ASSESSMENT OF PRESENT STATUS AND CONVEYANCE CAPACITY OF DRAINAGE SYSTEM IN SELECTED AREAS OF DHAKA CITY

MASTER OF SCIENCE IN
CIVIL & ENVIRONMENTAL ENGINEERING

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Abstract

Water logging has been a constant hazard for Dhaka city for quite a long time. The situation is severely aggravated during the monsoon. In many times, key portions of the city are inundated in rainwater several hours or even days after the torrent have been passed. The blame seldom goes to the unusual rainfall pattern and the drastic and unplanned urbanization of the city which have heavily contributed to this intolerable situation. However, the age old and poorly planned drainage network is mostly held liable for such a mishap according to the opinion of majority of the city dwellers as well as experts. To make things worse, the inadequate, existing network is very poorly maintained and as a result, the performance of this network itself has diminished drastically. The rivers and khals in and around the city of Dhaka is severely in the grasp of abuse, pollution and encroachment and losing its ground and capacity on a daily basis. Now a days, very few khals runs through the city and only a handful of lakes are available to be used as critical water reservoir.

A study area of 15.6 sq. km. within the heart of the city was selected to assess the said aspects of the drainage network. The study area is highly developed urban region consist of residential, commercial and business zone of national importance. After critically assessing the existing drainage network of study area, it was found that many of it are left unattended and uncared for years and as a result have lost most of its working capacity. In some places, drainage system elements like manholes, catchpits or conduits are found totally shut off and causing water logging even in the dry season. The present efficiency of the entire drainage network looks merely half of its design capacity. Calculations show that existing network have a mare capacity of discharging 324 cum per sec which is way below it's required limit. This below capacity network cannot handle this excess rainwater and hence results in severe waterlogging.

A probable supplementary network of conduits in addition to the existing network was proposed and theoretically implemented. A theoretical simulation shows that the proposed drainage network combined with the existing network can handle suggested historically probable high rainfall with considerable efficiency. However, it still fails to meet the needs if the rainfall goes excessively high. Designing a drainage network for such high probable intensity of rainfall is unrealistic and non-economic.

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List of Abbreviation

FAP	Flood Action Plan
BWDB	Bangladesh Water Development Board
DWASA	Dhaka Water And Sanitation Authority
WC	Water Closet
WTP	Water Treatment Plant
BNBC	Bangladesh National Building Code
DAP	Detailed Area Plan
EGL	Energy Grade Line
HGL	Hydraulic Grade Line
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
DEM	Digital Elevation Model
KML	Keyhole Markup Language
GIS	Global Information System
GPS	Global Positioning System
RAJUK	RAJdhani Unnayan Kartipakkha
DCC	Dhaka City Corporation
IWM	International Water Modeling
JICA	Japan International Cooperative Agency
SWM	Storm Water Management
APHA	American Public Health Association

CHAPTER 1

BACKGROUND & SCOPE OF THE STUDY

CHAPTER 1

BACKGROUND & SCOPE OF THE STUDY

1.1 Introduction

Water logging in the Dhaka Metropolitan area has become a part of city life due to its poor drainage system. Recurrence interval of this problem is alarmingly increasing. The city has been experiencing water logging for the last few years even after a little rain which in turn stall city dwellers in certain areas. Many areas remain inundated for couple of days just because of insufficient drainage system not complying with the rapid and unplanned growth of Dhaka city.

Built-up areas of the city should have the capacity of drainage to remove surface water runoff. Traditionally this has been achieved using underground pipe line systems designed for managing water (flows and volumes), to prevent local flooding conveying the water in the designated location as quickly as possible.

In the earlier days, drainage system of many canals (known as Khals) used to facilitate the drainage system. Those Canals would drain the City efficiently [Dewan and Yamaguchi, 2008]. In course of time this natural component of the drainage system is being lost due to rapid urbanization and blockage of existing canals. Still the remaining canals and the drainage pipes together - make the total drainage system of the city.

1.2 Drainage System of Dhaka City

Dhaka is geographically located between tropical and equinoctial region. Topography wise, the region is commonly a flat land and located mainly on fertile and silty alluvial terrace, technically known as the Modhupur terrace of the Pleistocene period [Miah & Bazlee, 1968]. Four major rivers, namely the Buriganga, Turag, Tongi and

Balu, surround Dhaka with their numberless tributaries and flow to the south, west, north and east sides of the city respectively.

The annual average precipitation of Dhaka city has been estimated to a about 2,000 mm, almost 80% of which occur during the rainy season or monsoon [Flood Action Plan (FAP), 1991]. The western part of Dhaka city is protected from river inundation by an encircling embankment known as the Dhaka-Narayanganj-Demra (DND) barrage. During most of the rainy season, the water level in these surrounding river systems remains higher than the water level inside barrage within the city area. This fact alone emphasizes the dependency of the drainage system of Dhaka city on the water levels of the peripheral river systems. The situation becomes worse when monsoon runoff generated from short duration and high intensity rainfall combines with high water level in river system. Main causes of floods in Dhaka City can be classified into two types [Flood Action Plan (FAP) 8A, 1991]. The first one results from high water level of peripheral river system and the other caused by rainfall in the city. Flooding in Dhaka City in 1996 caused by local high rainfall occurred in the built-up areas of the city. The severe water logging in September 1996 is believed to originate from insufficient drainage capacity of drainage system. For this reason, drainage of waste and storm water using the gravity flow is not always a feasible choice. In order to aide and support waste water and storm water drainage, installation of pumps at strategically advantageous locations to facilitate flood control and improved drainage of the city has been considered.

1.3 Urbanization and Flood Hazard

Seasonal inundations, floods and water loggings are some of the main natural hazards that Dhaka city faces every year. These hazards are closely associated with the monsoon and consequent river water overflow and rain water stagnation. Over the last few decades, the city has become more and more vulnerable to urban flooding of varying intensity due to moderate to heavy and unpredictable rainfall. The drainage capacity of the city has gone out of proportion and has decreased exponentially due to development of unplanned and unauthorized settlements. Illegal occupation of drainage canals and wetlands by land grabbers has further contributed to the problem. Study shows that Dhaka city expanded rapidly between 1960 and 2005 while the amount of urban land increased from 11% in 1960 to 34% in 2005 and the surface elevation of the key localized area of Dhaka ranges between 1 and 14 m and most of the built up areas located at the elevations of 6-8 m [Flood Action Plan (FAP), 1991]. The surrounding rivers like the Buriganga, Turag, Tongi and Balu are mainly fed by local rainfalls and also receive spills from three mighty rivers crisscrossing the country, namely the Ganges, Brahmamaputra and Meghna through their tributaries and distributaries in the monsoon. In terms of geomorphology, hydrology and socio-economics the newly built-up northeastern parts of Dhaka city are greatly vulnerable to seasonal inundations.

1.4 Characteristics of Urban Flooding of Dhaka City

As its capital city, Dhaka is situated in the heart of Bangladesh. In a broader sense, it lies in the sub-tropical monsoon zone under the humid climatic condition. According to Bangladesh Meteorological Department, the city experiences about 2,000 mm annual precipitation - of which more than 80% occurs during the month of June to September, commonly known as the monsoon season. For quite a long period of time now, the city of Dhaka, especially the low lying areas of Dhaka, has been suffering from floods of varying proportions, magnitudes, duration and nature. The extent of spread, depth, duration, frequency and overall nature of these floods are quite unprecedented and differs greatly from one flood to another or from one year to another. Analysis of various historical flood-data (i.e. hydrological reports) reveals that at least one eighth of total area of the city of Dhaka goes under water during a normal flood. However, during the time of some severe inundations (i.e. the floods of 1988 and 1998) about two-thirds or more area of the city was submerged under the floodwater [Borhan, 2004]. Usually, the typical floods or rain induced inundations suffer the city for shorter period. But, the unusual and greater floods, which are becoming more prevalent in the recent years in the city along with other parts of the country, occur and spread very fast and attain abnormally higher or deeper depths. At the same time these floods stay for longer time in different parts of the city.

The total flooded areas of normal flood in and around Dhaka City is found to cover about 25 sq. km or about 17 percent of the urbanized area where 42.78 percent of the submerged area is under low land with an elevation of 1.5 to 5m heights [Taleb, 2012]. These areas cover some parts of Dakshin Khan in the northeast, Barua, Khilkhet, Dumni, Bahatra, Kallyanpur, Baunia, Chak Digun, lower part of Mohammadpur, Joarsahara and Badda. During the severe floods of 1988, about 10 sq.km (11.75%) area of 6-13m elevation zone went under flood water in Dhaka City's urban area and 21.22 sq.km (29.67%) and 50.52 sq. km (33.93%) of 1.5-5 and 5-6m elevation zones were flooded respectively [Borhan, 2004]. In total about 82 sq. km of about 66 percent of the area of the city was affected by this severe inundation of 1988. However, it should be noted that this was an unusual occurrence in the city.

The average depth of normal flood in Dhaka city is roughly 1.0 m (BWDB 1989 and Islam 1996). In most areas of the city the depths of floods are determined or influenced by the degree of urbanization, nearby water body and amount and efficiency of the drainage infrastructure system of the area. The minimum and average flood duration in Dhaka City is 1 to 32 hours respectively [Flood Action Plan (FAP) 8A, 1991]. The depth of flood depends on the favorable sources of water coming into the city from the adjacent rivers, canals or water bodies and also various physiographic conditions in Dhaka city and its adjoining areas.

1.5 Rainfall Pattern of Dhaka City

Located at the heart of the Ganges Delta, Dhaka receives generous amount of monsoon during and around the rainy season. The torrent of rain tends to start from May and continue till October. However, historical rainfall data shows that the peak of the monsoon has shifted from June-July to August-September over the last decade. The peak rainfall recorded for a single day over the last 10 years is 341 mm which is the peak for the last 60 years as well. Details of the historical rainfall data for the last 10 years are presented in tabular and graphical format in Table 4.1 and Graph 4.1 respectively.

1.6 Drainage Network of Dhaka City

The Drainage System of Dhaka city is hybrid in nature and the Drainage Network itself consists of natural and artificial channels and conduits. Among the natural channels there are khals, rivers, lakes, ponds, ditches and other natural water bodies while the artificial drainage network consists of pipes, drains and box culverts of different shapes and sizes. The main drainage is fed by adjoining feeder lines which are connected to numerous manholes and catch pits which work as the primary intake points for the rainwater or surface water. The responsibility of the drainage service in Dhaka city lies primary on Dhaka Water and Sanitation Authority (Dhaka WASA or DWASA) along with Dhaka City Corporations – North and South and Water Development Board of Bangladesh (WDB). The drainage networks under Water Development Board have already been shifted to Dhaka WASA. The same procedure is currently under progress for the City Corporations. Currently, majority of the drainage networks lie under the jurisdiction of Dhaka WASA with only a few percentage of the small diameter feeder lines under the jurisdiction of Dhaka City Corporation.

Though the city of Dhaka is surrounded by the mighty rivers, namely the Buriganga, Balu & Turag and is crisscrossed by many khals, the study area does not directly contain any of these natural drainage elements which play a direct positive role in any drainage network. The DND Barrage, part of the Dhaka-Narayanganj-Demra (DND) Project located between the cities of Dhaka and Narayanganj and bounded by the buriganga and the shitalakshya river. However, during the rainy season, when the water level at the surrounding rivers goes up and surpasses that of the city inside the DND barrage, the existing drainage network is not able to drain the surplus rainwater out to the rivers. For such times, Dhaka WASA has eight high powered pumps installed on strategically crucial locations to pump out the rain water to the surrounding rivers over the DND Barrage. If the water levels at the surrounding rivers are excessively high, then there occurs a chance for backflow of water which adds up to the already stagnant water to make the situation worse.

A detailed area based layout of the drainage system of Dhaka city can be found in Annex. IV.

1.7 Efficiency of Drainage System of Dhaka City

Efficiency of a system refers to its functioning capacity in comparison to its full capacity. In case of the drainage system of Dhaka city, it is quite evident that the system is running well below its full capacity. The reasons behind this are:

- The channels and conduits; both natural and artificial, open and underground, are clogged with sludge and other solid wastes and their effective area have diminished severely.
- The natural open channels and water bodies are subjected to severe pollution and encroachment all around Dhaka city, which has reduced the efficiency, retaining and draining capacity of the natural drainage elements.
- In most cases, the manholes and catch pits, which act as the inlets or feeding points for the drainage networks, are clogged with household and other wastes, non-perishable plastic wastes as well as simple natural wastes like tree leaves. In some extreme cases, semi permanent to permanent structures are built over these inlets that severely hamper their workability.

1.8 Objectives of the study:

The general objectives of this research are as follows:

- To assess the capacity of existing drainage system in terms of adequacy of drainage lines, slope, manholes etc. (compared with peak flow) in Dhaka city.
- To assess the carrying capacity of existing canals for discharging surface runoff from Dhaka city.
- To assess the required quantity of flow through existing drainage system to avoid water logging in Dhaka city.
- To assess the existing water logging pattern from secondary data and finding measures of identifying the worst affected area.

1.9 Outcomes of the Study

- Providing a decision support system for the policy makers for necessary expansion and maintenance system of existing drainage system in Dhaka city.
- Identification of critical water logging areas and emphasizing the future investment on minimizing the inundation.
- Quantification of the gap will enhance estimation of possible investment to fill up the gap for projected future.
- Help determining further drainage outlets for mitigating inundation events.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Now-a-days, drainage system is a must in urban areas because of the synergic interaction between human activity and the natural water cycle. The two main forms of this interaction are the abstraction of water from the natural cycle to provide a system of water supply for human life and to provide covering of land with impermeable surfaces that ensure prompt diversion of water from locality as well as making sure that maximum degree of efficiency in terms of returning this diverted water into the natural water streams.

These two types of interaction give rise to two types of water that modern drainage systems need to handle: Wastewater and Stormwater [Brokenshire, 1995]. Wastewater is the residual or contaminated water that has been supplied to support life, maintain a standard life as well as to satisfy the needs of urban dwellers. Stormwater, on the other hand, is rainwater (or water resulting from any form of precipitation) falling on a built-up area. Poorly managed wastewater can result in environmental pollution where as poorly managed stormwater can result in unwanted flooding and water logging.

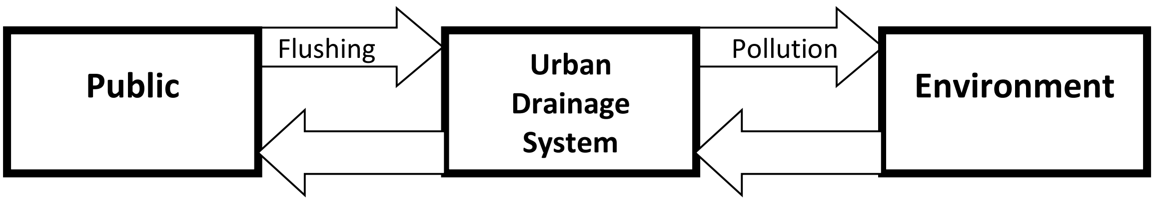


Fig. – 2.1: Interfaces with the Public & Environment

2.2 What is urban drainage?

Urban Drainage is composed of an artificial system of sewers: pipes and other related infrastructures that collect and disposes all sorts of disposable water an urban area can encounter. A modern drainage system should address all the aspects of urbanization problems, including the need for cost-effectiveness, socially acceptable technical improvements in existing systems, the need for assessment of the impact of those systems, and the need to search for sustainable solutions. Even though, these challenges cannot be considered to be the responsibility of one profession alone. Policy-makers, engineers, environment specialists, together with all citizens as a community, have a role. And these roles must be played in partnership. Engineers must understand the wider issues, while those who seek to influence policy must have some understanding of the technical problems.

2.3 Effects of urbanization on drainage

In nature, when rainwater falls on a natural surface, some water returns to the atmosphere through evaporation, or transpiration by plants; some infiltrates the surface and becomes groundwater; and some runs off the surface. The relative proportions depend on the nature of the surface, and vary with time during the storm. Both groundwater and surface runoff are likely to find their way to a river, but surface runoff arrives much faster. The groundwater will become a contribution to the river's general base flow rather than being part of the increase in flow due to any particular rainfall. Development of an urban area involves covering the ground with artificial surfaces and usually has a significant effect on these processes. The artificial surfaces increase the amount of surface runoff in relation to infiltration, and therefore increase the total volume of water reaching the river during or soon after the rain. Surface runoff travels quicker over hard surfaces and through sewers than it does over natural surfaces and along natural streams. This means that the flow will both arrive and die away faster and therefore the peak flow will be greater.

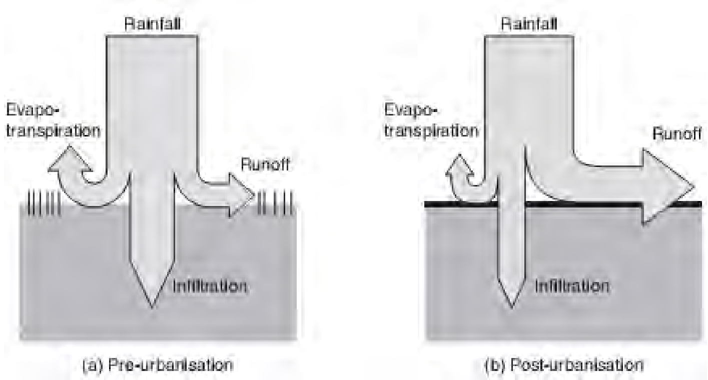


Fig. 2.2: Effect of Urbanization on Rainfall, Runoff & Infiltration

This obviously increases the danger of sudden flooding of the river which also has strong implications for water quality. The rapid runoff of stormwater is likely to cause pollutants and sediments to be washed off the surface or scoured by the river. Thus, in an artificial environment, there are likely to be more pollutants on the catchment surface and in the air than there would be in a natural environment [Evans, Thorne, Saul, Ashley, Sayers and Watkinson, 2003]. Also, drainage systems in which there is mixing of wastewater and stormwater may allow pollutants from the wastewater to enter the river.

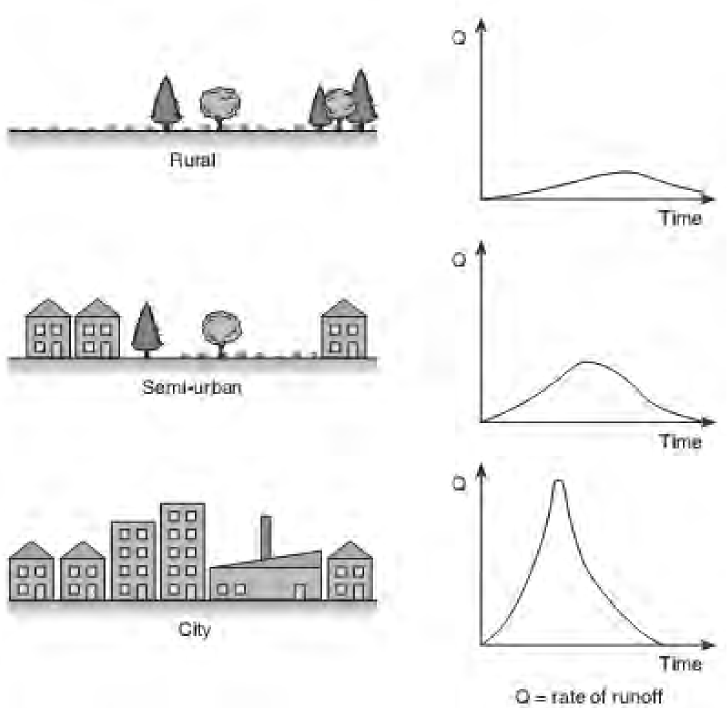


Fig. 2.3: Effect of Urbanization on Peak Rate of Runoff

The existence of wastewater in significant quantities is itself a consequence of urbanization. Water is also used as the principal medium for disposal of bodily waste, and varying amounts of bathroom litter, via WCs. In a developed system, much of the material that is added to the water while it is being turned into wastewater is removed at a wastewater treatment plant prior to its return to the urban water cycle. Nature itself would be capable of treating some types of material, but not in the quantities created by urbanization. The proportion of material that needs to be removed will depend in part on the capacity of the river to assimilate what remains.

2.4 Urban drainage and public health

The most valuable and direct benefit of an effective urban drainage system is the maintenance of public health. This particular objective is of extreme importance, particularly in protection against the spread of diseases. Urban drainage has a number of major roles in maintaining public health and safety. Human excreta (particularly faeces) are the principal vector for the transmission of many communicable diseases and urban drainage has a direct role in effectively removing excreta from the immediate vicinity of habitation [Lei, Wong, Liu and Tang, 1996]. On the other hand, there are further potential problems in large river basins in which the downstream discharges of one settlement that may become the upstream abstraction of another. This clearly indicates the vital importance of disinfection of water supplies as a public health measure. Another major public health issue in drainage system is water logging that can be largely avoided by effective drainage. This reduces the possible mosquito habitat and hence the spread of malaria and other diseases.

2.5 Geography of urban drainage

The main factors that determine the extent and nature of urban drainage provision in a particular region are:

- General wealth condition of the habitants
- Climate and other natural characteristics
- Degree of urbanization
- History and politics.

The greatest differences are the result of differences in wealth. Regions where rainfall tends to be occasional and heavy have naturally adopted different practices from those in which it is frequent and generally light. Intensity of urbanization has a strong influence on the percentage of the population connected to a main sewer system. Historical and political factors determine the age of the system, characteristics of operation such as whether or not the water/wastewater industry is publicly or privately financed, and strictness of statutory requirements for pollution control and the manner in which they are enforced.

2.6 Approaches to urban drainage: Types of system

Degree of development of an urban area can have a huge impact on drainage as discussed so far. Rain running off impermeable surfaces and travelling via a piped drainage system reaches a river far more rapidly than on the land in a natural state, and the result can be flooding and increased pollution. Thus, the first distinction between types of urban drainage system is the mode of disposal, those that are based fundamentally on pipe networks and those that are based on natural conduit.

2.7 Types of piped system: combined or separate

Urban drainage systems handle two types of flow – wastewater and stormwater. There are basically two types of conventional sewerage system: a combined system in which wastewater and stormwater flow together in the same pipe, and a separate system in which wastewater and stormwater are kept in separate pipes. Some systems are hybrid in nature, for example a 'partially-separate' system, in which wastewater is mixed with some stormwater, while the majority of stormwater is conveyed by a separate pipe [Brokenshire, 1995]. Many urban areas have hybrid systems for more accidental reasons: for example, because of a new town drained by a separate system includes a small old part drained by a combined system, or because wrong connections resulting from ignorance or malpractice have caused unintended mixing of the two types of flow. Dhaka is a nice example for such hybrid sewer system.

2.8 Combined system

The combined sewers carry both wastewater and stormwater together in the same pipe, and the ultimate destination is the wastewater treatment plant (WTP), usually located a short distance out of the town. In dry weather, the system carries wastewater flow. During rainfall, the flow in the sewers increases as a result of the addition of stormwater. Even in quite light rainfall, the stormwater flows will predominate, and in heavy falls the stormwater could be fifty or even one hundred times the average wastewater flow. However, it is simply not economically feasible to provide capacity for this flow along the full length of the sewers which, by implication, is designed to carry only a tiny proportion of the capacity most of the time. At the treatment plant, it would also be unfeasible to provide this capacity in the treatment processes. In Dhaka City, most of the sewerage systems are combined and this accounts for nearly 80% by total length. Many developed countries have a significant proportion of combined sewers: in France and Germany, for example, the figure is also around 70%, and in Denmark it is 45%.

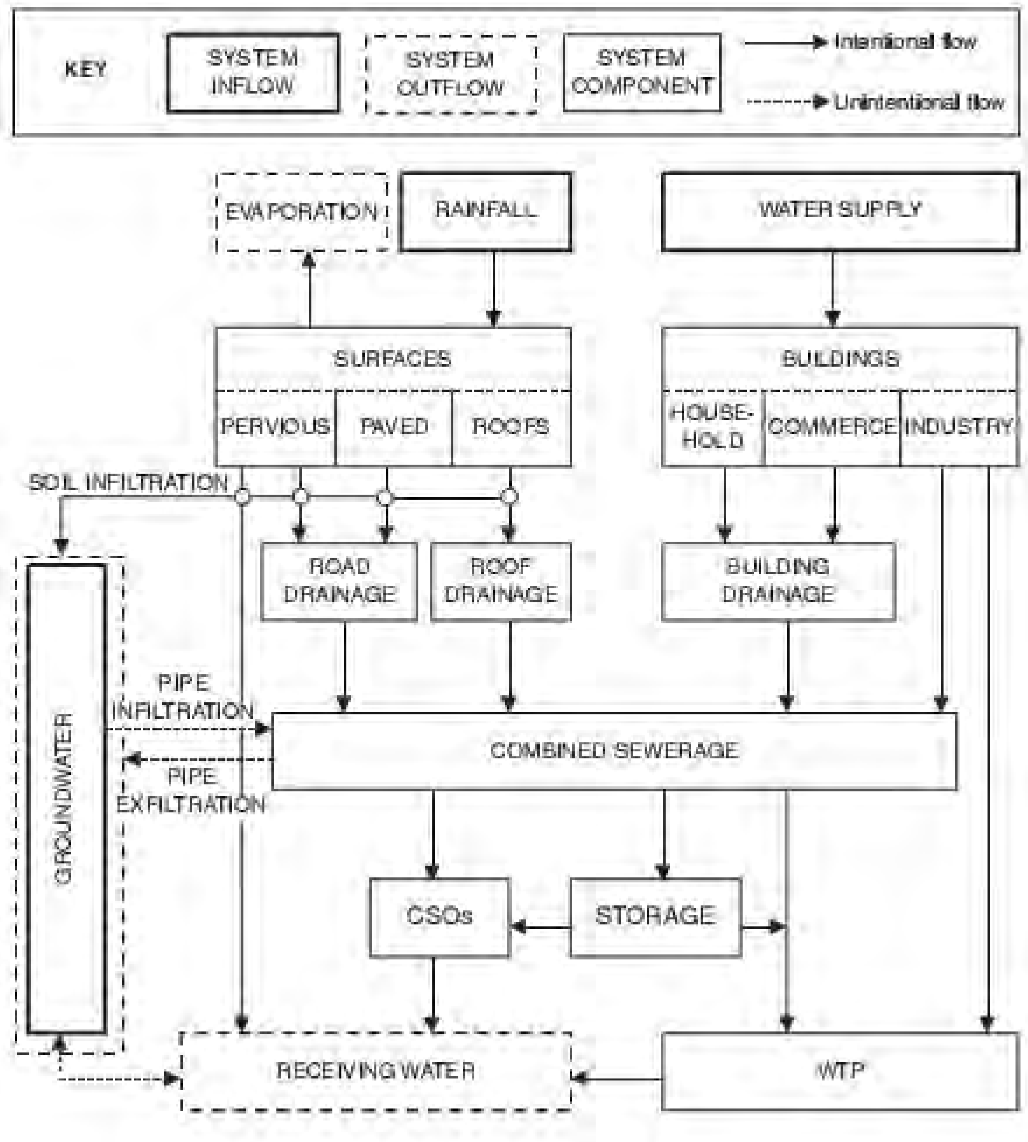


Fig. 2.4: Urban Water System : Combined Sewerage

2.9 Separate system

As the name suggests, separate system disposes sewer using the separate system. Wastewater and stormwater are carried in separate pipes, usually laid side-by-side. Waste water flows vary during the day, but the pipes are designed to carry the maximum flow all the way to the wastewater treatment plant. The stormwater is not mixed with wastewater and can be discharged to the water body at a convenient point.

The first obvious advantage of the separate system is efficiency. The network is designed to carry maximum flow at any given time. Also the pollutions associated with the sewer are avoided. The obvious disadvantage is cost.

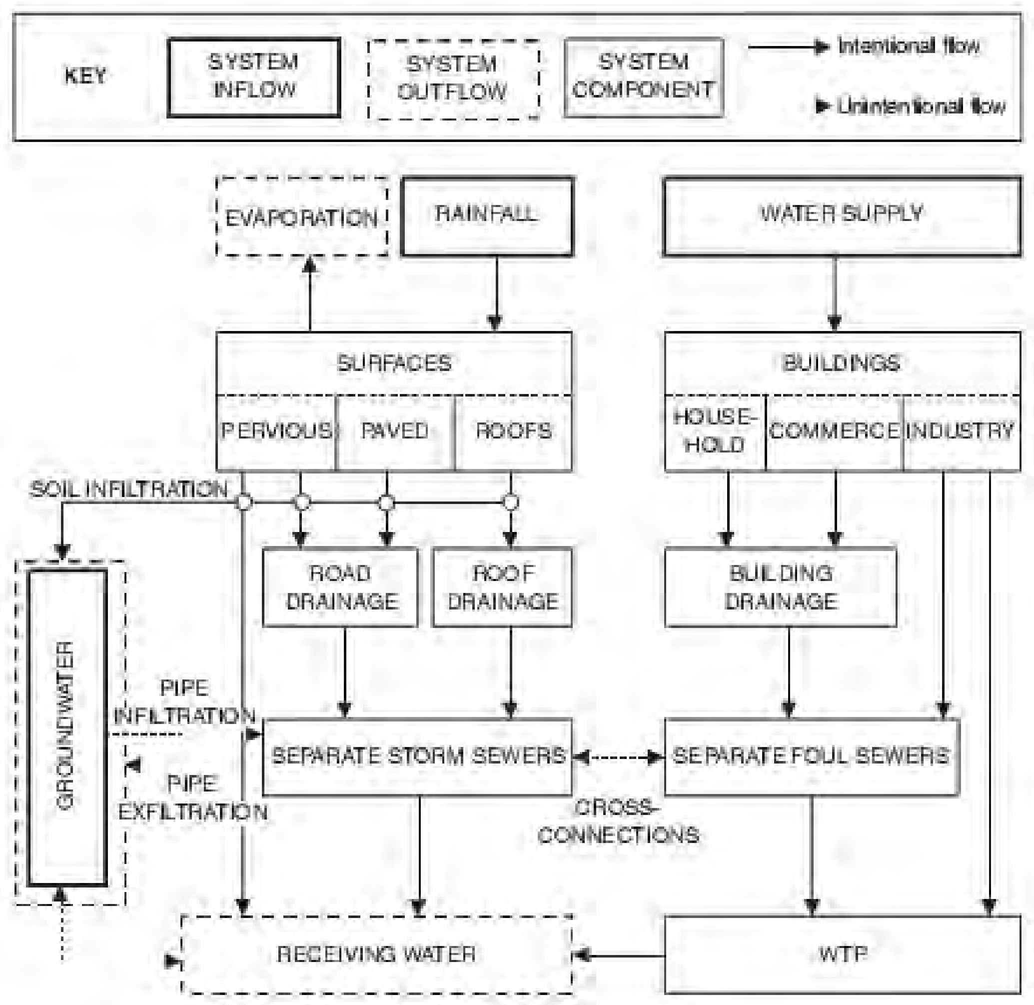


Fig. 2.5 Urban Water System: Separate Sewerage

2.10 Building drainage

Designing an urban drainage system does not necessarily involve the planning, design and construction of drainage of an individual building, but the knowledge on general building drainage practices and prevailing conditions in and around local households is of utmost important to understand the big picture. This includes, in particular, an understanding of how building drains connect with the main sewer system.

2.11 Soil and waste drainage

A common arrangement for the soil (WC) and waste (other appliances) drainage of modern domestic properties is shown in above figure. This illustrates a two-storey dwelling with appliances on both floors connected to a single vertical stack. Each appliance is protected by a trap (U-bend or S-bend) and water seal to prevent odors reaching the house from the downstream drainage system. The stack (typically 100–150mm in diameter) has a top open to atmosphere that should be at least 900mm from the top of any adjacent opening into the property. The flow regime in a vertical stack is quite different to that in sloping pipes. Flow tends to adhere to the perimeter of the pipe forming an annulus with a central air core. The pressure of the air in the core varies with height, depending on the appliances in use and can be both positive and negative. Design rules and details have been devised to avoid the risk of water being siphoned from the traps. Once outside the building, the drainage systems have a number of common components, particularly with provisions to access for testing, inspection and blockage-clearance from the surface. A Roding eye permits Roding along the drain from the surface. It consists of a vertical or inclined riser pipe with a sealed, removable cover. Access can also be gained using an inspection chamber, commonly known as inspection pit, over a pipe fitting with a sealed, removable cover. Gradients for the conduits are tend to be quite steep (>1:80 for 100 dia. pipes), although field evidence suggests that very flat drains are no more likely to block than steep ones [Lillywhite and Webster, 1979]; good quality construction is more influential in reducing blockage potential. Drains and private sewers are relatively shallow with a minimum ground cover of 0.75m and 1.25m under roads and paths.

The height, along with the length and gradient of the drain, determines the minimum feasible depth of the public sewer [Wise and Swaffield, 2002].

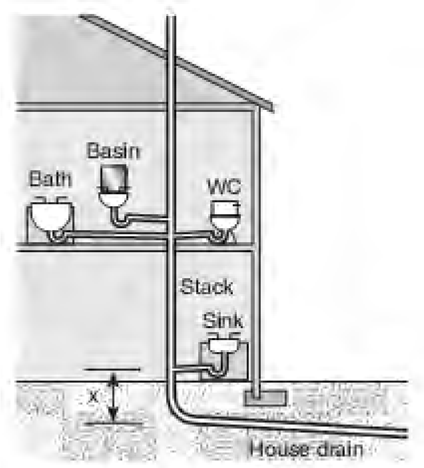


Fig. 2.6 Typical Building Drainage arrangement

The main aim of the layout of external building drainage is to minimize the length of pipe network and associated components, whilst ensuring that adequate accessibility is maintained. Generally, changes of direction should be minimized and appropriate access points provided where necessary. Building drains carrying soil and waste should discharge only to a public foul or combined sewer. Inspection chambers with sealed, removable covers should be placed at regular interval. A good practice is to provide an interceptor trap with water seal in the last inspection chamber before the sewer. These were provided to reduce the risk of odor release into the building drainage and to discourage the entry of rodents. However, they have tended to fall into disuse and disrepair and can be a source of blockage and odor problems in their own right. For this reason, they are not normally specified or provided in most domestic sewer system.

