area, crop field), grassland/fallow land (non-cultivated land), wetland (swamps, marshes, low lying waterbody), lake/pond (permanent and confined open waters) and river/stream (flowing waters). Not all of these categories of ecosystems were available in the study area and some additional categories were identified.

The classification of ecosystems was finalized after field-level verification and expert judgement. The ecosystems found in the study area included khal (canal; open channel), lake, jheel (abandoned channel bottom of a river having confined water), pond, wetland, cultivated land, park and rooftop garden, playground, open space/vacant plot, roadside trees and others (graveyards and mixed ecosystems). Map 2.1 shows the number and locations of these ecosystems. The National Botanical Garden and the Bangladesh National Zoo were categorized as ‘park’. Rooftop gardens were common in the study area. I used survey methods to identify numbers of rooftop gardens. Of the 510 holdings surveyed, 178 had rooftop gardens. Some ecosystems were difficult to identify separately because of the presence of more than one category of ecosystem in a relatively small area. There were a few graveyards in the study area. Graveyards were considered as distinct urban ecosystems. Mixed ecosystems and graveyards were categorized under ‘others’. The Sher-e-Bangla National cricket stadium and its outer stadium were categorized as a ‘playground/field’ ecosystem. It was difficult to identify ward-wise numbers of roadside trees. Trees on both sides of the roads and in the dividers in three major roads were counted and the diameters of each tree were measured (see Sub-section 2.2.5.2-A).



Map 2.1 Urban ecosystems in the study area.

2.3.2 Quantification

The total area of Mirpur-Pallabi zone of DNCC is 21.32 km^2 (Dhaka North City Corporation, ND). It's a highly built-up area with planned road communications. The categorized ecosystems together occupy about 31% of the study area (Figure 2.1). Wetlands (10%) were the dominant type of ecosystem followed by open space/vacant plot (7.7%) and park (6.5%). The total areas of wetlands, open spaces/vacant plots and parks were estimated to be 193.1 hectare (ha), 147.3 ha and 124.7 ha, respectively. Cultivated land was the least available ecosystem. At the time of measurement, only 0.1 ha in area was under cultivation (0.005% of the total study area). Table A.2.4 (Appendix II) has detailed area information for each ecosystem.

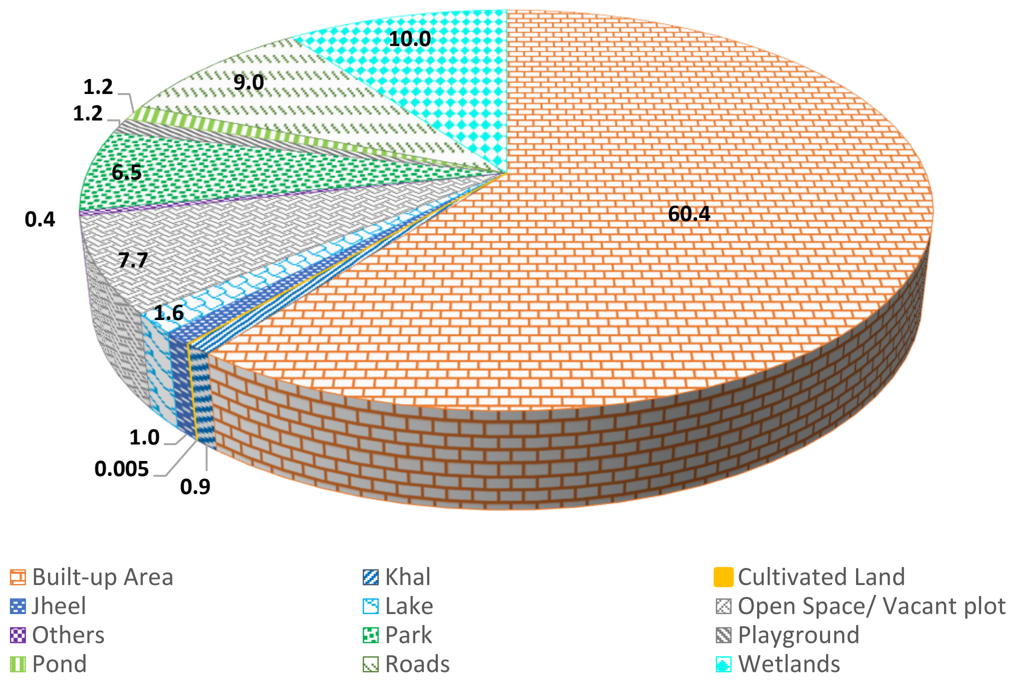


Figure 2.1 Shares of ecosystems as percentage of the total study area.

Ward-wise examination revealed that ward 15 had the highest share of ecosystems (10% of the ward, 190.5 ha) compared with the other wards. Wetlands and open space/vacant plot respectively comprised 72% and 24% of total ecosystems. Water could be found in these wetlands all year round. Most of the wetlands and open spaces/vacant plots were privately owned. Ward 15 was not yet fully developed. Building construction activities had recently started after the construction of a major road (Matikata road). Matikata road and the newly constructed Mirpur-Banani flyover at its end have made it easy for the Mirpur residents to travel to Gulshan, Banani, and Uttara areas of the DNCC within a relatively short time. Commercial activities were found to be increasing which, together with residential construction activities, suggests that both the wetlands and open spaces would soon become built-up areas.

Ward 8 had the second highest share of ecosystems, 9.2% (=179 ha) of its total area. Parks and lakes accounted for 69% and 18% of these ecosystems respectively. The parks and lakes were inside The National Botanical Garden and the Bangladesh National Zoo. The area of the zoo was 186.6 acres including two lakes. The North Lake and the South Lake comprised 14 acres and 18 acres respectively. The botanical garden had an area of 208 acres including 11 waterbodies of different sizes (NBG, 2014). Its vegetation area was 173.4 acres and waterbodies comprised 10 acres. Both these parks were environmentally, economically, and socially important. The parks were bounded by an extensive system of shallow ponds, marshlands, sandbars, hillocks, and shrubby wastelands on the north, northwest and southeast sides (BFD, 2014). A flood-control embankment protects Mirpur area from the adjacent river Turag which flowed across ward 8. There were some open spaces/vacant plots and wetlands alongside the road under privately-owned land.

Ward 2 had 4.7% area (99 ha) occupied by the identified ecosystems. Open spaces/vacant plots, wetlands and khals consisted of 58%, 24% and 4.5% of the area of the Ward respectively. The wetlands and open spaces were observed to have similar conditions to those of Ward 15. This ward had a number of ponds.

Of the total areas, wards 3, 4, 5, 6 and 7 had 0.2%, 1.7%, 1.4%, 1.9% and 1.7% of ecosystems, respectively. Wards 6 and 7 had two main khals and two jheels. The khals were Arambag khal and Rupnagar khal. The Pallabi jheel fell solely within ward 6, but the Arambag jheel was shared between wards 6 and 7. The khals and jheels were owned by the Ministry of Housing and Public Works. The DWASA was responsible for managing the khals. These wards have a number of playgrounds. Of these, the Sher-e-Bangla National cricket stadium was the most significant. Ward 4 was observed to have several ponds with limited public access. Ward 5 includes two graveyards that had many trees. The surface of the graveyards was typically covered with grasses. Detailed data on ward-wise ecosystems are presented in Table 2.1.

Table 2.1 Ward-wise areas (hectare) of the ecosystems in the study area in 2016.

Ecosystem Type	**Ward 2**	**Ward 3**	**Ward 4**	**Ward 5**	**Ward 6**	**Ward 7**	**Ward 8**	**Ward 15**
	Area (ha)							
Cultivated Land	0.04	0.00	0.00	0.00	0.02	0.00	0.02	0.02
Jheel	0.00	0.00	0.00	0.00	15.54	4.14	0.00	0.00
Khal	4.09	0.64	3.06	2.37	1.53	3.06	0.01	3.31
Lake	0.00	0.00	0.00	0.00	0.00	0.00	31.25	0.00
Open Space/Vacant plot	52.72	1.05	13.75	5.80	11.45	7.50	9.14	45.91
Others	3.01	0.08	0.00	1.68	3.75	0.00	0.00	0.00
Park	0.00	0.15	0.00	0.00	2.10	0.07	122.38	0.00
Playground/Field	3.01	0.71	3.40	0.92	1.77	12.45	1.21	0.48
Pond	6.46	0.11	6.73	0.00	0.71	0.12	5.13	4.58
Wetlands	21.66	1.45	5.02	15.12	0.08	4.87	8.75	136.17
Total	90.99	4.19	31.96	25.90	36.95	32.20	177.88	190.46

Table 2.2 presents the number of trees counted and measured inside the park. A total of 758 trees were measured of which 56% were mature trees. Their DBH ranged between 143.5 cm to 1.0 cm.

Table 2.2 Number of trees measured inside the park and classified based on the diameter at breast height (DBH).

Sub-plot no.	**Number of trees**			**Sub-plot total trees (no.)**
	Mature trees (DBH > 20 cm)	Poles (DBH 10-20 cm)	Saplings (DBH <10 cm)	
1	44	17	12	73
2	59	16	0	75
3	60	35	39	134
4	41	8	8	57
5	36	16	4	56
6	20	55	28	103
7	64	11	4	79
8	38	15	15	68
9	25	12	13	50
10	37	16	10	63
Total	**424**	**201**	**133**	**758**

Note: Understory vegetation and trees below 1.5m height excluded.

Roadside trees were found throughout the study area. There were no official statistics of the number and species type of roadside trees. Often, the city corporations lease out roadsides and dividers to private organizations for tree plantation and beautification. Table 2.3 shows the number of roadside trees and their sizes in the selected sub-plots of the total 5.73 km long (width: 0.03 km) surveyed roads. In total, 308 trees were measured. About 78% of these trees were mature trees and poles constituted 20% of trees measured. The maximum and minimum DBH estimated of all trees were 96 cm and 3 cm, respectively. Trees were found mostly in the dividers of the road rather than the two sides. Side trees were often cut for footpaths and road construction and/or maintenance works. The roadside tree species included weeping debdaru/deodar (*Polyalthia longifolia*), kathbadam/Almond (*Terminalia catappa*), *Thuja*, *Acacia*, radhachura/yellow poinciana (*Peltophorum pterocarpum*), ficus (*Ficus benjamina*), bot/banyan (*Ficus benghalensis*), mahogany (*Swietenia macrophylla*), palm tree, Kanthal/ jackfruit (*Artocarpus heterophyllus*), narkel/ coconut (*Cocos nucifera*) aam/mango (*Mangifera indica*) and Baganbilash (*Bougainvillea*). Other flowering trees were observed in the dividers of the roads but were not measured.

Table 2.3 Number of roadside trees measured in the study area and classified based on the diameter at breast height (DBH).

Road name	**Sub-plot no.**	**Number of trees**			**Sub-plot total trees (no.)**
		Mature trees (DBH > 20 cm)	Poles (DBH 10- 20 cm)	Saplings (DBH <10 cm)	
Zoo road	1	7	5	4	16
	2	10	18	4	32
	3	11	3	0	14
	4	20	5	0	25
Mirpur road	1	11	3	17	31
	2	10	4	15	29
	3	8	14	29	51
	4	10	6	25	41
Begum Rokeya Saroni	1	0	9	4	13
	2	7	5	18	30
	3	4	2	6	12
	4	9	0	0	9
	5	1	1	3	5
Total	**13**	**108**	**75**	**125**	**308**

Note: Understory vegetation and trees below 4.5 feet height excluded. See Section 2.2.5.2-A for information on the road segments considered for tree measurement.

2.4 INVENTORY OF URBAN ECOSYSTEM SERVICES

2.4.1 Provisioning Ecosystem Services (PES)

2.4.1.1. Food provision

Fruits, vegetables and crops

Urban agriculture in the highly built up residential and business areas of Dhaka city tends to include rooftop gardens, house peripheral gardens, and plants in balconies (Islam, 2002). Historically, many of the buildings in Dhaka's residential areas have had homestead gardens in front and in back yards where fruit trees, timber trees, ornamental plants, perennial flowering plants, and vegetables are grown (Fattah *et al.*, 2010). Almost all of these gardens have been subsumed accompanying demand for housing developments induced by rapid population growth (Fattah *et al.*, 2010; Islam, 2002). Rooftop gardening has gained popularity in Dhaka since the 1970s (Fattah *et al.*, 2010). It has the potential to ensure food security and to satisfy the nutritional needs of residents (Islam, 2002).

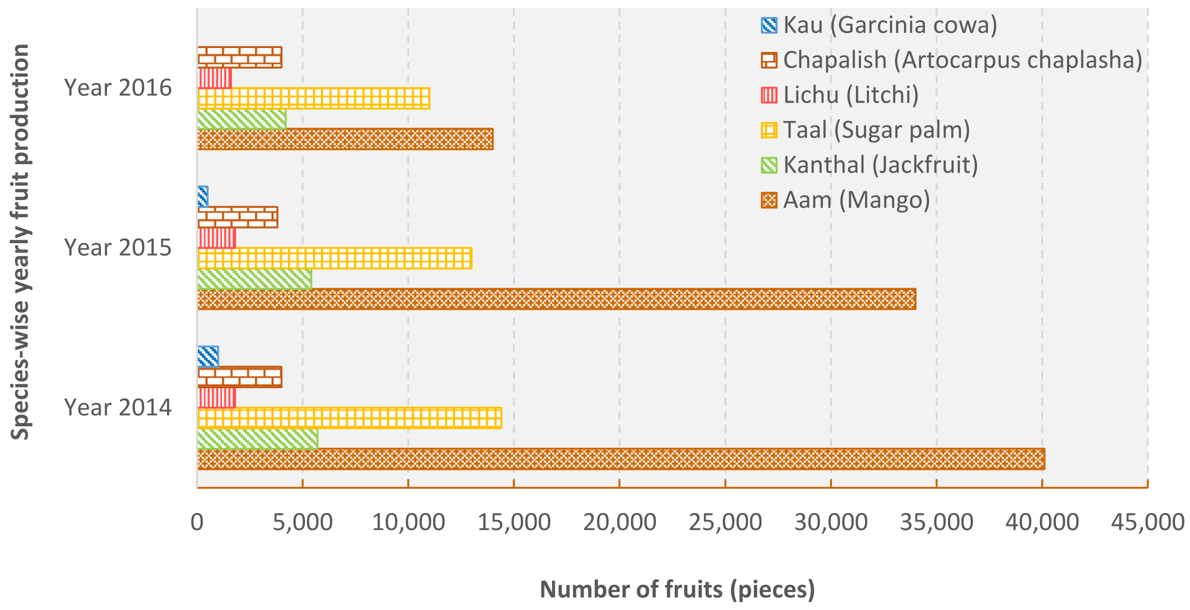
Of the surveyed rooftop gardens, mixed gardens account for 36% generally comprising seasonal fruits, vegetables, and flower/ornamental plants. Fruit gardens comprised 32% of rooftop gardens. Rooftop garden products are shown in Table 2.4. Image A.2.1 (Appendix II) presents rooftop structure and some products.

Table 2.4 Quantities of fruits and vegetables produced in the surveyed rooftop gardens.

Local/common names	Scientific names	Unit	Production quantity (units/year)
Aalu/Potato	*Solanum tuberosum*	Kg	60
Aam/Mango	*Mangifera indica*	Kg	665
Amra/Yellow mombin	*Spondias mombin*	Kg	11
Begun/Brinjal	*Solanum melongena*	Kg	53
Bel/Wood apple	*Aegle marmelos*	Piece	20
Borboti/String bean	*Vigna unguiculata ssp. sesquipedalis*	Kg	3
Boroi/Indian plum	*Ziziphus mauritiana*	Kg	113
Dalim/Pomegranate	*Punica granatum*	Kg	79
Dherosh/Ladies finger	*Abelmoschus esculentus*	Kg	11
Dhundul/Sponge gourd	*Luffa aegyptiaca*	Kg	6
Kalo Jaam/Java plum	*Syzygium cumini*	Kg	13
Jamrul/Java apple	*Syzygium samarangense*	Kg	50
Jhinga/Angled luffa	*Luffa acutangula*	Kg	13
Jolpai/Olive	*Elaeocarpus serratus*	Kg	4
Kamranga/Star fruit	*Averrhoa carambola*	Kg	13

Local/common names	Scientific names	Unit	Production quantity (units/year)
Kanthal/Jackfruit	*Artocarpus heterophyllus*	Piece	45
Kola/Banana	*Musa*	Piece	2,948
Komola/Orange/Malta	*Citrus × sinensis*	Kg	40
Korola/Bitter gourd	*Momordica charantia*	Kg	13
Lau/Bottle gourd	*Lagenaria siceraria*	Kg	48
Lebu/Lime	*Citrus × aurantiifolia*	Piece	1,326
Lichu/Litchi	*Litchi chinensis*	Kg	27
Kancha morich/Green chili	*Capsicum annuum*	Kg	17
Narkel/Coconut	*Cocos nucifera*	Piece	145
Pepe/Papaya	*Carica papaya*	Kg	148
Peyara/Guava	*Psidium guajava*	Kg	335
Potol/Pointed gourd	*Trichosanthes dioica*	Kg	2
Sajna/Moringa	*Moringa oleifera*	Kg	30
Shaak/Leafy vegetables		Kg	89
Sheem/Hyacinth bean	*Lablab purpureus*	Kg	23
Sobji/Mixed vegetables		Kg	42
Sofeda/Sapodilla	*Manilkara zapota*	Kg	6
Tomato	*Solanum lycopersicum*	Kg	60

Fruit is one of the sources of revenue from the National Botanical Garden in Dhaka. The garden authority calls for open tender each year to lease out fruit cultivation. Fruits included Aam/Mango (*Mangifera indica*), Kanthal/Jackfruit (*Artocarpus heterophyllus*), Taal/Palmyra palm (*Borassus flabellifer*), Lichu/Litchi (*Litchi chinensis*), Chapalish (*Artocarpus chaplasha*) and Kau (*Garcinia cowa*). Production of all fruits decreased over the years particularly for mangoes (Figure 2.2). Declining production reflects the declining number of mango trees (27, 28 and 20 in years 2014, 2015 and 2016, respectively). Even so, in fiscal year 2013-14 total earning from fruits was BDT 132,100 that increased to BDT 134,500 in 2014-15 (Director's office, the National Botanical Garden, 2016).



Source: Adapted from the Director's office, The National Botanical Garden, 2016.

Figure 2.2. Fruit production in the National Botanical Garden from 2014 to 2016.

The study area had very little cultivated land (0.1 ha). Paddy and mixed winter vegetables including common leafy vegetables, beans, lady's fingers, bottle gourds, and mula/white radish (*Raphanus sativus*) were observed being cultivated. The Pallabi jheel and other wetlands had abundant naturally-grown kochu/taro (*Colocasia esculenta*) that residents (mostly slum dwellers) consumed as vegetables.

<u>Fish</u>

The daily demand for fish in Dhaka city is about 250-300 tons. Fish are sourced from rivers and floodplains in Dhaka and in neighboring districts, aquaculture around the city and in other districts, and imports from world markets (Islam *et al.*, 2004b). Commercial aquaculture in Dhaka city is limited (FRSS, 2016). Pollution from household and human waste disposal and untreated industrial effluent release into open waters, run-off from agricultural fields containing chemicals and petroleum, frustrates sustainable aquaculture in Dhaka (Islam *et al.*, 2004b).

Fish culture in lakes, ponds and wetlands in the study area was observed. Apart from the lakes in the zoo, all of these waterbodies were privately owned. Data for the total production of fish from wetlands, lakes, jheel and ponds were not available. Pallabi jheel (ward 6) was leased out to the Dhaka Sangbadik Somobay Somiti Ltd (Cooperative Society of Journalists). According to local residents, about 150 kg fish were harvested three to four times per month from this jheel. Ruhi (*Labeo rohita*), pangas (*Pangasius pangasia*), Tilapia (*Oreochromis mossambicus*) and some other common species were cultured there. Image 2.1-A and B shows fish culture in Pallabi jheel. Ten ponds in the study area were selected for observation. Fish culture was observed in nine of these ponds. They included three ponds in Ward 8 (inside the Mazar of Hazrat Shah Ali Bughdadi (R)), three in Ward 2 (two in Mirpur DOHS, one in Sagufta N. M. Housing), two in Ward 4 (one in Police Staff College and one in Bangladesh Krishi Bank premises) and one in Ward 6 (in the corner of Eastern Housing entrance from the flood embankment road). None of these ponds were accessible to the public for fishing. Fishing activities were common in wetlands mainly in the monsoon season.

Source: Photography by the author, 2016.

Image 2.1 A and B) Fish culture in Pallabi jheel, Ward 6, DNCC; C) Rupnagar khal surface water usage in a climbing vegetable patch, Ward 7, DNCC; D) Fodder collection in Pallabi jheel, Ward 6, DNCC.

2.4.1.2. Water supply

The current demand for water in Dhaka city is 2,250-2,300 megalitres of water per day (MLD) (DWASA, 2016). The Dhaka Water Supply and Sewerage Authority (DWASA) typically produces 2,420 MLD, 78% of which originates from ground water and the remaining 22% is produced by treating surface water from the rivers Buriganga and Shitalakhya. The 'Tetuljhara-Bhakurta Well Field Construction Project' of DWASA supplies 150 MLD water to the Mirpur dwellers (the study area) (DWASA, 2016). The waters of Dhaka's peripheral rivers the Balu, the Turag, the Buriganga, and the Tongi khal are extremely polluted exceeding acceptable levels of water quality standards for surface water (see Rahman & Hossain, 2008 for details). Apart from rainfall, these rivers receive municipal and untreated industrial waste water, storm water through point sources such as city drains and sluice gates, and run off from the Ganges-Brahmaputra Rivers system (Nahar *et al.*, 2014). These waters are not suitable for use in the dry season but could be used in the wet season when the increased river flows (between 50%-90%) accompanying monsoonal rains improve the water quality by dilution effects from runoff (Rahman & Hossain, 2008).

Surface waters in the study area were observed to be sparsely used for household activities. The khal and jheel waters were visibly dirty and malodorous. About 73% of respondents perceived the surface waters to be extremely polluted to polluted. Survey results revealed dumping of waste from households, kitchen markets, slums, shops and factories, connections of drains to the waterbodies, lack of cleaning activities, and awareness, as the main reasons for the current states of khal and jheel waters. Pond waters in the study area were used for bathing, and for washing clothes and cooking utensils. Ponds also provide emergency water supplies for fire service. During the monsoon, the wetlands receive a huge quantity of water: this is used for household washing, bathing, cattle washing, and car washing. Industrial use of surface water was not observed in the study are. Surface water was observed to naturally irrigate cultivated lands in wards 2, 8 and 15. Holding owners and slum dwellers sometimes grow vegetables and fruits in fringe areas of khals and wetlands. Image 2.1-C and Image A.2.2 (Appendix II) show natural irrigation in the study area.

2.4.1.3. Other provisioning ecosystem services

Fodder

Fodder trees and shrubs are not cultivated as fodder in Bangladesh (Miah *et al.*, 2005). Rather, Kochuripana (common water hyacinth- *Eichhornia crassipes*), guine grass (*Megathyrsus maximus*), dal grass (*Hymenachne amplexicaulis*), nalkhagra (*Phragmites karka*), Kalmi (*Ipomoea aquatica*), and Dhaincha (*Sesbania bispinosa*) were found to grow naturally in the jheels, khals and wetlands of the study area. These plants were collected by people (living nearby) as fodder for their cattle. Image 2.1-D shows fodder collection activities in the study area. Locals informed that about three maunds (1 maund = 40 kg) of fodder were collected each week from the Pallabi jheel for about six months (mostly in winter) of a year.

Medicinal and ornamental plants

Medicinal plants are widely used by folk medicinal practitioners (kobiraj), tribal or river gypsy (bede) communities mostly in rural areas of Bangladesh (Hasan *et al.*, 2010; Rahmatullah *et al.*, 2011). Such plants are not known to be cultivated in Dhaka for commercial purposes, rather they are grown sporadically. The National Botanical Garden has a special section of medicinal plants that has about 200 plants comprising some 150 species (BFD, 2014; NBG, 2014). Ornamental and flowering plants have been historically grown in Dhaka (Fattah *et al.*, 2010; Islam, 2002). Flat dwellers prefer flowering, ornamental plants, and vegetables for growing on their balconies (Fattah *et al.*, 2010).

Medicinal plants such as tulsi (*Ocimum tenuiflorum)*, basak (*Justicia adhatoda)*, nayantara (*Catharanthus roseus*), neem (*Azadirachta indica*), ornamental, and flowering plants were observed in roof gardens, balconies, and in the periphery of houses in the study area. About 29% of the rooftop gardens surveyed consisted of only flower/ornamental plants. Balcony-based gardens were popular among tenants and residents of flats in high-rise buildings.

Fuelwood

Fuelwood is used for cooking, brick burning, and making charcoal (Uddin *et al.*, 2013). The rural population of Bangladesh largely depends on fuelwood for their daily energy needs (Hassan, Pelkonen, & Pappinen, 2014; Miah, Al Rashid, & Shin, 2009). Miah, Al Rashid, and

Shin (2009) found that 4.2 tons fuelwood were consumed per family per year in rural floodplain areas of the country. This practice is less common in Dhaka city.

Fuelwood was collected from the woody species grown in trees in opens paces/vacant plots, homestead gardens, roadside trees, the botanical gardens and the zoo, and around playgrounds in the study area. There were no records of annual fuelwood collection. However, fuelwoods and waste wood from construction works were sold in neighboring market places. These were used mainly by the slum dwellers in the study area. Local information indicated that a family of five members required about 5 kg fuelwood per day. Price of fuelwood was around BDT 10 per kg in 2016.

Timber

Timber is the most important ecosystem service supplied by natural and plantation forests in Bangladesh. Timber exploitation happens in 63% of the total natural forest area of the country (MoEF & FAO, 2007). Dhaka city no longer has any natural forests. Timber trees are available in Dhaka's protected parks/gardens: the National Botanical Garden, the Bangladesh National Zoo, Osmani Uddayan, Chandrima Uddyan, Suhrawardy Uddyan, Ramna Ramna park, and Baldha Garden.

Mahogany (*Swietenia macrophylla*), koroi (*Albizia lebbeck*), rain tree (*Albizia saman*) and kadam (*Neolamarckia cadamba*) were found in the study area. These were mostly found in road dividers and on roadsides. Timber trees were occasionally seen in house peripheries. Most of the trees observed inside the graveyards and around playgrounds were identified as common timber trees. The National Botanical Garden had 33,413 trees of 306 species (BFD, 2014). These timber trees were not harvested commercially.

2.4.2 Regulating Ecosystem Services (RES)

2.4.2.1. Influence on air quality- Capturing particulate matters

Air pollution in Dhaka is recognized as extremely harmful to public health (CASE, 2016). The sources of particulate matter (PM) emission in Dhaka include the brick kiln sector, vehicular emission, dust from roads, soil dust, biomass burning, construction, and industrial activities (Rahman, Begum, & Ahmed, 2016; Randall *et al.*, 2015; Salam *et al.*, 2013). The

Bangladesh National Ambient Air Quality Standards (BNAAQS) sets the daily allowable PM concentration levels to 150 μg/m^3 for PM_{10} (PM less than 10 micrometer diameter) and 65 μg/m^3 for $PM_{2.5}$ (PM less than 2.5 micrometer diameter). There is a Continuous Air Monitoring Station (CAMS) in the study area: Darus Salam, Mirpur. In Darus Salam the annual average concentrations of $PM_{2.5}$ were 90.2 μg/m^3 in 2013, 96.8 μg/m^3 in 2014, 88.4 μg/m^3 in 2015 and of PM_{10} were 156 μg/m^3 in 2013, 160 μg/m^3 in 2014 and 162 μg/m^3 in 2015 (CASE, 2016). Both PM levels were high and exceeded the allowable limits in all cases.

Urban air pollution affects health costs and therefore necessitates adoption of controlling measures. The banning of two-stroke three wheelers (locally known as baby taxi) in Dhaka by December 31, 2002 reduced PM_{10} by 30% and $PM_{2.5}$ emission by 40%. This was estimated to have saved about USD 25 million per year in health costs (WB, 2008). Experts (interviewees) suggested that the PM level is increasing in Dhaka city. An alternative approach of controlling PM is by increasing vegetation. Urban vegetation design (location, alignment, coverage) and choice (tall or short, dense or sparse, leaf shapes, leaf with or without hair) is important in reducing particulate matter concentrations (Janhäll, 2015; Leonard, McArthur, & Hochuli, 2016; Wang *et al.*, 2014). Chen *et al.* (2016) emphasized the effectiveness of planting design over tree species selection in urban settings as "*species selection criteria could hardly be generalized for practical use*". My study is the first to quantify PM removal by urban ecosystems in Dhaka (or elsewhere in Bangladesh) (Table 2.5).

Table 2.5 Particulate matter (PM) capture/removal quantity by roadside trees and park in the study area in 2016.

Summary	**PM removal quantity (Mg/year)**		**PM removal rate (Mg/ha/year)**	
	Roadside trees	Park	Roadside trees	Park
$PM_{2.5}$				
Average	1.4	11.7	0.2	
Max	7.6	62.1	0.9	
Min	0.5	4.4	0.1	
PM_{10}				
Average	2.7	22.1	0.3	
Max	14.5	118.5	1.7	
Min	1.0	8.6	0.1	

Note: See Table A.2.5 (Appendix II) for an example of detailed calculations. Tables A.2.6 and A.2.7 present monthly total pollutant capture by the park and roadside trees in 2016, respectively.

The green spaces in the study area were anticipated to contribute to air quality improvement. BFD (2014) considered the National Botanical Garden as the "*lung of Dhaka city*" contributing to air quality improvement. About 57% of the surveyed respondents perceived the ambient air quality in their neighborhoods to be slightly polluted and 35% considered it to be pure. The respondents referred to removal of trees, increased urbanization, increased use of cars, dust from roads and construction works, and odor from waste, as responsible for air pollution. Some respondents specifically mentioned the presence of the park (i.e., the National Botanical Garden) in reducing air pollution in their living areas. The interviewees had mixed perceptions: 52% stated Dhaka's urban green spaces in their current states played slight roles in PM capture and 44% absolutely disagreed about that. I quantified PM_{10} removal by roadside trees and park (Table 2.5) using methods described in Section 2.2.5.2-A and B. Roadside trees on average captured/removed 2.7 Mg of PM_{10} in 2016 whereas the park captured/removed 22.1 Mg during the same period. The average PM_{10} removal rate by both ecosystems was 0.3 Mg/ha/year.

2.4.2.2. Climate regulation

<u>Carbon sequestration (CS)</u>

It is well known that vegetation removes and stores carbon dioxide (CO_2) (and other forms of carbon) from the atmosphere. The rate of carbon sequestration increases as trees grow and, through this process, trees help in reducing greenhouse gases and mitigating global warming (Akbari, 2002). Neema and Jahan (2014) assessed carbon mitigation by roadside trees in Dhaka's Mirpur road and Begum Rokeya Saroni (parts of which fall within the boundary of my study area). They found that roadside trees, shrubs, herbs, and grass mitigate 2.6 kg carbon per km and 10.9 kg CO_2 per km in Mirpur Road and Begum Rokeya Saroni, respectively. Rahman *et al.* (2015a) estimated an average carbon biomass of 192.8 Mg/ha/year in the roadside plantations in south western districts of Bangladesh. Shin, Miah, and Lee (2007) evaluated above and below ground biomass and carbon stock in different forest types in Bangladesh and found that tree tissue, on average, stocked 92 tons of carbon per hectare in those forests. Miah et al (2001) (as cited in Shin, Miah, & Lee, 2007) estimated 79.36 ton/ha net total carbon in tree tissues and soil in three-year old trees in the Chittagong hill tracts of Bangladesh.

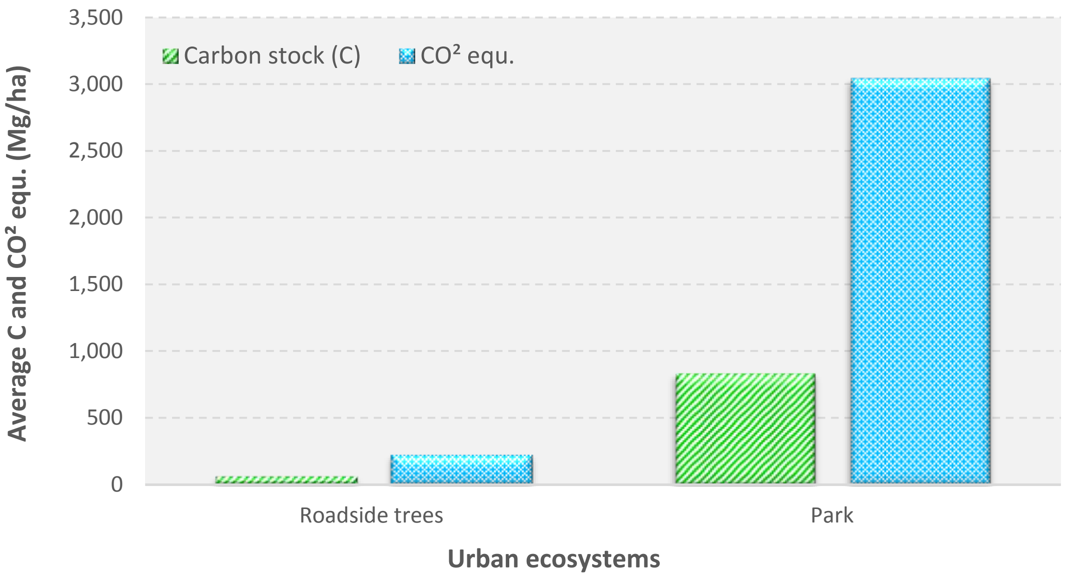


Figure 2.3. Average carbon stock and CO_2 equ. (Mg/ha) in roadside trees and the park in the study area in 2016.

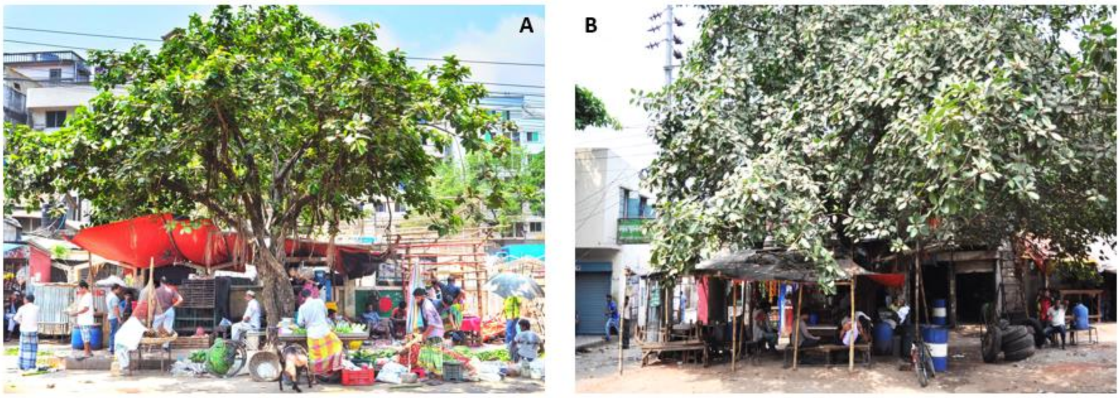
The roadside trees, private gardens (rooftop and peripheral), parks, graveyards, and trees around playgrounds in the study area were all expected to sequester carbon. Some 12% of interviewees strongly agreed that Dhaka city's urban ecosystems are important in carbon sequestration. About 48% and 40% interviewees agreed and disagreed, respectively, about this. Mixed opinions from experts suggests further research is necessary in this field. I estimated above ground carbon stock and equivalent CO_2 quantity in park and roadside trees applying methods described in Sub-section 2.2.5.2-A & C. In 2016, 61 Mg/ha carbon and 225 Mg/ha CO_2 equ. were sequestered, on average, by trees in the selected roads (Figure 2.3). In the case of the park, these figures were 828 Mg/ha and 3,040 Mg/ha, respectively for carbon stock and CO_2 equ. The park sequestered 58,126 Mg carbon in total in 2016 which was equivalent to 213,324 Mg CO_2. Total carbon stock and CO_2 equ. in roadside trees were 528 Mg and 1,938 Mg, respectively. Details of calculations are available in Table A.2.8 and Table A.2.9 (Appendix II).

<u>Microclimate regulation- Cooling effect</u>

Urbanization alters local climate. Urban surfaces influence the surface energy balance and boundary layer and thus create distinct urban climates (Coutts, Beringer, & Tapper, 2007).

Urban areas typically experience elevated temperature compared with adjacent peri-urban or rural surroundings. This is commonly known as the Urban Heat Island (UHI) effect (U.S. EPA, 2008). Dhaka city's climate is subtropical having humid and high rainfall monsoons, long, humid and hot summers, and cold and short winters (Barua, Akther, & Islam, 2016). The annual average maximum and minimum temperatures and rainfall are 34.5°C, 11.5°C and 1931 mm, respectively (BBS, 2012). The annual average relative humidity ranged between 55.3% and 71% during the period 2008-2011 (BBS, 2013a). Gray infrastructure (concrete and metallic) creates UHI in Dhaka city. The intensity of UHI has been increasing for the last two decades (Chaudhuri & Mishra, 2016). UHI is more prominent in summer (April-June) and directly responsible for the formation of tornadoes that in turn cause loss of lives and properties each year (Rana, 2011). Rapid and unplanned expansion of the built-up area, reduction of vegetation, waterbodies, and wetlands, increased usage of cars and air conditioners, contribute to the rise in UHI (Alam & Mullick, 2014; Dewan & Yamaguchi, 2009a). Temperature and relative humidity varies from location to location. Kakon, Mishima, and Kojima (2009) observed higher humidity in Dhaka's deep canyon (Siddeswari area) than in shallow (Motijheel area) and shallower canyon (Dhanmondi area). They found the maximum daytime difference of air temperature between shallower and deep canyons, shallow and deep canyons and shallower and shallow canyons to be 6.6°C, 6.0°C and 3.5°C, respectively. Sharmin, Steemers, and Matzarakis (2015) found moderate to very strong correlations between microclimatic variables and geometry of residential, commercial, and educational areas in Dhaka city. Their surveys on pedestrians revealed that people were more comfortable in areas with more diversity and openness than with formal planned or less diverse areas. Das *et al.* (ND) using a Weather Research Forecasting model found significant UHI intensity (ranging between 2.5°C to 7.5°C) in Dhaka both during day and night time. They observed major UHI zones in commercial and densely-populated residential areas and showed that green areas had the lowest temperatures. BFD (2014) stated the botanical gardens contributed to microclimate regulation in its surrounding areas. Rivers and surrounding areas had relatively higher humidity, which typically peaks at 12:00 UTC. Burkart *et al.* (2011) demonstrated a steep increase in heat-related mortality in urban areas of Bangladesh which may be aggravated with continued urbanization and UHI intensification (due to dense buildings structures and continuing global warming). They estimated the percentage increase in mortality to be up to 15% for each 1°C increase in temperature in urban areas. However, there is a general lack of targeted studies on microclimate regulation services of diverse urban ecosystems and their impacts in the context of Bangladesh.

From the above, it can be anticipated that my study area's ecosystems essentially contribute to microclimate regulation. Almost all of the surveyed respondents mentioned that climate of Dhaka had become noticeably hotter over the past 10 years. The respondents suggested rapid population growth, increase in built up area and, but most importantly, disappearance of green and blue spaces as major reasons for this temperature increase. I conducted a small comfort survey on randomly-selected respondents (34) inside the National Botanical Garden on June 3, 2016 (Friday-weekend in Bangladesh). About 85% respondents stated that they felt 'good' and the rest mentioned 'very good'. Temperature inside the zoo was recorded to be about 3°C lower than the outside surrounding area (Source: Curator, Bangladesh National Zoo). Shadows from large trees give comfort to people. Passersby were observed taking rests in the tree shadows and large trees attracted small business operators and kitchen markets (Image 2.2- A and B).



Source: Photography by the author, 2016.

Image 2.2 A and B) Small businesses, kitchen markets, and people taking rest in the shadows of roadside trees, Ward 7, DNCC.

Based on my interviews with the local citizens it is evident that the Mirpur-Pallabi area is cooler both in winter and summer months compared with the adjacent areas. This could be attributed to the presence of the parks, other vegetation, several wetlands, khals and jheels, closeness to the river Turag, and comparatively planned geometry of the built-up areas.

However, the relative temperature mitigation effects of different ecosystem categories require further investigation.

2.4.2.3. Regulation of water flows- Drainage

Dhaka city is crisscrossed by khals functioning as a natural drainage system. Dani (1962) (as mentioned in Islam *et al.* (2014) described that in the past Dhaka was regarded as the "*Venice of the east or the city of channels*". After the Independence of Bangladesh in 1971, Dhaka city had 47 khals (Rahman & Litu, 2010). Ishtiaque, Mahmud, and Rafi (2014) showed that the drainage system of Dhaka comprised 43 major khals that drained storm water runoff and domestic and sewerage wastewater to peripheral rivers. This natural drainage system once formed a lifeline for the city dwellers. However, most of these khals have now been blocked fully or partially (Murshed, 2011). DWASA manages the drainage infrastructure that includes 74 km of khals (DWASA, 2016). Dasgupta *et al.* (2015) found that 92% of the 26 khals under DWASA jurisdiction currently maintain water flows. Previously, khals were sufficient for draining storm water and for prevention of floods in the city (DWASA, 2016). Blockage of khals, and inadequate or clogged drainage systems are contributing factors to urban floods i.e. water logging during heavy rain events during the monsoons (June-September) and with sudden storms (Habitat International Coalition, 2009; Islam *et al.*, 2014). In just six hours Dhaka city received 448 mm rainwater following a storm on July 28, 2009 breaking a 53-year record (Hossain *et al.*, 2013). Continuous encroachment of khals, wetlands, lakes and low-lying lands, unplanned urbanization, and lack of coordination among the authorities responsible for maintaining the drainage system, are threatening to destroy Dhaka's natural drainage system (Ishtiaque, Mahmud, & Rafi, 2014; Mowla & Islam, 2013; Zamir, 2015).

