A STUDY ON THE APPROACHES TO RESIDENTIAL DEVELOPMENT IN LOWLANDS OF THE PERI-URBAN AREAS OF DHAKA CITY

By
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A thesis titled ‘A Study On The Approaches To Residential Development In Lowlands Of The Peri-Urban Areas Of Dhaka City’ submitted by Labib Hossain, Student Number 0412012022, Session April 2012 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Architecture on 8 August 2015

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma

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Abstract

Bangladesh is located within the world’s largest Ganges-Brahmaputra Delta and the unique relation between land and water is quite evident throughout the landscape of the country. Yet for the development of its capital, Dhaka city, its unique natural landscapes and its dynamics is quite often neglected. Available land of the city core area being filled up, the city has been stretching towards its periphery often by unplanned and unguided sandfilling the lowlands and wetlands of the existing watershed area. As a result of increasing impermeable surfaces resulting from such filling activities, degraded hydrologic conditions are increasing. The city is suffering from as a number of negative environmental consequences. Increasing flood vulnerability, impact of climate change, loss of habitat and water pollution are among the negative impacts. The existing natural wetlands need to be preserved and lost wetlands need to be restored by introducing constructed wetlands, to face the challenges the city. For the preservation and restoration process along with the residential development, the functions of wetlands need to be analyzed and retained as far as possible.

In this research, first stage of work involved mapping of categorized watersheds of Dhaka region to observe the current conditions and for identifying a study area in the periphery of Dhaka City. The field study analyzed the existing conditions of the area. GIS (Geographic Information System) and Remote Sensing methods were applied as tools for this mapping.

The research produced indicative design strategies as an outcome of the mapping study and field study. In order to limit the impact on the watershed general design strategies for the regional scale and indicative design strategies for the neighborhood scale have been presented. Finally design strategies pertaining to building scale have been presented that help adapt to the natural dynamics of its surrounding.
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Labib Hossain
August, 2015
Chapter One: Preamble

1.1 Introduction

1.2 Research Question

1.3 Objectives

1.4 Research Methodology

1.4.1 Literature study

1.4.2 Mapping study

1.4.3 Field Study

1.5 Scopes and Limitations of Research

1.6 Organization of the Research

1.7 Flow Diagram Of Thesis
Chapter One: Preamble

1.1 Introduction

Global city population is increasing rapidly and the challenges of contemporary cities especially those that are located in vulnerable landscapes and critical ecologies require deep understanding of context and its cultural, social, political, economical and environmental phenomenon. To face those challenges needs new kind of city thinking and therefore new kind of investigation integrating disciplines.

Bangladesh is located in the world’s largest delta with more than eight hundred waterways that flow down from the Himalayas in an intricate pattern of streams, tributaries and rivers (Ashraf 2010). For centuries, the Bangladeshi people have depended on the rivers flowing all over the country for transportation, trade, and generating livelihoods. Unfortunately, the unique relationship between the land and water is quite often being neglected in the development of its capital, Dhaka city. Dhaka is now growing at a mind-numbing speed spreading over less urbanized wetlands in every direction with dangerous environmental ramifications. The country’s population is expected to grow until it reaches 250 million and thus the expansion of the city is assumed due to increasing population (Rashid 2014). As all the highlands are already built and covered, rivers are being encroached and lowlands and wetlands are being filled up to accommodate its ever-increasing population. The satellite image of Dhaka city shows the presence of water bodies that girdle the city, particularly in the east and west periphery. These surrounding lowlands and wetlands, which generally acted as flood basin for Dhaka is now unable to fulfill its purpose (Ashraf 2010). Mainly, filling up of these lowlands is for the migrated low-middle income people, resulted in increasing imperviousness and negative impacts on the watershed\(^1\). This approach

\(^1\) A watershed is the area of land where all of the water that is under it or drains off of it goes into the same place (rivers, basins or seas).
to land development is affecting the resilience of the city (Islam S., et al. 2010). This disturbance on environment is making the situation worse for the inhabitants of Dhaka city. In order to avoid an impending environmental crisis, the existing natural matrix throughout the country need to be taken as a starting point for envisioning the future development of the city.

![Figure 1: Satellite image showing Dhaka city and surrounding environment, calendar year 1999](Source: Geology.com)

1.2 Problem Statement:

To protect the Dhaka city from flooding, numbers of human-interventions (such as dams, dikes, embankments, etc.) has been made. As a result of massive urbanization most of the inland waterbodies have been filled, encroached, canals

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2 The image is compiled using NASA's GeoCover data, collected during Calendar Year 1999 and was copyright by Geology.com. Website Link: [http://geology.com/world-cities/](http://geology.com/world-cities/)
converted to culverts. These interventions hampers the resiliency of the city and the situation become worse because of massive filling of lowlands and wetlands at the periphery of the city. Historic and current water management practices and urban development have resulted in significant environmental damage which is not only harming the fragile delta ecosystem, but also increasing flood risk. The surrounding lowlands generally hold the flood water is now unable to function properly.

Taken the fact that the city population will increase, the current approach of filling wetlands for current and future residential development need to be questioned critically. If the surrounding wetlands can not be filled and their functions need to be preserved then the research question can be coined as “How can the diverse ecology and unique natural dynamics of delta environment be restored and integrated with the new and existing urban residential development at the peri-urban areas of Dhaka city?”

The general common knowledge is to preserve the waterbodies along with their natural eco-system for their important contributing functions. This study have been tried to validate this general understanding through scientific enquiries. The enquiries include discussion from different disciplines include Architecture, Planning, Landscape Architecture, Geography and Engineering.

Figure 2: How to create meaningful coexistence of two different conditions
1.3 Objectives:

1. To develop a symbiosis paradigm, searching for a different approach, where housing formation is in harmony with surrounding wetland ecosystem.
2. To preserve natural wetlands and to restore lost wetlands by means of constructed wetlands. Against land filling or sand filling approach.

![Diagram: The different approach to residential development by preservation and restoration of wetlands]

Figure 3: The different approach to residential development by preservation and restoration of wetlands

1.4 Research Methodology:

1.4.1 Literature Review:
Related literature on Dhaka City’s growth have been reviewed and summarized to support the relevance of analyzing the impact of the loss of lowlands and increasing imperviousness in peri-urban areas. Established guidelines on imperviousness in different watersheds have been reviewed from international published papers, previously conducted research on developing strategies, the local standards and land development regulations have been studied from relevant published documents to contextualize the strategies. For the understanding of wetlands, ecology of wetlands have been discussed to give an overview of the necessary biological functions of natural wetlands and scope of constructed wetlands. Local literature has been referenced to contextualize the understandings through narratives, graphs, figures etc. For the extended discussion on constructed
wetlands, the components of wetlands and methods of general calculations for the sizing of constructed wetlands in residential developments have been reviewed.

1.4.2 Mapping Study:
A mapping of impervious surface of Dhaka will be created at first using ArcGIS 10.1 as a tool. Then using the threshold of imperviousness, a categorized watershed mapping of Dhaka city and surrounding will be produced. GIS and RS methods will be applied using ArchGIS 10.1 and ILWIS 3.4 as supportive tools. This mapping will help to identify the study area for future residential development with minimum intervention and for developing strategies. Then again after the field study, a projected map of impervious surface in Keraniganj (a suburban area located at the south-west of Dhaka city) will be created using the outcome of field study.

1.4.3 Field Study:
Field Study will be conducted on the selected area at the peri-urban of Dhaka city where typical land filling approach is present. This area will be identified from the categorized watershed map, produced from the mapping study. The study will be conducted in three different scales for better understanding of the existing situation. These three scales are regional scale, neighborhood scale and building scale. A case study will be analyzed using the outcome from the theoretical study of wetlands. The outcome will be interpreted through figures, graphs and sketches. These outcomes will help to generate indicative design strategies as findings at the end of this thesis.

1.5 Scopes and Limitations of Research:
The research has the following limitations and scopes:

Validity and Reliability: The maps used for GIS method is from 29th August, 2011 by U.S. Geological Survey. The maps of later dates were not available or very expensive to buy. But with the recent maps the generated maps of imperviousness and categorized watershed would be more accurate as the phenomena like
increasing built-up area, loss of waterbodies is very fast in this context for the last decade. However, one of the core topic of discussion in this thesis, the process of the conversion of sand-filled area to built up area is quite slow after 2011 due to DAP (Detail Area plan) proposed constrictions to built on lowlands.

Another limitation was inadequacy of research material. As the research is constructed on a set of inter-disciplinary (such as Urban planning, Landscape Architecture, Urban Design, Geography, Water management, Environmental management etc.) questions, the research needs explanation from different disciplines. Lack of relevant research by other disciplines particularly in local context and lack of access to archival materials have limited this investigation.

1.6 Organization of the Research:

This research has been organized in five different chapters. In First Chapter, general introduction to the study topic and the basis of the research question is explained with the existing thoughts and approach towards the research problem. At first, it outlines the research problem and sets the key objectives of this study. Second, it reviews the existing condition and local approach towards the problem and identifies the gap in local practice.

The Second Chapter briefly explains the urban context of the Dhaka region and its surrounding peri-urban areas, its landscape and surrounding matrix, its hydrologic network and concepts of ‘Eco-urbanism’ and prospects for the Dhaka city. In explaining the context, at first it gives the historical review of the city and then provides the scenario of urban development, landuse and its population that are related with the research problem of this study. For explaining the urban area and surrounding landscape, its morphology, condition of urban waterbodies are briefly described. Under urban hydrology, its deltaic landscape position and relation with the surrounding river system and hydrologic network are explained along with inland water system.
In the Third Chapter, Ecology of wetlands is briefly explained both its global aspects and local aspects. In suburban context, the ecology of both natural wetlands and constructed wetlands are explained with its biological features and also identifies its relation with the cityscape. The engineering of wetlands will be followed with the general discussion on the components of wetlands and the calculations for wetlands sizing. The chapter will then interrogates the impacts of imperviousness as a result of urbanization and degradation of hydrologic network as the result of current approach of land development particularly at the peri-urban area of Dhaka city. The thresholds for impervious surface will be discussed for the mapping study in next chapter.

The Fourth Chapter contains the mapping study and field survey. Geographic Information System (GIS) and Remote Sensing (RS) methods are applied for mapping the impervious surface and categorized watershed map of the Dhaka region to fix a study area for in-depth study in three scales, regional, neighborhood and building scale and developing strategies. ArcGIS 10.1 and ILWIS 3.4 are used as supportive tools in this process. Existing land development and its consequences are analyzed in relation with the output maps from GIS analysis and the limitations in the existing local rules and regulations specially in residential development are identified that are acting as catalyst for such negative consequences in peri-urban landscape.

The Fifth Chapter examines the inter-related aspects mentioned in the previous chapters and the findings are used to develop some indicative design strategies for residential development at the fringe of the city in three different scales: Regional scale, Community/Neighborhood scale and in Building scale. General strategies are outlined for the Regional scale strategies as most of it are under Planning level strategies. Indicative design strategies are given for Neighborhood scale and for Building scale to minimize the negative consequences of current approach of residential development at the peri-urban area of Dhaka city. After discussion on the preservation of the natural wetlands and restoration of the lost wetlands as
constructed wetlands, discussion on ‘connected wetlands/network’ comes automatically for having its actual advantages like as ecological network, transportation, hydrologic network, recreation/commerce etc. Each of these topics can be taken as scopes for further research as a continuation of this study.

The following chapter will discuss in detail on the urban context of Dhaka region and related urban issues and the concept of ‘ecological urbanism’ with the prospects of Dhaka city.
1.7 Flow Diagram Of Thesis:

Figure 4: Flow Diagram of thesis
References:


Rashid S. (2014), Compact Township and The Magical 10%, The University Press Limited, Chapter 1, pg. 1

Chapter 2: Urban Context and Surrounding Landscape

2.1 Introduction

2.2 History and Growth of Dhaka City

2.3 Urban Context of Dhaka Region

2.3.1 Landuse
2.3.2 Wetlands

2.3 Urban Area and Surrounding Landscape

2.4 Impact of Climate Change on Dhaka

2.4.1 Flood Vulnerability
2.4.2 Drainage Congestion
2.4.3 Micro-climatic Impact

2.5 Concept of Ecological Urbanism and prospect of Dhaka City
Chapter 2: Urban Context and Surrounding Landscape

2.1 Introduction

In this chapter, at first a short description of the history and growth of Dhaka city has been described. For the understanding of urban context of Dhaka region its landuse change and loss of wetlands have been presented along with the discussion on its surrounding landscape. As a consequence of these changes particularly loss of wetlands; flood vulnerability, drainage problem, and microclimatic impacts have been demonstrated as major climate change impacts on Dhaka city. At last the concepts of Ecological Urbanism have been discussed with the prospect of Dhaka city in this field.