2.12 System components of a sewer system

Most conduits for public sewer system are circular in cross-section and range upwards in diameter from 150 mm. They can be made of vitrified clay, concrete, fiber cement, uPVC or any other polymers, pitch fiber or brick.

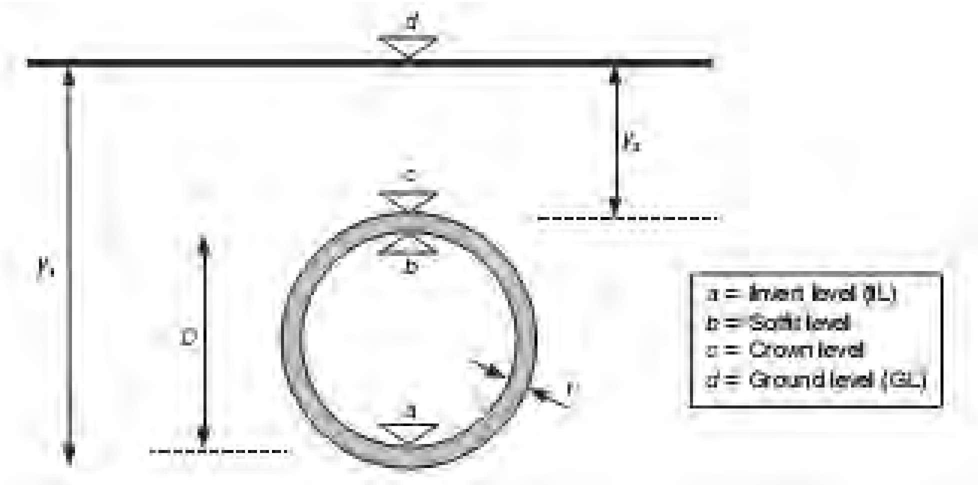


Fig. 2.7 Level definition associated with sewer conduit

The above Figure illustrates how the vertical position of a sewer is defined by its invert level (IL). The invert of a pipe refers to the lowest point on the inside of the pipe. The invert level is the vertical distance of the invert above some fixed level or datum. Other important levels shown in the Figure are the soffit level which is the highest point on the inside of the pipe and the crown which is the highest point on the outside of the pipe. Using these nomenclatures:

$$b = a + D$$

and

$$c = b + t = a + D + t$$

Where,

D = internal diameter of the pipe (mm)

T = pipe wall thickness (mm)

The depth of the pipe, y_1, is therefore:

$$y_1 = d - a + t$$

and the cover of the pipe, y_2, is:

$$y_2 = d - c = y_1 - D - 2t$$

Manholes

Similar to the building drainage systems, public or city drainage systems need access points for testing, inspection and cleaning. In sewer systems, access is usually ensured by providing sufficient number of manholes at convenient distance. Manholes are different from inspection chambers or inspection pits in that they are deeper (>1m) and can be entered if necessary. Manholes are provided when there is a:

- changes in direction
- heads of runs
- changes in conduit gradient
- changes in couduit size
- major junction with other sewers
- every 90 m.

In larger pipes, where man-access is possible, the spacing of manholes may be increased up to 200 m. Manholes are commonly constructed of precast concrete rings as specified in BS 5911. Smaller manholes may have precast benching. The diameter of the manhole will depend on the size of sewer and the orientation and number of inlets. Requirements for manhole covers and frames are given in BS EN 124: 1994. In situations where a high level sewer is connected to one of significantly lower level, a backdrop manhole can be used. These are typically used to bring the flow from higher level laterals into a manhole rather than lowering the length of the last sewer lengths. Drops may be external or internal to the manhole, or sloping ramps may be used, depending on the drop height and the diameter of the pipe. Drop manholes can require additional maintenance.

Gully inlets

Surface runoff is collected from roads and other paved areas via inlets known as 'gullies'. Gullies consist of a grating and usually an underlying sump (a 'gully pot') to collect heavy material in the flow. A water seal is incorporated to act as an odor trap for those gullies connected to sewer mains. The gully is connected to the sewer by a lateral pipe. The size, number and spacing of gullies will determine the extent of surface precipitation or runoff during storm events. Gullies are always placed at low points and, typically, are spaced along the road channel, adjacent to the curb. The simplest approach is to specify a standard of 50m spacing for fully paved catchment or to require one gully per 200m of impervious area. However, Mollinson (1958) proposed that:

$$L = (280\sqrt{s})/W$$

Where,

L = gully spacing (m)

S = longitudinal road gradient (%)

w = width of drainage area (m)

Ventilation

Ventilation is required in all urban drainage systems, but particularly in foul and combined sewers. It is needed to ensure that aerobic conditions are maintained within the pipe, and to avoid the possibility of build-up of toxic or explosive gases. Nearly all sewer systems are ventilated passively, i.e. without air extraction equipment. However, some major pumping stations and Treatment Plants can be equipped to be ventilated mechanically. Some systems use ventilated manhole covers. More modern practice is to utilize the ventilation provided by the soil stacks on individual buildings. Air is drawn through the system by the low pressure induced by the flow of air over the top of the stacks, and by the fall of wastewater. The water seals on domestic appliances avoid backup of sewer gases into the building interior.

2.13 Sewer Design

A number of fundamental stages need to be followed to design a rational and cost-effective urban drainage system. These stages are valid for almost any type of sewer system design anywhere in the world. The first stage is to define the contributing area (catchment area and population) and mark it on a topographical map. The map should already include contours, but other pertinent natural (e.g. rivers) and man-made (e.g. buildings, roads, services) features should also be marked up. Possible outfall or overflow points should be identified and investigations made as to the capacity of the receiving water body.

The next stage is to produce a preliminary horizontal alignment aiming to achieve a balance between the requirements to drain the whole contributing area and the need to minimize pipe run lengths. Least cost designs tend to result when the pipe network broadly follows the natural drainage patterns and is branched, converging to a single major outfall. After identifying the horizontal network for the pipes, the pipe sizes and gradients should be calculated based on estimated flows from the contributing areas. Conventionally, sewers should follow the slope of the ground as far as possible to minimize excavation. However, gradients flatter than 1:500 should be avoided as they are difficult to construct accurately. The next stage is to design a preliminary vertical alignment, again bearing in mind the balance between coverage of the area and depths of pipes. The alignment can be plotted on longitudinal profiles and ground levels can initially be taken from the OS map contours. However, an on-site level survey will eventually be required. Pumping should be avoided, particularly on storm sewer systems, but will be needed if excavations exceed about 10 m.

The final stage involves revising both the horizontal and vertical alignment to minimize cost by reducing pipe lengths, sizes and depths whilst meeting the hydraulic design criteria. If situation demands, longer sewer runs may be cost effective if shorter runs would require costlier excavation and/or pumping.

The stages for designing an urban drainage system are shown on the next page with a simple flow chart:

Topographical map

Obtain or develop a map of the contributing area. Add location and level of existing or proposed details such as:

- contours
- physical features (e.g. rivers)
- road layout
- buildings
- sewers and other services
- outfall point (e.g. near lowest point, next to receiving water body).

⇩

Preliminary horizontal layout

Sketch preliminary system layout (horizontal alignment):

- locate pipes so all potential users can readily connect into the system
- try to locate pipes perpendicular to contours
- try to follow natural drainage patterns
- locate manholes in readily-accessible positions.

⇩

Preliminary vertical layout

Draw preliminary longitudinal profiles (vertical alignment):

- ensure pipes are deep enough so all users can connect into the system
- try to locate pipes parallel to the ground surface
- ensure pipes arrive above outfall level
- avoid pumping if possible.

⇩

Preliminary sewer sizing

Establish preliminary pipe sizes and gradients.

⇩

Revise layout

Revise the horizontal and/or vertical alignment to minimize system cost by reducing pipe lengths, sizes & depths.

2.14 Hydraulics of Sewer

An understanding of hydraulics is needed in the design of new drainage systems in order to specify the appropriate size of system components, especially pipes, channels and tanks. It is also needed in the analysis and modeling of existing systems in order to predict the relationship between flow-rate and depth for varying inflows and conditions.

The study of engineering hydraulics tends to concentrate on two main types of flow. The first is pipe flow in which a liquid flows in a pipe under pressure. The liquid always fills the whole cross-section, and the pipe may be horizontal or inclined up or down in the direction of flow. The second is open-channel flow, in which a liquid flows in a channel by gravity, with a free surface at atmospheric pressure. The liquid only fills the channel when the flow-rate equals or exceeds the designed capacity, and the bed of the channel slopes down in the direction of flow. The most common type of flow in sewer systems is a hybrid of these two: partially full pipe flow, in which a liquid flows in a pipe by gravity, with a free surface. The liquid only fills the pipe area when the flow-rate equals or exceeds the designed capacity, and the bed of the pipe slopes down in the direction of flow. Traditionally the theories used are most closely related to those for full pipes, though actually part-full pipe flow is a special case of open-channel flow.

2.15 Basic principles of flowing fluids

Pressure

Pressure is defined as force per unit area. The common units for pressure are kN/m or bars (1 bar = 100 kN/m). Absolute pressure is pressure relative to a vacuum, and gauge pressure is pressure relative to atmospheric pressure. Gauge pressure is used in most hydraulic calculations. Atmospheric pressure varies but is approximately 1 bar. Pressure at a point is equal in all directions.

In a liquid in stagnant or still state, pressure increases with vertical depth:

$$\Delta p = \rho g \Delta y$$

Where,

Δp = increase in pressure (N/m)

ρ = density of liquid (for water, 1000 kg/m)

g = gravitational acceleration (9.81 m/s^2)

Δy = increase in depth (m)

Continuity of flow

In a section of pipe with constant diameter and no side connections in any period of time the mass of liquid entering must equal the mass leaving. Assuming that the liquid has a constant density (mass per unit volume), the volume entering must equal the volume leaving. The common units for flow-rate are m^3/s or l/s.

In terms of flow-rate (volume per unit time, Q):

$$Q_1 = Q_2$$

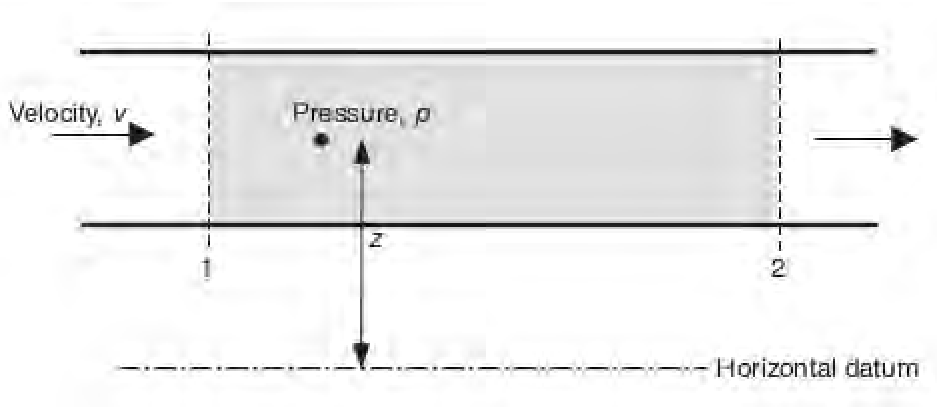


Fig. 2.8 Continuity and definition of symbols in conduit flow

The velocity of the liquid varies across the flow cross-section, with the maximum for a full pipe in the centre. 'Mean velocity' (v) is defined as flow-rate per unit area (A) through which the flow passes:

$$Q = v / A$$

Flow classification

In hydraulics there are two terms for 'constant': uniform and steady. Uniform means constant with distance, and steady means constant with time. These two terms defines the hydraulic conditions in urban drainage systems:

- Uniform Steady:
  The flow cross-sectional area is constant with distance, and flow-rate is constant with time
- Non Uniform Steady:
  The flow area varies with distance, but flow-rate is constant with time
- Uniform Unsteady:
  The flow area is constant with distance, but flow-rate varies with time
- Non Uniform Unsteady:
  The flow area varies with distance, and flow-rate varies with time.

Flow in sewers is generally unsteady to some extent: wastewater varies with the time of day, and storm flow varies during a storm. However, in many hydraulic calculations, it is not necessary to take this into account, and conditions are treated as steady for the sake of simplicity. In some cases, unsteady effects are significant and must be considered.

Laminar and turbulent flow

The property of a fluid that opposes its motion is called viscosity. Viscosity is caused by the interaction of the fluid molecules creating friction forces between the layers of fluid travelling at different velocities. Where velocities are low, fluid particles move in straight, parallel trajectories – known as laminar flow. Where velocities are high, fluid particles follow more chaotic paths and the flow is called turbulent. Flow can be identified as laminar or turbulent using Reynolds number (Re), defined for a pipe flowing full as:

$$R_e = \vartheta D / v$$

Where, v = velocity (m/s)

D = pipe diameter (m)

ϑ = kinematic viscosity of liquid (for water, typically 1.1x10 m^{-6}/s^{2})

When Re < 2000, the flow in the pipe is laminar; when Re > 4000, flow is turbulent. In most urban drainage applications, flow is firmly in the turbulent region.

2.16 Pipe flow

2.16.1 Head (energy) losses

A flowing liquid has three main types of energy: pressure, velocity and potential. In hydraulics, the most common way of expressing energy is in terms of head. Head is defined as energy per unit weight and expressed in units of height (commonly ft or m). The head or energy losses in flow in a pipe are due to the friction losses and local losses. Friction losses are caused by forces between the liquid and the solid boundary (distributed along the length of the pipe), and local losses are caused by disruptions to the flow at local features like bends and changes in cross-section. Total head loss h_L is the sum of these two components.

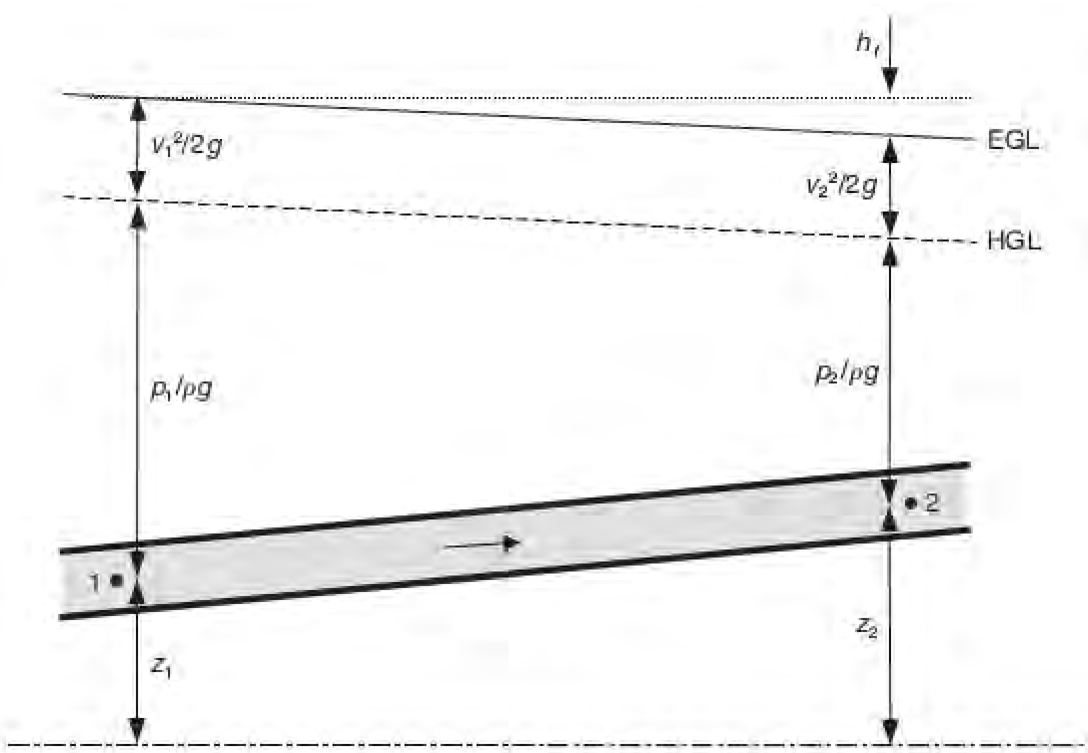


Fig. 2.9 EGL and HGL for a conduit flowing full

The distribution of head losses and its other components can be shown by two imaginary lines. The energy grade line (EGL) is drawn a vertical distance from the datum equal to the total head. The hydraulic grade line (HGL) is drawn a vertical distance below the energy grade line equal to the velocity head. The head loss can also be expressed as difference in pressure head and can be expressed as:

$$h_L = (p_1 - p_2)/\rho g$$

where,

h_L = Total Head loss between pt. 1 & pt. 2

p_1 = pressure head at pt. 1

p_2 = pressure head at pt. 2

ρ = density of liquid

g = gravitational acceleration (9.81 m/s^2)

2.16.2 Friction losses

A fundamental requirement in the hydraulic design and analysis of urban drainage systems is the estimation of friction loss. The basic representation of friction losses, valid for both laminar and turbulent flow, is the Darcy-Weisbach equation:

$$h_f = \frac{\lambda L}{D} \cdot \frac{v^2}{2g}$$

h_f	head loss due to friction (m)
λ	friction factor (no units)
L	pipe length (m)
D	pipe diameter (m)

The term hf /L is the gradient of the energy grade line, and (for uniform flow) of the hydraulic grade line, and is often referred to as the 'hydraulic gradient' or 'friction slope'.

2.16.3 Friction factor

The friction factor λ is one of the most interesting aspects of pipe hydraulics. As mentioned before, velocity varies over the flow area. In turbulent flow (the type of flow of most significance in urban drainage), velocity levels are quite similar across most of the cross-section, but fall rapidly near the pipe wall. Very near to the wall, a boundary layer exists, where the velocity is low and laminar conditions occur. Frictional losses are affected by the thickness of the laminar sub-layer relative to the 'size' of the roughness of the pipe wall [Van de Ven, Nelen and Geldof, 1992). In commercial pipes, the wall roughness is measured in terms of an equivalent sand roughness size (ks), and can be thought of as the mean projection height of the roughness from the pipe wall. Moody diagram is a plot of the friction factor λ, against Reynolds number Re for a range of values of relative roughness ks/D. The Moody diagram demonstrates the relative effects of the thickness of the laminar sub-layer and the size of the roughness. When the roughness projections are small compared with the thickness of the laminar sub-layer, the friction losses are independent of pipe roughness and dependent on Reynolds number. Such a flow is said to be 'smooth turbulent'. λ is a function of Re, but not of ks/D.

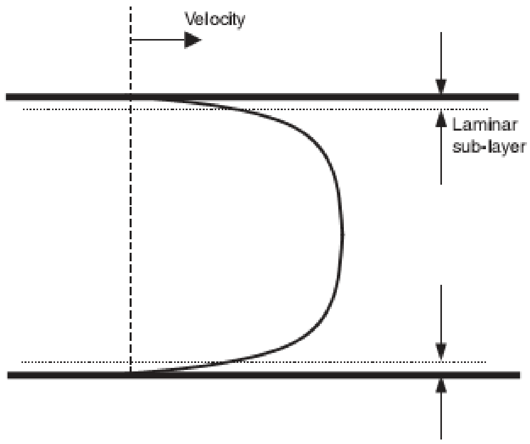


Fig. 2.10 Velocity Profile in Turbulent Flow with Laminar Sub Layer

When the roughness projections are much greater in height, losses are linked to pipe roughness only (not Reynolds number) and conditions are known as 'rough turbulent'. In such condition, λ is a function of ks/D, but not of Re. Between these two conditions lies a transitional turbulent region where conditions are dependent on roughness height and Reynolds number. Most urban drainage flows are rough or transitionally turbulent flows.

2.16.4 Local losses

Local losses occur at points where the flow is disrupted, such as bends, valves and changes of area. In certain circumstances, for example, where there are many fittings in a short length of pipe these can be equal to or greater than the friction losses. In gravity sewers, local losses occur at manholes, but these are only usually significant when the system is surcharged. Local losses are usually expressed in terms of velocity head as follows:

$$h_{Local} = k_L \times (v^2/ 2g)$$

where,

h_{Local} = local head loss (m)

k_L = a constant for particular type of fitting

2.17 Part-full pipe flow

The common flow condition in urban drainage conduits is part-full pipe flow. The presence of the free surface must be taken into account in hydraulic computations.

2.17.1 Normal depth

In uniform steady gravity flow, equilibrium exists along a part-full pipe or channel. The energy consumed by friction between the liquid and the pipe wall is in balance with the fall along the pipe length. If pipe slope could be increased for the same flow-rate, additional energy would be available to the flow, resulting in higher velocity and lower depth. This equilibrium depth is referred to as the normal depth.

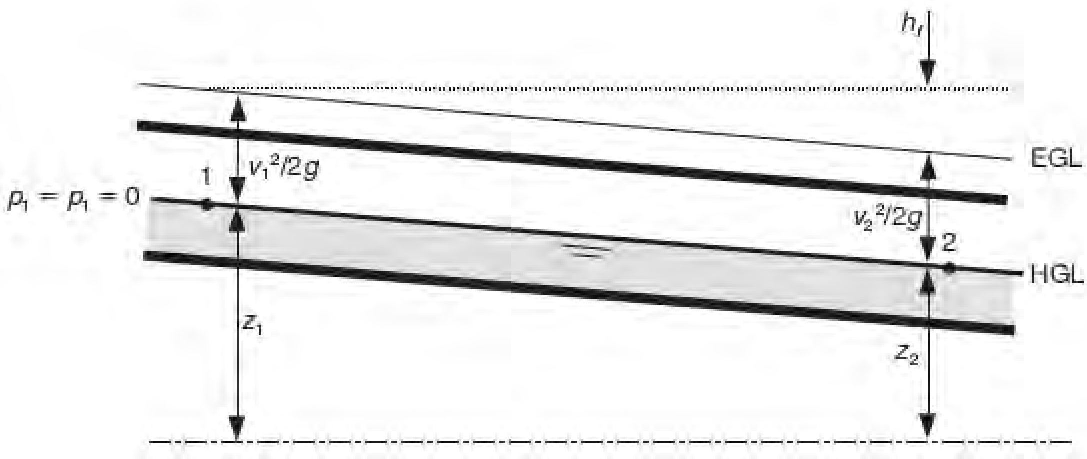


Fig. 2.11 EGL and HGL for a conduit with partial flow

Since depth of flow and velocity are constant when conditions are uniform, and pressure at the surface is atmospheric, the EGL and HGL are parallel to the bed, and the HGL coincides with the water surface.

2.17.2 Geometric and hydraulic elements

A circular cross-sectional shape is most common for sewers and drains. The need to understand the hydraulic conditions at a range of depths results from the wide variations in flow experienced by sewers during their working life. Hydraulic radius can be related to geometrical properties, and for a circular pipe running full:

Hydraulic Radius, R = A / P = D / 4

Where

D = pipe diameter (m)

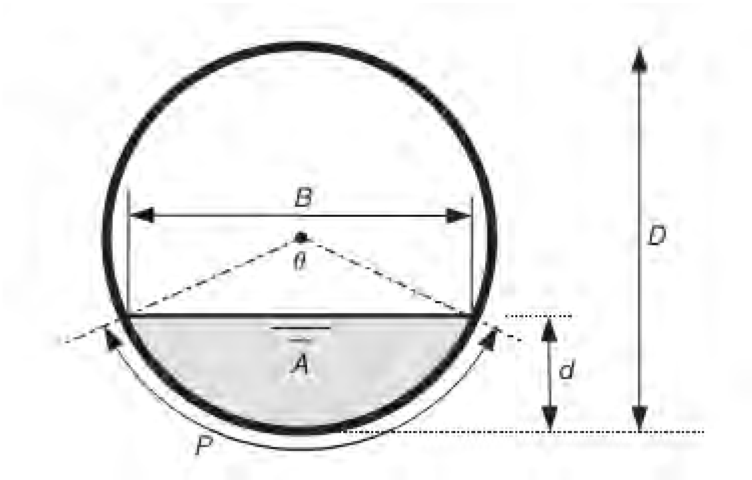


Fig. 2.12 Geometric elements of a circular conduit with partial flow

The above figure shows the cross-section of a pipe of diameter D with flow of depth d. The angle subtended at the pipe centre by the free surface is U. From geometrical considerations, U is related to proportional depth of flow d/D as follows:

$$\Theta = 2\cos^{-1}[1-2d/D]$$

Expressions for area (A), wetted perimeter (P), hydraulic radius (R), top width (B) and hydraulic mean depth (dm), based on D and U are given in following Table.

Parameter	*Expression (θ in radians)*
A	$\frac{D^2}{8}(\theta - \sin\theta)$
P	$\frac{D\theta}{2}$
R	$\frac{A}{P} = \frac{D}{4}\left[\frac{\theta - \sin\theta}{\theta}\right]$
B	$D\sin\frac{\theta}{2}$
d_m	$\frac{A}{B} = \frac{D(\theta - \sin\theta)}{8\sin\theta/2}$

Table 2.1 Expressions for geometric elements of a circular pipe with partial flow

Using these relationships, dimensionless relationships for part-full flow depth, cross-sectional area, wetted perimeter and hydraulic radius as a proportion of the full-depth value can be calculated.

In part-full pipes, maximum flow velocity and flow-rate do not occur when the pipe is running full; they occur when it is slightly less than full. This is because the circular shape affects the relative magnitudes of the flow area and the wetted perimeter (which determines the magnitude of the frictional resistance). At low flows, the wetted perimeter is high compared with flow area, resulting in low velocities. Velocity increases with depth until at the highest depths the increase in the wetted perimeter is again high compared with the flow area and this result in a fall in velocity. It follows that, eventually, the flow-rate will also fall, since flow-rate is the product of cross-sectional area and velocity.

2.17.3 Surcharge

Surcharging refers to pipes designed to run full or part-full, conveying flow under pressure. This can occur, for example, when flood flows exceed the design capacity, and it is therefore likely that all storm sewers will become surcharged at some time during their operational life. A sewer pipe can surcharge in one of two ways, normally referred to as ‘pipe surcharge’ and ‘manhole surcharge’.

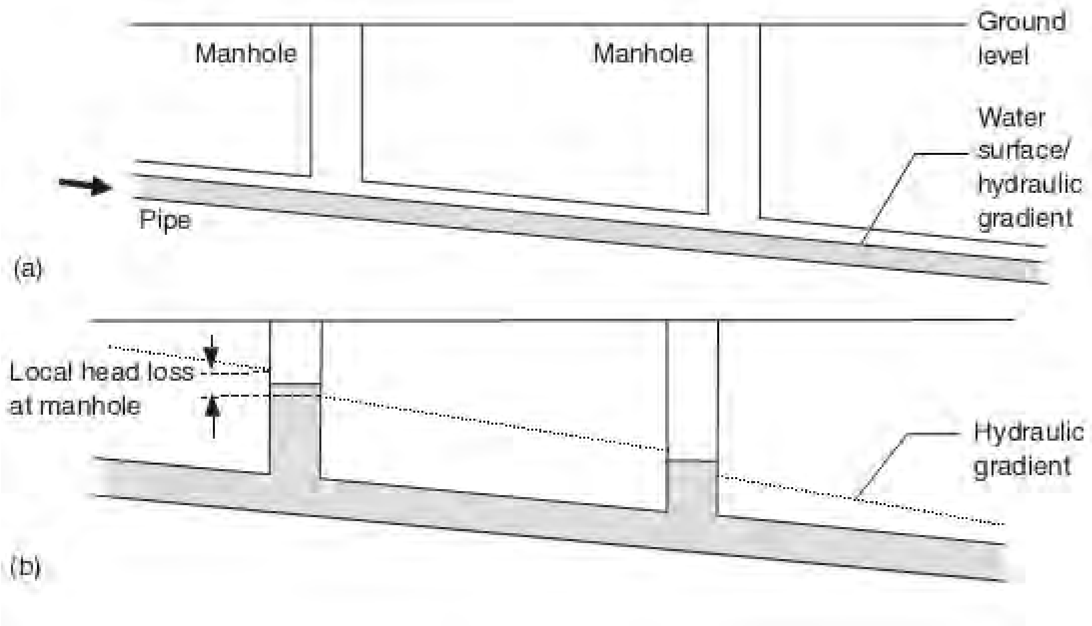


Fig. 2.13 Surcharge in pipe flow with partial and full flow.

The above figure (a) shows a longitudinal vertical section along a length of sewer running part-full (without surcharge). The hydraulic gradient coincides with the water surface (and is parallel to the pipe bed). If there is an increase in flow entering the sewer, the consequence will be that the depth of flow in the pipe will increase.

Now in case of figure (b), the sewer carrying the maximum flow-rate (just less than full). If there is an increase in flow entering the sewer, the carrying capacity of the pipe can no longer be increased by a simple increase in depth. The capacity of a pipe is a function of diameter, roughness and hydraulic gradient. To increase capacity, the only one of these that can change automatically is hydraulic gradient. It follows that the new hydraulic gradient must be greater than the old (equal to the gradient of the pipe), and the resulting pipe surcharge is shown on figure (b).

Increased local losses at manholes will further increase energy losses. If inflow continues to increase, the hydraulic gradient will increase. The obvious danger is that the hydraulic gradient will rise above ground level. This may cause manhole covers to lift and the flow to flood onto the surface – known as ‘manhole surcharge’. The transition from conditions in figure (a) to those in figure (b) is sudden. As mentioned before, maximum flow is carried when the pipe is less than full. If the pipe is running at this maximum level, a further slight increase in flow-rate or small disturbance will result in a sudden increase in pipe flow depth, not only filling the pipe completely, but also establishing a hydraulic gradient in excess of equilibrium.

2.17.4 Velocity profiles

Velocity of flow varies over the cross-section of a pipe. Velocity is at a minimum at the boundary due to surface friction and increases towards the centre. Maximum velocity may be at the surface when the flow depth is low or a little below it when the flow depth is higher. The presence of a sediment bed in the invert of the pipe also affects the profile. These profiles are significant when considering the transport of types of solids that are found only in specific parts of the cross-section; floating solids close to the surface, or heavy solids close to the bed.

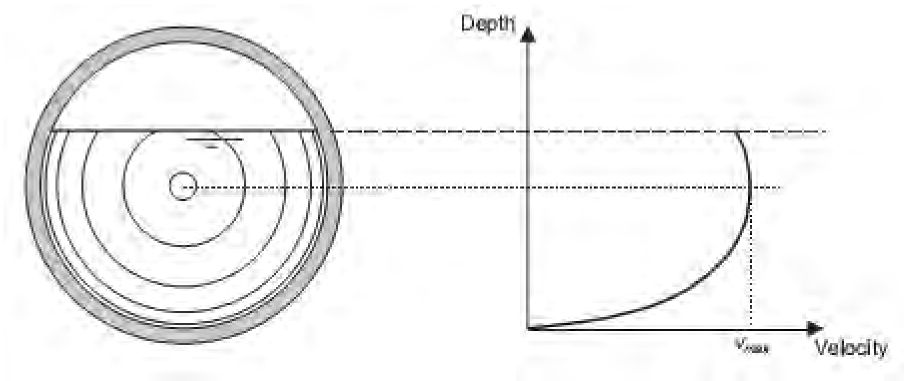


Fig. 2.14 Velocity profile in a conduit with partial flow

2.17.5 Minimum velocity

It is important that sewer to be able to carry wastewater or stormwater without long-term deposition of solid material. This is normally achieved by specifying a minimum mean velocity, a so-called 'self-cleansing' velocity, at a particular flow condition (e.g. pipe-full capacity) or for a particular frequency of occurrence (e.g. daily). A common design criterion is to specify a minimum velocity when the pipe runs full. A value of

1.0 m/s is typical. The basis of this is that, although the pipe may never flow precisely full, mean velocities exceed the pipe-full velocity for flow-rates greater than 0.5 Q_f. This method has the advantage of simplicity in computation, but lacks precision [Kay, 1999]. The other common approach is to specify self-cleansing velocities at some specified depth of flow (e.g. 0.75 m/s at d/D = 0.75). In the past, the velocity criterion has sometimes been relaxed for larger diameter sewers (>750mm). More recent research has shown this to be a mistake, and there is even evidence to suggest that higher self-cleansing velocities should be specified for larger diameters.

2.17.6 Maximum velocity

Historically, sewerage systems were designed so that velocity would not exceed a specified maximum. However, research has shown that abrasion is not normally a problem with modern pipe materials. Perkins (1977) has suggested that no fixed maximum limit is required, but where velocities are high (>3m/s) careful attention needs to be given to:

- energy losses at bends and junctions
- formation of hydraulic jumps leading to intermittent pipe choking
- cavitation causing structural damage
- air entrainment (significant when $v = \sqrt{5gR}$)
- the possible need for energy dissipation or scour prevention
- safety provisions.

2.18 Open-channel flow

2.18.1 Uniform flow

Part-full pipe flow is the most common condition in sewer systems. Design methods tend to be related to those for pipes flowing full. However, in hydraulic terms, part full pipe flow is considered as a special case of open-channel flow [Hamil, 2001]. Thus, the basic principles of open channel flow are applicable to some extent while considering part full pipe flow. The concepts of normal depth, and the nature of the energy grade line and hydraulic grade line apply to all cases of open-channel flow.

Manning's equation

A number of purely empirical formulae for uniform flow in open-channels have been developed over the years, a common example of which is Manning's equation:

$$v = 1/n(R^{2/3}S_0^{1/2})$$

where,

n = Manning's roughness coefficient

S_o = bed slope

R = Hydraulic Radius

v = velocity of fluid inside the conduit

Channel Material	n – range
Glass	0.009 – 0.013
Cement	0.010 – 0.015
Concrete	0.010 – 0.020
Brickwork	0.011 – 0.018

Table 2.2 Typical values of Manning's N

If Manning's equation is plotted on the Moody diagram, it gives a horizontal line indicating the equation is only applicable to rough turbulent flow. Ackers (1958) has shown that if ks/D is in the typical range of 0.001 to 0.01, the values of ks and n are related (to within 5%) by the relationship:

$$n = 0.012k_s^{1/6}$$

where,

k_s is in mm

n is as defined for Manning's equation

2.18.2 Non-uniform flow

In uniform free surface flow, when the flow depth is normal, the total energy line, hydraulic grade line and channel bed (or pipe invert) are all parallel. In many situations, however, such as changes in pipe slope, diameter or roughness, non-uniform flow conditions prevail and these lines are not parallel [Chadwick and Morfett, 1998]. In sewer systems, it is likely that there will be regions of uniform flow interconnected with zones of non-uniform flow.