Rupnagar khal, Journalist Colony khal (Kalshi nala), and Baishteki khal (locally known as Matikata khal and/or Bauniabadh khal) flow through the study area. Dasgupta *et al.* (2015) divided Rupnagar khal into Rupnagar Main khal (length: 2,430 m, width: 18 m), Rupnagar Branch-1 (Zoo) (length: 897 m, width: 3 m), Rupnagar Branch-2 (Arambag) (length: 1,160m, width: 12 m) and Rupnagar Branch-3 (Duaripara) (length: 823 m, width: 18 m). Based on field observations and on interviews with local residents, Rupnagar Branch-2 was Arambag khal and Rupnagar Branch-1, Rupnagar Branch-3 and Rupnagar Main was Rupnagar khal. Rupnagar and Arambag khals were shared between wards 6 and 7, Kalshi nala was under wards 4 and 5 and Bauniabadh khal mostly fell under ward 15. Portions of Bauniabadh khal and Kalshi nala occupied private properties (Dasgupta *et al.*, 2015). Locals informed that all of these khals were inter connected by box culvert, ring culvert and underground drains, and discharged to the adjacent river Turag. Rupnagar khal and Arambag khal were connected to Pallabi Jheel, which acted as water storage for the entire Pallabi area and linked to the Turag through a sluice gate. It is evident that the khals and wetlands are crucial for water flow regulation inside the city. They contribute to the societal wellbeing and to the economy saving costs (financial and human resources and time) involved in creating artificial drainage construction.

2.4.2.4. Moderation of extreme events

Flood prevention

Flood in Dhaka is of two types; urban flood (water logging) resulting from excessive rainwater accumulated in the built up inner city area; and river flood caused by overflows of the peripheral rivers mainly in the low altitude fringe areas outside the flood protection embankments (Mowla & Islam, 2013). Historically, Dhaka is surrounded by a ring of eight rivers, endowed with water retention areas (khals, lakes, drainage channels, ponds, ditches, wetlands) and about two thirds of the Dhaka Metropolitan Development Plan (DMDP) areas are characterized as flood zones (Alam, 2014; Alam & Mullick, 2014). These ecosystems contribute to the prevention or moderation of extreme events such as river and urban floods, storms, and cyclones. Dhaka city experiences urban flooding almost every year. Unplanned and rapid urbanization, encroachment of flood water retention areas, poor conditions of khals (see Sub-section 2.4.2.3) and waste dumping into surface drains, results in urban floods after each heavy rainfall event (Mowla & Islam, 2013; Murshed, 2011; Thiele-Eich, Burkart, & Simmer, 2015). Alam (2014) estimated that if rainfall increases by 1 mm an additional 50,000 m^3 runoff would be generated for about 100 km^2 of flood-flow zone areas converted by unauthorized projects. This could potentially increase the risk of urban flood. Khan (2001) as cited in Murshed (2011) stated that in Dhaka city, the depth of water logging ranges between 0.5 and 2.5 feet, and water logging prevails for 1.5 to 72 hours and occurs 5-20 times per year. River floods occur regularly in Dhaka given its geographic location and climatic conditions (Barua, Akther, & Islam, 2016). River water-level rises during monsoon periods. Dhaka experiences major flooding at least once every five years of which 1988, 1998, 2004 and 2007 floods are considered to be devastating (Haque & Jahan, 2016; Rabbani, Rahman, & Islam, 2011; Thiele-Eich, Burkart, & Simmer, 2015). Based on 32 events occurring between 1909 and 2009, Thiele-Eich, Burkart, and Simmer (2015) estimated the average duration of river floods in Dhaka to be 16.3 days.

Ecosystems serve as buffers and can protect human populations from the adverse impacts of extreme events (Barth & Döll, 2016; Watson *et al.*, 2016). Alam (2014) calculated that real estate developers converted 10,128 ha of land in the Dhaka Metropolitan Development Plan (DMDP) flood zone into housing projects and associated infrastructure. Shubho *et al.* (2015) estimated built up areas in Dhaka increased on average by 592 acres per year (44% rate of increase) in the period 1989-1999 and 757 acres per year (40% rate of increase) in 1999-2010. As a result, the vegetation cover declined by an average rate of 2,633 acres per year in 1989-1999 and 2,697 acres per year in 1999-2010, and wetlands were reduced by an average rate of 6,434 acres per year and 4,224 acres per year in 1989-1999 and 1999-2010, respectively. Islam *et al.* (2014) identified wetlands near Mirpur (study area), Pallabi (study area), cantonment area, and Mohammadpur that had been filled for urban development. Dewan *et al.* (2012) noted the 32-km flood protection embankment (Mirpur Beribandh) in the western part of Dhaka (passing by the study area) accelerated the encroachment of low-lying lands/wetlands. The lack of adequate retention areas with low capacity to retain floodwater increases the vulnerability of Dhaka to floods.

Floods affects human lives in terms of health, social, and economic aspects. Flood damage in greater Dhaka accounted for USD 2.2 million in 1988, USD 4.4 million in 1998 and USD 5.6 million in 2004 (Alam, 2014). Floods increase poverty by destroying agricultural production and creating shortages of food (Islam, 2002). The slum dwellers are more susceptible to health risks from water logging (Murshed, 2011). Floods pose both short term and long term risks including death, vector-borne diseases, and psychological effects (Thiele-Eich, Burkart, & Simmer, 2015). Floods in 2004 and 2007 induced fecal contamination of drinking water causing outbreaks of diarrhea, dysentery, typhoid fever, and gastro-intestinal diseases (Murshed, 2011). Relatively little research has been undertaken on the monetary valuation of flood mitigation by ecosystems in Bangladesh especially in urban areas.

About 72% of the respondents surveyed stated that there was less urban flood/water logging in the city now compared with the previous 10 years. The respondents mentioned that the occurrence of river floods in the Mirpur area was rare. They suggested that poor drainage systems, encroachment of khals and wetlands, inadequate sinks for storm water runoff, drains and khals filled with waste, resulted in reduced drainage. This, and unplanned construction and real estate works, were suggested as the main causes of urban floods. There were substantial housing development works going on in the study area. About 59% respondents stated that it took about 30 minutes more to commute on rainy days than on dry days. Such delays demonstrably impose unwanted costs on human lives. Water logging was observed in the study area during monsoon rains that prevailed for less than 24 hours. However, long term rainfall resulting from low pressure weather patterns in the Bay of Bengal often causes long-term water logging. Khals, jheels and other blue spaces do not have sufficient capacity to rapidly reduce water logging. Experts interviewed informed that additional pumping arrangements were necessary to reduce water logging in the city. Vegetation is expected to contribute to runoff mitigation and flood prevention.

Storm Protection

Every year Dhaka city experiences severe storms such as Nor'westers (local name-*kaalboishakhi jhor*) and cyclones (BBS, 2013a; Dewan *et al.*, 2012; Rabbani, Rahman, & Islam, 2011). The highest frequency of *kaalboishakhi jhor* was 26-52 times per year between 1954 and 2000 (Dewan *et al.*, 2012). Reduction of green and blue ecosystems together with increasing built up areas in the city give rise to UHI effects and subsequent storms causing huge damage to lives, livelihoods and properties (Rana, 2011). On average, Bangladesh experiences severe cyclones every three years with associated storm surge of coastal waters (Haque & Jahan, 2016). Among others, cyclone *Aila* (Category I cyclone) in 2009 and *Sidr* (Category IV cyclone) in 2007 were the two most devastating tropical cyclones Bangladesh had experienced in recent years (Islam & Hasan, 2016; Mallick, Rahaman, & Vogt, 2011; Saha, 2015). Dhaka, and other areas of Bangladesh, experienced cyclone *Sidr* on November 15, 2007 with a maximum wind speed of 240 km/hour, tidal waves of up to five meters, storm surges of up to 10 m (in some coastal areas) (Haque & Jahan, 2016).

Ecosystems play valuable roles in storm protection and damage reduction. Storms are associated with losses of lives and damage to properties and vital infrastructure. The Sundarbans, the world's largest mangrove forest and one of the UNESCO World Heritage Site, reduced the intensity of the wind and storm surge and effects of cyclone *Sidr* by serving as a buffer (Paul, 2009). It is anticipated that urban vegetation and waterbodies similarly mitigate storm impacts. Haque and Jahan (2016) estimated losses of BDT 186,234 million (USD 2,450 million) caused by a cyclone, such as *Sidr* (including a human death toll of 3,406 people in Dhaka). They further calculated BDT 6,934 million in damage to agriculture, industry, construction, housing services, trade services, and other sectors in Dhaka. Storm water in Dhaka city also gets contaminated with clinical waste, industrial effluents, silt, human waste, and other urban waste presenting considerable risk to human health (Murshed, 2011). Similarly, vector-borne diseases are often linked to storm incidents (Murshed, 2011; Thiele-Eich, Burkart, & Simmer, 2015).

2.4.2.5. Other Regulating Ecosystem Services

Water purification

Historically, Dhaka city has been endowed with bountiful water resources. Increased urbanization and anthropogenic activities (e.g., industrial effluents) have reduced significant number of waterbodies and wetlands, and decreased surface water quality especially in the lakes and surrounding rivers (Dewan *et al.*, 2012). Table A.2.12 (Appendix II) presents the Bangladesh standards for inland surface water. Bangladesh has a separate standard for drinking water. Surface waters of the city are contaminated with heavy metals, persistent organic pollutants (POPs), and nutrients affecting human health (Murshed, 2011). Nahar *et al.* (2014) showed that Dhaka's river waters are polluted from both the surrounding point and non-point sources that include sewage and municipal waste water and discharge from the tannery industry. Sohel, Chowdhury, and Ahmed (2003) suggested that unlimited migration from rural areas to Dhaka had increased surface water pollution. Dewan *et al.* (2012) observed that slum dwellers used open latrines beside roads which drained into nearby waterbodies causing severe water pollution. Ahmed *et al.* (2005) identified noticeable zinc contamination from industrial sources in Gulshan-1 and Gulshan-2 lakes. Murshed (2011) stated that the textile and leather plants located in Mirpur, Tejgaon, Mogbazar, Hazaribagh and other prominent places cause considerable POPs pollution.

Wetlands (constructed or natural marshes), water retention ponds, open water channels and vegetation (e.g., parks), purify water through dilution, assimilation, and chemical re-composition in urban areas and thus reduce health-related costs (de Groot, Wilson, & Boumans, 2002; Liquete *et al.*, 2016; Wang *et al.*, 2006). Similarly, wetlands can help in detoxification of industrial wastewater (Wang, Yao, & Ju, 2008). About half of the area of Bangladesh consists of wetlands (Shin, Miah, & Lee, 2007).

Source: Photography by the author, 2016.

Image 2.3 Waters in Arambag khal, Ward 6 (A and B), DNCC and Rupnaga khal, Ward 7 (C and D), DNCC.

Water from some of the waterbodies in the study area was utilized by the residents (see Sub-section 2.4.1.2). Most of the khal waters was not useful for any purpose. Image 2.3 vividly illustrates water quality in the khals of the study area. Pallabi jheel water (near a large slum) was used for fish culture. Slums lack proper waste management facilities and residents discard waste into the jheel. Wetlands in ward 15 had clearer waters but were polluted by industrial effluent. According to 73% of the surveyed respondents, the surface water of the khals and wetlands was polluted or extremely polluted in terms of turbidity and odor. Wards 6 and 7 included a number of slums. Open latrines to the khals were observed there. All three wards included industrial factories and kitchen markets. The respondents identified household, slum, kitchen market and industrial waste dumping in the khals and wetlands, connection of micro drains with the khals, lack of khal cleaning activities from the DWASA, reduction of vegetation, encroachment of waterbodies, and lack of awareness among residents, as the reasons for poor surface water quality. Thus, the blue spaces in the study area, in their current states, may not contribute much to water purification.

Noise abatement

Sound pollution in Dhaka city is a matter of concern as it is a serious threat to public health. The Government of Bangladesh has established maximum allowable levels of noise for different types of area (Table A.2.10, Appendix II). Dey, Kabir, and Efroymson (2002) showed that these standards were exceeded on a regular basis in major parts of the city. In 2002 they conducted a survey of 2,500 people, including students from 33 schools located in different areas (including Mirpur) of Dhaka city, drivers, and the general public. They identified horns from vehicles as the main cause of sound pollution, followed by public announcements (for processions, advertisements, election campaigns), three-wheeler baby taxis, brick crusher machines, and others (e.g. public meeting). Most (97%) of the students reported that traffic horns disrupted their studies. The respondents also revealed that sound pollution caused headaches, bad temper, lack of concentration, sleeping disorders, and hearing problems. Dewan *et al.* (2012) measured noise levels at 37 roadside points in the city and found the average noise levels in residential areas exceeded the statutory standards by 20% (e.g. 79.4 dB in Mirpur). They recorded the highest noise levels in commercial areas. Hasan and Mulamoottil (1994) referred to frequent use of horns, public meetings with high volume public address systems, and overnight *waz mahfil* (concert of religious talks and devotional songs) in winter months, as the main sources of urban sound pollution. Regular exposure to high noise levels can damage hearing, increase blood pressure and stress, and aggravate heart diseases (Dey, Kabir, & Efroymson, 2002).

Urban vegetation contributes to noise abatement by acting as a sound absorbing wall. Pathak, Tripathi, and Mishra (2007) based on an empirical study in Varanasi city, India showed that vegetation with appropriate height and width can reduce noise levels in urban areas. Bjørner (2004) found the expected willingness to pay for one dB noise reduction in

Copenhagen, Denmark increased with the level of noise, e.g., EUR 2 per year at 55 dB to EUR 10 per year at 75 dB. Wang *et al.* (2014) attributed maximum USD 20/person/year as a monetary value for noise regulation.

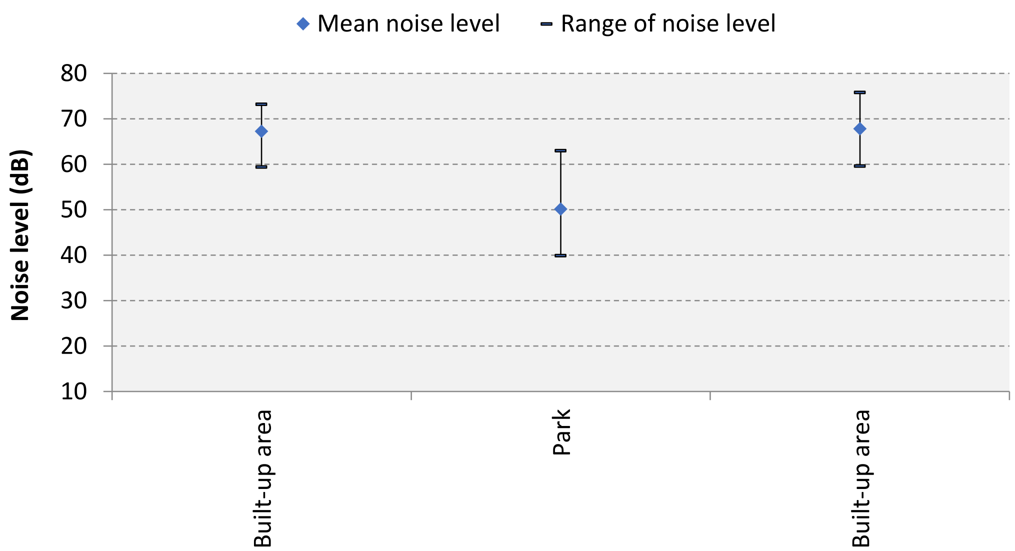


Figure 2.4. A 3-day average noise level (in decibels) in a built-up area to park to built-up area loop.

Noise levels in particular areas of wards 6, 7 and 8 were measured. Figure 2.4 presents a 3-day average noise level in a loop of built-up area to park (National Botanical Garden) to built-up area (see Table A.2.11, Appendix II for details). There was significantly less noise in the park than in the surrounding built up area. The park absorbed noise and nearby residents also received less noise from the main roads. Nevertheless, during field visits it was observed that the main entrances of both parks were extremely noisy due to loud music played by the leaseholder of the ticket counters. Pallabi jheel and Arambag playground/field were found to have approximately 10 dB less noise, on average, compared with neighboring built-up areas. The daytime mean noise level in the built-up areas near all of these ecosystems ranged from 65 dB to 71 dB clearly exceeding the national standards for both residential areas and for mixed areas. During the survey of the three wards, respondents were asked about their perceptions of their neighborhood noise levels. About 45% respondents found the study area to be quiet whereas 44% mentioned the existence of slight sound pollution. Only 3% indicated extreme sound pollution. An increased number of private cars, building construction activities, public meetings and processions of political parties, use of amplifiers in several mosques to deliver sermons (often at the same time), *waz mahfil* in winter nights, and loud music in shops/market places, all increase the noise levels beyond the maximum allowable levels. Many respondents reported hearing problems, headaches, and lowered concentration in works/studies especially those residents who live near main roads.

2.4.3 Cultural Ecosystem Services (CES)

2.4.3.1. Opportunities for recreation

Ecosystems are important in people's daily lives creating opportunities for recreational activities such as walking, swimming, fishing, spending leisure time, and relaxing (de Groot, Wilson, & Boumans, 2002). Akhter and Islam (2010) stated that open spaces provide many benefits including the physical, social, and psychological well-being of Dhaka residents. They mentioned Dhaka city's open spaces in the 1990s included 71 parks (93 ha land) and 21 playgrounds (16 ha land) with population-open space ratio of 0.023 ha/1000 population. Compared with the previous decade, many residents do not have current access to open spaces within a 0.5-mile walking distance of their homes. According to BBS (2013a), there were 99 stadium/playground and 17 park/amusement parks within the city corporation boundary. Fattah *et al.* (2010) presented a list of gardens/parks available in Dhaka city. The list included Osmani Uddayan in the heart of the city near Nagar Bhaban, Chandrima Uddyan in the north of the Jatiyo Sangsad Bhaban (National Parliament of Bangladesh), Suhrawardy Uddyan, and Ramna Park. Within the study area, DNCC owned the Pallabi Park (0.6 acre) in Mirpur 12, a children's park (1 acre) in Mirpur 13, eidgah field[10] (0.9 acre) in Mirpur 1 (beside the Zoo road) and a children's park (0.4 acre) in Mirpur 1 adjacent to Gudara ghat road. Apart from threatening encroachment, the public parks and playgrounds are in generally poor condition and anti-social activities, crimes, and security problems occur there (Akhter & Islam, 2010).

The National Botanical Garden has been a vital recreation location for Dhaka residents. It attracts about 4,000 visitors each day. Nearby residents visit for morning walks (Image 2.4-A), jogging, and exercise. Picnics and sports are not allowed inside this park. In fiscal year 2014-15 the National Botanical Garden earned around BDT 31 mill (USD 0.4 mill) from visitors (source: Director's office, National Botanical Garden). The Bangladesh National Zoo remain open for 313 days a year. On average, four million people visit each year. The Zoo earned BDT

[10] Eid prayer field.

54.2 million fiscal year 2015-16. During Eid holidays and on *Pohela Boishak* (Bangla New Year) up to 150,000 visit each day. The two lakes inside the Zoo remain accessible all year for fishing. About five to six people visit these lakes each day for fishing. There are two designated picnic sites (*Utsob Dwip* and *Nijhum Dwip*) inside the Zoo. These sites are booked for about 100 days each year. The Zoo also brings revenue from an on-site museum and deer sales. Adult deer are sold for more than BDT 35,000 each. All information above relating to the Zoo was collected from an interview with the Curator, Bangladesh National Zoo.

Source: Photography by the author, 2016.

Image 2.4 Recreation services derived from ecosystems in the study area. A) Morning walk inside the National Botanical Garden, Ward 8, DNCC; B) Young people playing at Harun Mollah playground/eidgah field, Ward 2, DNCC; C) Boishakhi fair at Arambag playground/eidgah field, Ward 6, DNCC; D) Eid prayer arrangement at Arambag playground/eidgah field, Ward 6, DNCC.

Small parks and/or playgrounds were observed in some residential areas of the study area. Many educational institutes had their own playgrounds. The Sher-e-Bangla National cricket stadium was the most significant playground in the study area. The stadium can accommodate about 25,000 people. It provides a venue for international cricket matches throughout the year (including two matches for the 2011 ICC Cricket World Cup). The outer stadium is used for cricket practice on a regular basis. The City Club Cricket Academy ground in Mirpur 11.5

(Sare Egaro, Ward 2) is often leased for picnics. The Harun Mollah eidgah field (between roads 3 and 4, Block A, Mirpur 12; Ward 2) is used as a playground (Image 2.4-B). About 50-100 people (mostly boys and young men) visited daily to play cricket, badminton, football, and other sporting activities. Similar activities were observed at Arambag playground (Ward 6). About 20 children visited daily for play. Both these playgrounds/fields were freely accessible. Most respondents preferred to visit the park (National Botanical Garden) (67.5%) followed by the Bangladesh National Zoo (16.5%) and jheel (13.5%) (Table 2.6). The mean frequency of visits to playgrounds, the park (the Garden), and jheels recorded was 56 times (respondents visited, n= 21), 49 times (respondents visited, n= 344) and 46 times per year (respondents visited, n= 69), respectively. More than 80% of respondents visited the parks for recreation. About 31% visited the Garden for walk and/or exercise. The mean distance of both parks from the respondents' residences was less than 2 km: some 20 minutes walking distance. The mean total cost for visiting the parks was about BDT 100 per person per visit. Costs increased when they visited with large groups of friends and/or family. Street trees were the most frequently visited ecosystems of 7% respondents. Street trees were close to the homes of respondents and so no costs were incurred. Almost 20% of respondents did not visit any ecosystems. They suggested that they might visit if the ecosystems were well maintained, or had tourist facilities and security.

2.4.3.2. Information for cognitive development- Research and education

Ecosystems provide unlimited opportunities for research and education by functioning as "*field laboratories*" (de Groot, Wilson, & Boumans, 2002). In the study area, the National Botanical Garden encourages the visit of researchers and students for their cognitive development. No fees are charged for organized educational excursions. The entry fee is reduced by half for those students who come for study tours, and for the researchers who perform research there. The Garden authorities provide comprehensive support and security for study and research. Researchers, students, and traditional users of medicinal plants can examine plants in the Garden. In the Zoo, more than 1,200 students from animal science disciplines undertake internships each year as part of their academic requirements (at no cost to the student).

Table 2.6 Cultural ecosystem services derived by the surveyed respondents in the study area.

Ecosystems	Respondent visit[1] (no.)	Average frequency of visit[2] (no./year)	Purpose of visit (no.)					Mean distance[3] (km)	Mean time required[4] (minute)	Mean total cost of visit[5] (BDT/person/visit)
			Recreation	Walk/ exercise	Sports	Religious reason	Cultural use			
Roadside trees	35	365	3	35	0	0	0	0.2	3	0
Park (National Botanical Garden)	344	49	277	107	2	0	8	1.3	21	98
Park (Bangladesh National Zoo)	84	6	79	2	0	0	0	1.3	24	97
Cultivated Land	0	-	-	-	-	-	-	-	-	-
Playground/field	21	56	5	6	4	16	9	0.6	8	0
Open Space/vacant plot	0	-	-	-	-	-	-	-	-	-
Pond	0	-	-	-	-	-	-	-	-	-
Jheel	69	46	50	19	0	0	1	0.8	11	11
Lake	0	-	-	-	-	-	-	-	-	-
Khal	10	27	3	6	0	0	0	0.8	11	1
Wetlands	0	-	-	-	-	-	-	-	-	-
Others	0	-	-	-	-	-	-	-	-	-

Note: 1. Total sample size, n=510; 2. Average frequency was calculated for the number of respondents who visited the ecosystems; 3. Mean distance between ecosystem and home (km); 4. Mean time required to reach ecosystem from home by walk (minute); 5. Total cost included all associated costs related to the visit to an ecosystem including entry fees, transport fare and food (if any).

2.4.3.3. Inspiration for culture and art and religious use

de Groot, Wilson, and Boumans (2002) suggested that people derive inspiration for art and culture and religious use from ecosystems. They state that ecosystems motivate people for creative pursuits such as writing, music, photography, filming, painting, and fashion. Furthermore, religious values are sometimes associated with ecosystems.

The aesthetics of ecosystems in the study area inspired people for culture and art (Table 2.6). On average, 20 filming activities took place each year inside the Botanical Garden. A few filming activities (about five per year) happen inside the Zoo. Filming for TV drama and telefilms often happened in the Mirpur DOHS area that had wetlands, parks and beautifully managed ponds (Ward 2). Photography and painting/sketching activities were common inside the parks and near the embankment road (Ward 8). Playgrounds had multiple uses. For example, the Arambag playground was used for hosting fairs (*mela* in Bangla) during *Pohela Boishakh* on April 14 every year (Image 2.4-C). About 43% respondents who visited playgrounds stated that they visited for cultural reasons (Table 2.6). In 2016, 20 temporary stalls were established for a 2-day fair. Different items including food, toys, clothes, and traditional items were sold at the fair. The *Boishakhi* fair generally attracted many people particularly nearby residents.

Eid al-Fitr and Eid al-Adha are the two most important religious festivals for Muslims. Eid prayers involve huge gatherings of people. In most of the residential areas of Dhaka there are designated eidgah fields. The Jummah prayers on Fridays are often held there. At other times these fields are used as playgrounds. The eidgah field in the Zoo road (ward 8), Harun Mollah eidgah field (Ward 2) and Arambag eidgah field (ward 6) were well known in the study area. About 76% respondents who visited playgrounds/eidgah fields stated that they did so for religious purposes (Table 2.6). A gathering of about 5,000 people occurred during the Eid al-Fitr prayer on July 7, 2016 at Arambag (Image 2.4-D). The cost of arranging the prayer space was covered by house and flat owners through the Arambag house owner's association.

2.4.4 Habitat Ecosystem Services (HES)

Ecosystems provide suitable living spaces (habitats) for plants and animals and therefore contribute to conservation of biological and genetic diversity, and of evolutionary processes (de Groot, Wilson, & Boumans, 2002). Habitat or supporting ecosystem services include nurseries, habitat for migratory species, and regional habitat for locally harvested species (Costanza *et al.*, 1997). Ecosystems maintain ecological balance by facilitating the breeding, feeding and resting of both resident and migratory species (de Groot *et al.*, 2006). Costanza *et al.* (2006) calculated habitat services provided by forests and wetlands in New Jersey, USA to be USD 1.4 million per year. de Groot *et al.* (2006) considered habitat services while valuing wetlands. Habitat ecosystem services are yet to be assessed for urban ecosystems.

The green and blue spaces of the study areas examined in Dhaka are expected to provide habitat ecosystem services. The Botanical Garden maintains threatened plant genetic resources as live collections through *ex-situ* conservation (NBG, 2014). It sustains "*plant genetic diversity through rearing, collecting and preserving samples of a wide range of rare and endangered wild species, multiplying and reproducing threatened species for reinforcement, reintroduction and introduction*" (BFD, 2014). The Garden serves as a unique habitat for different kinds of mammals, birds, reptiles and amphibians. In addition, the Gardens authority sells seedlings of plants as a source of revenue. In fiscal year 2013-14 the authority sold 9,000 seedlings for BDT 158,600 and in fiscal year 2014-15 they earned BDT 126,400 (Director's office, the National Botanical Garden, 2016). The trees on roadsides, around playgrounds and graveyards were observed to have birds' nests. The local residents informed that migratory birds visited the Botanical Garden, the Zoo lakes, wetlands and jheels of the study area in winter. Ducks were observed swimming in the khals. Islam *et al.* (2004b) mentioned waterbodies of Dhaka city as natural sources of fish production although this has declined in recent years. Rana *et al.* (2009) described the wetlands in Bangladesh as important in, among other uses, nutrient retention/removal, supporting food chains, biomass and fish seed production, and providing habitat for wildlife. It was assumed that ecosystems in the study area offered similar habitat services.

2.4.5 The Inventory Matrix

The ecosystem services inventory matrix (Table 2.7) was developed in light of the discussion above. Expert judgement (interviews) and literature review complemented this. The matrix broadly categorizes identified ecosystems in the study area under green and blue spaces. Currently-available ecosystem services are indicated. Some services might be offered by the ecosystems that were not included. Opportunities for future benefit and/or ecosystem services generated in the past were excluded.

Table 2.7 Inventory of urban ecosystems and ecosystem services in the study area.

Ecosystem Services (ES)		**Urban Ecosystems**										
		Green spaces						**Blue spaces**				
		Park/rooftop garden	Roadside trees	Cultivated land	Playground/ field	Open space/vacant plot	Graveyards	Pond	Jheel	Lake	Khal	Wetland
Provisioning ES	Crops, Fruits, Vegetables	x		x					x			x
	Fish							x	x	x		x
	Water supply							x	x		x	x
	Fodder								x		x	x
	Medicinal plants	x										
	Fuel wood	x	x		x	x	x					
	Timber	x	x	x	x	x	x					
Regulating ES	Particulate matter (PM) capture	x	x	x	x	x	x					
	Carbon sequestration	x	x	x	x	x	x					
	Microclimate regulation	x	x	x	x	x	x	x	x	x	x	x
	Drainage							x	x	x	x	x
	Flood prevention	x	x	x	x	x	x	x	x	x	x	x
	Strom protection	x	x		x		x	x	x	x	x	x
	Noise abatement	x			x	x	x		x		x	x
	Water purification											
Cultural ES	Opportunities for recreation	x	x		x				x	x	x	

Ecosystem Services (ES)		**Urban Ecosystems**										
		Green spaces						**Blue spaces**				
		Park/rooftop garden	Roadside trees	Cultivated land	Playground/ field	Open space/vacant plot	Graveyards	Pond	Jheel	Lake	Khal	Wetland
	Cognitive development-Research and education	x										
	Aesthetic information	x								x		x
	Inspiration for culture and art	x			x			x	x	x		x
	Religious use				x							
Habitat ES	Nursery service and refugia for resident and migratory birds	x	x			x	x	x	x	x	x	x
	Gene pool/biodiversity protection	x	x			x	x	x	x	x	x	x

2.5 ECONOMIC VALUES OF URBAN ECOSYSTEM SERVICES

2.5.1 Valuation of Direct Use Values

2.5.1.1. Park and rooftop garden provisioning ecosystem services

The National Botanical Garden's revenue included sales of fruits and seedlings. I considered seedlings to be provisioning ecosystem services. Accordingly, the total gross value of the provisioning ecosystem services was BDT 260,900 (USD 3,345) in 2014-15 (Director's office, the National Botanical Garden, 2016). Assuming that this value remained constant and after adjusting for inflation (5.92% in 2015-16) the gross value of provisioning services was estimated to be BDT 276,334 (USD 3,543) in 2016.

The gross value of fruits and vegetables produced in rooftop gardens in the surveyed holdings (n=510) was estimated to be BDT 213,867 (USD 2,742) in 2016. Extrapolating these findings for all holdings (n=9,156) in wards 6, 7, and 8 using Equation 2.1 (Sub-section 2.2.5.1) the gross values were estimated to be BDT 3.3 million (USD 0.04 million) for fruits and BDT 0.54 million (USD 0.01 million) for vegetables totaling BDT 3.84 million (~USD 0.05 million) in 2016 (Table 2.8).

Table 2.8. Estimated gross values (BDT) of the rooftop garden provisioning ecosystem services (PES) in the study area.

PES category	Name of PES	Average PES value (BDT/year)	Holding producing PES (as % of total sample size, n= 510)	Total PES value for the study area, n=9156 (mill BDT/year)
FRUITS	Banana	2,412	0.022	0.5
	Coconut	1,208	0.012	0.1
	Guava	440	0.139	0.6
	Indian plum	404	0.027	0.1
	Jackfruit	1,050	0.010	0.1
	Java apple	350	0.020	0.1
	Java plum	650	0.004	0.0
	Lime	133	0.114	0.1
	Litchi	882	0.010	0.1
	Mango	709	0.147	1.0
	Olive	300	0.004	0.0
	Orange/Malta	6,000	0.002	0.1
	Papaya	587	0.035	0.2
	Pomegranate	951	0.035	0.3
	Sapodilla	720	0.002	0.0

PES category	Name of PES	Average PES value (BDT/year)	Holding producing PES (as % of total sample size, n= 510)	Total PES value for the study area, n=9156 (mill BDT/year)
	Star fruit	347	0.006	0.0
	Wood apple	1,000	0.002	0.0
	Yellow mombin	183	0.006	0.0
VEGETABLES	Angled luffa	520	0.004	0.0
	Bitter gourd	303	0.004	0.0
	Bottle gourd	600	0.008	0.0
	Brinjal	1,051	0.004	0.0
	Chili	102	0.025	0.0
	Hyacinth bean	288	0.008	0.0
	Ladies finger	220	0.004	0.0
	Leafy Veg.	1,150	0.016	0.2
	Mixed Veg.	415	0.012	0.0
	Moringa	900	0.008	0.1
	Pointed gourd	80	0.002	0.0
	Potato	760	0.004	0.0
	String bean	300	0.002	0.0
	Sponge gourd	360	0.002	0.0
	Tomato	510	0.014	0.1

2.5.1.2. Other provisioning ecosystem services

Fish

Fish were harvested from Pallabi jheel year-round. Commercial fish culture was observed in about a quarter of the jheel (2.6 ha). As harvests occur three times a month, the total value of fish harvested from the jheel was estimated to be BDT 5,400 per year (see Sub-section 2.4.1.1). Market price of common fish was about BDT 200 per kg. The gross value of fish accounted for at least BDT 1.08 million (USD 13,846) in 2016.

Water supply

Surface water use for irrigation was insignificant as the study area is highly built up and has very little cultivated land (0.1 ha). According to the experts interviewed, 1 hectare of land requires about 300 mm of irrigation water costing about BDT 4,000. Thus, about 27 mm surface water was used for natural irrigation in the study area. For the available cultivated land, the minimum irrigation cost saved was estimated to be about BDT 365 (~USD 5) in 2016.

<u>Fodder</u>

The yearly fodder collection from the 10 ha (approx.) Pallabi jheel was about 2,880 kg (274 kg/ha). It was assumed that 40 kg fodder was collected every week for 24 weeks in a year (see Sub-section 2.4.1.3). The price of common fodder was about BDT 50 per kg in local markets. The gross value of fodder was estimated to be not less than BDT 144,000 (USD 1,846) in 2016.

2.5.1.3. Park cultural ecosystem services

<u>Recreation and filming</u>

The entry fee of the National Botanical Gardens was BDT 10 per person (adult), BDT 5 per person for students, and BDT 4 per person for children up to 10 years. Entry was free before 6 am. Yearly passes are available for about BDT 1,000 per person (usually purchased by people visiting for walking or other exercise). This park attracted revenue of BDT 31 million from visitors in 2014-15 (Sub-section 2.4.3.1). Assuming this value remained constant and adjusting for inflation (5.92% in 2015-16) the value of recreation was estimated to be BDT 32.8 mill (USD 0.42 million) in 2016. Filming fees inside the park was BDT 7,000 per activity. An additional BDT 200 was charged per vehicle. Considering 20 filming activities (see Sub-section 2.4.3.3), the gross value from this source was estimated to be BDT 140,000 (USD 1,795) per year.

As mentioned in Sub-section 2.4.3.1, the Bangladesh National Zoo earned BDT 54.2 mill (~USD 0.7 mill) in fiscal year 2015-16 from visitor's entry fees. Booking fees for the two picnic spots inside the Zoo were BDT 6,000/unit/day (Nijhum Dwip) and BDT 10,000/unit/day (Utsob Dwip). Filming costs inside the Zoo were charged at BDT 1,500/activity/day. Therefore, values of these cultural ecosystem services i.e. picnic and filming were BDT 1.6 mill (USD 20,513) and BDT 7,500 (USD 96) in 2016.

<u>Fishing</u>

Fishing is a popular activity in the Bangladesh National Zoo. A full-day fishing permit was BDT 2,000. Assuming all persons who went fishing (Sub-section 2.4.3.1) purchased full day permits, the value of this ecosystem service was estimated to be about BDT 3.65 mill (USD 46,795) in 2016.

2.5.1.4. Playground/field cultural ecosystem services

Religious value

The Eid al-Fitr prayer arrangement in the Arambag playground/field cost BDT 150,000 (USD 1,923) in 2016 (Sub-section 2.4.3.3). I assumed that the same cost applied for the Eid al-Adha prayer. Thus, total religious value of this playground/field was estimated to be BDT 300,000 (USD 3,846) per year.

Recreation and sports

During the *Boishakhi* fair, 20 temporary stalls were established in the Arambag playground/field for a payment of BDT 3,000 (USD 38.5) per stall (Sub-section 2.4.3.3). Thus at least BDT 60,000 (~USD 769) worth of revenue was generated from that event in 2016. The actual benefit may be more than this. This playground/field also generated revenue from sports. Children played there free of charge (Sub-section 2.4.3.1). A minimum entry fee of BDT 15 (less than US 5 cents) per person could have generated BDT 109,500 (USD 1,404) per year.

2.5.2 Valuation of Indirect Use Values

2.5.2.1. Roadside tree and park regulating ecosystem services

Particulate matter capture

Table 2.9 shows gross values of the PM_{10} capture service by urban green spaces in the study area (see Sub-section 2.4.2.1 for quantity and Sub-section 2.2.6 for price/cost information). Depending on the abatement method, roadside trees avoided costs of between BDT 19 million (USD 0.24 mill) and BDT 74 million (USD 0.94 mill) in 2016. In case of the park this estimated saving was BDT 1,264 mill (USD 16.2 mill) and BDT 4,905 mill (USD 63 mill) during the same period. This analysis implies that the presence of green spaces saves significant amount of money through vegetation absorption of PM and improving urban air quality.

Table 2.9 Gross values (mill BDT/year) of PM10 capture by roadside trees and the park in the study area in 2016.

Ecosystem	**PM_{10} abatement method**	**Value (mill BDT/year)**		
		Average	Max	Min
Roadside trees	Dry sweeping	19	102	7
	Wet sweeping	74	396	29
Park	Dry sweeping	1,264	6,788	490
	Wet sweeping	4,905	26,334	1,901

Carbon stock

Gross values of carbon stock in roadside trees ranged from BDT 617,778 to BDT 823,704 (USD 7,920-10,560) and in the park from BDT 68 mill to ~ BDT 91 mill (USD 0.87-1.16 mill) in 2016 (Table 2.10) (see Sub-section 2.4.2.2 for quantity and Sub-section 2.2.6 for price/cost information). The values of equivalent CO_2 sequestered would be evidently higher than this.

Table 2.10 Gross values (mill BDT/year) of carbon stock in roadside trees and the park in the study area in 2016.

Ecosystem	**Carbon price (USD/Mg)**	**Value (mill BDT/year)**
Roadside trees	20	0.82
	15	0.62
Park	20	90.68
	15	68.01

2.5.2.2. Khal regulating ecosystem service

Avoided damage cost and replacement cost methods are widely used for estimating values of waterbodies (See Jim & Chen, 2009; Park, Kim, & Kim, 2014; Watson *et al.*, 2016). The World Bank's Dhaka Water Supply and Sanitation Project included khal rehabilitation in Dhaka under its Component-2. Its objectives were to improve drainage flow and to prevent encroachment, using a 2-day rainfall for a one in five-year return period. Selected sections of 13 khals with a total of 20.9 km in length were rehabilitated for USD 17.8 million initial investment and operating and maintenance (O&M) costs of USD 0.31 million per year for the period 2016-2030 (WB, 2016, 2017). Rehabilitation had already been implemented through re-excavation, re-profiling, protection, and bank improvement. Through this rehabilitation, average drainage capacity was increased to 250 m^3/sec. The estimated economic benefit of khal rehabilitation from avoided damages was USD 34.8 million including initial investment and O&M costs for

15 years. The rehabilitation showed a positive net return (below the 13% discount rate). The khal rehabilitation produced other benefits including protection from encroachment, improvement of wastewater flow in off-peak season, and aesthetic enhancement.

Valuation of khals in the study area was challenging as measurements of area, volume and discharge were complex and time consuming. I estimated the value of drainage services provided by khals by applying a benefit transfer method using information from WB (2016) and WB (2017) (as discussed above). The rate of avoided damage by khals was assumed to be USD 0.11 million per km per year (USD 34.8/20.9 km = USD 1.67/km for 15 years). Furthermore, it was assumed that this rate prevailed throughout all khals in the study area. Thus, the gross value of Arambag and Rupnagar khals (5.31 km) was estimated to be USD 0.59 million (BDT 46 million) per year.

2.5.3 Total Gross Values of Ecosystem Services

Major ecosystem services were quantified and valued in monetary terms. Valuation was performed to evaluate the economic importance of marketed and non-marketed ecosystem services in the study area. Table 2.11 summarizes the total average gross value of selected ecosystem services in three wards of the study area for the year 2016. Gross values were estimated to be BDT 5.3 million (USD 68,465) for provisioning services, BDT 3,257 million (USD 42 million) for regulating services, and BDT 92.8 million (USD 1.19 million) for cultural services. In total the average gross value of the ecosystem services was estimated to be BDT 3,355 million (USD 43.02 million) in 2016.

Table 2.11 Total average gross values (BDT) of ecosystem services in the study area (3 wards) in 2016.

