INTEGRATED REMOTE SENSING AND GIS BASED STUDY ON STORM WATER FLOODING IN GUWAHATI

A Thesis submitted to Gauhati University

for the degree of

Doctor of Philosophy

in

Engineering

by

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(Enrolment No.: Engg. 06/10)

2016

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ABSTRACT

Urban flooding is a devastating natural hazard that affects cities globally and is expected to become worse in the near future. Unplanned urban development increases flood risk due to the local change in hydrological and hydro-meteorological change. This local change is developed mainly due to the variations in the land use/land cover (LULC) pattern of the city. Urbanization has a direct impact on the LULC pattern leading to an increase in the percentage of impervious layer. These increase in impervious layer results in the increase in the quantity of surface runoff. Urbanisation also leads to filling up of low lying land and thereby decreasing the water retention capacity. Guwahati city is surrounded by hillocks, and the city has undergone rapid urbanization in the last few decades. This has resulted in the city being transformed to a metropolitan city comparable with other cities in India and abroad. However, this transformation has also associated the city with a myriad of urban problems faced by many cities, flash flooding being one of the major concerns.

An attempt has been made to find the root causes for the urban stormwater flooding in the Guwahati city with the help of an integrated Geographic Information System (GIS) and Remote Sensing based approach.

The research works includes delineating the watershed of the Guwahati city under GIS environment, in the first phase of the work. It has been observed from the delineation that Guwahati has five numbers of drainage basins, viz., Bharalu, Mora Bharalu, Basistha, Silsako and Foreshore Basin.

Another phase of the study includes the generation and study of the LULC pattern of these basins. LULC maps have been generated for the study area. It has been found that there has been a vast change in the LULC pattern during the last few decades. Observations indicate a decrease in the agricultural land, forestland, and wetland, and an increase in the built-up areas and tree clad areas. Naturally, this change in the land use pattern has cause local changes.

A study of the rainfall pattern of the study area has indicated that there has been an increase in the intensity of rainfall pattern. This indication was obtained from the Intensity Duration Frequency (IDF curve), which has been generated for the local rainfall pattern for the Guwahati city.

The research work further aims and attempts to compare the efficiency of the existing drainage system of the study area with the designed section of the main drain of the watersheds (Bharalu Basin). This comparison indicates that the present drainage system is inadequate to cater to the surface runoff generated for the area. Even the Bharalu river section, in its present form, is inadequate to carry the runoff generated in the basin due to a storm event of even a 2-year return period.

Additionally, based on the various analysis carried out in this study an attempt has also been made to highlght the probable submergence scenario of Guwahati city. The submergence study has been carried out for different rainfall intensity and durations.

Finally, from the whole analysis and research work, it has been observed that insufficient and inadequate capacity of the existing drainage network has led to the flash flooding in the Guwahati city. In addition to this, the clogging and siltation problem in the drain is also a cause for the flash flood problem. All other important factors causing flash flood has been identified. A holistic approach incorporating all these factors responsible for the problem is accounted for while suggesting remedial measures to this problem. It is also demonstrated how with the combination of various alternatives a complete solution to the flash flood problem of Guwahati can be achieved.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Urban storm water flooding has become a major problem, of late, for many fast developing cities, not only in India but also in other parts of the world. The severity of this flash flood problem has been observed to grow unless steps are taken only after a detailed and systematic analysis in a holistic manner. Stormwater runoff is the water that has its origin from precipitation or melting of snow or ice. The stormwater runoff, when it flows through the Earth’s surface is retained by the soil through infiltration, gets evaporated from the surface, and flows into various streams, rivulets, rivers, lakes, seas, oceans. However, the flow of stormwater runoff varies depending on the land use pattern of the stormwater runoff basin. Stormwater runoff is thus a natural part of the hydrological cycle, which is the distribution and movement of water between the earth’s atmosphere, land, and water bodies (CSWQM, 2004).

In natural landscapes such as forests, the soil absorbs much of the water, and the dense vegetation helps in retention of the water close to where it falls. Thus a very less amount of water actually reaches various water bodies. Water retention basins such as ponds, lakes, beels etc. also play a major role in reducing the surface runoff. However, during urbanization and industrialization major portion of the soil loses its natural vegetative cover and is often rendered impervious due to various construction activities. This reduction in vegetative cover leads to a high amount of runoff of the water precipitating on the river basin. When city drains, channels or rivulets of the city fails to take this increased runoff load inundation of low lying areas occurs often resulting in sudden flooding. Due to the high concentration of human population in urban areas, the flooding often causes loss of property and even precious human life.

1.2 URBANIZATION AND STORM WATER FLOODING

Extensive urbanization and industrialization, urban land use change in cities around the world have resulted in disturbances of hydrological systems which are irreversible in nature (Hugget et. al., 2004). The after effects of this anthropogenic intervention are not immediately felt, but at a later stage when the symptoms appear after a long term, it becomes nearly impossible or very costly to address these problems (Du, 2010). The hydrological effects of urbanization have been summarized by Leopold (1968), as a change in a total runoff with an alteration of peak flow characteristics, a decline in water quality and a change in the hydrological amenities of streams. An explanation to this effect has been clearly demonstrated by Randolph (2004), who has shown that the increase in imperviousness (roads, parking lots, rooftops, concrete open spaces) associated with urban development alters the hydrologic system.

It is a fact that many water-related problems are the direct outcome of ill-conceived land use planning and development. As a result of these developments, vegetated and forest land which consists of pervious surfaces have been largely replaced by various land- use patterns. These changes in land-use pattern results in the formation of impervious layers, which increases the stormwater runoff quantity of a basin, decreases infiltration and ground water recharge and alters the natural drainage patterns. Figure 1.1 adopted from the Connecticut Storm Water Quality Manual (CSWQM) , 2004 clearly defines the relationship and alteration of drainage pattern of a basin regarding imperviousness, runoff, infiltration, and evapotranspiration.

As reported by Leopold (1968), there are four interrelated, but separable effects of land-use change on the hydrology of a basin: change in peak flow characteristics, total runoff, quality of water, and in the hydrologic amenities. Hydrologic amenities as defined by Leopold (1968) are the appearance or the impression which the river, its channel, and its valleys, leaves with the observer.

Urbanization is the major land use type which changes the hydrology of a basin (Leopold, 1968). Urbanization is not uniform in all areas; it varies from place to place in varying degrees. This varying degree of urbanization renders varying degree of imperviousness of the urbanized areas. Lull and Sopper (1966) have presented some data on the percentage of land rendered impervious by the different degrees of urbanization.

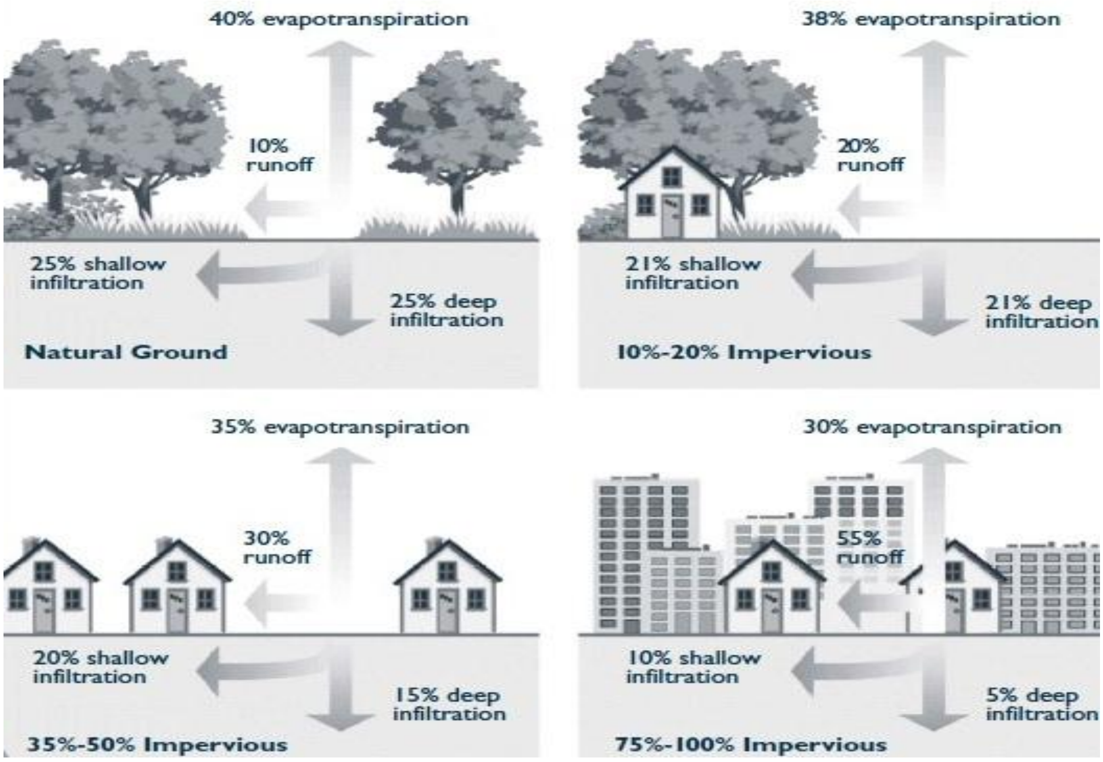

Figure 1.1: Impacts of Urbanization on the Hydrologic Cycle (CSWQM, 2004).

With the increase of the volume of runoff from a storm, the peak flood size also increases. Increased imperviousness thus leads to increase the amount of runoff during a storm. Another effect of urbanization is the sediment load carried by the stormwater runoff. This carriage of sediment by stormwater runoff occurs mainly when the bare ground has been exposed to various external agencies during construction. Sediment yield from urban areas tends to be more than in un-urbanized areas (Leopold, 1968). The sediment load of the stormwater runoff often is deposited in the hydrologic channels, rendering them clogged. This deposition of sediments often hampers the natural drainage of the basin, resulting in stormwater flooding.

Flooding is a localized hazard that is generally the result of excessive precipitation. Flooding can be classified into two categories: flash floods and general floods. Flash floods are the product of heavy localized precipitation in a short time period over a given location, while general floods, is caused by precipitation over a longer time-period and over a given river basin (Seyoram, 2011). Slow moving weather patterns known as convective rains generate intense rainfall over a small area which leads to the occurrence of flash floods. The important contributing factors to the flash floods include urban topography, where the water gets accumulated due to the high degree of imperviousness. During such an intense event, almost all the precipitation is converted into surface runoff. Shelton (2009), Suprit et. al. (2010) has reported that if the surface runoff is not routed efficiently in time, flash flooding occurs. Due to the fast catchment response and very short lead time of flash floods, coordination of hydro-meteorological forecasting and response becomes a challenge, and hence predetermined local information in invaluable (Prasad and Narayan, 2016). Flash floods are a situation when all the natural streams and manmade drainage systems fail to cater to the high amount of surface runoff during a heavy rainfall event (Youssef et. al., 2011, Srivastava et. al., 2012). It is reported by Brooks (2003) and Daniel et. al., (2012) that floods, although natural, the damage and loss occurred are mostly the consequence of urbanization without corresponding infrastructural restructuring to cater to the increase in surface runoff. Hence it becomes imperative to manage the surface runoff by suitable, sustainable practices of watershed management.

1.3 URBAN DRAINAGE SYSTEM

ASCE AND WEF (1992) defines urban drainage system as “physical facilities that collect and treat runoff in urban areas. These facilities normally include detention and retention facilities, streets, storm sewers, inlets, open channels, and special structures such as inlets, manholes, and energy dissipaters”.

Urban drainage systems are an indispensable part of an urban system because it serves many purposes. Water is an essential part of human life. In an urban environment, various interactions occur between human activity and natural water circulation. Nie (2003) has defined two distinct form of interaction: first, the abstraction of waste water from the systematic cycle after providing for the needs of human life, institutions activities, the consumption of industrial and commercial products; and secondly, diverting rainwater from the covering lands of impermeable surface away from local natural areas or systems.