2.18.3 Critical, subcritical and supercritical flow

The non-dimensional Froude number (Fr) is given by:

$$F_r = v / \sqrt{g d_m}$$

Where, d_m = hydraulic mean depth

It can be shown that Fr = 1 at critical depth. If Fr <1, flow is subcritical; the depth is relatively high and the velocity relatively low [Hamil, 2001]. This flow is sometimes referred to as 'tranquil' flow. If Fr >1, flow is supercritical; velocity is relatively high, and depth low. This flow is also called 'rapid' or 'shooting' flow.

The critical velocity vc is given by:

$$v_c = \sqrt{g d_m}$$

CHAPTER 3

METHODOLOGY AND RESEARCH FRAMEWORK

Chapter 3

METHODOLOGY AND RESEARCH FRAMEWORK

3.1 Research Philosophy

A research philosophy is a concept describing the way in which data regarding a phenomenon should be gathered, analyzed and used. The term epistemology (what is known to be true) as opposed to doxology (what is believed to be true) encompasses the various philosophies of research approach. The purpose of research is the process of transforming things believed into things known: doxa to episteme. Two major research philosophies have been described so far namely positivist (sometimes called scientific) and interpretivist (also known as anti-positivist) [Galliers, 1991].

Positivists believe that reality is stable and can be observed and described from an objective viewpoint [Levin, 1988], i.e. without interfering with the phenomena being studied. They contend that phenomena should be isolated and that observations should be repeatable. This often involves manipulation of reality with variations in only a single independent variable so as to identify regularities in, and to form relationships between, some of the constituent elements of the practical world. Predictions can be made on the basis of the previously observed and explained realities and their inter-relationships. Alavi and Carlson, in a review of 902 research articles, found that all the empirical studies were positivist in approach [Alavi and Carlson, 1992]. Positivism has also had a particularly successful association with the physical and natural sciences.

Interpretivists contend that only through the subjective interpretation of and intervention in reality can that reality be fully understood. The study of phenomena in their natural environment is keys to the interpretivist philosophy, together with the acknowledgement that scientists cannot avoid affecting those phenomena they study. It is possible that there may be many interpretations of reality, but maintaining these interpretations are in themselves a part of the scientific knowledge. Interpretivism has a tradition that is no less glorious than that of positivism, nor is it shorter.

3.2 Discussion and Rationale for Choice of Approach

It has often been observed that no single research methodology is intrinsically better than any other methodology [Benbasat, Goldstein and Mead, 1987], forcing the researchers to combine different research methods in order to improve the quality of research. This encouraged the researchers to adopt a certain "house style" methodology and hence, a single formed methodology characterized as methodological monism, i.e. the insistence on using a single research method has been avoided for current research which imposes the fact that every single methods are valuable if used appropriately and that research can include elements of both the positivist and interpretivist approaches.

However, an interpretivist philosophy is required for the purpose of current research, i.e. the understanding of how different systems of drainage network adopt and adapt to the changing nature of other variables, specifically under different geological pattern. This research involves an element of information sharing and transfer, insofar as the information was previously gathered by some of the other organizations. Furthermore, in order to measure how organizations can improve their final achievement with the support of GIS, recommendations are made for use of the GIS after analyzing existing available data. Nevertheless, recognizing the lack of objectivity sometimes associated with interpretivist research methods, a positivist approach was immediately adopted.

These various elements of the research approach are further elaborated in the following sections: Research Strategy, Research Instruments, Facilitation Software and Research Operationalization.

3.3 Research Strategy

There are several number of research methodologies, ranging from three to eighteen according to different scholars [Galliers, 1991][Alavi and Carlson, 1992]. Table 3.1 below enlists principal types of methodologies identified by the researchers, indicating whether they typically conform to the positivist or interpretivist paradigms. However, the justification of the choice of methodologies used here and explanation of how they operate and interoperate in our research are duly mentioned in the upcoming sections.

Scientific / Positivist		Interpretivist / Anti – Positivist	
Laboratory Experiments		Subjective / Argumentative	
Field Experiments		Reviews	
Surveys	Yes	Action Research	Yes
Case Studies		Case Studies	Yes
Theorem Proof		Descriptive / Interpretive	
Forecasting		Futures Research	
Simulation	Yes	Role / Game Playing	

Table 3.1: A Taxonomy of Research Methodologies

Surveys enable the researcher to obtain data about practices, situations or views at one point in time through questionnaires or interviews. Quantitative analytical techniques are then used to draw inferences from this data regarding existing relationships. The use of surveys permit a researcher to study more variables at one time than is typically possible in laboratory or field experiments, whilst data can be collected about real world environments. A key weakness is that it is very difficult to realize insights relating to the causes of or processes involved in the phenomena measured. There are, in addition, several sources of bias such as the possibly self-selecting nature of respondents, the point in time when the survey is conducted and in the researcher him/herself through the design of the survey itself.

Case studies involve an attempt to describe relationships that exist in reality, very often in a single organization. Case studies may be positivist or interpretivist in nature, depending on the approach of the researcher, the data collected and the analytical techniques employed. Reality can be captured in greater detail by an observer-researcher, with the analysis of more variables than is typically possible in experimental and survey research. Case studies can be considered weak as they are typically restricted to a single organization and it is difficult to generalize findings since it is hard to find similar cases with similar data that can be analyzed in a statistically meaningful way. Furthermore, different researchers may have different interpretations of the same data, thus adding research bias into the equation.

Simulation involves replicating the behavior of a system. Simulation is used in situations where it would be difficult normally to solve problems analytically and typically involves the introduction of random variables. As with experimental forms of research, it is difficult to make a simulation sufficiently realistic so that it resembles real world events.

Action research is a form of applied research where the researcher attempts to develop results or a solution that is of practical value to the people with whom the research is working, and at the same time developing theoretical knowledge. Through direct intervention in problems, the researcher aims to create practical, often emancipatory, outcomes while also aiming to reinform existing theory in the domain studied. As with case studies, action research is usually restricted to a single organization making it difficult to generalize findings, while different researchers may interpret events differently. The personal ethics of the researcher are critical, since the opportunity for direct researcher intervention is always present.

However, there are at least three reasons that make case study research equally viable for action research [Alavi and Carlson, 1992]. The differences between action research and case studies are highlighted below:

Case Study	Action Research
Researcher is Observer.	Researcher is Active Participant
Exploratory, explanatory or descriptive	Prescriptive, intervening
Focus on “How” and “Why”	Additional Focus on “How to”
May be positivist or interpretivist	Usually interpretivist

Table 3.2: Case Studies and Action Research

3.4 The Action Research - Case Study: A Combined Approach

While many scholars argue that action research belongs to the case study family of methodologies, it is more sensible to treat them as separate forms. It is to be noted that an action research study is likely to include cases, but a case study can certainly avoid using action research. In this research, both the methodologies were chosen for various reasons and applicability which relate back to the reasons mentioned earlier for why each methodology should be used.

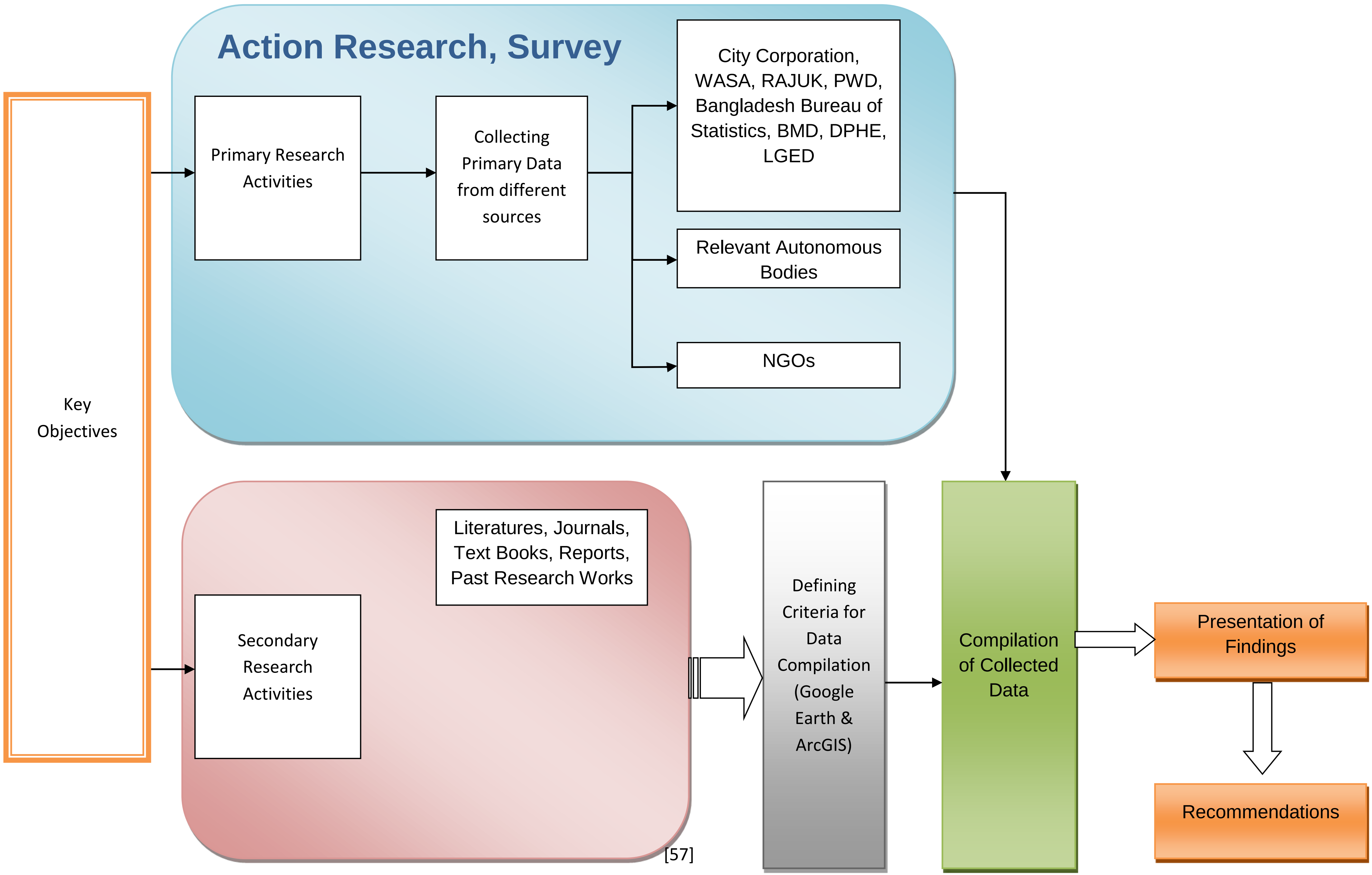
The data we are measuring (capacity of current drainage system to find out the most efficient possible drainage system) is believed to be too complex, uneconomic and non practical to be constructed and measured experimentally. Asking for the proper data set is important to understand the nature of the processes, while asking "how to" questions will assist us to interpret the data we collect and so to improve our accuracy to predict the exact scenario. No previous research on this issue are not known so far, which means that we are involved in theory building - an area where case studies are acknowledged as providing a suitable climate for data collection and theory construction.

3.5 Research Framework and Instrument

A research framework has several purposes. It is developed by the researcher and guides the research. It also provides the reader with an illustration of how the various phenomena in the research are conceived and how they relate to one another. Moreover, the framework can be used as a basis for other activities, such as the development of an instrument. In this research, a framework have been developed that attempts to explain the key processes that occur in the proceedings. Through an understanding of these phenomena or processes, and by relating these processes to the outcomes of a meeting emerges a path for better understanding of how we can attempt to improve the results and their outcomes. Also an instrument has been developed that reflects some of the phenomena in the framework and hence can be used to measure those phenomena.

The research framework is also invaluable in that it works as a guide to the development of an instrument to measure data sources relevance and authenticity. Due to the nature of current research problem, it is essential to collect data so that the existing situation can be measured. It is of fundamental importance firstly to identify which organizations are suitable for providing related data and information, in either media. In order to analyze the data, however, it is essential to have a validated and reliable instrument in order to collect information both prior to interpretation and post-interpretation, i.e. to measure how successful the interpretation has been. Then depending on the suitability to analyze their merit and elicit non related issues. At this point, the software or computer aid might intervene if necessary.

A graphical representation of Research Framework is provided below:


Action Research, Survey
Key Objectives
Primary Research Activities
Collecting Primary Data from different sources
City Corporation, WASA, RAJUK, PWD, Bangladesh Bureau of Statistics, BMD, DPHE, LGED
Relevant Autonomous Bodies
NGOs
Secondary Research Activities
Literatures, Journals, Text Books, Reports, Past Research Works
Defining Criteria for Data Compilation (Google Earth & ArcGIS)
Compilation of Collected Data
Presentation of Findings
Recommendations

3.10 Research Facilitation Software

Data collected in this research work are numerical in pattern and thus, a spreadsheet with data plotting facility is sufficient enough to carry out the work. However, for interpreting and presenting GIS data, computer aided programs with corresponding expertise was used accordingly. For general purposes, MS Excel 2007 was used as the key data storage and data devising tool. For word processing purposes, MS Word 2007 was used. There were several sources that provided data in GIS format. Being very informative and accurate, interpreting GIS based data as well as producing outputs in such format extends the scope and capacity of current research many folds and thus used of ArcGIS and web based Google Earth was quite common in such instances.

ArcGIS is a geographic information system (GIS) developed by the California based software developer ESRI (Environmental System Research Institute) that deals with maps detailed with different geographic information. It provides a scalable framework for implementing GIS for a single user or many users on desktops, in servers, over the web and in the field. ArcGIS is an integrated collection of GIS software package for building a complete GIS. The geodatabase, short for geographic database, is the core geographic information model to organize GIS data into thematic layers and spatial presentations. It is a comprehensive series of application logic and tools for accessing and managing GIS data. The cornerstone of ArcGIS is its ability to access GIS data in any format and use multiple database and file based datasets concurrently. It has a high level generic geographic data model for representing spatial information such as features, rasters and other spatial data types. ArcGIS supports an implementation of the data model for both file systems and database management systems. ArcGIS works over a vast horizon of single user desktop computers, interconnected multi user servers, over the worldwide network of web as well as handheld GIS devices. The version of ArcGIS used for interpreting the data for this research work was ArcGIS Desktop. ArcGIS Desktop is a suite of integrated applications including ArcCatalog, ArcMap, ArcGlobe, ArcToolbox and ModelBuilder. ArcMap was mostly used for data analysis and presenting during this research work. ArcMap is the central application of ArcGIS that is used for all map-based tasks including cartography, map analysis and editing. It offers two types of map views: Geographic data view and Page layout view. Geographic data view works with geographic layers to symbolize, analyze and compile GIS dataset of the given area. The Page layout view works with maps containing geographic data views as well as other map elements like scalebars, legends, directional arrows etc. and used to compose maps for printing and publishing.

Google Earth is a virtual globe, map and geographical information program that was originally created by Keyhole, Inc. (a CIA funded company) under the name EarthViewer 3D later acquired by Google in 2004. It maps the Earth by the superimposition of images obtained from satellite imagery, aerial photography and geographic information system (GIS). Google Earth, together with its web-based counterpart Google Maps, needs little introduction, having become an everyday tool for millions of computer users. Since its launch in 2005, Google claims that over 12 billion copies of Google Earth software have been downloaded worldwide. In addition to solving existing problems like creating and publishing a simple map of directions to an event, the combination of Google Earth and Google Maps with other web-based tools is prompting the creation by users of entirely new information-based services. Exchanging spatially-referenced data using Google-readable KML and KMZ files will become, it has been said, as commonplace as exchanging Excel spreadsheets or PDF documents. Google Earth is not the only 'virtual globe' software tool available. There are several others, including Microsoft's Virtual Earth and ESRI's ArcGIS Explorer (not to be confused with ArcGIS more generally which is a conventional GIS suite). However, Google Earth is by far the best known and widely used of these. Despite its ubiquity, there remains some confusion about what Google Earth actually is, and about how it compares with other tools for mapping, notably with conventional GIS software. It is important to note that Google Earth is several things: it is at the same time a software tool, a standard for exchanging spatial data, a massive collection of archived satellite and aerial imagery, and a community of people interested in developing new applications and services. On the other hand, by comparison with GIS, Google Earth is not a sophisticated cartographic (map drawing) system, nor a means of doing complex spatial analysis. However, its relatively limited core functionality makes it very easy to use and this, combined with the highly ‘immersive’ user experience which allows roaming the whole world in 3D, explains why it has generated its enormous user base and has driven growth of public interest in geospatial technologies in general. Google Earth was frequently used during formulating this research work due to:

- Capability of transfering aerial view from the screen to the paper report with high resolution printing.
- Use of the measuring tool that measures length, area, radius and corner straight from the screen.
- Use of batch geocoding that allows one to import spreadsheets of addresses instantly into the program.
- Incorporating GIS data with the professional GIS softwares like ArcGIS.

CHAPTER 4

DATA COLLECTION, ANALYSIS & FINDINGS

CHAPTER 4

DATA ANALYSIS, FINDINGS & RECOMMENDATIONS

4.1 Study Area

Location

Dhaka is the capital and the largest city of Bangladesh. It is located at the centre of the flat delta formed by the three major rivers of this region: the Ganges, the Brahmaputra and the Meghna. Due to its location, Dhaka enjoys a distinct supreme position in the national and regional hierarchy. The city is also surrounded by the distributaries of these rivers. Geographically, Dhaka lies on the northern bank of Buriganga and is bound by the Balu River and Turag river in the west and north sides respectively. The elevation of Dhaka lies between 2 to 13 m above mean sea level (msl) which makes it considerably high above the water of surrounding rivers in ordinary seasons of inundation [Flood Action Plan (FAP), 1991]. Most of the urbanized area lies at the elevation of 6 to 8 m above msl. For this research work, the key residential and business regions as well as the regions of national importance were selected as study area, duly marked in the following figures:

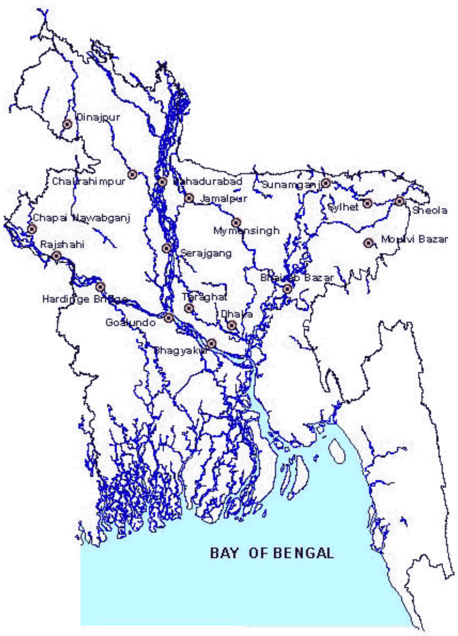


Fig: 4.1 Bangladesh & Its Major Rivers

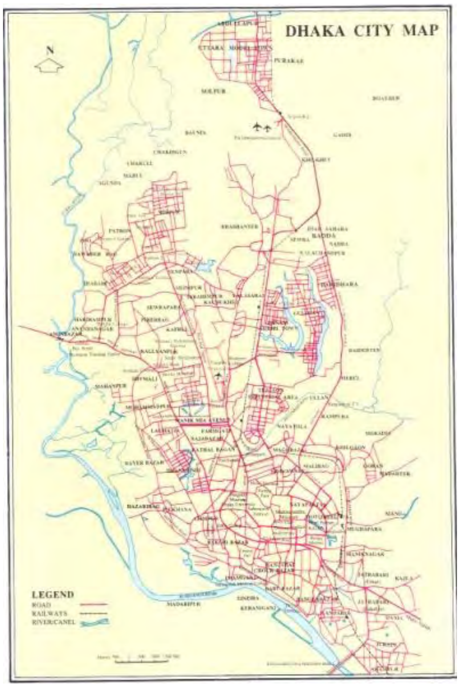


Fig: 4.2 Dhaka City Map

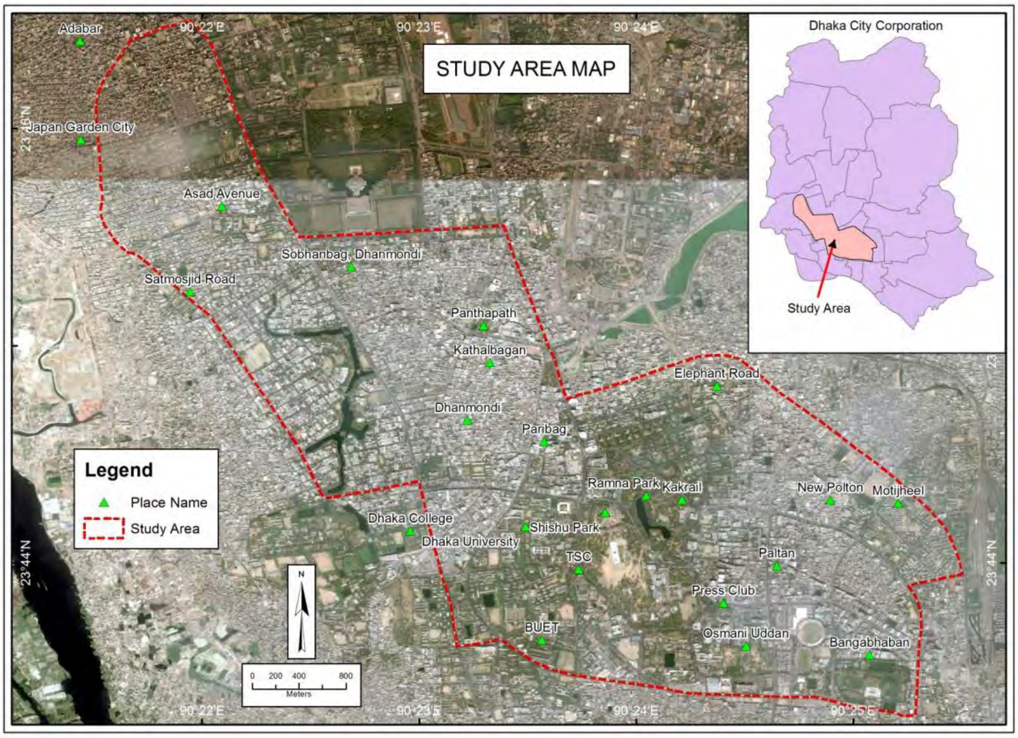


Fig: 4.3 Study Area within the Dhaka City

The study area lies between 23°46'29.24"N and 23°43'17.50"N Latitude and 90°21'32.39"E and 90°25'30.76"E Longitude. The area of the selected region is 15.60 sq. km. whereas the perimeter of the region is 21.5 km. The study area constitutes of Major residential areas of the city such as Mohammadpur, Lalmatia, Dhanmondi, Kalabagan, Malibag, Shahjahanpur, etc. as well as Commercial Hubs of the City such as Karwan Bazar, Paltan, Motijheel, Gulistan, etc. The study area also includes Key Point Installations such as Bangabhaban, Ganabhaban, National Secretariat and other places of national importance.

Google Earth 7 and ArcGIS 10.1 have been used for selection of the study area, delineate the catchment area as well as preparing slope of the study area. The study area has been digitized from Google Earth 7. The KML file from Google Earth has been converted to ShapeFile in ArcGIS 10.1. Georeferencing tool has been used to georeference the digitized shape file. DEM file of the study area has been collected from the ASTER Global Digital Elevation Map. And after that the slope of the catchment area was prepared by using special analysis tool in ArcGIS. And catchment delineate has been prepared using slope as well as roads networks.

Data Sources:

For this study Detailed Area Plan (DAP) prepared by RAJUK has been used as main data source for identifying road network, water body and Dhaka city corporation (DCC) boundary. The provision of DAP is inherent in the Structure Plan with some specific purposes. These are:

- Provide basic infrastructure and services in the study are through systematic planning.
- Improve drainage system of the area and protect flood flow from encroachment.

Google Earth Image has been used for all image analysis.

Catchment Delineate by ArcGIS:

Initially ASTER DEM data is collected from United State Geological Survey website. DEM file was clipped with study area boundary and layout of the required DEM (Fig 4.5) was prepared. Contour (Fig 4.6) of the study area was prepared using this DEM data. Slope map (Fig 4.7) was prepared from DEM data using ArcGIS Slope Analyst Tool. Catchment boundary is delineate by using the DEM data, Slope of the study area, Road network Data (Fig 4.4) as well as Google Earth Images. The map was finalized and layout was prepared. After That flow generation has been developed to observe the flow direction of the study area.

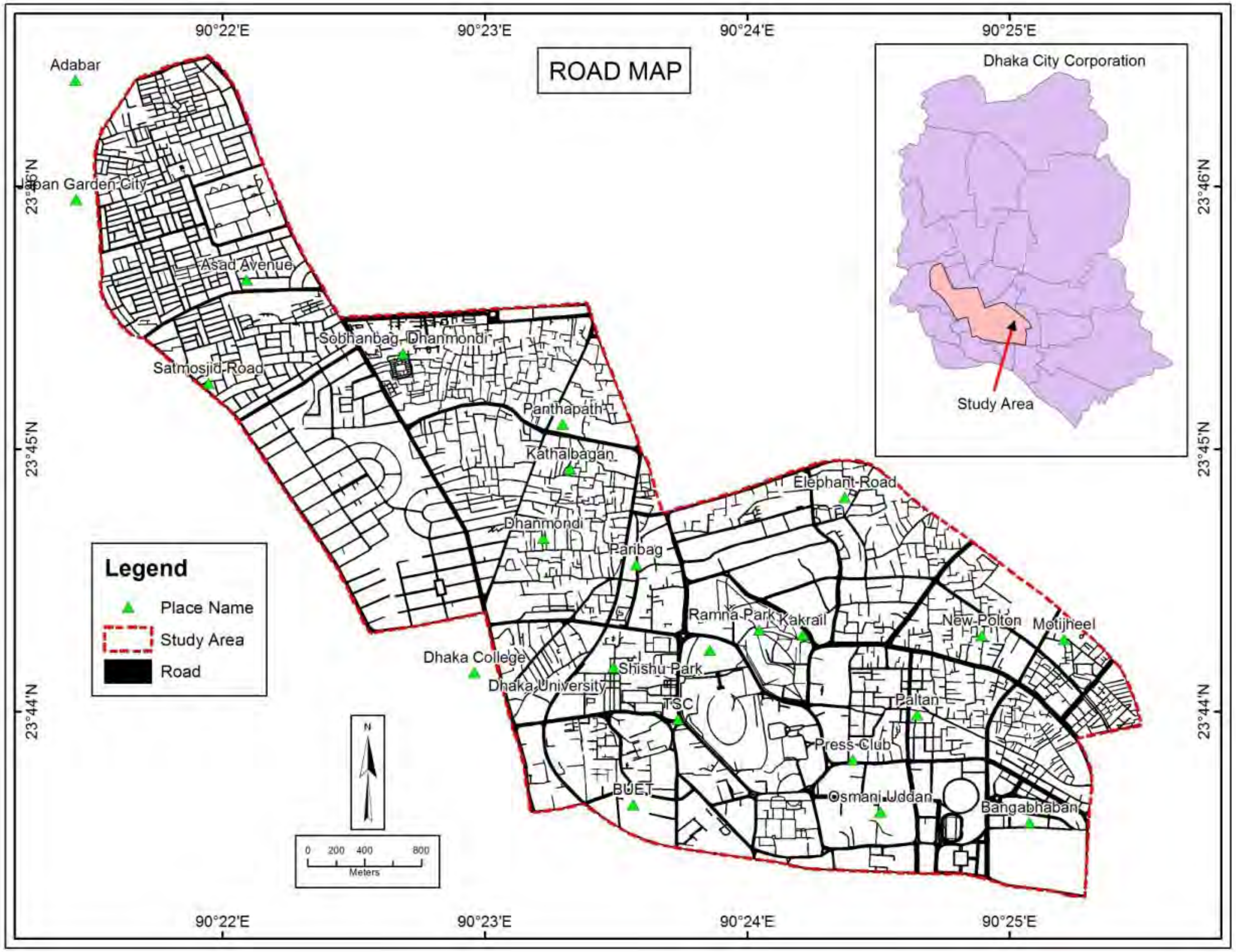


Fig 4.4: Existing Road map from Google Earth

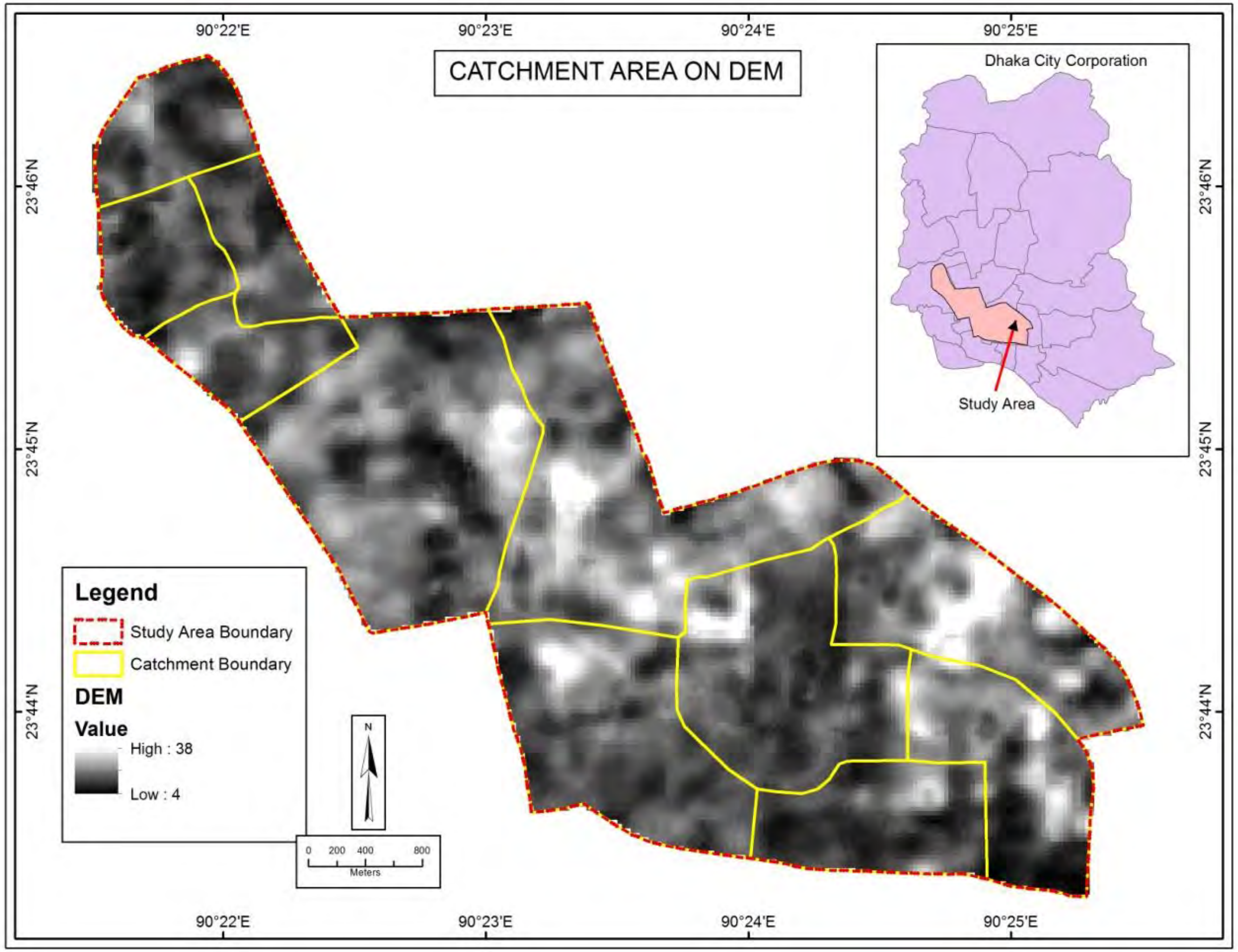


Fig 4.5: DEM file from ASTER DEM and delineate Catchment area.