Ecosystem	Number of ecosystems	Ecosystem services considered	Value (BDT/Year)
Direct use values: Values of provisioning ecosystem services			
Park (National Botanical Garden)	1	Fruits and seedlings	276,334
Rooftop garden	N/A	Fruits and vegetables	3,839,533
Cultivated land	N/A	Water supply	365
		Fish	1,080,000
Jheel	1	Fodder	144,000
Sub-total			**5,340,233**
Indirect use values: Values of regulating ecosystem services			
		PM capture	3,084,500,000
Park (National Botanical Garden)	1	Carbon stock	79,342,398
		PM capture	46,500,000
Roadside tree	N/A	Carbon stock	720,741
Khal	2	Drainage	45,997,970
Sub-total			**3,257,061,109**
Direct use values: Values of cultural ecosystem services			
		Recreation (Entry fee)	32,765,910
Park (National Botanical Garden)	1	Filming	140,000
		Recreation (Entry fee)	54,200,000
		Filming	7,500
Park (Bangladesh National Zoo)	1	Picnic activity	1,600,000
Lake	2	Fishing	3,650,000
		Cultural use	60,000
		Religious use	300,000
Playground/field	1	Sports	109,500
Sub-total			**92,832,910**
Grand total			**3,355,234,252**

2.6 CONCLUSIONS AND DISCUSSIONS

This Chapter presents ecosystems and ecosystem services and their associated values for a highly built-up area of Dhaka, the capital city of Bangladesh. The study area was the Mirpur-Pallabi Zone of Dhaka North City Corporation (DNCC) comprising eight wards totaling a 21.32 km^2 area. Ecosystems and ecosystem services were evaluated from field-level observation, household surveys, in-depth interviews with experts and local citizens, personal experiences and literature review methods. Approaches to analysis included GIS mapping, ecosystem services analysis and direct and indirect market valuation methods.

The typology of ecosystems in the study area included khal, lake, jheel, pond, wetland, cultivated land, park/rooftop garden, playground/field, open space/vacant plot, roadside trees and graveyards. There were river ecosystems nearby but none within the boundary of the study area. I considered graveyards to be distinct urban ecosystem. The ecosystems together occupied about 31% of the study area of which wetlands was the highest component followed by open spaces/vacant plots and parks. Cultivated land was the least available ecosystem. Ward-wise examination revealed that ward 15 had the highest share of ecosystems (10% of the ward,190.5 ha). Wetlands were the dominant ecosystem type in ward 15. Parks and lakes accounted for 69% and 18% of ecosystems in ward 8. Ecosystems in the other wards comprised 0.22% - 4.73% of ward areas. Roadside trees were found throughout the study area. However, no official statistics of the number and species type of roadside trees were available. I counted and measured tree diameters in three major roads. About 78% of these trees were mature trees and 20% were poles.

An inventory of available ecosystem services was produced for each ecosystem type under four categories: provisioning, regulating, cultural and habitat. Detailed analyses were performed to get an overview of currently available ecosystem services. Important provisioning services: fruits, vegetables, fish and fodder were generated by parks, rooftop gardens and jheels. Regulating services included carbon sequestration and particulate matter removal by park vegetation and roadside trees, drainage service by khals and wetlands, and noise abatement by parks. Opportunities for recreation, fishing and sports, walk/exercise, inspirations for art and culture and religious values were some cultural services people derived from parks, lakes and playgrounds/fields. Habitat services such as refugia for resident and migratory birds was noticeable in parks, lakes, wetlands and trees on roadsides, playgrounds/fields and graveyards.

Major ecosystem services of wards 6, 7 and 8 were quantified and valued in monetary terms (BDT and USD) for the year 2016. Valuation was performed to evaluate the economic importance of marketed and non-marketed ecosystem services in the study area. Average gross values were estimated to be BDT 3,355 million (USD 43 million) in 2016. Of this, regulating services (carbon stock, particulate matter removal, and drainage) accounted for 97% of the total estimated value, i.e., BDT 3,257 million (~USD 42 million). Provisioning and cultural services contributed 0.16% and 2.77%, respectively. Thus, non-marketed services or indirect use values of ecosystems were the most important ecosystem services in terms of economic value.

Performing the economic valuation of non-marketed ecosystem services was challenging given that this was an interdisciplinary research. Cost-benefit analysis and contribution of the ecosystem services in the national income were beyond the scope of this research. Many assumptions were made while quantifying and valuing ecosystem services due to unavailability of data (e.g., market price), time, and resource constraints. I valued some ecosystem services, which were not included in Sub-section 2.5. My valuation approach may fall short of economic analysis but it demonstrates significant economic and social consequences, and policy implications. Below I discuss my research limitations and ways to improve the research gaps.

Urban ecosystems and ecosystem services

Research on ecosystem services assessment and valuation is novel in Bangladesh. Very few studies have considered ecosystem approaches to assess environmental components. Hossain *et al.* (2015a), Hossain *et al.* (2015b), Uddin *et al.* (2013), Ahammad, Nandy, and Husnain (2013) and Nandy *et al.* (2013) studied coastal and mangrove ecosystems and services. Some studies considered some aspects of urban ecosystems and services such as parks (Haque *et al.*, 2013) and aquaculture (Islam *et al.*, 2004a) in Dhaka. Studies presented in the book *Dhaka Megacity* 2014) gave overviews of Dhaka’s environmental components. However, these studies lacked an ecosystem approach.

Urban ecosystems and associated services attract relatively little attention. Seminal studies on ecosystem services including Costanza *et al.* (1997), Costanza *et al.* (2014); MA (2005a) and TEEB database[11] by Van der Ploeg, De Groot, and Wang (2010) have very limited information

[11] http://doc.teebweb.org/wp-content/uploads/2017/03/teeb_database_teebweb.xlsx

on urban ecosystem services and values. The benefits of urban ecosystems extend to urban heat mitigation. Aesthetics associated with urban ecosystems contribute to social and economic wellbeing (Betancourth, 2011; Bhattacharya *et al.*, 2012; de Oliveira, 2014; Kazmierczak & Carter, 2010; Rahman *et al.*, 2015b). Zinia and McShane (2018a) recorded a reluctance by common people to invest directly in ecosystem-based (green) adaptation responses (by increasing urban green and blue spaces) in Dhaka. This reflects a general lack of awareness (consistent with other studies) implying that non-marketed benefits (particularly regulating ecosystem services) have little value among the community.

There were certain limitations of my research arising from concepts, assumptions, and uncertainties associated with valuation methods. Habitat ecosystem services were excluded from valuation to avoid double counting problems (see Sub-section 1.3.2.3, Chapter 1 for detailed justification). Gross values of ecosystem services were estimated. Net values were not considered as this required cost information beyond the scope of my research. I attempted to estimate marketed and non-marketed ecosystem services in the study area. Difficulties arose while estimating indirect use values, i.e., regulating ecosystem services. In the absence of price information, hypothetical markets were created to obtain values. Future values, option values, and non-use values of ecosystem services were not considered as my research focused on current time. Thus, my recorded values were likely to be under estimates. In reality, ecosystem services also add value by reducing energy demand through cooling effects, avoiding flood damage, and improving drainage systems. Inclusion of health benefits in valuation could also yield higher values.

<u>Quantification and valuation of urban ecosystem services</u>

Only a few ecosystem services were evaluated in my research. Quantitative information on ecosystem services from urban areas was difficult to obtain. My integrated assessment required inputs from distinct disciplines. Constraints on time, resources and technical applications limited the assessment. Therefore, the selection of ecosystem services was mainly based on expert judgements. Extrapolation was done in some cases (e.g., rooftop garden services) to apply estimates to a larger population. Estimates may not reflect true values. However, my comparative evaluation should be beneficial for decision-making. Some specific benefits follow:

- **Particulate matter (PM) removal**

According to Randall *et al.* (2015), the annual emissions of PM_{10} and $PM_{2.5}$ in Dhaka were 58,524 and 20,819 tons/year, respectively. Urban air pollution affects health and therefore necessitates adoption of controlling measures. About 1,200-3,500 lives can be saved and 80-235 million cases of sickness can be avoided per year in Bangladesh if PM_{10} is reduced by 20% of the national standard (CASE, 2016; WB, 2006). Annual health costs associated with air pollution in Bangladesh are estimated to be USD 169-492 million (WB, 2006). Particulate matter can be controlled either by abatement measures (such as introducing gas driven vehicles) or by increasing natural vegetation. Particulate matter removal by urban ecosystems in Dhaka or anywhere else in Bangladesh has not previously been studied. However, many such studies have been undertaken elsewhere. Jim and Chen (2008) found about 28.8 Mg (worth USD 28,304) removal of PM by vegetation in 2000 in Guangzhou, China with the removal rate of 89 kg/ha/year-133 kg/ha/year across different land use type. Nowak, Crane, and Stevens (2006) estimated yearly PM_{10} removal of 214,900 metric ton (worth USD 1 billion) by urban trees in 55 cities in the USA. Bottalico *et al.* (2016) assessed annual PM_{10} removal to be 0.0176 ton/ha for evergreen broadleaves, 0.015 ton/ha for deciduous broadleaves, 0.020 ton/ha for conifers, and 0.025 ton/ha for mixed forests in the city of Florence, Italy. Martin *et al.* (2012) estimated removal of 12.5 kg/ha/year and 102 kg/ha/year air pollution by maintained urban forest and protected urban forest, respectively, in Alabama, USA. My findings are comparable. The estimated average PM_{10} removal rate by the selected park and roadside trees in Dhaka was 0.3 Mg/ha in 2016. However, pollutant removal rate by roadside trees could be higher than park trees because of their close proximity to pollutant sources. Further analysis, including plant species and types of tree leaves, is required.

The dominant source of PM emission (more than 60%) in Dhaka is the brick kiln sector (Rahman, Begum, & Ahmed, 2016; Randall *et al.*, 2015). Other sources include vehicular emission, dust from roads, soil dust, biomass burning, construction, and industrial activities. There are about 1,200 brick fields around the city (Salam *et al.*, 2013). An estimated USD 40 million in PM_{10} abatement cost was avoided in 2016 as a result of trees in the study area. Abatement costs of $PM_{2.5}$ for Bangladesh was unavailable and therefore excluded from my valuation. I estimated the number of cases of mortality due to PM_{10} and values of mortality in the study area following Equations 2.7 and 2.8 (Khatun, 1997; Ostro, 1994; Quah & Boon, 2003):

$$\Delta Mortality = b \times \Delta PM10 \times 0.01 \times CDR \times POP \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.7)$$

where, Δ *Mortality* = total number of deaths (i.e., mortality effects in absolute numbers); b = the mortality coefficient (slope of the Dose-Response function of health impact: 0.062, 0.096 and 0.13 for lower, central and higher estimate, respectively), i.e., a 1 μg/m^3 change in PM_{10} concentration is associated with a 0.062 to 0.130 per cent change with a central estimate of 0.096 in mortality per person; *POP* = the population exposed to risk; *CDR* = Crude death rate per 1,000 people and the factor 1/100 (= 0.01) converts the change in mortality from percentages to absolute numbers.

$$VSL_{BD} = VSL_{US} \times \left(\frac{Y_{BD}}{Y_{US}}\right)^{\varepsilon} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.8)$$

where, VSL_{BD} = the value of statistical life in Bangladesh in 2016; VSL_{US} = the value of statistical life in the US at 2016 price; Y_{BD} = Purchasing Power Parity (PPP) estimates of GNP per capita in Bangladesh; Y_{US} = PPP estimates of GNP per capita in the US and ε = the income elasticity of willingness to pay (WTP) for environmental goods (for simplicity ε was assumed to be equal to 1 for Bangladesh). *VSL* was used as the cost of mortality due to PM_{10}.

The value of statistical life (or death avoided) for Dhaka city was estimated to be BDT 22.41 million in 2016 (Table A.2.13, Appendix II). Crude mortality rate was 5.1 per 1000 population (0.0051 per person) in Dhaka city. Total population in the three wards was 388,771. When there is no change in average PM_{10} concentration (158 μg/m^3), the number of cases of mortality was 194 (lower bound), 301 (central estimate), and 407 (upper bound). A 10 μg/m^3 reduction in average PM_{10} concentration could reduce mortality cases by 19 persons (central estimate) and thus value associated with mortality was estimated to be BDT 427 million (USD 5.47 million) (see Table A.2.14, Appendix II for detailed calculations). Morbidity number and costs were not estimated but were assumed similar. Therefore, it can be concluded that PM capture by vegetation not only saves abatement costs but also saves human lives and costs associated with mortality and morbidity.

- **Carbon sequestration**

Carbon sequestration varies depending on type, size, condition, and location of an ecosystem and plant species. Species that grow fast accumulate more carbon in the short term, but in the long term slow-growing species accumulate more carbon (Wang *et al.*, 2014). Carbon sequestration data for Bangladesh are limited (see Sub-section 2.4.2.2). Carbon sequestration can be calculated by established models[12], such as i-Tree Eco and i-Tree Streets. These models are data intensive and so less applicable for the study area.

I estimated above ground carbon stock and equivalent carbon dioxide (CO_2) quantities in park and roadside trees using measured tree diameter at breast height (DBH) data. I assumed carbon stock (kg) to be 47% of a tree's above ground biomass (AGB) with CO_2 equ. (kg) as 3.7 times higher than the estimated carbon stock. Furthermore, it was assumed that tree species were homogeneous in the study area and that their numbers, DBH, and other features remained constant throughout 2016. The selected park was highly protected and conserved diverse plant species. Its carbon sequestration rate (828 Mg carbon/ha) was noticeably higher than the maintained roadside trees areas (61 Mg carbon/ha). Martin *et al.* (2012) found similar results: 1,758 kg carbon /ha/year carbon in protected areas and 291 kg carbon/ha/year in maintained areas in Alabama, USA. They attributed their findings to the relatively healthier and larger conditions of trees in protected areas. According to Nowak (1994), in Chicago, USA the average carbon sequestration for trees of less than 8 cm DBH is 1.0 kg/tree/year which is 93 kg/tree/year for trees with more than 76 cm DBH. Akbari (2002) estimated that a planted shade tree in Los Angeles, USA sequestered 4.5-11 kg carbon annually. Annual carbon sequestration in urban areas of Chuncheon, Kangleung, and Seoul, Korea ranged between 0.41-0.62 kg C/m of tree cover per year, whereas average rates were 0.16-0.39 kg C/m of tree cover per year in more natural land uses (assuming 100% tree cover) (Nowak *et al.*, 2013). Kiran and Kinnary (2011) estimated that roadside trees in Vadodara city, India removed 22% (73.59 ton) of the city's total CO_2 production. Liu and Li (2012) found urban forests in highly industrialized city Shenyang, China sequestered 29,000 tons carbon/year equivalent in value to USD 1.19 million. I estimated that trees with 5 cm DBH and > 70 cm DBH sequestered 3.3 kg carbon/tree and more than 3,000 kg carbon/tree,

[12] https://www.itreetools.org/

respectively. These rates were higher for CO_2 equ. sequestration. Annual increments of carbon content in trees were not considered. Moreover, inclusion of tree species type, height, leaf area, and below ground biomass could have provided more accurate estimates.

- **Microclimate regulation**

The magnitude of surface urban heat island (UHI) varies seasonally with highest values occurring during summer days. Increased air pollution, anthropogenic activities, density and design of and materials used in urban structure, reduced horizontal airflow, reduced green and blue spaces (less cooling effect from shade and evapotranspiration), climatic factors, weather conditions, and proximity to large mountainous terrain and waterbodies, are some factors that influence UHI (Bonan, 2000; Coutts, Beringer, & Tapper, 2007; Coutts *et al.*, 2012; Smith & Levermore, 2008; U.S. EPA, 2008; Zhang *et al.*, 2014).

Several studies have focused on microclimate regulation services provided by urban green spaces. Shading and evapotranspiration from urban trees and grass potentially produce ‘oasis effects’ associated with significantly lower urban ambient temperatures (Zhang *et al.*, 2014). Berry, Livesley, and Aye (2013) measured tree shade cover, solar radiance, and external surface temperature of buildings in different seasons in Melbourne, Australia. They demonstrated up to 9°C reduction in wall surface temperature and up to 1°C reduction in external air temperatures. Zhang *et al.* (2014) revealed that 16,577 ha of urban green spaces in Beijing, China could absorb 3.33×10^{12}kJ of heat in summer through evapotranspiration. As a result, the demand for air conditioning reduced by 3.09×10^{8}kWh, which is equivalent to a 60% reduction in Beijing’s net cooling energy usage. Georgi and Dimitriou (2010) conducted a systematic study in Chania, Greece and showed a 3.1°C reduction in air temperature mainly through evapotranspiration in urban green areas. They found lower temperature values and discomfort indices in plant-shaded areas compared with sunlit pavements. Oliveira, Andrade, and Vaz (2011) assessed the thermal performance of a garden (24 ha) in Lisbon, Portugal, showing that differences between air temperatures of surrounding areas was as high as 6.9° Celsius. Giridharan *et al.* (2008) suggested that the UHI intensity could be reduced by a further 0.5°C by increasing tree cover by 25-40% in pocket parks of Hong Kong’s dense residential development areas. Ng *et al.* (2012) suggested that rooftop greening and planting grass on the ground may not have cooling effects on pedestrian areas in high rise and high-density Hong Kong but could contribute benefits by mitigating further warming. They suggested greening close to the level where anthropogenic activities are highest. This has implications for the relative mitigation effects of rooftop gardens in Dhaka. Water scarcity, however, may affect the vegetation that mitigate UHI. It is assumed that vegetation is healthy and that there is availability of water to support evapotranspiration and shading (Coutts *et al.*, 2012).

Cooling effects are also generated through microclimate regulation in urban blue spaces. According to Coutts *et al.* (2012), temperatures adjacent to, and downwind of, any open waterbody such as wetlands, ponds, creeks, canals and rivers, are about 1-2°C less compared with surrounding areas (especially during the day). Adjacent microclimatic conditions (e.g., relative humidity) influence cooling effects depending on the time of day. Saaroni and Ziv (2003) examined the 'lake effect', i.e., the downwind cooling influence of a pond (4 ha area) in Tel Aviv, Israel and concluded that small waterbodies have comforting effects on humans (within a range of 40 meters) in daytime under humid, hot and dry weather conditions. Water features including fountains in a city can mitigate high temperatures through enhanced latent heat flux (evaporation) from surfaces (Coutts *et al.*, 2012; Smith & Levermore, 2008). Bonan (2000) studied microclimate variability at a neighborhood level in Colorado, USA during different seasons and found that irrigated areas were cooler than non-irrigated areas. Kim *et al.* (2008) found restoration of the Cheonggye stream (5.8 Km long), an inner-city stream in Seoul, Korea contributed to a 0.4°C average local surface temperature reduction (with a maximum 0.9°C) during daytime. Murakawa *et al.* (1991) observed similar results for Ota River in Hiroshima, Japan but with higher impacts. The air temperature above the river fell by more than 5°C in warmer seasons the effects of which were spatially noticeable exceeding 80 meter vertically and a few hundred meters horizontally.

UHI decreases air and water quality, increases energy consumption and thus contributes to greenhouse gas emission and affects human health (Coutts, Beringer, & Tapper, 2007; U.S. EPA, 2008). Extreme heat events, expected to become more frequent and severe with climate change (Smith & Levermore, 2008), are amplified by UHI, endangering human lives (Coutts *et al.*, 2012). Burkart *et al.* (2011) recorded an increase in heat-related mortality in urban areas of Bangladesh. This mortality may further increase with continued urbanization and UHI intensification with continuing global warming. They estimated the percentage increase in mortality to be up to 15% for each 1°C increase in temperature in urban areas. However, there is a general lack of information on microclimate regulation services for diverse urban ecosystems and their impacts in the context of Bangladesh.

I attempted to derive a relationship between temperature and per capita electricity consumption in my study area with limited data (Equations 2.9 and 2.10). Annual mean land surface temperature (LST) (in °C) and fractional vegetation coverage (FVC) (range 0 to 1) information for Dhaka city were adapted from Dewan and Corner (2014a) and was assumed to apply throughout the study area. Equation 2.9 implies that if vegetation coverage is zero, the annual mean LST will be 29. 7°C and increase in vegetation will reduce LST.

$$Annual\ Mean\ LST = 29.67 - 7.68\ FVC \qquad (2.9)$$

Monthly electricity consumption (kWh) data for the Mirpur circle/zone from Dhaka Electric Supply Authority (DESCO)[13] were collected for 2013, 2014 and 2015. The DNCC zones and the DESCO zones were slightly different but assumed to be similar for simplicity of calculation. Per capita electricity consumption was estimated using population data (BBS, 2013a) for the whole Mirpur-Pallabi Zone. The data were regressed over the study area's monthly ambient/air temperature (T_{air}, in °C) data[14] from 2013 to 2015 (Equation 2.10) with seasonality adjusted with Fourier series. A highly significant (coefficient Sig. 0.002 at 95% confidence interval) positive relationship was shown for per capita electricity consumption and air temperature.

$$Per\ capita\ electricity\ consumption = 57.08 + 1.39\ T_{air} \qquad (2.10)$$

Cooling effects of ecosystems are typically measured using air temperature (See Ca, Asaeda, & Abu, 1998; Coutts *et al.*, 2012; Hathway & Sharples, 2012; Murakawa *et al.*, 1991; Oliveira, Andrade, & Vaz, 2011). The conversion from LST to air temperature was complex and required in-depth research. The literature suggests that LST air temperature varies with land cover, cloud conditions, altitudes, seasons, hot or cold environments, and

[13] https://www.desco.org.bd/index.php?page=monthly-operational-data
[14] http://case.doe.gov.bd/index.php?option=com_content&view=article&id=5&Itemid=9

daytime or night time temperatures (Cheng *et al.*, 2008; Gallo *et al.*, 2011; Mildrexler, Zhao, & Running, 2011; Vancutsem *et al.*, 2010). Several assumptions were made to assess the influence of vegetation on local air temperature in the study area: electricity consumption solely depends on air temperature, air temperature is higher than LST by a constant amount, LST is a function of fractional vegetation coverage (FVC), and change in electricity consumption is proportional to the changes in air temperature and FVC. It was estimated (Table 2.12) that a 50% vegetation coverage could reduce LST and air temperature by 3.8°C and per capita electricity consumption by 5.3 kWh/person/month in the study area. I could not verify the results shown in Table 2.12 because no comparable information was available for Bangladesh. Nevertheless, it is evident that the presence of urban ecosystems has cooling effects but the relative temperature mitigation effects of different ecosystem categories require further investigation. Additionally, it was difficult to collect specific information on heat-related diseases from public hospitals. Doctors from Dhaka Medical College and Hospital (DMCH) informed that approximately 500 people (mostly day laborers) visited the hospital every year. They were not generally admitted but rather discharged after initial treatments and observations.

Table 2.12 Change in per capita electricity consumption due to change in fractional vegetation coverage (FVC), land surface temperature (LST) and air temperature (Tair) in the study area.

FVC	**LST (°C)**	**Change in LST (°C)**	**Change in Tair (°C)**	**Electricity consumption (kWh/person/month)**	**Change in electricity consumption (kWh/person/month)**
0	29.7	0.0	0.0	57.1	0.0
0.1	28.9	-0.8	-0.8	56.0	-1.1
0.2	28.1	-1.5	-1.5	54.9	-2.1
0.3	27.4	-2.3	-2.3	53.9	-3.2
0.4	26.6	-3.1	-3.1	52.8	-4.3
0.5	25.8	-3.8	-3.8	51.7	-5.3
0.6	25.1	-4.6	-4.6	50.7	-6.4
0.7	24.3	-5.4	-5.4	49.6	-7.5
0.8	23.5	-6.1	-6.1	48.5	-8.5
0.9	22.8	-6.9	-6.9	47.5	-9.6
1	22.0	-7.7	-7.7	46.4	-10.7

I also estimated co-benefits from CO_2 sequestered by a park (National Botanical Garden) and roadside trees (see Sub-section 2.4.2.2) in the study area in terms of electrical energy saved. Zhang *et al.* (2014) estimated that 1 kWh electric energy is equivalent to 0.78 kg

CO_2. Electricity price of DESCO for 1 to 50 kWh was BDT 3.33 excluding service charge and related costs. The park potentially saved 271,750 MWh/year in electrical energy through carbon sequestration equivalent to BDT 905 million (USD 11.6 million) in 2016. In contrast, potential savings in electrical energy by the presence of roadside trees was estimated to be 2,469 kWh/year worth BDT 8,220 (USD 105) during the same period.

- **Natural drainage service**

Previously, khals were sufficient for draining storm water and for prevention of floods in the city (DWASA, 2016). However, several khals have been encroached by public entities such as Local Government Engineering Department (LGED) and RAJUK for road and embankment constructions and housing development, and by private land acquisition through land filling activities (Dasgupta *et al.*, 2015; Islam *et al.*, 2014). Accordingly, the water carrying capacity of the khals has been reduced. Wetlands, lakes and low-lying lands functioning as water retention areas form part of the urban drainage system but have undergone similar changes with land development (Mowla & Islam, 2013). Thus, continuous encroachment and unplanned urbanization are threatening to destroy Dhaka's drainage system (Ishtiaque, Mahmud, & Rafi, 2014).

Several studies consider avoided damage costs and replacement costs of waterbodies to identify their values. Watson *et al.* (2016) estimated the economic value of flood damage mitigation by Otter Creek wetland (7280 ha) in Middlebury, Vermont, USA ranged between USD 126,000 and USD 450,000 per year (rate: USD 13-63 per ha per year). Park, Kim, and Kim (2014) assumed construction cost of a municipal drainage system (50 years of service life) in Korea to be USD 500 million in 2012. They indicated that there were option values associated with such construction. Jim and Chen (2009) considered reservoir construction cost rates of RMB 1 per m^3 of water storage capacity in China.

WB (2016) and WB (2017) suggested that khal rehabilitation (re-excavation, re-profiling, protection and bank improvement) in Dhaka was economically beneficial. I estimated values of drainage services generated by khals in the study area by applying a benefit transfer method using information from the World Bank. Cross section data, data for slope, flow velocity and drainage capacity for individual khals were unavailable. Inclusion of these parameters could have produced more accurate estimates.

- **Cultural services**

Aesthetic value of ecosystems is not only important for the environment and human health (physical and psychological), but also holds economic importance (de Groot, Wilson, & Boumans, 2002; Fahmy, Sharples, & Yahiya, 2010; Gerstenberg & Hofmann, 2016; Wang *et al.*, 2014). Donovan and Butry (2010) using a hedonic price method, found that street trees added about USD 8,870 to house sales price in Portland, Oregon, USA. Wang *et al.* (2014) has attributed USD 25/person/year for aesthetic appreciation of urban green spaces.

Dhaka city's property prices are relatively high. Seventy-six percent of the interviewees mentioned that property prices were higher near urban green spaces. Twenty-eight percent stated a strong influence of blue spaces on property price; 32% agreed there was a positive correlation between property prices and existence of blue spaces. Twenty-four percent of the interviewees considered there to be no relationship between green/blue spaces and property prices. They reported that waterbody's poor management, malodorous water, and mosquitos as contributing factors to perceived low values. The appearance of many blue spaces (especially khals) was generally poor. Local senior citizens suggested that property prices in the study area were not influenced by the aesthetics. Rather, increased demand for housing caused by increased inward migration to Dhaka, location of the property, communication and transportation facilities were more important factors influencing house prices. In general, the residents purchased properties according to affordability and they tended to have less choices relating to ecosystems. Most the surveyed respondents noted affordability of properties (land or flat), closeness to work places, children's educational institutions and relatives, better transportation and security, as important considerations in purchasing a house. However, some mentioned green spaces as desirable.

The 510 respondents surveyed in three wards were asked about the availability of green and blue spaces in their neighborhoods. Most (85%) noted the absence of ecosystems within a 0.5-mile (0.8 km) walking distance from their houses. Specifically, 55% and 85% mentioned absence of sufficient green spaces and blue spaces, respectively, in their neighborhoods. Some 70% respondents stated that they were content with whatever little ecosystems were available. However, a few respondents (~7%), noted that the malodorous khals were also breeding grounds for mosquitoes. The respondents who had rooftop gardens mostly nurtured the gardens and consumed the fruits and vegetable products. Gardens also improved the aesthetics of the holdings and provided pleasurable private green spaces. There are wider community benefits from private rooftop gardens.

Hedonic price and travel cost methods were difficult to apply for valuing cultural services in my study area. A small survey of 34 randomly-selected people inside the park revealed 'recreation' to be the primary purpose of their visits. About 62% of visitors lived near the park. The average one-way travel cost (public transport fare) was 25 BDT/person/travel. My research investigated values of cultural ecosystem services provided by the park (National Botanical Garden) applying a contingent valuation approach which was not included in gross value estimation. The respondents were asked to state their willingness to pay (WTP) for an increased entry fee to the park. The mean WTP of the surveyed respondents (n= 510) was BDT 203/person/year. If the total population in the surveyed three wards (n= 388,771) had the same WTP, additional revenue of about BDT 79 mill (USD 1 mill) from the park could be generated each year.

Future research and policy implications

There is a pressing need to assess the states and values of urban ecosystems and their services in Dhaka. A standard typology of urban ecosystems for Bangladesh is necessary. Databases on trees (location, number, species, other features), rooftop gardens (number per ward, type), and waterbodies would be beneficial to city corporation and municipal authorities. Mapping of ecosystem services at city levels is desirable. In-depth research on microclimate regulation by ecosystems and carbon sequestration is necessary. Valuation could show the economic importance of ecosystem services and promote conservation and improvement.

My study is a necessary contribution to the local, regional, and the broader scientific communities. The findings of my research are expected to influence citizens and policy makers for sustainable urban ecosystem management at city scale. Further research is recommended to undertake a more precise assessment of ecosystems and services in Dhaka city and in other climate-exposed highly built-up cities in the developing world. This would assist in the development of strategies for preventing further degradation and to maintain or improve the contributions of ecosystem services to residents' wellbeing.

CHAPTER 3: URBAN ECOSYSTEMS, ECOSYSTEM SERVICES, AND GOVERNANCE REGIME

3.1 INTRODUCTION

'Governance' is a widely talked about concept but its definition is rather vague (Davies, 2002; Rhodes, 1996). Stoker (1998) referred to governance as "*a complex set of institutions and actors that are drawn from but also beyond government*" and stated "*governance recognizes the capacity to get things done which does not rest on the power of government to command or use its authority*". Weiss (2000) indicated governance is often considered as a composite of public and private structures and processes. Rhodes (1996) specified governance as "*self-organizing, interorganizational networks*" where the network participants (e.g., public and private sectors and other non-state actors) interact with each other under certain agreed upon rules. The above discussion broadly stipulates that governance is a set of rules which involves government and non-government actors where the actors interact with each other for a common goal. Governance is used in different sectors (e.g., state, corporate, and socio-cybernetic systems) (see Rhodes, 1996 for details) and thus its definition has been modified accordingly. The governance concept is also applied in the environment sector. Lemos and Agrawal (2006) defined environmental governance as "*the set of regulatory processes, mechanisms and organizations through which political actors influence environmental actions and outcomes*". Environmental governance includes planning, policymaking, management, and other governing processes (Ansell & Gash, 2008; Pahl-Wostl, 2009). Environmental governance also comprises concepts of space and scale (global, local; individual- and market-oriented instruments) and themes (environment as a whole and/or environmental components, such as water resources) (Bulkeley, 2005; Lemos & Agrawal, 2006; Wiek & Larson, 2012). Some widely acknowledged scholars (e.g., Paavola, Gouldson, & Kluvánková-Oravská, 2009; Pahl-Wostl, 2009) preferred 'governance regime' to be an all-inclusive term. Accordingly, I defined governance regime as the set of principles, rules, norms and prevailing practices for formulating and implementing collective choices (i.e., decision-making procedures) with involvement of government, non-government, and private sector stakeholders (Krasner, 1982; Paavola, Gouldson, & Kluvánková-Oravská, 2009; Pahl-Wostl, 2009; van de Meene, Brown, & Farrelly, 2011; Wiek & Larson, 2012).

Given the emphasis (in my study) of urban development and ecosystem services, it is important to assess how the ecosystems and ecosystem services are governed and who are the main actors involved in governing them in Bangladesh. Ecosystem governance is a relatively new field of research in Bangladesh. To date, there have been only a few studies conducted on ecosystem governance or on the governance regime as envisaged above in the context of Bangladesh However, governance issues have been studied related to: urban environments at macro (national- policies), meso (sub-national- municipalities), and micro (local- urban communities) levels (Mittal, Petrarulo, & Perera, 2015); co-management (government and local communities) of forest conservation (Ahammad, Hossain, & Husnain, 2014); legal frameworks for coastal and marine fisheries (Shamsuzzaman & Islam, 2018); water and ecological resources management at local, national and river (Ganges-Brahamputra) basin-wide scales (Hossen & Wagner, 2016); water resource management at international, intra-national, and intra-community scales (Hill, 2009); roles of government, private sector (market) and NGOs in land development for housing in Dhaka (Morshed & Asami, 2015); and roles of civil society and NGOs in environmental governance (Bahauddin, 2014). The extent of stakeholder involvement in governing ecosystems and ecosystem services has not been investigated for Bangladesh to date.

The Ministry of Environment and Forests (MoEF) is responsible for formulating environmental regulatory frameworks in Bangladesh and its Department of Environment (DoE) is in charge of enforcing those frameworks (Bahauddin, 2014) in coordination with other governmental agencies. The governmental agencies in Bangladesh mainly follow legal guidelines for governing environmental issues with significant support from international donor organizations such as: the World Bank, United Nations Development Programme (UNDP), Asian Development Bank (ADB), Japan International Cooperation Agency (JICA), the government of The Netherlands, and partial integration of NGOs (Ahmed & Roy, 2015). The donor organizations simultaneously support local and international NGOs (*ibid*, 2015). Bangladesh has "*one of the largest and most sophisticated NGO sectors*" (Gauri & Galef, 2005). Some notable Bangladeshi NGOs include BRAC, PROSHIKA, and Grameen Bank. The NGOs generally provide services in relation to microfinance, small industry, sanitation, education, healthcare, and livestock and fisheries projects (Haque, 2002). The environmental non-governmental organizations (ENGOs) in Bangladesh provide policy inputs and assistance with international negotiations, perform research, work on project implementation, support environmental movements, and play the watchdog roles (Ahmed & Roy, 2015). The country's civil society (e.g., professional associations, community based organizations, research groups, think tanks, and environmentalists) safeguard people's rights, ensure rule of law and justice, and promote good governance (Zafarullah & Rahman, 2002). The NGOs and the civil society not only play the roles of watchdogs but also influence the socio-political spheres (Haque, 2002; Zafarullah & Rahman, 2002). Together they have worked for raising awareness and establishing people's civil, socio-economic, political, and environmental rights (Gauri & Galef, 2005; Zafarullah & Rahman, 2002). Islam and Walkerden (2017) stated that the government legal guidelines generally overlook the capacity and contribution of local communities. The policy formulation and implementation follow a top-down approach dominated by the government and civil bureaucrats, community experts, international donor agencies, but the representatives from potentially the most vulnerable groups are virtually absent (Bahauddin, 2014; Islam & Walkerden, 2017). In contrast, the NGOs and civil society organizations have keen interest in involving the local communities for ecosystem governance (Bahauddin, 2014).

Local communities/citizens can actively contribute to ecosystem governance (Buijs *et al.*, 2016). Both the formal and informal organizations influence citizens' behaviors regarding ecosystem use (Wiek & Larson, 2012). Specifically, regulatory frameworks (policies and policy instruments), management practices (activities: analyzing, monitoring, developing and implementing measures), and ecosystem ownership are key factors in this context (Foresman, Pickett, & Zipperer, 1997; Pahl-Wostl, 2009). Non-governmental organizations (NGOs) are major stakeholders which connect local communities, private sectors, and the formal government agencies for common environmental welfare (Slavíková *et al.*, 2017) mainly in the developing countries (Gauri & Galef, 2005). The ENGOs are crucial promoters of conservation activities that also search for innovative solutions to manage environmental crises (Guillet, Mermet, & Roulot, 2016). The civil society effectively mobilize local communities for environmental protection and sustainability (Bahauddin, 2014). The NGOs, ENGOs, and civil society as lobbyists increasingly influence local and national government authorities (Gauri & Galef, 2005; Morshed & Asami, 2015) for environmental governance. In order to govern natural resources it is necessary to produce collaborative solutions involving the government, the non-government (donor agencies, NGOs), the knowledge sector, and the private sector (e.g., civil society) organizations (Gauri & Galef, 2005; Hattingh *et al.*, 2007). Ecosystem governance from such governance regime point of view has received little attention in studies relating to urban areas such as Dhaka, or as a whole, Bangladesh.

The objective of this Chapter is to investigate the current ecosystem governance system in urban areas of Bangladesh, mainly Dhaka city, under three governance regimes: government, non-government, and private sector organizations. Policy analysis, in-depth interviews, and household surveys were applied. My research is the first to provide a view of ecosystem governance system with a focus on the highly urbanized city of Dhaka. It is expected that the outcomes of this study would contribute to improve governance gaps and to improved integration of non-governmental organizations and, more importantly, citizens in ecosystem governance.

3.2 METHODS

3.2.1 In-depth Interviews

I undertook in-depth interviews of about 30 experts using a semi-structured format together with some open-ended questions to generate an overview of ecosystems and ecosystem services governance in Bangladesh. The interview questions covered, among other issues, current ecosystems and ecosystem services management practices, stakeholders involved in ecosystem governance, environmental awareness among common people, awareness raising activities, and legal frameworks for ecosystem governance. Experts included researchers, academics, government officials, economists, architects, civil engineers, urban planners, and local senior citizens. Details on the organizational affiliations of the interviewees are available in Table 1.3 and Sub-section 1.3.4.2 (Chapter 1). I analyzed the inputs from the interviewees categorizing them under different themes, scoring (e.g., high to low; agree and disagree), using direct quotes, and preparing figures. I tried to triangulate the interview data with the information from other sources: policy analysis and household surveys.

3.2.2 Policy Analysis

Policy analysis was undertaken to provide insights into existing government legal guidelines and the roles of non-government organizations and citizens regarding ecosystem governance in Bangladesh with a focus on urban areas and Dhaka city. I collected 17 environment related government legal guidelines from different government agencies. For brief descriptions, please see The Government Legal Guidelines: A.3.1-A.3.17, Appendix III. As part of the policy analysis, I also took into account the environmental agendas of some selected NGOs and private sector organizations. Sub-section 1.3.6.4, Chapter 1 has more information on policy analysis.

Relating to government legal guidelines, I evaluated ecosystems and ecosystem services that they addressed, applicability of the legal guidelines in urban areas, authorities responsible for implementing the guidelines, implementation approaches of the responsible authorities, governance challenges, and ways to address the challenges. Furthermore, following Cortinovis and Geneletti (2018), I assessed the priority ecosystems governance in the legal guidelines:

- Conservation (preserve the current state of ecosystems to secure ecosystem services provision);
- Improvement (improve the state of existing ecosystems to enhance ecosystem services provision);
- Restoration (recover the health and functionality of ecosystems to get back original level of ecosystem services provision); and
- New ecosystem or ecosystem services generation (create new ecosystems to provide new ecosystem services in an area).

Table 3.1 List of non-government and private sector organizations selected for the policy analysis.

Sl. No.	Organization name	Organization type
1	World Bank	International development organization
2	Asian Development Bank	International development organization
3	International Union for Conservation of Nature (IUCN)	International Environmental NGO
4	Transparency International Bangladesh (TIB)	International civil society organization
5	Bangladesh Environmental Lawyers Association (BELA)	National civil society organization
6	Center for Environmental and Geographic Information Services (CEGIS)	National environmental research organization
7	Bangladesh Centre for Advanced Studies (BCAS)	Environmental research organization (National NGO)
8	Proshika Manobik Unnayan Kendro (PROSHIKA)	Development organization (National NGO)
9	Bangladesh Rural Advancement Committee (BRAC)	Development organization (National NGO)
10	Arambag Housing Association, Ward 6, DNCC	Local civil society organization

Note: See Table A.3.2, Appendix III for details on the organizations.

Table 3.1 includes the list of organizations that were included in the policy analysis. The environmental agendas of international development organizations and ENGOs, and private sector (e.g., national NGOs, research organizations, civil society organizations) were analyzed using information from in-depth interviews, and a literature review (reports, websites, and journal articles). My analysis concentrated on ecosystem governance undertaken by the selected organizations. This analysis was based on their visions, missions, activities (e.g., projects/programs), priorities (ecosystem conservation, restoration, improvement, and new ecosystem/ecosystem service generation) (See Cortinovis & Geneletti, 2018 for details), and overall roles in environmental governance as identified in Slavíková et al. (2017) as watchdog, value perceiver, field actor and action coordinator, knowledge transmitter, and partner in collaborative governance. Indicators for identifying the roles are shown in Table A.3.1 (Appendix III). I also evaluated challenges in the organizations' governance approaches and ways to address such challenges.

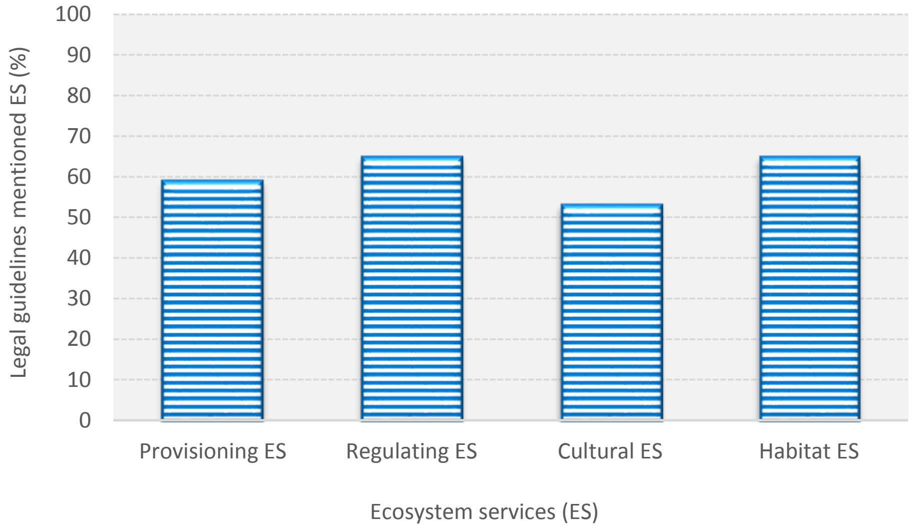
3.2.3 Household Surveys and Observations

I conducted a questionnaire-based survey of 510 households in wards 6, 7, and 8 of Mirpur-Pallabi Zone, Dhaka North City Corporation (DNCC). Details of the survey and study area are described in Sub-sections 1.3.4.3 and 1.3.2.1 (Chapter 1). For this part of my research, the randomly-selected respondents were asked structured questions to assess the level of environmental awareness and citizens' roles in ecosystem governance. Observation (Sub-section 1.3.4.1, Chapter 1) or more generally, the Ecosystem Services Analysis (ESA) (Sub-section 1.3.6.2, Chapter 1) results supplemented the contents of this Chapter. Observations of ecosystem and ecosystem services in the study area were performed to assess their current conditions. Photographs I took while observing were analyzed here (using the ESA approach).