The urban drainage systems can be completely artificial, or a combination of manmade sewer facilities and naturally occurring watercourses. A state-of-the-art urban drainage system as proposed by Walesh (1989) and reported by Nie (2003) consisted of two main components: the convenience-oriented, or the minor system and the emergency or the major system. The minor system consisted of the components that accommodated the frequent, small runoff events, while the major system comprised the components that control infrequent but large runoff volume.

1.4 DRAINAGE SYSTEM AND STORM WATER FLOODING OF GUWAHATI CITY

Guwahati, the capital city of Assam in India covers an area of about 262sq.km. The Guwahati city being located almost at the center of the northeast Indian region, acts as the gateway and transit point of transportation and communication for the seven sister states of the north-eastern region of India. It is the largest commercial, industrial and educational center of the northeast Indian region.

The capital of Assam was shifted from Shillong to Guwahati in 1972. This shifting has increased its importance manifold. People from all over Assam and also of the neighboring states have been migrating to Guwahati for job, business and education. This migration has resulted in very fast and unplanned growth of the city.

1.4.1 Geography of Guwahati City

The Guwahati city is a part of Kamrup District and is located at 91º33'E-91º52'E and 26º08'N-26º14'N and is surrounded by - toward the north is the mighty river Brahmaputra and hills, hillocks towards the south, east and west direction separated by flat valleys.

The city is situated on an undulating plain with varying altitudes of 49.5m to 55.5m above the Mean Sea Level (MSL). The southern and eastern sides of the city are surrounded by hillocks. Apart from the hilly tracts, various low lying areas which include swamps, marshlands and water bodies are also located in the city. The bharalu river which flow through the heart of the city serves as a major natural drainage system having its outlet to the Brahmaputra river. Figure 1.2 depicts a general map of Guwahati city area.

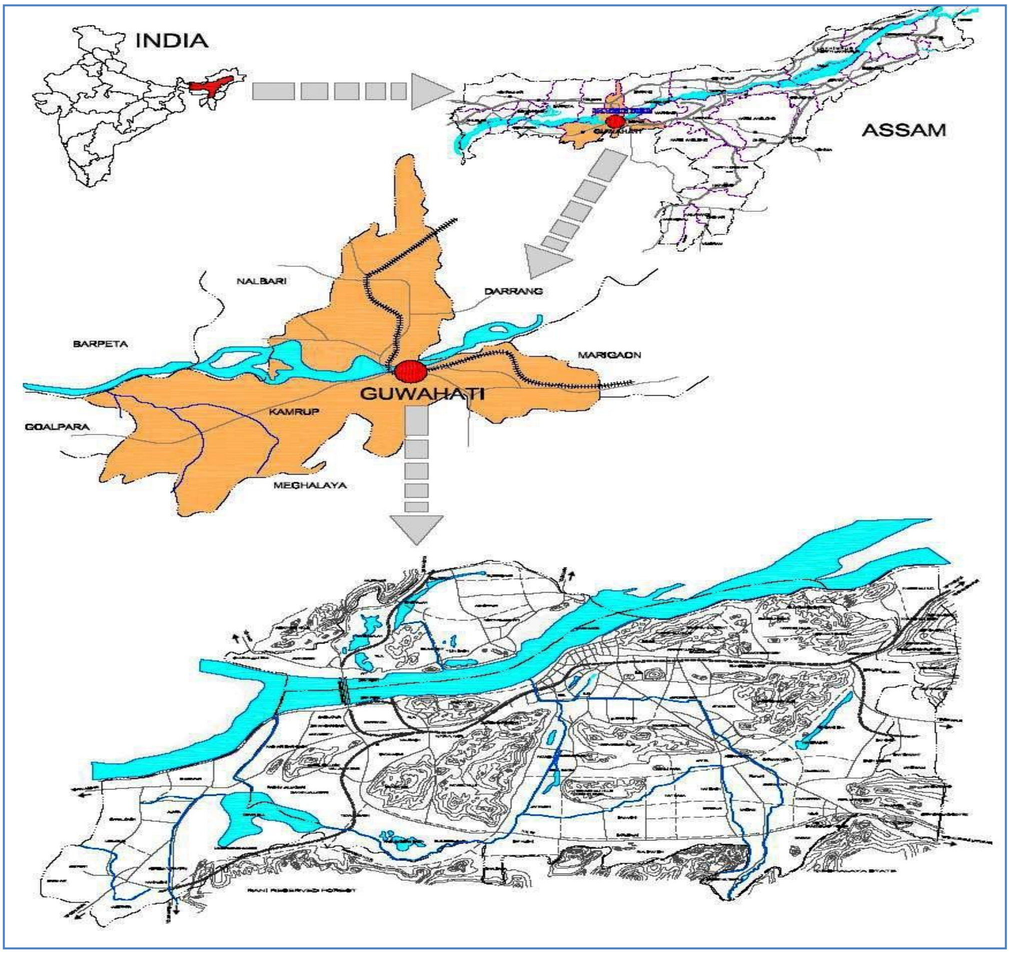

Figure 1.2: Map of Guwahati (CDP, 2006)

1.4.2 Drainage System of Guwahati

The drainage system of Guwahati can be classified to fall under a system of manmade drains, and modified naturally occurring watercourses. Most of the drains are roadside drains which are basically designed to cater to the surface runoff of the impervious road surface. The roadside drains have also to cater to the sewage generated by the domestic households, commercial establishments, institutions as well as industries.

1.4.3 Stormwater Flooding of Guwahati City

Storm water flooding has been a major concern and poses a great challenge to the sustainability of Guwahati city. Figure 1.3 depicts some very common scenes in Guwahati city during the rainy season. Stagnation of water having a depth of around

5 ft has become an annual phenomenon in some areas of the city. Further escalating the situation of storm water flooding is the alarming decrease in the number of the water bodies due to various human activities. Hill cutting and filling up of low-lying areas is seen as a major concern and a factor contributing to the flooding.

Figure 1.3: Common flood scenes in Guwahati City

1.5 PREVIOUS STUDIES

A very few study devoted to the causes and mitigations of the storm water has been carried out. City Development Plan (CDP, 2006), a study by Department of Soil Conservation, South Bank Division (2003) and Thakur et al. (1993), are some of very few studies carried out based on the flash flooding of Guwahati. However, no comprehensive study devoted to the urban storm water flooding, has been carried out for the Guwahati city. Hence, it becomes imperative to study the causes of urbanization and related stormwater flooding in the Guwahati area.

1.6 OBJECTIVE OF STUDY

Glimpses of storm water flooding in Guwahati are presented in Fig. 1.3. This results in paralyzing the whole city including threat to human life and property. Hence, Guwahati having a regional importance, study of the flash flood problem of Guwahati is felt to be necessary. A holistic approach based on GIS and Remote Sensing is adopted to study the causal factors and possible remedial measures.

The broad objectives set for the work are-

- To identify the root cause of the urban flood problem and to study measures for possible solution to Guwahati flash flood problem.
- To prepare a drainage and flood information database of the study area using, Remote sensing data and other ancillary database in the GIS Platform.

To achieve the objectives in the research work, following step-by-step procedure as described in Cl. 1.7 is adopted.

1.7 METHODOLOGY

The general methodology as adopted is explained below-

1. The work begins with the preparation of the Base Map of the study area.
2. The existing natural drainage system in the study area is then mapped under Geographic Information System (GIS) environment.
3. The Digital Elevation Model (DEM) of the study area is then generated in GIS environment.

4. The slope map, aspect map, contour map of the study area is then obtained from the DEM.
5. Delineation of the watershed of the Bharalu and Bahini river is undertaken in the DEM.
6. Identification of the basins of the study area is carried out using DEM
7. Rainfall analysis and generation of IDF-curve for the study area is carried out using rainfall data collected from Regional Meteorological Centre (RMC), Guwahati.
8. The estimation of runoff from the study area is carried out by employing the Rational Formula. This runoff is then used to obtain required section of drains at various outlets.
9. A comparative study of the existing channels/drains with the design section as obtained in the previous step is then carried out.
10. Submergence probability of the study area is carried out with the data obtained from all the above analyses.

1.8 ORGANISATION OF THE THESIS

In this thesis the complete research work is presented eleven chapters.

An introduction to the problem of urban flooding with a special reference to Guwahati city is presented in **Chapter 1**. The necessity to carry out such a study in context to the study area is presented in this chapter.

A review of the earlier research works in storm water flood management is provided in **Chapter 2**, entitled, LITERATURE REVIEW. This chapter gives an insight into various stormwater management approaches as well as practices used in the field. Review of the different researchers incorporating different methods are discussed and presented.

Chapter 3, entitled, GENESIS OF THE FLOOD PROBLEM, highlights the various problems which has a direct impact on the storm water flooding of the Guwahati city. It depicts the causes and problems associated with the study area.

Chapter 4, entitled, METHODOLOGY, provides the overall view of the methodologies involved to find the root cause for the flooding in the study area

The process of delineation of the watershed along with generation of Slope map, aspect map and other related data has been discussed in the **Chapter 5**, DELINEATION OF WATERSHED OF THE STUDY AREA.

The **Chapter 6,** which is INTEGRATED GIS AND REMOTE SENSING BASED STUDY ON THE CHANGES IN LANDUSE/LANDCOVER PATTERN OF GUWAHATI CITY AND GENERAL CONSEQUENCES discusses about the change in the Landsuse/Landcover (LULC) pattern of the study area from 1972 to 2011. These chapter further attempts to highlight the effects of the LULC changes, which directly or indirectly contributes to the urban storm water flooding.

Generation of Intensity Duration Frequency (IDF) curve of Guwahati city is presented in **Chapter 7** with a title GENERATION OF INTENSITY DURATION FREQUENCY CURVE USING SHORT DURATION RAINFALL DATA FOR DIFFERENT RETURN PERIOD FOR GUWAHATI CITY.

Chapter 8 deals with ESTIMATION OF RUNOFF FOR THE WATERSHED AND DRAINAGE DESIGN. It is devoted to estimation of runoff of the watershed of the study area.

Chapter 9 depicts the submergence depth of the study area for the different storm event for different intensity of rainfall at different storm duration. It also predicts the area to be inundated for such storm event. This chapter is entitled as FLASH FLOOD/SUBMERGENCE SCENARIO FOR VARIOUS RAINFALL INTENSITY AND DURATION USING GEOGRAPHIC INFORMATION SYSTEM.

The remedial measures and possible solution to the urban flooding have been discussed in the **Chapter 10**. The chapter is entitled as REMEDIAL MEASURES AND OTHER MANAGEMENT MEASURES FOR LONG RUN SUSTAINABILITY.

The thesis concludes with **Chapter 11**, entitled as CONCLUSIONS AND SCOPE FOR FURTHER RESEARCH where in concluding remarks are given for the causes as well as remedial measures for the Guwahati urban flood. Management measures for long term sustenance of flood free Guwahati is also discussed herein. The scope for further work in this research topic is also included in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Understanding how to manage properly the urban stormwater, has been a critical concern to civil and environmental engineers all over the world. Mismanagement of stormwater and urban runoff often results in flooding, erosion, and water quality problems. To develop better management techniques, engineers have come to rely on computer simulation and advanced mathematical modeling techniques to help plan and predict water system performance.