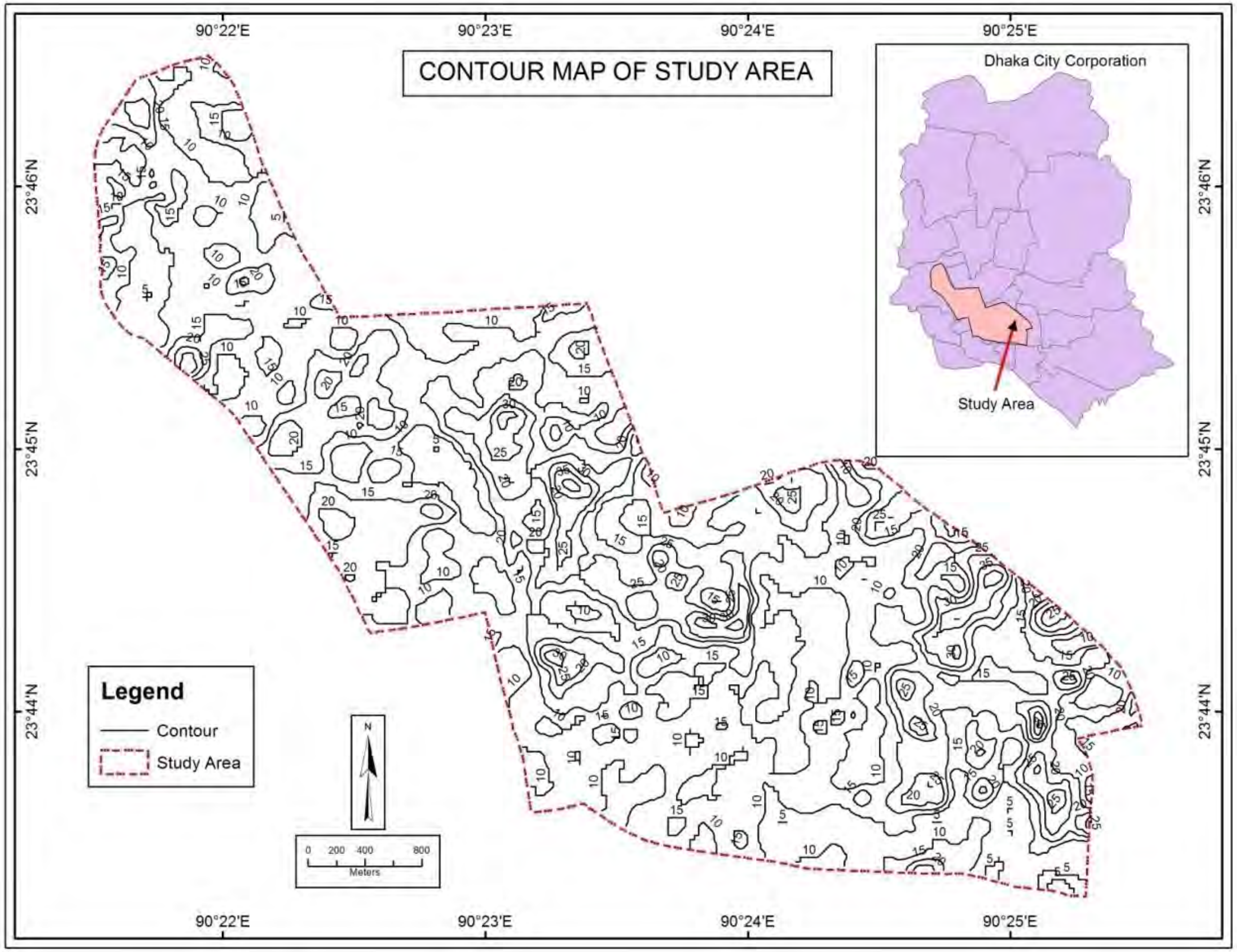


Fig 4.6: Contour of the study area

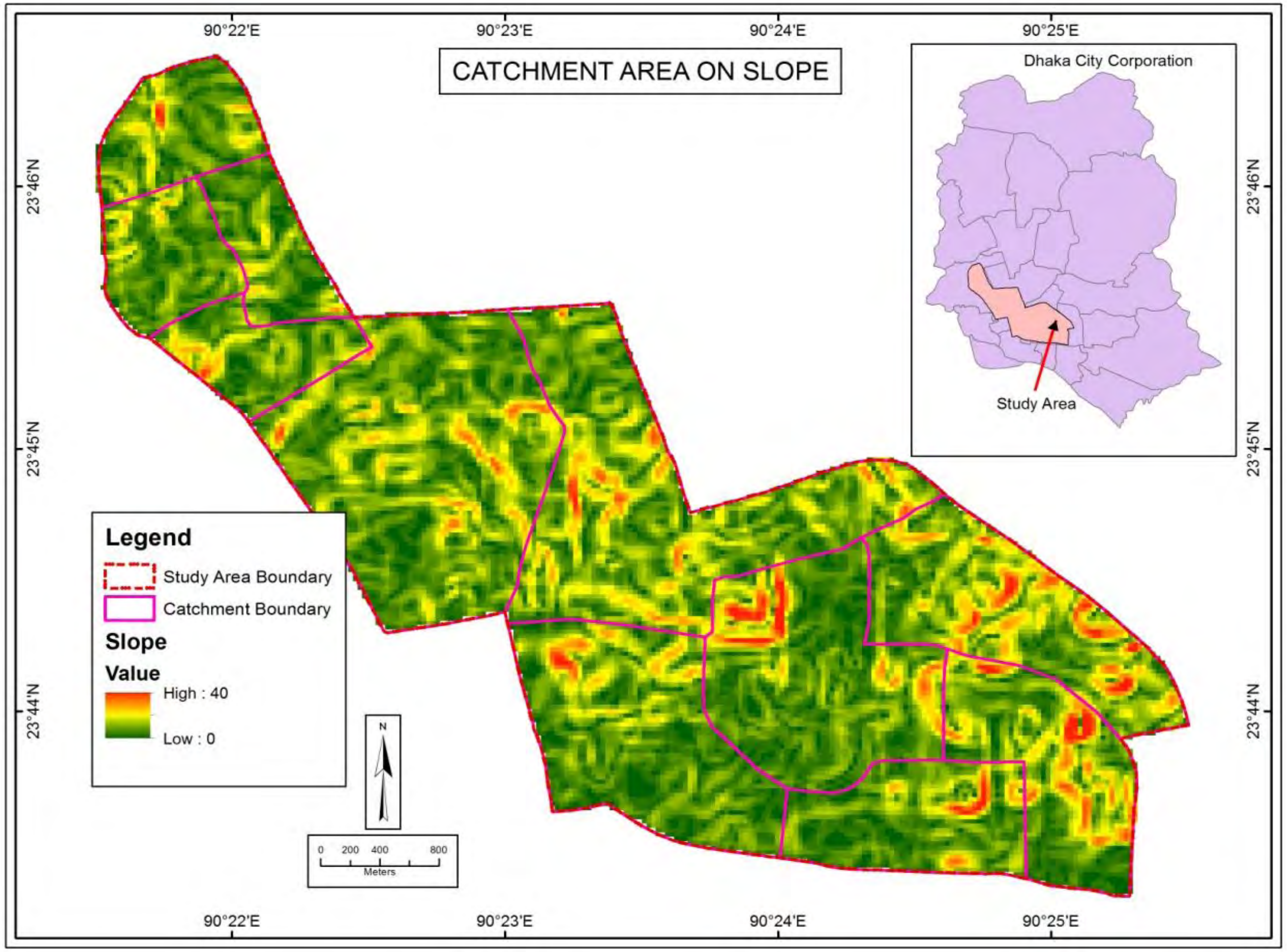


Fig 4.7: Slope of the Study area using Special Analysis Tools.

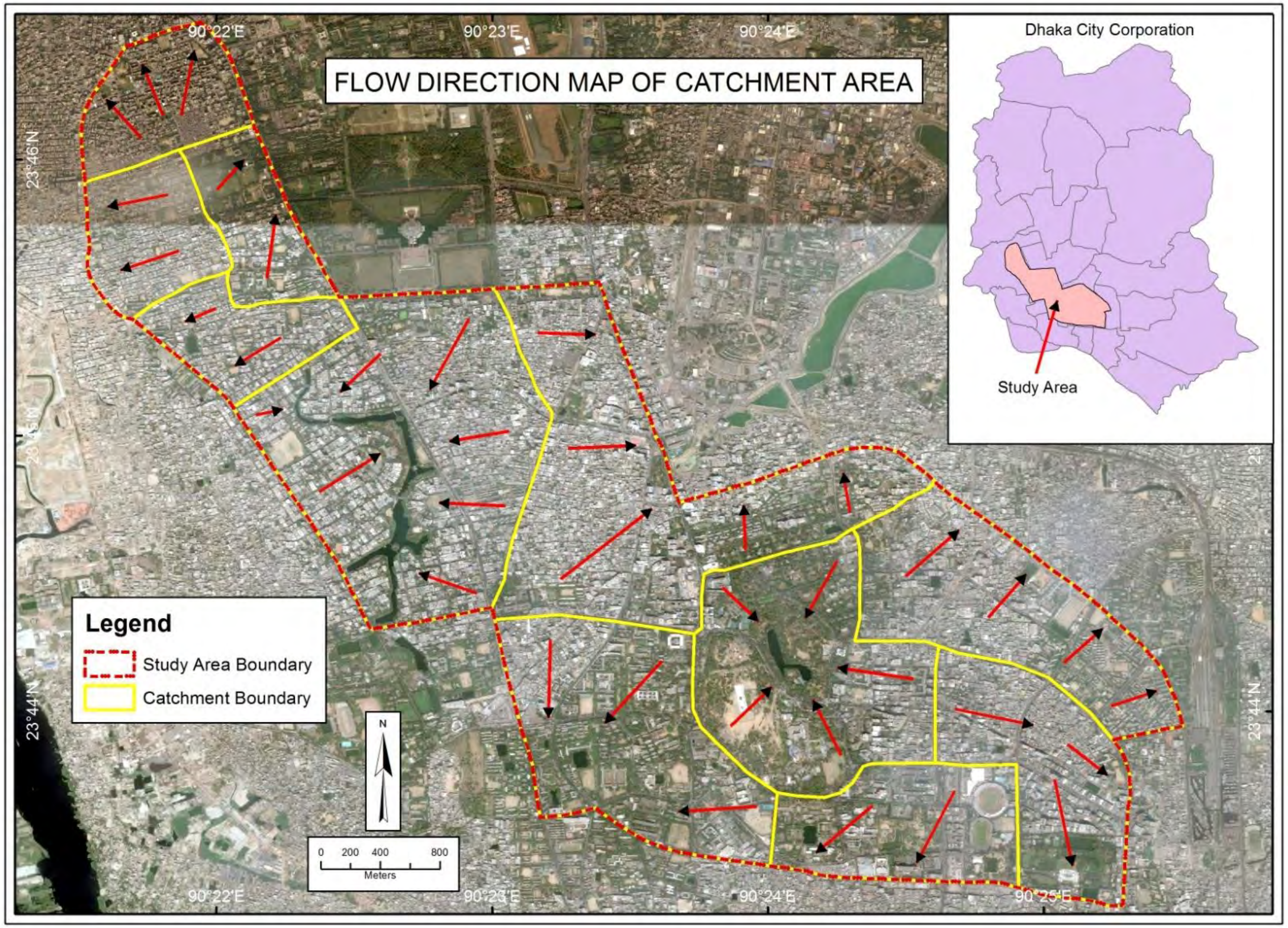


Fig 4.8 Flow Direction of the Study Area

Climate & Meteorological Pattern

Being in the centre of Dhaka city, the study area receives generous amount of monsoon during and around the rainy season. The torrent of rain tends to start from May and continue till October. However, historical rainfall data shows that the peak of the monsoon has shifted from June-July to August-September over the last decade. The peak rainfall recorded for a single day over the last 10 years is 341 mm which is the peak for the last 60 years as well. Details of the historical rainfall data for the last 14 years as well as the monthly maximum rainfall of this period are presented in tabular and graphical format Appendix - II.

Land Use

The study area, along with the rest of the capital, has gone through a massive expansion and development for the last couple of decades. The study area is mostly composed of high to moderate populated upper and medium class residential area, diplomatic and nationally important establishments, dense commercial area, permanently paved area and a huge network of paved roadways with a slight hint of greenery and water bodies. The actual zone based land use pattern of the study area is presented in table 4.3 and zonal ward maps of the relevant areas are provided in Appendix - V.

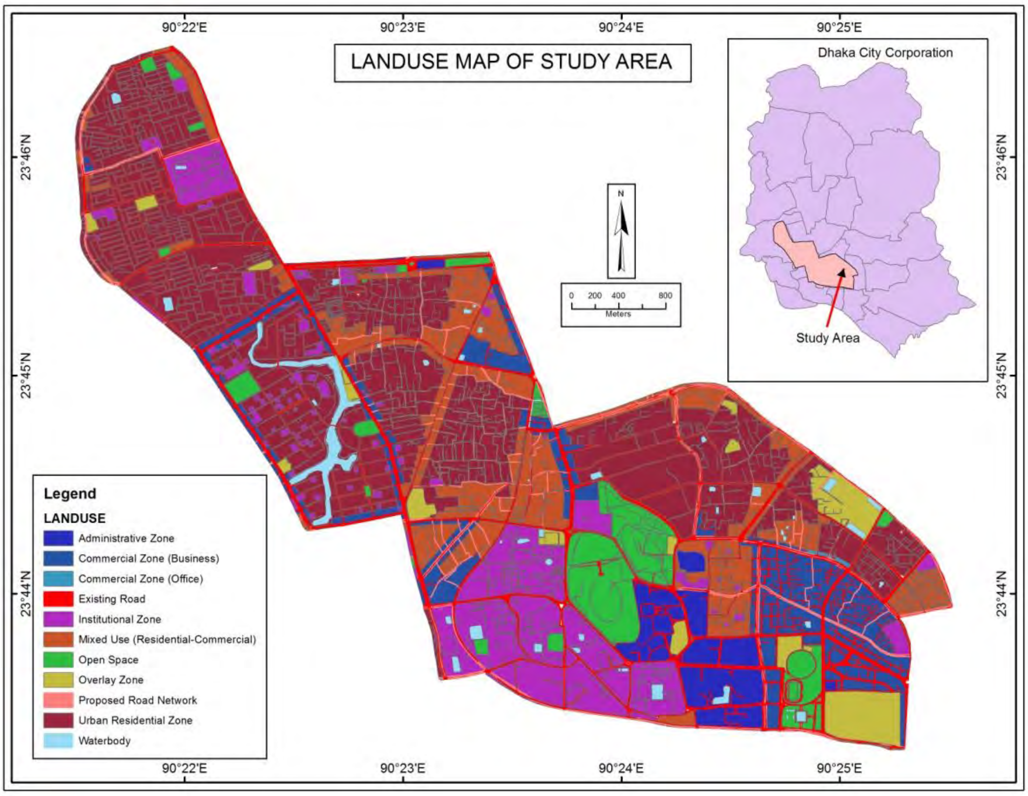


Fig 4.9: Land Use Map of the Study Area

4.2 Capacity of the Existing Rainwater Drainage Network of Dhaka City

The drainage system of Dhaka city is traditionally maintained by several different organizations. Among these organizations Dhaka Water And Sanitation Authority (Dhaka WASA), Dhaka City Corporation (North & South) and Water Development Board are noteworthy. Several meetings with concerned individuals of these organizations revealed that nearly all the drainage of Water Development Board in and around of Dhaka were handed over to Dhaka WASA. The same process is currently under way for Dhaka City Corporation (North & South) and only feeder lines with smaller diameters and surface drains with small cross section belonging to both the City Corporations of Dhaka, North & South.

The current drainage network of Dhaka WASA comprises mostly of underground and surface conduits of different cross section shapes and sizes along with open to surface natural or manmade channels and other water bodies. The underground conduits vary from circular concrete pipes with diameters ranging from 450 mm to 2000 mm. A dedicated network of pipes with diameters of 60 mm, 75 mm and 90 mm runs along majority of the road network of the city. Manholes and catch pits are located in strategic and convenient locations to catch and feed storm water to the main drainage system. Most manholes and catch pits are connected with the main drainage network through 300 mm and 450 mm pipes. Apart from the pipes, there are brick sewers with cross section of 1700 sq. mm, 1900 sq. mm & 2100 sq. mm. and open surface drain of 600 mm width & 600 mm depth. Some old man made open channels have been turned into box culverts and now run through the city. Apart from these manmade artificial drainage networks, natural channels and reservoirs in forms of khals, rivers and water bodies of different size work similarly to dissipate and store rain water. In 2007, Dhaka WASA in congruence and with the help of International Water Modeling (IWM), an internationally renowned research institute of Bangladesh, produced a detailed GIS based model for the water distribution, sewerage and drainage network for Dhaka WASA showing in detail the locations, dimensions and flow of the network elements. The relevant parts of those maps could be found attached with this report in Annex. IV.

Within our study area situates several densely populated low lying areas as well as busy business hubs and nationally important establishments. To be precise, the study area is the heart of the Dhaka city and it could be deducted that drainage system in this region is among the best that the city has to offer. Still then, within the study area are confined some of the most problematic locations in terms of drainage and water logging. The low lying areas of

Moghbazar, Shiddheswari, Eskaton, Rajabazar, Shanti Nagar, Paltan, Arambagh, Paribagh, Shukrabad, Lalmatia, Mohammadpur are very few names to say as an example of the areas that suffer water logging most. Through field study and collected data from several organizations suggested that the study area is facilitated with nearly 75 km. length of drain networks of various shape, size and cross sections. Also within the selected area, there are the major water bodies like Dhanmondi Lake and Ramna Lake along with many other ponds and ditches that sums up in nearly 175 thousand sq. m. in total. However, there are no part of any rivers or khals in the study area. There are 1107 manholes and 1377 catch pits in the region. The detailed description of the total drainage network of the study area is given in tabular form in Table. 4.1.

It could be said with minimum doubt that the existing network capacity of the drainage system of Dhaka city is far from ideal. To make things even worse, the efficiency of this existing networks and channels is also not free from question. The regular and periodic maintenance of the sewer pipes rarely performed and as a result the pipes are seriously clogged. The situation is better in case of the surface channels but that still is far from ideal. In most cases, the accumulation of sludge, debris and other non-perishable wastes blockade the conduits and hamper its working efficiency to acute degree. In extreme cases, it was found that the manholes were totally shut off with sludge and other solid wastes, blocking flow to every conduit passing through it. The condition of the manholes is depicted in the following figures:

Fig. 4.10: Blockage in Manholes and Catch Pits

Table: 4.1 Length and Capacity of the existing drainage network of Dhaka city

	Pipe Length (m)	Capacity (cum)
1700 mm wide Brick Sewer	2,056.40	3,495.88
2100 mm wide Brick Sewer	1,054.88	2,215.25
12 ft x 18 ft Box Culvert	2,178.96	43,725.02
600 mm dia Storm Sewer	18,734.77	5,294.45
750 mm dia Storm Sewer	11,982.58	5,291.06
900 mm dia Storm Sewer	12,337.22	7,844.62
450 mm dia Pipe Drain	1,337.80	212.66
600 mm dia Pipe Drain	4,646.95	1,313.23
750 mm dia Pipe Drain	5,188.11	2,290.87
900 mm dia Pipe Drain	6,614.02	4,205.53
1200 mm dia Pipe Drain	4,096.34	4,630.50
1700 mm dia Pipe Drain	1,061.59	2,408.37
2000 mm dia Pipe Drain	367.68	1,154.52
600 mm wide Surface Drain	2,778.05	1,000.10
		85,082.06

[Derived from Dhaka WASA – IWM Drainage Map]

However, the situation is better in the newly built pipes and conduits. Determining the actual level of efficiency of the pipe network requires more effort, time and labor and is out of the scope of current research. At this condition, the overall efficiency of the drainage network can be empirically set to be in the vicinity of around 50% of total capacity. From the data presented above, the total retention volume of the drainage network was found to be 4,29,094 cum. at 100% efficiency. At the efficiency level of 50%, the retention volume drops down to approximately 215,000 cum.

4.3 Natural Water Bodies within the Study Area

The study area selected for the current study comprises mostly of the highly developed residential, commercial and business hub of the city. As the very center of the city, abundance of natural water bodies within the study area is almost a harsh expectation. Many of the water bodies including several khals and channels have been soiled off for development purpose. Most of such free water bodies have been encroached to feed the hunger for more and more development. Still though, the study are contains several prominent natural water bodies such as dhanmondi lake and ramna lake. The hatirjheel lake lays just outside of the study area and can easily be linked to the drainage network of the study area as a key exit point.

Historic data describes Dhanmondi lake as originally a separated channel of the Kawran Bazar River which is now a dead river. The lake is also said to be connected with the Turag River located at the east of the lake. Nearly 3 km long and over 30 square km. of wetted area, dhanmondi lake hosts as the refuge for the natural reservoir of the entire dhanmondi area. Almost all the waste water and rainwater of the watershed area are routed to Dhanmondi lake. Dhanmondi lake is connected to Begun Bari Khal located to its west through a makeshift box culvert channel which is now being operated and maintained by Dhaka WASA.

4.4 Rainfall Pattern

The amount of rainfall is directly proportional to the amount of storm discharge considering the terrain, formation and surface runoff coefficient of that area. The monsoon in Dhaka city begins in April and lasts till October with its peak around the month of June-July. A quick review of the historical data on daily rainfall over the study area for the last 14 years reveals that the peak rainfall has started to shift from May-June to August-September. Also the highest level of daily rainfall was recorded on 2004 and 2009 which is in accordance with the recent flood history. A month based table of highest rainfall data for the year 2000 to 2013 and the monthly maximum rainfall is presented in Appendix - II.

The amount of rain water that the drainage network has to work with depends on several factors - namely terrain, time of concentration, surface runoff coefficient of the study area, etc. The surface runoff coefficient of the study area has already been determined as 0.9338, which means that 93.38% of the rainwater will flow over the ground in search for an outlet following the terrain and only 6.62% of it will seep through ground on its way. This data shows the extensive amount of urbanization in the study area that most of the ground has been paved and made impervious to water that the amount of percolation is significantly low. Had there been sufficient planning, guidelines and regulations to keep more green areas in the urban reason, the drainage network had to deal with much lower level of water load.

From the capacity of the present drainage network calculated in the previous section, the optimum level of rainfall for the study area is found to be in the vicinity of 27 mm. That means, if the average rainfall over the study area is 27 mm or less, than the existing drainage is capable to drain the storm water off the area and there should be no water logging. However, this may not be the fact all the time as the basin (terrain) and the catchment area plays a vital role in this issue, i.e., water will run down to lower regions from higher regions leaving the drainage system of the higher altitude region less than useful and causing water logging in the lower areas of the terrain. Also, time of concentration of that certain catchment area is equally important in this regard. The Time of Concentration has an inverse relation with the flooding effect, i.e., the higher is the Time of Concentration for a certain watershed area, the chances of flooding and water logging is equally lesser.

It is to be noted that the drainage system works as a conduit for storm water rather than a mare reservoir. The capacity might represent the abundance of drainage facility of a certain area, but considering only the capacity of the drainage system will result in ambiguous outcome. The key function of the drainage system is to channel rain water from the study area to the outlet and this function has to be taken into consideration. Using Manning's Equation, the flow velocity and discharge capacity of different elements of the drainage system has been determined (Table: 4.2). However, the number of points of entry to the drainage network or the number of catch pits would play a vital role as long as the main conduits (i.e. the conduits with larger cross sections) are running partially filled. The instance the main conduits are completely filled and its entire wetted perimeter is put into action, the flow through these conduits would mostly govern the flow of the entire network irrespective of the rainfall intensity or the number or efficiency of the catch pits. Again, working with conventional rainfall data for a certain area may not present the actual picture of precipitation as well as the drainage of that area. In general, the intensity of precipitation over a certain period over a specific time period is recorded, the units being millimeters or inches for precipitation and 24 hours for the time. It can be easily conceived that the intensity of rainfall is not evenly distributed over this period of time. Using such average rainfall data on daily basis in hydrological and drainage design will result in inefficient design which will result in unused drainage capacity when the rainfall is below the design intensity and water logging when the rainfall is above that, which may have duration of hours to even days. Thus, for proper assessment, a detailed rainfall intensity chart showing rainfall level in every hour of a day is necessary. But unfortunately, there is no agency in Bangladesh that keeps such extensively detailed rainfall data. To imitate a more realistic scenario, an average duration of three hours of rainfall on daily basis was considered. Using an efficiency level of 50% and the maximum rainfall intensity since the year 2000, it was found that rainfall over the intensity of 260 mm / 3 hrs will cause water logging with the current drainage network.

4.5 Runoff Coefficient & Retention

The city of Dhaka evolved and expanded drastically over the last century. The city has undergone a major growth of nearly 1500% in the last 60 years, from 85.45 sq. km. in 1951 to 1352.82 sq. km. in 2001 as in total city area. With the massive urbanization of Dhaka city, amount of free green has gone down substantially. While the greenery and free land is being converted to concrete junkyard, ways to return rainwater back into the ground water table is being destroyed in the process. As a result, the ground water table is getting depleted day by day while the drainage system has to handle the excess rain water as surface ground water.

Table: 4.2 Discharge Capacity of the existing drainage network of Dhaka city

	Channel / Conduit Area, A		Flow Velocity, V		Flow Capacity, Q	
	sq. ft.	sq. m.	ft / sec	m / sec	cft / sec	cu m / sec.
1700 mm wide Brick Sewer	1810.04	168.1564328	2.79	0.850609756	5050	143.0189748
2100 mm wide Brick Sewer	2099.71	195.07	3.42	1.04	7181.00	203.37
12 ft x 18 ft Box Culvert	1696.96	157.65	5.60	1.71	9503.00	269.13
600 mm dia Storm Sewer	3.01	0.28	1.40	0.43	4.21	0.12
750 mm dia Storm Sewer	4.77	0.44	1.60	0.49	7.64	0.22
900 mm dia Storm Sewer	6.86	0.64	1.81	0.55	12.42	0.35
450 mm dia Pipe Drain	1.72	0.16	1.14	0.35	1.96	0.06
600 mm dia Pipe Drain	3.01	0.28	1.40	0.43	4.21	0.12
750 mm dia Pipe Drain	4.77	0.44	1.60	0.49	7.64	0.22
900 mm dia Pipe Drain	6.86	0.64	1.81	0.55	12.42	0.35
1200 mm dia Pipe Drain	12.16	1.13	2.20	0.67	26.75	0.76
1700 mm dia Pipe Drain	24.44	2.27	2.77	0.84	67.70	1.92
2000 mm dia Pipe Drain	33.71	3.13	3.10	0.95	104.50	2.96
600 mm wide Surface Drain	601.35	55.87	1.48	0.45	890.00	25.21

[Derived from Dhaka WASA – IWM Drainage Map]

In 1991, JICA conducted a survey on the Storm Water Management (SWM) of Dhaka City and developed coefficients for different land use zones depending on ground water level, surface condition, slope, etc. Since then, the pattern of land use in Dhaka city has changed to a great extent, but the coefficients seems to be considerable till date. According to the recent survey, the study area is mostly consists of dense commercial zones, high end to mid level residential zones and paved lots and roadways. From these data, the runoff coefficient of the study area was determined to be 93.38% (0.9338), giving a percolation rate of 6.62% (0.0662). The source maps for determining the land use pattern and runoff coefficient can be found in Appendix - V.

Table: 4.3 Land use pattern of study area

Land Use	Proposed Runoff Coefficient	Total Area within Study Area (sqm)	Percentage	Weighted Percentage	Equated Runoff Coeff.
Commercial Area	0.65	3,661,412	23.47%	15.26%	93.38%
Industrial Area	0.55	1,052,927	6.91%	3.80%	
High Class Residential Area	0.30	2,836,932	18.18%	5.45%	
Middle & Low Class Residential Area	0.50	4,634,772	29.71%	14.86%	
Green Zone & Others	0.20	1,775,115	11.52%	2.30%	
Roadways & Other Paved Aeras	0.50	1,413,989	9.07%	4.54%	
Water Bodies	0.10	177,840	1.14%	0.11%	

[Derived from DCC North & DCC South Zone Maps]

The study area contains nearly 175,000 sq. meters of open water bodies among the total study area of 15.4 sq. km. or 15,600,000 sq. meters that comprises nearly 1.12% of the total study area. However, in most cases, especially during monsoon, these open water bodies are filled with water to their capacity. Also, natural channels leading to these water bodies are mostly congested or blocked. Due to these reasons, these water bodies cannot readily retain much of the rainwater within themselves. For the current research work, the retention capacity of these water bodies has been decided to be limited at 1.5% of their total capacity.

4.6 Simulation: Relation between Rainfall Intensity and Waterlog

To understand the existing relation between the Intensity of Rainfall and Severity of Water logging in the catchment area, a static simulation was developed and run using the data obtained through this research. It is obvious to mention that the severity of water logging in any area is directly proportional to the intensity of rainfall in that region. However, the relation can either be linear or non-linear. From the point of rainfall and the point of water logging, there are several geological variables that can alter the pattern of water logging. Such variables may include use of land in that region, rate of seepage, surface and slope of the terrain, presence of free water bodies in that area and their effectiveness and so on.

The simulation was conducted based on the following criterion:

- The intensity of the rainfall was decided to be at 341 mm as the highest rainfall intensity recorded in Dhaka city since 2000, which coincidentally happens to be the highest recorded rainfall in Dhaka city one day for the last 60 years.
- The duration of rainfall was assumed to be 3 (Three) continuous hours or 180 continuous minutes spread over a slab of 30 (Thirty) minutes each. However, the intensity of rainfall could be dispersed evenly or unevenly over this period of time. For better understanding of the simulation, different levels of rainfall intensity were tried over this trial period. For experimental purpose, the rainfall was disperse in a hypothetical distribution of 7.5%, 12.5%, 30.0%, 30.0%, 12.5% and 7.5% respectively over six slab of 30 minutes each.
- Considering the runoff region and the land use pattern of that area, level of seepage or percolation of the rain water for the design rainfall intensity was determined. As the runoff coefficient for the study area was determined to be 0.9338 (or 93.38%), the level of percolation for the area as determined as 0.0662.
- The study area contains a good number of natural water bodies of the Dhaka city including well known Dhanmondi Lake and Ramna Lake. These water bodies work as a natural reservoir for ground water table as well as water derived from different forms of precipitation. However, much of these water bodies are heavily occupied with their own contents. Also, routes to these water bodies for the rain water running on the surface are not prominent as well. Considering the above facts as well as the cumulative area of these water bodies compared to the total area of the study area, a total retention rate of 1.5% (0.015) was determined.
- As stated beforehand, the capacity of the drainage network within the study area is seriously hampered by the blockage caused by sludge and other solid waste inside of both within the pipes as well as the manholes which functions as a hub of pipes and also the primary inlet. Also, in many cases, over the surface garbage, debris, leaves and other perishable and non-perishable wastes block out the inlets of the manholes and catch pits. Considering the above facts, the capacity of the drainage pipe

networks was set to 50% which gives it an approximate discharge rate of 324 cum/sec.

The simulation was conducted for several combinations of rainfall pattern and intensity with different length of times for precipitation other than the design period of 3 (three) hours. The outcomes of the test are listed below:

- With longer lengths of design rainfall period, the likelihood of water logging comes down. That means, for a fixed amount of rainfall of 341 mm/day, the more is the time of precipitation, the intensity of rainfall in design time slab comes down and the chance of water logging plummets.
- The optimum level of rainfall according to this simulation was determined to be 42 mm / 30 minutes. This is the highest capacity of rainfall over a certain design period that the entire existing drainage network of the design area can consume efficiently. Any less rainfall over this level will cause the existing drainage remain unutilized and any rainfall more than this level will create congestion of water or water logging in the catchment area, preferably on and around the inlet area. The intensity and duration of the water logging is directly proportional to the intensity of rainfall over this period.
- At a design rainfall of 341 mm/day, the optimum duration for rainfall is a little over 8 hours, considering the intensity of rainfall is dispersed uniformly over this period.

Graphical representations of the simulation under different parameters can be found in Annex. III.

4.7 Proposed Drainage Network for the Study Area

As stated before, it was neither practically feasible nor scope wise justifiable to determine the actual duration and frequency of maximum rainfall over the study area. Collecting such data as first hand information was out of the scope of the study and no such elaborated information was readily available to any local or foreign agencies to use as secondary data. For this reason, it was assumed that the maximum rainfall occurred uniformly over a period of 3 (three) hours or 180 (one hundred and eighty) minutes to make things less complex for this study. It was seen that even with this lowered intensity, the amount of rainwater is too much for the existing drainage network to handle and thus creates waterlog for various durations.

To reduce the duration of waterlog to a considerable level or even to an absolute nil, a tentative drainage network was designed for the study area as a supplement to the existing drainage network. Since the selected highest rainfall of 341mm a day is also the highest recorded rainfall in this area for the past 60 years, it is quite safe to conclude that the magnitude of daily rainfall will most likely be below this level. On the other hand, the study area has a width of 8.35 km and 3.16 km along its long and short direction respectively and capacity of the desired drainage network should be such that it can discharge the precipitated rain water in such a rate so that the water can travel fast enough before the following torrent of rainwater hits the drainage pipes. In case that the velocity of rainwater is insufficient to clear the drains before the next torrent, there will be a blockage and consequent waterlog in the upstream portion. Considering the above assumptions, the quantity of logged water or the rainfall excess of the drainage capacity is in the vicinity of 236,000 cu. meters and a supplementary drainage network of such capacity should be sufficient to render a solution to the current water logging situation. A tentative drainage network design comprising of conduits of similar size diameter pipes as in existing network is presented in Table. 4.4.

The proposed design under consideration is depicts a parallel drainage network along with the existing network. The extended 450 mm and 600 mm lines would serve as the feeder lines for the most of its length that collects and accumulates rainwater from the low lying areas of the central region as well as from the more peripheral areas along the network. These conduits relay the accumulated rainwater to the main 1200 mm and 1700 mm dia conduits along with the box canels and concrete pipe network that work as the main workforce for rainwater disposal. The increased flow and storage capacity of these conduits provides the drainage network with extra volume to accommodate more rainwater as well as the extra rainwater that have already been accumulated in the upstream region during this elapsed time. The most outer portion of the network comprises of 2000 mm dia conduits that discharges the entire rainwater of the region to the adjacent canals, rivers or other water bodies or other means of water disposal facility.

The static simulation designed for the purpose of this study is run again to associate the data for the newly proposed combined drainage network. The simulation indicates that the proposed network is well off dealing the design 341 mm of rainfall dispersed uniformly over a period of 3 hours without causing any visible waterlog whatsoever. However, the network still vulnerable against a spatially distributed rainfall pattern and any precipitation causing a water load over 950880 cum or 61 mm of rainfall over a 30 min span can still cause a waterlog. The duration and intensity of such waterlog would mostly depend on the undue deviation of the dispersion. In case of the previous dispersion, the newly proposed drainage network causes a waterlog of only 15 minutes once the precipitation stops. Like any other engineering problem, designing and implementing a full proof drainage network for any amount of rainfall would be uneconomic and non-feasible.