2.2 History and Growth of Dhaka City

From its beginning as a small city with a few thousand people, Dhaka actually experienced dramatic turns upward and today it has become one of the fastest growing mega cities of the world. Its existence as a major urban assemblage has been consistent over a period of 400 years.

In the 16th century, it was a thana or military outpost having a population of only 3000 people with an area of 2 sq-km (UNEP 2005). Dhaka declared as a capital city of the eastern province in 1608 was a major incident in Dhaka’s history. Since then Dhaka has experienced urbanization and trends of development.

The whole 17th century is remembered as a golden age in the history of Dhaka as the Dhaka extended from the bank of river Buriganga to the east, west and north (Rahman 2010). Buriganga river played an important role in the development of Dhaka city (Dani 1962). Its journey starts from the bank of that river and it was the main medium for transporting goods to the city. As a capital for its suitable location Dhaka soon became an important commercial hub and manufacturing station with 0.9 million population, its total area was expanded to 50 km2 (UNEP,
In 1717 the capital was again shifted from Dhaka resulting in sharp decline of its demographic and urban structure. (Rahman 2010)

However, Dhaka started turning back from 1850-60 when Dhaka municipality was established in 1864 and the city expanded up to some extent in eastern and western side. Also numbers of roads were built that time, advancements in infrastructure, community facilities and aesthetics of the city was noticeable. One of the most significant establishments was the riverfront Buckland Embankment. At that time, the Buriganga river was the front of the city with beautiful riverside buildings like Ahsan Monjil, Mitford hospital and Ruplal house. (Figure 6) However the population of Dhaka, at the end of British period was 0.3 million within 64.7 km2 area. (UNEP 2005).

Dhaka becoming the provincial capital of East Pakistan after partition of the subcontinent in 1947, the action of development began and spread out in 1960. After the liberation war in 1971, Dhaka experienced maximum growth to meet the needs of the newly independent country's capital. The city's population suddenly reach to 2 million in 1974 and it jumped to 3 million in an extended area covering
510 sq-km by 1981. Then Dhaka city faced its highest rate of physical and population growth during 1981-1991 when its population just doubled and the area expanded from 510 sq-km to 1353 sq-km. (Hossain 2008). With this current trend of growth, Dhaka today having a population estimated over 20 million. With the increasing population the adjacent Buriganga river lost its charm and soon become the back of the city, a place for garbage disposal and for urban poor.

![Figure 6: Some sketches of Buriganga Riverfront during 1840 (British Library)](image)

### 2.2 Urban Context of Dhaka

Dhaka is ranked among top ten least-livable cities by The Economist Intelligence Unit’s Global Liveability Index (GLI) in 2014. At one end, there is unmanageable population, which is still increasing because of migrated people and on other side
ongoing unplanned sprawl making the situation worse for its inhabitants. Urban greeneries and waterbodies (including wetlands) of Dhaka Metropolitan Area (DMA) are now decreased to 3,730 ha and 9,230 ha respectively in 2005 which was 6,109 ha and 16,480 ha in 1960. (Table 1) Because of this unplanned growth increasing flood magnitude, microclimate degradation, urban heat-island effect, energy crisis, water logging during monsoon etc. are the common severe problems that the inhabitants of Dhaka city are dealing with in their every-day life. Following sections will discuss on landuse, wetlands and climate change impacts on the city due to human interventions.

2.2.2 Landuse

Like other developing countries, Bangladesh experienced a fast increase of urban population in the recent decades (14.1 million in 1981, 22.5 million in 1991, 31.1 million in 2001; BBS 2001), and 35 million in 2005 (CUS et al. 2006). Dhaka Metropolitan has gone through sharp change in landuse according to the following maps (Figure 7) and table. The maps showed that from 1960 to 2005, built-up areas increased approximately 15,924 ha, while agricultural land decreased 7,614 ha, vegetation decreased 2,336 ha, wetland/lowland de-creased 6,385 ha, and water bodies decreased about 864 ha. (Dewan 2008) In percentage, only 11.1% of the total landuse area was built-up area in 1960 increased into almost half of the total Area, and on the other hand the percentage of wetlands and cultivable lands were 32.5% and 33.3% respectively, decreased into 17.2% and 15% respectively in 2005 (Table 1).

---

3 Dhaka Metropolitan Area (DMA) is the entire Dhaka City Corporation (DCC) area as well as its adjacent unions with an area of 303 sq-km. It is bounded by four rivers, the Buriganga to the south, Balu to the east, Turag to the west and Tongi Khal to the north. DMA is commonly referred to as 'Dhaka' by most people.
Figure 7: Landuse of Dhaka from 1975 to 2003 (using topographic maps and multi-temporal remotely sensed data from 1960 to 2005. The Maximum likelihood supervised classification technique was used to extract information from satellite data, and post-classification change detection method was employed to detect and monitor land use/cover change, Dewan 2008)

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Table 1 Summary of land use/cover classification statistics between 1960 and 2005 (area in hectares) (Dewan 2008)

2.2.2 Wetlands

Like many other cities, Dhaka as one the most fast growing mega city of the world is also expanding by exploiting its surrounding natural resources and paying little attention to her ecological and social values. The recent trend of development in Dhaka has become an alarming threat for her remaining wetlands which has a
Analysis on wetland conversion by Islam I. reveals, relatively faster loss of wetlands during the period 1999-2005 than 1989-1999. Table 2 provides information on area coverage of wetlands of Dhaka (DMDP area) city during the year 1989, 1999 and 2005. The rate of loss of wetland during the 1999-2005 period is 1922 hectare/year, whereas during the 1989-1999 period; loss was 502.5 hectare/year. Only 16.9% of Dhaka’s land area remained as wetlands in 2005. If this trend continues then before the year 2035 all temporary (seasonal) wetlands of Dhaka will disappear (Figure 8). (Islam 2009)

Table 2: Wetlands (in Hectare) of DMDP areas in the years, 1989, 1999 and 2005 (Islam I. 2009)

<table>
<thead>
<tr>
<th>Item</th>
<th>1989</th>
<th>1999</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area(ha)</td>
<td>%</td>
<td>Area(ha)</td>
</tr>
<tr>
<td>Permanent water-bodies</td>
<td>5,608</td>
<td>3.9</td>
<td>5,608</td>
</tr>
<tr>
<td>Temporary</td>
<td>40,765</td>
<td>28.5</td>
<td>35,740</td>
</tr>
<tr>
<td>Others</td>
<td>96,770</td>
<td>67.6</td>
<td>101,795</td>
</tr>
</tbody>
</table>

Figure 8: Trends of wetland loss in Dhaka Metropolitan Area (Islam I. 2009)
Analysis on wetland reduction done by Islam et al. covered a longer timeframe which also revealed that area covered by wetlands in the city significantly reduced over the period 1960 to 2008 (Table 2). In 1960, the area of the lowland was 13527.58 hectares, which became 6414.57 hectares in the year 2008 (Figure 9,10,11). The area of the permanent water-body was found to be 1990.71 hectares in the year 2008, which was 2952.02 hectares in 1960. The reduction of area in the permanent water-body was 961.31 hectares (Table 2). Permanent water-body has been mostly changed by the land filling and storm and deposits from waste water. (Islam et al. 2012) Most of the cases, channels are narrowed or lost due to either encroachment or acquisition for construction of roads, box culverts or underground drains. Urban expansion has been encroaching in the low-lying areas to cope with population growth, is the main reason for the reduction of wetland areas in the city. (Islam et al. 2012) From the history of growth of the city, e.g. (Islam 1996) demonstrated that the city was remaining almost same up to the late 1980s. Earlier study, Reza and Alam (2002) showed that area of water-bodies in the western part of the city reduced to 91% of 1963 in 1990, which dropped to 63% of 1963 in 2000. In the present study the change in lowland areas (open water-bodies) over the entire metropolitan area is calculated to be reduced by 53% in the year 2008 compare to 1960. From the earlier work e.g. (Dewan and Nishigaki 2006) it is evident that the city areas in the early 1990s were extending the western low-lying areas while in the late 1990s and as well as in the 2000s the urbanization activities redirected to the eastern wetlands. (Islam et al. 2012)

Table 3: Summary of analysis on the changes in wetland in the year 1960 and 2008 (Islam et al. 2012)

<table>
<thead>
<tr>
<th>Categories of wetlands</th>
<th>1960 area (ha)</th>
<th>2008 area (ha)</th>
<th>1960-2008 area changed (ha)</th>
<th>% of changed Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent water-bodies</td>
<td>2952.02</td>
<td>1990.71</td>
<td>-961.31</td>
<td>32.57</td>
</tr>
<tr>
<td>Lowlands</td>
<td>13527.58</td>
<td>6414.57</td>
<td>-7113.01</td>
<td>52.58</td>
</tr>
<tr>
<td>Total</td>
<td>16479.87</td>
<td>8405.28</td>
<td>-8074.59</td>
<td>49.00</td>
</tr>
</tbody>
</table>
Figure 9: Wetlands of Dhaka in 1960 (Islam et al. 2012)
Figure 10: Wetlands of Dhaka in 1988 (Islam et al. 2012)
Figure 11: Wetlands of Dhaka in 2008 (Islam et al. 2012)
2.3 Urban Area and Surrounding Landscape

Landscape of Dhaka city has been undergoing continuous changes and modifications due to relatively rapid urbanization for the last few decades. In 1968, the total area of marshy and inundated low-lying areas was 133 sq-km, which was measured 67 sq-km in the year 2001. The total area of inland lakes as estimated from the aerial photos of 1968 was 5.1 sq-km which became 1.8 sq-km in the year 2001 as seen in SPOT image. (Islam, et al. 2012) More than 50% of the wetland area reduced over the period 1968 to 2001. (Dewan 2008) These wetlands/lowlands loss occurred mostly in the peri-urban areas. In most cases, for the sake of urban expansion, wetlands and lowlands get filled and or compartmentalized the water bodies, causing numerous problems including water loggings problem, loss of biodiversity and natural function, increasing flood magnitude during wet-season in various part of the city etc.. Existing natural Hydrological conditions were not considered so far in such unplanned urban development and alternation.

Urbanization is the major demographic development, which is occurring very fast and with larger magnitude in the developing countries. In many cases, specifically, in the poor economic countries urbanization is a demand driven un-planned and bottom up process, which transforming the existing landscape without considering the possible consequences and requirement for environmental sustainability (Islam, et al. 2012). In the tropical region where monsoon causes huge rain-fall during some part of the year are naturally drains by the gravity drainage through stream-river networks, and wet-lands works as natural retention storage. (Islam, et al. 2012) Unplanned Urbanization usually hampered the natural state of drainage, and hence causes sudden inundation and water- logging. However, considering natural hydrology during urban planning and development can reduce the adverse effects through preservation of wetlands and stream-networks or designing constructed wetlands that can cope with man-made interventions.
2.4 Impact of Climate Change in Dhaka

Wetland is one of the most important ecosystems of earth that provides enormous services to the human being and the environment. Loss of these precious wetlands worldwide, has climate change impacts on this planet earth. Wetland conversions due to manmade interventions (discussed in the previous section) have negative consequences on the environment of Dhaka city as well. Flood vulnerability, drainage congestion and microclimate change are among the severe negative impacts of climate change due to loss of wetlands.

2.4.1 Flood Vulnerability

Flood Vulnerability is considered as the major consequence because of the loss of wetlands and unplanned human interventions. Major floods previously affected Dhaka have been occurred in 1954, 1955, 1970, 1974, 1980, 1987, 1988, 1998, 2004 and 2007 (Islam 2012). During 1988 flood, about 77 percent areas of Dhaka City (total area 260 sq. km) were submerged to depth ranging from 0.3 to over 4.5 meter (Islam 2009). Following the severe floods of 1987 and 1988, National Flood Action Plan (FAP)\(^4\) was formulated. Objectives of FAP was to provide a relatively flood free living environment within the framework of a long term flood protection program for Dhaka. Proposals included embankment, improvement of Khals, construction of pumping station acquiring land for retention pond etc. where most of them were hard engineering solutions.