Urbanization modifies hydrological processes of a basin by replacing the vegetated land cover with impervious surfaces. The existing drainage system in a basin is modified and extended to include ponds, ditches and conduits laid over or under the ground level (Leopold, 1968; Hall, 1984; Konrad and Booth, 2002; Mansell 2003; Berthier *et al*., 2006; Xiao *et al*. 2007; Dow, 2007). The impervious surface reduces infiltration which in turn results in increased surface runoff and reduced base flow. Artificial ditches and conduits alter the runoff courses and change the pattern of stormwater drainage. In catchments or basins in an urban area, the surface flow may be diverted to artificial ponds or flood detention ponds, which are built to reduce flood risks or in some cases for irrigation purposes. An urban storm water drainage system, in general, consist of two elements: (1) surface components such as streets, rooftops, ditches; and (2) subsurface components such as pipes network and other manmade stormwater drainage networks (Schmitt, *et. al.*, 2004; Smith, 2006a). These two elements are linked through inlets and manholes provided at street level. On the other hand, in semi-urbanized catchments, these urban drainage components are often mixed with the natural channel. As reported by Smith (2006a) surface storage of runoff very often is another component of urban drainage systems, and is sized so as to maintain consistency between post-urbanized catchments under extreme conditions with pre-urbanization extremes. The effects of urbanization on hydrological processes of a basin can be studied through integrated field studies and accurate modeling. Field studies of effects of urbanization on runoff have often used paired catchment and longitudinal (long time series) methods where one component of the pair or a basin in the latter part of a longitudinal record has undergone urbanization. Excellent field studies can be found in Changnon and Demissie (1996), Moscrip and Montgomery (1997), Leith and Whitfield (2000), Beighley and Moglen (2002), Jennings and Jarnagin (2002), Konrad and Booth (2002), Burns *et al*. (2005), Dow (2007), and Chang (2007). Essentially, all of these studies indicate that urbanization leads to increase in the various peak flow characteristics. Additionally, various inferred effects of urbanization, on mean annual flow has provided a mixed response (Changnon and Demissie, 1996; Konrad and Booth, 2002; Burns *et al*. 2005, Chang, 2007). In some reported cases, annual flows have increased as the result of increased storm runoff. Some other report that annual flow shows a reduction of infiltration during storms and in dry period. It is often very complicated to interpret the field studies of urbanization effects on streamflow due to spatial variation of climate, physical characteristics of the study basin, unaccounted for human interventions, and observation deficiencies (Chang, 2007). A major advantage of model studies is that most of the above confounding factors can be controlled, notwithstanding that field data are critical for the evaluation of model performance. Model studies focuses on the objective of engineering and municipal management of runoff and is often used to predict urban flooding and the probable placement of structures and various other measures to control flooding. Such models simulate the hydrodynamics of overland flow, often in the form of a diffusive wave. Typical use of GIS and digital elevation models to determine surface runoff direction, the location of street, storm sewer pipes, street inlets, and manholes is involved. Such models often consist of separate surface runoff and pipe flow networks. The connections between the two modules are manholes and street inlets. Excellent examples of this type of model can be found in Hsu *et al*. (2000), Schmitt *et al.* (2004), Smith (2006b), and Xiao *et al.* (2007). However, in most applications of this class of model, validation of data are limited, and hence the simulation quality is quiet difficult to assess other than through high-performance measures (Mignot *et al*., 2006). The domain of these urban hydrology models, which are primarily used for various engineering design purposes, mostly in densely populated cities and towns, but they are less appropriate to 'mixed' (partially natural, partially urbanized) watersheds.

This chapter attempts in providing the various methods employed by different researchers in studying the storm water flooding of urban areas.

2.2 APPROACHES TO STORMWATER MANAGEMENT

Traditional approaches for the management of urban stormwater has been directed at maintaining public hygiene as well as protecting urban dwellings and dwellers from local flooding. These approaches have mainly focused on the rapid and quick removal of storm waters away from urban areas using rather standardized methods (e.g. the rational method) and designs (i.e.,.design of pipe sections) with very little consideration for secondary downstream effects (Chocat, et. al. 2001). This removal of storm water may consist of combined or separate sewers to carry water flows mixed with domestic wastewater. This practice has resulted in a rather reactive practice of systematically increasing the capacity of combined or separate sewers as urbanization processes and local flooding occurs. This has contributed to the increase of stormwater peak flows and flood risk downstream (Marsalek, et. al. 2006). Chocat et. al. (2001) and Henze et. al. (1997) have highlighted the apparent inefficiency of such traditional approaches in achieving public hygiene, flooding and environmental protection. However, in most of the urban drainage systems the common factors like quantity, quality, and operational problems, affecting the key objectives of public hygiene, flooding and environmental protection still remain (Chocat, et. al., 2004). Furthermore, the emerging issues like introduction of new chemicals which has an uncertain effect on water bodies, contaminants accumulated on waterbeds and the challenges arising from the effects of climate change may again compromise the existing urban storm drainage systems (Chocat et. al., 2004). As a response to this situation, various approaches have been adopted to address the problems related to urban storm water flooding.

Chocat (2001) and Krebs et. al (2001) has reported that many of the practices of stormwater management were developed way back in the 1800s. The rational method, first proposed in by L.K. Sherman in the year 1932 (Chow et. al., 1988) has been used as a key concept and first step in the flood assessment of a region. The rational method was intended to provide a simple rational method for size culverts. The basis for the rational method has been to associate overland flow of precipitation to three aspects of a given area; the area in acres, the surface characteristics and rainfall intensity (Ferguson, 1998).

The new urban drainage related problems are very complex for a particular approach to providing a comprehensive solution. Chocat (2001) and Krebs et. al. (2001) has reported that there is a need for transfer of knowledge among various disciplines which have a stake at urban drainage and establish a like between them. This has been validated by Villarreal (2004), where it is reported that conventional stormwater practices are not sustainable. Further, it has also accepted that the approaches towards the solution of urban stormwater problems require integrated practices with interlinkage between various processes.

Conventional controls that utilize various structural methods for the management of stormwater are termed as Best Management Practices (BMP). Although conventional methods have provided many benefits, it has been observed from experience that structural BMP's such as detention ponds create many environmental, economic and hydrologic problems downstream from the discharge points (USEPA, 1999; Coffman, 2002).

Recently, with the availability of various mathematical models the approach to address and evaluate the problem of urban flooding has been directed towards the use of computer based model since the 1960s. Some of the most popular and widely used mathematical methods are frequency ratio (Pradhan et. al., 2011; Lee, et. al., 2012), Artificial Neural Network (Kia et. al., 2012), Analytical Hierarchy Process (AHP) (Rahmati et. al. 2015), logistic regression (Nampak et. al., 2014), fuzzy logic (Pourghasemi et. al., 2012b), support vector machine (Tehrany et. al., 2015a) and decision tree (Tehrany et. al., 2013b). Liao and Carin (2009) have reported that Frequency ratio is one of the most powerful statistical methods which has a simple concept to be understood. Zou et. al., (2013) suggested AHP method as a quite cost-effective, easy to understand, and useful method. Multi Criteria Descision making Analysis (MCDA) is an important tool in the analysis of complex dicision problems which often need incomparable criteria or data (Hwang and Lin, 1987; Malczewski, 2006).

Further, with the advent of GIS technology the approach towards evaluating the stormwater effects has shown a tremendous dependence on computer simulation. Various computer codes (e.g.,. Arc GIS, HEC-RAS) for the assessment of storm water flooding of a region is available. This availability has resulted in the development of various GIS-based integrated urban watershed management practice (IUWM) models and method.

2.3 GIS BASED APPROACH

GIS literature is very broad because a wide variety of areas utilize the geographic data. Extensive use of Remote Sensing (RS) techniques along with Geographic Information System (GIS) have been reported in recent times and are recognized as powerful and effective tools for the detection of land-use change, flood mapping and flood risk assessment (Sarma, 1999; Islam and Sado, 2000; Sanyal and Lu, 2004; Dewan, et. al., 2007). It is a computer-based tool for mapping and analyzing spatially referenced data (Quan, et. al., 2001). The software is capable of integrating hardware and data for capturing, managing, analyzing and displaying all forms of geographically referenced information. It help one to view, understand, question, interpret, and visualize the data in many ways that generally reveal relationships, patterns and trends in the form of maps, globes, reports and charts. Therefore the GIS software is a vital tool concerning the planning for floods, educating the population at risk and managing the floods. In addition, GIS. improves disaster management by offering more efficiency and speed in the input, management, manipulation, analysis and output data or information. The main significant of using GIS for flood management is not only generates a visualization of flooding, but also allows practical estimation of probable hazard due to floods. Several scholars employing GIS have identified the capacity of GIS to be used as a platform for the collection of various forms of spatially referenced data that can be used for planning. An excellent overview of the concepts of GIS and their application in within the field of natural hydrology is available in Singh and Fiorentino (1996). A very excellent state of the art report on GIS and water resources modelling is available in Samsi (1999). During the 1990s the use of GIS in modeling urban stormwater systems has been more limited to the need for large expensive and detailed databases, along with the fact that many computer tools used in urban stormwater modeling are not easily amenable to integration with GIS (Heaney et. al., 2001). However at present this drawback is nullified as can be seen from the various GIS-based studies (Dewan et. al., 2007; Kourgialas and Karatzas, 2011; Haq et. al., 2012, Patel and Srivastava, 2013;Ouma and Tateishi, 2014; Kazakis et. al., 2015) conducted in recent years which are devoted to the study of urban stormwater flooding and assessment.

A number of approaches have been used to solicit community based data for integration with G.I.S. Depending on data availability, researchers either engage directly with the community or use pre-existing information on the community. In an global context, for example, Meyer et al. (2009) have assessed the flood risk in the Mulde River, where official statistics on the risk-prone community was used in addition to as well as land use and flood data held by the local authorities. The official statistics included data from insurance, taxation and environmental studies collected within the area of study. Employing a different approach, Tran et al. (2009), used GIS and local knowledge, which contributed to proper planning and resource allocation for disaster preparedness in Thua Thien Hue, Central Vietnam. Coupled MCDA-GIS method has been used in spatial modeling and analysis of natural disasters and especially in flooding (Maclczewski, 2006; Scheuer et. al., 2011; Paquette and Lowry, 2012; Solin, 2012; Kazakis et. al. 2015; Rahmati et. al. 2015b). The performance of MCDA and GIS were evaluated by Fernandez and Lutz (2010) for mapping of the areas that were vulnerable to flooding in Argentina. Their research have showed that the AHP technique in GIS is a powerful method to prepare maps of natural disasters with a fair degree of accuracy.

2.4 CASE STUDIES

Some case studies which involve the use of GIS in storm water management practices are presnted below.

Barbe et al. (1993) integrated data transfer from a GIS and a Supervisory Control and Data acquisition (SCADA) system to a Storm Water Management Model (SWMM) model of the Jefferson Parish stormwater stormwater system in Louisiana. The SWMM RUNOFF block was used to simulate the hydrologic runoff characteristics of the area. Geospatial data were transferred from the GIS to the

SWMM RUNOFF data file. Similarly, the EXTRAN block was used to simulate the pipe network, and the network connectivity was transferred from the GIS to the SWMM EXTRAN data file. Time series data from 150 monitoring sites were transferred from a SCADA system to the SWMM model for calibration purposes.

For the purposes of urban stormwater modeling, spatial data may usually be viewed as static. Changes in geographic data are typically modeled in a scenario manner, e.g., a model run may be done for an undeveloped watershed, and then a developed scenario is performed using the same hydrologic conditions. Hydrologic and meteorological data are commonly a time series of discrete values. Therefore some attention must be paid to the integration of spatial and time series data. This idea of consistency among data is key to the concept of hydroinformatics. Pryl et al. (1998) describe the integration of time series with GIS to accomplish urban stormwater master planning in the Czech Republic. Similarly, Rodriguez et al. (1998) use time series in their analysis of the water budget based on parcel-level urban spatial data. Time series integration was a key element in the work reported by Barbe et. al. (1996) in Louisiana. A large network of 150 monitoring locations fed a SCADA system with many time series data that were integrated with GIS data and the SWMM model. An Oracle database was used to manage non-spatial data for this project.

Refsgaard et al. (1995) describe the evolution of DHI’s land process hydrologic model, SHE, and its extensive use of GIS.

Tskhai et al. (1995) used a GIS linked with an optimization model to evaluate ecological and economic alternatives for the Upper Ob River in the Altai region of Russia. While not strictly an urban runoff model in the traditional sense, this project does link urban management decisions with an economic optimization model.