Table: 4.4 Proposed Drainage Network

	Proposed Supplementary Length (m)	Proposed Combined Length (m)	Conduit Capacity (cum)	Flow Capacity (cum/sec)
1700 mm wide Brick Sewer	943.60	3000.00	5100.00	208.62
2100 mm wide Brick Sewer	545.12	1600.00	3360.00	308.42
12 ft x 18 ft Box Culvert	1221.04	3400.00	68227.49	419.89
600 mm dia Storm Sewer	11265.23	30000.00	33912.00	0.19
750 mm dia Storm Sewer	4990.15	11000.00	24727.50	0.25
900 mm dia Storm Sewer	8971.59	23000.00	58498.20	0.66
450 mm dia Pipe Drain	662.20	2000.00	1271.71	0.08
600 mm dia Pipe Drain	2553.05	7200.00	8138.88	0.18
750 mm dia Pipe Drain	3011.89	8200.00	14483.25	0.34
900 mm dia Pipe Drain	3385.98	10000.00	25434.01	0.53
1200 mm dia Pipe Drain	1903.66	6000.00	27129.61	1.11
1700 mm dia Pipe Drain	638.41	1700.00	15426.78	3.07
2000 mm dia Pipe Drain	232.32	600.00	7536.04	4.83
600 mm wide Surface Drain	1421.95	4200.00	1512.00	38.10
				986.27

4.8 Expected Improvement in Effective Water Logging

The proposed drainage network for the study area is supposed to have greater impact over the study area in terms of reducing water logged areas as well as water logging period. However, reducing the level of water logging in the study area to an absolute zero was always out of the scope of this study as mentioned in previous section. While designing a drainage network to result a waterlogging free area is always theoretically possible – implementing and maintaining such an elaborate and high maintenance network is always void of feasibility in financial and human terms. For this reason, even with the proposed drainage network, certain level of waterlogging is always expected.

From the DEM file for the study area, it is evident that the study area ranges from 4 meters to 38 meters in height from MSL. As we know that the terrain of Dhaka city is pretty much plain and monotonous, this high range of elevation change could mostly be credited to manmade structures and geographically not natural. The available DEM file was analyzed and sections with elevations of 1 meter apart were separated and counted. Each pixel in the DEM file represents 900 square meters of land area in real world which as used to calculate actual areas of land in the real world for each meter of elevation. Fig 4.11 represents the cumulative percentage of the land in the study area arranged ascendingly in terms of elevation over MSL within an interval of 1 meter. It could be assumed that whatever amount of water will remain available excess of the drainage capacity, it will inundate the area of lowest elevation first. From the simulation designed in the previous section, the highest volume of logged water can be found for any intensity of rainfall for both uniform and spatial distribution. As it was established during the course of simulation that spatial distribution of designed rainfall generates more water logging than uniform one, it carries more significance while evaluating the possible improvement of water logging pattern. Calculating the volume of the logged water for different design rainfall, the specific locations of water logging along with the depth of inundation as well as the percentage of inundated area within the study could be calculated mathematically and graphically.

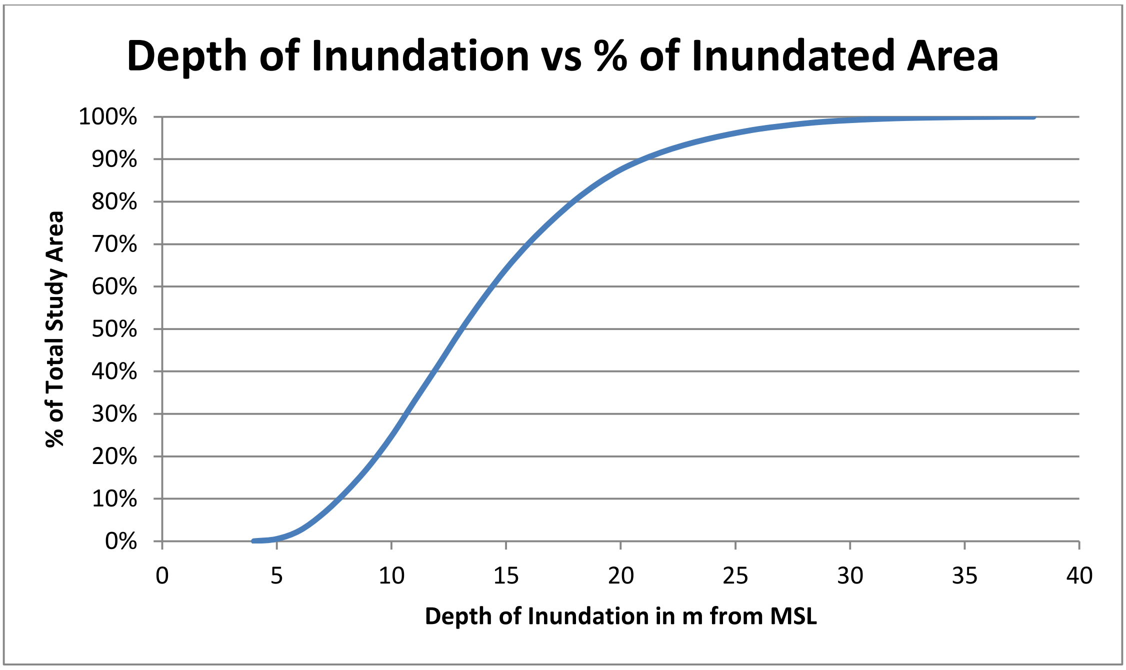


Fig. 4.11 Depth of Inundation over % of Total Land of Study Area

To evaluate the improvement in water logging pattern, three levels of design rainfall of 250 mm, 300 mm and 341 mm was selected considering a spatial distribution as employed in the simulation section. Graphical and mathematical data show that for 250 mm, 300 mm and 341 mm rainfall, the proposed network has reduced the water logged infected area within the study area by 53.41%, 57.26% and 48.25% respectively.

Table 4.5 Details of Anticipated Improvement of Proposed Drainage

Design Rainfall (mm)		Volume of Logged Water (cum)	Level of Inundation (m)	Inundated Area	Improvement
250	Existing	888,911	6.78	5.43%	53.41%
	Proposed	411,192	6.01	2.53%	
300	Existing	1,416,975	8.05	11.70%	57.26%
	Proposed	848,210	6.72	5.00%	
341	Existing	1,887,115	8.48	14.30%	48.25%
	Proposed	1,206,565	7.22	7.40%	

Details of the improvement data is shown in Table 4.5 and graphical representations are presented in Annexure III.

4.9 Limitations in Research

The research does not properly address the following facts in developing the simulation mentioned:

- Though the city of Dhaka is surrounded by the mighty rivers, namely the Buriganga, Balu & Turag and is crisscrossed by many khals, the study area does not directly contain any of these natural drainage elements which play a direct positive role in any drainage network. The DND Barrage, part of the Dhaka-Narayanganj-Demra (DND) Project located between the cities of Dhaka and Narayanganj and bounded by the buriganga and the shitalakshya river.
- On the contrary, during the rainy season, when the water level at the surrounding rivers goes up and surpasses that of the city inside the DND barrage, the existing drainage network is not able to drain the surplus rainwater out to the rivers. For such times, Dhaka WASA has eight high powered pumps installed on strategically crucial locations to pump out the rain water to the surrounding rivers over the DND Barrage. If the water levels at the surrounding rivers are excessively high, then there occurs a chance for backflow of water which adds up to the already stagnant water to make the situation worse.
- The inlets of the manholes and catch pits are found to be blocked with leaves, household wastes and other non perishable wastes to such degree that this elements virtually becomes unavailable and impractical for rain water to get access to. Even in many cases, semi-permanent / permanent structures were seen to be constructed over the manholes or catch pits entirely blocking the inlets facilities. In such cases, the efficiency of the surrounding drainage system comes down even to zero.

4.10 Recommendations

- The existing drainage network is much less than adequate for a well developed and highly populated mega city like Dhaka. Much of the pipes in the existing network are not of adequate size. The competent authority along with all the concerned parties should work together to develop the existing drainage network to meet the soaring load of rain water.
- The efficiency of the existing drainage system is far from ideal. Proper measures should be taken to clean out the pipes, manholes, catch pits and other drainage elements to ensure high level of efficiency as well as longevity of the drainage system. Also, the surface of the manhole and catch pits should be kept free of waste and garbage to avoid clogging of rain water.

- Saving and restoring natural drainage system and water bodies. A densely populated city like Dhaka requires 25 per cent wetland for ecological balance and sustainability of habitats. But Dhaka has less than 8 per cent wetland, which too is threatened.
- Over the last few decades, many of the lakes and khals of Dhaka city have totally disappeared and almost all of the rest have lost their width & area and are at the point of death due to illegal encroachment and waste disposal. Filling of such water bodies and flood retention areas in the name of development must be stopped and the lost khals and lakes are to be restored.
- The increased congestion of Dhaka city, the high population density and the rapid growth all around it has made it quite hard to manage solid waste efficiently. Collection and disposal of solid waste has thus been a tough challenge and sworn responsibility on the part of the concerned authorities, both on financial and managerial ground. A participatory planning approach is necessary to cultivate a process through consultation, collaboration and coordination among the stakeholders – both from within and outside the regulatory authorities.
- There should be a comprehensive drainage improvement plan for Dhaka city to overcome the water logging problem permanently. The entire drainage system of the city will have to be overhauled to mitigate the problem and should be properly linked through a well planned & designed network. However, it can be managed in a more efficient, economic and sustainable fashion with the assistance of professional development organizations. This will develop the skill of manpower of concerned authorities through transfer of technology and training. The proposed comprehensive drainage improvement plan could be exchanged with other utility organization to avoid overlapping and duplication and to ensure a high degree of close coordination.
- In general, the people of our country are illiterate and they are not even aware of the after effects of the filling of natural drainage and water bodies or blocking the manholes and catch pits. Therefore, the concerned authorities should take steps to initiate an awareness development program to enlighten these people regarding the necessity of natural canals and water bodies and if possible to involve them in the program for their preservation.
- Legal instruments have an important role to play in changing the attitude, behavior and lifestyle of the people in a society. There are a set of acts, rules, and policies in the country to deal with the environmental issues. However, there are some old laws that cannot cater to the need of the present age. Some laws are void of reality and needs amendment to accommodate the existing environmental scenario. Consolidation of all environment laws into a single law and arrangement of all environmental activities under one umbrella may bring good result towards conservation and improvement of environment.

CHAPTER 5

CONCLUSION

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5.1 Conclusion

Water logging in Dhaka City is a logical consequence of a spectrum of unplanned development. The situation has been further deteriorated by rapid urbanization with unplanned construction, encroachment of free water bodies as well as filling up, diversion and obstruction of the flow within this water bodies and natural water conduits. The network of artificial drainage system is often also abruptly interrupted by manmade wastage and nuisances. All these factors result in severe water logging in Dhaka city every year, especially in monsoon season, creating millions in terms of adverse social, physical, economic and environmental costs.

The dire situation has called for urgent long term measure in terms of planning, design, construction and operation of an effective and efficient drainage network as well as recovery of the lost natural water bodies. While the planning, design and construction part are mostly supposed to be executed by the government, the operation and maintenance of a running network calls for sensible and responsible approach from general mass (i.e. the users) as well. Being part of a developing country with very limited resources - planning, design, operation and maintenance of urban drainage systems has always been a challenge for concerned urban authorities because of unplanned development activities and mindset of the general users. Also, the effectiveness of storm water management systems can be directly linked to the efficacy of urban management. Therefore, for urban drainage systems to be managed effectively and operationally sustainable, greater emphasis needs to be placed upon:

- Co-ordination among different urban authorities and agencies responsible for different aspects of urban drainage and management.
- Collaboration among government bodies, non-governmental organizations and common users to promote an effective and synergetic effort between government and the private sector;
- Raising consciousness and training of human resource for improved planning, design, and operation of existing urban drainage systems.

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ANNEXURE I

List of concerned resource persons with Dates, Times and Places of Meeting

Sl. No.	Name & Designation	Date of Meeting	Place of Meeting
1.	Prof. Dr. M. Monwar Hossain Executive Director IWM Contact: (02) 882 4590	27 – 10 – 2014	House # 496, Road # 32, New Mohakhali DOHS Dhaka – 1206
2.	Dr. A. F. M. Afzal Hossain Deputy Executive Director IWM Contact: (02) 882 2105	03 – 11 – 2014	House # 496, Road # 32, New Mohakhali DOHS Dhaka – 1206
3.	Md. Firoz Alam Executive Engineer Drainage (R&D) Div – 2 Dhaka WASA Contact: (02) 956 8999	20 – 11 – 2014	Drainage (R&D) Div – 2 Dhaka WASA Abdul Gani Road Segun Bagicha, Dhaka.
4.	Mohammad Abul Kashem Executive Engineer Zone-2 (Mirpur) Dhaka City Corporation North	24 – 11 – 2014	Zone – 2 Dhaka City Corporation (North) Zoo Road, Mirpur, Dhaka.

ANNEXURE II

RAINFALL INTENSITY OF DHAKA CITY

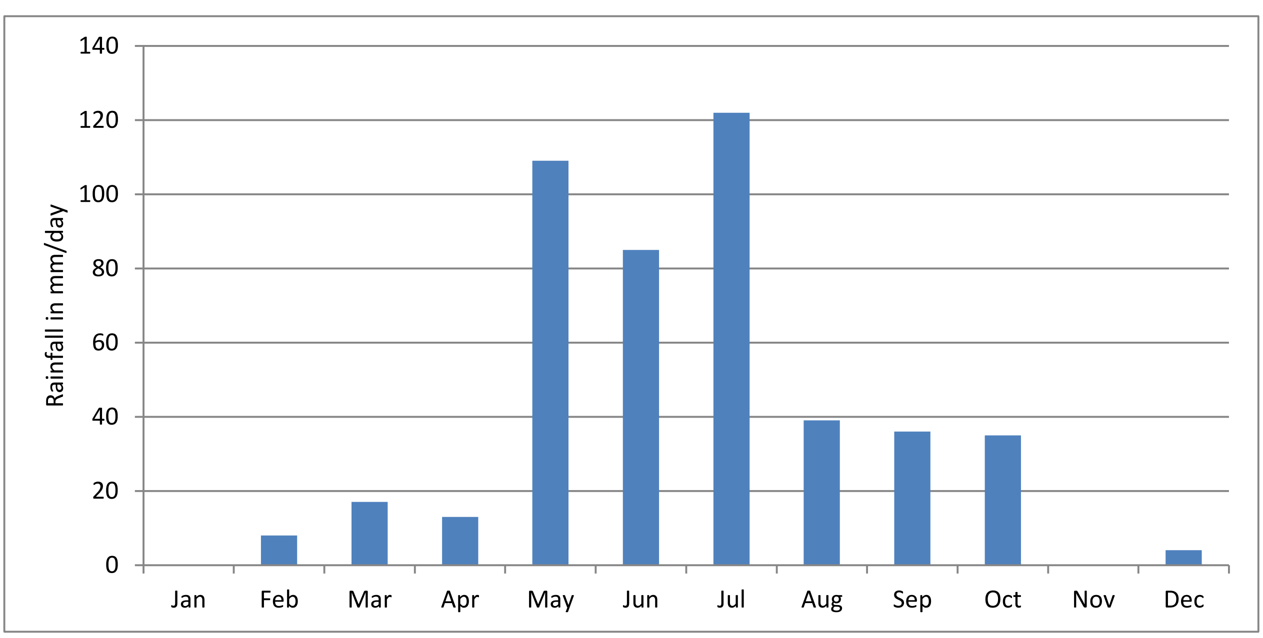
(2000 – 2013)

Rainfall Intensity of Dhaka City: Year 2013 (mm / day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	2	0	12	5	4	10	5	0	0
2	0	0	0	0	0	0	0	6	16	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	17	1	4	0	0
5	0	0	0	0	4	0	28	0	24	30	0	0
6	0	0	0	0	2	1	0	3	0	13	0	0
7	0	0	0	0	17	37	0	20	1	3	0	0
8	0	0	0	0	18	20	0	39	1	1	0	0
9	0	0	0	0	40	0	0	1	36	0	0	0
10	0	0	0	0	0	0	0	1	0	0	0	0
11	0	0	0	0	0	0	1	18	3	0	0	0
12	0	0	0	0	7	0	0	4	2	0	0	0
13	0	0	0	0	3	0	5	4	1	4	0	0
14	0	0	8	0	19	0	6	1	0	1	0	0
15	0	0	0	0	0	1	3	0	24	0	0	0
16	0	0	0	0	3	0	0	30	7	6	0	0
17	0	0	0	3	75	0	1	8	0	1	0	0
18	0	8	0	4	0	0	1	1	0	0	0	0
19	0	0	0	0	3	0	2	0	1	0	0	0
20	0	0	0	9	0	9	41	0	0	0	0	0
21	0	0	0	0	30	34	11	1	0	3	0	4
22	0	0	0	0	4	11	2	11	1	35	0	0
23	0	0	17	1	1	0	0	7	15	13	0	0
24	0	0	1	0	109	1	1	0	0	0	0	0
25	0	0	0	0	22	1	0	0	0	0	0	0
26	0	0	0	0	0	32	5	0	6	11	0	0
27	0	0	0	0	0	10	29	17	2	1	0	0
28	0	0	0	13	0	14	122	5	0	0	0	0
29	0	-	0	0	1	85	35	4	0	0	0	0
30	0	-	0	0	1	57	3	9	21	0	0	0
31	0	-	0	-	19	-	1	1	-	0	-	0
Max	**0**	**8**	**17**	**13**	**109**	**85**	**122**	**39**	**36**	**35**	**0**	**4**

[Source: Bangladesh Meteorological Department]

Table 4.14: Monthly Maximum Rainfall for the year 2013



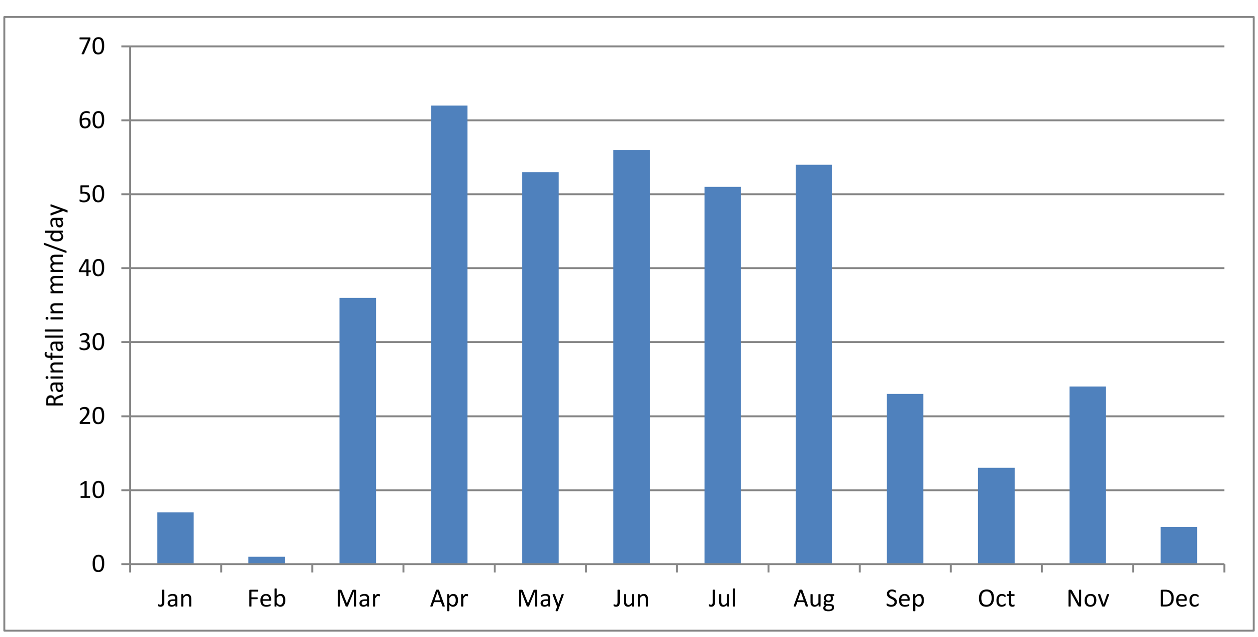
Graph 4.14: Monthly Maximum Rainfall for the year 2013

Rainfall Intensity of Dhaka City: Year 2012 (mm / day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	1	0	0	3	17	11	0	0	0	0
2	0	0	0	0	53	0	7	1	0	0	0	0
3	1	0	0	0	13	1	2	0	1	0	0	0
4	0	0	0	0	16	0	18	9	0	2	4	0
5	0	0	0	0	6	8	29	1	3	13	22	0
6	0	0	0	0	0	56	2	2	23	0	18	0
7	1	0	0	62	0	0	4	6	0	0	24	0
8	0	0	0	9	0	2	0	26	0	0	0	0
9	0	0	0	18	0	0	1	16	0	0	0	0
10	7	0	0	9	0	0	10	0	10	2	0	0
11	1	0	0	0	0	0	1	0	0	7	0	0
12	0	0	0	0	0	0	4	2	1	2	0	5
13	0	0	0	40	1	0	16	54	4	1	0	0
14	0	0	0	0	0	0	6	13	12	11	0	0
15	0	0	0	0	0	0	14	2	2	0	0	0
16	0	0	0	11	1	0	0	0	0	0	0	0
17	0	0	0	0	10	9	0	7	5	0	0	0
18	0	0	36	0	4	17	51	0	8	0	0	0
19	0	0	0	52	1	42	2	1	0	0	0	0
20	0	0	0	0	1	2	2	8	0	0	0	0
21	0	0	0	8	1	6	1	34	0	0	0	0
22	0	0	0	29	0	0	5	40	0	0	0	0
23	0	0	0	0	0	0	5	0	0	0	0	0
24	0	0	0	0	0	8	0	2	0	0	0	0
25	0	0	0	0	4	7	0	24	0	0	0	0
26	0	0	0	31	0	10	0	0	0	0	0	0
27	0	0	0	0	0	0	9	0	0	0	0	0
28	0	0	0	0	0	0	1	21	8	0	0	0
29	0	1	0	0	2	0	18	1	0	0	0	0
30	0		0	0	0	4	1	1	4	0	0	0
31	0		0		24		0	0		0		0
Max	**7**	**1**	**36**	**62**	**53**	**56**	**51**	**54**	**23**	**13**	**24**	**5**

[Source: Bangladesh Meteorological Department]

Table 4.13: Monthly Maximum Rainfall for the year 2012



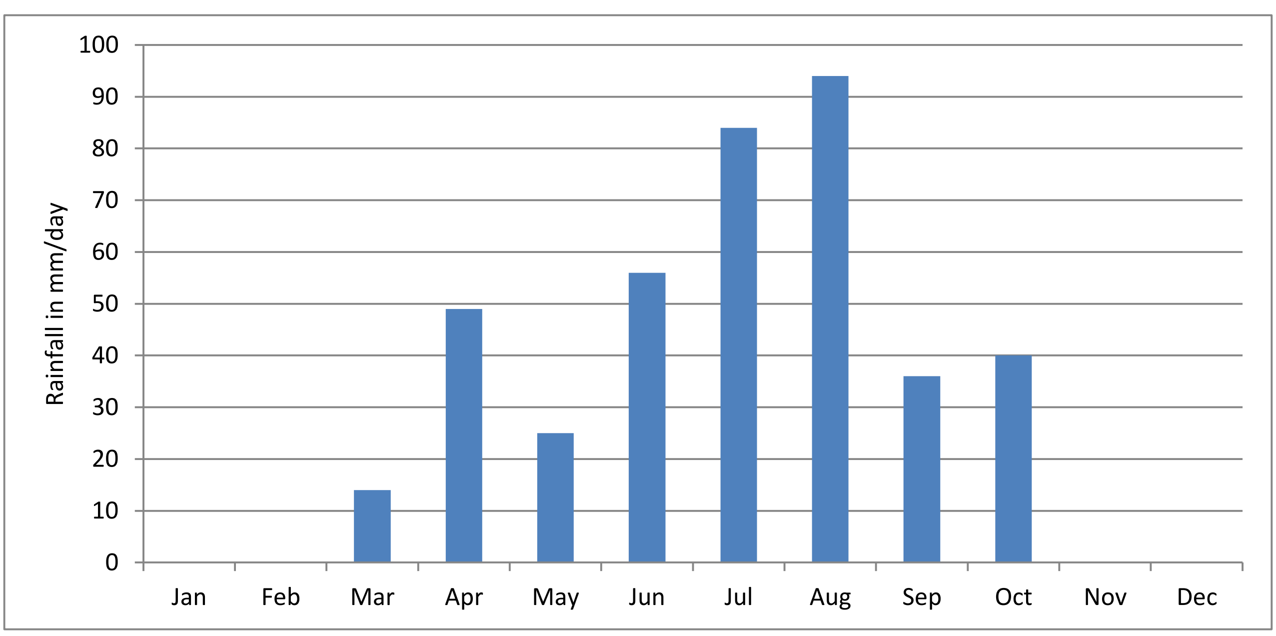
Graph 4.13: Monthly Maximum Rainfall for the year 2012

Rainfall Intensity of Dhaka City: Year 2011 (mm / day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	11	0	46	35	0	1	0	0	0
2	0	0	0	0	5	0	34	0	5	40	0	0
3	0	0	0	49	0	13	7	7	9	1	0	0
4	0	0	0	8	0	11	0	5	0	0	0	0
5	0	0	0	5	3	0	0	2	1	0	0	0
6	0	0	0	0	23	0	1	26	4	0	0	0
7	0	0	0	0	10	0	1	22	0	0	0	0
8	0	0	0	0	0	0	33	9	25	0	0	0
9	0	0	0	0	0	0	7	79	3	27	0	0
10	0	0	0	0	20	0	0	94	1	13	0	0
11	0	0	0	0	17	9	0	15	0	5	0	0
12	0	0	0	0	25	40	7	7	0	0	0	0
13	0	0	0	0	0	0	9	0	0	0	0	0
14	0	0	0	0	14	1	1	11	1	0	0	0
15	0	0	0	9	0	0	21	0	18	0	0	0
16	0	0	0	0	0	3	1	0	36	0	0	0
17	0	0	0	9	1	13	0	32	17	0	0	0
18	0	0	0	0	1	15	25	28	1	0	0	0
19	0	0	0	0	15	56	21	0	10	6	0	0
20	0	0	0	5	3	0	84	5	5	2	0	0
21	0	0	0	0	0	7	23	1	13	0	0	0
22	0	0	0	5	24	0	32	3	0	7	0	0
23	0	0	0	0	11	0	14	12	0	11	0	0
24	0	0	0	0	17	0	0	9	0	0	0	0
25	0	0	1	0	3	11	0	37	11	0	0	0
26	0	0	0	0	13	2	0	3	1	0	0	0
27	0	0	14	1	0	23	0	2	26	0	0	0
28	0	0	1	0	10	17	0	0	19	0	0	0
29	0		0	21	3	19	0	0	0	0	0	0
30	0		0	0	17	28	0	0	0	0	0	0
31	0		4		0		0	0		0		0
Max	**0**	**0**	**14**	**49**	**25**	**56**	**84**	**94**	**36**	**40**	**0**	**0**

[Source: Bangladesh Meteorological Department]

Table 4.12: Monthly Maximum Rainfall for the year 2011



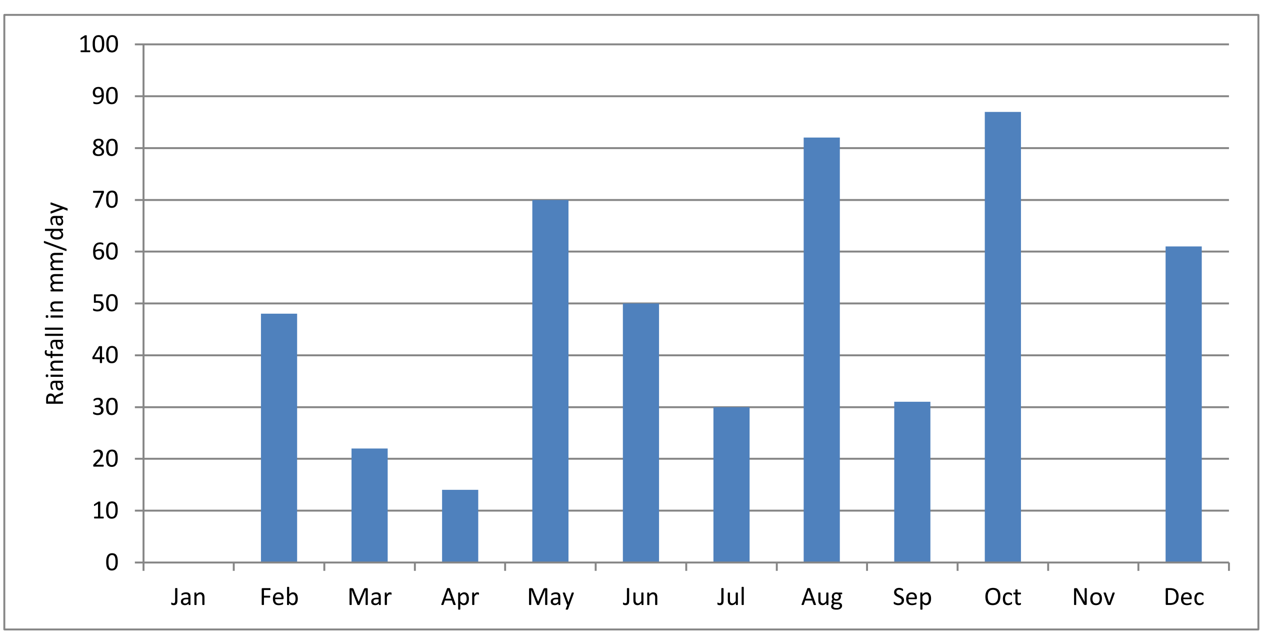
Graph 4.12: Monthly Maximum Rainfall for the year 2011

Rainfall Intensity of Dhaka City: Year 2010 (mm / day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	28	0	14	1	5	0	0
2	0	0	0	0	0	0	1	23	2	0	0	0
3	0	0	0	0	27	10	19	0	0	0	0	0
4	0	0	0	0	0	21	3	0	3	0	0	0
5	0	0	0	0	0	49	0	31	0	0	0	0
6	0	0	0	0	2	45	16	0	0	1	0	0
7	0	0	0	0	0	0	1	2	13	20	0	0
8	0	0	0	0	3	0	0	0	1	27	0	0
9	0	0	0	0	0	0	6	6	1	87	0	20
10	0	0	0	0	0	0	0	0	1	0	0	61
11	0	0	0	0	0	0	13	5	2	0	0	0
12	0	0	0	0	0	0	2	82	0	0	0	0
13	0	0	0	0	0	3	1	1	4	0	0	0
14	0	0	0	0	0	0	30	1	1	0	0	0
15	0	0	0	0	29	0	1	20	31	31	0	0
16	0	0	22	14	0	8	1	6	1	0	0	0
17	0	0	0	0	2	0	0	3	24	0	0	0
18	0	0	0	0	0	35	0	0	2	0	0	0
19	0	0	0	0	0	1	0	0	5	0	0	0
20	0	0	0	0	0	0	0	65	6	0	0	0
21	0	0	0	0	70	4	0	2	0	1	0	0
22	0	0	0	0	12	0	0	9	0	0	0	0
23	0	0	0	0	1	0	8	0	2	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
25	0	48	0	2	0	0	16	21	15	0	0	0
26	0	0	0	0	19	3	11	34	29	2	0	0
27	0	0	0	11	1	28	0	3	7	0	0	0
28	0	0	0	0	9	11	0	5	0	0	0	0
29	0		0	10	2	50	9	0	18	0	0	0
30	0		0	0	0	12	20	0	0	0	0	0
31	0		0		0		9	7		0		0
Max	**0**	**48**	**22**	**14**	**70**	**50**	**30**	**82**	**31**	**87**	**0**	**61**

[Source: Bangladesh Meteorological Department]

Graph 4.11: Monthly Maximum Rainfall for the year 2010



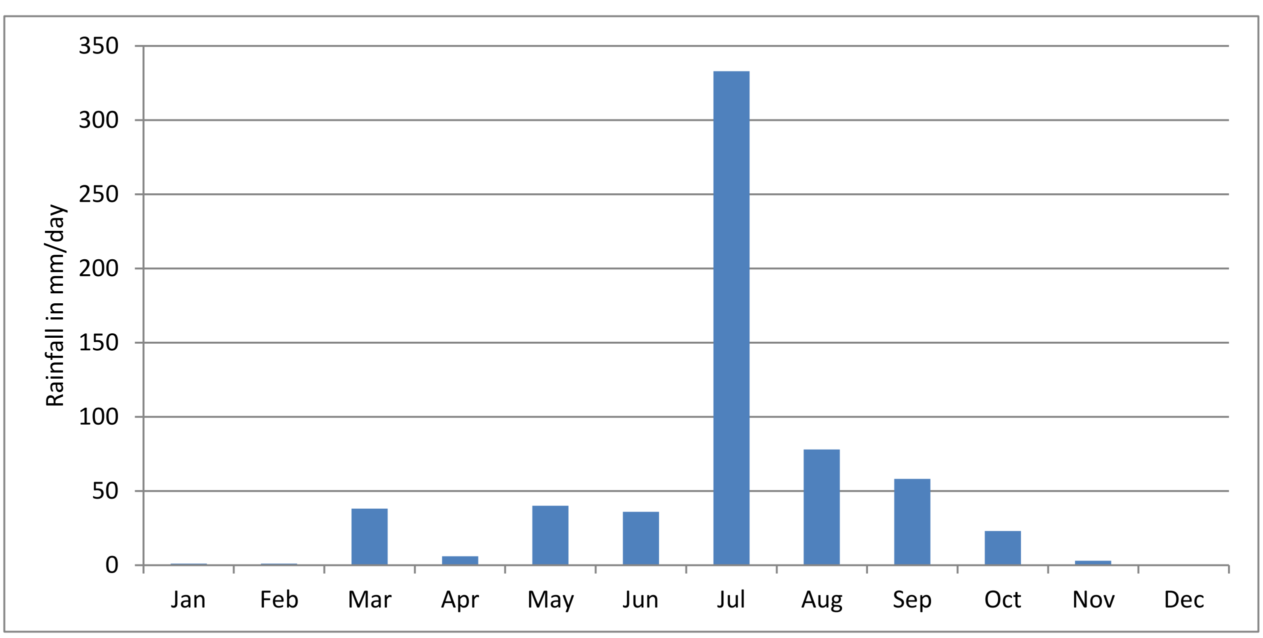
Graph 4.11: Monthly Maximum Rainfall for the year 2010