Pre-urban and post-urban flood Analysis done by Islam S. et al. and IWFM\(^5\) reveals the increasing flood vulnerability as an impact of urbanization. Here the pre-urban time period is considered as 1970-1988 and the period 1988-present referred as

---

\(^4\) Flood Action Plan (FAP) is an initiative to study the causes and nature of flood in Bangladesh and to prepare guidelines for controlling it. FAP was based on earlier studies by UNDP, a French Engineering consortium, USAID and JICA (Japan International Cooperation Agency).

\(^5\) IWFM (Institute of Water and Flood Modelling) is an institute of Bangladesh University and Technology, pursues research and capacity development in the field of water and flood.
post-urban period. The frequency, magnitude, and duration of floods have increased substantially during the last few decades. Due to rapid urban growth after 1990 and accelerated loss of wetlands, flood vulnerability increased with increasing water level (higher than danger level) and elongation period. (Figure 12) 1998 flood affected 56% of the city and 2004 flood inundated 50% of the city (Figure 13) (Islam I 2009). In 1998 flood, 64 affected wards of Dhaka City had estimated total damage of of Tk 2.0 billion or $US 41.0 million (Mohit and Akther, 2002).

![Figure 12: Buriganga and Turag Rivers water levels during Pre-urban(1970-88) and Post-urban(1988-present) floods (IWFM 2008)](image)

![Figure 13: Historical Flood Inundation maps of Dhaka city (Dewan 2009)](image)
Structural solutions, such as the building of dams and embankments along the rivers will not solve the flooding problems, but will result in many adverse environmental, hydrologic, economic, ecological, and geologic consequences (Rahman and Chowdhury 1998). Solutions to flooding problems can be achieved by adopting and exercising watershed-scale management practices that include: floodplain zoning, planned urbanization, restoration of abundant channels and lakes, dredging rivers and streams, efficient storm sewer systems, establishing buffer zones along rivers, controlled runoff at construction sites, good governance, indigenous adjustment of life-style and crop patterns (Khalequzzaman 2000).

2.4.2 Drainage Congestion

Drainage congestion in an area can vary greatly with a change in the: (a) water carrying capacity of a drainage basin and amount of runoff that results from precipitation in a watershed, (b) amount of impermeable surfaces, and (c) change in land elevations with respect to riverbeds and sea level (Khalequzzaman 2000). An increase in runoff component of the hydrologic cycle in a watershed and impermeable surfaces, a decrease in water carrying capacity of a drainage system, and a decrease in land elevations will increase drainage congestions and flooding propensity in an area.

It is difficult for an urbanized area to deal with heavy rainfall within a short duration. Sufficient amount of retention area and flood flow zones are required to accommodate the excess water during flood or monsoon period. In recent times, Dhaka city dwellers experienced the flooding due to heavy rainfall (341 ml, highest in last 50 years) in September, 2004. The two-day long monsoon rainfall almost collapsed the entire city function (Islam I 2012).

For example, in a city that is totally served by storm drains, and where 60% of the land surface is covered by roads and buildings (like Dhaka City), floods are almost six times more devastating (Pipkin and Cunnings 1983). For an increasing amount
of impervious surface by 10% in a watershed, 23% increase in the drainage capacity by dredging or deepening of streams is suggested by Sauer et al. (1983). Dhaka City is located in the watersheds of Buriganga and Sitalakha Rivers. A significant increase in the amount of impervious surface in these watersheds has taken place due to expansion of the Dhaka Metropolitan area over the last few decades resulted in drainage congestion during heavy rainfall.

2.4.3 Microclimatic Impact

The temperature of Dhaka varies with different morphological (buildings, roads, green parks, water body and others) character within the city fabric (Ahmed, 1995). Urban open spaces including vegetation surface and waterbodies are essential components of urban design in tropics where increasing built density is resulting in inadvertent environmental modifications (Ahmed, 1995). In case of Dhaka city, its peripheral lowlands have been played a significant part that absorbs the solar gain greatly and performed an important role on climate of the city.

The city is now expanding at the cost of its inland and surrounding open spaces including lowlands and wetlands. As a result, there are very limited green open spaces in Dhaka city (Hossain, 2010) and in surrounding area. Due to rapid loss of these natural features, the situation is getting worse by increasing urban heat island effects.

2.5 Concept of Ecological Urbanism and prospect of Dhaka City

“Humans' survival as a species depends upon adapting ourselves and our settlements in new, life-sustaining ways, shaping contexts that acknowledge connections to air, earth, water, life, and to each other, and that help us feel and understand these connections, landscapes that are functional, sustainable, meaningful, and artful” (Spirn 1998).
The aim of Ecological urbanism is to advance this goal. It combines different disciplines, landscape architecture, urban design, architecture, city design and planning, with the insights of ecology, as a means of adaptation – the study of the relationships between living organisms and their environment and the processes that shape both – and other environmental disciplines, such as climatology, hydrology, geography, history, and art. (Spirn 2012)

An ecological approach to urban design is not new and grew out of ideas and action in landscape architecture, architecture, and urban design and planning. Ecological urbanism is critical to the future of the city and its design: it provides a framework for addressing challenges that threaten humanity, such as global warming, rising sea level, declining oil reserves, and rising energy demands, while fulfilling human needs for health, safety, welfare and other issues. (Steiner 2002)

“Important concepts of ecological urbanism include: cities are part of the natural world; cities are for habitats; cities are ecosystems; urban ecosystems are dynamic and interconnected; every city has a deep, enduring context; urban design is a tool of human adaptation” (Spirn 2012).

The notion that the nature is ubiquitous, a total that contains the city, has powerful implications for how the city is built and maintained, and for the health, safety, and welfare of every resident (Williams 1980). Geddes, who was educated as a biologist, viewed each city and its surrounding countryside as an evolving organic whole whose future plan should be based on an understanding of its natural and cultural history and its “life- processes in the present” (Geddes 1915).

Despite overwhelming evidence to the contrary, “the belief that the city is an entity apart from nature and even antithetical to it has dominated the way in which the city is perceived and continues to effect how it is built. This attitude has aggravated and even created many of the city’s environmental problems: poisoned air and water; depleted or irretrievable resources; more frequent and more destructive floods; increased energy demands and higher construction and maintenance costs than existed prior to urbanization” (Spirn 1984).
Like Geddes, McHarg asserted, “any place can only be understood through its physical evolution” (McHarg 1967). Lynch and McHarg shared the conviction that cities must be viewed in their regional context and that the natural environment has a social value to be cultivated in urban design. While McHarg focused more on the natural processes and environment, Lynch stressed the importance of how people perceive the city, proceeding from human perception to understanding the sense of place. For Lynch, the city is first and foremost a human habitat, and he judged “good city form” by how well it sustains human life (Lynch 1981).

The key is to think in terms of the ways that human activities and urban form interact with natural processes of air (heat transfer and air flow), earth (geology and soils), water (water flow), life (reproduction, growth, and behavior), and ecosystems (flows of energy, information, and materials, succession of plant species and behavior of plants and animals) (Spirn 2012). This is not just a matter of blindly imitating the shape of natural features or of using indigenous materials, but of adapting urban form to natural processes. By focusing on the processes that shape and structure the environment, designers and planners can accommodate dynamic change, make connections among seemingly unrelated elements and issues, and can realize opportunities (Steiner 2002).

Urban ecosystems are dynamic and inter-connected. For better understanding the dynamics is to identify and portray the interplay of natural and social processes that shape and structure the city. Ian McHarg overlaid different maps of diverse natural and social factors in order to better understand the interaction of natural and social processes (McHarg 1967). Such overlays can reveal surprising relationships among seemingly unrelated phenomena, such as the correlation between buried floodplains and vacant land in low-income inner-city neighborhoods, but they portray these relationships as static (Spirn 2000). James Corner, Anu Mathur, Dilip da Cunha, and Alan Berger, among others, have developed mapping techniques that enable designers to visualize how processes operate in space and time (Mathur and Da Cunha 2001, Berger 2006) that is quite new contribution in the field of landscape urbanism. In Houston, Texas, for
example, floods and ground subsidence in the city are aggravated by suburban developments many miles upstream, which are within the watershed of the city’s streams and/or on the recharge areas for an aquifer which underlies the city (Spirn 2003).

The reasons for embracing and promoting ecological urbanism for the future of the cities are compelling. At stake is the future of humanity: whether we can adapt our behavior and settlements to meet the challenges we face (those posed by climate change and environmental contamination) and whether we can do so in ways that are life-enhancing and life-expanding. Ecological urbanists have an essential role, not merely in producing safer and healthier urban habitats, but in making legible and tangible the systems that support life, and in changing the perception of what is possible (Spirn 2012).

For the case of Dhaka city, due to tremendous growth and loss of waterbodies; increasing flood risk, degradation of hydrology and network, water logging and water pollution, etc. are the threatening problems mentioned in the earlier sections of this chapter indicates the urgency of ecological urbanism approach for facing the current and future challenges of the city. Dhaka once called ‘the Venice of the east’ (Dani 1962) for its peaceful connection with the Buriganga River, from which it was started more than 400 years before. Till then, the city experienced opposites of all the necessary actions; it was never taken as a part of nature, underlying inter-connected and dynamic layers were not considered, above all its context and natural settings were neglected. Currently Dhaka’s peri-urban areas are going through major transformation following the same unplanned and destructive trend. In the next chapter, different necessary topics will be discussed through the aperture of ecological urbanism.
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Chapter Three: Wetlands and Urbanization

3.1 Introduction

3.2 Ecology of Wetlands
   3.2.1 Ecology of Natural Wetlands
   3.2.3 Constructed Wetlands

3.3 Engineering of Wetlands
   3.3.1 Components of Constructed Wetlands
   3.3.2 Calculation of Wetland Sizing

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   3.4.1 Increasing Imperviousness
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3.5 Theoretical Base of Wetland Sizing and Threshold of Imperviousness

3.6 Conclusion
Chapter Three: Wetlands and Urbanization

3.1 Introduction

Following the previous chapter with general discussion on Urban Context and loss of Wetlands, this chapter has focused more on the technical issues of Wetlands, particularly the ecology of natural and constructed wetlands and then demonstrated the engineering of wetlands. Leaving in-depth technical terms and complex calculations, this section will discuss the components of constructed wetlands and general calculation for obtaining the wetland size from given data. After this, the chapter will be followed by the impact of Urbanization, specially suburbanization and how it is imposing negative impacts on the natural functions of wetlands and lowlands.

3.2 Ecology of Wetlands

‘Wetland’ means the transitional landscape between land and water. Constructed wetlands are designed to mimic natural wetlands and their physical, biological, and chemical processes (Balderas-Guzman 2013). In nature, wetlands perform many important functions in the landscape; functions that constructed wetlands can also perform. These important functions include flood water retention, groundwater recharge, place for habitat, pollution prevention, erosion control etc.

3.2.1 Ecology of Natural Wetlands

Hydrology defines the condition of natural wetland system (Figure 14) that initiated with climate and geomorphology, which dictate where wetlands occur and their water depth, flow patterns, duration and frequency of flooding (Mitsch and Gosselink 2007). The major flows into wetlands include precipitation, surface
flows, evapotranspiration, tides and these flows bring energy, nutrients and organic other materials to the wetlands. These all creates the physiochemical condition of wetlands which impacts the biota, species and ecosystem productivity (Mitsch and Gosselink 2007). Wetland biota adapted to the inherent dynamic environment of a wetland (Balderas-Guzmán 2013).

Figure 14. Hydrology as the basis of wetland systems, (Balderas-Guzmán 2013, adapted from Mitsch & Gosselink 2007)

Wetlands perform various important functions like flood protection, storing and retaining water during monsoon and flood, ground water recharge, increasing biodiversity, enhancing micro-climate, create habitation for various species etc. In case of Urban wetlands, its water retaining function is considered the most important one. Wetlands perform flood protection by storing and slowly releasing flood water. The flood retention capacity depends on its size, shape, location, depth
to the water table, soil permeability, and slope (Mitsch and Gosselink 2007). This water retaining ability helps to prevent downstream areas from flooding. However, these wetland functions are most compromised in Urban areas. As a result reliance on engineered solutions like dams, culverts and embankments get increased which are not at all economical specially for a lower-middle income country like Bangladesh.