Da Costa et al. (1995, 1996) examined this problem in developing the Portuguese Water Resources Information System. The integration of GIS with temporal data is described as one of the great challenges of developing this system (da Costa et al. 1996). To accomplish this integration, a database was developed using Oracle software to underlie the information system. A special processing module was developed to interface time series data with the GIS. The GIS portion used the ESRI ArcView software.

Sorensen et al. (1996) described the use of time series in an application of MIKE GIS in Bangladesh.

Wolf-Schumann and Vaillant (1996) describe in detail the need for integrated time series with georeferenced data. The development of TimeView, a time series management tool, is described as adding a whole dimension (time) to spatial data. TimeView is integrated with ArcView, so that a user can select a geographic feature in ArcView (e.g. a monitored manhole), and TimeView returns a time series of measured data in graphical format.

Olivera et al. (1996) used GIS to calculate hydrographic properties of terrain for non-point load estimation. Flow paths calculated from paths of steepest descent are used to calculate flow properties of basins.

Cluis et al. (1996) use topographic data and GIS functions to derive important hydrographic characteristics of the terrain such as overland flow paths in a raster based format.

Mercado (1996) describes the use of detailed spatial information in the creation of a stormwater model in Tallahassee, Florida using XPSWMM software. Scanned and geo-rectified black and white aerial photography was used as a background with other GIS based data, including two foot contour elevations, streams, buildings, roads, etc. A Digital Elevation Model (DEM) was created in ArcInfo, and the Triangulated Irregular Network (TIN) and Grid functions were used to define areas of high slope and erosion potential, flow gradients and very accurate subbasin delineation.

Herath et al. (1996) used high-resolution raster data sets to develop a distributed GIS-based urban hydrologic model. Data sets included 50 m x 50 m and 20 m x 20 m land use grids; 1:25,000 plans were used to develop imperviousness by land use, a 50 m x 50 m DEM, population density, water supply data, and rainfall.

Ribeiro (1996) describes the use of a raster-based GIS to interface with Hydrologic Simulation Program Fortran (HSPF) to analyze the effects of basin urbanization.

Hellweger (1996) developed an ArcView application using the Avenue scripting language to perform the model calculations of United States Department of Agriculture (USDA)'s hydrologic model TR-55.

Bellal et al. (1996) studied partly urbanized basins using a linked GIS and hydrologic model. The hydrologic model was based on a non-urban water budget, with modifications to account for urbanization. The GIS was based on a DEM and raster-based land use data

Shamsi and Fletcher (1996) describe in detail the linkage of ArcView and SWMM for the City of Huntington, WV. ArcView is shown to be a user-friendly environment to perform stormwater modeling.

Feinberg and Uhrick (1997) discussed the integration of an infrastructure database in Broward County, FL with a GIS and water distribution and wastewater models. The HydroWorks model is used to simulate the wastewater collection system, with close integration with the database of infrastructure characteristics and the GIS.

Mark et al. (1997) use the MOUSE program from DHI to evaluate stormwater in Dhaka, along the banks of the Ganges and Bramaputra rivers in Bangladesh. Integration of GIS, time series, and the hydraulic model were accomplished to better understand flooding characteristics. Maximum inundation and duration of inundation were mapped using MOUSE and GIS.

Olivera et al. (1998) describe HECPrePro as a system of ArcView scripting programs and controls to extract hydrographic information from spatial databases and prepare an input file to HEC-HMS. Using Soil Conservation Service (SCS) curve numbers and a DEM, HEC-PrePro delineates streams and basin boundaries, determines their interconnectivity, and calculates parameters for each stream and basin. A benefit to automating the calculation of hydrologic parameters that were traditionally estimated manually is that results are reproducible, i.e., they are not dependent on the bias or experience of the modeler.

Sotic et al. (1998) began a preliminary design of Combined Sewer Outflow (CSO) facilities in Kumodraz, Yugoslavia with paper maps. Existing paper maps and other data were used to create a GIS, which in turn was used to aid in the design and analysis of the CSO system. This "hydroinformatic" approach consists of developing a set of tools to collect and process data in a consistent manner. The attention to consistency in data transferability is to assure that the greatest value is achieved from the dataset. In this case, the GIS was used to integrate a Digital Elevation Model (DEM), the street network, and the sewer network; then this information was transferred to the BEAMUS hydraulic simulation model.

A similar hydroinformatic approach is described for the town of Pilsen in the Czech Republic by **Hora et al. (1998).** Beginning with paper maps, a GIS was built from the ground-up. The complete process is described, ending with an information tool that was used to create a hydrodynamic model of the sewer system, store monitored flow and rain data, evaluate current hydraulic sewer capacity and evaluate the feasibility of alternative sewer developments.

Shamsi (1998) discusses the difference between transferring data files between ArcView and SWMM and creating an interface that uses SWMM output as a spatial coverage layer in a GIS. This "interface method" (as opposed to the interchange method described above) involves creating a SWMM menu within ArcView. Pre- and post-processors of SWMM input and output files create input files, read output files, and join and unjoin data files (Shamsi 1998). These options are made available in ArcView; however SWMM is run separately from ArcView (Shamsi 1998).

Rodriguez et al. (1998) describe an integrated GIS and urban hydrologic model to evaluate small storm hydrology for parcel level management decisions.

Makropoulos et al. (1998) focus on urban sustainability to evaluate stormwater systems. Beginning with the idea that low energy solutions that control impacts at the source are more sustainable. It was demonstrated how a raster-based GIS (IDRISI) can be used to integrate theoretical concepts and site specific spatial characteristics. The strength of GIS can be used as a common ground between specialists and non-specialists to help them communicate effectively.

Bhaduri et al. (2000) used Long Term Hydrologic Impact Assessment (L-THIA) in the assessment of land-use change, where special attention was given to small and low-frequency storms in the Little Eagle Creek in Indianapolis, Indiana. Simulation were conducted by obtaining the record of daily precipitation from 1966 to 1995, with 1973, 1984, and 1991 land-use data. The study came to a conclusion that an increase of 18 % in the urban and impervious areas has resulted in approximately 80% increase in annual average runoff volume, more than 50% increase in heavy metal and 15% increase in nutrient loads.

Kim et al. (2002) carried out a study to evaluate the impact of changes in land-use on runoff. Rainfall events of 1, 5, 10, 50, and 100 year return periods for 24 hour, 30 years of daily rainfall, and land-use data of 1920, 1943, and 1990 were used for the analysis. The study concluded that runoff increases in the study watershed as a result of changes in land-use, especially with increase in urbanization. Between years 1920 and 1943, estimated average annual runoff for the study area increased by a range of 10 - 26% due to increased urbanization in that area. Between 1943 and 1990, the range was 37 – 69 % increase. Between years 1920 and 1990, estimated average annual runoff increased by 49% -113%.

Engel et al. (2001) in their study presented the long-term hydrological impact assessment (L-THIA) web application as a decision support system (DSS), which was based on an integration of web-based programs, GIS capabilities, and databases. The study intended to support decision makers who required information regarding the hydrologic impacts of water quantity and quality

Tang et al. (2004) presented a web-based decision support system, Sediment and Erosion Control Planning, Design and SPECification Information and Guidance Tool (SEDSPEC) with an illustrative case study. The tool involve integrated web based GIS technology to help users estimate watershed boundaries and to access a spatial database while obtaining land-use and hydrologic soil group data for a given watershed. The tool also employs the Rational Method and TR-55 to simulate short‒term peak runoff, based on site-specific hydrologic soil groups and land-use patterns. The tool allowed an user to estimate the dimensions and explore various options for the implementation and maintenance costs of hydrologic, sediment and related erosion mitigating structures.

Shi et al. (2004) discussed the design principles and strategies of a web based GIS and Hierarchical Watershed Decision Support System for the United States. The tool incorporated other decision support tools such as the online watershed delineation and L-THIA model. The paper illustrated the functionality of the system and reported the progress made on the project.

Choi et al. (2005a) described a conceptual web-based Spatial Decision Support Systems (SDSS) framework. It was based on web-GIS for watershed delineation, map interfaces and data preparation routines, a hydrologic model for hydrologic/water quality impact analysis (by emplyoing the L-THIA model), and web communication programs for Internet-based system operation. The authors illustrated how a web-based SDSS system can be beneficial for watershed management decision-makers and interested stakeholders. The role that GIS and information technologies play in creating readily accessible and useable SDSS capabilities has also been highlighted in the paper.

Tang et al. (2005) explored the impacts of urbanization on hydrology and water quality. The study used the land-use change model (LTM) to predict land use change from 1978 to 2040. The L-THIA model was used to estimate hydrologic and water quality changes associated with the estimated land use changes associated within this time period. Two types of developments were evaluated: sprawl and non-sprawl developments. Results showed that increase in urban expansion results in increase in runoff volume and nonpoint source pollution.

Lim et al. (2006) has discussed the importance of calibration in simulating hydrologic and water quality impacts of land use changes with that of the L-THIA model. The study attempted to develop an automated calibration procedure and shows that calibration will improve the accuracy of the L-THIA model in the estimation of pollutant loads. The model was calibrated and validated data of a single year data for daily simulations. The data of first six months were used for model calibration and the last six months were used for model validation. Calibration predicted that for this watershed estimated average annual direct runoff increase by 34%, 24% for total nitrogen, 22% for total phosphorus, and 43% for total lead.

Muthukrishnan et al. (2006) had developed a simple method to calibrate the L-THIA model using simple linear regression of predicted direct runoff by L-THIA and USGS observed direct runoff values, which were derived from hydrograph separation of stream flow data, which included both direct runoff and baseflow. Four test data were used in the calibration and validation of the model. In the first test, data from year 1973 to 1982 were used for calibration and data available from year 1983 to 1991 were used to verify the model. While in the second test, data available from year 1982 to 1991 were used for calibration and data from year 1973 to 1981 were used fo model verification. In the third test, the entire dataset was divided into odd-even years, where data of odd years were used for calibration and the data of even years were used to verify the model. Finally, in the fourth test, calibration was based on the whole dataset ranging from the year 1973 to 1991, and compared with the other three calibration models. A comparison of linear as well as nonlinear regression models indicated that a linear model was the best model. This suggested that probably more complex models are not necessary in this particular case. In general, L-THIA model predictions have been found to be approximately 50% lower than actual observed direct runoff for the watershed due to the intrinsic developmental conditions of the CN values which might not be representative of the conditions in this particular watershed. The study provided valuable information into the factors that control runoff generation and systematic under prediction of direct runoff by the L-THIA model as compared to the actually observed runoff data.

Rongrong and Guishan (2007) exposed the influence of land use/land cover changes (LUCC) in the short term flooding process. The HEC-HMS code was used to delineate the basin, achieved by a series of connective hydrologic and hydraulic components. The inverse-distance-squared method was applied to calculate the mean – areal precipitation depth in each sub-basin which took into account, the spatial variation of precipitation. Soil Conservation Service (SCS) and Curve Number (CN) were selected to estimate the excess precipitation. Kinematic wave model was employed to model direct runoff and channel routing. Finally, they suggested that afforestation would mitigate flood disaster and urbanization would contribute to flood disaster.

Langhammer and Vilimek (2008) analyzed the connection between the various landscape alteration and the consequences of the catastrophic flood in Otava river basin, Czech Republic. Historical maps, available GIS data, remote sensing and field mapping were used in deriving the intensity of landscape modifications. Determination of the interrelations among the landscape modifications, physio-geographical features of the river basin and the flood course was carried out by cluster analysis. Their results indicated that a very limited impact on flooding was observed due to the shortening of river course, river bed modifications and drainage from agricultural areas. On the other hand, land-use pattern of the floodplain and structures impeding free water flow have increased the consequences of flooding.