3.3 GOVERNANCE OF ECOSYSTEMS AND ECOSYSTEM SERVICES

3.3.1 The government legal guidelines

I performed a comprehensive analysis of the selected government legal guidelines from an ecosystem perspective (Table 3.2). The term 'ecosystem' was explicitly mentioned in about 60% (n=17) of these legal guidelines. The main ecosystems examined included agricultural land, waterbodies (river, wetlands, khals, coastal and marine ecosystems.), and forests (e.g., hills, protected forests, and mangroves). 'Ecosystem services' were explicitly (direct mention of ecosystem services) or implicitly (indirect mention of ecosystem services) mentioned in 65% of the guidelines. I categorized these ecosystem services as provisioning, regulating, cultural, and habitat ecosystem services. About 59% of the guidelines mentioned provisioning ecosystem services: crops, fisheries, aquaculture, water supply (surface and ground) for drinking and irrigation; 65% mentioned regulating ecosystem services: control river bank erosion, soil salinity, and pollutions (air, water, soil), improve natural drainage, mitigate flood risk and damage; 53% mentioned cultural ecosystem services: use of waterbodies for tourism and recreation, protection of national forest, archaeological places and ancient monuments, and game reserves; and 65% mentioned habitat ecosystem services: wildlife habitat/sanctuary and biodiversity conservation (Figure 3.1). Ahmed and Roy (2015) also described the government of Bangladesh (GoB) focus on a few issues relating to environmental governance: topsoil degradation, water (ground and surface) contamination, urban air pollution, biodiversity loss in coastal areas, and deforestation. Thus, it is understandable that the GoB gives relatively more importance to regulating and habitat ecosystem services.



Note: Figure prepared based on Table A.3.3 (Appendix III).

Figure 3.1 Percentage of the government legal guidelines mentioning ecosystem services.

Table 3.2 Legal guidelines of the Bangladesh government for ecosystem governance.

No.	Legal guidelines	Ecosystem mentioned	Main ecosystem addressed	Major ecosystem services (ES)* mentioned	Applicable for urban areas	Main responsible authority
P1	*The National Environment Policy, 1992*	Yes	Agriculture land, waterbodies, forests	**PES:** Fisheries conservation **RES:** Surface and ground water management, Protection of soil fertility, Control of soil erosion, soil salinity and air pollution **CES:** Usage of waterbodies for amenity services in cities **HES:** Biodiversity conservation	Yes	Ministry of Environment and Forests and Department of Environment
P2	*Bangladesh Environment Conservation Act, 1995*	Yes	Nothing specific	Nothing specific	Yes	Department of Environment
P3	*The Environment Conservation Rules, 1997*	No	Ecologically Critical Area (e.g., waterbodies and forests)	**RES:** Set standards for air, water, soil, noise, odor, sewage discharge and emission of waste. **CES:** Protection of national forest, archaeological places and ancient monuments, game reserves through declaration of Ecologically Critical Area (ECA) **HES:** Conservation of wildlife habitat, sanctuary, forest, waterbodies, local biodiversity by declaring them ECA	Yes	Department of Environment
P4	*National Water Policy, 1999*	Yes	Waterbodies (e.g., river, haor, baor, beel, wetland, coastal estuary, lake, pond, khal, tank, streams and water channels)	**PES:** Increasing efficiency of water use in irrigation, reserving waterbodies for fish production and development, specific zone for brackish aquaculture, developing haors for dry season agriculture **RES:** Tracking groundwater recharge, surface and groundwater use, and changes in surface and groundwater quality, preventing water pollution,	Yes	National Water Resources Council in coordination with all institutions working with the water sector

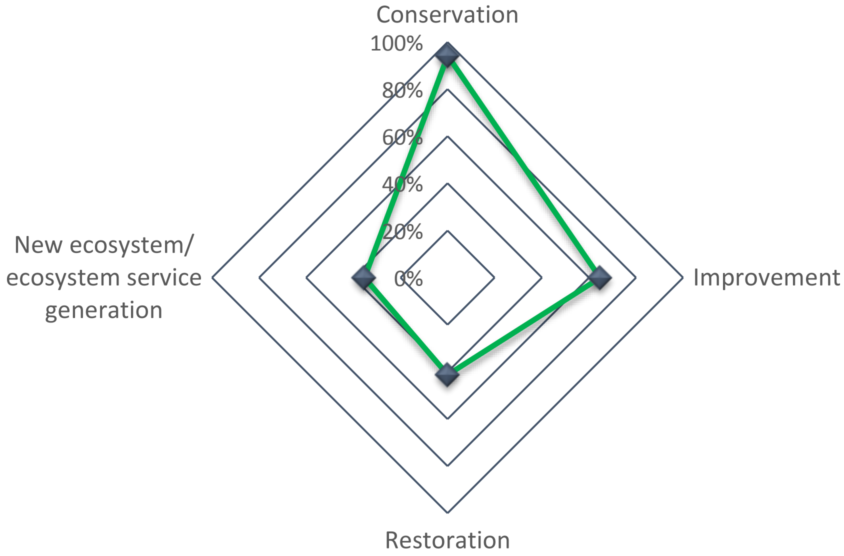
No.	Legal guidelines	Ecosystem mentioned	Main ecosystem addressed	Major ecosystem services (ES)* mentioned	Applicable for urban areas	Main responsible authority
				preserving haro, baor and beel etc. for facilitating drainage **CES:** Introducing tourism facilities at or around waterbodies, e.g., at the sites of reservoirs, lakes, dighis (big ponds), sea resorts, etc. **HES:** Aquatic biodiversity protection in natural waterbodies		
P5	*National Adaptation Programmes of Action (NAPA), 2009*	Yes	All ecosystems that are threatened to climate change (e.g., wetlands, mangrove forest)	**PES:** Production of agriculture crops, fisheries, and livestock, water resources management **HES:** Biodiversity protection	Yes	Ministry of Environment and Forests
P6	*Bangladesh Climate Change Strategy and Action Plan (BCCSAP), 2009*	Yes	All ecosystems that are threatened to climate change (e.g., wetlands, mangrove forest)	**PES:** Supply of food, water, and fuelwood **RES:** Carbon sequestration, prevention of soil erosion and landslide, drainage **CES:** Commercial tourism and ecotourism **HES:** Biodiversity protection	Yes	National Environment Committee and Ministry of Environment and Forests
P7	*Bangladesh Environment Conservation (Amendment) Act, 2000*	Yes	Nothing specific	Nothing specific	Yes	Department of Environment

No.	Legal guidelines	Ecosystem mentioned	Main ecosystem addressed	Major ecosystem services (ES)* mentioned	Applicable for urban areas	Main responsible authority
P8	*Metropolis, sectional areas of all the municipal area of the city and district municipal playgrounds, open spaces, parks and natural reservoirs protection Law, 2000*	No	Playground (fields), open space (e.g., eidgah), park and natural reservoir (river, khal, stream, beel, other waterbodies)	Nothing specific	Yes	RAJUK and other divisional, city corporation and municipal development authorities
P9	*Land Use Policy, 2001*	No	Charland, government khas land, forest, and waterbodies.	**PES:** Fish production and water supply **RES:** Mitigating air pollution, controlling river bank erosion and soil pollution	Yes	National Land Use Committee
P10	*Bangladesh Environment Conservation (Amendment) Act, 2002*	No	None	**RES:** Improve air quality by stricter embargo on harmful smoke emission, Protect water and soil by restricting use of polythene bags	Yes	Department of Environment
P11	*Bangladesh Environment Conservation (Amendment) Act, 2010*	Yes	Waterbodies and hill	Nothing specific	Yes	Department of Environment
P12	*Environment Court Act, 2010*	No	Nothing specific	Nothing specific	Yes	Department of Environment
P13	*Disaster Management Act, 2012*	No	Nothing specific	Nothing specific	Yes	Department of Disaster Management (proposed)
P14	*Haor Master Plan, 2012*	Yes		**PES:** Crop and fish production, pearl culture, water supply	No	Ministry of Water Resources and

No.	Legal guidelines	Ecosystem mentioned	Main ecosystem addressed	Major ecosystem services (ES)* mentioned	Applicable for urban areas	Main responsible authority
			Haor, wetlands, rivers, khals, beels	**RES:** Flood risk and damage mitigation **CES:** Tourism enhancement **HES:** Biodiversity conservation		Bangladesh Haor and Wetland Development Board
P15	*Water Act, 2013*	No	Waterbodies	**PES:** Water supply for drinking, irrigation, fish culture, other usage **RES:** Water flow regulation, pollution control **CES:** Waterbodies for recreation **HES:** Biodiversity and wildlife protection	Yes	National Water Resource Board (proposed)
P16	*Ecologically Critical Area Management Rules, 2016*	Yes	All ecosystems that qualify as ECA	All ecosystem services	Yes	National Committee (proposed)
P17	*Bangladesh Delta Plan 2100*	Yes	All ecosystems (e.g., forests, wetlands, marine, river, hill, barind/drought prone areas, urban areas)	All ecosystem services	Yes	General Economic Division, Planning Commission for implementing the *Bangladesh Delta Plan 2100* formulation project

Note: *PES- Provisioning ecosystem services, RES- Regulating ecosystem services, CES- Cultural ecosystem services, and HES- Habitat ecosystem services. Details of the guidelines are provided in Appendix III (The Government Legal Guidelines: A.3.1-A.3.17).

More recently, the GoB is working towards conservation and pollution control (Ahmed & Roy, 2015). My analysis shows that while conservation of ecosystems and ecosystem services was emphasized in 94% of the reviewed legal guidelines, far less attention was directed towards quality improvement (65%), restoration (41%) and new ecosystem and ecosystem services generation (35%) in Bangladesh (Figure 3.2). When asked the reasons for such emphasis on intervention, some interviewees (e.g., Interviewees 5 and 14) suggested the global environmental movement/agendas and international aid opportunities influences the government's priority for ecosystem governance. Bangladesh has signed/ratified a number of globally recognized treaties/conventions/protocols such as, the Ramsar Convention, i.e., Convention on Wetlands of International Importance especially as Waterfowl Habitat, 1971; Convention Concerning the Protection of the World Cultural and Natural Heritage, 1972; and Kyoto protocol to the United Nations Framework Convention on Climate Change, 1997 (DoE, ND) which certainly influenced the GoB's emphasis on environmental intervention (Bahauddin, 2014).



Note: Figure prepared based on Table A.3.3 (Appendix III).

Figure 3.2 Priority of the government of Bangladesh for ecosystem governance.

Hossain and Huq (2013) stated that the development policies and programs of Bangladesh have a rural bias and none of the milestone policy documents give priority to urban development. I found that, although most guidelines were applicable within urban areas of Bangladesh, only two guidelines specifically addressed urban spaces: P8 and P17 (Table 3.1). The guideline P8 focused on conserving play grounds (field), open space (e.g., eidgah field), park and natural reservoirs (river, khal, other waterbody) ecosystems. These ecosystem categories are similar to those that I found in the study area (Sub-section 2.3.1, Chapter 2). However, this guideline did not address any provisioning, regulating, cultural, or habitat ecosystem services offered by the urban ecosystems.

In urban areas, the municipal system (city corporations and pourasabhas) is tasked with urban development issues related to climate smart initiatives, among others (Hossain & Huq, 2013). The Dhaka North City Corporation (DNCC) authority (Interviewee 26) informed that the DNCC was mainly responsible for micro-drain management, waste management, roadside tree plantation, and street lighting. The Corporation worked in collaboration with other government agencies for urban development. For instance, the micro-drainage system was connected to the storm sewer system and khals (canals) which is managed under the Dhaka Water Supply and Sewerage Authority (DWASA). The involvement of several government agencies, overlapping jurisdictions (Bahauddin, 2014), and lack of coordination among these hampers urban development of Dhaka (Interviewees 13, 17, and 8).

"37 institutions work on Dhaka city with their own mandates, some of which overlaps".

Source: Interviewee 13.

With regards to implementation, most of the legal guidelines followed a top-down approach (Bahauddin, 2014). The main responsible authorities were the Ministry of Environment and Forests (MoEF) and the Department of Environment (DoE). These authorities can legally involve other relevant government agencies at national, divisional, district, municipal/city corporation levels as required. A few guidelines encouraged involvement of public-private institutions (e.g., P4 and P16- Table 3.1), NGOs (P9- Table 3.1), and local communities (P1, P5 and P14- Table 3.1). In most cases, local communities were involved when the government imposed penalties on them and local communities appealed against the lawsuits.

"Environmental degradation is a profitable business, for example, deforestation and capture of wetlands, which happens by politically backed up a numbered few ".

Source: Interviewee 17.

The interviewees revealed consensus in that Bangladesh had reasonable coverage of legal provisions for ecosystem governance. However, they clearly indicated that the legal guidelines were mostly non-functional. During my fieldwork in Dhaka, a local shop owner informed that sometimes the government mobile court randomly came to check environmental compliance. Once he paid BDT 50,000 fine for using polythene bags, however, continued using them afterwards to reduce costs and, as the shop owner mentioned, to meet "*customer demand*". Image 3.1 (A and C) (see Image 2.4, Sub-section 2.4.2.5 for more evidence) shows abundance of polythene bags in the khals of the study area. Often local people dump construction materials in the waterbodies (Image 3.1-C). The interviewees unanimously stated the social elites (mainly political leaders and powerful businesspersons) dispose waste for encroachment of waterbodies. I asked many local residents (mainly people from low-income groups living in slums or low-cost houses) whether they used waters from the khals for any purposes. All said that the water was polluted because the khals were connected to latrines, malodorous, full of garbage, and breeding grounds for mosquitoes (Image 3.1-B) and so not useable. This response shows that the citizens have basic hygiene sense and awareness. A few interviewees (e.g., Interviewee 5) indicated Bangladeshi citizens, especially the city dwellers were aware of pollution but they did not act based on such awareness because the government did not monitor or enforce existing rules and regulations (Ahmed & Roy, 2015).

The ecosystem governance faces severe challenges in terms of service delivery (Bahauddin, 2014). The interviewees noted challenges including: non-implementation of the legal guidelines, limited governance capacity at all levels (government, NGOs, and community); lack of coordination to form a functionally coordinated unit; and corrupt and inefficient political leadership. "*The regulator must not be the implementer*" (Source: Interviewee 8). A decentralized governance system along with visible enforcement of the legal guidelines could mitigate deteriorating conditions of Dhaka's ecosystems and ecosystem services (Source: Interviewees 3, 5, and 17).

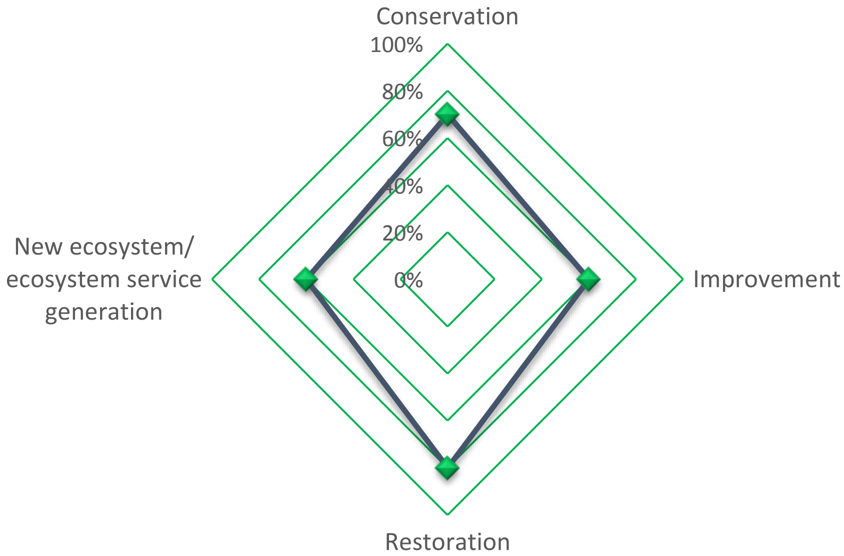
Source: Photography by the author, 2016.

Image 3.1 Polythene waste (A) and open latrine (B) in the Rupnagar khal, Ward 7, DNCC and waste (construction materials) disposal action in the Arambag khal, Ward 6, DNCC.

3.3.2 The roles of NGOs and private sector organizations

Most of the interviewees suggested that the NGOs, development and civil society organizations were active in ecosystem governance in Bangladesh, which was reflected in their involvement at national and local levels. The GoB gives increasing importance to the opinions and views of these organizations and, to some extent, depends on them (Bahauddin, 2014). However, some of the interviewees (e.g., Interviewee 17) believed that the civil society at large was not as active in advocacy as necessary and indicated that their activities were influenced by political parties. I found that almost all of the selected NGOs and private sector organizations (see Table 3.1) addressed ecosystem and ecosystem services directly or indirectly (See Table A.3.2, Appendix III). These organizations gave priority to provisioning services (e.g., safe water supply, agriculture/food production), and regulating ecosystem services including building climate change resilience (afforestation, reforestation) and river flow regulation. The activities of these organizations were mostly concentrated in rural and coastal areas. However, urban areas received some attention. The civil society organization BELA was found to be the most active organization in Dhaka city for protecting urban ecosystems (Source: Interviewee 8). BELA's notable works included cases on environmental issues: river pollution, industrial pollution, vehicular pollution, encroachment and degradation of important wetlands, and writ petitions: to save the river Buriganaga ecosystem; against construction and filling up the lakes and lakeside areas in Gulshan, Banani and Baridhara Model Town; and against vehicular pollution in Dhaka city (BELA, 2018b).

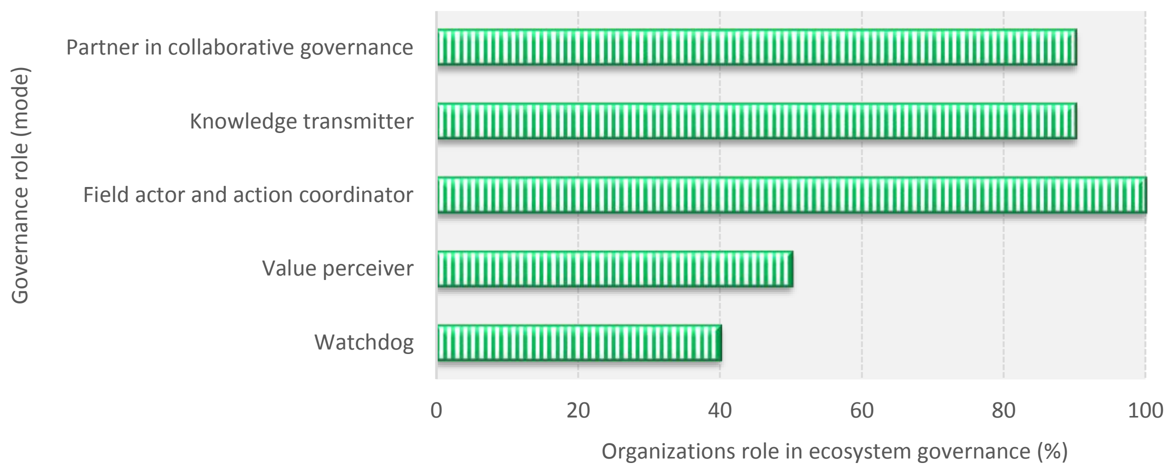
My analysis of the organizations' ecosystem related activities (projects/programs) showed that 80% of the organizations prioritized restoration followed by conservation (70%), quality improvement (60%), and new ecosystem and ecosystem services generation (60%) in Bangladesh (Figure 3.3). Some of their major activities are listed in Table A.3.2, Appendix III.



Note: Figure prepared based on Table A.3.4 (Appendix III).

Figure 3.3 Ecosystem related action priority of the selected NGOs and private sector organizations.

The modes of ecosystem governance of the selected NGOs and private sector organizations were diverse (Figure 3.4). These organizations were actively involved as field actors and action coordinators (100%), knowledge transmitters (90%), and partners in collaborative governance (90%). The civil society organizations (BELA and TIB) and international development organizations (World Bank and Asian Development Bank) acted as watchdogs through monitoring existing environmental norm fulfilment, engaging in mandatory participation processes, and pursuing legal actions against projects or campaigns that are harmful for the environment (Interviewees 2, 3, 4, 8, and 20) (ADB, 2016; BELA, 2016, 2018b; TIB, ND-a). The local development organizations (BRAC and PROSHIKA) and the civil society organizations arranged environmental awareness programs and promoted environmental values especially at national, local, and grass root levels (Interviewees 5, 6, and 13) (Ahmed & Roy, 2015; Akter, 1997; Alam, 1996; Boyle, 2002; Haque, 2002; Khan, 2008). Training, workshops, public meetings/seminars, processions, cartoons, dramas, and other electronic and print media methods were widely adopted activities.



Note: Figure prepared based on Table A.3.4 (Appendix III).

Figure 3.4 Ecosystem governance roles of the NGOs and private sector organizations.

The NGOs and private sector organizations worked with each other under different projects initiated by the government or funded by the international development organizations (Lewis, 2004; Lewis, 1997). Very few NGOs in Bangladesh (e.g., BCAS, BRAC, and PROSHIKA) worked on self-funded projects (Interviewee 5 and 13). Most NGOs and private sector organizations were predominantly funded by international donor agencies and the donors funding objectives largely determined their project priorities and study/intervention areas (Interviewees 5, 22 and 24). The environmental research organizations (BCAS and CEGIS), BRAC, PROSHIKA, TIB, BELA, and IUCN outreached to local communities while performing field works, such as surveys, public consultation meetings, focused group discussions, key informant interviews (See Table A.3.2 in the Appendix III for details). The interviewees stated that people's perceptions were generally recorded in the organizations' project reports. Nevertheless, the influence of public perception on the organizations' subsequent activities or the government regulatory guidelines was not assessed.

"The government should be the regulator only and community, local community-based organizations, and NGOs should be the managers of ecosystems and ecosystem services".

Source: Interviewee 8.

The interviewees advised that the ecosystem governance should be decentralized: not only the government funding but also the citizens' consensus and involvement were crucial for Dhaka's environmental management (e.g., Interviewee 3 and 9). The active participation of citizens may contribute to increased environmental, social, and institutional resilience of a city (Buijs *et al.*, 2016). About 80% of the experts interviewed stated that the environmental awareness level of common people in Dhaka city is dissatisfactory. The interviewees added that existing environmental awareness campaign/activities in Bangladesh were not satisfactory. They suggested the younger generation should be made more aware of environmental degradation, reasons, consequences, and ways to mitigate or improve the environment.

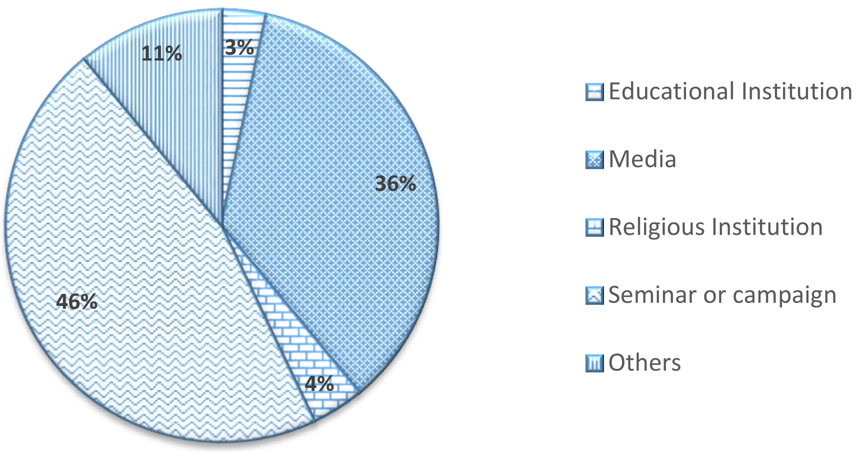


Figure 3.5. Respondents suggested ways of raising awareness for ecosystem management in Dhaka.

During the household surveys, the respondents suggested various ways for raising awareness and motivating people for ecosystem and ecosystem services governance at neighborhood scales (Figure 3.5). Broadly, these included seminar/campaigns: distribution of plants and seeds free of cost, organizing street drama, informative cultural programs, and environment fairs/seminars (46%); mass media: advertisements and programs on television, radio, social networking sites and print media (newspaper, poster and banner) (36%); sermon by religious leaders; individually informing friends and family in informal meetings (get together, parties, morning walk, clubs); enlightening school and college going students with environmental knowledge; arranging neighborhood meetings at regular intervals; creating volunteer groups involving young generations for taking care of neighborhood green and blue spaces; announcing rewards for encouraging good works; campaign through DNCC and DoE and having provisions for easy loans. In particular, the respondents showed willingness to adopt environment friendly measures such as, rooftop garden with individual and collective efforts (for details see Sub-section 4.4.1, Chapter 4). The local residents interviewed informed that collectively they often clean up khals in their neighborhood, culture fish in jheels, and protect playground/fields for cultural purposes (Source: Interviewees 18, 19, 20, 21, 32, and 33). About 33% respondents stated that they would be willing to take institutional loans (if available) with easy conditions for implementing such measures. However, the citizens need access to information/knowledge and facilities in terms of training and resources, which the government and the NGOs can facilitate (Source: Interviewees 22 and 33).

3.4 CONCLUSIONS AND DISCUSSIONS

Ecosystems and ecosystem services are essential for social, cultural, economic, psychological, and health-related wellbeing (discussed in detail in Chapter 2). Ecosystems need to be healthy for a better quality of life. Ecosystems and ecosystem services are declining due to rapid urbanization, especially in cities such as Dhaka (see Chapter 4 for details). Globally, the assessment of urban ecosystems receives little attention. This Chapter presents a holistic overview of the current ecosystem governance (ecosystems and ecosystem services prioritized, governance priority, key stakeholders, governance challenges, and ways to address them) in Bangladesh. A focus on the environmental governance of urbanized Dhaka city includes an assessment of policies/activities of three governance regimes: government, NGOs, and private sector organizations.

Agricultural land, rivers, wetlands, and mangrove forests in rural and coastal areas are governance priorities in Bangladesh. Urban ecosystems receive much less attention (Hossain & Huq, 2013) in all three governance regimes. The GoB emphasizes regulating (riverbank erosion, soil salinity, and pollutions, natural drainage, flood risk and damage) and habitat (wildlife habitat/sanctuary and biodiversity) ecosystem services. In comparison, the selected NGOs and private sector organizations highlight provisioning (e.g., safe water supply, agriculture/food production) as well as regulating ecosystem services: building climate change resilience (afforestation, reforestation) and river flow regulation. The GoB gives very high priority (Table 3.3) to ecosystem conservation. In contrast, the NGOs and the private sector organizations prioritize conservation and restoration of ecosystem/ecosystem services. Those NGOs and private sector organizations evaluated gave higher priority to new ecosystem/ecosystem services generation than did the government. However, my analysis revealed that the funding priority of the donor agencies and focus of the global environmental agendas influenced actions of the organizations.

Table 3.3 A comparison of ecosystem governance priority of the government, NGOs, and private sector organizations in Bangladesh.

Ecosystem governance priority	**Government of Bangladesh**	**NGOs and private sector organizations**
Conservation	+ + + + +	+ + + +
Improvement	+ + + +	+ + +
Restoration	+ + +	+ + + +
New ecosystem/ ecosystem service generation	+ +	+ + +

Note: Very high priority + + + + +, High priority + + + +, Moderate priority + + +, Low to moderate priority + +, Low priority + and No priority -. Priority scores were categorized based on percentages shown in Figures 3.2 and 3.3. See Table A.3.5 (Appendix III) for scoring category.

The GoB understands the importance of ecosystem governance, as reflected in its various legal actions over time (in the forms of policies, acts, rules, and plans), and increasing involvement in the globally-recognized treaties/conventions/protocols. Although Bangladesh has reasonable coverage of legal provisions for ecosystem governance, these are mostly non-functional in terms of delivering services and creating impacts. Bahauddin (2014) and Ahmed and Roy (2015) found similar results. The effectiveness of legal guidelines needs to be evaluated for better governance of ecosystems.

I have shown that the NGOs and private sector organizations were actively involved in ecosystem governance as field actors and action coordinators, knowledge transmitters, and partners in collaborative governance, and watchdogs. They often worked with each other and side by side with the government, which reflects inter-dependence on each other. These organizations arranged environmental awareness programs and promoted environmental values especially at national, local, and grass root levels. Outside the state, the NGOs and private sector organizations in Bangladesh are recognized as powerful lobbyists that advocate for ecosystem governance through engaging community level participation and influencing the socio-political spheres of the country (Bahauddin, 2014; Gauri & Galef, 2005; Haque, 2002; Morshed & Asami, 2015). These organizations are particularly important in planning and service provision (Morshed & Asami, 2015). The ENGOs are also involved in international policy committees. It is understandable that the NGOs and private sector organizations are important and influential in ecosystem governance. However, the degree to which these organizations can actually influence government policy is yet to be assessed.

Local communities/citizens are key stakeholders important in ecosystem governance (Buijs *et al.*, 2016). Although the government and other organizations encouraged citizen involvement, they were found to be less empowered when it came to implementation of legal guidelines or project activities. Overall, current environmental awareness level of citizens in Dhaka city is unsatisfactory. Non-implementation of the legal guidelines, limited governance capacity at all levels (government, NGOs, and community); lack of coordination among governing organizations; and corrupted and inefficient political leadership were found to be the main obstacles to effective ecosystem governance at all scales. Roy (2009a) found similar obstacles when used the concept informality ("a state of deregulation, one where the ownership, use, and purpose of land cannot be fixed and mapped according to any prescribed set of regulations or the law") to discuss why policies and plans are only selectively taken up by governments. According to the same, informalities in terms of, for instance, power conflicts and use/misuse of laws affect urban planning and "future-proofing" cities. An impact assessment of current governance system in Bangladesh and comparative analysis of similar South Asian countries are necessary for improving local and regional ecosystem governance and urban development.

I did not assess organizational structures of the selected NGOs and private sector organizations; government governance hierarchy, government mobile court programs targeted to monitoring legal compliance; effectiveness of environment related projects led by the GoB, and other selected organizations. Translating the legal guidelines to English from Bangla for analysis was sometimes difficult and may exclude some relevant terminologies. Inclusion of participants from the law enforcement agencies could have generated more insights into the environmental governance issues.

Urbanization and urban expansion in Dhaka demonstrably impact on ecosystems (wetlands, rivers, parks, agriculture land, forest) and on services generated by them (see Chapter 4). Bangladesh needs a policy focus on urban ecosystem and ecosystem services. New ecosystem creation/ecosystem services generation (e.g., establishing community gardens, harvesting fruits and vegetables from rooftop gardens, utilizing khals and other waterbodies for recreation-fishing/boating, and planting tree species on roadsides that are more efficient in capturing particulate matters) in urban areas (Zinia & McShane, 2018a, 2018b) should be emphasized in governance. Duplications and contradictions of the government legal guidelines and coordination problems among the government and other responsible agencies should be addressed (Bahauddin, 2014). To ensure effective stewardship of urban ecosystems, the governance system needs to be decentralized. ‘Collaborative governance’ (Ansell & Gash, 2008) or ‘mosaic governance’ (Buijs *et al.*, 2016) are globally acknowledged to be effective measures for this. Collaborative governance that encompasses horizontally and vertically coordinated joint efforts of the government, donor agencies, NGOs, civil society, other private sector organizations, and more importantly citizens is required (Mittal, Petrarulo, & Perera, 2015). Behavioral changes of the common people through mass media, public seminars/programs, religious and educational institutions can assist in a collaborative approach to effective ecosystem governance. All of these together may potentially mitigate political biases and corruption in ecosystem governance in Bangladesh.

CHAPTER 4: GREEN ADAPTATIONS, SOCIAL ACCEPTANCE, AND ECONOMIC FEASIBILITY

4.1 INTRODUCTION

More than half of the world's population (54%) live in urban settings and this is expected to increase to 66% by 2050 (United Nations, 2014). Urbanization is problematic in developing countries (Khadka & Shrestha, 2011; Rana, 2011) as ad hoc development and high population growth exerts pressure on social, economic, and environmental wellbeing (Zinia & Kroeze, 2015). This is particularly the case for Dhaka, Bangladesh, one of the world's most densely populated cities. Dhaka is the socio-economic and cultural center of the country (Zinia & McShane, 2018b). Informal settlements, housing development projects, and associated infrastructure construction is proceeding at the cost of loss or degradation of Dhaka's wetlands and vegetation (Alam & Mullick, 2014; Shubho et al., 2015; Zinia & Kroeze, 2015) and thus threatening or reducing crucial provisioning ecosystem services, i.e., the goods and services humans obtain from ecosystems (MA, 2003). The residents of Dhaka also face climate change (particularly extreme heat and extreme weather events) and poverty. Green adaptation strategies for maintenance or improvement of ecosystem services can present an effective response but, to date, no formal or coordinated activities have progressed.

In considering ecosystem services and associated green adaptation strategies, urban areas are often categorized as separate ecosystems (see Bolund & Hunhammar, 1999; Foresman, Pickett, & Zipperer, 1997; Grimm & Redman, 2004; Mcintyre, Knowles-Yánez, & Hope, 2000; Niemelä *et al.*, 2010). To evaluate green adaptation strategies for Dhaka, ecosystem services are defined as the benefits generated from ecosystem functions that contribute to human wellbeing (Costanza *et al.*, 1997; Daily, 1997; de Groot, Wilson, & Boumans, 2002; MA, 2005a; TEEB, 2010a). Common services provided by urban ecosystems include production of fruits, grains and seeds; carbon sequestration; microclimate regulation; noise abatement; air, water and pollutant filtration; pollination; and recreation (e.g., boating, fishing, picnic) (Bastian, Haase, & Grunewald, 2012; Bolund & Hunhammar, 1999; Costanza *et al.*, 2006; Escobedo, Kroeger, & Wagner, 2011; Haase, 2015; Zinia & McShane, 2018b).

Green infrastructure, ecosystem-based adaptation, or eco-infrastructure are well-known strategies for management of urban ecosystem services (Betancourth, 2011; Cameron *et al.*, 2012; Geneletti & Zardo, 2016). Integration of urban green spaces with other urban infrastructure can be effective adaptive responses to, for example, extreme heat events (Hansen & Pauleit, 2014). Importantly, for developing countries, green adaptation responses (see Sub-section 1.3.2.3 for definition) present affordable options, utilize ecosystems for multifunctional purposes, and involve multiple stakeholders (Goodess *et al.*, 2013; Hulsman, Van der Meulen, & Van Wesenbeeck, 2011).

Feasibility is a key issue influencing the adoption of green adaptation strategies for ecosystem services management. There is a clear distinction between economic and financial feasibility analyses. Economic analysis evaluates a proposed intervention in terms of economic (cost, benefit), social, and environmental issues relating to the value to the community and to the developer or user. Financial analysis considers the cash flow (income and expenses) associated with the proposed intervention (Halil *et al.*, 2016; Liang & van Dijk, 2010). Several studies consider both analyses: Liang and van Dijk (2010) for decentralized waste water reuse systems, Giurco *et al.* (2011) for water treatment and industrial water reuse synergies, and Halil *et al.* (2016) for green building projects. I assessed economic feasibility in a qualitative manner focusing on individual and collective affordability, i.e., the purchasing power (Jana *et al.*, 2016) for implementing green adaptation strategies in Dhaka.

Social acceptance is crucial for successful implementation of strategies and projects for current and future planning (Khorsand *et al.*, 2015; Yuan, Zuo, & Huisingh, 2015). I defined social acceptance as an individual's or a group of local residents' support(s) (high to low) reflected in their preferences for adoption of green adaptation strategies. This follows the findings of related studies (e.g. Chin *et al.*, 2014; Schweizer-Ries, 2008; Wüstenhagen, Wolsink, & Bürer, 2007; Zhao *et al.*, 2015) including studies particularly focused on green adaptation strategies (see Jung *et al.*, 2016; Zhao *et al.*, 2015).

Dhaka is the capital city of Bangladesh located at the confluence of three major rivers, the Ganges, the Brahmaputra and the Meghna. More than 12 million residents occupy a total area of about 1,464 km^2 (BBS, 2013a). Its annual population growth rate is 3.5% (BBS, 2012). Urban expansion is expected to occur in the peri-urban (fringe) areas (Roy, 2009b). Typical of Bangladesh more generally, Dhaka is experiencing extensive land use change led by rapid urbanization (Dewan & Yamaguchi, 2009a). Mostly, agricultural lands are converted to built-up areas, brick fields are established in the fringe areas, forests are destroyed to meet fuel needs, and illegal encroachment of common resources such as rivers, lakes and wetlands by developers is prevalent affecting ecosystem services (Rana, 2011). Growth of informal settlements such as slums is contributing to environmental pollution in Dhaka (Dewan & Corner, 2014b; Dewan & Yamaguchi, 2009b). Urbanization, together with urban expansion, poses severe impacts on ecosystems (wetlands, rivers, parks, agriculture land, forest) at multidimensional scales (Byomkesh, Nakagoshi, & Dewan, 2012; Dewan, Yamaguchi, & Rahman, 2012; Zinia & Kroeze, 2015). There is an urgent need to assess the states of these ecosystems and to implement measures to stop further deterioration and to maintain or improve ecosystem services for human wellbeing. Yet, until now, no empirical research has been undertaken on green adaptation strategies for managing ecosystem services in Dhaka.

Here, I evaluated relevant literature to formulate a list of green adaptation strategies for urban ecosystem services management. From this assessment, I contextualized green adaptation strategies given the extant literature on urban development and related impacts on ecosystem services more generally. Then I evaluated social acceptance and economic feasibility of green adaptation strategies for urban development of Dhaka. Finally, I focused on green adaptations that are possible to implement individually and/or collectively, are less technology and capital-intensive, and require minimum government support. My empirical research is novel in that as it integrates social, economic, and environmental aspects of urban development: the first study for Dhaka city and for Bangladesh.

4.2 METHODS

4.2.1 Search and Selection of Studies

I searched electronic journal databases Science Direct and Springer Link to identify best practices, i.e., green adaptation strategies already implemented worldwide for managing urban ecosystem services. Keywords for the search included ‘green and blue infrastructure’, ‘multifunctional infrastructure’ and ‘green adaptation’. From this, I chose 115 peer-reviewed publications ranging from 2005 to early 2016 for further selection of articles. Literature containing empirical studies at city scales was then examined.

4.2.2 Household Survey and In-depth Interviews

For this part of my research, I focused on three wards under Mirpur-Pallabi Zone (Zone-2), Dhaka North City Corporation (DNCC) (Map 1.2, Sub-section 1.3.2.1, Chapter 1). I selected wards 6, 7, and 8 based on field level observations, expert judgements, and literature review. These three wards cover 41% of Zone-2 (DNCC, 2017). The demographic conditions and land-use patterns across the wards under DNCC are similar (BBS, 2013a; DNCC, 2017). Furthermore, I considered the presence of a wide range of ecosystems in these wards, access to them and to households within wards for surveys.

To assess social acceptance of green adaptation strategies I conducted questionnaire-based surveys of 510 households in 2016. I did a pilot survey beforehand for pre-testing the questionnaire and determining the sample size for the main survey. Please see Sub-section 1.3.4.3 (Chapter 1) for detailed sampling procedure and for locations of the surveyed households (in Map 1.3). There were 175 (34.3%), 174 (34.1%), and 161 (31.6%) respondents from ward 6, ward 7, and ward 8, respectively. About 63% respondents were male. The proportion of females surveyed ranged from 31-44% across wards. Most of the respondents (42%) were aged between 35-45 years, held bachelor degrees (36%), and were married (91%). Average monthly household income was greater than 50 thousand BDT. Most of the respondents (66%) did not own their own houses paying 5-10 thousand BDT rent per month. I asked randomly-selected respondents structured questions on selected green adaptation strategies (Table 4.3, Sub-section 4.4.1). Furthermore, I evaluated the respondents' willingness to pay (WTP) for implementing their preferred green adaptation strategy. Of note, Bangladeshi Taka (BDT) 78 BDT = 1 USD, as of October 2016. Tables A.4.1- A.4.8 in Appendix IV describes additional materials related to the survey.

To evaluate the economic feasibility of green adaptation strategies in Dhaka I undertook in-depth interviews of about 30 experts using a semi-structured format (i.e., perspective mapping) together with some open-ended questions. Experts included researchers, academics, government officials, economists, civil engineers, architects, urban planners, and local senior citizens. The experts I selected for this part of my research were from the International Center for Climate Change and Development (ICCCAD); the International Union for Conservation of Nature (IUCN) Bangladesh; BanDuDeltAS; the World Bank; Climate Change and Health Initiative, the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR,B); Climate Finance Governance, Transparency International Bangladesh (TIB); Dhaka North City Corporation (DNCC); the Center for Environmental and Geographic Information Service (CEGIS); Bangladesh Centre for Advanced Studies (BCAS); Department of Urban and Regional Planning, Bangladesh University of Engineering and Technology (BUET); Department of Economics, East West University; Department of Development Studies, University of Dhaka; Centre for Climate Change and Environmental Research, BRAC University and Latitude-23, Dhaka. Please see Sub-section 1.3.4.2, Chapter 1 for details on interview.