Table 4. Watershed Functions of Different Wetland Types (Wright et al. 2006)

<table>
<thead>
<tr>
<th>Wetland Type</th>
<th>Description</th>
<th>Functions &amp; Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depressional</td>
<td>Topographic depression with closed contours, may or may not have inlets or outlets</td>
<td>• Flood Storage • Place for Habitat • Pollution treatment • Erosion control</td>
</tr>
<tr>
<td>Slope</td>
<td>Surface discharge of groundwater on sloping land that does not accumulate</td>
<td>• Habitat • Pollution prevention • Erosion control</td>
</tr>
<tr>
<td>Flat</td>
<td>Low topographic gradients with moderate to abundant rainfall</td>
<td>• Habitat • Pollution prevention • Flood storage • Limited recreation</td>
</tr>
<tr>
<td>Riverine</td>
<td>Occur in floodplain and riparian corridor of larger streams and rivers</td>
<td>• Flood conveyance and storage • Shoreline protection • Erosion control • Pollution treatment • Fish and waterfowl habitat • Recreation</td>
</tr>
<tr>
<td>Fringe</td>
<td>Adjacent to lakes or estuaries</td>
<td>• Habitat • Pollution treatment • Water supply protection • Shoreline protection • Erosion control • Recreation</td>
</tr>
</tbody>
</table>

Another important function of wetland is to recharge ground water levels. These functions are useful for urban areas that rely on groundwater for drinking supply. This relation between wetland and ground water is very complex depending on various factors like soil permeability, vegetation density, water flow, discharge and groundwater levels. The extent of groundwater recharge by a wetland is dependent upon different aspects, such as soil, vegetation, site, perimeter to volume ratio, and water table gradient (Winter 1999). The soil under most
wetlands in Dhaka city is relatively impermeable; however, perennial presence of these wetlands may signify their potential contribution to groundwater recharge. Moreover, some wetlands particularly around the built-up area have lesser thickness of silt clay at the bottom; have the higher potential to groundwater recharge. The wetlands around the built-up area and rivers around the city have found to play a significant role in the groundwater recharge (Ahmed and Burgess 2003). Demand driven abstraction of groundwater in the city has been failing to balance with amount of recharge in the recent years leading declining groundwater level and aquifer dewatering in many parts (Hoque et al. 2007). This may have been further enhanced by the reduction of wetland area.

In landscape, wetlands perform these complex functions in a larger network and intervention in any part affects the total network. Also it can be said that wetlands perform well in a big scale network rather in isolated parts. In case of Urban development, filling and compartmentalization affects greatly and degrade the overall performance of wetlands.

Wetlands are one of the most ecologically productive ecosystems in the world per unit area. Wetlands are well-known for their capacity to provide habitat for a diverse number of aquatic, terrestrial, and avian species. (Mitsch 2007). The most important part is the gradient or edge which can be short like an meter to a vast area. This gradient has many parts (Figure 15), each having significant characteristics, thus support specific species to grow. From research, it reveals that almost two-third of the extinction species are from the wetlands (particularly wetland gradients) or riparian zone that also indicate the urgency of preservation of the natural edge along with its natural functions. As they produce high amount of biomass and home of micro-habitats, wetlands can support high biodiversity. Many species including birds, and fishes depend on wetlands for feeding, breeding, nesting etc. Many plants found in this region adapted with seasonal inundation support this birds and the surrounding eco-system. Figure 16 shows the available plants and birds that have been found in specific parts of wetland gradient in Keraniganj, a peri-urban area of Dhaka city. The names were found from the book of Sharma and from field study.
Figure 15: The transient edge or the wetland gradient (After Sobhan et al. 2012)
3.2.3 Constructed Wetlands

Constructed wetlands are man-made and their function is to imitate natural wetlands. As they are man-made, hydrology in constructed wetlands is largely artificial. However, the ecology of constructed wetland can be as similar as natural wetlands if proper flow is maintained. For example, constructed wetlands are
capable of having as high or higher population sizes and biodiversity as natural wetlands. (Knight et al. 2001) A study of a very limited number of surface flow constructed treatment wetlands (for various water treatment purposes) found a total of 361 bird species, 342 aquatic invertebrate species, 78 fish species, 22 mammal species, 10 amphibian species, and 7 reptile species where present throughout the wetlands studied. This study concludes that treatment wetlands can reproduce all major animal groups that exist in natural wetlands. (Balderas-Guzmán 2013). However, the practice of constructed wetland is not popular in Bangladesh yet.

The following section will discuss on the technical issues of constructed wetlands including its components and sizing calculations.

3.3 Engineering of Wetlands

In a constructed wetland, ecological functions and pollutant removal occurs through interaction with some or all of the following: a medium (such as soil or gravel); floating, emergent and/or submerged vegetation; and microbes. (Mitsch and Gosselink 2007). There are three major components work together to perform its functions. Its treatment performance is affected by many factors, such as water levels, pollution levels, temperature variations, solar exposure, plant growth cycles, etc. (Scholz 2011). However, the sizing of wetlands depends directly on Rainfall, Imperviousness and the Site area. One common method will be discussed in the ‘sizing of wetland’ section. However, the seasonality and changing frequency of rainfall is not considered in this method.

3.3.1 Components of Constructed Wetlands

There are two major considerations needed to be considered to maintain the water treatment performance of constructed wetlands, creating plug-flow conditions and creating ecological diversity (Balderas-Guzmán 2013). Plug-flow conditions means
a hydraulic state where water is moving along the wetland with uniform speed along the width of the wetland. If water can find a short-cut way to travel then it means some volume of water spends less time in the wetland, getting less treatment as a result. Creating ecological diversity ensures that water will be exposed to a variety of conditions where different treatment processes can take place. Wetlands need shallow zones were water will come into contact with plant roots, its components and with microbes. (Mitsch and Gosselink 2007) For the complexity of its water treatment performance, engineers have been leading the design of constructed wetlands, especially when it comes to hydraulic considerations. Following are the general overview of its typical components and sizing calculation adapted from different literature including Mitsch and Gosselink, Celina Balderas-Guzmán and Kadlec and Wallace.

Constructed wetlands have three major components: 1. The Forebay, 2. Marsh Zone, and 3. Deep Zones. (Figure 17) The forebay receives water from an inlet, before that water enters the main wetland, generally up to six feet deep, This depth allows it to capture sediments, which are abundant in stormwater. The forebay normally store 10% of the total wetland's water volume.

Figure 17: Three major Components of Wetlands

The main wetland is composed of alternating marsh and deep zones. Alternating these zones helps ensure that water is maintained at plug-flow conditions and that water is exposed to both shallow wetland areas and deep areas where different water treatment processes can take place as mentioned above. In order to keep water at plug-flow conditions, the length of the deep zones need to be
Figure 18: Marsh Zone, the shallow component of wetland (Balderas-Guzmán 2013)

Figure 19: Deep Zone, a component of wetland (Balderas-Guzmán 2013)

approximately 15 times the depth of the marsh zone. Thus, if a marsh zone is 1 foot deep, then the adjacent deep zone must be at least 15 feet long. (Balderas-Guzmán 2013) According to research, they should not be used when a wetland is less than 50m long or in a wetland that is undersized relative to the contaminant being
treated. Deep zones should comprise up to 35% of the wetland’s area and be cultivated with floating and submerged aquatic vegetation. (Lightbody 2007) By volume, in wetlands, Marsh zone typically hold 60% of the volume and 40% in deep zones.

There are other parameters to increase treatment effectiveness outlined by engineers. The aspect ratio of a wetland (length to width) is an important factor that influences the degree to which plug-flow conditions can be achieved, and thus treatment performance, of a wetland (Balderas-Guzmán 2013). It is recommended that wetlands have an aspect ratio of at least 5:1, optimally 20:1. (Whittle and Philcoc 1996) The main notion is to reduce short-circuiting and increasing detention time. Better treatment can also be achieved by using multiple wetland cells, which promote lateral mixing of water. (Kadlec 1999)

### 3.3.2 Sizing of Wetlands

There is no single way to size or design a wetland. Even wetland engineers will admit the difficulties in designing and sizing wetland. However, there is one of two common typical methods for the sizing of constructed wetlands, one of them is the design storm method. The following method described here is extracted from the paper of Balderas-Guzmán and from the writing of Kadlec and Wallace ‘Treatment Wetlands’. The example calculation used the local rain fall data of Dhaka Region. This method finally calculates wetland size and hydraulic loading rate (HLR), two variables that define the pollution reduction performance of a wetland. The HLR describes the desired flow in a wetland as equivalent to rainfall (Kadlec and Wallace 2009). Following is the function of the wetland size and water flow rate:

\[
q = \frac{Q}{A}
\]

where, \( q \) = hydraulic loading rate (m/day),

\( A \) = wetland area (m\(^2\)), and

\( Q \) = water flow rate (m\(^3\)/day).
The **design storm approach** starts with a specific storm or desired treatment volume, for example, the 80\textsuperscript{th} percentile storm. The following steps are used to calculate the size of a wetland based on a design storm:

- **Step One**: To identify the desired design storm. For example, in Dhaka, the 80\textsuperscript{th} percentile storm\textsuperscript{6} is 1.97 inches or 0.050 meters, with total annual rainfall of 73 inches or 1.854 meters per year.

- **Step Two**: To calculate the watershed area in square meters. For example, 50 acres or 202,343 m\textsuperscript{2}.

- **Step Three**: Next is to calculate the watershed's runoff coefficient and total runoff volume. The runoff coefficient is the fraction of rainfall that becomes runoff. Runoff is very site-specific, as it is dependent on soil conditions, slopes, and other factors. (see section 3.5) However, most urban hydrologists use the following equation to estimate the runoff coefficient:

  \[
  \text{runoff coefficient} = 0.05 + (0.009 \times \text{percentage impervious})
  \]

  For a residential area with 37\% impervious cover, the equation would yield a runoff coefficient of 0.383 Therefore, the total runoff volume would be the watershed area multiplied by the design storm and the runoff coefficient:

  \[
  \text{Total runoff volume} = \text{Site Area} \times \text{Design Storm} \times \text{Runoff Co-efficient}
  \]

  \[
  = 202,343 \text{ sq-m} \times 0.050 \text{ m} \times 0.383 = 3,875 \text{ m}^3 \text{ of runoff}
  \]

- **Step Four**: To allocate the total runoff volume to wetland components to obtain a wetland size. In this example, if 60\% of the 3,875 m\textsuperscript{3} volume is allocated to 1ft deep marsh zones, and 40\% is allocated to 4ft deep zones, then the wetland will be 8,210 m\textsuperscript{2} or 2.03 acres.

\textsuperscript{6} 80\textsuperscript{th} percentile storm means taking account of 80\% of total monthly rainfall of that region, for example, in case of Dhaka total annual average rainfall is 1.854 meter. Thus 1.854/30 X 0.80 or 0.50 is the 80\textsuperscript{th} percentile storm of Dhaka.
Next, few other terms are discussed that are not directly required for the sizing of the wetlands but will help to understand the performance of the wetland with above calculations.

- Given the wetland size, wetland-to-watershed ratio (WWAR) can be calculated. This ratio is typically expressed as a percentage. In this case, the WWAR is $\frac{2.03}{100} \text{ acres} = 0.017 \times 100 = 4.06\%$

- The annual flow through the wetland is the amount of water that will pass through the wetland in a year. This number is the runoff coefficient multiplied by the total annual rainfall and the watershed area: $0.383 \times 1.854 \text{ m/yr} \times 202,343 \text{ m}^2 = 143,680 \text{ m}^3 \text{ per yr}$

- The average annual detention time is an estimate of how long water remains in the wetland, on average over the year. This is calculated by dividing the total runoff volume from the design storm by the annual flow: $\frac{3,875 \text{ m}^3}{143,680 \text{ m}^3 \text{ per yr}} = 0.027 \text{ years} \text{ or} 10 \text{ days} (0.027 \times 365)$.

- Finally, the annual **hydraulic loading rate (HLR)** is calculated by dividing the annual flow by the wetland area: $\frac{143,680 \text{ m}^3 \text{ per yr}}{3,875 \text{ m}^2} = 17.5 \text{ m/yr} \text{ or} 4.8 \text{ cm/day}$. The HLR is the key parameter that determines a wetlands pollution reduction performance. Generally, wetlands with lower HLR values perform better.