Saghafian et al (2008) in their study attempted to integrate hydrologic models, GIS and remotely sensing data. This integration was done to assess the effect of past land-use changes and to predict the effect of future land use scenarios on the flood regime of Golestan Watershed in Iran. Land-use patterns in 1967 and 1996 were simulated using a calibrated event-based rainfall-runoff model and flood hydrographs. The contribution of each watershed to flood peak at the outlet was quantified using Unit Flood Response (UFR) technique. The subwatershed were then ranked based on the contribution per unit area to flood peak at the outlet. The relative changes in the peak flow of the two subsequent conditions i.e. 1967 and 1996 land-use pattern were estimated for different return periods. Their results indicated that land cover deterioration resulted in the increase of the flood peak and volume. Additionally, it was also observed that the flood peak was more sensitive to land use change in comparison to flood volume.

Shang and Wilson (2009) examined the effect of watershed urbanization on stream flow behavior. Stream gauge data, spatially distributed rainfall data, land use/land cover and population census data were used to quantify the change in flood behavior and urbanization in multiple watersheds. They used methods which were GIS-based for the quantification of spatially distributed rainfall and surface imperviousness.

They finally concluded that both the frequent and rare floods were indeed very sensitive to the processes of urbanization and results in increased magnitude of floods with respect to various recurrence intervals.

Waheed et al (2010) in their study investigated the impacts of urbanization on geomorphic parameters like channel width, depth, velocity, slope, roughness of various channel materials and discharge of the Kaduna river, Nigeria. A detailed and comprehensive hydrological investigation, which was aimed at determining the causes, level and the probability of occurrences of flooding in the Kaduna river valley, was carried out. Field investigation and Topographic surveys were employed for the collection of data on geomorphology, river mechanics and channel hydraulic geometry. The surveyed cross section data was superimosed on the topographical map of the area taken in 1962 and the extent of encroachments in the flood plain was evaluated. The extents of flood risk zones corresponding to the 2, 5, 10, 25, 50, 100 and 200 year return period floods were established by reading the water stages. Their results indicated that urbanization factors have progressively modified the Kaduna river flood plain and its flow.

Lim et al. (2010) showcased the importance of calibration of both runoff and baseflow when trying to assess the hydrologic and water quality impacts of land use changes with the L-THIA model which was calibrated using the BFLOW and the Eckhardt filtered direct runoff values. Their study showed that L-THIA direct runoff estimates could be incorrect by 33% and nonpoint source pollutant loading estimation by more than 20%, if the accuracy of the baseflow separation method is not validated for the study watershed before model comparison. The authors used the L-THIA model for documentation of the importance of baseflow separation in hydrologic and water quality modeling.

Wilson and Weng (2010) assessed the impacts of land use change on runoff and surface water quality using ArcHydro GIS extension and a modified version of the L-THIA model. This was carried out to estimate runoff and nonpoint source pollutant concentration around Lake Calumet between the year 1992 and 2001. The model calibration was done using split-sample method and the size of the study area was

220.7 km2. The authors reported that surface water quality depended on the extent of LULC change over time and also the spatial extent of hydrologically active areas within the watershed. The model predicted that an increase in runoff volume will contribute to differential increases in concentration among most pollutants. Conversely, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) properties of surface water demonstrated a opposite pattern to the aforementioned one. The study demonstrated that the level of concentration of nonpoint source pollutants in surface water within an urban watershed heavily depends on the spatiotemporal variations in areas that contribute towards runoff compared to the spatial extent of change in major land use/land cover.

Ahiablame et al. (2012) developed a framework to represent, evaluate, and report the effectiveness of low impact development practices using the Long-Term Hydrologic Impact Assessment Low Impact Development (L-THIA LID) model. The modeling procedure was applied to a 71 ha residential subdivision in Lafayette, Indiana (the Brookfield Heights (BH) subdivision). 20 years of daily rainfall data and the 2001 National Landcover Data Set set were used for annual simulations. The effectiveness of LID practices in the study area was examined in 8 simulation scenarios using 6 practices. This practices included rain barrels and cisterns, bioretention, green roof, porous pavement, open wooded space, and permeable patio. Results clearly showed that the average annual runoff and pollutant loads increased for post-developed conditions compared to pre-developed conditions, indicating that the construction of the BH subdivision influenced pre-development hydrology and water quality. Simulations of LID scenarios, showed that LID design principles could be used to bring post-developed hydrology to a level comparable to that of pre-development. This study indicated that a reduction in runoff is greatly influenced by reduction in impervious surfaces. The authors stressed on the due importance that has to be given to LID practices in water resources planning and management, applicable for the preservation of natural hydrology..

Gunn et al. (2012) in their study, developed two simple metrics to quantify hydrologic impacts of land-uses resulting from urbanization. The indices consist of the pre versus post development index (PPH) and the extent of maximum index (EH) and were applied in three case studies of residential subdivisions in Lafayette, Indiana. The uncalibrated L-THIA model was used in the computation of annual runoff volume with daily precipitation data for evaluation of the metrics. The case studies illustrated how to interpret the resulting index values.

2.5 CRITICAL REVIEW COMMENTS

In this chapter a detailed review of various metholodologies used in the analysis of urban storm water flooding has been presented. Various techniques applying the Geographic Information System (GIS) and Remote Sensing (RS) techniques has been reviewed. From the above review the following points become apparent

1. GIS technique is a very widely applied technology in the study of urban storm water runoff related flooding assessment.
2. GIS and RS data provides a very versatile platform for the analysis of spatially varying data without the loss of accuracy.
3. The data of GIS and RS canbe used for the analysis in various simulated environments and as they are based on modern computing devices, it results in considerable time saving.

It has also been seen from the review studies that very few studies devoted to the urban storm water flooding of Guwahati city has been undertaken. This provides an ample scope for the evaluation and assessment of the flooding pattern. It also provides an opportunity for the determination of various causes and factors related to the urban flooding problem associated with Guwahati City, with the application of an integrated approach using GIS and RS data.

CHAPTER 3

GENESIS OF THE FLOOD PROBLEM

3.1 INTRODUCTION

The study area (Guwahati City) has been subjected to very acute and frequent urban floods during the last few decades. Even a medium intensity amount rainfall for a small duration causes inundation of the low-lying areas of Guwahati paralyzing normal functioning of the city. Many of the main roads become inundated after a quick shower bringing the city transportation system to a standstill. The severity of the flash flood problem can be envisaged by the fact that marooned people are to be evacuated by rubber boat by National Disaster Response Force (NDRF) team or Army. Essential items like drinking water, foodstuff, medicines are to be distributed to the flood-affected people and has become regular a regular exercise in the premier city of the Northern Eastern India. The genesis of the flood problem and the increase in its severity is thought to be because of the primary factors as described in the following sub-sections.

3.2 DEPLETION OF THE STORAGE OF STORMWATER RUNOFF

With the shifting of the capital of Assam from Shillong to Guwahati in 1972 and the subsequent declaration of Guwahati as the permanent capital of Assam Guwahati has seen and exponential growth in the term of human settlement. Construction of the building of the structure in places earlier used to act as storm water retention basins, gradually depleted. Lack of proper planning of urban storm water drainage coupled with filling up of the low-lying areas like paddy fields, ponds and lakes, for construction purposes as well as unscientific cutting and deforestation of the Guwahati city hillocks are some of the reasons pertaining to the rapidly growing problem of flash flooding.

Primary factors responsible for the depletion of storm water storage in the study area is discussed in more detail in the following sub-sections.

3.2.1 Factors Responsible for Depletion of Storage of Stormwater in the Study Area

The following factors may be attributed as the main contributing reasons for depletion of storm water storage in Guwahati.

3.2.1.1 Degradation of the Wetlands

The degradation in the natural storage in the city and settlement in these wetland or storage reservoirs has a direct impact on the flash flooding in the city. It has been observed from the Survey of India (SOI) map 1972 and present satellite imagery that there is a vast change in the landscape in the city. The city has been subjected to rapid urbanization. From a comparison of the topography map of SOI of the past and present satellite imagery, it has been observed that almost 95% of the agricultural land has been converted into built-up areas. Various reasons of degradation of wetlands may be attributed to natural siltation process, earth filling, encroachment, and garbage dumping. In fact, a large part of Guwahati has developed on wetlands leading to their destruction. After the economic boom in the 1990s, wetlands were sold dirt-cheap. It is observed from central places of the Guwahati region that the wetlands have been reclaimed, and various commercial complexes and apartments have come up, especially in residential areas like Tarun Nagar and Lachitnagar (Bera, 2011b). Marshy areas have also been used for settlement by the urban poor and as the value of the settled land increases, they get transferred to economically well-off people. Large settlements of the poor have emerged by filling up low-lying areas at Bhaskar Nagar near R.G. Baruah Road, and on marshy land near Pandu area (Borah & Gogoi, 2012).

The degrading condition of some of the wetlands (Beel) is discussed below.

Deepor Beel

The Deepor Beel is located in the South-western part of Guwahati. It was listed as a wetland under the Ramsar Convention in November 2002. In 2008, a 4.1 km area of Deepor was notified as a wildlife sanctuary (Bera 2011a; 2011b). As a Ramsar site, conservation measures should have been undertaken. However, after three years of being listed under the Ramsar Convention, a 24-hectare municipal dump yard was designated in the eastern corner of Deepor, degrading the environment further. Large-scale encroachments, quarrying, heavy siltation from the denuded hills, accumulation of filth and waste from Bharalu and Bahini rivers, unregulated fishing practices and invasion of aquatic weeds has made the situation worse. Squatter colonies have also emerged. All these activities have resulted in the decrease of the area coverage of over 40 sq.km. (Ramsar notification was for 40.1 sq.km.), to 5 sq.km.

Silsako Beel

The Silsako Beel is located in the South-eastern part of the city. Earlier it was spread over 120 hectares, but the construction of a multiplex, tennis court, a hotel, a hotel management institute, and a research institute has shrunk the wetland. On the other side of this wetland, there are over 1000 huts where families have been residing for about 15 years. Most of them are migrants driven to the city due to the collapse of the rural and agricultural economy in the post-1990s period (Bera, 2011b).

Sola Beel

Sola Beel, which consists of the Borsola Beel and Sorusola Beel, is situated near Paltan Bazar. Sorusola Beel serves the Chandmari, Gandhibasti, Solapur, Ulubari, Manipuribasti, Fancy Bazar, Panbazar, Lakhtokia, Tokobari, and AT Road areas as a stormwater reservoir. Over the years, the State government had issued land holdings (patta) to people residing on these beels. Due to this, the *beel* was blocked, creating artificial floods in Lakhtokia, Krishnanagar, Chatribari and other areas. The same problem occurred on the nearby Borsola Beel. In July 1995, a high-level committee on wetland conservation had taken a resolution on the conservation of the *beel*. The committee had stated that no more settlement should be given in and around the Sola Beel. The resolution had also called for steps by the Revenue Department to cancel all the allotments made earlier in and around the wetland area. Following the decision of the Committee, the Revenue Department had canceled allotment on about 30 *bighas*16 of the wetland area through a letter. However, ignoring the committee's resolution, in 2006, the Revenue Department had allotted land inside a part of Sorusola Beel to the K.C. Das College, an eye hospital and some businessmen. The people residing in its fringe areas also extended the areas under their possession by encroaching upon the *beel* land. Borsola Beel was given to the Tourism department and to some private businessmen. In fact, in the midst of this, in 2000, the Sola beel Unnayan Samiti had moved the High Court for the conservation of the Beel. Even after the High Court had ordered the State government to take care of the wetlands in the city, the Revenue Department had allotted land in the Beel in 2006 for construction. The Unnayan Samiti then moved the High Court against the administration for contempt of the court. The High Court issued a stay order in 2006 on the building project (CSE, n.d.). By 2012, the Sorusola Beel had lost 25 *bighas* of its 45 *bighas,* and the Borsola Beel had lost 20 of its 85-90 *bighas* (The Sentinel 2012).