Rainfall Intensity of Dhaka City: Year 2009 (mm / day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	6	5	4	36	8	0	0	0	0
2	0	0	0	0	6	0	29	0	0	0	0	0
3	0	0	0	0	6	0	40	14	5	7	0	0
4	0	0	0	0	10	9	7	2	2	1	0	0
5	0	0	0	0	0	0	0	0	0	18	0	0
6	0	0	0	0	0	0	0	4	13	8	0	0
7	0	0	0	5	7	2	11	75	2	23	0	0
8	0	0	0	0	0	36	2	3	8	7	0	0
9	0	0	0	0	0	20	5	12	0	7	0	0
10	0	0	0	2	0	15	9	0	19	0	0	0
11	0	0	0	0	11	0	4	0	0	0	0	0
12	0	0	0	0	3	0	0	0	3	0	0	0
13	0	1	0	0	0	33	5	1	0	0	0	0
14	0	0	0	0	1	0	0	1	0	0	0	0
15	0	0	0	0	0	6	0	0	8	0	0	0
16	0	0	0	0	16	0	6	29	45	1	0	0
17	0	0	0	0	1	0	1	7	12	0	0	0
18	0	0	0	0	9	0	0	5	4	0	3	0
19	0	0	0	0	40	0	3	70	16	2	1	0
20	0	0	0	1	0	0	0	55	2	0	0	0
21	0	0	0	0	0	0	0	5	0	0	0	0
22	0	0	0	0	0	0	0	1	44	0	0	0
23	0	0	0	0	0	0	2	0	30	0	0	0
24	0	0	0	0	0	0	2	78	58	0	0	0
25	0	0	0	0	13	2	15	8	0	0	0	0
26	0	0	0	0	38	0	0	0	0	0	0	0
27	1	0	0	0	0	0	89	13	0	0	0	0
28	0	0	0	0	0	2	333	35	4	0	0	0
29	0		1	0	0	26	17	0	20	0	0	0
30	0		38	0	2	15	41	0	3	0	0	0
31	0		4		0		19	56		0		0
Max	**1**	**1**	**38**	**6**	**40**	**36**	**333**	**78**	**58**	**23**	**3**	**0**

[Source: Bangladesh Meteorological Department]

Table 4.10: Monthly Maximum Rainfall for the year 2009



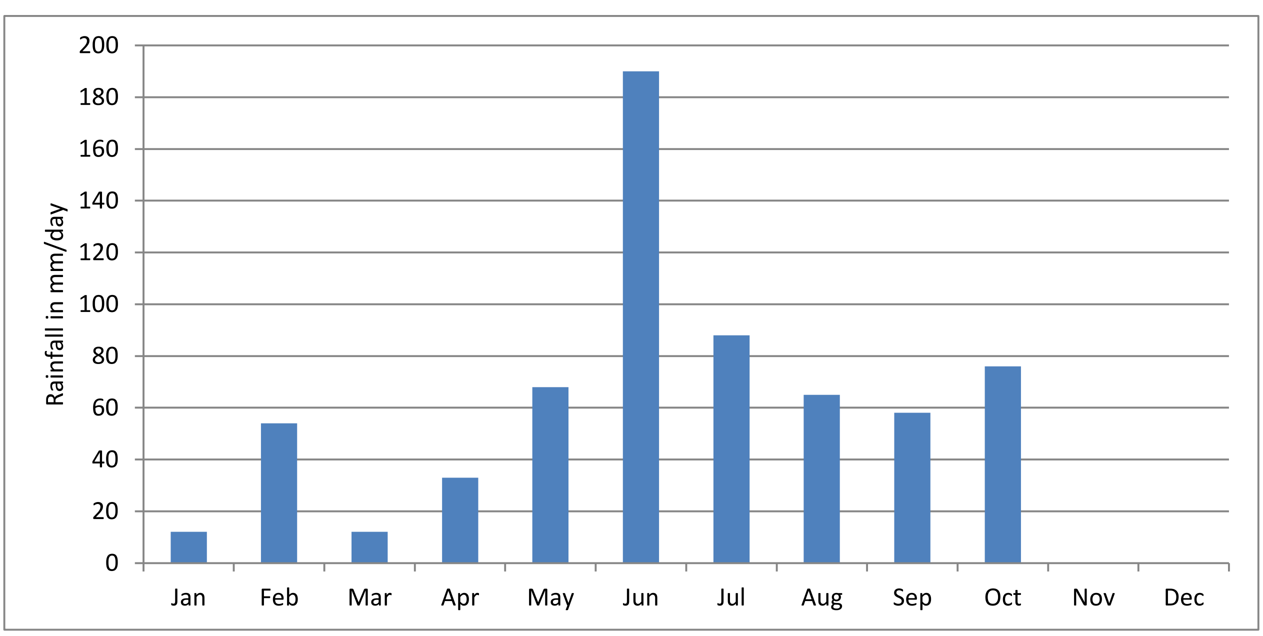
Graph 4.10: Monthly Maximum Rainfall for the year 2009

Rainfall Intensity of Dhaka City: Year 2008 (mm / day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	38	0	0	0	0	0
2	0	0	0	0	0	0	88	4	0	0	0	0
3	0	0	0	33	5	85	1	1	0	27	0	0
4	0	0	8	25	22	5	61	7	2	6	0	0
5	0	0	12	0	0	190	10	2	7	1	0	0
6	0	0	0	0	15	0	3	18	0	8	0	0
7	0	0	0	0	0	14	1	0	0	0	0	0
8	0	0	0	0	1	0	1	0	35	0	0	0
9	0	0	0	0	23	35	1	5	10	33	0	0
10	0	2	0	0	0	7	63	7	0	26	0	0
11	0	0	0	0	2	1	11	65	0	0	0	0
12	0	0	0	0	0	12	56	19	5	0	0	0
13	0	0	0	0	0	0	30	12	1	0	0	0
14	0	0	0	25	2	0	3	8	3	0	0	0
15	0	0	0	0	0	0	28	8	0	0	0	0
16	0	0	1	0	0	2	46	0	26	0	0	0
17	0	0	0	0	7	1	32	5	0	0	0	0
18	0	0	0	8	0	27	4	10	3	0	0	0
19	0	0	0	0	32	22	5	26	12	0	0	0
20	0	54	6	0	1	10	13	48	44	0	0	0
21	0	0	6	0	0	9	59	1	1	0	0	0
22	0	0	0	0	0	0	0	0	34	0	0	0
23	0	0	0	0	4	0	0	0	20	0	0	0
24	0	0	0	0	0	0	0	13	5	0	0	0
25	4	0	0	0	3	3	0	0	0	3	0	0
26	12	0	0	0	3	0	0	0	0	47	0	0
27	7	0	0	0	68	0	3	8	58	76	0	0
28	0	0	12	0	0	3	6	3	13	0	0	0
29	0	0	0	0	15	111	0	39	0	0	0	0
30	0		0	0	0	40	0	9	0	0	0	0
31	0		0		2		0	1		0		0
Max	**12**	**54**	**12**	**33**	**68**	**190**	**88**	**65**	**58**	**76**	**0**	**0**

[Source: Bangladesh Meteorological Department]

Table 4.9: Monthly Maximum Rainfall for the year 2008



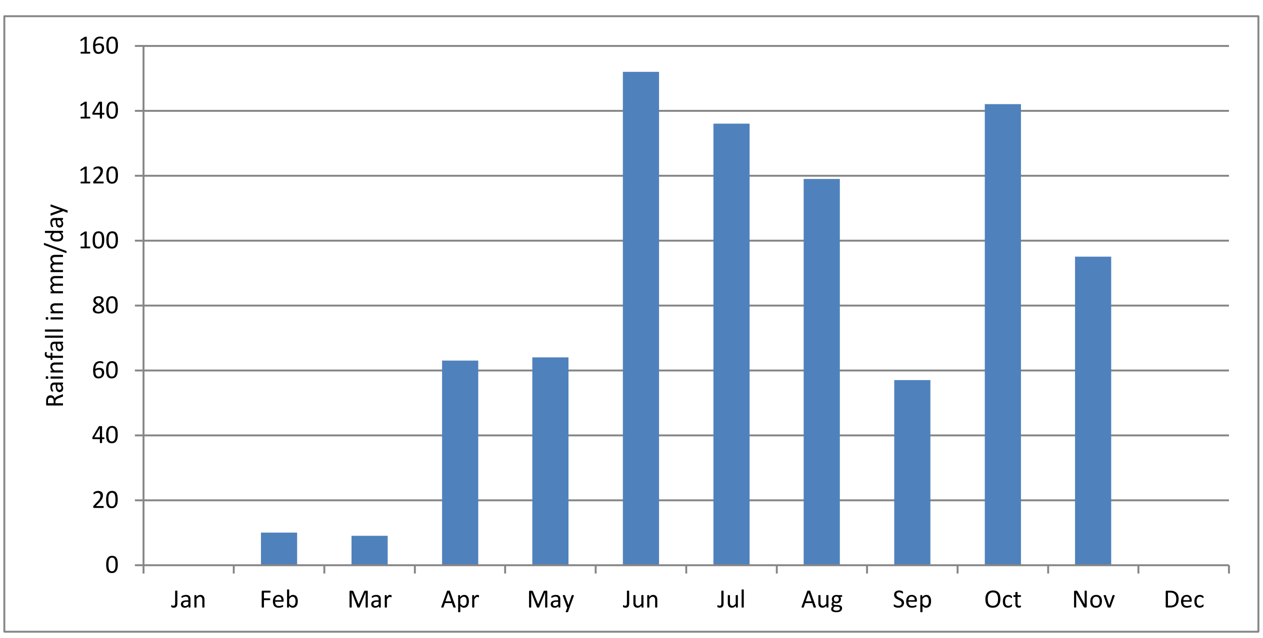
Graph 4.9: Monthly Maximum Rainfall for the year 2008

Rainfall Intensity of Dhaka City: Year 2007 (mm / day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	0	38	0	3	2	0
2	0	0	9	0	0	20	18	4	1	10	1	0
3	0	0	1	0	0	0	1	0	0	0	0	0
4	0	0	0	0	0	1	6	0	1	0	0	0
5	0	10	0	0	0	61	6	0	18	0	12	0
6	0	0	0	0	0	34	17	8	35	0	0	0
7	0	0	0	0	2	27	1	3	6	0	0	0
8	0	3	0	0	21	102	19	6	15	28	0	0
9	0	4	0	0	0	3	12	10	14	142	0	0
10	0	0	0	0	7	18	0	0	0	16	0	0
11	0	0	0	0	0	152	18	6	57	0	0	0
12	0	0	0	2	2	30	0	9	14	0	0	0
13	0	0	0	1	1	13	0	4	2	0	0	0
14	0	9	0	0	0	0	0	59	0	0	0	0
15	0	4	0	0	2	0	15	9	1	2	1	0
16	0	0	0	0	1	36	70	37	3	69	95	0
17	0	0	0	0	0	52	25	8	0	1	0	0
18	0	0	0	0	1	19	2	61	4	0	0	0
19	0	0	0	20	1	0	15	0	0	46	0	0
20	0	0	0	0	64	0	16	0	1	3	0	0
21	0	0	0	0	50	22	32	29	0	0	0	0
22	0	0	0	15	4	0	72	11	0	0	0	0
23	0	0	1	63	0	30	136	0	0	0	0	0
24	0	0	0	23	0	2	80	0	3	0	0	0
25	0	0	0	3	29	0	41	119	2	0	0	0
26	0	0	0	0	0	0	27	1	2	0	0	0
27	0	0	0	35	0	0	63	63	0	0	0	0
28	0	0	0	1	0	1	9	0	0	0	0	0
29	0		0	0	0	3	48	1	0	0	0	0
30	0		0	0	0	2	0	1	0	0	0	0
31	0		0		0		4	18		0		0
Max	**0**	**10**	**9**	**63**	**64**	**152**	**136**	**119**	**57**	**142**	**95**	**0**

[Source: Bangladesh Meteorological Department]

Table 4.8: Monthly Maximum Rainfall for the year 2007



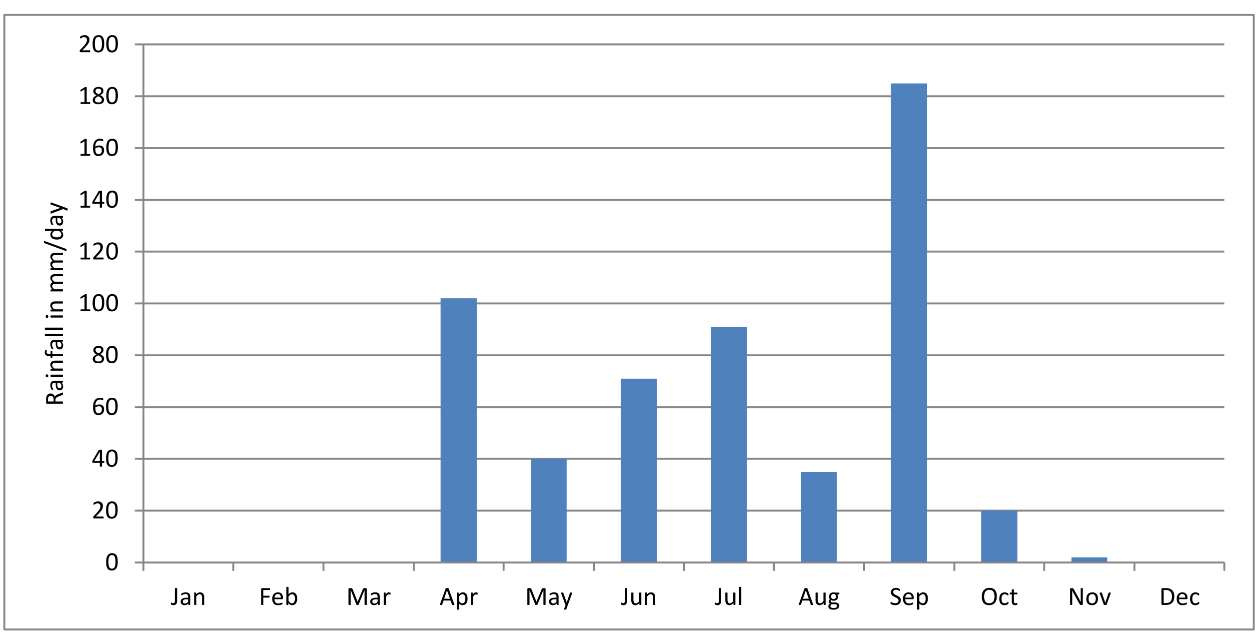
Graph 4.8: Monthly Maximum Rainfall for the year 2007

Rainfall Intensity of Dhaka City: Year 2006 (mm / day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	24	2	1	7	1	0	0
2	0	0	0	0	0	2	1	1	0	0	2	0
3	0	0	0	0	0	35	0	0	17	2	0	0
4	0	0	0	0	0	36	8	0	0	0	0	0
5	0	0	0	102	0	11	4	0	0	0	0	0
6	0	0	0	38	0	2	19	35	0	0	0	0
7	0	0	0	3	10	4	58	2	0	20	0	0
8	0	0	0	1	14	0	33	1	0	0	0	0
9	0	0	0	0	1	2	1	4	35	0	0	0
10	0	0	0	0	2	40	22	29	0	0	0	0
11	0	0	0	0	21	58	8	1	40	0	0	0
12	0	0	0	0	14	0	91	0	185	1	1	0
13	0	0	0	0	40	0	0	0	12	7	0	0
14	0	0	0	24	1	0	0	1	0	13	0	0
15	0	0	0	0	0	2	0	4	8	4	0	0
16	0	0	0	0	0	4	0	0	0	0	0	0
17	0	0	0	0	0	71	10	0	0	1	0	0
18	0	0	0	1	0	0	2	1	0	9	0	0
19	0	0	0	6	0	14	8	0	15	0	0	0
20	0	0	0	0	0	14	28	17	5	0	0	0
21	0	0	0	0	0	2	2	34	25	3	0	0
22	0	0	0	2	3	4	2	0	114	0	0	0
23	0	0	0	4	0	0	0	11	86	0	0	0
24	0	0	0	0	2	0	0	6	99	0	0	0
25	0	0	0	0	18	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	1	0	0	0	0
27	0	0	0	0	36	0	0	0	0	0	2	0
28	0	0	0	0	4	0	12	1	0	0	0	0
29	0		0	0	12	1	6	8	14	0	0	0
30	0		0	0	6	0	9	8	1	0	0	0
31	0		0		1		5	1		0		0
Max	**0**	**0**	**0**	**102**	**40**	**71**	**91**	**35**	**185**	**20**	**2**	**0**

[Source: Bangladesh Meteorological Department]

Table 4.7: Monthly Maximum Rainfall for the year 2006



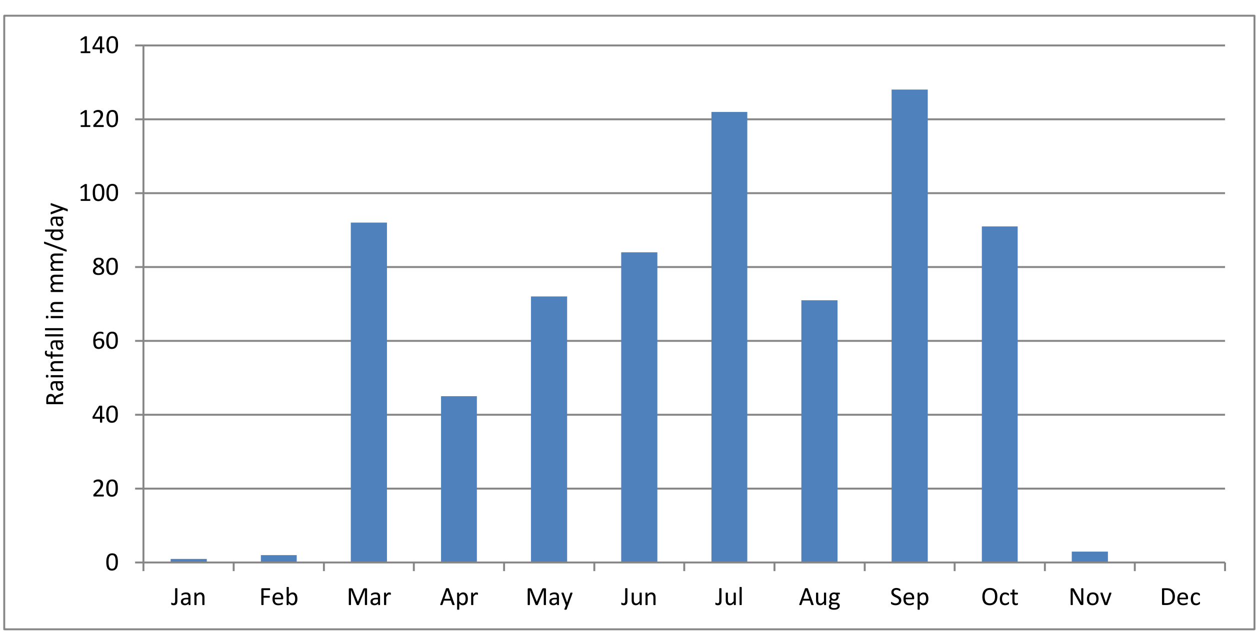
Graph 4.7: Monthly Maximum Rainfall for the year 2006

Rainfall Intensity of Dhaka City: Year 2005 (mm / day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	5	0	0	0	0	30	91	0	0
2	0	0	0	0	0	0	59	0	1	41	0	0
3	0	0	0	0	0	0	101	1	0	18	0	0
4	0	0	0	3	0	1	61	0	0	42	0	0
5	0	0	0	0	6	1	21	13	0	3	0	0
6	0	0	0	0	16	84	18	22	12	6	0	0
7	0	0	0	0	0	0	0	1	0	0	0	0
8	0	0	0	0	0	10	0	4	67	0	0	0
9	0	0	0	0	0	0	0	26	18	4	0	0
10	0	0	0	0	10	0	5	71	11	0	3	0
11	0	0	0	0	0	6	5	22	14	0	0	0
12	0	0	0	0	0	0	16	25	1	0	0	0
13	0	0	0	0	8	0	1	68	0	0	0	0
14	0	0	0	0	38	11	122	1	20	0	0	0
15	0	0	0	0	0	52	33	1	0	0	0	0
16	0	0	0	0	0	2	25	7	0	0	0	0
17	0	0	0	0	10	21	0	19	0	4	0	0
18	0	0	0	0	63	1	0	8	0	31	0	0
19	1	0	0	0	0	0	0	6	0	16	0	0
20	0	2	2	0	38	0	11	2	128	10	0	0
21	0	0	0	1	0	0	28	10	64	36	0	0
22	0	1	0	0	28	1	4	6	1	16	0	0
23	0	0	4	0	72	25	5	12	8	28	0	0
24	0	0	46	0	0	12	2	6	7	71	0	0
25	0	0	11	6	2	5	11	30	61	0	0	0
26	0	0	0	23	0	0	2	0	2	0	0	0
27	0	0	0	45	0	3	0	0	4	0	0	0
28	0	0	0	1	0	10	0	0	35	0	0	0
29	0		0	0	0	14	0	0	30	0	0	0
30	0		0	7	0	0	5	0	0	0	0	0
31	0		92		0		7	0		0		0
Max	**1**	**2**	**92**	**45**	**72**	**84**	**122**	**71**	**128**	**91**	**3**	**0**

[Source: Bangladesh Meteorological Department]

Table 4.6: Monthly Maximum Rainfall for the year 2005



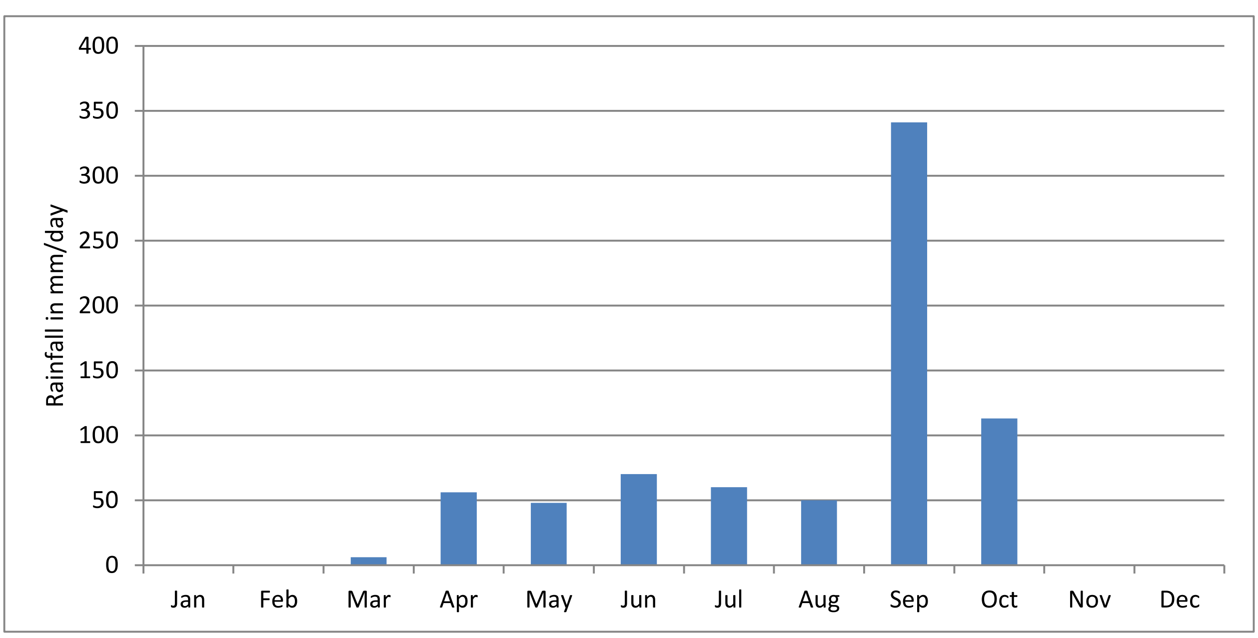
Graph 4.6: Monthly Maximum Rainfall for the year 2005

Rainfall Intensity of Dhaka City: Year 2004 (mm / day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	0	3	6	0	0	0
2	0	0	0	2	0	0	2	0	0	1	0	0
3	0	0	0	0	0	15	13	2	7	1	0	0
4	0	0	0	0	0	13	9	5	11	7	0	0
5	0	0	0	23	0	0	14	22	22	5	0	0
6	0	0	0	0	0	0	10	9	1	8	0	0
7	0	0	0	35	0	29	12	6	0	53	0	0
8	0	0	1	0	0	0	18	0	0	113	0	0
9	0	0	0	0	0	0	6	13	3	0	0	0
10	0	0	2	5	0	0	6	4	9	0	0	0
11	0	0	6	14	0	1	0	1	32	0	0	0
12	0	0	0	0	0	29	18	9	29	0	0	0
13	0	0	0	0	0	6	12	15	156	0	0	0
14	0	0	0	0	13	39	0	8	341	20	0	0
15	0	0	0	0	0	1	6	1	23	0	0	0
16	0	0	0	0	0	0	32	0	51	0	0	0
17	0	0	0	0	0	67	5	0	20	0	0	0
18	0	0	0	0	0	0	1	0	0	0	0	0
19	0	0	0	28	0	49	13	0	20	0	0	0
20	0	0	0	0	0	21	60	9	0	0	0	0
21	0	0	0	0	39	4	2	0	0	0	0	0
22	0	0	0	0	16	39	8	1	31	0	0	0
23	0	0	0	0	48	21	0	0	12	0	0	0
24	0	0	0	56	7	70	2	1	0	0	0	0
25	0	0	0	0	1	13	16	0	0	0	0	0
26	0	0	0	0	0	25	6	31	21	0	0	0
27	0	0	0	3	0	25	1	0	2	0	0	0
28	0	0	0	1	8	7	2	50	3	0	0	0
29	0	0	0	0	0	1	2	0	13	0	0	0
30	0		0	0	0	1	16	0	26	0	0	0
31	0		0		30		3	1		0		0
Max	**0**	**0**	**6**	**56**	**48**	**70**	**60**	**50**	**341**	**113**	**0**	**0**

[Source: Bangladesh Meteorological Department]

Table 4.5: Monthly Maximum Rainfall for the year 2004



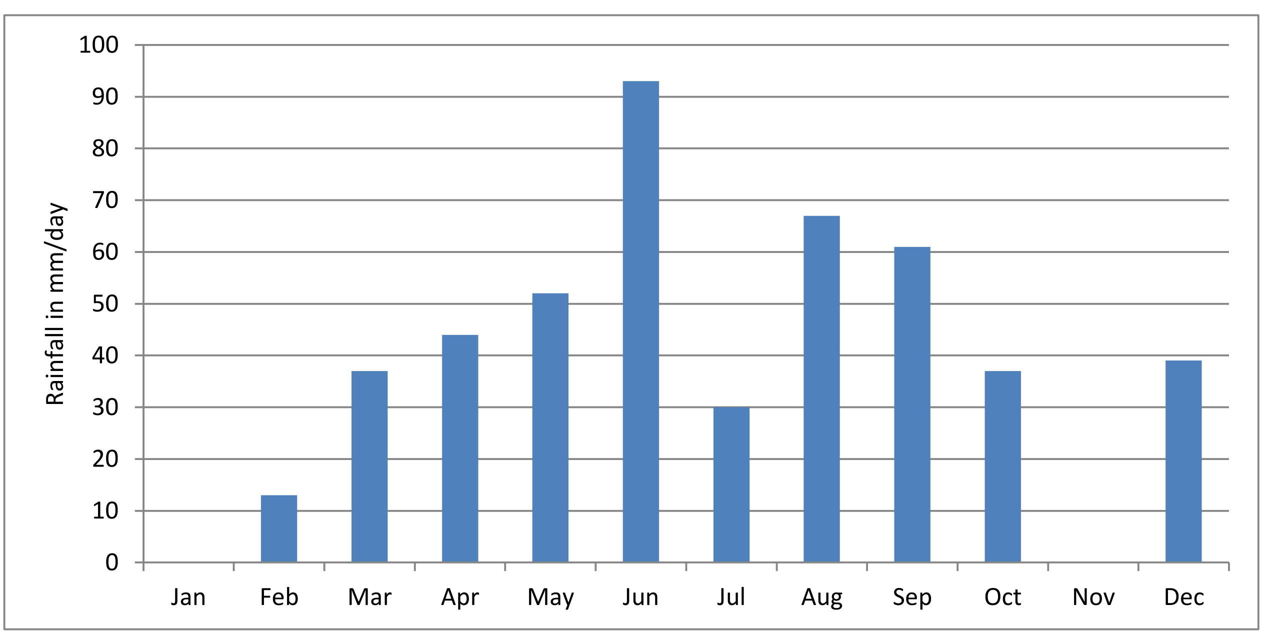
Graph 4.5: Monthly Maximum Rainfall for the year 2004

Rainfall Intensity of Dhaka City: Year 2003 (mm / day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	11	0	0	22	2	3	0	0	0
2	0	0	0	0	0	0	0	5	19	0	0	0
3	0	0	0	0	52	0	0	0	7	15	0	0
4	0	0	0	0	0	0	5	0	5	1	0	0
5	0	0	0	1	0	6	12	0	0	0	0	0
6	0	0	0	0	0	93	3	0	0	0	0	0
7	0	0	0	0	18	0	8	0	8	16	0	0
8	0	0	0	0	0	45	3	0	4	16	0	0
9	0	0	0	0	17	0	14	0	0	37	0	0
10	0	0	0	0	2	8	0	4	2	15	0	0
11	0	0	0	0	0	0	3	22	2	4	0	0
12	0	7	0	0	0	10	15	23	11	0	0	0
13	0	13	9	0	2	0	7	67	29	0	0	0
14	0	4	0	0	0	0	0	8	15	0	0	0
15	0	0	13	44	0	66	2	3	0	0	0	0
16	0	0	1	0	1	0	1	0	8	0	0	0
17	0	0	37	0	0	0	2	0	1	0	0	1
18	0	0	1	0	0	3	0	0	3	0	0	1
19	0	0	0	0	0	0	0	18	2	4	0	39
20	0	1	7	0	0	2	0	4	4	0	0	0
21	0	0	0	13	25	13	0	0	4	0	0	0
22	0	0	1	6	0	86	0	9	11	0	0	0
23	0	0	0	16	1	11	0	7	6	0	0	0
24	0	0	0	0	0	14	5	6	1	0	0	0
25	0	0	0	0	14	0	8	1	3	0	0	0
26	0	0	0	0	0	0	30	0	50	1	0	0
27	0	0	12	0	0	1	0	0	61	11	0	0
28	0	0	0	0	8	61	4	0	0	14	0	0
29	0		0	5	0	17	23	7	0	0	0	4
30	0		0	27	0	37	20	13	5	0	0	0
31	0		15		0		4	3		0		0
Max	**0**	**13**	**37**	**44**	**52**	**93**	**30**	**67**	**61**	**37**	**0**	**39**

[Source: Bangladesh Meteorological Department]

Table 4.4: Monthly Maximum Rainfall for the year 2003



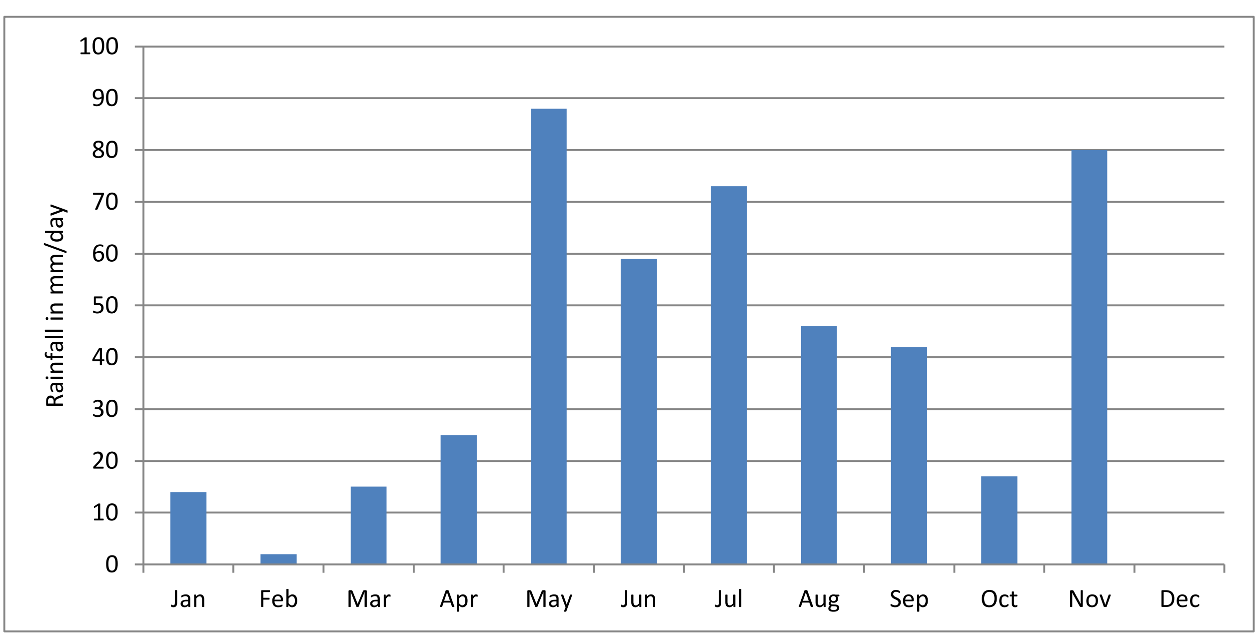
Graph 4.4: Monthly Maximum Rainfall for the year 2003