This calculation for constructed wetland sizing is important to understand the relation between rainfall, run-off volume with the components of wetlands or the required wetland area. The theoretical base for localizing the calculation has been mentioned in section 3.5 and the method is applied in a case study in next chapter.

The ecology of Natural wetlands, and other waterbodies like streams, channels, rivers are highly compromised for the sake of urbanization. This case is similar for the expanding Dhaka city as well. Most of the waterbodies at the fringe area are already filled or in danger. The following section describes the reasons and extent of the impacts urbanization has on hydrologic networks.
3.4 Urbanization and Degradation of Hydrologic Networks

Dhaka’s urbanization grew at unprecedented rate after 1971. Amount of urban area increased from 46.25 sq-km to 205.49 sq-km, almost 4 times between 1960 to 2005 (Dewan 2006). From the analysis of Ishrat Islam, it has been found that the growth was largely accommodated on fringes of Dhaka city after 1990/2000 when almost all of the highlands of Dhaka are built or covered. Developers went for the surrounding lowlands after 2000 and the rapid conversion of wetlands and vegetated surface has been observed during the last decade. Therefore it can be said that the suburbanization is the main cause to blame for wetland/lowland destruction at the periphery of the Dhaka city. The main reason behind this suburbanization is the need of housing (Islam 2009), thus targeting residential neighborhood would be getting at the heart of what is causing wetland loss in recent times.

Urbanization not only affects wetlands directly by sand filling them, it also instigates a series of changes that affect the entire hydrologic network. These changes result from the increasing impervious cover created by urbanization. Therefore, imperviousness is a good predictor of the impact on the hydrologic network by urbanization. (Schueler 1994)

3.4.1 Increasing Imperviousness

The common scenario of urbanization is increasing amount of built area and thus loss of vegetation, waterbodies, agricultural land is associated with this. The goal of Urbanization is to maximizing the use of space by increasing density. To achieve this goal, lowlands and wetlands are filled, streams are straightened, channelized or buried, and drainage infrastructure is installed underground. In some cases because of unplanned urbanization, most of the canals of Dhaka cities are filled, or buried underground as box culverts. Above ground, concrete and asphalt are poured in abundance to create roads, buildings, paves removing native vegetation in the process. The result is high amounts of impervious cover and soil compaction.
that greatly reduce infiltration of rainfall into the soil (Figure 20). Imperviousness is a major factor in the impairment of a region’s hydrology and the degradation of water bodies and water quality (Schueler 1994). Fortunately, imperviousness can be quantitatively measured using GIS or aerial surveys and has the potential to be controlled by planning policy.

Actually, in the development of a city, most imperviousness is created by mostly roads not roof areas. This is particularly true in suburbs and rural areas. Apart from generating large amounts of runoff, roads have also been found to have strong negative effects on species particularly aquatic animal species. These findings are consistent with other studies on aquatic species and urbanization. (Vos and Chardon 1998) These roads resulted in compartmentalization of wetland and hampering hydrological network and isolate animal communities (Sultana et al. 2009). Roads could also introduce other disturbance such as noise, light, and pollution that can degrade wetland habitats. (Warren 2006) As a major contributor of impervious cover, road areas often have not been addressed properly.

The health of water bodies, including wetlands, is hampered by impervious cover for many reasons. Because of Urbanization in a watershed, streams and wetlands experience increasing peak flows and water velocities. Peak flows increase because impervious cover produces more runoff. Water velocities increase because pavement and pipes convey water very quickly. These hydrologic changes force an enlargement of the stream channel, this way the stream channel becomes unstable, leading to loss of micro-habitats (Schueler 2000) In time, streams become homogeneous in form, straighter in length, and more extreme in the water volume they carry, resulting in less biodiversity. Also, impervious surfaces absorb more heat than natural cover, producing runoff with warmer water temperatures that can disturb the ecological balance by encouraging the growth of harmful bacteria. (Balderas-Guzmán 2013)

Imperviousness impacts ground water and as a result impacts water bodies in another way. Groundwater provides base flows for other wetlands and if
groundwater is too low, then those wetlands will run dry in the low rainfall season increasing their variability in water levels. Because imperviousness hampers infiltration, groundwater is not able to recharge with rainfall. The result is that during storm events, urbanization overloads natural water bodies with water, but during the dry season, it deprives them of water. These extremes of high water volumes in the wet season and little water in the dry season largely degrade the ecology of natural water bodies. They are less able to sustain plant and animal life.

In wetlands, water level fluctuation (WLF) is the difference between minimum and maximum water levels for a given time period. Imperviousness is the best predictor of WLF in wetlands. (Wright 2006) Wetlands naturally experience a limited range of WLF, and wetland species are adapted with this. However, urbanization’s hydrologic effects because of imperviousness can radically alter the WLF to levels beyond those wetland species can tolerate (Mitsch 2007).

As a result of urban expansion, roads, bridges, and other structures are built crossing either the wetland itself or upstream tributaries create flow constriction and have great impact on hydrology network. Even the common culvert under a road can be a problem. Although culverts are normally constructed under roads and bridges to allow flow, sedimentation quickly tends to diminish their conveyance capacity, impacting wetlands. The high occurrence of road crossings means that urban wetlands are very likely to have some degree of flow constriction. (Wright 2006) Flow constriction constitutes another change to a wetland’s hydrology. Since a wetland’s hydrology is the main factor that influences its ecological structure, flow constriction can cause a decrease in ecosystem functionality (Richardson and Nunnery 2001).

The impacts to wetland ecology by urbanization are not only loss of biodiversity and wildlife habitat. These losses indicate an overall loss of ecosystem functionality, which impacts urban areas in some ways as well. The loss of ecosystem functionality in wetlands means that those wetlands are less able to accommodate flooding, treat water pollution, and provide recreational space, three important functions required for urban areas (Balderas-Guzmán 2013). Wetlands
generally work like a sponge and provide flooding protection, their loss will increase flood vulnerability and resulted in relying on expensive engineering solutions like dams, embankments etc. Because wetlands provide pollution treatment, their loss will incur increased costs in the construction of proper infrastructure to treat water and infrastructure to manage stormwater and prevent floods. Biodiversity and wildlife habitat will also be greatly diminished by the loss of wetlands, as well as recreational, aesthetic, and educational benefits. (Wright 2006) By Identifying the thresholds where ecosystem functionality of wetlands is compromised will indicate where natural wetlands must be preserved and constructed wetlands would be the suitable and desired intervention. (Balderas-Guzmán 2013)

**3.4.2. Thresholds of Imperviousness**

Researchers have found the thresholds where streams and wetlands are compromised based on the amount of impervious cover in an urban area, using the watershed as the planning unit. As discussed above, impervious cover is a major factor in the degradation of hydrologic networks. Based on the threshold amount of impervious cover, watersheds can be divided into three management categories: sensitive, impacted, and non-supporting (figure 20 and 21). Tom Schueler in “The Importance of Imperviousness” outlined these categories as management categories for streams based on the levels of impervious cover in their watershed.

The first management category is **sensitive watersheds**, those with 0 to 10% impervious cover. As discussed earlier, water level fluctuations in wetlands begin at 4% impervious cover. For streams, the threshold where a stream is impacted is slightly higher at 10% impervious cover. In sensitive watersheds, stream and wetland buffers and other stormwater management practices have the potential to maintain the original, pre-development quality of those hydrologic features. Next, **impacted watersheds** are those with 11 to 25% impervious cover and will experience degradation, particularly instability of the stream channel and loss of
some biodiversity. However, the degradation can be limited by effective stormwater management practices (Schueler 1994). Stream protection should focus on limiting hard surface through minimum intervention and maintaining certain critical aspects of stream quality. Finally, **non-supporting watersheds** are those with 25 to 100% impervious cover. Even with effective stormwater management practices, streams in these areas will never regain their full, pre-development quality. The protection or restoration of biodiversity and habitat is extremely difficult and necessitates intensive restoration techniques in priority areas (Schueler 1994). For the case of Dhaka Metropolitan Area because of intensive dense development, most of the lost waterbodies may not be restorable. Instead, the management objective of these streams should be to minimize downstream damage by removing urban pollutants from water (Schueler 1994). Therefore, the areas where preserving and restoring wetlands can have the most impact are in sensitive and impacted watersheds. In other words, restoring wetlands are ideal for watersheds under 25% impervious covers. Because development is low-density in sensitive and impacted watersheds, more space is available for wetlands large enough to be effective and the hydrologic network is not entirely degraded. Specifically, suburban residential neighborhoods should be targeted because; these areas are the leading cause of wetland loss and take up significant portions of cities by unplanned sand-filling and land-filling (Islam 2009).

Furthermore, restored wetlands in these areas will bolster and add to hydrologic network but if built in isolation, the benefits of constructed wetlands lose the opportunity to be enhanced. Restored wetlands can bring networked benefits to the entire hydrologic network, if connected with surrounding natural wetlands and considered as a system or network (section 5.3).
Figure 20: How increasing impervious cover and densities gradually degrades stream channels and wetlands and the thresholds of Impervious Cover in percentage (Balderas-Guzmán 2013)
Figure 21: Compromised Wetland Functions with increasing Impervious Surface
(After 'The Importance of Imperviousness' by Schueler T. 1994)
3.5 Theoretical Base of Wetland Sizing and Threshold of Imperviousness

The Calculations of Wetland Sizing for constructed wetlands (discussed in Section 3.3.2) and Thresholds of Impervious Surface (discussed in Section 3.4.2) described here is based on the work of Tom Schuler’s “Importance of Imperviousness” (1994) and Balderas-Guzmán’s “Strategies for Systemic Urban Constructed Wetlands” (2013). While both papers are site-specific, following discussion will present the theoretical base for adapting the calculation method to the local context.

The calculations for wetland sizing and Hydraulic Loading Rate (HLR) named ‘design storm approach’ adapted from the writing of Balderas-Guzmán included four steps. (Section 3.3.2). Among the four steps, the third step is site specific which takes into account the soil conditions, slopes and other factors to calculate watershed's runoff coefficient. However, urban hydrologists use this equation to estimate run-off co-efficient in most of the regions.

\[
\text{runoff coefficient} = 0.05 + (0.009 \times \text{percentage impervious})
\]

Here percentage impervious cover is subjected to design and can be controlled or modified. But other factors like soil conditions and slopes factorized by the constant values in the above equation. The numbers will differ for various contexts and need to be researched to localize the equation for more accurate sizing.

The calculation has still some limitations. It does not consider the frequency of rainfall and seasonality. This method aggregate rainfall over the whole year thus ignores seasonality. As discussed earlier, in extreme dry or monsoon condition, water level fluctuation can get higher which will cause disturbance in the ecosystem and will degrade its treatment performance.
The thresholds of Impervious surface derived from the research of Tom Schuler’s are also need do be researched further to get more accurate thresholds for the context of Dhaka. The key issues considered in the Schuler’s research were pollutant loads, characteristics of surface material, solar gain, biodiversity and economics of impervious cover. Pollutant loads are site specific and can vary in different contexts. Due to lack of management policy, pollutant load of Dhaka city will be higher than the cities of eastern region of US, the study area of Schuler. Characteristics of surface material is important due to its reflectance property which can increase the temperature of run-off thus impacts on the hydrology. Again biodiversity is site dependent hence deltaic landscape can offer more biodiversity even in critical conditions because of the richness of its soil condition. Lastly economics of impervious consider the unit cost of different surface conversion, like building roads, promenades or clearing forest etc. that will vary due to variation of available resources. With the extensive local research on these issues, more accurate thresholds can be deduced.

3.6 Conclusion

The information and threshold amount derived from literature mentioned in this chapter will be used in the following chapter for the mapping study and field survey analysis.
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Chapter Four: Mapping Study and Field Survey

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Chapter Four: Mapping Study and Field Survey

4.1 Introduction

Mapping study is done here using GIS (Geographic Information System) and RS (Remote Sensing) method to identify the study area for field survey and analysis. In the mapping study, at first impervious surface area is identified using image classification method. Then the impervious map is classified in degree of imperviousness as percentage using other parametric tools of GIS softwares. This map is then converted to watershed map of Dhaka based on the threshold amount of impervious cover and three management categories mentioned in the previous chapter. Using the watershed map, potential study area is identified for field survey and mapping data analysis.