4.2.3 Statistical Analysis

I applied three statistical measures using SPSS to assess association between the surveyed respondents' preferences of green adaptations (dependent variables) and their gender, age, education, household income, years living in the holding, and ownership of holding (independent variables). The statistical measures were Pearson Chi-squared test, multiple linear regression model and binary logistic regression model. In all cases 5% level of significance was considered. A linear regression model was used as it was easy to compute. Here categories within the independent variables (e.g., income groups) were expressed as a single variable. It was expected that both linear and nonlinear estimation, i.e., logistic regression would generate similar marginal effects (see Chapter 3, Angrist & Pischke, 2009).

Pearson Chi-squared test was chosen as my variables were categorical and included data measured on a nominal or an ordinal scale. This test detected association between variables but did not indicate direction and strength of association/relationship. First, the Chi-squared values were calculated based on which Cramer's V values of the statistically significant (*p*-values less than the significance level 0.05) associated variables were identified to determine the strength of association between the nominal variables. Cramer's V value ranges between 0 (no association) and 1 (perfect association).

Predictors of the respondents' preferences for any green adaptations were found from multiple linear regression model analysis and presented in Table A.4.10 (Appendix IV). This Table contains the statistically significant values of unstandardized coefficients. Standardized coefficients were inappropriate as the dependent variables were in binary form (Yes and No) (Tarling, 2009). The model predicted that one unit change in any independent variable changes the dependent variable by units shown under the unstandardized coefficient columns, holding everything else constant.

Some categories of an independent variable may not be significant even if that independent variable as a whole is significant and vice versa. The binary logistic regression model was analyzed to see how well any specific category of the independent variable predicted respondents' preferences of green adaptations (Table A.4.11, Appendix IV). In this case, the dependent variables were dichotomous (coded as 0= No and 1= Yes) and the categorical independent variables were indicator coded (e.g., Age: 1= <25 years, 2= 25-35 years, 3= 35-45 years and 4= >45 years). This model quantified the effects of an independent variable in terms of an odds ratio (OR) (Harrell, 2001). Odds (range from 0 to infinity) is the ratio of the probability of occurring an event (*p*) to the probability of not occurring it (1-*p*) and an odds ratio is the ratio of two odds (Tarling, 2009) (Equation 4.1).

$$Odds = \frac{p}{(1-p)} \qquad (4.1)$$

4.3 GREEN ADAPTATIONS: A REVIEW

4.3.1 Urban Green Management

Table 4.1 shows implemented green adaptation strategies contributing to ecosystem services by urban green space management. This Table presents evidence that anthropogenic construction of green spaces (i.e., green adaptations) contributes to ecosystem services management and generation. These services include: mitigation of extreme heat arising from Urban Heat Island (UHI) effects; prevention of floods though rainwater retention; improvement of air quality by capturing fine dust; provision of UV-protection and carbon sequestration; conservation of biodiversity, and improvement of aesthetics.

Table 4.1 Green adaptations at city scale contributing to ecosystem services through urban green management.

Green adaptations for managing green spaces	**Contribution to ecosystem services**	**Urban area (city, country)**	**Reference**
Park, pocket park, open spaces	- Microclimate regulation - Influence on air quality	Stuttgart, Germany	Kazmierczak and Carter (2010)
Green wall	- Insulation - Influence on air quality	Staffordshire, UK	Chiquet, Dover, and Mitchell (2013)
Grasses planted in tram tracks	- Microclimate regulation - Influence on air quality	Stuttgart, Germany	Kazmierczak and Carter (2010)
Green facades	- Aesthetics - Urban flood prevention - Microclimate regulation	Berlin, Germany	Kazmierczak and Carter (2010); Francis and Lorimer (2011)
Private/domestic/home garden	- Biodiversity conservation - Habitat creation - Cognitive development (ecological knowledge) - Social activities - Microclimate regulation - Aesthetics - Food availability - Pollination - Influence on air quality - Erosion prevention - Urban flood prevention	Phoenix, Arizona; Maastricht, The Netherlands; North West Province & Gauteng Province, South Africa, Stockholm, Sweden; Dunedin, New Zealand; Edinburgh and Leicester, UK; León, Nicaragua	Beumer and Martens (2015); Goddard, Dougill, and Benton (2010); Davoren *et al.* (2015)
Green/living roof	- Storm water management - Urban flood prevention - Microclimate regulation - Influence on air quality - Encourage urban biodiversity - Food availability - Pollination - Aesthetics	Toronto, Canada; Philadelphia, USA; Stuttgart, Germany; Berlin, Germany; Augustenborg, Malmö, Sweden; Basel, Switzerland	Kazmierczak and Carter (2010); Francis and Lorimer (2011)
Rooftop garden (intensive green roof)	- Microclimate regulation - Influence on air quality - Aesthetics - Recreation	Kuala Lumpur, Malaysia	Rahman *et al.* (2015b)

Green adaptations for managing green spaces	Contribution to ecosystem services	Urban area (city, country)	Reference
Street/roadside trees	- Microclimate regulation - Influence on air quality - Encourage species diversity - Wildlife habitat	Toronto, Canada; Stuttgart, Germany; Vantaa, Helsinki, Finland	Kazmierczak and Carter (2010); Ranta *et al.* (2015)
Green courtyards	- Urban flood prevention - Microclimate regulation	Berlin, Germany	Kazmierczak and Carter (2010)
Community garden	- Urban flood prevention - Microclimate regulation	Berlin, Germany	Kazmierczak and Carter (2010)
Tree plantation	- Urban flood prevention - Extreme event protection	Coastal provinces, Vietnam	McCarthy (2012)
Continuous linear parks as greenways	- Noise abatement - Recreation - Social activities - Preservation of native trees, shrubs - Reduced soil erosion - Water purification	Campinas, Novo Horizonte and São José do Rio Preto, Brazil	Frischenbruder and Pellegrino (2006)
Greenbelt (network of parks, courtyards, squares, tree-lined streets and green roofs)	- Noise abatement - Influence on air quality - Wildlife habitat/corridor - Recreation - Aesthetics	Dongtan & Shanghai, China	de Oliveira (2014)

4.3.2 Urban Blue Management

Blue spaces are important providers of ecosystem services in urban settings (Table 4.2). Blue spaces include: storm water management; urban flood prevention; microclimate regulation; water supply for irrigation, garden watering, toilet flushing, cleaning, washing, water purification by controlling nutrients; ground water recharge; biodiversity protection, and aesthetics.

Table 4.2. Green adaptations at city scale contributing to ecosystem services through urban blue management.

Green adaptations for managing blue spaces	**Contribution to ecosystem services**	**Urban area (city, country)**	**Reference**
Porous/permeable pavements	- Urban flood prevention - Storm water management	Toronto, Canada; Philadelphia, USA	Kazmierczak and Carter (2010); Maksimović, Kurian, and Ardakanian (2015)
Rainwater harvest (tank/barrel)	- Water supply - Emergency water supply for household use & firefighting - Urban flood prevention - Storm water quality & flow management - Aesthetics	Seoul, South Korea; Albury, New South Wales & Brisbane, Australia	Maksimović, Kurian, and Ardakanian (2015); Mitchell (2006)
Storm water retention pond	- Storm water management - Urban flood prevention - Aesthetics	Toronto, Canada; Augustenborg, Malmö, Sweden	Kazmierczak and Carter (2010)
Wetland preservation/artificial wetland creation	- Food availability - Storm water management - Urban flood prevention - Increase climate resilience - Biodiversity protection - Waste treatment - Water purification - Provision for industrial raw materials	Toronto, Canada; New Orleans, USA; Binzhou, China; Kolkata, India	Kazmierczak and Carter (2010); Wang, Yao, and Ju (2008); Bhattacharya *et al.* (2012)
Infiltration of runoff in large shallow ponds	- Groundwater recharge - Mitigate dropping groundwater levels	Los Angeles, USA	Porse *et al.* (2015)
Storm water bump-out & storm water planter boxes	- Microclimate regulation - Recreation - Aesthetics - Social activities	Philadelphia, USA	Kazmierczak and Carter (2010)
Watershed restoration	- Water supply - Wildfire risk management - Biodiversity protection	Santa Fe, USA	McCarthy (2012)

Green adaptations for managing blue spaces	Contribution to ecosystem services	Urban area (city, country)	Reference
Bluebelt (connecting canal, lake, pond, minor waterways, wetlands)	- Increase resilience to natural hazards & extreme events - Shoreline protection - Coastal & riverine settlement protection	Dongtan & Shanghai, China	de Oliveira (2014); Betancourth (2011)
Water sensitive urban design (using grass swales, underlying gravel trench, artificial wetland, open space, ornamental lake)	- Storm water management - Aesthetics - Water purification (nutrients control)	Lynbrook Estate, Melbourne, Australia	Kazmierczak and Carter (2010)
Dual reticulation of non-potable treated wastewater for toilet flushing, garden watering, car washing	- Storm water flow & quality management - Water purification (nutrients control)	Sydney, Australia	Mitchell (2006)

4.3.3 Implementation of Green Adaptation Strategies

My review reveals that developing countries are prioritizing private gardens (Jim & Zhang, 2015) in response to rapid urbanization. León (Nicaragua) has private urban patios comprising 86% of its total green space whereas cities in developed countries- Stockholm (Sweden) and Dunedin (New Zealand) have 16% and 36% shares of private gardens in urban areas, respectively (Goddard, Dougill, & Benton, 2010). Campinas in Brazil delineated continuous linear park or greenways in a regional plan which has been implemented with local stakeholders including neighborhood association, firms, local high schools and public institutions for funding, maintenance and monitoring (Frischenbruder & Pellegrino, 2006). Collective management of urban commons such as parks or community gardens can promote environmental stewardship and diversified learning streams (Lovell & Taylor, 2013). Restoration and protection of nature brings direct economic benefits in terms of increasing property values through improved aesthetics (McCarthy, 2012; Rahman *et al.*, 2015b). According to Francis and Lorimer (2011), green facades have long been used for aesthetic or horticultural purposes. There are many examples where NGOs and government promote conservation of biodiversity with green spaces (Goddard, Dougill, & Benton, 2010). Stuttgart (Germany) banned building in the hills around the city and prevented construction projects likely to obstruct night-time air ventilation (Kazmierczak & Carter, 2010). Berlin (Germany) promoted green courtyards and green roofs with public subsidies and Basel (Switzerland) successfully implemented regulations for green roofs (Kazmierczak & Carter, 2010).

Blue space management is more challenging. Building grey infrastructure (e.g. dikes, reservoirs, dams, sea walls) can influence natural systems and related ecosystem services (Betancourth, 2011). In Seoul, South Korea, rain water harvest tanks were installed in housing complexes and schools of which 36% were constructed only for storm water management (Maksimović, Kurian, & Ardakanian, 2015). Use of a constructed wetland for detoxification of industrial wastewater reduced water scarcity and pollution in Binzhou City, China (Wang, Yao, & Ju, 2008). Preservation of natural wetlands in east Kolkata, India helped in resource recovery based on combined aquaculture and agriculture practices which supported more than 20,000 low-income families by creating food provisions- fish and vegetables (Bhattacharya *et al.*, 2012). In Brisbane, Australia, rain water harvesting reduced potable water usage by more than 80% meeting 70-80% of household water demand (Mitchell, 2006). Green roofs, planted trees, open storm-water systems and installed bat and bird boxes in Augustenborg, Malmö, Sweden increased biodiversity by 50% (Kazmierczak & Carter, 2010). Implementation of green adaptation strategies for managing urban blue spaces requires extensive planning and government involvement. Melbourne Water (managed by the Victorian state government, Australia) created a green-field residential area (Maksimović, Kurian, & Ardakanian, 2015). Philadelphia Water Department developed a green adaptation plan in collaboration with the private sector (*ibid*, 2015). Most cases cited above reveal participatory approaches as a key factors in successful implementation. Community-managed watershed restoration activities (including preparing local residents for management and local science-management partnership) in Santa Fe, USA proceeded with public grants (McCarthy, 2012). Similarly, in Augustenborg, Sweden, leadership, external collaboration, and empowerment of the local community resulted in retrofitting sustainable drainage systems in an urban regeneration area (Kazmierczak & Carter, 2010).

Often, green adaptation strategies are implemented combining green and blue spaces. Examples include water-sensitive urban design in Lynbrook, Melbourne, Australia; sustainable urban drainage systems in Augustenborg, Malmö, Sweden; greenbelt and bluebelt in Dongtan and Shanghai, China. Managing urban green and blue spaces with green adaptation contributes to natural systems as well as to socio-economic systems. Benefits include reduced energy demand, reduction in extreme heat events, availability of food, promotion of social activities, provision of psychological and health benefits. Furthermore, economic benefits accrue from increased land values, reduced costs of, for example, drainage construction and freely available food (Kazmierczak & Carter, 2010; Younos, 2011). Well-managed ecosystems sometimes become objects of pride for local residents and raise awareness of the benefits of green adaptation (Frischenbruder & Pellegrino, 2006).

Green adaptation strategies, as reviewed above, are mostly implemented in the developed country contexts. They are in planning phases in many countries (Kazmierczak & Carter, 2010) including Bangladesh. However, not all strategies are implementable everywhere. Geographic location and climatic conditions of the area, social acceptance, and economic feasibility of the strategies are thus important considerations.

4.4 CITIZENS' PREFERENCES OF GREEN ADAPTATIONS IN DHAKA

4.4.1 Social Acceptance of Green Adaptations

The respondents revealed their preferred green adaptation strategies/green adaptations that they considered to be implementable with individual (Figure 4.1-A) and collective (Figure 4.1-B) efforts and stated willingness to pay for the preferred strategies (Table 4.3).

Most of the respondents (85%) preferred rooftop garden/agriculture as the most implementable adaptation strategy by individuals, followed by green roof (22%), green façade/wall (14%), and rainwater harvest tank (14%). Ward 6 had the greatest number of respondents preferring rooftop garden/agriculture (95%), green roof (25%), and green façade/wall (17%). About 22% respondents in Ward 7 preferred rain water harvest tank: the highest of all wards surveyed. A total of 10% respondents preferred none of the nominated strategies. Those who did not believe green adaptations to be implementable were mostly from Ward 8 (22%).

Almost all the green adaptation strategies presented were preferred by respondents for implementation with collective actions. Greenbelt development (tree plantation around neighborhoods) was preferred by about 60% of the respondents surveyed across all wards followed by existing khal (canal)/lake management (48%), and community garden development (40%). Artificial wetlands and fountains were the least preferred strategies. In most cases, Ward 6 had the highest percentages of the respondents' preferences. About 10% of the respondents considered that no green adaptation strategies were implementable even with collective efforts.

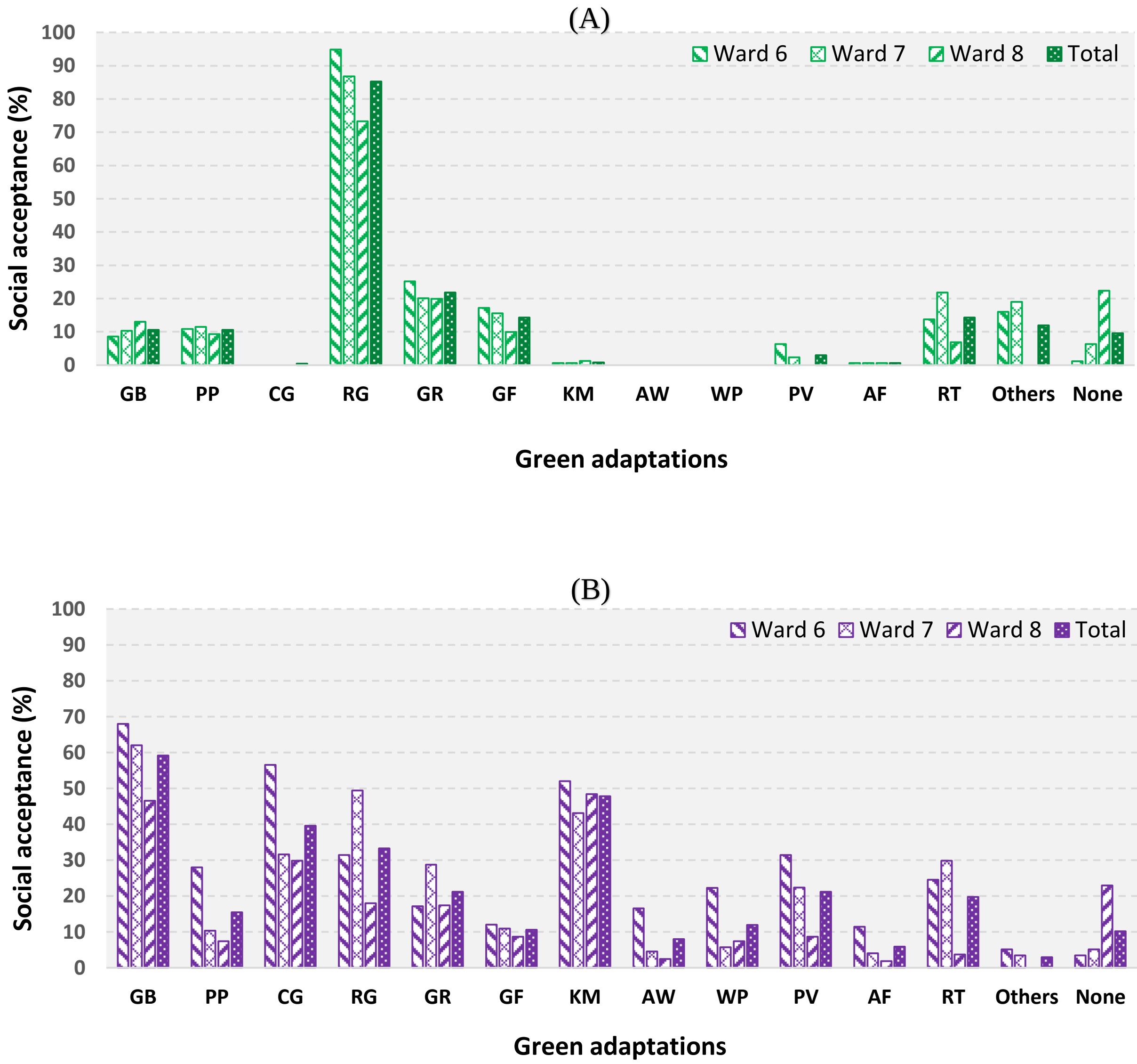


Figure 4.1. Social acceptances (%) of green adaptations implementable with individual effort (A) and collective effort (B). Here, GB- Green belt, PP- Pocket park, CG- Community garden, RG- Rooftop garden/agriculture, GR- Green roof, GF- Green façade/wall, KM- Existing khal/lake management, AW- Artificial wetland, WP- Water retention pond, PV- Porous pavement, AF- Artificial fountain and RT- Rainwater harvest tank.

About 35% of the households surveyed had rooftop gardens of which almost 70% belonged to the owners of houses. House front and house peripheral gardens were also identified (in about

5% of the households). Many respondents had plants in balconies. Image 4.1 shows images of rooftop/balcony gardens in the study area. Fruit and flower gardens were identified in 32% and 29% of cases, respectively. Mixed gardens (seasonal fruits, vegetables and flower/ornamental plants) were found in 36% of houses. Common fruits grown in rooftop gardens included aam/mango (*Mangifera indica*), pepe/papaya (*Carica papaya*), lebu/lime (*Citrus aurantiifolia*), dalim/pomegranate (*Punica granatum*), peyara/guava (*Psidium guajava*), and jamrul/java apple (*Syzygium samarangense*). Vegetables included leafy vegetables, green chili, tomato and gourds of different kinds. The gardens were mostly maintained by the occupants who also consumed the fruit or vegetable products. Respondents considered that the gardens increased the aesthetic appeal of their houses.

Source: Photography by the author, 2016.

Image 4.1. Images of rooftop/balcony gardens in the study area. (A) A flower garden (front) and a fruit garden (back); (B) Fruits harvested from a roof garden; (C) Reclining vegetables in a balcony.

In general, respondents were selective in willingness to pay for their preferred green adaptation strategy (Table 4.3). Of the surveyed respondents, 76% were willing to pay for rooftop garden/agriculture with a mean payment of BDT 320 per month. Twenty-nine per cent of respondents were willing to pay an average of BDT 109 and BDT 237 per month for greenbelt and existing khal/lake management, respectively. Relatively few respondents were willing to pay for artificial wetlands, artificial fountains, water retention ponds, green façade/walls, porous pavements, pocket parks or rainwater harvest tanks.

Table 4.3 Summary statistics of respondents' willingness to pay (WTP) for green adaptations for ecosystem services management.

Green Adaptations (GA)	**Respondents WTP for GA (as % of total sample size, n =510)**	**WTP (BDT per month)**	
		Mean	Median
Green belt	29	109	69
Pocket park	6	80	64
Community garden	22	116	89
Rooftop garden/agriculture	76	320	143
Green roof	20	366	105
Green façade/wall	4	104	75
Existing canal/lake management	29	237	72
Artificial wetland	0	55	55
Water retention pond	1	55	50
Porous pavements	4	62	20
Artificial fountains	0	0	0
Rain water harvest tank	9	107	94

In case of individually implementable green adaptations, rooftop garden/agriculture (0.29) and green roof (0.28) had moderately strong and green façade/wall (0.22) had moderate association with household income. Rooftop garden (0.23) and rainwater harvest tank (0.21) were moderately associated with ownership of holding and number of years living in the holding, respectively. The following associations were found to be interesting for collectively implementable green adaptations:

- Very strong association: Green roof and household income (0.39);
- Moderately strong association: Pocket park and household income (0.28), green façade and household income (0.27), green roof and number of years living in the holding (0.25);
- Moderate association: Green belt (0.23), community garden (0.23) and rooftop garden (0.23) with household income, community garden (0.22) and rainwater harvest tank (0.20) with number of years living in the holding;
- In most cases, association between the dependent and independent variables were found to be weak (0.15 to 0.20), very weak (0.00 to 0.15), or none.

Table A.4.10 (Appendix IV) presents multiple linear regression model analysis determining the predictors of the respondents' preferences for any green adaptations. Most of the independent variables were not significant predictors of citizens' preferences of green adaptations at 5% level of significance. Changes in the significant predictors' categories (see Sub-section 4.2.3 for details) changed the preferences by -0.110 to 0.068 units and -0.137 to 0.154 units for green adaptations implementable with individual and collective efforts respectively. Thus, it is clear from this analysis that the independent variables had little influence on the respondents' preferences of green adaptations.

Box 4.1

The respondents' preferences of green adaptations with individual effort

Green roof
The respondents having household incomes of BDT 10,000-20,000/month (OR 4.54) and BDT 20,000-30,000/month (OR 2.19) had higher likelihoods to prefer green roofs compared to those having household income more than BDT 50,000/month. In addition, the respondents living in their holdings for 1-5 years were less likely (OR 0.43) to prefer green roofs than those living in the holding for more than 10 years.

Green façade/wall
The likelihood for the male respondents to prefer green façades/walls was higher (OR 2.15) than the female respondents.

Rooftop garden
The respondents aged 35-45 years had lower odds (OR 0.33) than those aged more than 45 years for preferring rooftop gardens. As regards household income, the odds of preference for rooftop garden were 0.15 and 0.17 times lower respectively for the respondents having household incomes of BDT 20,000-30,000/month and BDT 30,000-40,000/month compared to those having household income more than BDT 50,000/month.

Table A.4.11 (Appendix IV) presents statistically significant categories of the predictors, i.e., independent variables of green adaptations preference with individual and collective efforts using binary logistic regression model analysis (see Sub-section 4.2.3 for details). Corresponding odds ratio (OR) and the reference categories are available in there. From this Table it is understandable that at 5% level of significance, most of the categories of the independent variables played insignificant roles in the respondents' preferences of green adaptations. Some interesting features of the respondents' preferences of green adaptations resulted from the binary logistic regression model analysis are presented in Box 4.1 (individual effort) and Box 4.2 (collective effort).

Box 4.2

The respondents' preferences of green adaptations with collective effort

Greenbelt (tree plantation around neighborhood)
The respondents having household incomes of BDT 20,000-30,000/month (OR 0.24), BDT 30,000-40,000/month (OR 0.33), and BDT 40,000-50,000/month (OR 0.48) were somewhat less likely to prefer greenbelt than for those having household income more than BDT 50,000/month.

Existing canal/lake management
The odds of preference for existing canal/lake management was 0.45 times lower for the respondents aged between 25 to 35 years than for those aged more than 45 years, if all other variables remain the same.

Community garden
The respondents living in the holding for less than one year had higher likelihood (OR 3.29) of preferring community gardens compared to the respondents living in the holdings for more than 10 years. Interestingly, the owners of holdings had less preference (OR 0.38) than the leaseholders.

4.4.2 Economic Feasibility of Green Adaptations

In-depth interviews showed that rooftop gardening was the most affordable green adaptation strategy for individuals in Dhaka (Figure 4.2). Almost all the nominated strategies were considered affordable with collective efforts: pocket park (100%), existing khal/lake management (100%), green roof (92%), rainwater harvest tank (92%), green façade/wall (92%), rooftop garden (88%), porous pavement (84%), and community garden (80%). Green roof, green façade/wall, and community gardens were found to be not culturally appreciated in Dhaka. Notionally, green roof and façades were considered to detrimentally affect holdings. Community gardens and water retention pond necessitate common open spaces. There were provisions for open spaces/parks/playgrounds/water retention areas in many residential areas but most were not functional. In a densely-populated city such as Dhaka with relatively high land prices, it is difficult to arrange common space without government intervention. Thus, greenbelt development, artificial wetlands, and artificial fountain construction entail higher government involvement as they require extensive planning, funding and land.

The interviewees revealed concerns regarding implementation of green adaptation strategies even if affordable. They anticipated that citizens would willingly adopt such strategies if the benefits were visible and if the government facilitated their implementation. Costs of implementation would vary depending on location, size, land, labor, capital and technology requirements. Not all green adaptations were considered to be economically viable for citizens from every income groups.

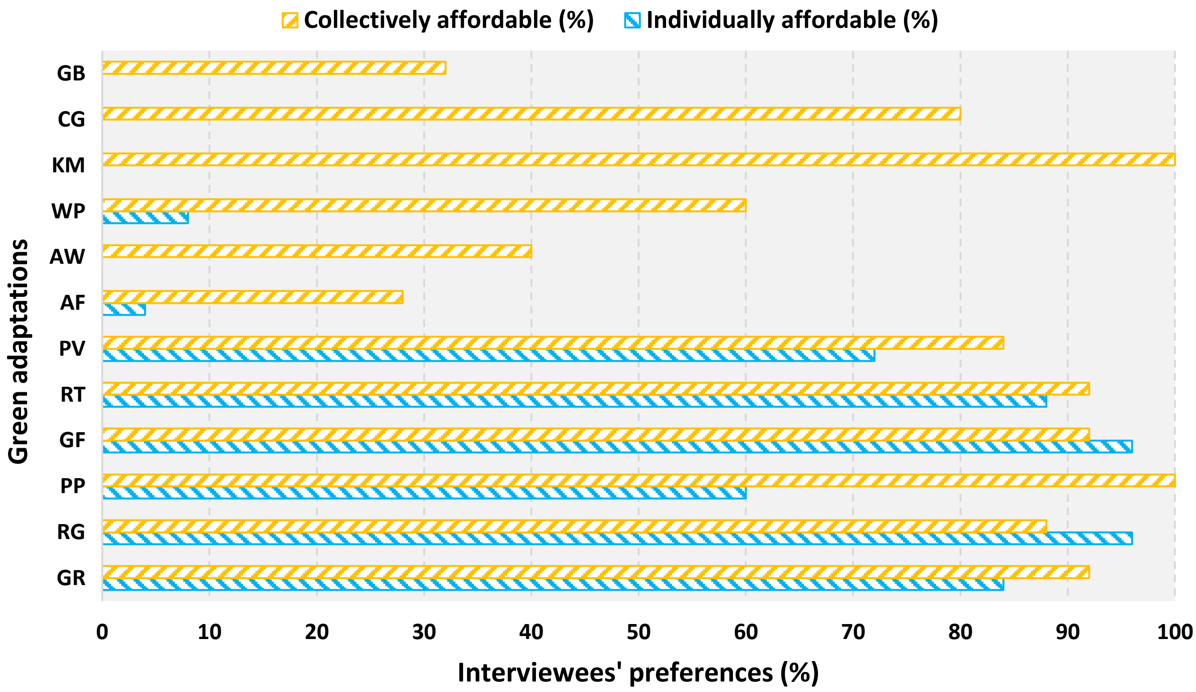


Figure 4.2 Interviewees preferences (%) of green adaptations economically feasible to implement with individual and collective efforts. Here, GB- Green belt, CG- Community garden, KM- Existing khal/lake management, WP- Water retention pond, AW- Artificial wetland, AF- Artificial fountain, PV- Porous pavement, RT- Rainwater harvest tank, GF- Green façade/wall, PP- Pocket park, RG- Rooftop garden/agriculture and GR- Green roof.

4.4.3 Social Acceptance and Economic Feasibility: A Comparison

Table 4.4 compares citizens' preferences of green adaptation strategies for managing Dhaka's urban greens and blues and associated ecosystem services with respect to social acceptance and economic feasibility considering individual and collective efforts for implementation.

Rooftop garden/agriculture showed very high social acceptance for implementation by individuals (Table 4.4). This green adaptation was also considered highly economically feasible/affordable for an individual. Most other nominated strategies had low social acceptance. Green roof, green façades/wall, and rainwater harvest tank were all considered affordable for individuals but had low to moderate social acceptance.

Table 4.4. Social acceptance versus economic feasibility of green adaptations in Dhaka with individual and collective implementation efforts.

	Green adaptations	**Social acceptance**	**Economic feasibility**
Individual effort	Green roof	+ +	+ + + + +
	Rooftop garden/agriculture	+ + + + +	+ + + + +
	Pocket park	+	+ + +
	Green façade/wall	+	+ + + + +
	Rainwater harvest tank	+	+ + + + +
	Porous pavement	+	+ + + +
	Artificial fountain	+	+
	Artificial wetland	-	-
	Water retention pond	-	+
	Existing khal/lake management	+	-
	Community garden	-	-
	Green belt	+	-
Collective effort	Green roof	+	+ + + + +
	Rooftop garden/agriculture	+ +	+ + + + +
	Pocket park	+	+ + + + +
	Green façade/wall	+	+ + + + +
	Rainwater harvest tank	+	+ + + + +
	Porous pavement	+ +	+ + + + +
	Artificial fountain	+	+ +
	Artificial wetland	+	+ +
	Water retention pond	+	+ + +
	Existing khal/lake management	+ + +	+ + + + +
	Community garden	+ +	+ + + + +
	Green belt	+ + +	+ +

Note: Very high preference + + + + +, High preference + + + +, Moderate preference + + +, Low to moderate preference + +, Low preference + and No preference -. Preference scores were categorized based on percentages shown in Figures 4.1 and 4.2. See Table A.4.9 (Appendix IV) for scoring category.

Green adaptation strategies facilitated by collective efforts including: greenbelt/tree plantation around neighborhoods and existing khal/lake management were considered to have moderate social acceptance (Table 4.4). Existing khal/lake management was considered to be economically feasible for communal implementation but greenbelt development was assessed as having low to moderate economic feasibility for implementation in Dhaka without large-scale government involvement. Nonetheless, pocket park, green roof, rainwater harvest tank, green façades/wall, porous pavement, and community gardens were found to be very highly feasible for implementation with collective efforts but with relatively low social acceptance.

4.5 CONCLUSIONS AND DISCUSSIONS

I have shown that green adaptation strategies, prominent in many of the world's major cities, are beneficial to ecosystem services. For densely populated cities such as Dhaka, ecosystem services offer important environmental, social, and economic benefits. These include adaptive responses to urban development, e.g., current pressures from demographic and land use changes as well as emerging climate change threats, particularly extreme heat and extreme weather events. Ecosystem services offer benefits including reduced energy demand, increased land values, avoided cost of drainage maintenance, cool and clean environment, higher social interaction, psychological and health benefits (Barth & Döll, 2016; Jim & Chen, 2008; Liu & Li, 2012; Watson *et al.*, 2016).

My surveys of Dhaka households and interviews with experts revealed that rooftop garden/agriculture had very high social acceptance and economic feasibility for implementation as a green adaptation strategy. Vegetation in dense urban settings can mitigate the UHI effect: thermal accumulation exacerbated through hard surface heating and convection. Shading and evapotranspiration from urban trees and other vegetation create an 'oasis effect' lowering ambient temperatures (Zhang *et al.*, 2014). Berry, Livesley, and Aye (2013) showed that trees in urban settings caused up to 9°C reduction in wall surface temperature and up to 1°C reduction in external air temperature. Giridharan *et al.* (2008) demonstrated increasing tree cover (by 25-40%) in dense residential development areas could reduce UHI intensity by a further 0.5°C. Rooftop gardens also provided direct economic benefits such as fruit and vegetable produce: an incentive for residents to further develop gardens (see also Islam, 2002). Rooftop gardening was common in Dhaka particularly among homeowners (rather than lessees). The respondents' preferences for rooftop garden/agriculture were found to have moderately strong association with household income.

The respondents were generally selective when expressing their willingness to pay for green adaptation strategies. Few were willing to pay for artificial wetlands, artificial fountains, water retention ponds, green façade/walls, porous pavements, pocket parks, and rainwater harvest tanks. Possibly, Dhaka residents are not culturally familiar with these adaptation strategies and might be unaware of their benefits. Many respondents supported collective action, particularly from government, for the construction and maintenance of communal adaptation measures, e.g., parks, community gardens, greenbelts and water features. Social and economic benefits of green adaptations are expected to outweigh environmental benefits as their contribution in generating non-marketed ecosystem services including microclimate regulation, air pollution control, flood prevention are not generally valued in monetary terms. For Dhaka, a densely populated city with scarce available land, public commitment to green spaces is relatively costly. Behavioral changes through awareness raising campaigns are necessary. Enforcement of laws and strong commitment from the government's end will be beneficial but, so far, this has not been forthcoming.

Blue space adaptations are not as popular as green spaces in considering ecosystem services and their utility in Dhaka. Probably, this is because (as the respondents in my research reported) blue spaces (water features) are mostly polluted, malodourous, and harbor mosquitoes and other pests. Yet blue spaces offer many benefits through ecosystem services. Bonan (2000) studied microclimate variability at neighborhood level in Colorado, USA during different seasons and found that irrigated areas were cooler than non-irrigated areas. Kim *et al.* (2008) found restoration of the Cheonggye stream (5.8 Km long), an inner-city stream in Seoul, Korea contributed to a 0.4°C average local surface temperature reduction (with a maximum 0.9°C) during daytime.

My analysis was undertaken on a relatively small spatial scale and relatively low sample size due to time and resource constraints. Differences in preferences were shown by the respondents from the three wards surveyed. I adopted a qualitative approach for economic feasibility analysis of green adaptations. A quantitative approach including in-depth benefit-cost analysis could provide better input to the respondents for decision making and provide an empirical framework to influence government policy for green adaptation strategies in response to climate change. Yet I have shown affordable and practical adaptation strategies for a city struggling to adapt to urban development and climate change.

For developing countries, citizens forgo green adaptations for urban development: the necessities of housing are considered more important than green adaptation strategies. Most successful green adaptation implementation followed participatory approaches such as public engagement and collaborative activities (see Frischenbruder & Pellegrino, 2006; Kazmierczak & Carter, 2010; Lovell & Taylor, 2013; Maksimović, Kurian, & Ardakanian, 2015; McCarthy, 2012). The densely-populated city of Dhaka (like many other mega cities in Asia) presents challenges associated with the affordability and practicality of maintaining green adaptation strategies and related ecosystem services given widespread poverty and the relatively high price of land (for green and/or blue spaces). Even so, for a climate-exposed city green adaptations may be not only desirable but essential to avoid catastrophic impact of extreme weather events exacerbated by built environment. My review and empirical analyses suggest that successful green adaptation will require public participation at all stages. Social acceptance and economic feasibility analyses for green adaptation strategy implementation might be useful in decision making. Green adaptations will potentially solve ‘brown’ issues (Williams, 1997) related to ecosystems (air pollution, waste discharge, drainage) and make cities more resilient to pressures from demographic change and from climate change. It will increase the attractiveness of landscape with associated benefits. An environmentally sustainable city ensures citizens quality of life and social justice (Savage, 2006). My study is a first step, which could serve as a basis for in-depth analysis for sustainable urban environmental management in Dhaka. Such continuing research would be valuable for other cities in Bangladesh and in other developing countries similarly exposed to climate change and urban population growth.

CHAPTER 5: SYNTHESIS

People increasingly tend to reside in urban areas. This is a global phenomenon. Unplanned and rapid urbanization often directly affect ecosystems and ecosystem services. Urban populations are susceptible to the acute impacts induced by loss of green (vegetation) and blue (waterbody) spaces/ecosystems and diminished ecosystem services, resilience, and quality. This is particularly the case for Dhaka, the capital of Bangladesh: among the most densely populated and climate exposed cities and countries on Earth. Yet, Dhaka's urban ecosystem and ecosystem services have received very little research attention.

My interdisciplinary study addressed five key concepts: urban ecosystems, ecosystem services, valuation, ecosystem governance, and green adaptation. The fundamental questions that I posed for examining urban ecosystems and ecosystem services in Dhaka city were 'why', 'how', and 'what': *why* are urban ecosystems/ecosystems important?; how are the urban ecosystems/ecosystems governed?; and *what* can citizens do to improve the management of urban ecosystems/ecosystems. My study is the first interdisciplinary assessment of urban ecosystem services for the highly built-up city Dhaka with potential consequences for the entire South Asia region.

My study area was the Mirpur-Pallabi Zone of Dhaka North City Corporation with an area of 21.32 km^2 and one million residents. I undertook field-level observations, surveys, in-depth interviews with experts, and collected secondary data from the literature. I undertook a mixed methods approach to my research where I incorporated both quantitative and qualitative approaches and I delivered an overall composite evaluation. More particularly, I applied satellite image analysis and GIS mapping, ecosystem services analysis, direct and indirect market valuation methods, and policy analysis.

Urban ecosystems and ecosystem services are less studied globally. No specific sets of ecosystems/ecosystem services are applicable for all urban areas. I developed a typology of urban ecosystems for my study area: perhaps representative of many large cities in Asia. The typology included khal, lake, jheel, pond, wetland, cultivated land, park, rooftop garden, playground/field, open space/vacant plot, roadside trees, and others (graveyards and mixed ecosystems). Wetland ecosystems were the most frequent followed by open spaces/vacant plots and parks. Cultivated land was the least available ecosystem. I proposed graveyards to be considered as a distinct urban ecosystem. Roadside trees were seen throughout the study area; however, no official statistics of the number and species type of roadside trees were available.

I counted and measured tree diameters in three major roads. About 78% of these trees were mature trees and 20% were poles. I analyzed current states of the ecosystems in detail and categorized the ecosystem services they provided under four categories: provisioning (fruits, vegetables, fish, fodder), regulating (carbon sequestration, particulate matter removal, natural drainage, noise abatement), cultural (recreation, walk/exercise, inspirations for art and culture, religious use), and habitat (refugia for resident and migratory birds). I then evaluated and compared the economic importance of selected ecosystem services. My study revealed the average gross value of the ecosystem services to be BDT 3,355 million (USD 43 million) in 2016. Contribution of provisioning, regulating, and cultural ecosystem services accounted for 97%, 0.16% and 2.77%, respectively. I excluded habitat ecosystem services from the calculation to avoid double counting problems. In reality, ecosystem services also add value by reducing energy demand through cooling effects, avoiding flood damage, and improving drainage systems. Inclusion of health benefits and habitat services could also generate higher values. My valuation approach did not consider cost-benefit analysis or contribution of the ecosystems to national income; nevertheless, my findings clearly demonstrated significant socio-economic consequences and policy implications.

Ecosystem services evidently improve human wellbeing and so how they are governed is an important concern. I assessed ecosystem governance mechanism in practice in Bangladesh, or more specifically urban areas and Dhaka city, under three governance regimes: government, national and international non-governmental (NGOs) and private sector (donor, civil society, local community) organizations. I emphasized the involvement of local communities in governing ecosystems/ecosystem services. Agricultural land, rivers, wetlands, and mangrove forests in rural and coastal areas are governance priorities in Bangladesh. Urban ecosystems receive much less attention in all three governance regimes. The government emphasizes regulating (riverbank erosion, soil salinity, and pollutions, natural drainage, flood risk and damage) and habitat (wildlife habitat/sanctuary and biodiversity protection) ecosystem services. In contrast, the NGOs and private sector organizations emphasized regulating (afforestation, reforestation, river flow regulation) and provisioning (safe water supply, agriculture/food production) ecosystem services. Initiatives for new ecosystems/ecosystem services generation (e.g., establishing community gardens, harvesting fruits and vegetables from rooftop gardens, utilizing waterbodies for recreation- fishing/boating, and planting tree species on roadsides that are more efficient in capturing particulate matters) were given less importance relative to ecosystem conservation and restoration. Adaptation to climate change impacts through increasing resilience was highly prioritized under the three regimes. My analysis revealed that the funding priority of the donor agencies and focus of the global environmental agendas influenced actions of the organizations evaluated. The NGOs and private sector organizations were actively involved in ecosystem governance as field actors and action coordinators, knowledge transmitters, and partners in collaborative governance, and environment sentinels. They worked closely with each other and with the government. The government and other organizations encouraged citizen participation in ecosystem governance. However, I found them to be less empowered when it came to implementation of legal guidelines or project activities.