All around the city, in the rural settlements as well, which may integrate with Guwahati Municipal Corporation (GMC) area in the future, *beels* are being encroached upon, with houses on stilts to begin with. In the study area , ie, Guwahati City, the Hansora, and Damol wetlands already have disappeared completely (Bera 2011b). With the disappearance or eutrophication of the wetlands, which serve as storm water basins, the incidence of flash floods has increased in Guwahati. This disappearance of wetlands has led to the Guwahati Water Bodies (Preservation and Conservation) Act, 2008, which notified the Sorusola, Borsola, Silsako, Deepor and Bondajan water-bodies for protection and conservation. However, it has failed to bring any positive changes. The Kamrup Metro district administration constituted four task forces in January 2013 for the preservation, protection, regulation and maintenance of the two important natural waterbodies of the city, Silsako Beel and Bondjan (Kalita, 2013). Prior to this The Assam Hill Land and Ecological Sites (Prevention and Management) Act, 2006, had been enacted to provide for the preservation, protection, regulation, acquisition, and maintenance of hill land and other ecological sites of the State and more specifically within the jurisdiction of the GMC. The implementing authority is the State Government through the formation of Advisory Committees, chaired by the Commissioner of Lower Assam Division for Guwahati and the respective commissioner of the other divisions in the rest of the State. This legislation was to prohibit anyone indulging in (i) any earth cutting activities or carrying any portion of a hill land causing damage or destruction of such hill, (ii) removal or filling up or dredging or any way altering any of the ecological sites, and (iii) undertaking any such activity which may cause damage or destruction to the vegetative cover and wildlife resources of any designated area (Das, 2012).

It has been observed that the impact of urban growth has a negative effect on the conservation of wetlands. The growth of the development has been done at the cost of the natural environment, and this is a major factor which causes flash flood in the Guwahati city during heavy downpour since the city has lost its storage capacity of the stormwater. From the Table 3.1, it is observed that the city has an increasing trend of the urban areas since 1911.

Table 3.1: Increasing trend in the Urban Area

Year	Urban Area (Sq.km)
1911	7.00
1971	43.82
1990	121.93
2002	135.48
2011	216.00
2016	328.00

Thus in the name of the development and urban growth of the city, its has lost its valuable natural stormwater storage reservoir and giving way to the pluvial flooding.

3.2.1.2 Increase in population & residential area in the study area.

It has been observed from data provided in Table 3.2 that, from 1950 to 1971 there was a very slow growth in the residential areas the Guwahati city, and gradually there was a decreasing trend till early 1980’s. However, after shifting the capital of Assam from Shillong to Guwahati, the increasing trend in the residential areas along with the population growth had gone up. Thus, it has been observed the population of the study area has the tendency to increase in the near future.

Table 3.2: Increase population trend (Census, 2011)

Year	Population (in Lakh)
1901	11616
1911	12418
1921	16480
1931	21797
1941	29598
1951	43615
1961	100702
1971	123783
1991	584342
2001	809895
2011	963429

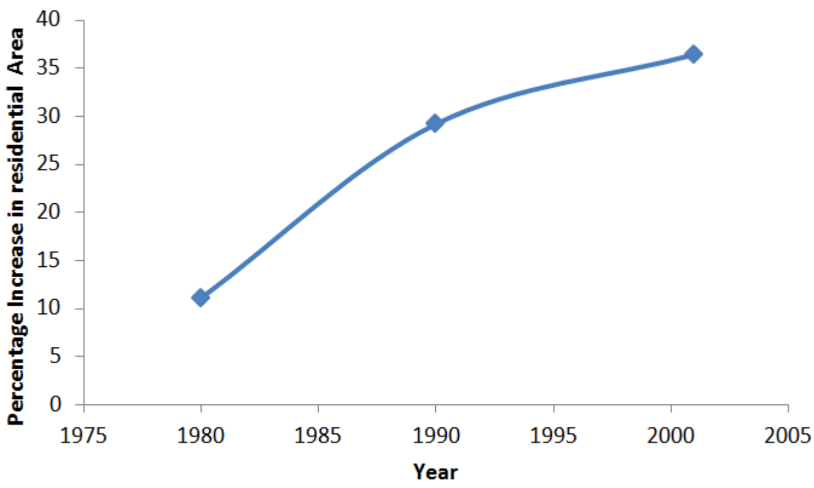

Figure 3.1: Percentage Residential Area

It is observed from Fig. 3.1that the increase in the population has led to increasing in the residential area due to population pressure. Moreover, this increase in the residential area has decreased the open lands in the study area. The area covered by the resident has made the land impervious and decreased the storage capacity of the soil in the study area.

It has also observed, from the Fig. 3.2, the considering the percentage open land area of the GMC with respect to the open lands shows a decreasing trend in the 1960's to 1970's., but there was an increase in the 1980's. However, after 1980 there is a decreasing trend of the open land in the study area. These open lands are directly related to the flash flood because they are responsible for the increase the time of concentration of runoff and also is the source to recharge the ground water by the process of percolation or infiltration.

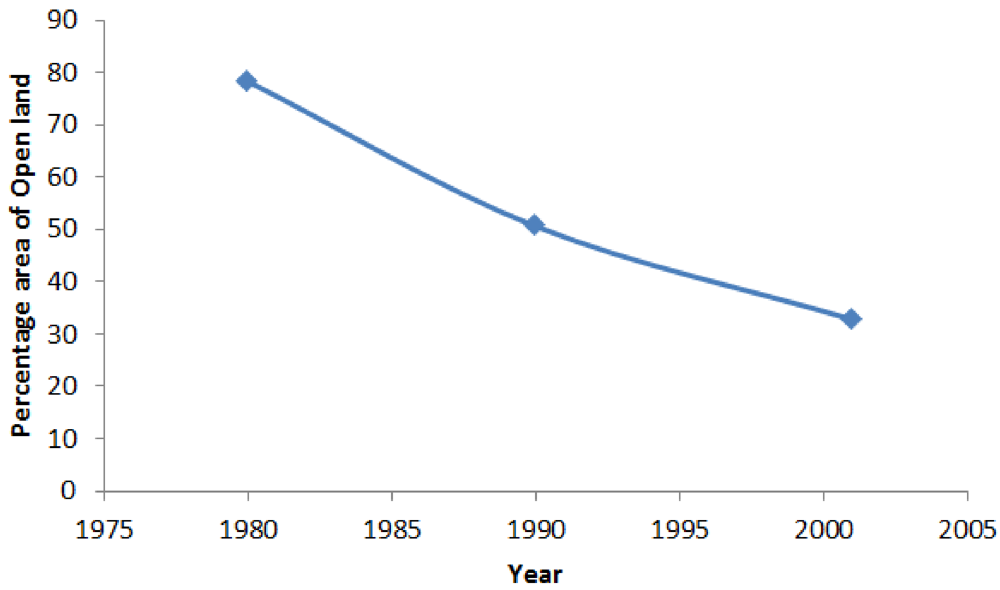

Figure 3.2: Profile of the open land in GMC area in recent years.

3.2.1.3 Settlement in Hills and its degradation

It has been observed that people belonging to different socio-economic groups have gradually settled in the hills present in the Guwahati city region. The urban poor on the hills comprises of three main groups. It has been observed that mainly the poor and lower-income non-tribals have increasingly gone to live in the hills because of the lack of vacant lands in the plains and the high cost of land and housing in the informal sector in the plains. While these groups have been denied land rights like many amongst the middle class, it is the poorer groups living on the Reserve Forest lands in the hills that have recently borne the brunt of the State's denial of land rights. The state has attempted to label these as "hill encroachments" and remove them in the name of ecological concerns. But in spite of all actions, the government has failed to remove the settlements in the hills and thus due to the construction and other man-made hazards it has created instability and the hills and creates erosion in the hill. And during storm, these hills soil runs to the plain as sediment and chokes the existing drains and decrease the carrying capacity of the soil.

From the data provided in Table 3.3, it is clear that settlement on the hills has directly contributed to the excess runoff during a heavy downpour resulting in flash flood in Guwahati city

Table 3.3: List of hills in Guwahati, Population and proportion of households.

(after AC Neilson, 2011)

No	Hill Name	Population (No of households)	Reserve Forest (RF)	Govt. Land (other than RF land)	Private patta land owned by others	Private patta land owned by self	Unknown
1	Jalukbari / Lankeswar	127	0.0	99.2	0.0	0.0	0.8
2	Fatashil	7471	9.8	63.3	14.8	4.8	2.2
3	Gotanagar	2038	41.8	38.2	13.2	6.9	0.0
4	Kharguli	2822	0.0	78.0	17.9	7.1	0.0
5	Nabhagraha	4183	0.0	85.5	8.5	6.9	0.0
6	Noonmati	7715	0.0	86.9	8.9	4.2	0.0
7	Kamakhya/Nilachal	4837	0.0	78.3	16.1	5.6	0.0
8	Kalapahar	2233	17.3	73.2	8.1	0.1	0.2
9	Narengi	1365	15.5	84.2	0.1	0.1	0.2
10	Hengrabari	5636	13.0	74.5	8.8	3.2	0.4
11	Sarania	701	8.4	56.8	19.7	13.6	1.6
12	Narakasur	8959	0.0	93.1	1.7	4.5	0.7
13	Sunsali	21730.0	0.0	100.0	0.0	0.0	0.0
14	Kainadhara	1283	0.0	85.9	11.9	2.2	0.0
15	Khanapara RF/Amcheng RF	5996	6.3	92.2	1.0	0.5	0.0
16	Gharbhanga	8355	99.7	0.3	0.0	0.0	0.0
	Total	65894	17.7	71.0	7.3	3.6	0.4

It has also observed that the natural forestry cover in the study area has affected the climatic environment. It observed from the satellite imagery of 1999, 2005 & 2010, with Normalized Difference Vegetation Index (NVDI), that the vegetation health over the study period has been degraded. (Mohan ad Singh, 2013)

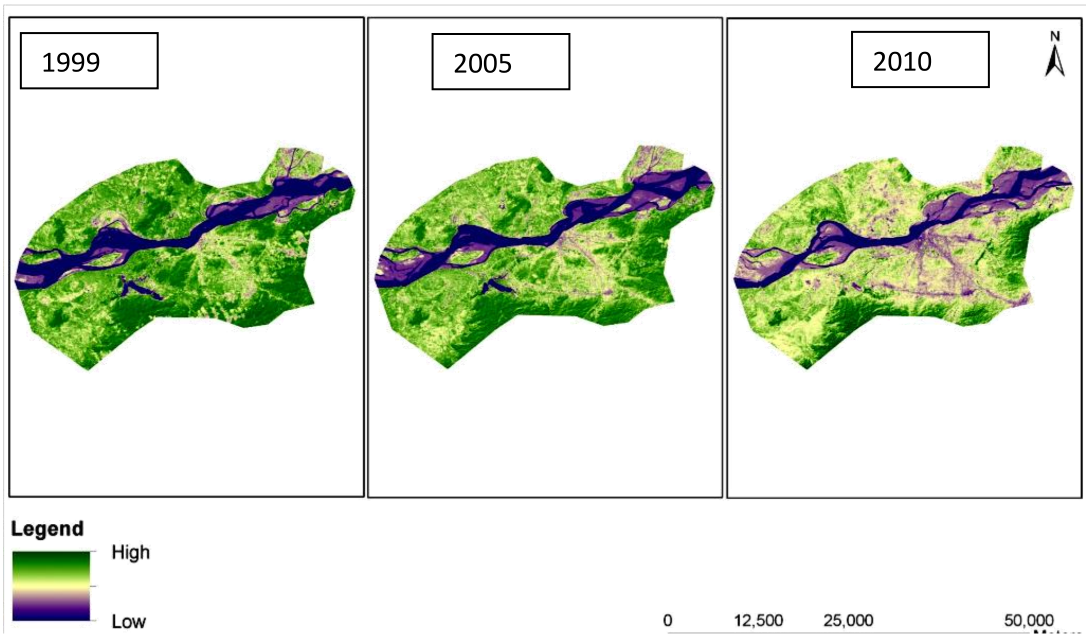

Figure 3.3: Degradation in the Vegetation cover over the years.