4.2 Mapping of Imperviousness and Watersheds of Dhaka Region: GIS and RS Method

GIS (Geographic Information System) is a System or a Tool for collecting, storing, manipulating, analyzing, displaying, and querying geographically related information. Remote sensing is defined by Lillesand and Kiefer (1987) as the science of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with object, area, or phenomenon under investigation. Remote sensing has been determined to be a cost-effective approach to document different land surface features and changes over large areas and even geographic regions (Lunetta et al., 2004).

The use of remote sensing techniques has great advantages because of their characteristics in the application to monitoring, evaluating and forecasting any change in landcover or particularly built area or impervious surface. By using remote sensing techniques, the user can grasp the present situation, evaluate
processes such as increasing impervious trends, and can also provide a scientific basis for the prevention and administration of surface area change in cityscape.

For the mapping of Imperviousness and Categorized Watersheds of Dhaka Region, ArcGIS 10.1 software is used as the main tool. Also ILWIS 3.4 is used as supportive tool during a process of image classification. At first data maps are collected from U.S. Geological Survey (USGS), Earth explorer, Landsat Archive free of cost. UGS 84 UTM zone 46N co-ordinate system is applied. The total process is shown by the figure 22. In the later part of this chapter a comparison of impervious surface from chronological maps and a projected map of impervious surface in Keraniganj is produced using the same tools and method.

![Figure 22: Flow Diagram of GIS and RS Method](image-url)
4.2.1 Images used

At first, the data sets for Dhaka city are collected from USGS, EarthExplorer. From the Landsat Archive, Landsat 4-5 TM Sensor data sets are collected dated 29th August 2011. These images have the resolution of 30 X 30 m with the approximate scene size of 170 km north-south by 183 km east-west (USGS).

4.2.2 Subset of the image

Dhaka region falls under two different data sets of the acquired data of USGS. Using the tool of ‘mosaic’ and ‘mask’ the new raster data sets have been prepared by ArcGIS 10.1 combining the adjacent two Data sets to combine and get the total Dhaka Region in one single raster map. This image is reduced to cover only the Dhaka Region and its surrounding peri-urban areas. This eliminated unnecessary data amounts, which also speeds up processing.

4.2.3 Creating Composite maps

Landsat images are composed of seven different bands, each representing a different portion of the electromagnetic spectrum. Individual bands can be composited in a Red, Green, Blue (RGB) combination in order to visualize the data in color. There are many different combinations that can be made, and each has their own advantages and disadvantages. In this case 5-4-1 RGB composition is used as it can visualize built area distinctly and can separate the built area and sand-filled area which are very closely placed in the spectral band. Here Dark pink pixels are the impervious surface and Light coloured pink pixels are sand-filled area. Other pixel colours along with sand-filled area are classified as non-built area. The composite map is prepared using the ‘image analysis’ tool in ArcGIS 10.1.

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7 ‘Image analysis’ is a tool in ArcGIS 10.1, that can process different bands of images to process the composite map.
4.2.4 Supervised Image Classification

Then for the classification of Landsat image, ‘supervised classification’\(^8\) is applied. Using ‘training sample manager’\(^9\) fifteen different polygon is identified for the hard surface region on the composite map for supervised classification and saved as a signature file. There are generally four types of classifications used under supervised classification. Among the four, ‘maximum likelihood classification’\(^10\) is applied. Using the signature file as an input, the classified map of hard surface of Dhaka is prepared. This map has only two category: built-up and non build-up. To create the watershed map, this map needed to be categorized according to the threshold of imperviousness identified by Tom Schueler.

4.2.5 Fishnet Used for converting impervious surface in percentages

For the categorized map of imperviousness ‘fishnet’ tool is applied to subdivide the previous classified map extent by 90m X 90m grid. (the previous map had the resolution of 30m Grid) The previously created raster image is converted into polygon using ‘raster to polygon’. Then by using ‘union’ combining the fishnet grid and polygon that combined data set map will be prepared for calculate geometry. In the following case about 1.5 million polygon was created. The new raster map is then filtered to get the clearer version of the map with distinct edges. In the new raster map five categories are applied for imperviousness, 0-10%, 10-25%, 25-50%, 50-75% and 75-100% based on the thresholds discussed in the previous chapter, section 3.4.2.

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\(^8\) **Supervised Classification** is a type of image classification where different classes or training samples of an image are need to be identified manually. There are four different types of supervised classifications in ArcGIS 10.1.

\(^9\) **Training Sample Manager** allows to see and change the properties of the selected training samples.

\(^10\) **Maximum Likelihood Classification** is among one of the four types of Supervised Classification. It is the popular method among four types.
4.2.6 Categorized Watershed Mapping

After the impervious map of Dhaka city has been created, using the 'property manager' tool, it is converted into watershed map with three main distinct category as classified followed, 0-10% as sensitive watershed, 10-25% as impacted watershed and 25-100% as Non-supportive watershed (Section 3.4.1). The non-supportive watershed has three subdivisions in gray scale coloured as 25-50%, 50-75% and 75-100%. It helps to identify the expansion nature of the city towards the periphery of impacted and sensitive watershed zone. In case of Dhaka this expansion is evident specially in east and west periphery.

Figure 23: Composite map of Dhaka created from ArcGIS 10.1 (Band 3-2-1 formation, image Date: 29th August, 2011)
Figure 24: Impervious Cover of Dhaka and surrounding using GIS and RS Method
(Tool used: ArcGIS 10.1, Data map: USGS, earthglovis and Date of map: 29th August 2011)
Figure 25: Threshold mapped in Dhaka city and surrounding (Date of map: 29th August 2011)
From the mapping of watershed category, impacted and sensitive watershed are identified on the periphery of the core city. The central part of the city is almost totally categorized as non-supportive watershed with above 25% imperviousness. The important thing to note is sand-fill area is identified as non-built (pervious surface) during sample collection of mapping study in ArGIS. Though the image date is from 2011, but still most of the sand-fill area is still unbuilt because of the DAP imposed regulation not to build on identified flood-flow zone. But these areas will be developed soon if there is no proper guideline given by the planners and architects. Following projection of what will be the scenario if the sand-filled portion is built typically is demonstrated below following the same procedure and tools. In this case, only sand-filled portion is included in the impervious category. From figure 26, it is clear that the increase of impervious surface is identified at the periphery of the Dhaka region. A significant increase is located at the north-east (Purbachal and surrounding model towns) and south-west (Keraniganj) region.

Figure 26: Comparison of Imperviousness of Dhaka region, left: existing impervious surface, right: sand-fill area considered as impervious surface to show what will be the scenario if they (sand-filled) built typically without considering the hydrology and landscape, Red circled are the future threatened zones
4.3 Field Survey

From the Mapping of watershed and comparison of Impervious surface of Dhaka region in the previous section, Keraniganj located at the south west of Dhaka city at the opposite of Buriganga and Turag river is chosen for field survey and study of regional, neighborhood and in building scale.

4.3.1 Study in Regional Scale

Keraniganj is one of the closest suburban areas of the city connected by three bridges over Buriganga river. Demand of low-income and middle-income housing near the city core accelerates its development. The riverside part of Keraniganj, located at the south west of Dhaka city is almost covered up by haphazard filling and unplanned development but the inner part of Keraniganj still reveals its ‘delta character’ with wetlands and lowlands.

Land-filling and plot division for unplanned housing has been increased since 2000. (figure 27) Before 2000, there were not much change observed in wetland loss but the situation changed after 2000 when all the highlands were built or covered (figure 28) and there were no space left within the core city. Numerous dredging pipes are identified for the support of these housing projects. With the pace of residential development, numerous roads are being built without any proper planning resulting in wetland compartmentalization. (figure 30) This type of structures are seriously hampering the hydrologic functions of the wetlands and creates stagnancy of water.
Figure 28: Chronological satellite images of South Keraniganj showing the impact of sandfilling in the region, from 2003 to 2013. (Google Earth)
Figure 29: From upper left (clockwise), 1. Sand-filling for housing, 2. Internal roads compartmentalizing the wetlands, 3. Numbers of brick fields to meet the future need, 4. Dredging pipes for sand-filling

Figure 30: Compartmentalization of wetlands because of Roads and unplanned development

Because of this unplanned plotting and division resulted in compartmentalization of waterbodies, Disturbance in Hydrology and fluidity of water, biodiversity and ecological functions leading to increase in natural disasters. Figure 31 showing the inundation of internal and regional roads creating problem in transportation.
4.3.2 Study in Community/Neighborhood Scale

There are numbers of housing projects identified in Keraniganj, waiting for its approval (figure 32). Currently most of them are found in barren sand-filled site. Some of the major housing projects are, Jhilmil Housing by RAJUK, the development authority of Bangladesh, itself is a huge landfill project filling about 168 acres of land. The Bashundhara Riverview Housing project also occupied more than 100 acres of land. There are other notable housing projects observed during the survey.
In all the above mentioned cases, the total site area is sand-filled at the level of 10-15 feet in depth to make it entirely flood-free. Where there were comparatively high-lands and lowlands, the undulating topography is disregarded and made plain flood free chunk of land. The result is, the required space for extra monsoon water or flash flood water is reduced in great amount resulting in high risk of flood in future. Also the connection between the lowlands is getting lost. The ecological function, hydrology and other functions of wetlands are disturbed as well.

Figure 34: Existing Approach of Residential Development in Keraniganj
4.3.2.1 Case Study: Jhilmil Housing by RAJUK

The total area of Jhilmil Housing project is about 168 acre. The entire site was sand-filled about 10-15 feet in depth. The filling started from 2009 and completed the entire filling in 2013. Still the construction is not started yet.

According to the thresholds, the impervious surface should be limited under 25% of the area and in this case, the open area will not perform like before because of the compact sand-filling. Thus the restoration by constructed wetland is necessary to revive the lost wetlands. The goal of restoration is to reconstruct or repair a damaged ecosystem in order to return it to a former, healthy condition (Spirn 2012). According to the general calculations described in chapter 3, section 3.3.2, following calculations are done for the size of the proposed constructed wetland of this site.
Wetland Area Calculation:

Site Area = 168 Acre = 679,872 sq-m
Total Annual Rainfall = 1855 mm / 73 inch (per year, in Bangladesh)
80th percentile Rain = 0.050 (design storm)

- Runoff co-efficient = 0.05 + (.009 X Imperviousness in %)
  = 0.05 + (.009 X 25)
  = 0.275

- TOTAL RUNOFF VOLUME = Runoff co-efficient X Site Area X Design Storm
  = 0.275 X 679,872 X 0.050 = 9,348.24 m³

- 60% of 9,348.24 m³ volume in 1’ (.3m) marsh zone = 18,696 sq-m
- 40% of 9,348.24 m³ volume in 4’ (1.3m) deep marsh = 2,876 sq-m

- Total Wetland Area = 21,572 sq-m = 5.3 Acre

(wetland area will increase if the impervious surface increase more than 25% or the design storm taken higher than 80th percentile)

Other Important parameters:

- Wetland-to-Watershed Ratio (WWAR) = 5.3 acre / 168 acre = ~ 4 %
- Annual Flow Through The Wetland = 0.275 X 1.854 (m/yr) X 679,872 (m²)
  = 346,632 (m³/yr)

- Average Annual Detention Time = 9,348 (m³) / 346,632 (m³/yr) = 0.027 yr
  = 10 days
• **Annual Hydraulic Loading Rate (HLR)** = \( \frac{346,632}{21,572} = 16 \, \text{m/yr} \) or 4.38 cm/day

As discussed above, Lower Hydraulic Rate performs better. In this case, if impervious surface can be minimized or wetland area can be increased, then HLR can be lowered, that will enhance the performance of the wetland.

To consider the seasonality and extreme flooding like 20 year flood or 25 year flood, the same calculations are done again, but this time **design storm taken as 95th percentile** which is 0.060.