Citizens can actively contribute to ecosystem management by adopting green strategies (individually and/or collectively) that require less technology, capital, and minimum government support. I reviewed green adaptation strategies already in practice worldwide at city scales for managing urban green and blue spaces, and their associated ecosystem services. Such strategies include parks, gardens, green roof, rainwater harvest, green façades/wall, and porous pavement. Green adaptation strategies are beneficial to ecosystem services that offer important environmental, social, and economic benefits. I assessed social acceptance and economic feasibility of these strategies for implementation in Dhaka. Rooftop garden/agriculture had very high social acceptance (85%) and economic feasibility and was commonly practiced in Dhaka particularly among house owners. Pocket park, green roof, rainwater harvest, green façades/wall, porous pavement and community garden were all considered to be highly feasible for implementation with collective efforts but had lower social acceptance.

In conclusion, I produced an inventory of current goods/services (i.e., ecosystem services) generated by green and blue spaces that support life systems in a large Asian city. I quantified and valued marketed and non-marketed ecosystem services in monetary terms. I assessed ecosystem governance practice by the government of Bangladesh, NGOs, and private sector organizations. More importantly, I identified social acceptance and economic feasibility of a set of green strategies for managing ecosystem services in an urban setting. My study is a necessary contribution to the local, regional, and the broader scientific communities. The findings of my research can be used to inform decision makers on the necessity of mainstreaming a policy focus on urban ecosystem and ecosystem services. Challenges in urban development, not just in Bangladesh but more generally throughout the region will require effective (decentralized and collaborative) stewardship of urban ecosystems. This essential policy and operational response through green adaptation will make cities more resilient to pressures from demographic change and climate change. I hope that my research findings will provoke a response from citizens regarding their responsibilities and inspire them for social actions towards sustainable urban development in cities in Bangladesh and in other developing countries similarly exposed to climate change and urban population growth.

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APPENDIX I

Additional materials for Chapter 1

Table A.2.1. Specifications of the multi-function environment meter.

Function	Range	Resolution	Accuracy (%rdg+digits)
Temperature	-20ºC~200ºC	0.1ºC	±(3.0%+2ºC)
	-20ºC~750ºC	1ºC	±(3.0%+2ºC) ≤150ºC; ±3.0% ≥150ºC
Humidity	35%~95%RH	0.1%RH	±5.0%RH at 25ºC
Sound Level	35dB~100dB	0.1dB	±3.5dB at 94dB sound level, 1KHz sine wave

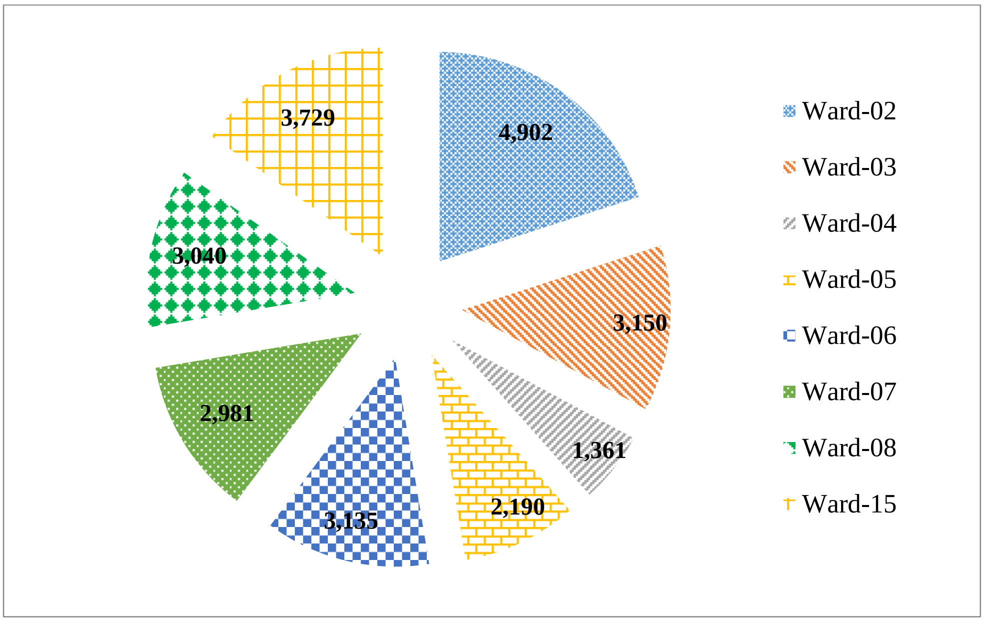
Table A.1.2. Ecosystem Services (ES) Valuation Approaches and Methods.

Valuation Approaches/Methods		Description	Strengths	Weaknesses
Direct Market Valuation Approaches	**Market price based approach**	▪ Prevailing market prices for goods and services are considered for valuation.	▪ Applicable for direct (provisioning ES- food) and indirect (cultural ES- recreation) use values. ▪ Usage of data from real markets reflecting actual preferences/ costs to individuals. ▪ Relatively easier to collect prices, quantities, costs etc. data.	▪ Data may not be available if markets do not exist for some ES. ▪ Prices may not be a good reflection of preferences/ costs if markets are distorted due to, for instance, subsidy. Thus the estimated ES values will be biased. ▪ Seasonal variations and other effects on prices are necessary to consider.
	Cost based approaches ▪ *Avoided cost method* (costs that would have been incurred in the absence of ES). ▪ *Replacement cost method* (costs incurred by replacing ES with artificial substitutes). ▪ *Mitigation/ restoration cost method* (costs incurred for mitigating the effects caused by the loss of ES/ for restoring ES).	▪ Costs incurred for artificially recreating ES are considered for valuation.	▪ Applicable for direct and indirect (regulating ES- flood prevention) use values. ▪ Easier to measure costs of producing benefits than the benefits themselves when ES markets do not exist. ▪ Less data intensive.	▪ Costs may not accurately measure true benefits. ▪ Perfect substitute for replacement may not be available. ▪ Uncertainties need to be dealt with caution.
	Production function/ Factor income based approach	▪ Contribution of ES to deliver economic output i.e. value of a non-marketed ES in terms of changes in economic activity is considered.	▪ Applicable for indirect use values. ▪ Utilization of scientific knowledge to determine causal relationship between ES and economic output. ▪ Widely used for estimating impacts on economic activities (farming, fishing) due to ES destruction.	▪ Adequate data may not be available. ▪ The likelihood of double counting problem may increase due to the interdependencies and interconnectivity of ES.

Valuation Approaches/Methods		Description	Strengths	Weaknesses
Revealed Preference Approaches	**Travel cost method**	▪ Willingness to pay for ES is derived at a specific location by using monetary and time costs that people incur to visit that location.	▪ Applicable for direct use values. ▪ Commonly used to estimate values of recreational sites (public parks). ▪ Quality and quantity of the recreational site can be deduced from estimation of the demand function for visiting the site.	▪ Data intensive method, expensive and time consuming. ▪ Assumptions about consumer behavior are restrictive. ▪ Market imperfection and policy failures may distort the estimated monetary value of ES.
	Hedonic pricing	▪ Information about the implicit demand for an environmental attribute of marketed commodities is utilized (proximity of a property to forest).	▪ Applicable for direct and indirect use values. ▪ The value of a change in the non-marketed environmental benefit generated by ES (forest) can be estimated by analyzing demand function for an economic good (property).	▪ Same as Travel cost method.
Stated Preference Approaches	**Contingent valuation method**	▪ A hypothetical market is constructed to elicit respondents' willingness to pay for increasing or enhancing the provision of an ES or willingness to accept for its degradation or loss.	▪ Applicable for use and non-use values. ▪ A market and demand for ES is stimulated through surveys on hypothetical changes in the provision of ES. ▪ Used when no surrogate market exists from which ES value can be inferred. ▪ Provides an estimate of total economic value of an ecosystem. ▪ Sometimes reveals stakeholders conflict.	▪ Questionnaire design, survey implementation and interviewing technique may generate biases. ▪ Hypothetical nature of the market restricts the validity of estimation. ▪ Hypothetical answers may not reflect their behavior if respondents were faced with costs in real life. ▪ Willingness to pay and accept may differ for identical ES due to faults in questionnaire, interviewing

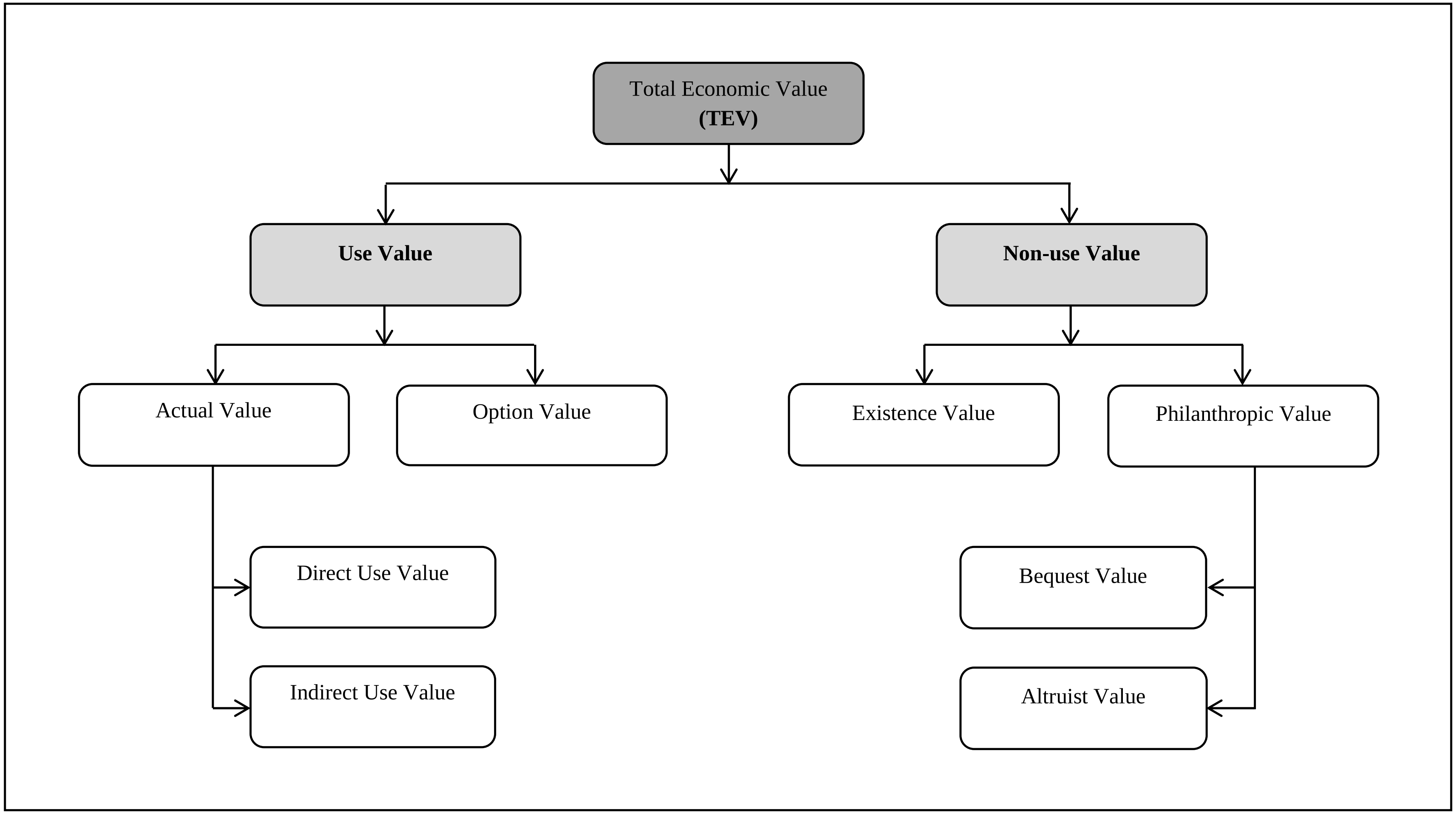
Valuation Approaches/Methods		Description	Strengths	Weaknesses
			▪ Biases can be taken care of by providing the respondents with a clear description and objective of the concerned issue in understandable language while asking for their preferences.	technique or strategic behavior of respondents. ▪ Double counting bias arises due to embedding problem i.e. one ES value might be embedded in another ES but valued twice for their different usage.
	Choice modelling	▪ Decision processes of people are analyzed by giving them a choice between several alternatives with shared attributes of the concerned ES.	▪ Applicable for use and non-use values. ▪ More capable of providing value estimates for changes in specific feature of an ecosystem.	▪ Same as Contingent valuation method.
	Group valuation	▪ Valuation of ES results from an open public deliberation rather than aggregating separately measured individual preferences. Its valuation process is similar to Contingent valuation method.	▪ Same as Contingent valuation method. ▪ An increasingly used method of valuation. ▪ Consensus can be reached regarding the value of an ES.	▪ Same as Contingent valuation method.
Benefit Transfer Approach		▪ Values of ES are taken from existing studies took place in a different time or focused on a different region.	▪ Applicable for use and non-use values. ▪ More useful in cases of time, human resources or budget constraints. ▪ Provides a reasonable estimation of ES values based on which policy decisions can be made.	▪ Validity and reliability of values may be questioned. ▪ Welfare estimates can be highly biased because of careless benefit transfer.

Source: Adapted from de Groot *et al.* (2006); DEFRA (2007); Farber, Costanza, and Wilson (2002); MA (2003); Richardson *et al.* (2015); TEEB (2010b)



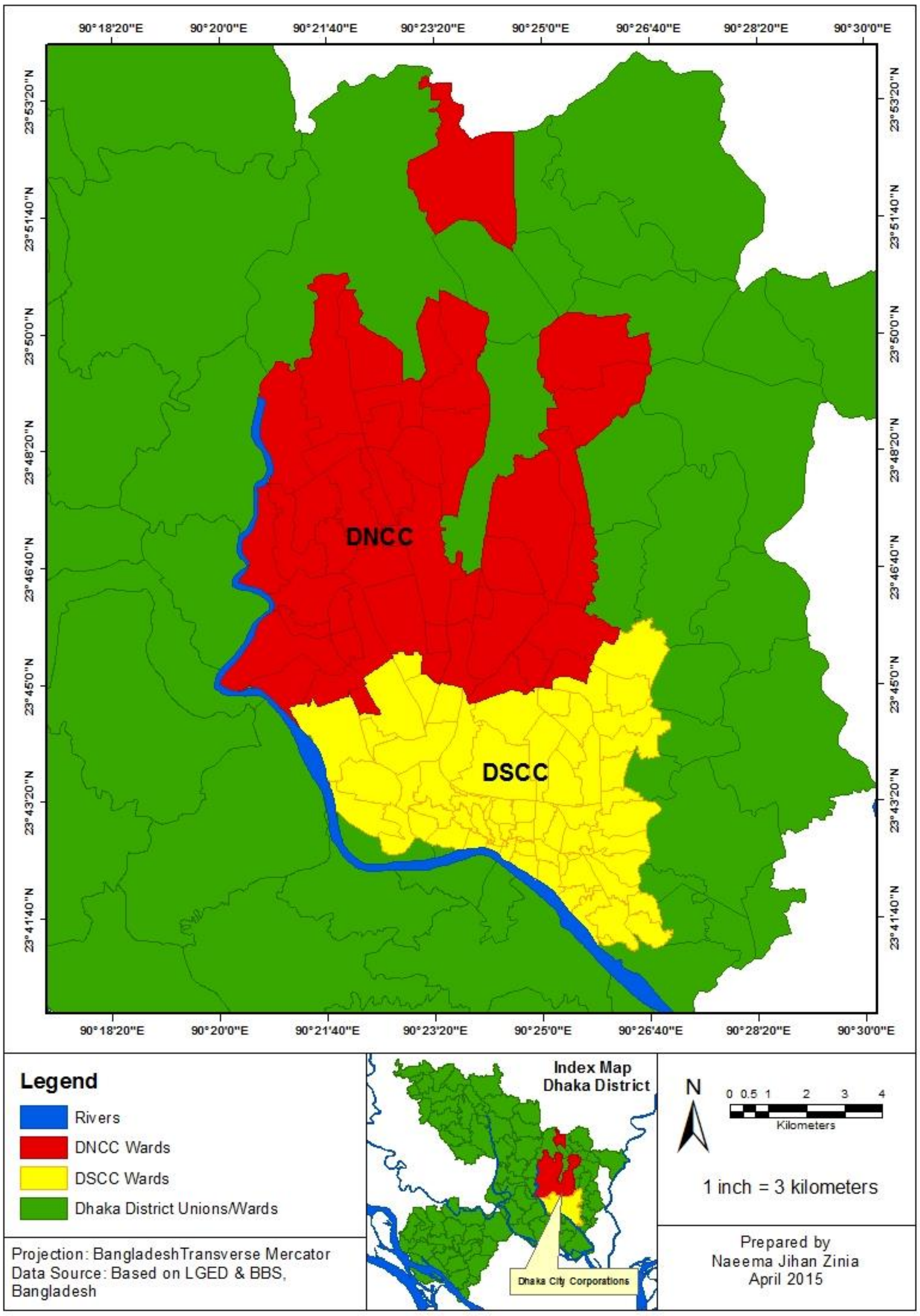
Source: Based on DNCC (2017)

Figure A.1.1. Number of Households by Wards in Zone 2, DNCC.



Source: Adapted from de Groot *et al.* (2006); DEFRA (2007); MA (2003); TEEB (2010b).

Figure A.1.2. A Typology of Values in Total Economic Value (TEV) Framework.



Map A.1.1. City Corporations in Dhaka city.

Image A.1.1. Location of the roads considered for roadside tree count and measurement in Zone 2, DNCC. Here, (1) Zoo road, (2) Mirpur road, and (3) Begum Rokeya Saroni.

APPENDIX II

Additional materials for Chapter 2

Table A.2.1. List of Ecosystem Services and Ecosystem Sub-services.

Sl No.	Ecosystem Services (ES)	Ecosystem Sub-services
Provisioning Services		
1	Food provision	Fish
		Meat
		Fruit
		Crop
		Other food
2	Water supply	Drinking water
		Industrial water
		Irrigation water
3	Provisioning of raw materials provision	Fibres
		Timber
		Fuel wood and charcoal
		Fodder
		Fertilizers
		Other raw materials
		Sand, rock, gravel, coral etc.
		Biomass fuels
4	Provisioning of genetic resources	Plant genetic resources
		Animal genetic resources
5	Provisioning of medical resources	Biochemical
		Models
		Test-organisms
		Bioprospecting
6	Provisioning of ornamental resources	Decorative Plants
		Fashion
		Decorations / Handicrafts
Regulating Services		
7	Influence on air quality	Capturing fine dust
		UV-protection
8	Climate regulation	C-sequestration
		Microclimate regulation
		Gas regulation
9	Moderation of extreme events	Storm protection
		Flood prevention
		Fire Prevention
10	Regulation of water flows	Drainage
		River discharge

		Natural irrigation
11	Waste treatment and water purification	Water purification
		Soil detoxification
		Abatement of noise
12	Erosion prevention	Erosion prevention
13	Maintenance of soil fertility	Maintenance of soil structure
		Deposition of nutrients
		Soil formation
		Nutrient cycling
14	Pollination	Pollination of crops
		Pollination of wild plants
15	Biological control	Seed dispersal
		Pest control
		Disease control
Supporting Services		
16	Lifecycle maintenance	Nursery service
		Refugia for migratory and resident species
17	Protection of gene pool (conservation)	Biodiversity protection
Cultural Services		
18	Aesthetic information	Attractive landscapes
19	Opportunities for recreation and tourism	Recreation
		Tourism
		Eco-tourism
		Hunting and fishing
20	Inspiration for culture, art and design	Artistic inspiration
		Cultural use
21	Spiritual experience	Spiritual / Religious use
22	Information for cognitive development (Education and science)	Science / Research
		Education

Source: Adapted from Van der Ploeg, De Groot, and Wang (2010) and de Groot *et al.* (2012)

Table A.2.2. Methods applied for ecosystem services valuation in the study area.

Type of Value	Ecosystem Services	Quantity Data Description	Data Collection Method				Valuation Method
			Review	Observation	Interview	Survey	
Provisioning Ecosystem Services							
DUV	Fruit and vegetable	Fruit and vegetable production			X	X	MP
DUV	Fish (culture fish)	Fish harvest			X		
DUV	Water supply (surface water)	Water use for natural irrigation		X	X		
DUV	Fodder	Fodder collection			X		
Regulating Ecosystem Services							
IUV	Particulate matter (PM) capture	Vegetation area measurement		X	X		ACM
		Average concentration of PM_{10}	X				
		Deposition velocity of PM_{10}	X				
IUV	Carbon sequestration	Tree diameter measurement				X	ACM
		Carbon stock and CO_2 equ conversion	X				
IUV	Drainage	Khal length estimation	X				BTM
		Benefit from avoided damage	X				
Cultural Ecosystem Services							
DUV	Recreation and other cultural services	Recreation			X	X	MP, CVM
		Filming			X		MP
		Fishing			X		
		Sports		X		X	
		Religious use		X	X	X	

Note: MP- Market Price Based Approach, ACM- Avoided Cost Method, BTM- Benefit Transfer Method and CVM- Contingent Valuation Method.

Table A.2.3. Monthly average concentration of pollutant data for Darus-Salam, Mipur (CAMS-3) in the year 2016.

Pollutant	Unit	Summary	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
		Average	212	153	113	44.7	50.5	31.7	19.2	31.6	32.7	44.1	105	169
PM2.5 (24 hr)	μg/m3	Max	249	290	247	83.5	87.1	59	32.1	72.4	71.8	75.2	170	269
		Min	179	33.2	48.2	29.4	18.4	16.9	10.7	11.3	17.5	19	15	85.9
		Average	335	285	270	105	100	71.8	44.3	70.2	62.6	91.7	188	272
		Max	525	448	476	142	161	145	158	186	123	148	298	447
PM10 (24 hr)	μg/m3	Min	152	113	192	78.1	34	44.4	20.7	26.9	35.8	43.8	36.9	163
		Max	0.23	4.64	36.3	3.56	6.98	21.3	7.43	0.02	0.02	0.03	3.48	0.05
		Min	0.02	0.02	0.02	0.02	0.02	0.02	0.02	43	28	81	0.02	0.02

Note: CAMS-2 (Farmgate) data used for PM2.5 February 2016 as CAMS-3 (Darus-Salam) data unavailable and it’s the closest station to CAMS-3.

Source: http://case.doe.gov.bd/index.php?option=com_content&view=article&id=5&Itemid=9

Table A.2.4. Areas (hectare) of the ecosystems in the study area.

Ecosystem Type	Area (ha)
Canal	18.08
Cultivated Land	0.09
Jheel	19.68
Lake	31.25
Open Space/ Vacant plot	147.32
Others	8.53
Park	124.70
Playground/ Field	23.94
Pond	23.84
Wetlands	193.11

Table A.2.5. Monthly concentration of pollutants in Darus-Salam, Mirpur and particles capture by the park in Januray 2016.

Pollutant	Summary	Deposition velocity (cm/sec)	Pollutant concentration (g/cm3)	Pollutant flux (g/cm2/sec)	Tree cover (cm2)	Time period (sec) (24 hr=86400 sec)	Total pollutant flux (g/86400 sec for total area)	Total pollutant flux (kg/86400 sec for total area)	Total pollutant flux (kg/month for total area)	Removal rate (Kg/ha/ month)	Total pollutant flux (Mg/month for total area)
PM10 (24 hr)	Average (g/cm3)	0.64	3.35E-10	2.144E-10	7017259869	86400	129989	130.0	3900	55.6	3.9
	Max (g/cm3)	2	5.25E-10	1.05E-09	7017259869	86400	636606	636.6	19098	272.2	19.1
	Min (g/cm3)	0.5	1.52E-10	7.6E-11	7017259869	86400	46078	46.1	1382	19.7	1.4

Conversions: 1 g/cm3 = 1000000000 ppb; 1 µg/m3 = 0.000000000001 g/cm3; 1 ha = 100000000 cm2; 0.01 ha = 1000000 cm2; 1 ha = 2.47105 acre; 1 kg = 1000 g; 1 Mega gram (Mg) = 1000 kg

Table A.2.6. Particles capture or removal (Mg/month) by park in the study area in 2016.

Pollutant	Summary	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
	Average	2.47	1.78	1.32	0.52	0.59	0.37	0.22	0.37	0.38	0.51	1.22	1.97
PM2.5	Max	9.06	10.55	8.99	3.04	3.17	2.15	1.17	2.63	2.61	2.74	6.18	9.79
	Min	1.63	0.30	0.44	0.27	0.17	0.15	0.10	0.10	0.16	0.17	0.14	0.78
	Average	3.90	3.32	3.14	1.22	1.16	0.84	0.52	0.82	0.73	1.07	2.19	3.17
	Max	19.10	16.30	17.32	5.17	5.86	5.27	5.75	6.77	4.47	5.38	10.84	16.26
PM10	Min	1.38	1.03	1.75	0.71	0.31	0.40	0.19	0.24	0.33	0.40	0.34	1.48

Table A.2.7. Particles capture or removal (Mg/month) by roadside trees in the study area in 2016.

Pollutant	Summary	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
	Average	0.30	0.22	0.16	0.06	0.07	0.05	0.03	0.05	0.05	0.06	0.15	0.24
$PM_{2.5}$	Max	1.11	1.29	1.10	0.37	0.39	0.26	0.14	0.32	0.32	0.34	0.76	1.20
	Min	0.20	0.04	0.05	0.03	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.10
	Average	0.48	0.41	0.39	0.15	0.14	0.10	0.06	0.10	0.09	0.13	0.27	0.39
PM_{10}	Max	2.34	2.00	2.12	0.63	0.72	0.65	0.70	0.83	0.55	0.66	1.33	1.99
	Min	0.17	0.13	0.21	0.09	0.04	0.05	0.02	0.03	0.04	0.05	0.04	0.18

Table A.2.8. Carbon stock and CO2 equ. (Mg/ha) estimation in the park trees in the study area in 2016.

Sub-plot no.	AGB (kg)	Carbon stock (kg/400m2)	AGB (ton)	Carbon stock (ton/400m2)	Carbon stock (kg/ha)	Carbon stock (Mg/ha)	CO^2 equ. (Mg/ha)
1	52237	24552	52.2	24.6	613790	614	2253
2	119670	56245	119.7	56.2	1406119	1406	5160
3	130940	61542	130.9	61.5	1538541	1538	5646
4	63069	29642	63.1	29.6	741056	741	2720
5	93295	43849	93.3	43.8	1096221	1096	4023
6	24237	11391	24.2	11.4	284788	285	1045
7	93861	44115	93.9	44.1	1102872	1103	4047
8	54670	25695	54.7	25.7	642368	642	2357
9	28708	13493	28.7	13.5	337317	337	1238
10	44303	20823	44.3	20.8	520566	521	1910
Sub-plot total	704991	331346	705.0	331.3	8283640	8284	30401
Average	128180	33135	70.5	33.1	828364	828	3040

Table A.2.9. Carbon stock and CO2 equ. (Mg/ha) estimation in roadside trees in the study area in 2016.

Sub-plot no.	AGB (kg)	Carbon stock (kg/900m2)	AGB (ton)	Carbon stock (ton/900m2)	Carbon stock (kg/ha)	Carbon stock (Mg/ha)	CO^2 equ. (Mg/ha)
1	6732	3164	6.7	3.2	35154	35	129
2	16860	7924	16.9	7.9	88045	88	323
3	33665	15823	33.7	15.8	175808	176	645
4	23492	11041	23.5	11.0	122682	123	450
5	1029	484	1.0	0.5	5373	5	20
6	4808	2260	4.8	2.3	25108	251	92
7	2902	1364	2.9	1.4	15156	15	56
8	6867	3228	6.9	3.2	35864	36	132
9	479	225	0.5	0.2	2502	2	9
10	7102	3338	7.1	3.3	37087	37	136
11	19684	9251	19.68	9.25	102794	103	377
12	20841	9795	20.84	9.80	108837	109	399
13	8378	3938	8.38	3.94	43752	44	161
Sub-plot total	152840	71835	152.8	71.8	798163	798	2929
Average	11757	5526	11.8	5.5	61397	61	225

Table A.2.10. Bangladesh Standards for Noise.

Area Category	Standard Values (in dB)	
	Day (6 am- 9 pm)	Night (9 pm- 6 am)
Silent zone	50	40
Residential area	55	45
Mixed area (basically residential and together used for commercial and industrial purposes)	60	50
Commercial	70	60
Industrial	75	70

Note: Silent zones are areas up to a radius of 100 meter around hospitals, educational institutes or special establishments declared or to be declared as such by the government. Use of vehicular horns, other signals and loudspeakers is prohibited in silent zones.

Source: *The Sound Pollution (Control) Rules, 2006* and *The Environment Conservation Rules, 1997.*

Table A.2.11. A 3-day average noise level (in decibels) in a built-up area to park to built-up area loop.

Summary	Built-up area	Park	Built-up area
Mean noise level	67.3	50.1	67.9
Range of noise level	59.5	40.0	59.7
	73.3	63.0	75.9

Table A.2.12. Bangladesh Standards for Inland Surface Water.

Best Practice based Classification	Parameters			
	pH	BOD (mg/L)	DO (mg/L)	Total coliform (number /100)
Source of drinking water for supply only after disinfecting	6.5–8.5	2 or less	6 or above	50 or less
Water usable for recreational activity	6.5 – 8.5	3 or less	5 or more	200 or less
Source of drinking water for supply after conventional treatment	6.5 – 8.5	6 or less	6 or more	5000 or less
Water usable by fisheries	6.5 – 8.5	6 or less	5 or more	-
Water usable by various process and cooling industries	6.5 – 8.5	10 or less	5 or more	5000 or less
Water usable for irrigation	6.5 – 8.5	10 or less	5 or more	1000 or less

Notes: In water used for pisiculture, maximum limit of presence of ammonia as Nitrogen is 1.2 mg/L; Electrical conductivity for irrigation water – 2250 μmhos/cm (at a temperature of 25°C); Sodium less than 26%; boron less than 0.2%.

Source: *The Environment Conservation Rules, 1997.*

Table A.2.13. Value of Statistical Life (or the Value of Statistical Death Avoided) for Dhaka city.

Pollutant	**PM10**	**PM10**	**PM10**
Location	Dhaka city	Dhaka city	Dhaka city
Year	1990	2016	2016
VSL (million BDT)	5.35	22.41	16.83
VSL (million USD)	0.15	0.29	0.22
Price level	1990	2016	2016
ε	1	1	0.8
Source	(Khatun, 1997)	This research, 2017	This research, 2017

Table A.2.14. Values of mortality due to PM10 in the study area.

Summary	**Annual PM10 concentration (µg/m3)**	**b**			**Mortality rate**	**Population**	**The number of cases of mortality due to PM10**			**Cost of mortality (VSL) in million BDT**	**Values of mortality (mill BDT 2016)**		
		Lower bound	Central estimate	Upper bound			Lower bound	Central estimate	Upper bound		Lower bound	Central estimate	Upper bound
Minimum (PM10)	68.4	0.062	0.096	0.13	0.0051	388,771	84	130	176	22.41	1,884	2,917	3,950
Average (PM10)	148	0.062	0.096	0.13	0.0051	388,771	182	282	381	22.41	4,076	6,311	8,546
Maximum (PM10)	261.4	0.062	0.096	0.13	0.0051	388,771	321	498	674	22.41	7,201	11,149	15,098
Minimum (PM10)	78.4	0.062	0.096	0.13	0.0051	388,771	96	149	202	22.41	2,159	3,343	4,527
Average (PM10)	158	0.062	0.096	0.13	0.0051	388,771	194	301	407	22.41	4,351	6,737	9,123
Maximum (PM10)	271.4	0.062	0.096	0.13	0.0051	388,771	334	517	700	22.41	7,476	11,576	15,676

Source: Photography by Naeema Jihan Zinia, 2016.

Image A.2.1 Rooftop structure (bottom) and produces in the study area.

Source: Photography by Naeema Jihan Zinia, 2016.

Image A.2.2 Natural irrigation in the study area. A) Wetland water usage in a paddy cultivation land, Ward 15, DNCC; B) Arambag khal water usage in a vegetable patch, Ward 6, DNCC; C) Rupnagar khal water usage in a climbing vegetable patch, Ward 7, DNCC.

APPENDIX III

Additional materials for Chapter 3

Table A.3.1. Indicators for identifying the selected NGOs and private sector organizations roles in ecosystem governance.

Role	Indicator
Watchdog	Monitor existing environmental norm fulfilment
	Engage in mandatory participation processes
	Pursue legal action against environmentally harmful projects or campaigns
Value perceiver	Promote environmental values beyond existing regulations
	Raise citizen awareness
Field actor and action coordinator	Provide environmental public goods
	Ensure landscape maintenance
	Coordinate field projects in cooperation with local communities
Knowledge transmitter	Educate stakeholders
	Cooperate with research organizations
	Consult land use agendas and problems
Partner in collaborative governance	Influence formulation and implementation of public policy
	Consult or address environmental issues and projects
	Organize resource control schemes

Source: Adapted from Slavíková et al. (2017)

Table A.3.2. Features of the selected NGOs and private sector organizations.

Name of organization	**Vision**	**Objectives/Mission**	**Ecosystem and ecosystem services addressed**	**Ecosystem related major activities/projects**	**Active in urban areas**	**References**
World Bank	To end extreme poverty and promote shared prosperity in a sustainable way		Yes	Clean Air and Sustainable Environment Project; Water Supply Improvement and Sanitation Project; Bangladesh Weather and Climate Services Regional Project; National Agricultural Technology Program; Coastal Embankment Improvement Project; Climate Resilient Participatory Afforestation and Reforestation Project; Community Climate Change Project; Aquatic Biodiversity Conservation; Forest Resources Management Project	Yes	WB (ND-a, ND-b); Interviewee 2, 3, and 4
Asian Development Bank	An Asia and the Pacific free from poverty	Help developing member countries reduce poverty and improve the quality of life of their people.	Yes	Sustainable Management of Community Development for Chittagong Hill Tracts; Ganges-Kobadak Irrigation Modernization Project; Dhaka Water Supply Network Improvement; Flood and Riverbank Erosion Risk Management Investment Program; Irrigation Management Improvement Project; Dhaka Environmentally Sustainable Water Supply Project; Participatory Small-Scale Water Resources Sector Project	Yes	ADB (2016, ND-a, ND-b)
International Union for Conservation of Nature (IUCN)	A just world that values and conserves nature.	Influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable.	Yes	Prepare the IUCN Red List of Threatened species for Bangladesh; Establishing pilot co-management system for the Tanguar Haor wetland ecosystem in Northern Bangladesh; Updating the National Biodiversity Strategy and Action Plan; Ensuring the long term conservation of Asian elephants and their habitats; Improved conservation of Gyps vulture species including the white-rumped vulture; Monitoring of wetland biodiversity; Ecosystem Based Sustainable Management	No	IUCN (2017); Interviewee 15

Name of organization	Vision	Objectives/Mission	Ecosystem and ecosystem services addressed	Ecosystem related major activities/projects	Active in urban areas	References
				of a Marine Protected Area in the Nijhum Dwip Seascape; Promoting responsible tourism to develop climate resilient tourism industry		
Transparency International Bangladesh (TIB)	A vision of Bangladesh in which government, politics, business, civil society and the daily lives of the people shall be free from corruption.	Catalyze and strengthen a participatory social movement to promote and develop institutions, laws and practices for combating corruption in Bangladesh and establishing an efficient and transparent system of governance, politics and business.	No	Climate Finance Governance Program; Governance challenges in implementation of Climate projects implemented by Bangladesh Water Development Board (BWDB), Department of Forest (DoF), Local Government and Engineering Department (LGED), and Local Government Institutions; Studies on governance in the procurement connected with publicly funded projects, and on urban governance covering urban settlements utilities, transport, health, etc.	Yes	TIB (ND-a, ND-b); Interviewee 8
Bangladesh Environmental Lawyers Association (BELA)	Promote environmental justice and contribute towards the development of a sound environmental jurisprudence.	Ensuring environmental protection through due processes of law; Anthropocentric environmentalism that seeks conservation inclusive of the natural resource dependent poor; Community ownership and management of natural resources in a just, equitable and gender sensitive way; Upholding the rights of people, particularly the poor and the women, to	Yes	Cases on environmental issues-river pollution, industrial pollution, vehicular pollution, labor welfare, compensation for losses inflicted by development projects, encroachment and derogation of important wetlands, relocation of industries, prevention of hill cutting, conservation of forests, defending forest rights, fishermen;s rights & farmers rights amongst others; Writ petition to save the river Buriganaga ecosystem; Writ petition against construction and filling up the lakes and lakeside areas in Gulshan, Banani and Baridhara Model Town; Writ petition against vehicular pollution in Dhaka city	Yes	BELA (2016, 2018a, 2018b)

Name of organization	Vision	Objectives/Mission	Ecosystem and ecosystem services addressed	Ecosystem related major activities/projects	Active in urban areas	References
		their environmental entitlements.				
Center for Environmental and Geographic Information Services (CEGIS)	Become a center of excellence for providing advisory services, research, databases and training in multifarious fields including environment, geographic information system, remote sensing of a wide group of national and international organizations for purposes of enhanced efficiency in planning, implementation and monitoring of projects and programs.	Support the management of natural resources for sustainable socio-economic development at home and abroad, using integrated environmental analysis, geographic information systems, remote sensing techniques, database, information technology and other modern technology outfits.	Yes	The Haor Master Plan preparation project; The Khulna-Jessore Drainage Rehabilitation Project (KJDRP); Environmental and social impact assessment of KJDRP; The Gorai River Restoration Project (GRRP); River Bank Erosion Prediction; Assessment of Climate Change Impacts, Vulnerability and Adaptation for Sustainable Rice Production; Multi-hazard Zone Maps for Community Risk Assessment; SMS Gateway System for Monitoring Avian Influenza (Bird Flu) to Reduce Community Health Risk; Investigation of Impact of Sea Level Rise on Coastal Communities; Monitoring of the Re-excavation of the Kabodak River Project	Yes	CEGIS (ND); Interviewee 12, 22, and 24
Bangladesh Centre for Advanced Studies (BCAS)	Undertake action research on policy issues and implementation at local, national, regional and international levels for advancing and supporting sustainable development; Develop ideas and models for efficient resource management, conservation of the environment with an aim to promote sustainable development; Ensure people's and community participation in planning, implementation and management of resources; Undertake collaborative research with scientists in both national and international organizations to share knowledge and experience; Motivate and facilitate the private sector to adopt cleaner production methods, pollution abatement techniques and ensure clean environment and sustainable trade; Enhance the capacity of civil		Yes	Contribute to prepare National Environment Management Action Plan (NEMAP); Socio-Economic and Environmental Baseline Survey on Wildlife Conservation in Sundarban Impact Zones; Ecosystem-based Approaches to Adaptation (EbA); Strengthening the Evidence and Informing Policy Project in Bangladesh (IIED-BCAS-BMUB); Strategic research on coastal agriculture and livestock development for policy advocacy with Honorable Members of Parliament (BCAS-PRODIP); Preparation of Dhaka City State of Environment Report (SoE) 2003; Chittagong Hill Tracts Improved Natural Resources Management;	Yes	Ahmed and Roy (2015); BCAS (2018, ND); Interviewee 13

Name of organization	Vision	Objectives/Mission	Ecosystem and ecosystem services addressed	Ecosystem related major activities/projects	Active in urban areas	References
	society, private and public sectors in the areas of environment and natural resource management and promote pathways to green economy for ensuring sustainable development; Closely work with various agencies and departments of the Government in different countries as well as development partners, international institutions and Multilateral Environmental Agreements (MEAs)			Participatory Wetland Management Project; Community Based Resource Management in the Modhumati Floodplains, Sustainable Environment Management Project (SEMP); Wetland Research and Training Centre (WRTC) in Gopalganj district of Bangladesh		
Proshika Manobik Unnayan Kendro	Empowering the poor by enabling them to participate in mainstream economic activities.	Creating group self-development processes in rural poor through self-organizing, becoming critically conscious of their position and making united and collective efforts to improve their socioeconomic condition.	Yes	Social forestry activities: Homestead plantation, roadside and embankment plantation, nursery establishment, agroforestry and woodlot forestry, and forest protection; Promote income-generation activities like livestock rearing, fisheries, sericulture, and seed production; Ecological Agriculture Program: increase crop diversification, improve soil fertility and productivity and reduce pest infestation by using ecological methods; Education and awareness for disaster preparedness.	Yes	Ahmed and Roy (2015); Alam (1996); Boyle (2002); Haque (2002); Khan (2008); Khatun (1997)
Bangladesh Rural Advancement Committee (BRAC)	A world free from all forms of exploitation and discrimination where everyone has the opportunity to realize their potential.	Empower people and communities in situations of poverty, illiteracy, disease and social injustice. Our interventions aim to achieve large scale, positive changes through economic and social programs that enable men and women to realize their potential.	Yes	Water, sanitation and hygiene program: access to safe water in saline and arsenic-affected areas through installing tubewells, pond sand filter, and piped water supply system; Agriculture and food security program: increase crop and fish production by research and extension activities in the northern and southern parts of Bangladesh and integrated agricultural practices in gher, or fish enclosures, and community-based culture fishery in seasonal floodplains; Education and awareness for disaster preparedness	No	Ahmed and Roy (2015); Khan (2008); Interviewee 5 and 6

Name of organization	Vision	Objectives/Mission	Ecosystem and ecosystem services addressed	Ecosystem related major activities/projects	Active in urban areas	References
Arambag Housing Association	A safe, clean, and healthy living environment		Yes	Rooftop gardening by individual holding owners; Cleaning up of khals; Protecting playground/eidgah field	Yes	Interviewee 18, 19, 32, and 33

Table A.3.3. Scoring for assessing the ecosystem governance roles of the government legal guidelines. Here ‘0’ indicates ‘No’ and ‘1’ indicates ‘Yes’.