It is observed that during the last two decades the has undergone several changes in LULC pattern , Fig. 3.3 and the loss of the natural cover or vegetative cover and thus these changes has resulted an increase in the surface temperature and transform the Guwahati into urban heat island within and its surrounding areas.

Other than the above primary factors climate change is also a significant factor for flash flood problem of Guwahati.

3.3 CLIMATE CHANGE

There has been a changing pattern in the seasonal rainfall and an increase in the extreme storm event. It normal climate temperature had increases in both the minimum and maximum temperature.

3.3.1 Rainfall.

There is a change in the rainfall pattern in the last few decades, Fig. 3.4. It is observed, there is an increase trend in the extreme rainfall events in the last decade and decreasing trend in the seasonal rainfall for the monsoon period.

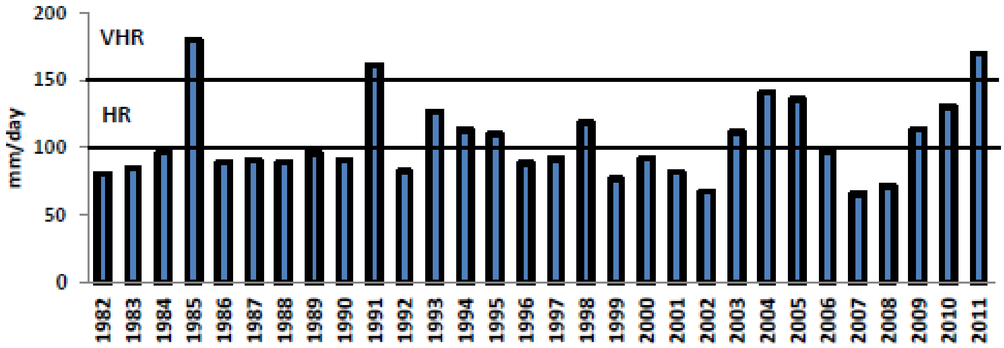

Figure 3.4: Extreme Rainfall Events

3.3.2 Temperature

It has observed, as shown in Fig. 3.5 there is an increasing trend in the maximum temperature

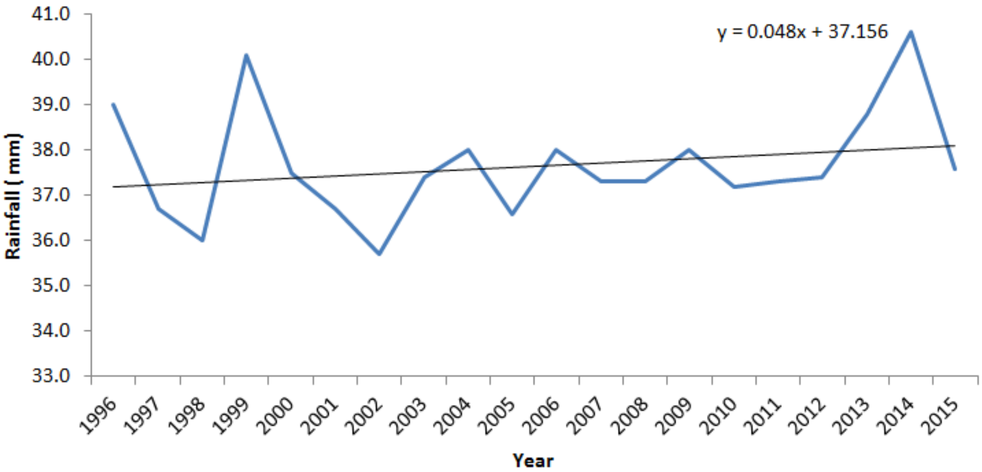

Figure 3.5: Increase trend in the Maximum temperature

(source: RMC Guwahati)

. Urban Heat Island (UHI) Formation

The changes in the rainfall pattern and the increasing trend in the temperature and decrease in the amount of seasonal rainfall with an increasing trend in the extreme event of rainfall is generally observed in urban areas. These wholesome changes are the main factors for the change of the hydrological cycle of the developed area and transformation of this area into the heat island. In India, many metropolitan cities have also experienced Urban Heat Island (UHI) in this decade

(Deosthali, 2000; Amirtham et al. 2005; and Badrinath et al. 2005). Since Guwahati, the major city of North-East India, has also experienced its warmest year in 2009 . As Guwahati servesas a gateway to North-East India is characterized by a phenomenal change in urbanization in last few years. As mentioned earlier, the population of Guwahati has increased from 809, 895 in 2001 to 963,429 in 2011 with an increase in population density from 3736 persons per Sq. km. to 4445 persons per Sq. Km. respectively (Census , 2011). This rapid rate of urbanization has its effect on the vegetation cover and thus to the atmosphere in the city. An analysis of Landsat imageries has revealed subsequent decrease of land cover with a distinct spatial heterogeneity of land surface temperature from 1991 to 2008. Due to detoriation of the of vegetation cover, some hotspots on surrounding hillocks were identified, the surface temperature of which is as high as the downtown. Figure 3.6 depicts the surface temperature of Guwahati.

Thus during the last 20 years, the Guwahati Metropolitan area has undergone phenomenal change in urban landscape that resulted in the loss of natural land cover. As a result, the surface temperature of the city has increased, and a prominent urban heat island is formed in and around the settlement areas. All these have severe environmental (rainfall pattern and hydrological cycle) and health consequences. The continuous intervention of human settlement to natural land covers in Guwahati metropolitan area has revealed the failure of land use zoning and regulatory action, (Borthakur and Nath, 2012).

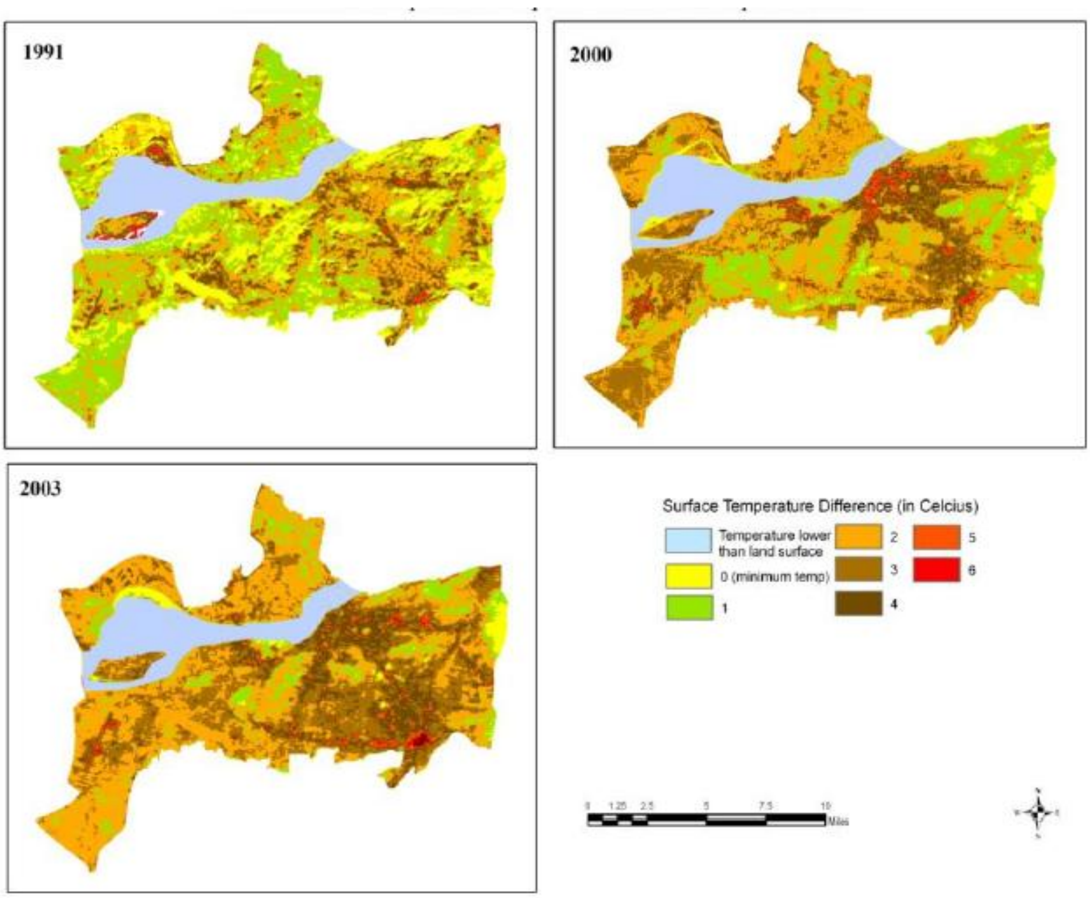

Figure 3.6: Surface temperature map Guwahati City.

(Borthakur and Nath, 2012)

3.4 SUMMARY

From the discussions in this chapter may be summarized that as the development and urbanization of the Guwahati city have increased and trend to grow and expand more in future, the storage volume of the city has to be monitored for maintaining a sustainable, healthy and safe environment of the city. It has been observed that all the factors are directly responsible for the decrease in the storage of the storm water. Moreover, due to this, when heavy downpour occurs for one hour or less, there is an increase in the peak discharge. The volume of runoff thus increases and since the storage capacity is decreased the volume of storm water becomes equal to the surface runoff. This increase results in the inundation of not only the low-lying area but also the in the impervious area or other lands where the existing drainage failed to drain out the accumulated storm water in required time.

CHAPTER 4

METHODOLOGY

4.1 INTRODUCTION

Various data has been collected from field and also by interacting with the common masses, mainly the victims of the flash flood.

The methodology for the preliminary study based on which the present research work has been conducted, comprises of –

(a) A ***preliminary field study*** in and around the study area has been done to know the ground truth to relate with the GIS environment, to have first-hand knowledge about the flash flooding in the study area.

(b) ***Collection of auxiliary data and information*** through verbal interaction with the people of the study area and through personal observations.

(c) ***Collection of secondary data*** about the drains and related materials of required for the flash flooding for the study area from the local newspaper, published reports, booklets, and reports published by various state government department related to the drains and water and related research journals.

The whole methodology adopted emphasized the use of field data, GIS, and Remote Sensing data, in order to achieve the objective sets in the study, is summarized as -

1) The ***base map*** has been prepared from the Survey of India, toposheet of the year 1972.
2) The Aster DEM of METI and NASA, has been used and has been processed by the versatile GIS software ArcGIS 9.0 in order to obtain the following data set:
    a) The ***contour map***, which is to be generated under the GIS environment using the ArcGIS 9.3 Software.
    b) The ***Slope map***, to be generated from the DEM.
    c) The **Aspect map** to be generated from the DEM.
    d) The ***delineation of the watershed*** of the study area to be done under GIS environment using the ArcGIS 9.3 software.

e) The ***delineation of the existing natural and man-made channels*** to be done with the Survey of India, Toposheet, 1972 and Google Earth Pro. satellite image.

f) The ***hydrological properties*** of the watershed to be determined carried under field & GIS environment are as follows:

   i. Area
   ii. Slope
   iii. Elevation

3) The ***urban hydrological and geotechnical data*** sets are then to be established by using different sets of data and methods as stated below

   a) Rainfall data
   b) Flow pattern of the natural rivers
   c) Land use and land cover Pattern
   d) Development of IDF Curve
   e) Estimation of the Runoff by Rational Method
   f) Existing capacity of the natural and man-made channels.
   g) Soil erosion by USLE-method.

4.2 DISCHARGE CALCULATION

For the discharge calculation, the Manning's equation has been used.

A = Cross-Sectional Area

P = Wetted Perimeter

R = A/P = Hydraulic Radius

Figure 4.1: Cross Section of a river

For the calculation of open channel flow empirical equations, Manning formula is has been adopted. This equation is applied to steady, uniform flow. The flow is steady and uniform when in the reach of the channel under consideration, the velocity **V**, the cross-sectional area of flow **A** and the hydraulic gradient **S** are everywhere the same and do not change with time. The hydraulic gradient is the change in water level per unit length. With the assumptions of steady, uniform flow, the hydraulic gradient equals the bed slope of the channel.