Rainfall Intensity of Dhaka City: Year 2002 (mm / day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	8	0	26	0	0	3	0	0
2	0	0	0	0	0	31	62	18	0	0	0	0
3	0	0	1	23	2	47	0	20	0	0	0	0
4	0	0	1	10	4	0	42	4	16	0	0	0
5	0	0	0	0	0	30	73	2	0	0	0	0
6	0	0	0	15	18	0	4	0	0	0	0	0
7	0	0	0	0	62	0	7	2	42	0	0	0
8	0	0	0	0	1	12	12	1	0	0	0	0
9	0	0	0	17	1	0	0	1	1	1	0	0
10	0	0	0	0	3	5	0	3	1	4	0	0
11	0	0	0	0	16	21	15	46	2	1	0	0
12	0	0	0	0	18	1	0	14	0	6	18	0
13	0	0	0	0	0	33	0	2	0	0	18	0
14	0	0	0	0	0	59	14	43	0	0	80	0
15	0	0	0	0	1	33	0	3	0	7	0	0
16	0	0	0	0	0	0	9	16	9	0	0	0
17	0	0	0	0	0	5	5	4	0	0	0	0
18	0	0	0	0	7	8	6	17	0	0	0	0
19	0	0	0	0	0	0	18	5	0	17	0	0
20	0	0	0	0	0	0	9	2	0	13	0	0
21	0	0	0	0	0	1	12	0	0	0	0	0
22	0	0	0	2	3	18	71	13	11	0	0	0
23	14	2	0	0	18	41	1	2	1	0	0	0
24	2	0	5	0	0	7	0	1	2	0	0	0
25	0	0	9	0	0	1	21	0	7	0	0	0
26	0	2	15	0	6	3	0	1	26	0	0	0
27	0	0	8	19	88	7	0	9	2	0	0	0
28	0	0	12	0	10	0	1	6	35	0	0	0
29	5		0	0	1	10	37	37	0	0	0	0
30	1		0	25	5	0	0	0	1	0	0	0
31	0		0		0		1	0		0		0
Max	**14**	**2**	**15**	**25**	**88**	**59**	**73**	**46**	**42**	**17**	**80**	**0**

[Source: Bangladesh Meteorological Department]

Table 4.3: Monthly Maximum Rainfall for the year 2002



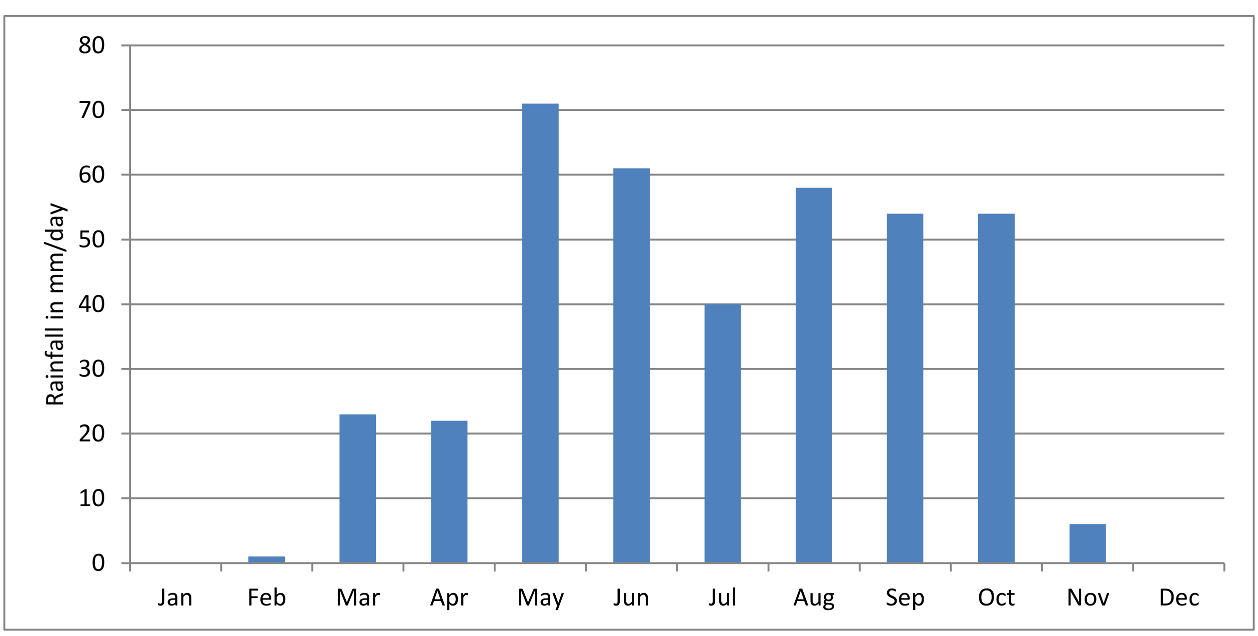
Graph 4.1: Monthly Maximum Rainfall for the year 2002

Rainfall Intensity of Dhaka City: Year 2001 (mm / day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	1	0	18	17	40	45	13	7	0	0
2	0	0	0	10	0	0	0	0	6	3	0	0
3	0	0	0	6	48	5	1	13	0	14	0	0
4	0	0	0	0	10	20	0	0	0	13	0	0
5	0	0	0	0	6	16	0	12	0	10	0	0
6	0	0	0	0	4	61	0	9	0	6	0	0
7	0	0	0	0	0	10	0	0	15	0	3	0
8	0	0	0	0	71	23	1	5	0	0	1	0
9	0	0	0	0	52	0	0	58	19	11	0	0
10	0	0	0	0	8	7	1	0	10	6	0	0
11	0	0	0	0	32	0	3	4	2	0	1	0
12	0	0	0	0	0	18	8	5	11	0	6	0
13	0	0	0	0	0	4	11	1	1	0	3	0
14	0	0	0	0	0	6	15	5	23	8	0	0
15	0	0	0	0	0	49	0	0	0	10	0	0
16	0	0	0	4	0	6	0	5	0	1	0	0
17	0	0	0	0	0	59	0	2	2	1	0	0
18	0	0	7	22	0	6	2	6	54	21	0	0
19	0	0	0	0	0	16	0	0	7	54	1	0
20	0	0	0	0	6	29	0	10	0	0	3	0
21	0	0	0	0	40	11	21	1	0	0	0	0
22	0	1	0	0	0	1	4	0	0	0	0	0
23	0	0	1	0	27	0	12	4	0	0	0	0
24	0	0	0	0	7	0	1	1	19	0	0	0
25	0	0	0	0	0	0	12	3	25	0	0	0
26	0	0	0	0	0	0	26	10	0	0	0	0
27	0	0	0	0	23	3	5	1	0	0	0	0
28	0	0	0	0	0	9	4	1	0	1	0	0
29	0		23	4	0	1	10	0	0	0	0	0
30	0		0	0	49	9	23	4	2	0	0	0
31	0		1		1		2	0		11		0
Max	**0**	**1**	**23**	**22**	**71**	**61**	**40**	**58**	**54**	**54**	**6**	**0**

[Source: Bangladesh Meteorological Department]

Table 4.2: Monthly Maximum Rainfall for the year 2001



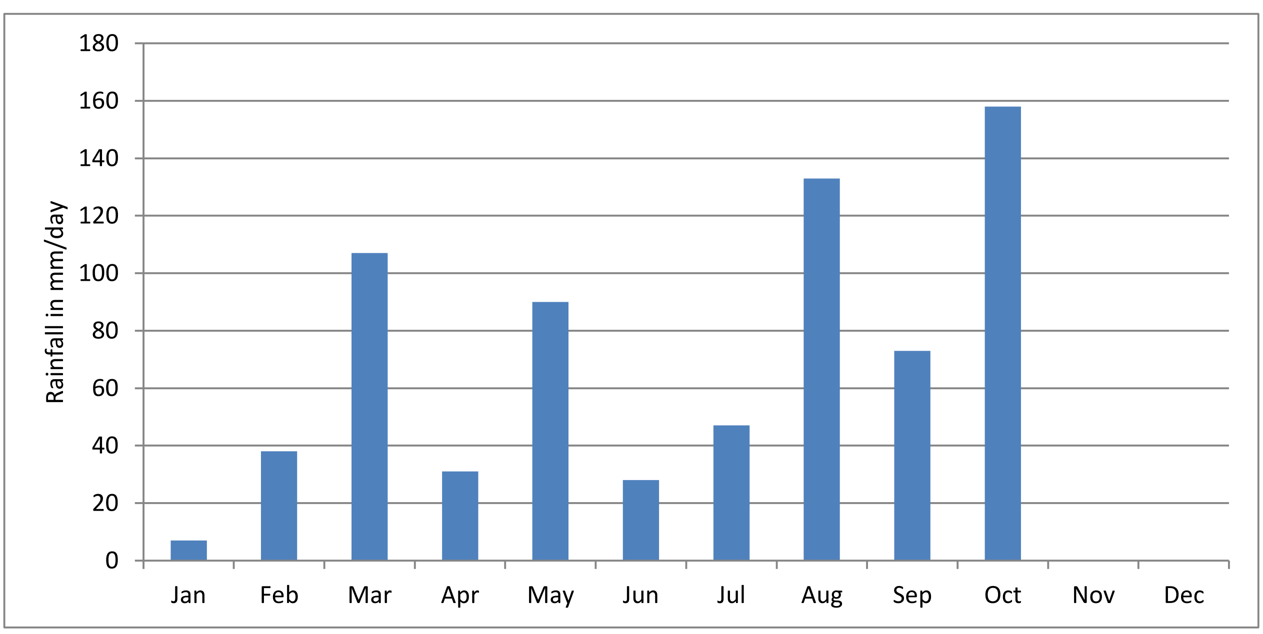
Graph 4.2: Monthly Maximum Rainfall for the year 2001

Rainfall Intensity of Dhaka City: Year 2000 (mm / day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	1	0	4	73	5	0	0
2	0	0	0	0	58	0	0	133	0	9	0	0
3	0	0	0	0	1	0	0	126	1	0	0	0
4	0	0	0	0	0	0	0	3	0	0	0	0
5	0	1	2	0	0	0	0	10	0	2	0	0
6	0	38	0	0	11	1	0	2	1	0	0	0
7	0	5	0	0	0	12	1	0	0	0	0	0
8	0	0	0	0	0	0	27	0	4	15	0	0
9	0	0	0	0	0	17	6	0	5	0	0	0
10	0	0	0	0	0	4	25	1	12	18	0	0
11	0	0	0	0	0	23	0	0	12	5	0	0
12	0	0	0	1	0	8	0	5	0	0	0	0
13	0	0	54	0	0	0	7	4	0	0	0	0
14	0	0	107	0	0	0	6	23	0	0	0	0
15	0	0	9	31	0	0	7	24	5	0	0	0
16	1	0	0	14	0	1	3	0	18	0	0	0
17	0	0	0	0	0	28	0	3	0	0	0	0
18	0	0	0	3	7	2	1	0	3	0	0	0
19	0	0	0	0	0	4	18	1	16	0	0	0
20	0	0	0	0	65	11	10	0	30	0	0	0
21	0	0	0	29	15	4	11	5	24	5	0	0
22	2	0	0	2	22	7	47	0	0	0	0	0
23	0	0	0	7	49	7	6	0	0	0	0	0
24	7	0	0	0	1	4	11	0	12	0	0	0
25	0	0	0	28	6	20	3	0	0	0	0	0
26	0	0	0	20	43	0	0	5	0	0	0	0
27	0	0	0	31	52	0	8	0	0	5	0	0
28	0	0	0	0	90	0	0	5	0	55	0	0
29	1	0	0	14	23	0	0	0	0	158	0	0
30	2		0	9	0	11	0	2	0	1	0	0
31	0		0		48		0	3		0		0
Max	**7**	**38**	**107**	**31**	**90**	**28**	**47**	**133**	**73**	**158**	**0**	**0**

[Source: Bangladesh Meteorological Department]

Table 4.1: Monthly Maximum Rainfall for the year 2000



Graph 4.1: Monthly Maximum Rainfall for the year 2000

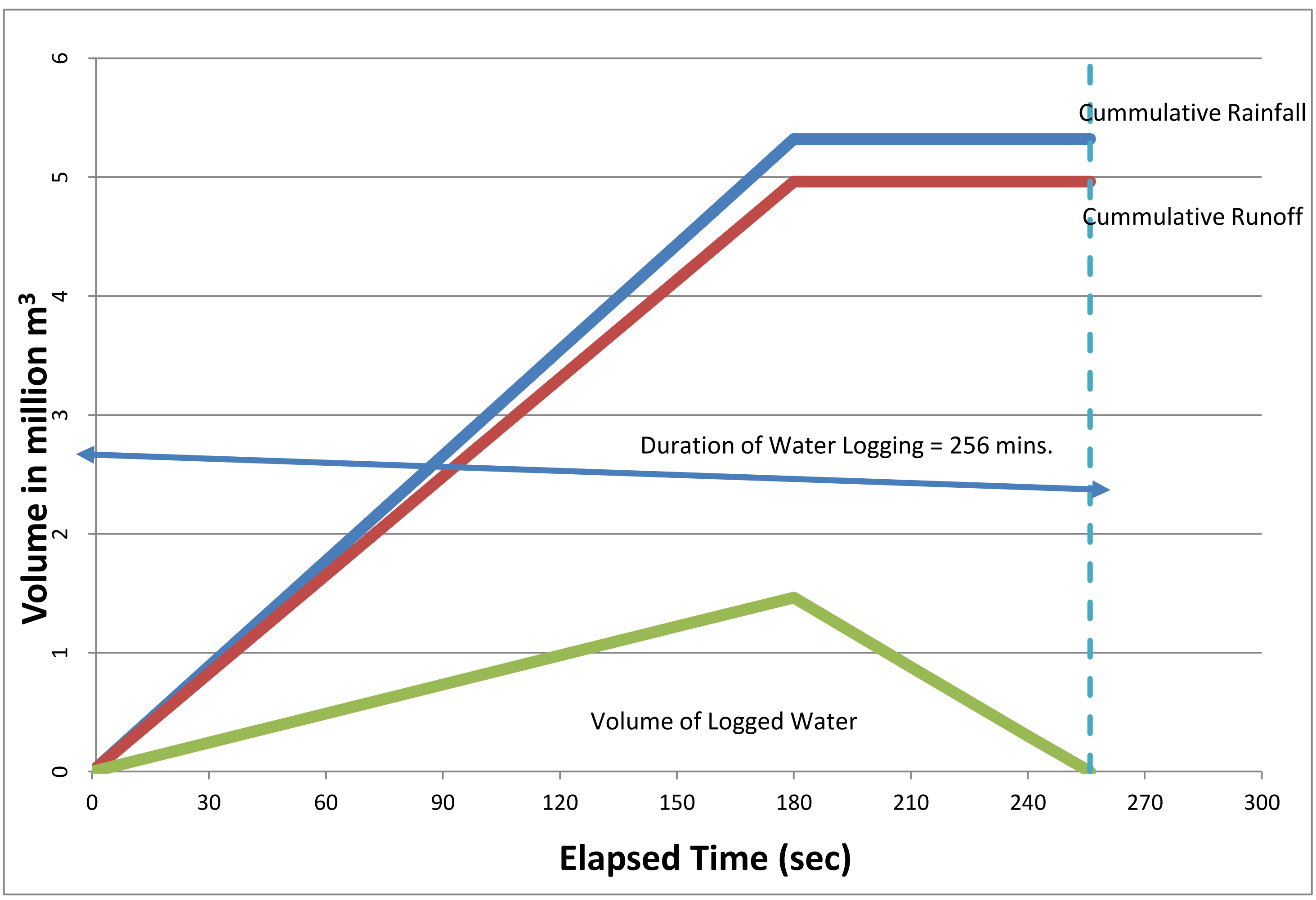
ANNEXURE III

SIMULATION CHARTS

Water Log Pattern with Existing Drainage Network System

(Assuming Uniform Distribution of Daily Rainfall)

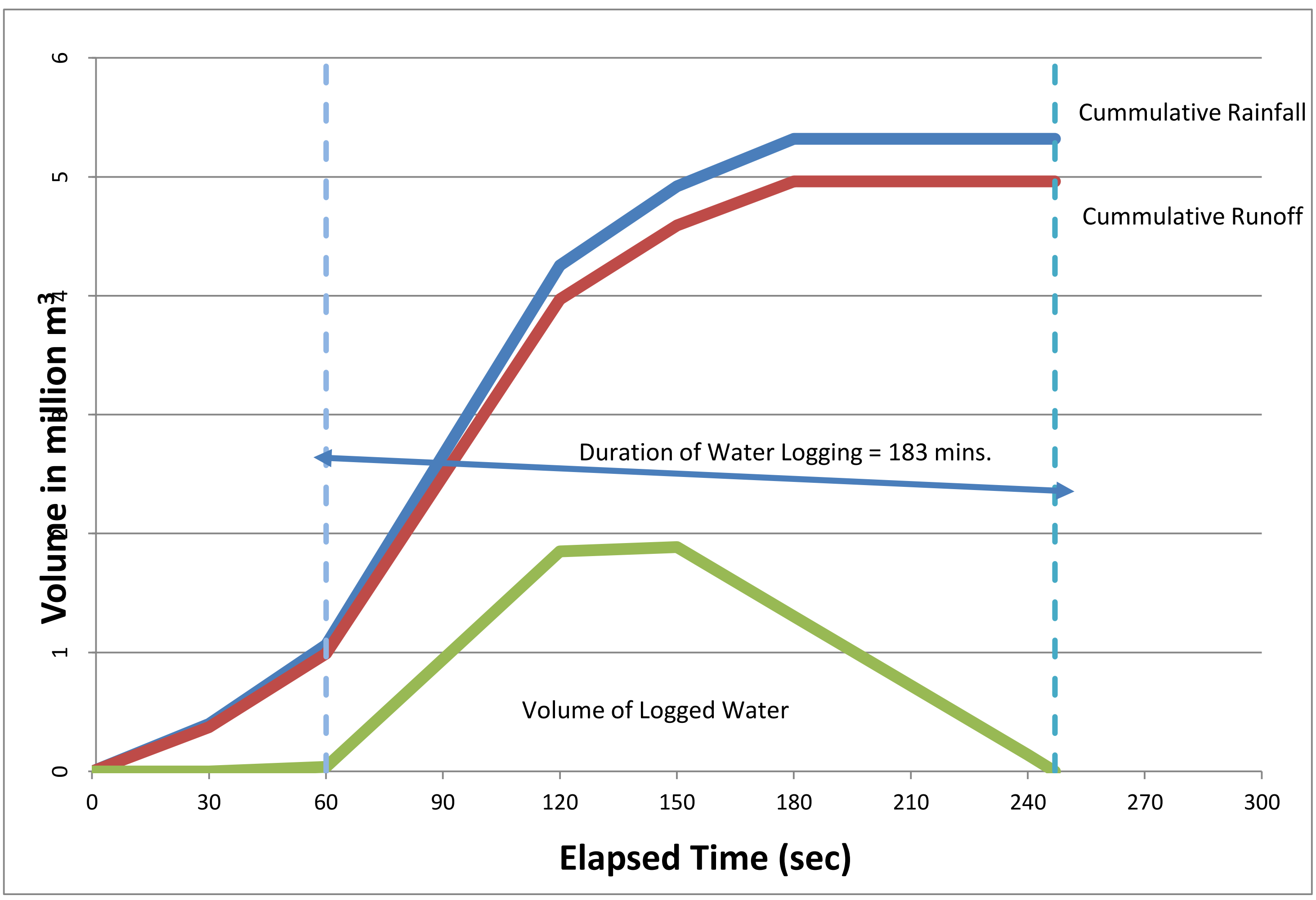
Time (min)	Rainfall (cum)		Percolation (cum)		Retention (cum)		Runoff (cum)		Drainage (cum)	Water Log (cum)	
	Actual	Cumm.	Actual	Cumm.	Actual	Cumm.	Actual	Cumm.		Actual	Cumm.
0	0	0	0	0	0	0	0	0	0	0	0
30	886600	886600	58693	58693	873	873	827034	827034	582930	244104	244104
60	886600	1773200	58693	117386	873	1746	827034	1654068	582930	244104	488208
90	886600	2659800	58693	176079	873	2619	827034	2481103	582930	244104	732313
120	886600	3546400	58693	234772	873	3491	827034	3308137	582930	244104	976417
150	886600	4433000	58693	293465	873	4364	827034	4135171	582930	244104	1220521
180	886600	5319600	58693	352158	873	5237	827034	4962205	582930	244104	1464625
210	0	5319600	0	352158	0	5237	0	4962205	582930	-582930	881695
240	0	5319600	0	352158	0	5237	0	4962205	582930	-582930	298765
256	0	5319600	0	352158	0	5237	0	4962205	298765	-298765	0



Water Log Pattern with Existing Drainage Network System

(Assuming Spatial Distribution of Daily Rainfall)

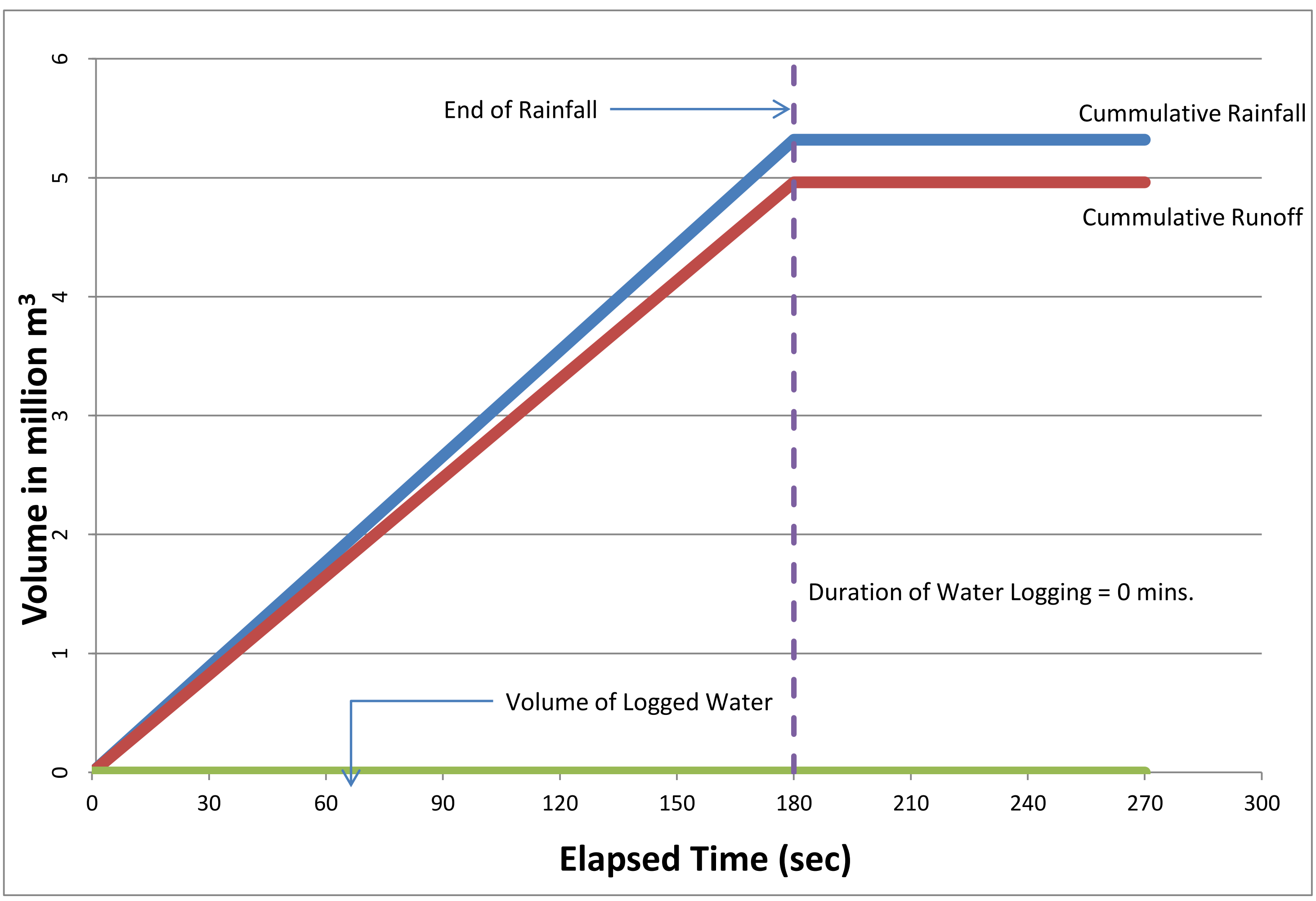
Time (min)	Rainfall (cum)		Percolation (cum)		Retention (cum)		Runoff (cum)		Drainage (cum)	Water Log (cum)	
	Actual	Cumm.	Actual	Cumm.	Actual	Cumm.	Actual	Cumm.		Actual	Cumm.
0	0	0	0	0	0	0	0	0	0	0	0
30	398970	398970	26412	26412	873	873	371685	371685	582930	0	0
60	664950	1063920	44020	70432	873	1746	620057	991743	582930	37127	37127
90	1595880	2659800	105647	176079	873	2619	1489360	2481103	582930	906430	943557
120	1595880	4255680	105647	281726	873	3491	1489360	3970463	582930	906430	1849987
150	664950	4920630	44020	325746	873	4364	620057	4590520	582930	37127	1887115
180	398970	5319600	26412	352158	873	5237	371685	4962205	582930	0	1304185
210	0	5319600	0	352158	0	5237	0	4962205	582930	0	721255
240	0	5319600	0	352158	0	5237	0	4962205	582930	0	138325
247	0	5319600	0	352158	0	5237	0	4962205	138325	0	0



Water Log Pattern with Proposed Drainage Network System

(Assuming Uniform Distribution of Daily Rainfall)

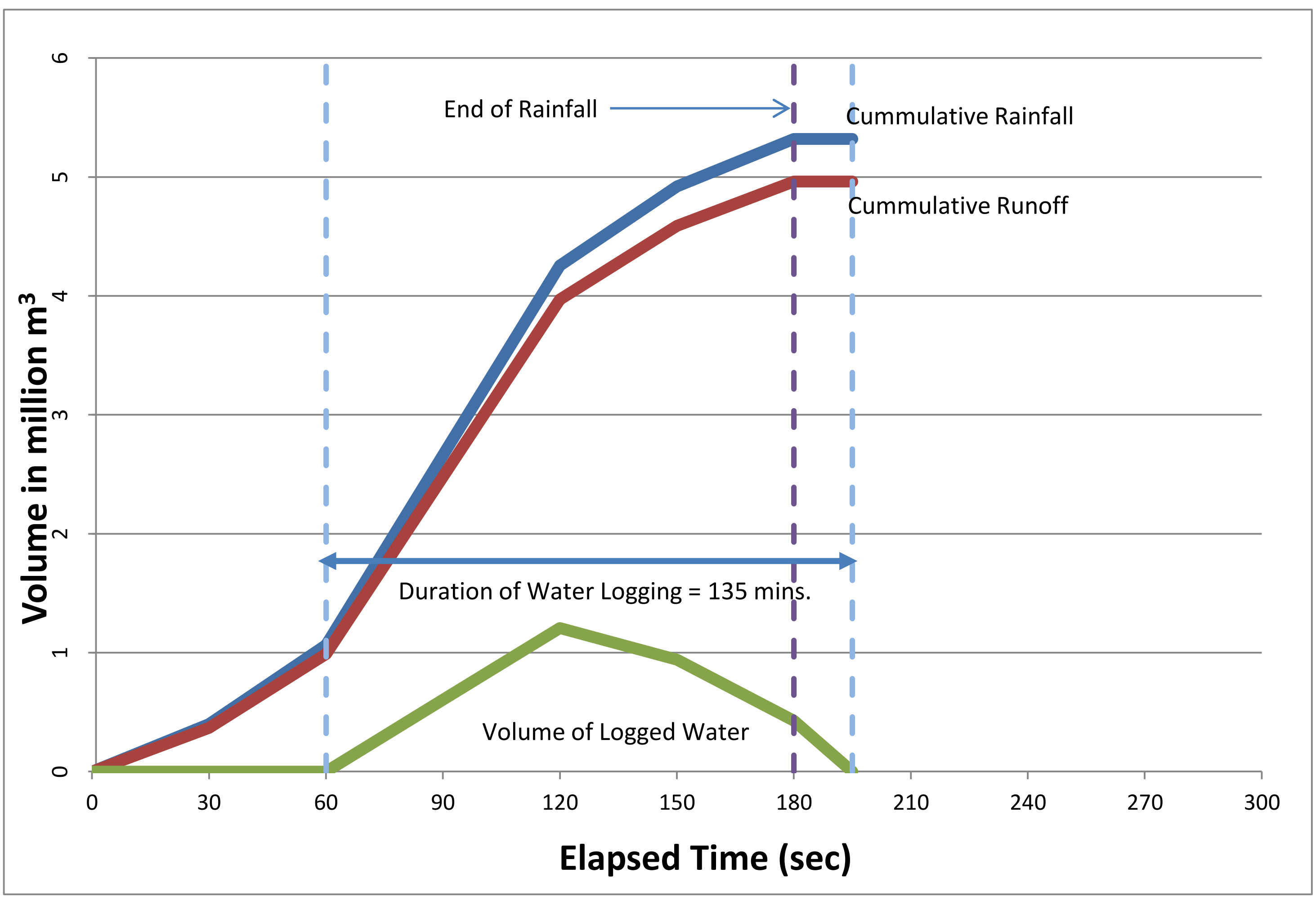
Time (min)	Rainfall (cum)		Percolation (cum)		Retention (cum)		Runoff (cum)		Drainage (cum)	Water Log (cum)	
	Actual	Cumm.	Actual	Cumm.	Actual	Cumm.	Actual	Cumm.		Actual	Cumm.
0	0	0	0	0	0	0	0	0	0	0	0
30	886600	886600	58693	58693	5237	5237	822670	822670	886950	0	0
60	886600	1773200	58693	117386	0	5237	827907	1650577	886950	0	0
90	886600	2659800	58693	176079	0	5237	827907	2478484	886950	0	0
120	886600	3546400	58693	234772	0	5237	827907	3306391	886950	0	0
150	886600	4433000	58693	293465	0	5237	827907	4134298	886950	0	0
180	886600	5319600	58693	352158	0	5237	827907	4962205	886950	0	0
210	0	5319600	0	352158	0	5237	0	4962205	886950	0	0
240	0	5319600	0	352158	0	5237	0	4962205	886950	0	0
270	0	5319600	0	352158	0	5237	0	4962205	886950	0	0

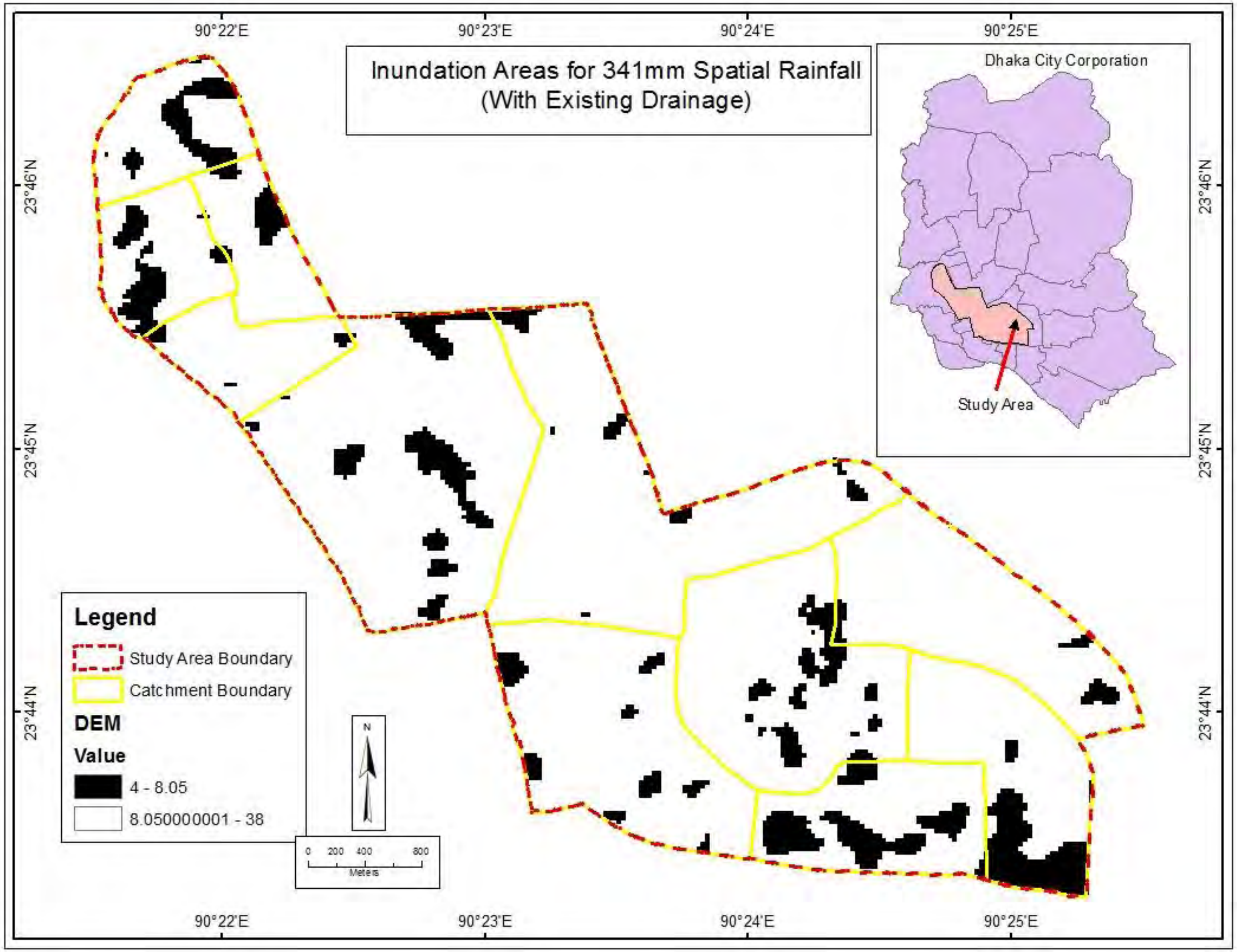


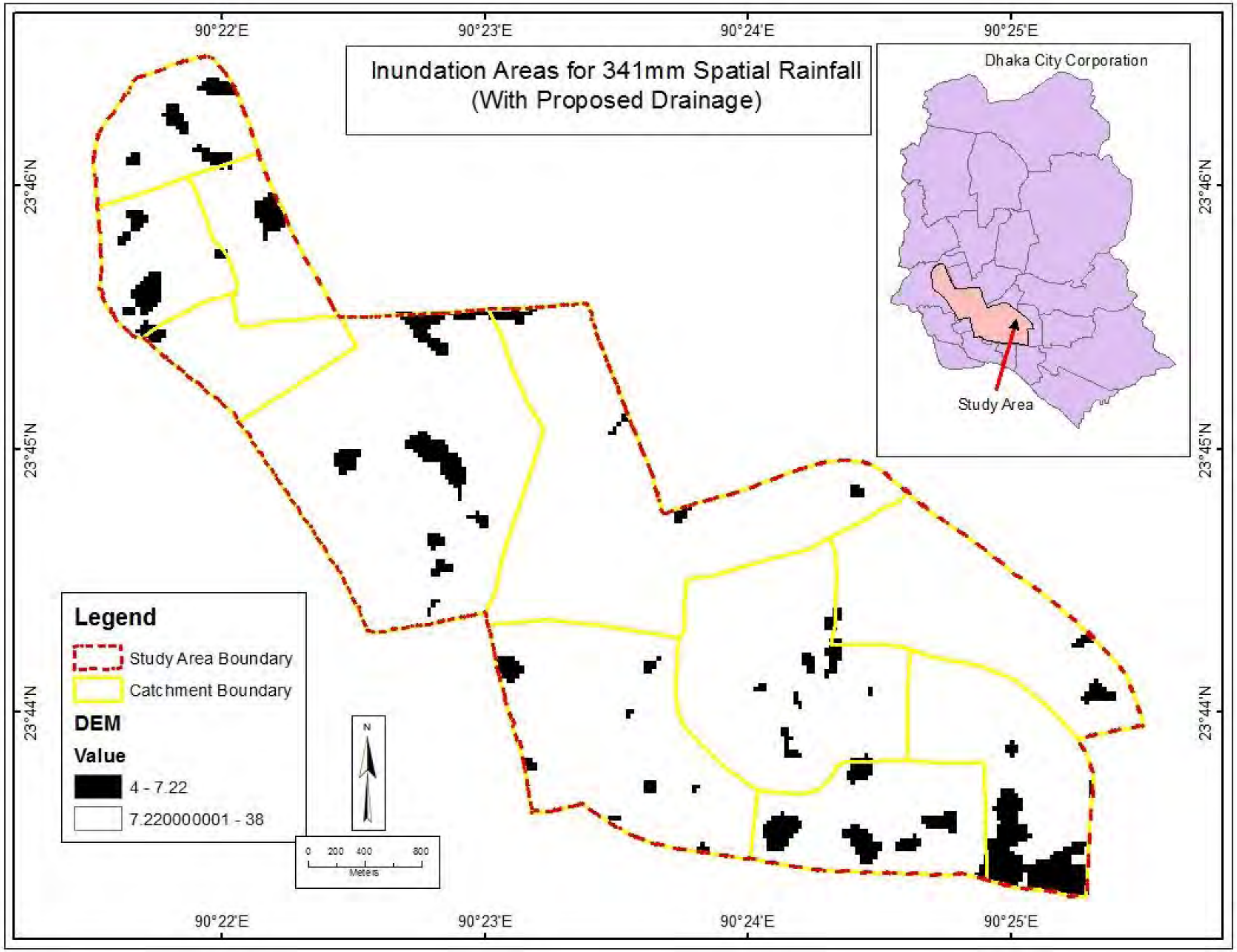
Water Log Pattern with Proposed Drainage Network System