Sl No*	Ecosystem services (ES) addressed				Action aim/priority of the guidelines			
	Provisioning ES	Regulating ES	Cultural ES	Habitat ES	Conservation	Restoration	Improvement	New ecosystem/ES
P1	1	1	1	1	1	1	1	0
P2	0	0	0	0	1	1	1	0
P3	0	1	1	1	1	1	0	0
P4	1	1	1	1	1	0	1	1
P5	1	0	0	1	1	1	1	1
P6	1	1	1	1	1	1	1	1
P7	0	0	0	0	1	0	0	0
P8	0	0	0	0	1	0	0	0
P9	1	1	0	1	1	0	1	1
P10	0	1	0	0	1	0	1	0
P11	0	0	0	0	1	0	0	0
P12	0	0	0	0	1	0	0	0
P13	1	1	1	1	0	1	0	0
P14	1	1	1	1	1	0	1	1
P15	1	1	1	1	1	0	1	0
P16	1	1	1	1	1	0	1	0
P17	1	1	1	1	1	1	1	1

Total	10	11	9	11	16	7	11	6

Note: Scoring was done based Table 3.2 (Sub-section 3.3.1, Chapter 3). *See Table 3.2 for the names of the government legal guidelines.

Table A.3.4. Scoring for assessing the roles of the NGOs and private sector organizations in ecosystem governance. Here '0' indicates 'No' and '1' indicates 'Yes'.

Name of organization	Environmental governance role					Action aim/priority			
	Watchdog	Value perceiver	Field actor and action coordinator	Knowledge transmitter	Partner in collaborative governance	Conservation	Restoration	Improvement	New ecosystem/ ecosystem service generation
World Bank	1	0	1	1	1	1	1	1	1
Asian Development Bank	1	0	1	1	1	1	1	1	1
International Union for Conservation of Nature (IUCN)	0	0	1	1	1	1	1	1	0
Transparency International Bangladesh (TIB)	1	1	1	1	1	0	0	0	0
Bangladesh Environmental Lawyers Association (BELA)	1	1	1	1	1	1	1	1	0
Center for Environmental and Geographic Information Services (CEGIS)	0	0	1	1	1	0	1	0	0
Bangladesh Centre for Advanced Studies (BCAS)	0	1	1	1	1	1	1	1	1
Proshika Manobik Unnayan Kendro	0	1	1	1	1	1	1	1	1
Bangladesh Rural Advancement Committee (BRAC)	0	1	1	1	1	0	1	0	1
Arambag Housing Association	0	0	1	0	0	1	0	0	1
Total	**4**	**5**	**10**	**9**	**9**	**7**	**8**	**6**	**6**

Note: Scoring was done based on Table A.3.2.

Table A.3.5. Scoring category.

Score	**%**	**Score meaning**
-	0	No priority
+	01 to 20	Low priority
+ +	21 to 40	Low to moderate priority
+ + +	41 to 60	Moderate priority
+ + + +	61 to 80	Strong priority
+ + + + +	81 to 100	Very strong priority

THE GOVERNMENT LEGAL GUIDELINES

A.3.1 *National Environment Policy, 1992*

Bangladesh has acknowledged the necessity for environmental protection and development at national level for the first time in 1992 in the *National Environmental Policy*. Its objectives included conserve nature's balance, promote environment friendly development, protect the country from natural disasters, identify and control pollutions of all kinds, ensure sustainable and long term utilization of all national resources and remain actively involved in environment related international initiatives. This Policy provided legal and institutional frameworks for improvement, protection and conservation of the environment. It introduced Environmental Impact Assessment (EIA) for industrial activities.

The *National Environmental Policy, 1992* covered nationwide geographical regions and 15 development sectors of which some are directly related to this study: agriculture, water development, flood control and irrigation, land, forest, wildlife and biodiversity, fisheries and livestock and housing and urbanization. This Policy presented general guidelines for these development sectors and involves relevant ministries and departments for its implementation.

A.3.2 *Bangladesh Environment Conservation Act, 1995*

This Act focused on conservation of the environment, improvement of environmental standards and control and mitigation of environmental pollution. It defined *environment* as the mutual relationships of human beings, other living species, plants and microorganisms with water, air, soil or physical resources. C*onservation of environment*, *ecosystem*, *environment pollutant,* *hazardous substance, pollution* and *waste* are also defined there. This Act presented conditions required for declaring Ecologically Critical Area. It imposed restrictions on activities that were injurious to ecosystems directly or indirectly, for example, smoke emission from vehicles.

The *Bangladesh Environment Conservation Act, 1995* has set the requirement for obtaining the Environmental Clearance Certificate before setting up industries, industrial units and projects. It imposed penalties for violating this Act which was imprisonments not exceeding five years or fine not exceeding BDT 100,000 or both subject to the extent of offence.

A.3.3 *Environment Conservation Rules, 1997*

The *Environment Conservation Rules, 1997* supplemented the *Environment Conservation Act, 1995* by further specification of issues mentioned in it. These rules determined factors to be considered while declaring Ecologically Critical Area, procedures for issuing Environmental Clearance Certificate (ECA) and Pollution under Control Certificate along with their validities and most importantly set environmental standards for air, water, soil, noise, odor, sewage discharge and emission of waste. Classification of industrial units or projects into different categories (Green, Orange and Red) were done in details for obtaining ECA. ECA fees and renewal process, services provided by the Department of Environment (e.g. analytical information or data or test results of samples of water, effluent, air and noise) and their fees and procedures were fixed by these Rules. They elaborated on appeal including requirements of documents to be accompanied with each appeal, procedure to be followed by Appellate Authority and procedure for hearing of appeal.

A.3.4 *National Water Policy, 1999*

The *National Water Policy, 1999* was formulated for improved and socially just water resource management for current and future generations. It aimed at ensuring efficient and equitable ground and surface water management, availability of water to everyone, sustainable public and private system for water delivery, institutional changes enhancing decentralization and capacity building for water resource management in future. This Policy gives specific directives for water use and management in 16 sections including agriculture, fisheries and wildlife, navigation, hydropower and recreation, preservation of natural waterbodies (*haor, baor* and *beel*) and future plan, research and stakeholder involvement.

Explicit policy directives for urban areas were given: preservation of natural depression and waterbodies for aquifer recharge, rainwater management, prevention of water wastage and pollution by human actions by municipalities and water related institutions, improvement in conjunctive use of surface and ground water for irrigation and urban water supply and banning filling of public waterbodies and depressions.

A.3.5 *National Adaptation Programmes of Action (NAPA), 2009*

The NAPA addressed adverse impacts of climate change and identified key adaptation needs. The degree of impacts on natural ecosystems (coastal zone, freshwater), production system (agriculture, fisheries, livestock, industries, biodiversity), and the human system (poverty, livelihood, food security, health security) were considered while assessing the urgency and immediacy of adaptation needs. The NAPA emphasized on four basic national security issues: food security, energy security, water security and livelihood security (including right to health) and respect for local community on resource management and extraction. It proposed 16 projects comprising 38 adaptation measures to be implemented by different ministries and departments. Some relevant projects were monitoring of ecosystem and biodiversity changes and their impacts, wildlife management in forests, coastal green belt expansion, afforestation and reforestation and enhancing resilience of urban infrastructure.

A.3.6 *Bangladesh Climate Change Strategy and Action Plan (BCCSAP), 2009*

The BCCSAP was a 10-year program (2009-2018) that was prepared as a living document in the light of the NAPA reflecting the development priorities of the country for future economic, social and human developments under climate change scenarios. It was built on six themes: food security, social protection and health, comprehensive disaster management, infrastructure, research and knowledge management, mitigation and low carbon development and capacity building and institutional strengthening. Each theme comprised specific short/medium term capacity building programs with objectives, justifications, actions and designated implementation authorities. Some relevant programs included development of climate resilient cropping systems, lower emission from agricultural land, monitoring of ecosystems and biodiversity changes and their impacts, adaptations in fisheries and livestock sectors, afforestation and reforestation, energy and water efficiency in built environment, improvement of urban drainage and urban waste management. It strongly recommended strengthening human resources and institutional capacities.

A.3.7 *Bangladesh Environment Conservation (Amendment) Act, 2000*

This was the first amendment to the *Bangladesh Environment Conservation* Act, 1995. It elaborated the actions for direct and indirect injury to ecosystems and increased penalties for its violation to imprisonments not exceeding 10 years or fine not exceeding BDT 1 million or both and compensation on top of these subject to the extent of offence. This implies increasing importance given to environmental conservation.

A.3.8 *Metropolis, sectional areas of all the municipal area of the city and district municipal playgrounds, open spaces, parks and natural reservoirs protection Law, 2000*

This Law considered playground (fields), open space (eidgah field), park and natural reservoir (river, khal, stream, beel, other waterbody) as identified in the master plans prepared by RAJUK and other divisional, city corporation and municipal development authorities. It banned land use changes (building construction, land filling, tree removal) and renting or leasing of these ecosystems. Provisions for making necessary changes in the ecosystems classes could be allowed upon submission of written application and after investigation of their impacts on the environment and the objectives of the master plans. Violation of this Law might enforce penalties to imprisonments not exceeding 5 years or fine not exceeding BDT 50,000 or both. It is more urban focused legal framework.

A.3.9 Land Use Policy, 2001

The *Land Use Policy, 2001* emphasized on preventing continuous declining rate of cultivated land for ensuring crop production, controlling unplanned urbanization by zoning of lands, utilizing *charlands* (mid-channel islands in rivers, *haors* and the sea) for rehabilitating the landless and government *khas* lands for future needs, ensuring environment friendly use of lands and encouraging vertical expansion of government and non-government institutions to minimize land requirement. This Policy gave utmost importance to forestation in *charlands* and coastal areas and preservation of existing forests for mitigating air pollution. It advocated for controlling river bank erosion and soil pollution, prohibiting hill cutting, preserving waterbodies (river, khal, bee, haor, baor) for fish production and water supply.

A.3.10 *Bangladesh Environment Conservation (Amendment) Act, 2002*

The *Bangladesh Environment Conservation Act, 1995* was amended once again in 2002. It enabled collaboration with law enforcement agencies or other government organizations for taking actions or completing tasks on behalf of the Department of Environment. This Act emphasized on harmful smoke emission from vehicles and production, sale and storage of hazardous elements. It explained the allowable usage of polythene bags. It specified penalties for Section or Sub-section-wise violation of the Act that ranged between imprisonments not exceeding 10 years or fine not exceeding BDT 1 million or both to imprisonment not exceeding six months or fine not exceeding BDT 10,000 thousand or both subject to the extent of offence.

A.3.11 *Bangladesh Environment Conservation (Amendment) Act, 2010*

The latest amendment of the *Bangladesh Environment Conservation Act, 1995* was done in 2010. It clearly defined waterbody, highlighted proper ecosystem management for Ecologically Critical Areas and attaining Environmental Clearance Certificate before any industrial act. Many important environmental concerns such as conservation of waterbody, hill cutting and or razing, ship breaking, and hazardous waste disposal were overviewed. This amendment set maximum and minimum amount of monetary penalty and imprisonment for first time and continuing offender for Section or Sub-section-wise violation of the Act. Affected persons were allowed to lodge complaint or take legal actions against the polluters or any entity troubling them.

A.3.12 *Environment Court Act, 2010*

This Act created provisions for establishing one or more environment court(s) and special magistrate court(s) in each districts and identified their jurisdictions: lodging lawsuit, imposing penalties and seizing instruments, products or vehicles in association with offences and explained the judgement procedures of both courts. Disobeying the decisions of the court might result in penalties: imprisonments not exceeding 5 years or fine not exceeding BDT 500,000 or both. This Act endorsed settlements with a minimum fine of BDT 50,000 and created provisions for environment appeal court.

A.3.13 *Disaster Management Act, 2012*

The *Disaster Management Act, 2012* aimed at making disaster management activities coordinated, strengthening disaster preparedness from national to local levels and decrease losses to life, assets and the environment. This Act defined disaster, proposed establishment of a Department of Disaster Management and a National Disaster Management Council, identified responsibilities and functions of the proposed department and council, created provisions for formulating National Disaster Management Policy and National and Local Disaster Management Plan. It explained procedures for declaring distressed zones and activities to be performed in there and advocated for involvement of private organizations and individuals in distressed area management. This Act enacted participation of armed forces and law and order protection forces in emergency response activities and proposed forming national and district disaster management funds. It specified monetary punishments and imprisonments of varying ranges for offenses such as impeding duties, disobeying directives and failure to comply, presenting false claim, increasing value of essential items in disaster area and creating salinity or flood or creating impediment to current water flow or damage to embankment.

A.3.14 *Haor Master Plan, 2012*

It was a 20-year Master Plan (2012-32) aiming at achieving sustainable development of the haors in the north-eastern region of Bangladesh (about 1.99 million ha) with an integrated planning and implementation through multi-organizational involvement and community participation. This Master Plan targeted to conserve haor ecosystem and optimize resource utilization and poverty reduction. A total of 154 projects would be implemented in three phases (short, medium and long terms) developing several sectors: water resources, agriculture, fisheries, pearl culture, livestock, forest, education, health, transportation, housing and settlement, water supply and sanitation, industry, energy and power, mineral resources, biodiversity and wetland, tourism and social services. Ecosystem services that got priorities included flood risk and damage mitigation, crop and fish production and biodiversity conservation.

A.3.15 *Water Act, 2013*

The *Water Act, 2013* was formulated for sustainable integrated water resources management. It provided legal basis for development, management, extraction, distribution, usage, protection, and conservation of water resources. This Act prioritized water usage in water resource critical areas in the following order: drinking water, domestic usage, irrigation, fish culture, biodiversity, wildlife, instream flow, industry, salinity control, power generation, recreation and etc. Initiatives for regional and international cooperation, water zone declaration and water pollution control were among other concerns focused in the *Water* Act, 2013. It created provisions for penalties for non-compliance to the Act ranging between imprisonments not exceeding 3 months to 5 years or fine not exceeding BDT 2,000 to BDT 10,000 or both imprisonments and financial penalties depending on the offense.

A.3.16 *Ecologically Critical Area Management Rules, 2016*

These Rules proposed formation of a National Committee involving relevant ministries, departments and institutions and stated its responsibilities and functions for recommending and managing Ecologically Critical Areas (ECA). Procedures for declaring ECA and factors to be considered for recommending ECA identified, for instance, current states of ecosystems (forests, waterbodies, sanctuaries) and ecosystem services (biodiversity, site of object of world heritage and historical importance), inhabitants livelihoods and religious and cultural values. It banned any activities that might deteriorate the ecosystems and services in the ECA, encouraged co-management of public and private institutions, proposed for creating a fund for ECA conservation and development and imposed penalties of imprisonments not exceeding 2 years or fine not exceeding BDT 200,000 or both for violation of the Rules.

A.3.17 *Bangladesh Delta Plan (BDP) 2100*

The BDP 2100 (under process as of 2017) was a holistic, adaptive and long term (50-100 years) strategic plan for land and water management to improve safe living and sound economic development in the Bangladesh delta, while taking climate change into account. It aimed to integrate spatial and sectoral plans and to frame strategies to contribute to food security, water safety, disaster risk reduction, climate change resilience and adaptation and economic development. The BDP intended to have a particular focus on a number of "hotspots" such as coastal zone, haor/flash flood and Barind/drought prone areas, Dhaka and major cities that were vulnerable to, among others, flood, water scarcity and sanitation problem. The draft Plan[15] prepared separate sections on urban area strategies and urban water management. It would apply a participatory approach to gain an increasing degree of involvement and trust between parties and ownership on problems and solutions.

[15] http://www.bangladeshdeltaplan2100.org/wp-content/uploads/2017/09/Final-GED-Version_V24092017_Website-1.pdf

APPENDIX IV

Additional materials for Chapter 4

Table A.4.1. Ward-wise gender of respondents (Number)

Ward No.	Male	Female	Total
Ward 6	120	55	175
Ward 7	111	63	174
Ward 8	91	70	161

Table A.4.2. Ward-wise age of respondents (Number)

Ward No.	<25	25-35	35-45	>45	Total
Ward 6	1	58	55	61	175
Ward 7	2	47	88	37	174
Ward 8	4	42	73	42	161

Table A.4.3. Ward-wise education of respondents (Number)

Ward No.	None	Primary	SSC	HSC	Bachelor	Master	PhD	Total
Ward 6	0	6	24	34	57	53	1	175
Ward 7	0	4	19	44	59	48	0	174
Ward 8	0	6	20	54	68	13	0	161

Table A.4.4. Ward-wise household income (BDT per month) of respondents (Number)

Ward No.	< 5,000	5,000-10,000	10,000-20,000	20,000-30,000	30,000-40,000	40,000-50,000	>50,000	Total
Ward 6	0	2	27	33	27	16	70	175
Ward 7	0	0	18	33	37	27	59	174
Ward 8	0	1	14	50	45	24	27	161

Table A.4.5. Ward-wise respondents ownership of holding (Number)

Ward No.	Yes	No	Total
Ward 6	67	108	175
Ward 7	56	118	174
Ward 8	50	111	161

Table A.4.6. Ward-wise respondents preferences of green adaptation (GA) strategies implementable with individual effort (in %)

GA strategy	Ward 6	Ward 7	Ward 8	Total
Green belt	9	10	13	11
Pocket park	11	11	9	11
Community garden	1	1	0	0
Rooftop garden/ agriculture	95	87	73	85
Green roof	25	20	20	22
Green facade/wall	17	16	10	14
Existing canal/lake management	1	1	1	1
Artificial wetland	0	0	0	0
Water retention pond	0	0	0	0
Porous pavements	6	2	0	3
Artificial fountains	1	1	1	1
Rainwater harvest tank	14	22	7	14
Others	16	19	0	12
None	1	6	22	10

Table A.4.7. Ward-wise respondents preferences of green adaptation (GA) strategies implementable with collective efforts (in %)

GA strategy	Ward 6	Ward 7	Ward 8	Total
Green belt	68	62	47	59
Pocket park	28	10	7	15
Community garden	57	32	30	40
Rooftop garden/ agriculture	31	49	18	33
Green roof	17	29	17	21
Green facade/wall	12	11	9	11
Existing canal/lake management	52	43	48	48
Artificial wetland	17	5	2	8
Water retention pond	22	6	7	12
Porous pavements	31	22	9	21
Artificial fountains	11	4	2	6
Rainwater harvest tank	25	30	4	20
Others	5	3	0	3
None	3	5	23	10

Table A.4.8. Social acceptance and economic feasibility of green adaptation (GA) strategies in Dhaka with individual and collective implementation efforts (in %).

GA strategy	**Social acceptance of GA with individual effort (%)**	**Social acceptance of GA with collective efforts (%)**	**Economic feasibility of GA with individual effort (%)**	**Economic feasibility of GA with collective efforts (%)**
Green belt	11	59	0	32
Pocket park	11	15	60	100
Community garden	0	40	0	80
Rooftop garden/ agriculture	85	33	96	88
Green roof	22	21	84	92
Green facade/wall	14	11	96	92
Existing canal/lake management	1	48	0	100
Artificial wetland	0	8	0	40
Water retention pond	0	12	8	60
Porous pavements	3	21	72	84
Artificial fountains	1	6	4	28
Rainwater harvest tank	14	20	88	92

Table A.4.9. Scoring category

Score	**%**	**Score meaning**
-	0	No preference
+	1-20	Low preference
+ +	21-40	Low to moderate preference
+ + +	41-60	Moderate preference
+ + + +	61-80	Strong preference
+ + + + +	81-100	Very strong preference

Table A.4.10. Linear regression model results for significant predictors of respondents' Green Adaptation (GA) preferences implemnetable with individual and collective efforts.

Preference of GA (Dependent variable)	**GA implementable with individual effort**			**GA implementable with collective effort**		
	Predictor (Independent variable)	**Unstandardized coefficient**	**Sig.***	**Predictor (Independent variable)**	**Unstandardized coefficient**	**Sig.***
Green belt	Gender	-0.08	0.01	Marital status	-0.14	0.00
	Household income	-0.04	0.00	Household income	0.06	0.01
				Number of years living	-0.07	0.01
Pocket park	Age	-0.04	0.04	Age	0.06	0.01
	Household income	0.06	0.00	Household members number	0.08	0.01
	Number of years living	-0.04	0.03	Household income	-0.07	0.00
Community garden				Age	0.06	0.05
				Household members number	0.08	0.04
				Household income	0.07	0.00
				Number of years living	-0.11	0.00
Rooftop garden/ agriculture	Gender	-0.06	0.05	Household income	-0.05	0.01
	Marital status	-0.09	0.01			
	Household income	0.04	0.01			
	Ownership of holding	-0.11	0.01			
Green roof	Gender	-0.09	0.02	Gender	-0.08	0.04
	Household members number	0.07	0.05	Household income	-0.09	0.00
	Household income	-0.06	0.00			
Green facade/ wall	Gender	-0.09	0.01	Age	0.04	0.04
	Household members number	0.06	0.03	Household income	-0.06	0.00
	Household income	0.05	0.00			
Existing canal/ lake management				Age	0.08	0.02
				Marital status	0.15	0.00
				Household income	-0.05	0.01
				Number of years living	0.06	0.02
Artificial wetland				Age	0.04	0.04
				Household members number	0.07	0.00
				Household income	-0.05	0.00
Water retention pond				Age	0.05	0.02
				Household members number	0.06	0.04

Preference of GA (Dependent variable)	GA implementable with individual effort			GA implementable with collective effort		
	Predictor (Independent variable)	Unstandardized coefficient	Sig.*	Predictor (Independent variable)	Unstandardized coefficient	Sig.*
				Household income	-0.03	0.03
				Ownership of holding	0.08	0.05
Porous pavements				Education	0.05	0.01
				Household members number	0.10	0.01
				Number of years living	-0.04	0.08
Artificial fountains				Age	0.06	0.00
				Household members number	0.06	0.01
				Household income	-0.05	0.00
Rainwater harvest tank				Education	0.04	0.05

Note: *Sig. indicates p-value of t-statistic for unstandardized coefficient at 5% level of significance.

Table A.4.11. Binary logistic regression model results for significant predictors of respondents' Green Adaptation (GA) preferences implemnetable with individual and collective efforts.

Preference of green adaptation (GA)	GA implementable with individual effort			GA implementable with collective effort		
	Significant* category	Odds ratio	Reference category	Significant* category	Odds ratio	Reference category
Green belt	Age: <25 years	84.91	> 45 years	Household income: BDT 20-30 thousand per month	0.24	> BDT 50 thousand per month
	Household income: BDT 10-20 thousand per month	7.98	> BDT 50 thousand per month	Household income: BDT 30-40 thousand per month	0.33	
	Household income: BDT 20-30 thousand per month	3.94		Household income: BDT 40-50 thousand per month	0.48	

Preference of green adaptation (GA)	GA implementable with individual effort			GA implementable with collective effort		
	Significant* category	**Odds ratio**	**Reference category**	**Significant* category**	**Odds ratio**	**Reference category**
				Ownership of holding: Yes	0.54	No
Pocket park	Age: 25-35 years	4.81	> 45 years	Age: 25-35 years	0.35	> 45 years
	Household income: BDT 10-20 thousand per month	0.11	> BDT 50 thousand per month	Age: 35-45 years	0.21	
	Household income: BDT 20-30 thousand per month	0.18		Household income: BDT 20-30 thousand per month	4.43	> BDT 50 thousand per month
	Household income: BDT 30-40 thousand per month	0.21				
Community garden				Age: 35-45 years	0.47	> 45 years
				Household income: BDT 20-30 thousand per month	0.26	> BDT 50 thousand per month
				Household income: BDT 30-40 thousand per month	0.28	
				Household income: BDT 40-50 thousand per month	0.49	
				Number of years living: < 1 year	3.29	> 10 years
				Ownership of holding: Yes	0.38	No
Rooftop garden/ agriculture	Age: 35-45 years	0.33	> 45 years	Age: <25 years	16.49	> 45 years
	Household income: BDT 20-30 thousand per month	0.15	> BDT 50 thousand per month	Household income: BDT 20-30 thousand per month	2.01	> BDT 50 thousand per month
	Household income: BDT 30-40 thousand per month	0.17				
Green roof	Household income: BDT 10-20 thousand per month	4.54	> BDT 50 thousand per month	Household income: BDT 10-20 thousand per month	9.21	> BDT 50 thousand per month
	Household income: BDT 20-30 thousand per month	2.19		Household income: BDT 20-30 thousand per month	6.30	
	Number of years living: 1-5 years	0.43	> 10 years	Number of years living: 1-5 years	4.00	> 10 years
Green façade/wall	Gender: Male	2.15	Female	Age: 25-35 years	0.29	> 45 years
	Household income: BDT 10-20 thousand per month	0.31	> BDT 50 thousand per month	Age: 35-45 years	0.39	

Preference of green adaptation (GA)	GA implementable with individual effort			GA implementable with collective effort		
	Significant* category	**Odds ratio**	**Reference category**	**Significant* category**	**Odds ratio**	**Reference category**
	Household income: BDT 20-30 thousand per month	0.22		Household income: BDT 10-20 thousand per month	11.64	> BDT 50 thousand per month
	Household income: BDT 30-40 thousand per month	0.21		Household income: BDT 20-30 thousand per month	10.17	
Existing canal/ lake management				Age: 25-35 years	0.45	> 45 years
				Household income: BDT 20-30 thousand per month	1.87	> BDT 50 thousand per month
				Number of years living: < 1 year	0.35	> 10 years
Artificial wetland				Age: 25-35 years	0.32	> 45 years
				Age: 35-45 years	0.20	
				Household income: BDT 10-20 thousand per month	18.79	> BDT 50 thousand per month
				Household income: BDT 20-30 thousand per month	6.12	
Water retention pond				Age: 25-35 years	0.36	> 45 years
				Age: 35-45 years	0.37	
				Household income: BDT 10-20 thousand per month	3.15	> BDT 50 thousand per month
				Ownership of holding: Yes	0.28	No
Porous pavements				Household income: BDT 10-20 thousand per month	2.65	> BDT 50 thousand per month
				Household income: BDT 30-40 thousand per month	0.40	
Artificial fountains				Gender: Male	0.33	Female
				Age: 25-35 years	0.08	> 45 years
				Age: 35-45 years	0.14	
				Household income: BDT 10-20 thousand per month	236.97	> BDT 50 thousand per month

Preference of green adaptation (GA)	GA implementable with individual effort			GA implementable with collective effort		
	Significant* category	**Odds ratio**	**Reference category**	**Significant* category**	**Odds ratio**	**Reference category**
				Household income: BDT 20-30 thousand per month	115.27	
				Household income: BDT 30-40 thousand per month	21.93	
Rainwater harvest tank				Household income: BDT 30-40 thousand per month	0.40	> BDT 50 thousand per month
				Number of years living: 5-10 years	2.55	> 10 years

Note: *At 5% level of significance.

APPENDIX V

Observation Framework

Observation Framework					
Instruction: Tick (√) in the blank spaces (where applicable).					
Who (Name of the observer)					
When					
Date			Day		
Time	Morning (9:00-12:00)		Afternoon (12:00-18:00)		
Where					
Ward no.		GPS coordinates & Accuracy level			
Park		Fallow land/Grassland		Pond	
Street trees		River/Stream		Lake	
Play ground		Canal		Wetland (low land/other waterbody)	
Agriculture land		Jheel		Others (please specify)	
Ecosystem property right		Public		Private	
What (Ecosystem Services Type)					
1	Food provision	Fish		Crop	
		Meat		Others (please specify)	
		Fruit			
2	Water supply	Drinking water		Irrigation water	
		Industrial water			
3	Provisioning of raw materials	Fibres		Fertilizers	
		Timber		Minerals	
		Fuel wood and charcoal		Biomass fuels	
		Fodder		Others (please specify)	
4	Provisioning of genetic resources	Plant genetic resources		Animal genetic resources	
5	Provisioning of medical resources	Biochemical		Test-organisms	
		Models		Bioprospecting	
6	Provisioning of ornamental resources	Decorative Plants		Decorations / Handicrafts	
		Fashion			
7	Influence on air quality	Capturing fine dust		UV-protection	
8	Climate regulation	C-sequestration		Gas regulation	
		Microclimate regulation			

9	Moderation of extreme events	Storm protection		Fire Prevention	
		Flood prevention			
10	Regulation of water flows	Drainage		Natural irrigation	
		River discharge			
11	Waste treatment and water purification	Water purification		Abatement of noise	
		Soil detoxification			
12	Erosion prevention	Erosion prevention			
13	Maintenance of soil fertility	Maintenance of soil structure		Soil formation	
		Deposition of nutrients		Nutrient cycling	
14	Pollination	Pollination of crops		Pollination of wild plants	
15	Biological control	Seed dispersal		Disease control	
		Pest control			
16	Lifecycle maintenance	Nursery service		Refugia for migratory and resident species	
17	Protection of gene pool (conservation)	Biodiversity protection			
18	Aesthetic information	Attractive landscapes			
19	Opportunities for recreation and tourism	Recreation		Eco-tourism	
		Tourism		Hunting and fishing	
20	Inspiration for culture, art and design	Artistic inspiration		Cultural use	
21	Spiritual experience	Spiritual / Religious use			
22	Information for cognitive development	Science/Research		Education	

Note: Ecosystem services types are adapted from Van der Ploeg, De Groot, and Wang (2010) and De Groot et al. (2012).

Interview: Perspective mapping

Scores indicate Strongly agree= 6, Agree= 5, Slightly agree= 4, Slightly disagree= 3, Disagree= 2, Strongly disagree=1, Undecided/Not applicable= 0.

Perspectives Mapping								
Sl No	**Contents**	**Score**						
1	There are enough green spaces in Dhaka city	6	5	4	3	2	1	0
2	More green spaces are needed in Dhaka city	6	5	4	3	2	1	0
3	There are enough blue spaces in Dhaka city	6	5	4	3	2	1	0
4	More blue spaces are needed in Dhaka city	6	5	4	3	2	1	0
5	Urban ecosystems in Dhaka city play significant roles in (micro)climate regulation in terms of generating cooling effects in their adjacent areas	6	5	4	3	2	1	0
6	Urban ecosystems in Dhaka city play significant roles in carbon sequestration	6	5	4	3	2	1	0
7	Urban ecosystems in Dhaka city play significant roles in capturing particulate matters	6	5	4	3	2	1	0
8	Urban ecosystems in Dhaka city play significant roles in urban flood prevention	6	5	4	3	2	1	0
9	Urban ecosystems in Dhaka city play significant roles in water purification	6	5	4	3	2	1	0
10	Urban ecosystems in Dhaka city are playing significant roles in noise abatement	6	5	4	3	2	1	0
11	Current air quality status of Dhaka city is highly satisfactory	6	5	4	3	2	1	0
12	Current water quality status of Dhaka city's water-bodies is highly satisfactory	6	5	4	3	2	1	0
13	Urban ecosystems & ecosystem services management practices in Dhaka city are highly satisfactory	6	5	4	3	2	1	0
14	(More) urban ecosystems & ecosystem services management measures are needed in Dhaka city	6	5	4	3	2	1	0
15	Environmental awareness among common people in Dhaka is highly satisfactory	6	5	4	3	2	1	0
16	Existing environmental awareness campaign/activities in Bangladesh are highly satisfactory	6	5	4	3	2	1	0
17	(More) environmental awareness campaign/activities are needed in Bangladesh	6	5	4	3	2	1	0
18	Relevant laws/legislations specifically for urban environmental management are available in Bangladesh	6	5	4	3	2	1	0
19	Dhaka's Ecosystems & ecosystem services play very important roles in the society	6	5	4	3	2	1	0
20	Dhaka's Ecosystems & ecosystem services play very important roles in the economy	6	5	4	3	2	1	0
21	Property prices are higher near urban green spaces in Dhaka city	6	5	4	3	2	1	0
22	Property prices are higher near urban blue spaces in Dhaka city	6	5	4	3	2	1	0
23	Which Green adaptation (GA) strategies are economically feasible to implement with individual effort in Dhaka city?	Yes	No					
	Installing green roofs							
	Rooftop gardening/agriculture							
	Establishing pocket parks							
	Creating facades of buildings covered with plants/ Green wall							

	Installing rain water harvesting tank		
	Installing porous pavements		
	Using fountains as cooling elements		
	Creating artificial urban wetlands		
	Constructing rain water retention pond		
24	Which Green adaptation strategies are economically feasible to implement with collective efforts in Dhaka city?	Yes	No
	Installing green roofs		
	Rooftop gardening/agriculture		
	Community gardening		
	Establishing pocket parks		
	Establishing green belts around the city/neighborhood		
	Managing lake/canal around the neighborhood		
	Creating facades of buildings covered with plants/ Green wall		
	Installing rain water harvesting tank		
	Installing porous pavements		
	Using fountains as cooling elements		
	Creating artificial urban wetlands		
	Constructing rain water retention pond		

Interview: Checklist/open ended questions

Sl. No.	Topic category	Contents
1	Ecosystem & Ecosystem Services (ES)	What is your impression about the overall ecosystem (availability, state, challenges, maintenance costs) in Dhaka considering current time period?
2		Are their states/conditions and numbers different now compared to 5, 10 or 20 years back? How much different? What are the reasons behind this?
3		How would you relate climate change with urban ecosystems in Dhaka? (current and future aspects)
4		What is your impression about Urban Heat Island (UHI) in urban & peri-urban areas of Dhaka (past, present, future); Reasons?
5		What are the main ecosystem services (ES) offered by the ecosystems in the study area?
6		Which type of ES (provisioning, regulating, cultural) in your opinion play the most crucial role in the study area? Why so?
7		Do you think there are any non-use values of the listed ecosystems; if yes, how would you rate it?
8	Stakeholders, Society, Economy	Who do you think are the main stakeholders (actors-individuals/organizations) of the ecosystems? Who are affected the most? Who are affecting the most? What should be the ideal situation?
9		How do you think the ecosystems & ES are connected to the society?

Sl. No.	Topic category	Contents
10		How do you think the ecosystems & ES are linked to the economy?
11	Ecosystem & ES management, Policy, Green Adaptation (GA)	Do you think there are relevant laws/legislations in Bangladesh for urban environmental management? If yes, please name some; if not why not? What can be done? Who will do this?
12		What is your opinion about current ES management practices in Dhaka (their strengths/weaknesses)?
13		What role the NGOs, international organizations, govt. play in current ecosystem management?
14		Do you think the green adaptation (GA) measures are already in practice in Dhaka? If yes, success/failure; If no, can be implemented in Dhaka? If no, why? Any plan to implement these?
15		What role the NGOs, international organizations, govt. may play in implementing GA?
16		Who do you think would benefit the most if GA is implemented? How?
17		How can we aware people for environmental management? Do you think payment for ES can be an option for ES management in Dhaka?

Household survey questionnaire

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Questionnaire Code (Your initial in three digits-Ward no.-No. of survey; e.g. NJZ-W6-1):

Survey Questionnaire										
Date				**Day**						
Instructions: Tick (√) where applicable and take notes in the blank spaces										
Name of Surveyor										
Location	Ward no.		GPS coordinates & Accuracy level							
GENERAL INFORMATION **সাধারণ তথ্য**										
G1.1	Gender	□ Male	□ Female	□ Other	**G1.2**	Age বয়স	□ <25	□ 25-35	□ 35-45	□ >45
G1.3	Education শিক্ষাগত যোগ্যতা	□ None □ HSC	□ Primary □ Bachelor	□ SSC □ Master	**G1.4**	Marital status বৈবাহিক অবস্থা	□ Married	□ Unmarried	□ Other	
G2	Household (HH) members (no.) পরিবারের সদস্য সংখ্যা (এক চুলায় খায়)	□ 1 - 3	□ 4 - 6			□ 7 - 10		□ > 10		
G3	Occupation পেশা				**G4**	How many of your HH members earn? আপনার পরিবারের কত জন উপার্জনক্ষম?				
G4.1	HH income (BDT/month) পারবারিক মাসিক আয়	□ < 5,000	□ 5,000-10,000	□ 10,000-20,000		□ 20,000-30,000	□ 30,000-40,000	□ 40,000-50,000	□ >50,000	
G5	For how long you are living here? আপনি কতদিন থেকে এখানে বসবাস করছেন?	□ < 1 year	□ 1 - 5			□ 5 - 10		□ > 10 years		
G5.1	Why do you live here? আপনি এই স্থানে কি কারণে বসবাস করছেন?									
G6	Are you the owner of this holding? আপনি কি এই জমির মালিক?	□ Yes				□ No				
G6.1	If "Yes", how much land do you own here? "হ্যাঁ" হলে, কি পরিমাণ জমি আছে এখানে?									
G6.2	If "No", how much (BDT/month) do you pay as rent? উত্তর "না" হলে, মাসিক বাড়ি ভাড়া কত?	□ < 5,000	□ 5,000-10,000			□ 10,000-20,000		□ > 20,000		

Green Adaptation to Ecosystem Services Management in Dhaka: A Socio-economic Evaluation 1

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INFORMATION ON ECOSYSTEMS						
E1	Which ecosystems are available in your neighborhood? (Multiple answers possible) কোন প্রাকৃতিক পরিবেশটি আপনার বসবাসরত এলাকায় আছে (৫-১০ মিনিট হাঁটা পথ)? (একাধিক উত্তর সম্ভব)	□ Street trees	□ Park/ Botanical Garden/ Zoo	□ Agriculture land	□ Fallow land/ Grassland/ Playground/Open space	□ River
		□ Pond/ Jheel	□ Lake/ Canal	□ Wetland	□ Others (Specify)	□ None
E2	Are there enough green spaces available in your neighborhood? আপনার বসবাসরত এলাকায় যথেষ্ট পরিমাণ সবুজ শ্যামল (গাছ পালা, পার্ক, ইত্যাদি) জায়গা আছে?	□ Yes			□ No	
E3	Are there enough blue (water body) spaces in your neighborhood? আপনার বসবাসরত এলাকায় যথেষ্ট পরিমাণ জলাশয় আছে?	□ Yes			□ No	
E4	Who manages these green/blue ecosystems? এই সবুজ শ্যামল জায়গা/ জলাশয় তত্ত্বাবধান করে কে?					
E5	Do you own the property right of any of these ecosystems? এই প্রাকৃতিক পরিবেশ গুলোর কোনটা কি আপনার মালিকানাধীন?	□ Yes			□ No	
E5.1	If "Yes", what is the total area (ha or any unit) of that? If "No" go to **P1** উত্তর "হ্যাঁ" হলে, এর মোট এরিয়া কতো?; উত্তর "না" হলে, **P1** এ যান।					
E5.2	How do you utilize this area? এই জায়গাটি আপনি কি কি কাজে ব্যবহার করেন? (এবং ভবিষ্যৎ পরিকল্পনা কি?)					
E5.3	How much (BDT/ha/year) do you earn from it? এই জায়গা থেকে বছরে/ মাসে কত টাকা আয় হয়?					