The calculations follows the same procedures,

• Runoff coefficient = 0.05 + (.009 X Imperviousness in %)
  
  \[ = 0.05 + (.009 \times 25) \]
  
  \[ = 0.275 \]

• Total Run-off Volume = \( 0.275 \times 679,872 \times 0.060 = 11,625 \, \text{m}^3 \)

• 60% of 11,625 m$^3$ volume in 1'(0.3m) marsh zone = 18,696 sq-m

• 40% of 11,625 m$^3$ volume in 4'(1.3m) deep marsh = 2,876 sq-m

• **Total Wetland Area** = 26,828 sq-km = **6.6 Acre**

But According to the Dhaka Building Construction Rules, 2008, 5th Chapter, clause 46, 50% of the mandatory open space needs to be soakable Area for Residential Approval from RAJUK (Bangladesh Gazette 2008). Again in clause 46, it mentioned about maximum 50% Ground coverage for residential plot more than 1206 sq-m, which means the current law allows imperviousness 75% (for more than 1206 sq-m plot) to maximum 83.75% for plot area less than 134 sq-m. If this amount of impervious surface percentage used in the calculation then the Wetland Size comes 11.63 Acre for 95th percentile Design Storm and 9.69 Acre for 80th percentile. The procedures followed again for 37% impervious surface, and 7.4
acre and 8.9 acre area for wetlands for 80th and 95th percentile rainfall respectively, resulted from the calculation. From the above results, a relation between wetland area and impervious surface is plotted in a graph (Figure 31).

**Figure 36: Wetland Sizing Analysis for Jhilmil Housing**

According to the Private Land Development Act, a housing area needs to have 30% of mandatory open spaces and to accommodate the necessary common facilities like playfield, park etc. The wetland area, about 6.6 acre area (for 25% Impervious Surface) in this case can be incorporated with the park by design. Also, the issue of seasonal variation can be adapted in design in such a way, that the addition area needed for wetlands for monsoon or flood can be used for other functions in other time of the year (Indicative design strategies are discussed in detail in chapter five). But careful considerations should be taken not to make the entire zone publicly active so that it can harm the species to evolve and create disturbance in performing biological functions.
4.3.3 Study in Building Scale

Many different types of building typologies are found throughout the region starting from typical plotting (similar to the high lands), raised plinth to building on stilts. (figure 37). Typical plotting housing following the similar grid iron pattern like highlands are the most recent typologies. Some raising plinth structures were found that can make connection with the structures from the past.

Figure 37: Different building typologies found in Keraniganj

Figure 38: Two historic building with raised plinths, left: Imam Bara Dalan, Right: Shat Gambuj Mosque, Dhaka (Old Photo Archive)
Many historic buildings can still be found that followed the deltaic landscape of Bengal. Two examples can be the ‘Imam Bari Residence’ and the ‘Sat Gambuj Mosque’ at Dhaka, beside Buriganga River. (Figure 38) The most prominent feature of this two houses are, they were built on high raised plinth over the annual flood level. Not the entre site or compound is raised, only the plinth that is protecting the building from high level water. This strategy impose less impact on landscape than sandfilling the entire site. These can be followed in proposed building typologies with different levels in plinth level corresponding with the water fluctuation of the local context. (details in next chapter)

4.4 Limitation of Existing Regulations of Housing Development in Keraniganj

The Dhaka Metropolitan Development Plan (DMDP) is the last master plan for Dhaka for the time frame of 1995-2015. It was a three-tier plan package, named the Structure Plan, Urban Area Plan and Detailed Area Plan (DAP). The Dhaka Structure Plan (1995-2015) and the Urban Area Plan (1995-2015), approved and published in the Bangladesh Gazette. It considered preserving the low-lands and wetlands by mapping them as flood flow zones. But for the ever-increasing need of extra population it did not outline the ways to accommodate housing. In the land-use mapping, it identified big chunk of flood flow zones where partial high lands are present, also identifies few residential zones where wetlands/lowlands are present. (Figure 39) For the absence of ways of development in such landscape, the conventional ways of landfilling are still following destroying the natural setting even by changing the DAP itself in some cases. For these reasons, though the policies have the intention to preserve the wetlands and lowlands but for the lack of integrated holistic approach the intention is failed to fulfill its purpose. The following chapter will describe the strategies and ways of development in three different scales.
Figure 39: Existing lowlands and seasonal inundation in Dap Proposed Residential Zone in Location-3 Keraniganj, (Right) Dhaka; DAP Proposed land-use in location 3 Keraniganj, Dhaka (left)
4.5 Observation on Image Classifications and Chronological Maps

From the impervious map it is quite clear that the core city is almost covered with hard surface except the lakes and inland waterbodies and expanding towards its periphery. The agglomeration other than the core city is observed mostly in north (Gazipur, Tongi, Savar area) and south (Demra) of Dhaka. Dhaka is girdled by huge patch of wetlands and lowlands in east and west sides (from Fig 1). From the impervious map, city expansion is also visible in these two sides. At the south-west of Dhaka, the other side of Buriganga river is mainly the

Figure 40: Increasing Imperviousness from 1977 to 2011 (using ArcGIS 10.2, USGS data sets, Landsat Archives, L 4-5 TM Sensor data and UGS 84 UTM zone 46N co-ordinate system, image dates from left: 08-02-77, 24-11-99 and 29-08-11)

Keraniganj Upazilla which is occupied mostly by unplanned developments and sand-filled residential projects mentioned above. At the east, most of the lowlands region is occupied by Bashundhara, Pinkcity model town, Aftab Nagar and other housing estates. From the historic growth of impervious surface (figure 40) and chronological maps of wetland loss, it is clear that the expansion occurred at increased rate upto 1990-2000 in the central highlands of core Dhaka and after 2000, the expansion stretched towards peri-urban regions. Because of no specific
guideline and strategy of residential development in such landscape, the hard surface is covering the region rapidly.

4.6 Projection of Impervious surface in Keraniganj:

In the previous chapter, it is discussed that wetlands can function in sensitive and impacted watershed only. The impervious surface of the core city mostly above 75%, (from fig. ) thus classified under non-supportive watershed. Although from the chronological maps, it is clear that the expansion is occurring at the periphery, but still most of the periphery region is classified under impacted or sensitive watershed. To keep and preserve the natural landscape there should be guidelines for development to limit the imperviousness under 25% for future developments in these regions.

A projection map of impervious surface in Keraniganj is done from the mapping study and field study. From the mapping study, a recent condition of impervious surface is created. From ArcGIS data analysis, total impervious surface found 31.8 sq-km, which is 19.1% of the total area of 166.87 sq-km. From the field study, numbers of housing projects were identifies. Most of them are in sand-filling state right now. These projects will be built soon if there were no proper guideline given. Already some projects get approval changing the restriction from DAP in last year (Daily start, 2014). Using the same method and ArcGIS as the main tool, a projection map of Keranigang is created where all these sand-filled housing projects considered as impervious surface. (Figure 41) From the figure below, the impervious surface of projected Keraniganj will increased to 56.2 sq-km almost 33.7% of total area. There are significant portion categorized as impacted and sensitive watershed in Keraniganj in the present watershed categorized map of Dhaka region. If this increase happens, it will surely convert most of the impacted watershed of Keraniganj into non-supportive watershed and degrade the hydrology and other functions of the surrounding wetlands.
Projected Map of Impervious Surface in Keraniganj:

Figure 41: Comparison of Imperviousness of Keraniganj region, up: existing imperviousness, down: sand-fill area considered as impervious surface to show what will be the scenario if they (sand-filled) built typically without considering the hydrology and landscape (using ArcGIS 10.2, USGS data sets, Landsat Archives, L 4-5 TM Sensor data and UGS 84 UTM zone 46N co-ordinate system)
4.7 Conclusion

From the Mapping Analysis and from the Field study of three different levels, regional, community and building scale, some indicative design strategies for residential development in the peri-urban region of Dhaka city will be discussed in the following chapter.

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Threshold in Dhaka (Watershed Category)

Figure 42: Threshold mapped in Dhaka city and surrounding
Chapter Five: Findings and Conclusion

5.1 Introduction

5.2 Indicative Design Strategies by Scale

5.4.1 Regional Scale
5.4.2 Neighborhood/Community Scale
5.4.3 Building Scale

5.5 Wetlands as Network

5.6 Scope for future work

5.7 Conclusion
Chapter Five: Findings and Conclusion

5.1 Introduction

This chapter has continued the discussion from the previous chapter and developed some indicative design strategies for residential development at the peri-urban area of the city, particularly for Keraniganj Upazilla, as it was taken as the study area for field study. The discussion has included three different scales: Regional scale, Community/Neighborhood scale and in Building scale using the outcome from mapping study and field study. General strategies are outlined for the Regional scale strategies mostly related to urban design and planning. Indicative design strategies are given for Neighborhood scale and for Building scale to minimize the negative impacts of current approach of residential development at the peri-urban area of Dhaka city.

5.2 Indicative Design Strategies by Scale

From the previous research on thresholds of impervious cover, wetlands preservation and restoration are recommended for sensitive and impacted watersheds, which are under 25% impervious cover (see Figure 14 and 15). These watersheds correspond to low-density suburban areas, at the east and west periphery of Dhaka city and mainly composed of residential neighborhoods. As suburbanization, driven by residential need, is the primary cause of wetland loss of Dhaka city, this thesis proposes to target suburban residential neighborhoods for developing indicative design strategies.

For planning and designing effective residential neighborhoods, preserving and restoring wetlands requires work at multiple scales. At the regional scale, watersheds under 25% impervious cover must be identified and general guidelines need to be outlined to limit this threshold. At the neighborhood and site
scale, detail design strategies will be discussed to limit the impact on the hydrologic network.

### 5.2.1 Regional Scale

At the regional scale, general strategies will be discussed for three different watersheds, classified in watershed mapping of Dhaka region in previous chapter. As discussed in chapter 3, sensitive watersheds are with 0% to 10% impervious cover (Figure 43). These watersheds mainly comprise of rural development, characterized by dispersed pockets of very low-density development and agriculture. For sensitive watersheds with 0% to 10% impervious cover, the main focus should be on wetland preservation that maintains biodiversity and other natural functions. Preservation and conservation are most appropriate when the ecosystem is vital and intact and the task is to manage it. Guidelines should establish impervious cover limits at this watershed in order to control future impact of development. In these areas, it is very important to preserve large continuous open area of wetlands and lowlands. The new policies need to restrict development in these zones and allows transference of developments out of sensitive watersheds into more highly urbanized watersheds. (Balderas-Guzmán 2013).

Impacted watersheds are those with impervious cover between 10% and 25%, which has degraded existing streams and wetlands (see Figure 44). These watersheds are characterized by widespread suburban development, low density residential neighborhoods and associated development, which exists on the fringes of cities. Also there are numbers of housing projects by private and public authority waiting for approval. With the increasing amount of impervious surface, still there are some critical aspects of stream and wetland quality that can still be maintained. The focus should be on protecting these specific features. (Balderas-Guzmán 2013) New policies and guidelines should implement impervious cover limits on the site scale in order to decrease any additional impacts on the hydrologic network. Roads generate most of the impervious surface of a region.
Sensitive Watershed:

Figure 43: Representative Area from a Sensitive Watershed in Dhaka Region
Impacted Watershed:

Figure 44: Representative Area from an Impacted Watershed in Dhaka Region
Non-Supportive Watershed:

Figure 45: Representative Area from a Non-Supportive Watershed in Dhaka Region
Thus policies should take this into account to design efficient connecting network with roads as minimum as possible in impacted watersheds. Policy makers should acknowledge that they can not stop growth from occurring in that region. Unlike DAP proposal, they should adopt strategies that direct how and where growth occurs, rather than imposing limits in one place only to have growth happen elsewhere, where it may cause more damage to the hydrologic network. (Balderas-Guzmán 2013) This implies a focus on limiting impervious cover, rather than limiting population density, which is mentioned as the only limiting factor in our local guideline for residential development. For development in both sensitive and impacted watersheds, new policies should concentrate growth in clusters, and away from sensitive ecological areas. Clustering would help decrease the amount of connecting roads and services. As roads are a major generator of impervious cover, new policies can target the transportation network as another way to limit impervious cover in watersheds. Therefore, planning at the metropolitan level should focus on limiting the amount of roadways and minimizing the number of road crossings over wetlands and streams. (Balderas-Guzmán 2013) In case of the Dhaka for its deltaic landscape, seasonal variation can be addressed as well. Waterways were the main mode of transportation for Dhaka in its initial phase. Later it converted into road/land dependent transportation and rivers become the back of the city and the canals are filled up or encroached under the pressure of land crisis. In case of the development of the peri-urban region of Dhaka, if the waterway transportation can be considered initially, it can be implemented that will reduce the dependency on hard surface roads which is the major generator of impervious surface as mentioned earlier. As an alternative, waterway transportation can be promoted in Keraniganj, to reduce the pressure on land-based transportation (Section 5.4).