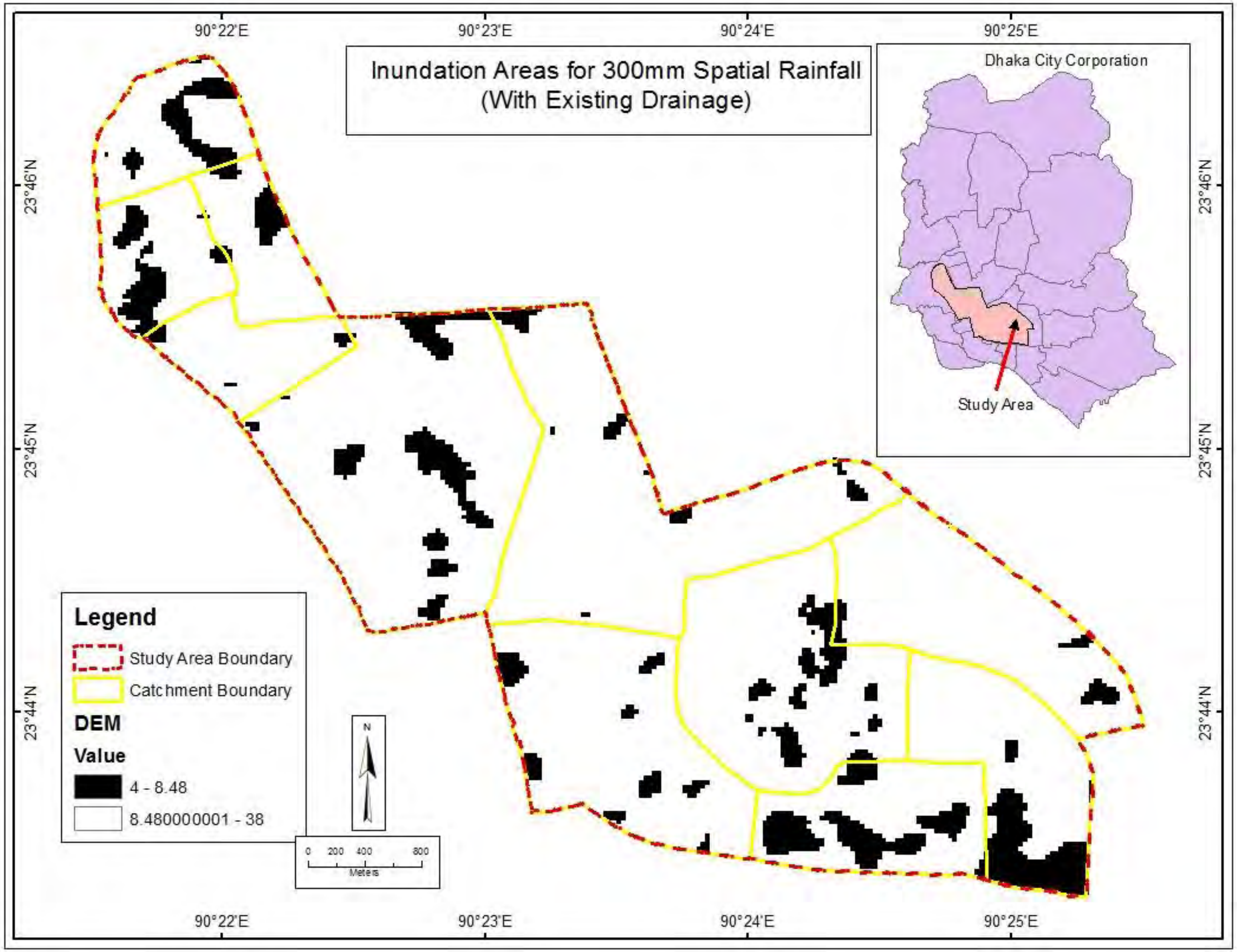
(Assuming Spatial Distribution of Daily Rainfall)

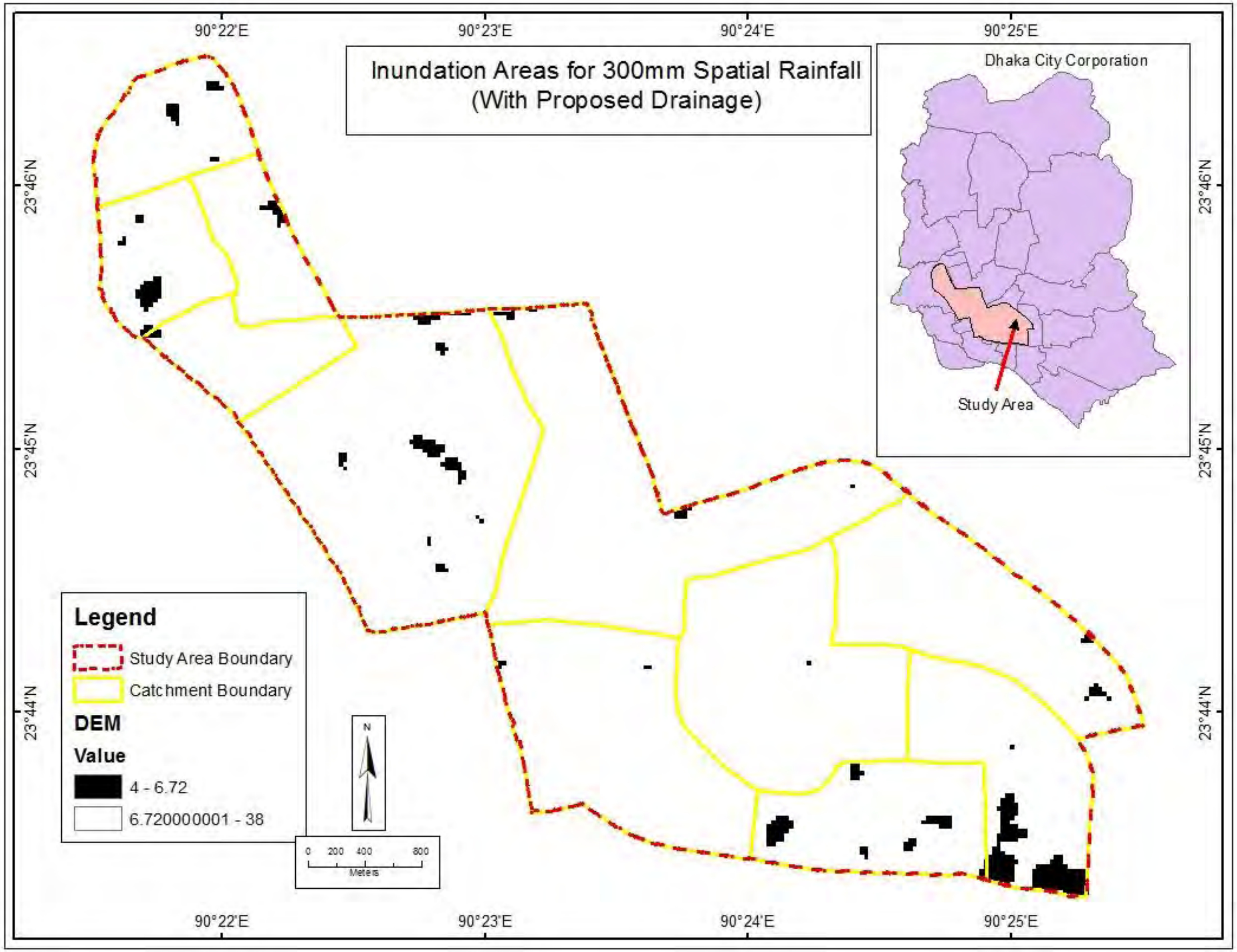
Time (min)	Rainfall (cum)		Percolation (cum)		Retention (cum)		Runoff (cum)		Drainage (cum)	Water Log (cum)	
	Actual	Cumm.	Actual	Cumm.	Actual	Cumm.	Actual	Cumm.		Actual	Cumm.
0	0	0	0	0	0	0	0	0	0	0	0
30	398970	398970	26412	26412	5237	5237	367321	367321	886950	0	0
60	664950	1063920	44020	70432	0	5237	620930	988251	886950	0	0
90	1595880	2659800	105647	176079	0	5237	1490233	2478484	886950	603283	603283
120	1595880	4255680	105647	281726	0	5237	1490233	3968717	886950	603283	1206565
150	664950	4920630	44020	325746	0	5237	620930	4589647	886950	-266020	940546
180	398970	5319600	26412	352158	0	5237	372558	4962205	886950	-514392	426154
195	0	5319600	0	352158	0	5237	0	4962205	443475	-443475	0

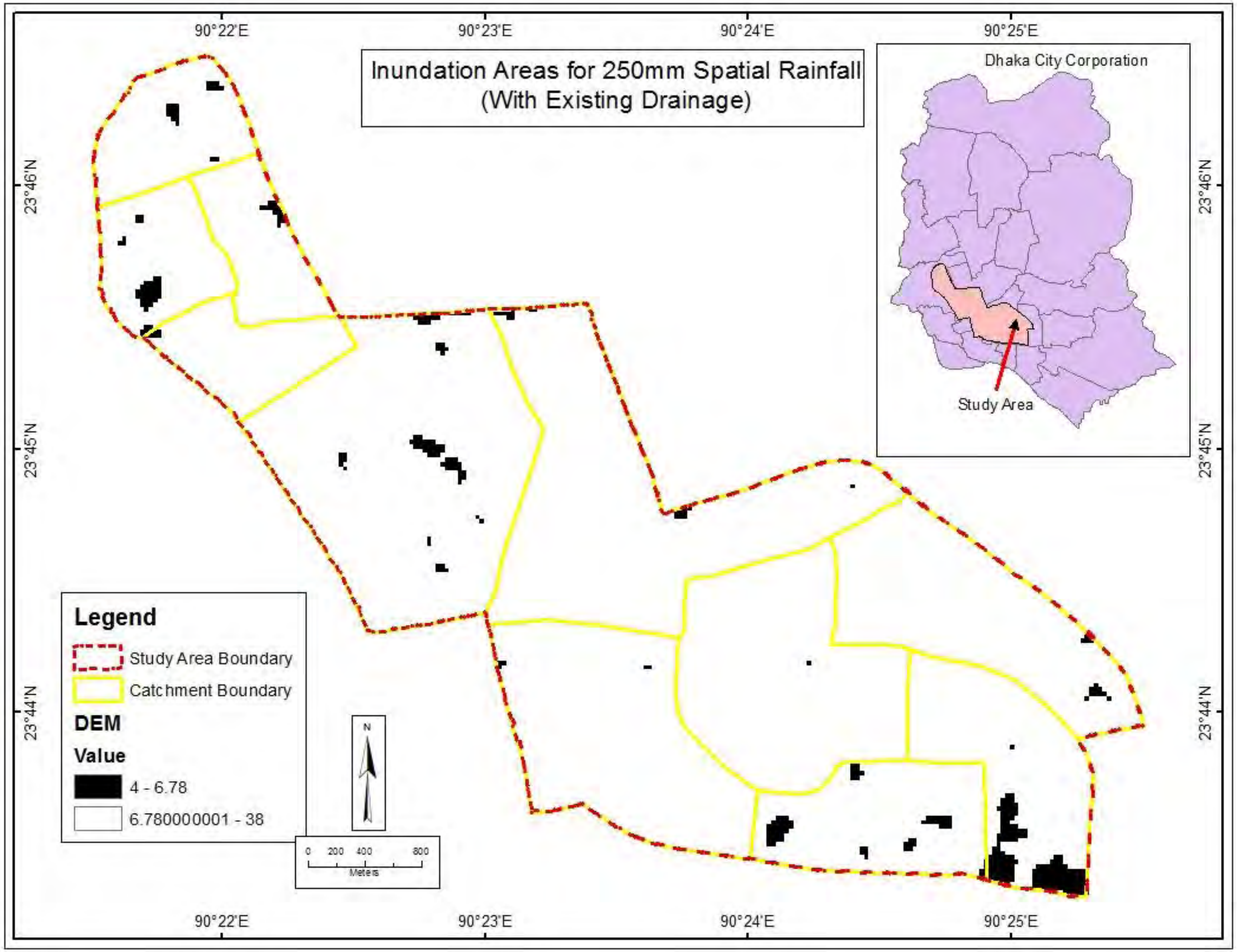


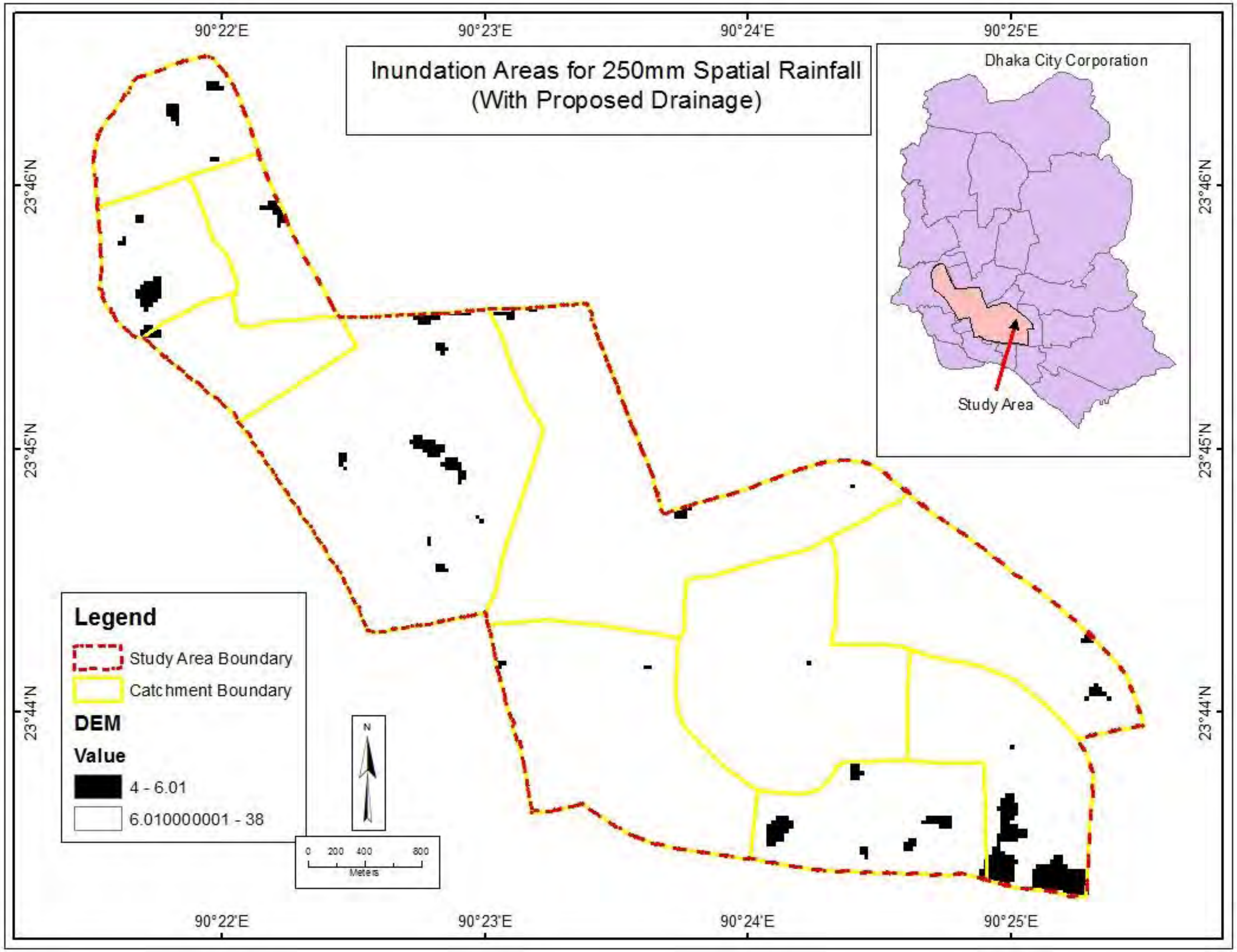

Inundation Areas for 341mm Spatial Rainfall
(With Existing Drainage)
Dhaka City Corporation
Study Area
Legend
Study Area Boundary
Catchment Boundary
DEM
Value
4 - 8.05
8.050000001 - 38
N
0 200 400 800
Meters
90°22'E
90°23'E
90°24'E
90°25'E
23°46'N
23°45'N
23°44'N


Inundation Areas for 341mm Spatial Rainfall
(With Proposed Drainage)
90°22'E
90°23'E
90°24'E
90°25'E
23°46'N
23°45'N
23°44'N
Dhaka City Corporation
Study Area
Legend
Study Area Boundary
Catchment Boundary
DEM
Value
4 - 7.22
7.220000001 - 38
N
0 200 400 800
Meters

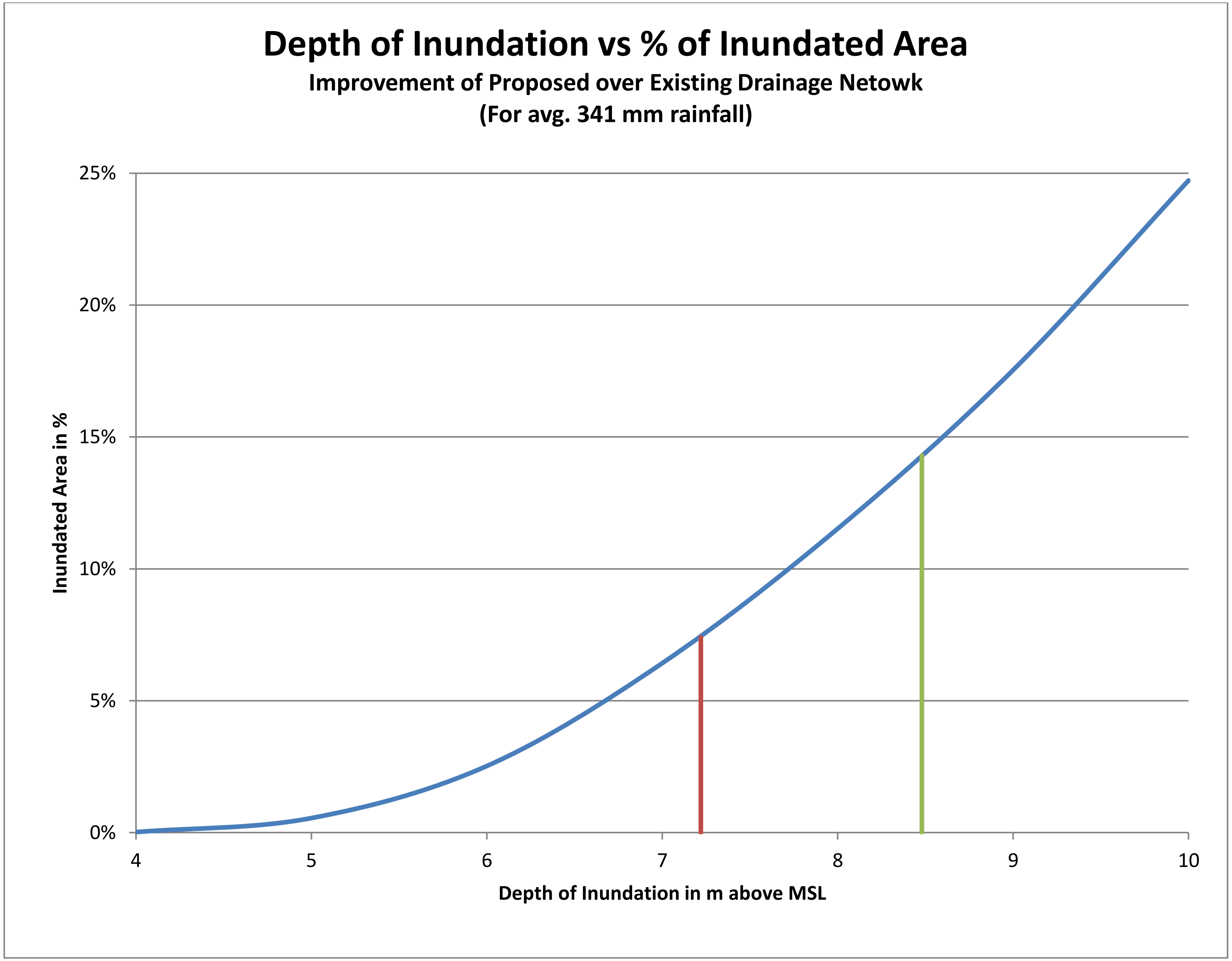

Inundation Areas for 300mm Spatial Rainfall
(With Existing Drainage)
Dhaka City Corporation
Study Area
90°22'E
90°23'E
90°24'E
90°25'E
23°46'N
23°45'N
23°44'N
Legend
Study Area Boundary
Catchment Boundary
DEM
Value
4 - 8.48
8.480000001 - 38
N
0 200 400 800
Meters

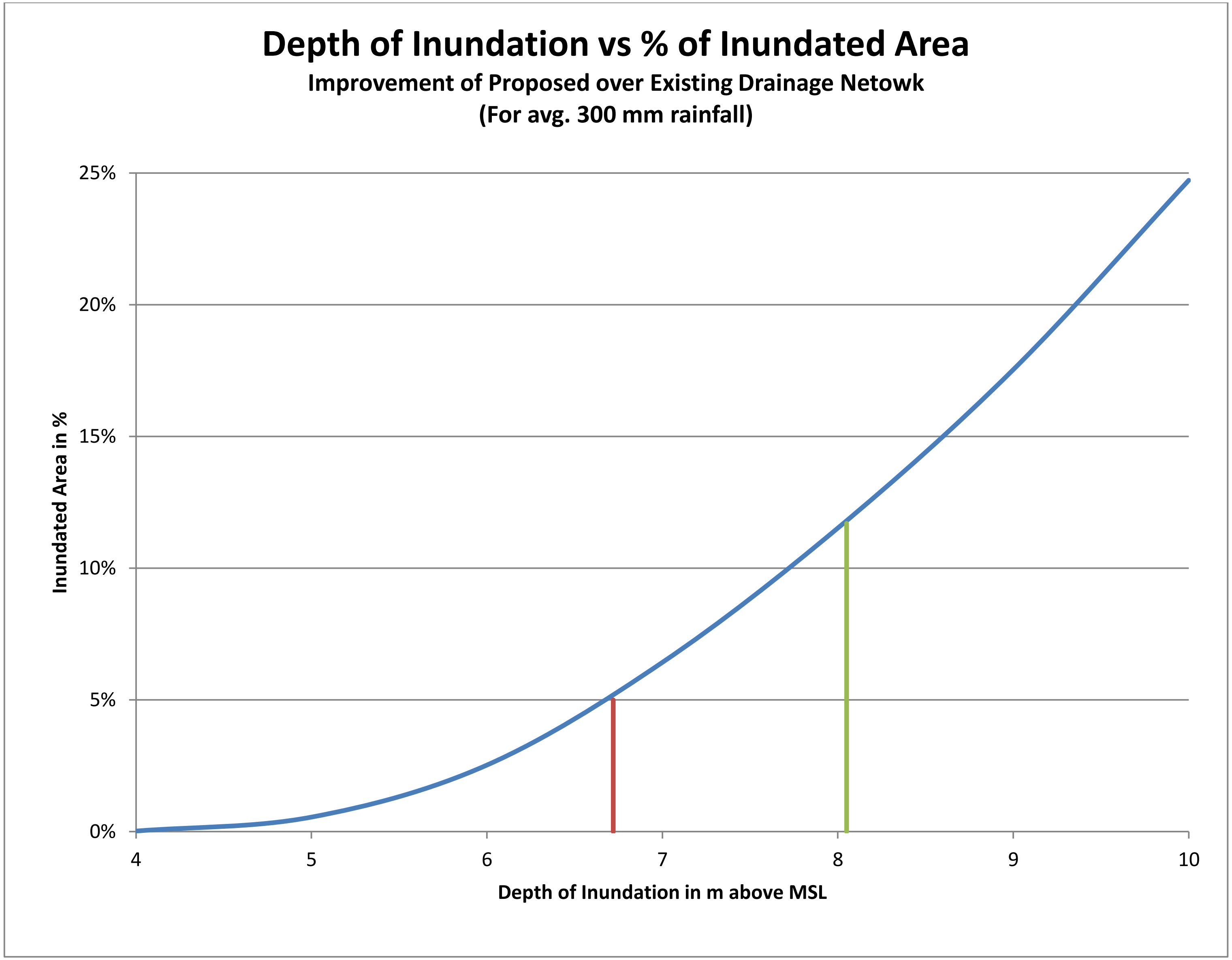

Inundation Areas for 300mm Spatial Rainfall
(With Proposed Drainage)
Dhaka City Corporation
Study Area
90°22'E
90°23'E
90°24'E
90°25'E
23°46'N
23°45'N
23°44'N
Legend
Study Area Boundary
Catchment Boundary
DEM
Value
4 - 6.72
6.720000001 - 38
N
0 200 400 800
Meters

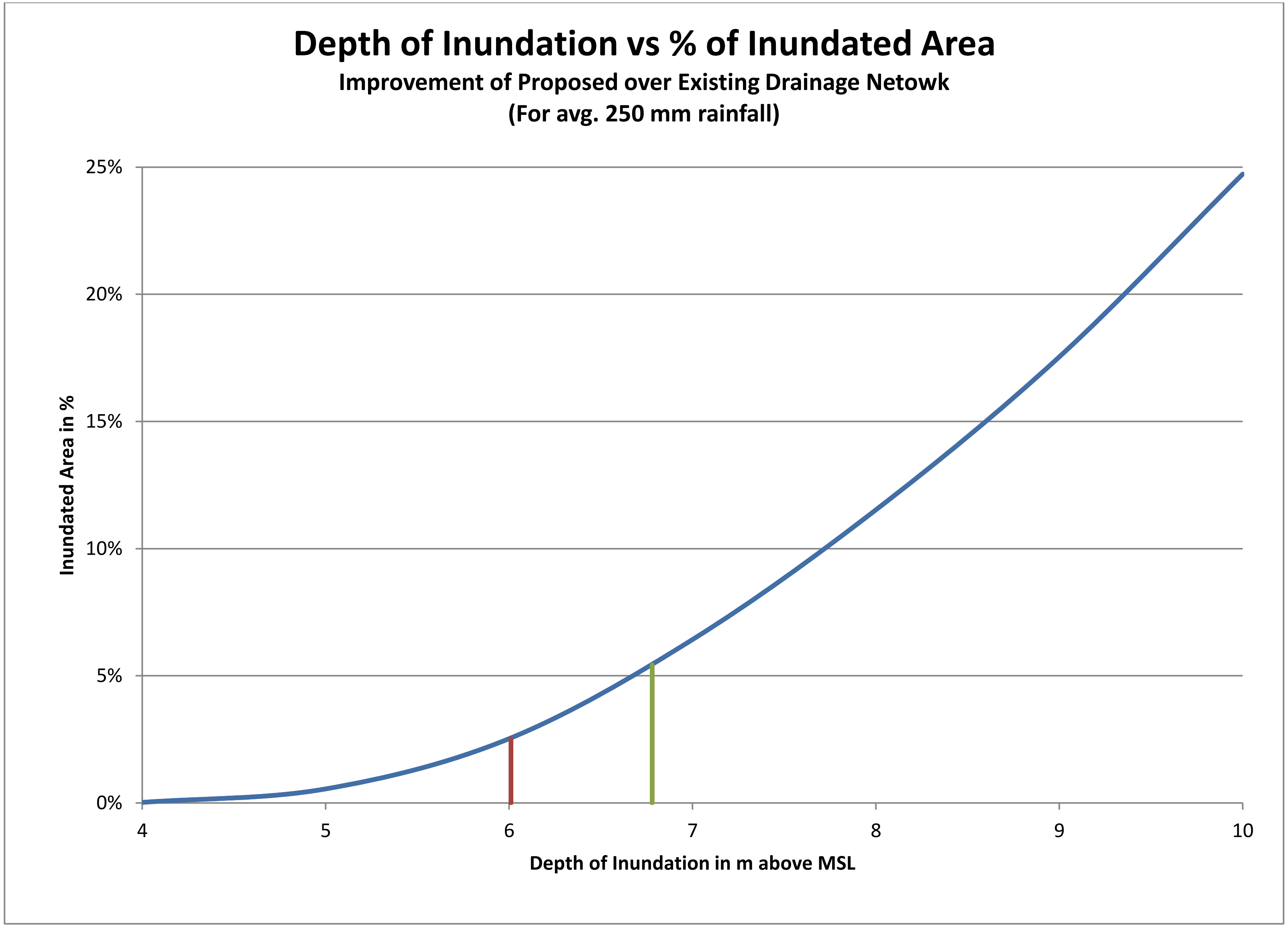

Inundation Areas for 250mm Spatial Rainfall
(With Existing Drainage)
90°22'E
90°23'E
90°24'E
90°25'E
23°46'N
23°45'N
23°44'N
Dhaka City Corporation
Study Area
Legend
Study Area Boundary
Catchment Boundary
DEM
Value
4 - 6.78
6.780000001 - 38
N
0 200 400 800
Meters



Inundation Areas for 250mm Spatial Rainfall
(With Proposed Drainage)
90°22'E
90°23'E
90°24'E
90°25'E
23°46'N
23°45'N
23°44'N
Dhaka City Corporation
Study Area
Legend
Study Area Boundary
Catchment Boundary
DEM
Value
4 - 6.01
6.010000001 - 38
N
0 200 400 800
Meters


Depth of Inundation vs % of Inundated Area
Improvement of Proposed over Existing Drainage Netowk
(For avg. 341 mm rainfall)
Inundated Area in %
25%
20%
15%
10%
5%
0%
4
5
6
7
8
9
10
Depth of Inundation in m above MSL


Depth of Inundation vs % of Inundated Area
Improvement of Proposed over Existing Drainage Netowk
(For avg. 300 mm rainfall)
25%
20%
15%
10%
5%
0%
Inundated Area in %
4
5
6
7
8
9
10
Depth of Inundation in m above MSL


Depth of Inundation vs % of Inundated Area
Improvement of Proposed over Existing Drainage Netowk
(For avg. 250 mm rainfall)
Inundated Area in %
25%
20%
15%
10%
5%
0%
4
5
6
7
8
9
10
Depth of Inundation in m above MSL

ANNEXURE IV

DRAINAGE NETWORK MAPS OF DHAKA CITY

ANNEXURE V

ZONING MAPS OF RELEVANT WARDS