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INFORMATION ON PROVISIONING ECOSYSTEM SERVICES (PES)							
P1	Do you have rooftop garden? আপনার ছাদে বাগান আছে? উত্তর "না" হলে **P3** তে যান	□ Yes			□ No		
P2	Quantities (kg/year) of PES you obtain from your rooftop garden. ছাদের বাগান থেকে কি পরিমাণ উৎপাদন হয় (কেজি/বছর)?						
P3	Which of the following PES do you obtain from your neighborhood ecosystems? (Multiple answers possible) কোন সার্ভিস গুলো আপনার নিকটবর্তী প্রাকৃতিক পরিবেশ থেকে পেয়ে থাকেন? (একাধিক উত্তর সম্ভব)	□ Fish	□ Crop	□ Vegetables	□ Fruits	□ Industrial use of water	□ Irrigation water
		□ Household use of water	□ Fuel wood/ Charcoal	□ Fodder (গবাদি পশুর খাবার)	□ Others (Specify)	□ Others (Specify)	□ None
P4	Quantities (kg/year, L/year) of PES you obtain from your neighborhood ecosystems. ইকোসিস্টেম সার্ভিস গুলোর পরিমাণ কত (কেজি/ বছর বা লিটার/বছর)?	□ Fish	□ Crop	□ Vegetables	□ Fruits	□ Industrial use of water	□ Irrigation water
		□ Household use of water	□ Fuel wood/ Charcoal	□ Fodder	□ Others (Specify)	□ Others (Specify)	□ N/A
P5	Average Market prices (BDT/kg or BDT/L) of ES **TO BE COLLECTED BY SURVEYORS FROM MARKETS**	□ Fish	□ Crop	□ Vegetables	□ Fruits	□ Industrial use of water	□ Irrigation water
		□ Household use of water	□ Fuel wood/ Charcoal	□ Fodder	□ Others (Specify)	□ Others (Specify)	□ Others (Specify)

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INFORMATION ON REGULATING ECOSYSTEM SERVICES (RES)							
R1	What do you think about the **air quality** status in your neighborhood? আপনার বসবাসরত এলাকার বাতাসের গুণগত মান (পরিষ্কার, গন্ধহীন) সম্পর্কে আপনার মতামত কি?	□ Extremely pure (সাঙ্ঘাতিক বিশুদ্ধ)	□ Pure (বিশুদ্ধ)	□ Slightly polluted (সামান্য দূষিত)	□ Polluted (দূষিত)	□ Extremely polluted (সাঙ্ঘাতিক দূষিত)	□ Undecided/ Not applicable (সিদ্ধান্ত নেই/ প্রযোজ্য নয়)
R1.1	Reasons behind this quality in your opinion. আপনার মতে এর কারণসমূহ কি?						
R1.2	How to improve air quality? কিভাবে বাতাসের গুণগত মান উন্নত করা যায়?						
R2	What do you think about the surface **water quality** status in your neighborhood? আপনার বসবাসরত এলাকার ভূ-উপরিভাগের পানির গুণগত মান (পরিষ্কার, গন্ধহীন) সম্পর্কে আপনার মতামত কি?	□ Extremely pure (সাঙ্ঘাতিক বিশুদ্ধ)	□ Pure (বিশুদ্ধ)	□ Slightly polluted (সামান্য দূষিত)	□ Polluted (দূষিত)	□ Extremely polluted (সাঙ্ঘাতিক দূষিত)	□ Undecided/ Not applicable (সিদ্ধান্ত নেই/ প্রযোজ্য নয়)
R2.1	Reasons behind this quality in your opinion. আপনার মতে এর কারণসমূহ কি?						
R2.2	How to improve water quality? কিভাবে ভূ-উপরিভাগের পানির গুণগত মান উন্নত করা যায়?						
R3	Do you think now its hotter compared to 10 years back? (If "Yes", why?) আপনি কি মনে করেন বর্তমানে আবহাওয়া ১০ বছর আগের তুলনায় বেশি গরম? (উত্তর "হ্যাঁ" হলে, কেন?)	□ Yes			□ No		
R4	How many air conditioner (AC) do you have at home? আপনার বাসায় কয়টি এ. সি. আছে?	□ 0	□ 1	□ 2	□ 3	□ > 3 (Specify)	

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R5	Do you think now winter is colder compared to 10 years back? আপনি কি মনে করেন বর্তমানে শীতকালে ১০ বছর আগের তুলনায় ঠাণ্ডা বেশি পড়ে?	□ Yes			□ No		
R6	Do you think now there are more (urban) floods in Dhaka compared to 10 years back? (If "Yes", why?) আপনি কি মনে করেন বর্তমানে ঢাকা শহরে ১০ বছর আগের তুলনায় জলাবদ্ধতা বেশি হয়? (উত্তর "হ্যাঁ" হলে, কেন?)	□ Yes			□ No		
R7	What do you think about the **noise level** (traffic, construction) in your neighborhood? আপনার বসবাসরত এলাকায় শব্দের মাত্রা (রাস্তা, বিল্ডিং তৈরি) সম্পর্কে আপনার মতামত কি?	□ Extremely quiet (সাঙ্ঘাতিক নীরব)	□ Quiet (নীরব)	□ Slight sound pollution (সামান্য শব্দ দূষণ)	□ Sound pollution (শব্দ দূষণ)	□ Extreme sound pollution (সাঙ্ঘাতিক শব্দ দূষণ)	□ Undecided/ Not applicable (সিদ্ধান্ত নেই/ প্রযোজ্য নয়)
R8	How do you feel in the presence of your neighborhood ecosystems? আপনার নিকটবর্তী প্রাকৃতিক পরিবেশ এর উপস্থিতিতে আপনি কি রকম অনুভব করেন?	□ Extremely good (সাঙ্ঘাতিক ভালো লাগে)	□ Good (ভালো লাগে)	□ Slightly good (সামান্য ভালো লাগে)	□ Bad (ভালো লাগে না)	□ Extremely bad feeling (সাঙ্ঘাতিক খারাপ লাগে)	□ Undecided/ Not applicable (সিদ্ধান্ত নেই/ প্রযোজ্য নয়)
R9	How often (day/week) do you commute/travel? প্রতি সপ্তাহে আপনি কতদিন বাসার বাইরে যাতায়াত করেন?						
R9.1	What kind of transport do you use? (Multiple answers possible) বাসার বাইরে যাতায়াতের জন্য কি ধরনের যানবাহন ব্যবহার করেন? (একাধিক উত্তর সম্ভব)						
R9.2	How far is your travel destination? আপনার গন্তব্য সাধারণত কত দূর (কিলোমিটার) হয়ে থাকে এবং কত সময় (মিনিট) লাগে পৌঁছাতে?	Distance (km)			Time (minute)		

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R9.3	What is your average transportation cost (BDT/travel)? প্রতিবার (ওয়ান ওয়ে) যাতায়াতের খরচ কত টাকা?	□ < 100	□ 100 - 200	□ 200 - 300	□ 300 - 400	□ > 400 (Specify)
R9.4	Does it take more time to commute in wet days compared to dry days? If "Yes", how much more on average? বর্ষাকালে যাতায়াতের সময় বেশি লাগে শুকনা দিনের তুলনায়? (উত্তর "হ্যাঁ" হলে, আনুমানিক কতখানি সময় বেশি লাগে?)	□ Yes			□ No	
R9.5	How much are you willing to pay (WTP) more to move faster in wet days (BDT/person)? প্রতিদিন দ্রুত যাতায়াতের জন্য আপনি সর্বোচ্চ কত টাকা বেশি খরচ করতে রাজী আছেন?					

INFORMATION ON CULTURAL ECOSYSTEM SERVICES (CES)						
C1	Which of the following ecosystems do you visit? (Multiple answers possible) কোন প্রাকৃতিক পরিবেশ গুলো আপনি ভিজিট করেন (একাধিক উত্তর সম্ভব)?	□ Street trees	□ Park/ Botanical Garden/ Zoo	□ Agriculture land	□ Fallow land/ Grassland/ Playground/ Open space	□ River
		□ Pond/ Jheel	□ Lake/ Canal	□ Wetland	□ Others (Specify)	□ None
	উত্তর "না" হলে, কারণ সমূহ কি? এবং C1.1 থেকে C5.1 পর্যন্ত বাদ দিয়ে M1 এ চলে যান।					
C1.1	How often (no./year) do you visit the ecosystems? প্রাকৃতিক পরিবেশ গুলো আপনি বছরে কতবার ভিজিট করেন? (ইকোসিস্টেম এর নামের পাশে নাম্বার লিখে নিতে হবে)	□ Street trees	□ Park/ Garden/ Zoo	□ Agriculture land	□ Fallow land/ Grassland/ Playground/ Open space	□ River
		□ Pond/ Jheel	□ Lake/ Canal	□ Wetland	□ Others (Specify)	□ Not applicable (N/A)

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C1.2	What are your purposes to visit these ecosystems? (Multiple answers possible) প্রাকৃতিক পরিবেশ গুলো আপনি কেন ভিজিট করেন? (একাধিক উত্তর সম্ভব)	***Street trees***	***Park/ Garden/ Zoo***	***Agriculture land***	***Fallow land/Grassland/ Playground/Open space***	***River***
		□ Recreation	□ Recreation	□ Recreation	□ Recreation	□ Recreation
		□ Walk/Exercise	□ Walk/Exercise	□ Walk/Exercise	□ Walk/Exercise	□ Walk/Exercise
		□ Fishing/Sports	□ Fishing/Sports	□ Fishing/Sports	□ Fishing/Sports	□ Fishing/Sports
		□ Spiritual/ Religious reason	□ Spiritual/ Religious reason	□ Spiritual/ Religious reason	□ Spiritual/ Religious reason	□ Spiritual/ Religious reason
		□ Cultural use	□ Cultural use	□ Cultural use	□ Cultural use	□ Cultural use
		□ Others (Specify)	□ Others (Specify)	□ Others (Specify)	□ Others (Specify)	□ Others (Specify)
		Pond/ Jheel	***Lake/ Canal***	***Wetland***	***Others (Specify)***	*N/A*
		□ Recreation	□ Recreation	□ Recreation	□ Recreation	
		□ Walk/Exercise	□ Walk/Exercise	□ Walk/Exercise	□ Walk/Exercise	
		□ Fishing/Sports	□ Fishing/Sports	□ Fishing/Sports	□ Fishing/Sports	
		□ Spiritual/ Religious reason	□ Spiritual/ Religious reason	□ Spiritual/ Religious reason	□ Spiritual/ Religious reason	
		□ Cultural use	□ Cultural use	□ Cultural use	□ Cultural use	
		□ Others (Specify)	□ Others (Specify)	□ Others (Specify)	□ Others (Specify)	
C2	How far (distance in km) are the ecosystems from your home? প্রাকৃতিক পরিবেশ গুলো আপনার বাসা থেকে কত দূরে (কিলোমিটার) অবস্থিত? (ইকোসিস্টেম এর নামের পাশে নাম্বার লিখে নিতে হবে)	□ Street trees	□ Park/ Garden/ Zoo	□ Agriculture land	□ Fallow land/ Grassland/ Playground/ Open space	□ River
		□ Pond/ Jheel	□ Lake/ Canal	□ Wetland	□ Others (Specify)	□ N/A
C3	How long (time in minute) does it take to reach an ecosystem by walking? প্রাকৃতিক পরিবেশ গুলো তে আপনার বাসা থেকে পায়ে হেঁটে পৌঁছাতে কত সময় (মিনিট) লাগে? (ইকোসিস্টেম এর নামের পাশে নাম্বার লিখে নিতে হবে)	□ Street trees	□ Park/ Garden/ Zoo	□ Agriculture land	□ Fallow land/ Grassland/ Playground/Open space	□ River
		□ Pond/ Jheel	□ Lake/ Canal	□ Wetland	□ Others (Specify)	□ N/A

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C4	What is your cost (BDT/travel) to visit the ecosystems? প্রাকৃতিক পরিবেশ গুলো ভিজিট করতে প্রতিবার আপনার কত টাকা খরচ হয়? (ইকোসিস্টেম এর নামের পাশে নাম্বার লিখে নিতে হবে)	□ Street trees	□ Park/ Garden/ Zoo	□ Agriculture land	□ Fallow land/ Grassland/ Playground/Open space	□ River
		□ Pond/ Jheel	□ Lake/ Canal	□ Wetland	□ Others (Specify)	□ N/A
C5	Will you be WTP more if there is any cost involved and/or entry fees are raised? ভবিষ্যতে প্রাকৃতিক পরিবেশ গুলো ভিজিট করতে টাকা খরচ হলে অথবা বর্তমানের তুলনায় এন্ট্রি খরচ বৃদ্ধি পেলে কি আপনি এগুলো ভিজিট করতে আগ্রহী হবেন?	□ Yes			□ No	
C5.1	If "Yes", how much (BDT/month) will be your WTP for the ES? (If the respondent has the property right then ask the Willingness to Accept) উত্তর "হ্যাঁ" হলে, প্রতিবার ভিজিটে আপনি কোন সার্ভিসের জন্য সর্বোচ্চ কত টাকা খরচ করতে রাজী আছেন? (ইকোসিস্টেম সার্ভিসের নামের পাশে নাম্বার লিখে নিতে হবে)	***Street trees***	***Park/ Garden/ Zoo***	***Agriculture land***	***Fallow land/Grassland/ Playground/Open space***	***River***
		□ Recreation	□ Recreation	□ Recreation	□ Recreation	□ Recreation
		□ Walk/ Exercise	□ Walk/Exercise	□ Walk/Exercise	□ Walk/Exercise	□ Walk/Exercise
		□ Fishing/Sports	□ Fishing/Sports	□ Fishing/Sports	□ Fishing/Sports	□ Fishing/Sports
		□ Spiritual/ Religious reason	□ Spiritual/ Religious reason	□ Spiritual/ Religious reason	□ Spiritual/ Religious reason	□ Spiritual/ Religious reason
		□ Cultural use	□ Cultural use	□ Cultural use	□ Cultural use	□ Cultural use
		□ Others (Specify)	□ Others (Specify)	□ Others (Specify)	□ Others (Specify)	□ Others (Specify)
		Pond/ Jheel	***Lake/ Canal***	***Wetland***	***Others (Specify)***	*N/A*
		□ Recreation	□ Recreation	□ Recreation	□ Recreation	
		□ Walk/Exercise	□ Walk/Exercise	□ Walk/Exercise	□ Walk/Exercise	
		□ Fishing/Sports	□ Fishing/Sports	□ Fishing/Sports	□ Fishing/Sports	
		□ Spiritual/ Religious reason	□ Spiritual/ Religious reason	□ Spiritual/ Religious reason	□ Spiritual/ Religious reason	
		□ Cultural use	□ Cultural use	□ Cultural use	□ Cultural use	
		□ Others (Specify)	□ Others (Specify)	□ Others (Specify)	□ Others (Specify)	

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INFORMATION ON GREEN ADAPTATION (GA) FOR ECOSYSTEM SERVICES (ES) MANAGEMENT						
M1	Which GA measures do you think are implementable with individual effort? পরিবেশ বান্ধব কোন পদ্ধতি গুলো আপনার কাছে ব্যক্তিগত চেষ্টায় বাস্তবায়ন যোগ্য বলে মনে হয়? (একাধিক উত্তর সম্ভব)	□ Green belt around the neighborhood (বসবাসরত এলাকা ঘিরে সবুজ বেষ্টনী)	□ Pocket park (ছোট পার্ক)	□ Community garden (যৌথ বাগান)	□ Rooftop garden/ agriculture (ছাদের বাগান/ ছাদ কৃষি)	□ Green roof (মাটি ভরাট করা সবুজ ছাদ)
		□ Green facade (কার্পেটের মতো লতানো গাছ বিছানো সবুজ ফটক)	□ Lake around the neighborhood (managing existing lake/canal) (নিকটবর্তী লেক/ খাল সৃষ্টি বা ব্যবস্থাপনা)	□ Artificial wetland (কৃত্রিম জলাভূমি)	□ Water retention pond (বৃষ্টির পানি জমানোর পুকুর)	□ porous pavements (সচ্ছিদ্র ফুটপাথ)
		□ Artificial fountains (কৃত্রিম ফোয়ারা)	□ Rain water harvest tank in the building (নিজস্ব বাড়িতে বৃষ্টির পানি ধরে রাখার ট্যাঙ্ক)	□ Others (Specify)	□ Others (Specify)	□ None
M2	Which GA measures do you think are implementable with community effort? পরিবেশ বান্ধব কোন পদ্ধতি গুলো আপনার কাছে সমষ্টিগত ভাবে বাস্তবায়ন যোগ্য বলে মনে হয়? (একাধিক উত্তর সম্ভব)	□ Green belt around the neighborhood (বসবাসরত এলাকা ঘিরে সবুজ বেষ্টনী)	□ Pocket park (ছোট পার্ক)	□ Community garden (যৌথ বাগান)	□ Rooftop garden/ agriculture (ছাদের বাগান/ ছাদ কৃষি)	□ Green roof (মাটি ভরাট করা সবুজ ছাদ)
		□ Green facade (কার্পেটের মতো লতানো গাছ বিছানো সবুজ ফটক)	□ Lake around the neighborhood (managing existing lake/canal) (নিকটবর্তী লেক/ খাল সৃষ্টি বা ব্যবস্থাপনা)	□ Artificial wetland (কৃত্রিম জলাভূমি)	□ Water retention pond (বৃষ্টির পানি জমানোর পুকুর)	□ porous pavements (সচ্ছিদ্র ফুটপাথ)
		□ Artificial fountains (কৃত্রিম ফোয়ারা)	□ Rain water harvest tank in the building (নিজস্ব বাড়িতে বৃষ্টির পানি ধরে রাখার ট্যাঙ্ক)	□ Others (Specify)	□ Others (Specify)	□ None

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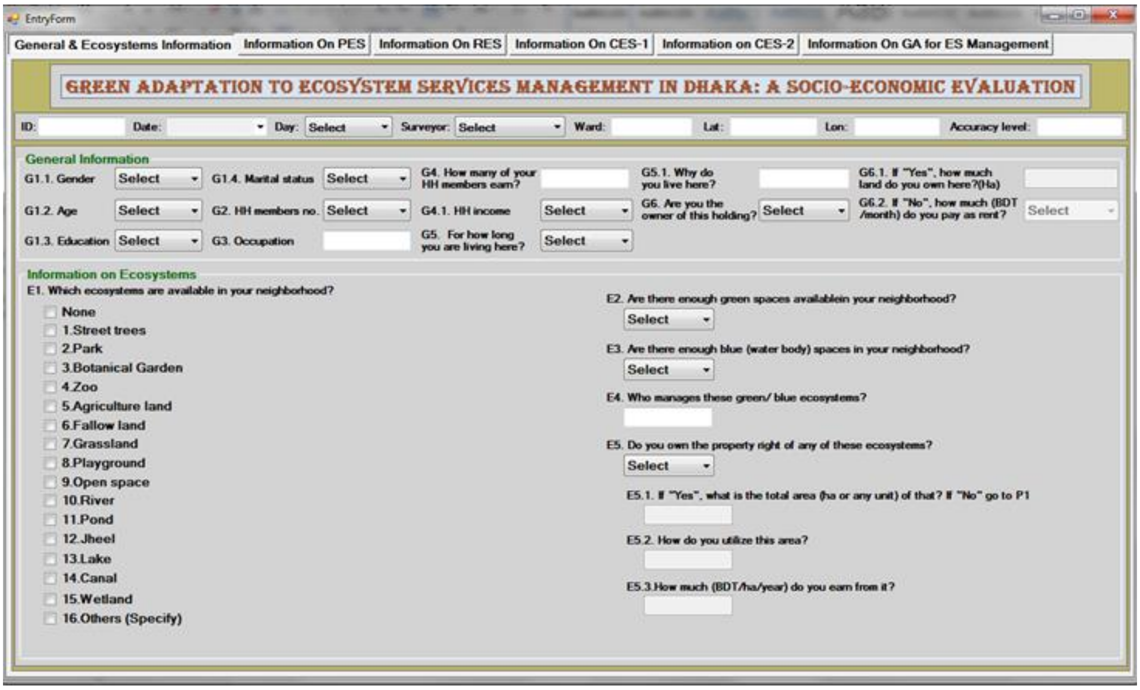
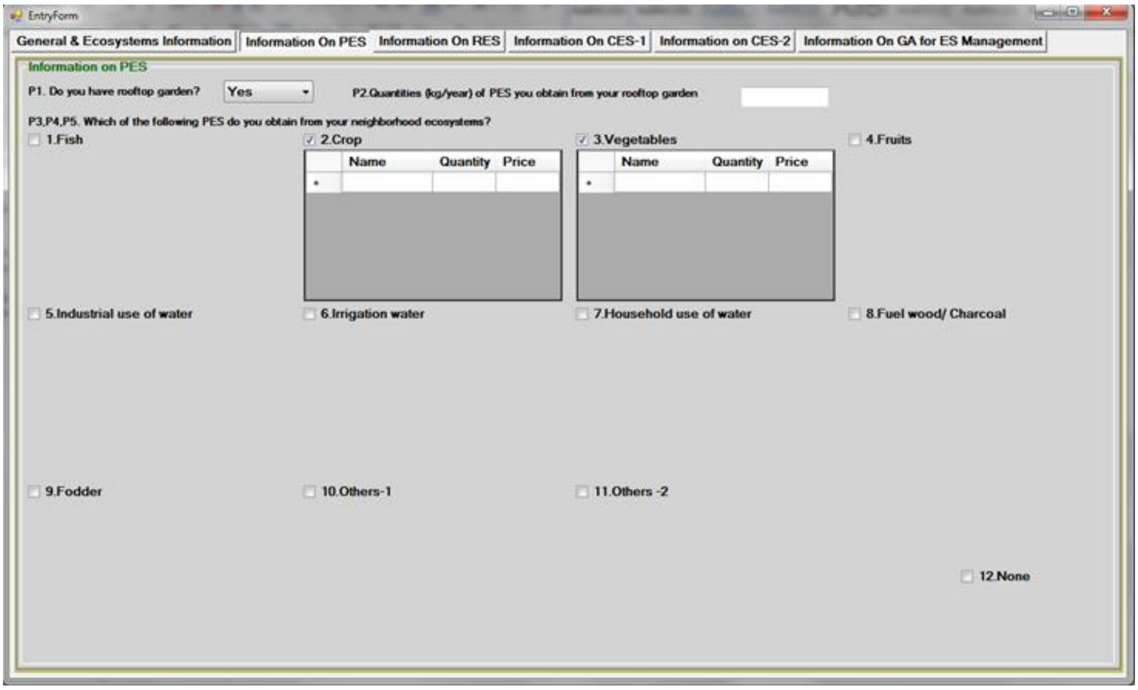
M3	How much are you WTP (BDT/month) to implement the chosen measures? আপনার পছন্দের পরিবেশ বান্ধব পদ্ধতি গুলো বাস্তবায়নের জন্য আপনি প্রতি মাসে সর্বোচ্চ কত (টাকা) খরচ করতে রাজী আছেন? (একাধিক উত্তর সম্ভব)	Green belt around the neighborhood		Pocket park		Community garden		Rooftop garden/ agriculture		Green roof	
		Green facade		Lake around the neighborhood (managing existing lake/canal)		Artificial wetland		Water retention pond		porous pavements	
		Artificial fountains		Rain water harvest tank in the building		Others (Specify)		Others (Specify)		N/A	
M4	Will you be interested to implement GA measures if you get access to easy loan from banks? পরিবেশ বান্ধব পদ্ধতি গুলো বাস্তবায়নের জন্য ব্যাংক থেকে সহজ শর্তে ঋণ পাওয়ার সুযোগ পেলে আপনি তা নিতে আগ্রহী হবেন?	□ Yes				□ No					
M5	In what ways awareness can be raised/people can be motivated for environmental management in your neighborhood? বসবাসরত এলাকার প্রাকৃতিক পরিবেশ সুন্দর রাখার জন্য জনগণকে কিভাবে সচেতন/উদ্বুদ্ধ করা যেতে পারে?										
M6	Do you know where is your household waste deposited after collection? আপনি কি জানেন আপনার ঘরের প্রতিদিনের গৃহস্থালি ময়লা সংগ্রহের পর কোথায় ফেলা হয়?	□ Yes				□ No					
M7	Will you be interested to do source separation of waste in your home? আপনি কি আপনার ঘরে গৃহস্থালি ময়লা পৃথকীকরণ পদ্ধতি অবলম্বন করতে আগ্রহী হবেন?	□ Yes				□ No					

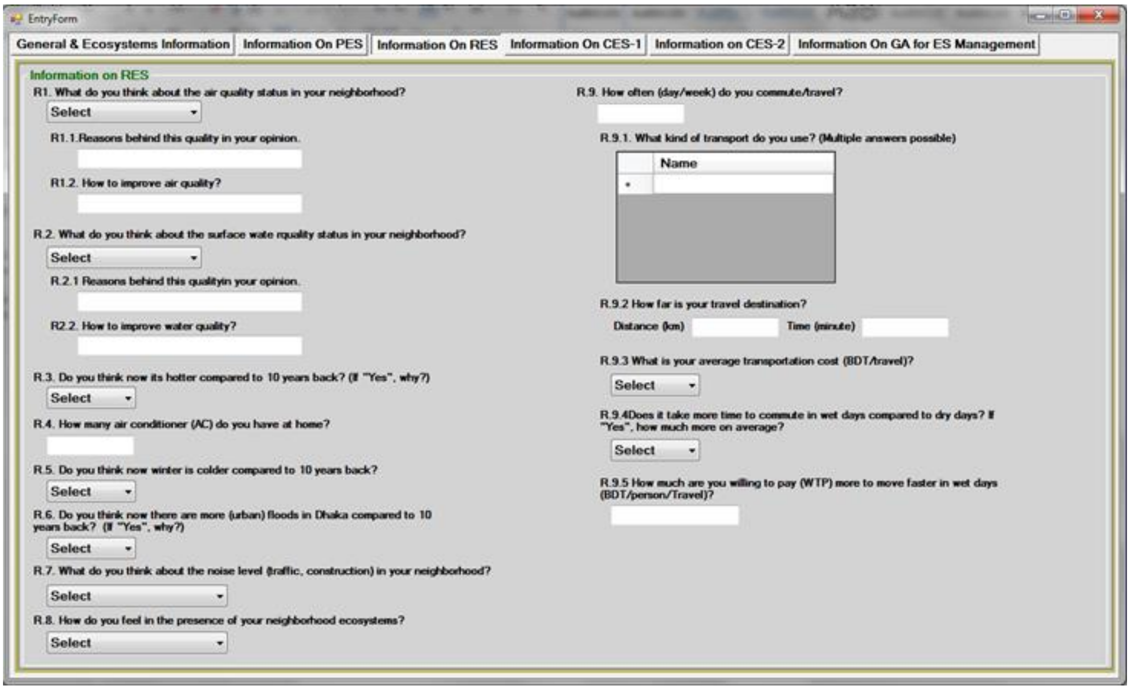
THANK YOU VERY MUCH FOR YOUR TIME AND VALUABLE OPINION.

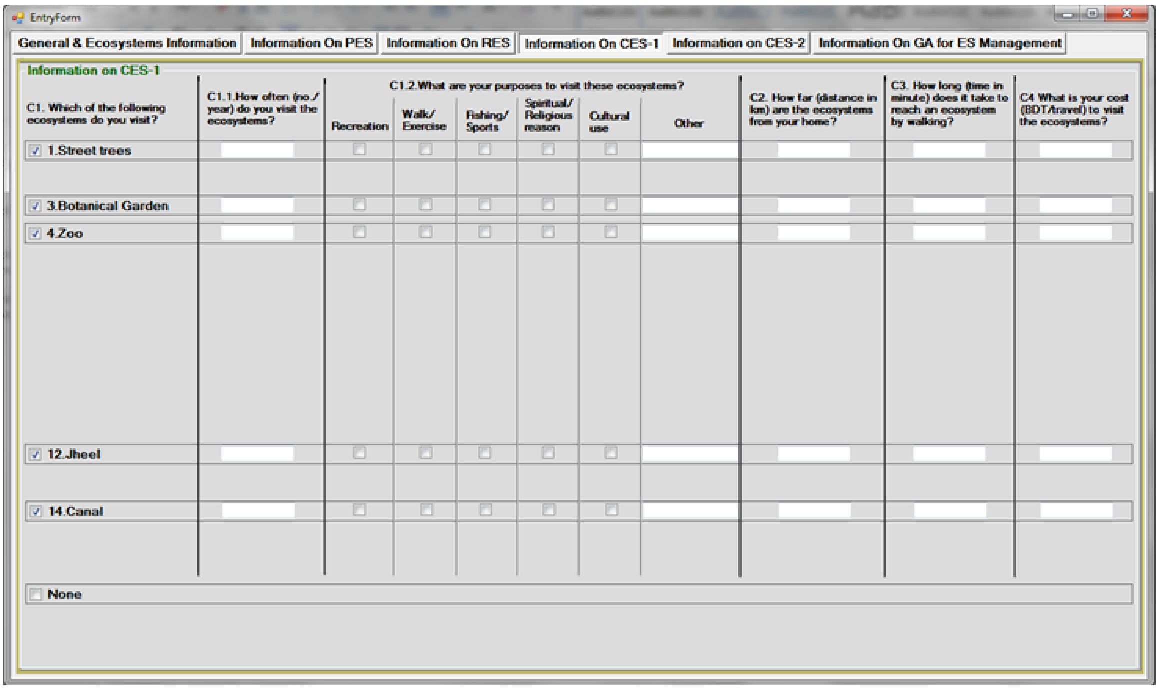
Green Adaptation to Ecosystem Services Management in Dhaka: A Socio-economic Evaluation 10

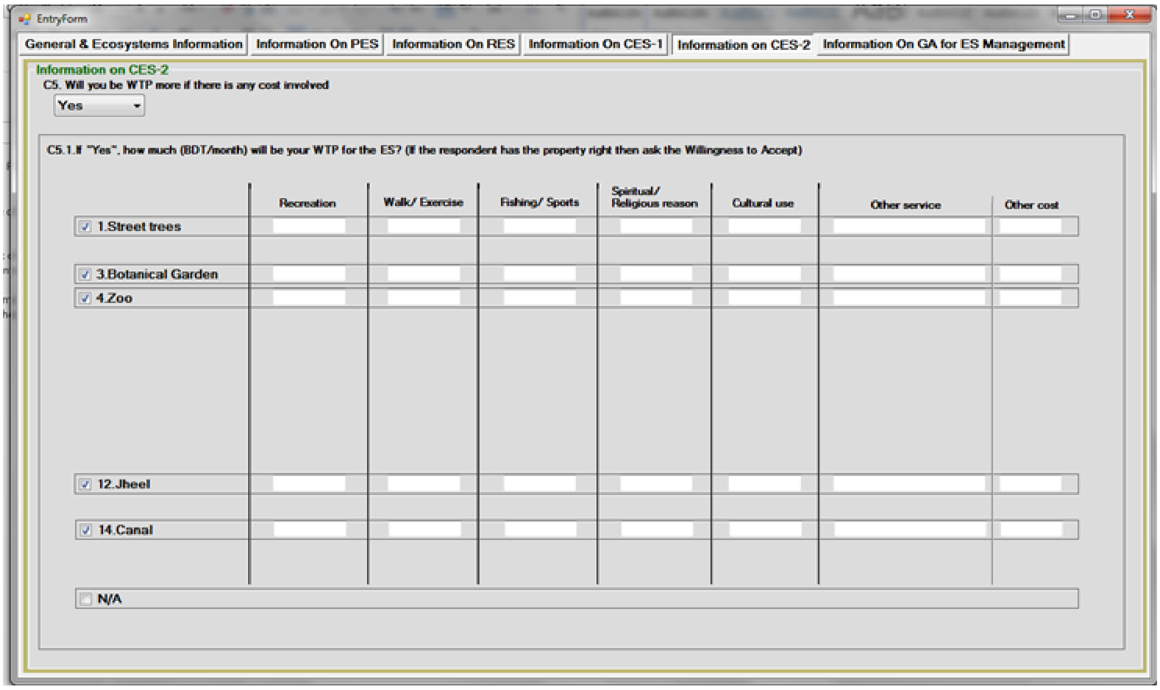
Data entry software for survey data digitalization

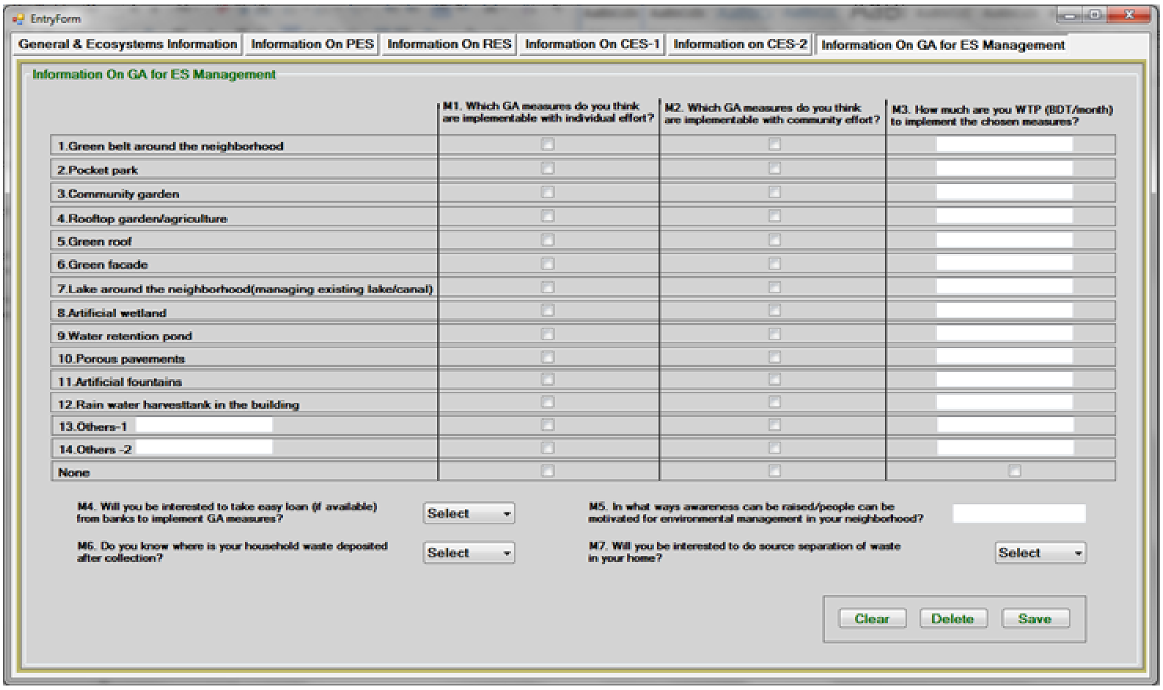



EntryForm
General & Ecosystems Information
Information On PES
Information On RES
Information On CES-1
Information on CES-2
Information On GA for ES Management
Information on PES
P1. Do you have rooftop garden?
Yes
P2.Quantities (kg/year) of PES you obtain from your rooftop garden
P3,P4,P5. Which of the following PES do you obtain from your neighborhood ecosystems?
1.Fish
2.Crop
Name Quantity Price
3.Vegetables
Name Quantity Price
4.Fruits
5.Industrial use of water
6.Irrigation water
7.Household use of water
8.Fuel wood/ Charcoal
9.Fodder
10.Others-1
11.Others -2
12.None


EntryForm
General & Ecosystems Information
Information On PES
Information On RES
Information On CES-1
Information on CES-2
Information On GA for ES Management
Information on RES
R1. What do you think about the air quality status in your neighborhood?
Select
R1.1.Reasons behind this quality in your opinion.
R1.2. How to improve air quality?
R.2. What do you think about the surface wate rquality status in your neighborhood?
Select
R.2.1 Reasons behind this qualityin your opinion.
R2.2. How to improve water quality?
R.3. Do you think now its hotter compared to 10 years back? (If "Yes", why?)
Select
R.4. How many air conditioner (AC) do you have at home?
R.5. Do you think now winter is colder compared to 10 years back?
Select
R.6. Do you think now there are more (urban) floods in Dhaka compared to 10 years back? (If "Yes", why?)
Select
R.7. What do you think about the noise level (traffic, construction) in your neighborhood?
Select
R.8. How do you feel in the presence of your neighborhood ecosystems?
Select
R.9. How often (day/week) do you commute/travel?
R.9.1. What kind of transport do you use? (Multiple answers possible)
Name
R.9.2 How far is your travel destination?
Distance (km)
Time (minute)
R.9.3 What is your average transportation cost (BDT/travel)?
Select
R.9.4Does it take more time to commute in wet days compared to dry days? If "Yes", how much more on average?
Select
R.9.5 How much are you willing to pay (WTP) more to move faster in wet days (BDT/person/Travel)?


EntryForm
General & Ecosystems Information
Information On PES
Information On RES
Information On CES-1
Information on CES-2
Information On GA for ES Management
Information on CES-1
C1. Which of the following ecosystems do you visit?
C1.1.How often (no./year) do you visit the ecosystems?
C1.2.What are your purposes to visit these ecosystems?
Recreation
Walk/ Exercise
Fishing/ Sports
Spiritual/ Religious reason
Cultural use
Other
C2. How far (distance in km) are the ecosystems from your home?
C3. How long (time in minute) does it take to reach an ecosystem by walking?
C4 What is your cost (BDT/travel) to visit the ecosystems?
1.Street trees
3.Botanical Garden
4.Zoo
12.Jheel
14.Canal
None


EntryForm
General & Ecosystems Information
Information On PES
Information On RES
Information On CES-1
Information on CES-2
Information On GA for ES Management
Information on CES-2
C5. Will you be WTP more if there is any cost involved
Yes
C5.1.If "Yes", how much (BDT/month) will be your WTP for the ES? (If the respondent has the property right then ask the Willingness to Accept)
Recreation
Walk/ Exercise
Fishing/ Sports
Spiritual/ Religious reason
Cultural use
Other service
Other cost
1.Street trees
3.Botanical Garden
4.Zoo
12.Jheel
14.Canal
N/A



EntryForm

General & Ecosystems Information | Information On PES | Information On RES | Information On CES-1 | Information on CES-2 | Information On GA for ES Management

Information On GA for ES Management

	M1. Which GA measures do you think are implementable with individual effort?	M2. Which GA measures do you think are implementable with community effort?	M3. How much are you WTP (BDT/month) to implement the chosen measures?
1.Green belt around the neighborhood			
2.Pocket park			
3.Community garden			
4.Rooftop garden/agriculture			
5.Green roof			
6.Green facade			
7.Lake around the neighborhood(managing existing lake/canal)			
8.Artificial wetland			
9.Water retention pond			
10.Porous pavements			
11.Artificial fountains			
12.Rain water harvesttank in the building			
13.Others-1			
14.Others -2			
None			

M4. Will you be interested to take easy loan (if available) from banks to implement GA measures? Select

M5. In what ways awareness can be raised/people can be motivated for environmental management in your neighborhood?

M6. Do you know where is your household waste deposited after collection? Select

M7. Will you be interested to do source separation of waste in your home? Select

Clear Delete Save

Snapshots taken during fieldwork in Dhaka.

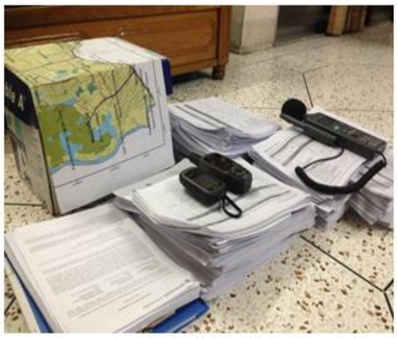
Planning for field work

Roadside tree measurement

Observing noise level

Survey activity

A hand-held GPS device



Materials used for data collection

List of courses attended at Monash University

Activity Type Title	Total Hours	Activity	Activity Title	Module Title	Date
GRD/Research Essentials	3.00	M11009	Starting a research project	Graduate Researcher Development Module 1	21/04/2015
GRD/Research Essentials	6.00	M11039	Preparing for confirmation	Graduate Researcher Development Module 1	23/10/2015
GRD/Research Essentials	3.00	M11057	How to plan your PhD	Graduate Researcher Development Module 1	21/05/2015
GRD/Research Essentials	1.50	M11063	Thesis writing essentials-- Editing and proofreading your thesis for readability	Graduate Researcher Development Module 1	3/11/2015
GRD/Research Essentials	7.00	M11509	MS Excel 2013: Data analysis (2016)	Graduate Researcher Development Module 1	12/08/2016
GRD/Research Essentials	2.00	M11706	Introduction to Statistical Tests (2016)	Graduate Researcher Development Module 1	10/08/2016
Compulsory Training/Learning Domain	0.00	M31098	Monash Graduate Research Induction (Online)	Compulsory Training Module	30/12/2016
DED/Learning Domain	30.00	M31069	Advanced Research Methods Workshop	Compulsory Training Module	30/03/2015

List of events attended/other activities performed during PhD enrolment

Paper presented on *Significance of urban green and blue spaces: Identifying and valuing provisioning ecosystem services in Dhaka city* in the 5th International Conference on Sustainable Development (ICSD), September 2017, Rome, Italy.

Gave a seminar on *Unacknowledged values of urban ecosystems* at the University of Southampton, August 2017, Southampton, United Kingdom.

Gave a seminar on *Unacknowledged values of urban ecosystems* at Mercy Corps Indonesia, August 2017, Jakarta, Indonesia.

Published a photo essay on *Intercropping, a climate change adaptation initiative in the Philippines* on the Asian Cities Climate Change Resilience Network (ACCCRN) website, June 6, 2017. https://www.acccrn.net/blog/label/Stories%20from%20the%20Field?page=5

Attended a 5-day *Photography expedition to climate resilient projects* organized by Asian Cities Climate Change Resilience Network (ACCCRN), May 2017, Batangas City, The Philippines.

Voted as one of the finalists for the photo essay on *Breathing in a jungle of concrete* in the ACCCRN 2017 Photo Essay Competition, May 15, 2017.
https://www.acccrn.net/blog/breathing-jungle-concrete

Presented on *Importance of urban green and blue spaces: The case of Dhaka city* in the Australia Awards Short Course: Overcoming Barriers to Small and Medium Enterprise Development Indonesia, Monash University, May 11, 2017, Melbourne, Australia.

Presented on *Rooftop Gardening: An adaptation solution for a highly built-up city- Dhaka* in the Australia Awards Short Course: Sustainable Development of Indonesia's Aquatic Living Resources program, Monash University, February 20, 2017, Melbourne, Australia..

Paper presented on *Rooftop gardening in Dhaka: An adaptation measure of the commoners* in the 3rd annual Gobeshona Conference for research on climate change in Bangladesh, January 2017, Dhaka, Bangladesh.

Presented on *Women's preferences of urban ecosystem management: An assessment for Dhaka city* in the Australia Awards Short Course: Empowering Women for Sustainable Development of Indonesia's Aquatic Living Resources program, Monash University, October 20, 2016, Melbourne, Australia.

Gave a lecture on *Urban ecosystems* in the Climate Change and Development MSc program at Independent University Bangladesh (IUB), March 25, 2016, Dhaka, Bangladesh.

Gave a seminar on *My PhD research* at International Centre for Climate Change and Development (ICCCAD), February 4, 2016, Dhaka, Bangladesh.

Was a Visiting Researcher at International Centre for Climate Change and Development (ICCCAD), January - June, 2016, Dhaka, Bangladesh.

ABOUT THE AUTHOR

Naeema Jihan Zinia was born in Dhaka, Bangladesh. She graduated from Holy Cross Girls' High School and Holy Cross College. Zinia holds a Bachelor of Social Sciences (Honours) degree and a Master of Social Sciences degree in Economics from the University of Dhaka. She also attained her Master of Science degree in Urban Environmental Management with the specialization in Environmental Systems Analysis from Wageningen University in the Netherlands.

Prior to starting her doctoral research at Monash University, Zinia worked as a researcher at the Centre for Environmental and Geographic Information Services (CEGIS) in Dhaka, where she was actively involved in several projects of national and international significance. Her key responsibilities included assessing environmental and economic impact, developing economic modelling of climate change adaptation strategies, designing questionnaires, conducting field visit, training surveyors, analyzing and interpreting data, writing project reports, organizing events, and being the project leader for overall project management. She also has teaching experience at undergraduate levels.

From her very childhood, Zinia has been witnessing her beloved city growing primarily in an unsustainable and unplanned manner. In addition, she has had the opportunity to visit many natural hazard prone places in Bangladesh. Zinia always felt that Bangladeshi citizens were less aware of environmental resource management at all scales. Her primary motivation, therefore, has been to equip herself with the relevant knowledge to understand the reasons behind environmental management challenges and to find ways to mitigate that. Whatever she does for her homeland may be insignificant; nevertheless, she finds it important that to take action.

শাপলা | Water Lily

বাংলাদেশ জাতীয় উদ্ভিদ উদ্যান, মিরপুর, ঢাকা