Lastly, impervious cover greater than 25% is non-supporting watersheds (Figure 45). These watersheds can be roughly characterized by any urban development with greater density or impervious cover, including inner-city neighborhoods, industrial areas, commercial areas, etc. Water bodies in this watersheds have been degraded beyond the threshold, strategies should focus on removing pollution and
limiting the volume of stormwater generation (Schueler 1994). In this region, the rain water run-off and the pollutants in water are very high that are responsible for water pollution. To restore wetlands in this region will not be effective as it will be very expensive to acquire lands necessary for an effective wetland. Instead, strategies should focus on the site-scale and include bio-swales, rain gardens, pocket greeneries and buffer strips, which are mainly intended to retain or slow the flow of stormwater and to reduce the amount of pollution.

5.2.2 Neighborhood/Community Scale

Since sensitive and impacted watersheds are those with the most potential for wetland preservation and restoration, there are further strategies that architects can use at smaller scales. The role of architect and planner becomes even more important at the neighborhood, and especially the site scale.

- **Roads and network**
  At the watershed scale, to decrease impervious cover, cluster development need to be considered in order to reduce that length of roads necessary for service development. At the neighborhood scale, for example, reducing road widths from the typical suburban width of 30 feet to 20 feet results in about 33.3% reduction of impervious surface, or 52,800 square feet per linear mile. Designers can examine the clustering of individual developments to minimize the length of roads and plot sizes. Also for the internal connections within a collective housing, pedestrian network can be promoted with minimum pervious paving that can allow water to be absorbed.

- **Natural site preservation and site division**
  Architects should maintain the natural contours and vegetation of the neighborhood as much as possible during master planning of a housing in order to retain as much of the natural hydrologic functions of the site. For this, for designing the masterplan of a housing, at first the site can be divided in two
separate parts ‘nature interface’ and ‘manmade interface’. ‘Nature interface’ includes the preserved or restored wetlands and other natural landscape elements that are existing in the site. ‘Man-made interface’ are all the man made structures including housing blocks, buildings for common facilities etc.

![Figure 46: Conceptual Site division](image)

- **Density and Plot Division**
  It should also be noted the relationship between density and imperviousness is not straightforward, making it difficult to judge the imperviousness of an area based on density alone for some reasons. (Balderas-Guzmán 2013) Though suburban areas may have low levels of imperviousness, the pervious area in suburban areas often behaves as impervious because of soil compaction from heavy machinery and the filling of depressions during the construction phase of the housing. (Schueler 1994) This compaction can persist for years and even increase with dense root networks. These factors can cause open areas to produce more runoff than an undisturbed natural area of equal size. Because of these issues, fewer houses on larger plots does not perform better than collective housing or cluster development. In a new suburban development, it is best to promote collective housing and cluster development and leave as much natural area undisturbed as possible.

- **Common Facilities**
  There are several common functions need to be provided in a housing, for example, playfield, park, school, community hall, bazar etc. In our guideline, according to the Private Land Development Policy 2008, at least 30% of open spaces need to be allocated for these common functions within a housing site. This percentage can be modified for housing sites at impacted or sensitive watershed to
maximize undisturbed natural landscape as ‘nature interface’ within a housing site and clustering housing block with higher density as ‘manmade interface’ in the remaining portion of the site. The ‘nature interface’ can be utilized by making it a park or a portion of it as a playfield with minimum intervention. These ‘nature interfaces’ need to be connected with adjacent sites to create an effective network. (section 5.3)

- **Limiting Footprint and Impervious Surface**

  The layout of a housing can have more roads compared to another area of the same density, creating more impervious surface. The design of housing cluster depending on two-story or five-story may also add impervious surface. Other structures, such as shops or garages, can create more impervious area. Architects can design the masterplan of a housing that minimize imperviousness by minimizing road area, clustering houses, minimizing the house footprint and eliminating surface parking, additional paving and long driveways. Planners can create policies that limit imperviousness by regulating building footprints, roadway areas, and the building of ancillary structures. These policies could either be part of zoning requirements, or could be indirectly encouraged by policies such as stormwater fees. (Balderas-Guzmán 2013) Some cities like Houston, charge stormwater fees based on the amount of impervious cover of a lot, encouraging landowners to keep as much pervious area as possible. Decreasing impervious cover can be economically beneficial as well.

- **Preserving Wetland Gradient**

  As discussed in chapter 3, the natural edge of the wetland is the most important part of wetlands in terms of biodiversity and other biological functions and need to be preserved wherever possible. There are several common functions other than residential blocks in a housing and there are opportunities to preserve the natural edge by design and merging it with those functions. From the figure 47 it is shown
that how the gradient can be preserved as a ‘partial gradient’ or ‘fragmented gradient’ with parks, playfield or other common functions within the housing site.

Figure 47: Wetland gradient incorporated with different elements of a housing

5.2.3 Strategies for Building Scale

At the site scale, architects should design to reduce the amount of impervious cover with minimum footprint of houses. Also the seasonality and extreme events need to be considered. For examples, even if impervious surfaces need to exceed 25% threshold, the hard surfaces need to be designed in a way that can provide room for extra water in extreme flooding or high rainfall during monsoon when water level gets higher. (Figure 48) Several strategies for building scale, discussed below:

- **Building storey:**
  Footprint of the houses can be minimum by increasing building levels. For example three-four storey houses instead of one-two storey floor plan. Again increasing building level have some negative impacts as well. It will need strong foundation for tall buildings in suburban lowlands. For example higher than four or five story
buildings need piling foundation at the east and west fringe areas of Dhaka city which will result in high cost to make the foundation only. Again it increases earthquake vulnerability and liquefaction effect on such landscape. Traditionally local or the migrated people of the fringe areas have strong connection with ground which can be lost if they are transferred into tall building. For the above mentioned reasons the thresholds for building height can be three to five story depending on the soil quality and other factors.

- **Building Plinth**

From the above discussions it is evident that the main notion is to limit imperviousness and landfilling wherever possible. As the amount of hard surface is increasing and lowlands are getting filled, there is no provision for monsoon or flood water retention. Water level getting high is a seasonal phenomenon and need to be addressed not only in Regional and Community scale but also at building scale as well.

To address the seasonal flux, building plinth can be of different levels according to the water levels of different seasons of that region. Different levels of plinth will address the seasonal water level variation, for example the lower level can be submerged under water during monsoon period and can be used as direct transfer point for waterway transportation. The next level of plinth can be inundated in five-year or ten-year flood. Other time this plinth can be used for recreational purposes or children play area during rainy days.

The plinth area should have minimum footprint but not entirely soft surface as it will increase dampness and will become negative spaces. Rather it can be hard surface that can be inundated at different times of the year. The adaptive sections and different plinth levels (Figure 48) are not constant rather it will change according to the geographical position and site location.
Figure 48: A building section with varied plinth levels and Connections (Hossain, 2012)

- **Physical Connections**

  There can be one minimum land based connection for each cluster connected with the higher level of plinth or with the first floor level. Waterway transport can be connected with a common point of a cluster or with the lower plinth level of a building that will be submerged under water during monsoon period and can be used as direct transfer point for waterway connection. Careful consideration is needed to avoid connections over water as minimum as possible as such connection creates disturbance and hamper wetland functions.

Figure 49: Physical Connections
Figure 50: Matrix of a housing in lowlands with indicative design strategies
The indicative design strategies for residential development presented here are primarily for the suburban fringes of cities, not the city cores. With holistic design approach the connected ‘nature interface’ will work as a system and maximize the benefits even co existing with the residential zone ‘man-made interface’. (figure 50)

5.3 Wetlands as Network

Isolated wetlands can never produce maximized benefits and contribute to the larger hydrologic network (Emerson). To get the maximum potential benefits, wetlands need to be considered as a part of larger network. In this notion, if a wetland is restored or preserved it needs to be connected with adjacent wetlands to maximize its benefit. In this way, constructed wetlands also have the potential of forming closed loops of material, air, water, and species flows in the environment. Then many opportunities will arise, for example to use the network as recreation, transportation, habitat for species and overall enhancing the functions of local hydrology. Network of wetlands can also act against flooding and other water-based problems and contribute to the resiliency of the city.

5.4 Scope for future work

There were limitations of this research as discussed on chapter one. But there are different aspects identified that need further research at the next level. Mapping of watershed is done based on the writing of Tom Schueler as an international guideline. The indicators and values can be changed if considered the local factors and unique deltaic landscape of Bengal. Further research is needed to examine the functions of our wetlands particularly at the east and west periphery of Dhaka to finalize the limiting values of imperviousness as a guideline for development where architects, planners, landscape designers need to work closely with ecologists and environmentalists. Further study is needed for reviving the
waterways and for visioning the water based fringe areas. Building services on this unique development need to be examined, that will cast minimum impact on the landscape.

5.5 Conclusion

The growth of Dhaka city started from the river Buriganga when the river was the main hub for trade, commerce and recreation. It was the main attraction of the city. After that, for the lack of proper visioning and for unplanned urban sprawl, these rivers, canals, wetlands have been an undervalued landscape that has been destroyed on a vast scale. Since the 2000s, urbanization, especially suburbanization is the primary cause of current wetland destruction. At the same time, urbanization destroys wetlands and canals, it also implements embankments, water treatment plants, piped infrastructure, underground drainage system and lays down large amounts of impervious surface that severely degrade the hydrologic network. The result is compromised hydrological function and health in the urban areas of Dhaka city.

Most of the sand filled (or going to be filled) areas at the Dhaka’s fringe are the different residential projects and are the primary target for wetland preservation and restoration. From the mapping, it was also clear that these areas are classified under 25% imperviousness and need to be preserved to maintain hydrological functions. Different strategies are discussed at three different scales where the main notion was to limit the impervious surface with integrated planning and design. Connected wetlands could improve the water flows throughout the hydrologic network, reinforce biodiversity and habitat, create closed loops of material flows, and become part of a regional recreational network. (Balderas-Guzmán 2013) By focusing on suburban residential neighborhoods, the city would greatly benefit from higher water quality, flooding protection, enhancing microclimate and other benefits.

As climate change, environmental degradation, and resource scarcity have become
important drivers for planning and design, wetland preservation and restoration can help to mitigate the complex environmental challenges of today. Through the proper symbiosis, where ‘manmade interface’ will get benefit from ‘nature interface’ without destroying its natural functions; the notion of complex landscape that conceptualizes the new housing typology where human, other species and natural functions of wetland can co-exist.

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Glossary

**Dhaka Metropolitan Area (DMA)** is the entire Dhaka City Corporation (DCC) area as well as its adjacent unions with an area of 303 sq-km. It is bounded by four rivers, the Buriganga to the south, Balu to the east, Turag to the west and Tongi Khal to the north. DMA is commonly referred to as 'Dhaka' by most people.

**Flood Action Plan** (FAP) is an initiative to study the causes and nature of flood in Bangladesh and to prepare guidelines for controlling it. FAP was based on earlier studies by UNDP, a French Engineering consortium, USAID and JICA (Japan International Cooperation Agency).

**IWFM** (Institute of Water and Flood Modelling) is an institute of Bangladesh University and Technology, pursues research and capacity development in the field of water and flood.

**Plug-flow conditions** means a hydraulic state where water is moving along the wetland with uniform speed along the width of the wetland.

**Sensitive watersheds** are those with 0 to 10% impervious cover. As discussed earlier, water level fluctuations in wetlands begin at 4% impervious cover. In sensitive watersheds, stream and wetland buffers and other stormwater management practices have the potential to maintain the original, pre-development quality of those hydrologic features.

**Impacted watersheds** are those with 11 to 25% impervious cover and will experience degradation, particularly instability of the stream channel and loss of some biodiversity.
Non-supporting watersheds are those with 25 to 100% impervious cover. Even with effective stormwater management practices, streams in these areas will never regain their full, pre-development quality.

Supervised Classification is a type of image classification where different classes or training samples of an image are need to be identified manually. There are four different types of supervised classifications in ArcGIS 10.1.

Training Sample Manager allows to see and change the properties of the selected training samples.

Maximum Likelihood Classification is among one of the four types of Supervised Classification. It is the popular method among four types.

Water level fluctuation (WLF) is the difference between minimum and maximum water levels for a given time period.

Watershed: A watershed is the area of land where all of the water that is under it or drains off of it goes into the same place (rivers, basins or seas).
Appendices

Appendix 1: Impervious Cover of Dhaka
Appendix 2: Categorized Watershed Map of Dhaka