The equation for Manning may be written as in Eq. 3.1.

$$V = \frac{1}{n} R^{2/3} S^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where, v = average velocity of flow (m/sec)

n = Manning's coefficient

R = hydraulic radius (m) =A/P

S = channel bed slope

The hydraulic radius is the cross-sectional area divided by the wetted perimeter as explained in **Fig. 4.1**.

The Eq. 3.1 is used to estimate discharge, Q in m^3/sec.

The discharge equation is,

$$Q = A \times V \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where, A = Area of the channel in m^2

V = Velocity of the Channel in m/sec

4.3 RUNOFF CALCULATION

For the calculation of the surface runoff the rational method is used. This rational method is based on a simple formula that relates runoff-producing potential of the watershed, the average intensity of rainfall for a particular length of time (the time of concentration), and the watershed drainage area. The formula is

$$Q = C \times i \times A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

Where, Q = design discharge in cumec

C = co-efficient of run-off(dimensionless),

i = design rainfall intensity

A = drainage area

4.4 CALCULATION OF TIME OF CONCENTRATION (t_c)

The time required for rainwater to flow from the most remote point of the area to the outlet, once the soil has become saturated and minor depressions are filled is defined as the time of concentration. It is assumed that when the duration of the storm equals the time of concentration, all parts of the watershed are contributing simultaneously to the discharge at the outlet. There are several methods for computing time of concentration. Two of the most popular methods for determination of time of concentration are the Kirpich equation and the SCS lag formula. For smaller drainage basins that are dominated by channel flow, Kirpich (1940) equation can be used.

The Kirpich equation is given by Eq. 3.4.

$$t_c = 0.01947 x L^{0.77} x S^{-0:385} \quad \ldots\ldots(3.4)$$

Where, t_c = time of concentration (min),

L = length of main channel (in m), and

S = slope of the catchment.

4.5 SOIL LOSS

The Universal Soil Loss Equation (USLE) is used to predict the long-term average annual rate of erosion on a field slope. It is based on data related to rainfall pattern, soil type, topography, crop system and various management practices adopted. USLE only predicts the soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind or tillage erosion. The USLE more accurately represent long-term averages.

$$\mathbf{A = R \times K \times LS \times C \times P} \ldots\ldots (3.5)$$

Where,

A, represents the potential long-term average annual soil loss in tons per acre per year. This is the amount, which is compared to the 'tolerable soil loss' limits.

R, is the rainfall and runoff factor by geographic location. The greater the intensity and duration of the rain storm, the higher the erosion potential.

K , is the soil erodibility factor. It is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. The texture is the principal factor affecting K, but structure organic matter and permeability also contribute.

LS, is the slope length-gradient factor. It represents a ratio of the soil loss under given conditions to that at a site with the standard slope steepness of 9% and slope length of 72.6 feet. The steeper and longer the slope the higher is the risk for erosion

C, is the crop/vegetation and management factor. It is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. The C factor is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss from continuously fallow and tilled land.

P, is the support practice factor. It reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. The P factor represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope.

Thus to obtain the overall objects of the study area a systematic diagram of the functional integration of the data sets with the urban hydrology has been adopted and shown in Fig. 4.2.

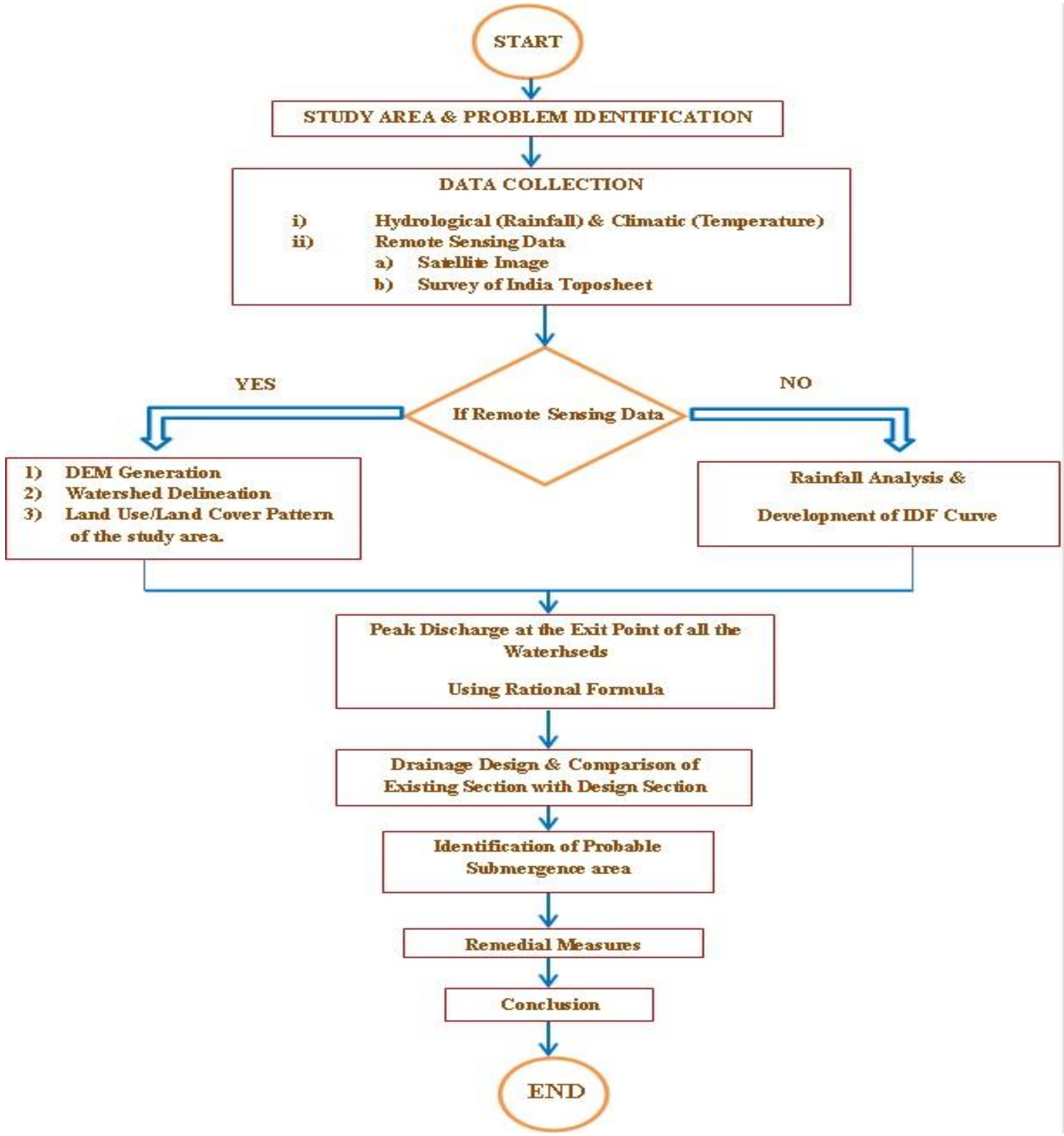

Figure 4.2: Methodology Adopted

4.6 SUMMARY

This chapter discusses about the methodology adopt for the present study. Various parameters that is aimed to be estimated are also highlighted in the chapter.

CHAPTER 5

DELINEATION OF WATERSHED OF THE STUDY AREA

5.1 INTRODUCTION

This chapter highlights the watershed characteristic and its basic parameters used in the hydrologic analysis and design. Then the delineation of the watershed of the study area with the Digital Elevation Model, (Aster DEM of NASA & METI) under the GIS environment has been discussed. The contour map, slope map, aspect maps has been generated using the DEM dataset. The stream network has also been discussed, and their relationship with the watershed has been shown. The essence of these parameters and its technical background has been discussed and finally the hydrologic parameters of the watershed been extracted. This chapter also focused on the existing drainage network of the study area.

5.2 WATERSHED AND ITS CHARACTERISTICS

The entire area of a channel watershed whose surface runoff (due to a storm) drains into the channel in the watershed is considered as a hydrologic unit and is called as drainage area or a catchment area of the channel flowing.

The boundary line, along a topographic ridge, separating two adjacent watersheds is called the drainage divide. The single point or the location at which all surface drainage from the watershed comes together or concentrates as outflow from the watershed in the stream channel is called the concentration point or the measuring point, since the stream outflow is usually measured in that point. The time required for the rain falling at the most distant point in a drainage area (i.e. the fringe of the catchment) to reached the concentrated point is called the concentration time. This is very significant variable since only such storms of duration greater than the time of concentration will be able to produce runoff from the entire the entire catchment area and cause high-intensity floods.

5.3 BASIC HYDROLOGICAL PROCESS IN A WATERSHED

The watershed is a drainage basin that is bound by topographic features, such as ridge tops. A watershed has three primary functions. Firstly, the watershed captures water from the atmosphere. Ideally, all moisture received by a watershed, whether in liquid or solid form, enters the ground where it falls. The water infiltrates into the soil and then percolates downward. Several different factors that affect the infiltration rate are topography, soil type, vegetative cover and climate. Percolation is also greatly aided by the activity of burrowing animals, insects, and earthworms. Secondly, the watershed stores rainwater once it filters through the soil. Once the soil in the watershed is saturated, water will either percolate deeper or flow as runoff on the surface. Thus, it results in the formation of freshwater aquifers and springs. Also, the type and quantity of vegetation, and the plant community structure, greatly affect the storage capacity in any watershed. The root mass associated with a healthy vegetative cover retains and increases the permeability of the soil. This in turn allows the moisture to percolate deep into the soil, thus increasing the storage capacity. The quantity and quality of water moving through the soil are greatly affected by the vegetation in the riparian zone. Finally, water moves through the soil to seeps and springs and is ultimately released into various water bodies. Slow release rates are preferable over rapid release rates, which result in short and severe peaks instream flow. Storm events which generate large amounts of runoff can lead to flooding, soil erosion and siltation of streams. The physical processes essential to the understanding of watershed systems are precipitation, infiltration, percolation, runoff, evaporation, transpiration, and erosion

5.3.1 Precipitation

Precipitation in its various forms is the major contributor to the quantity of water available for infiltration and runoff. Furthermore, precipitation plays a significant role in erosion and pollutant transport. Rainfall causes unprotected soil particles of the basin to get dislodged from the surface, which is the first step in the erosion process (Schwab et al. 1992). Rainfall also has the potential to transport airborne pollutants. An example of precipitation transporting airborne pollutants is given by Krecek and Horicka (2001), where it is reported that the watersheds in the

Black Triangle region of the Czech Republic have been undergoing restoration from the damage caused by acid rain resulting from upwind lignite coal-burning operations. Another study, Krecek and Horicka (2001), also reports that due to deposition of sulfate by rainfall in the Jizera Mountains, defoliation of spruce trees and low pH in reservoirs was observed. This deposition also resulted in increased sedimentation, and increased levels of aluminum, which affected the aquatic life. However, as reported by Krecek and Horicka (2001), with decreased coal power production in central Europe, improved forestry methods, and lining of reservoirs, water quality has been improving since the late 1980s. Precipitation depth and duration of a storm event are the important parameters used for estimation of the volume of water draining to the watershed outlet. Water depth divided by the time over which that depth fell is the intensity of the rainfall.

5.3.2 Infiltration and Percolation

Infiltration is the main process by which precipitation enters the soil mass. This process may be limited by the occurrence of surface compaction, crusting, sealing, or by the presence of an impervious layer (such as bedrock or clay) beneath the surface. Soil properties, surface cover, rainfall intensity, and the degree to which the soil is already saturated are the factors that influence the amount of rainfall that will enter the soil in a given period. Tillage generally influences the ability of the soil to absorb precipitation, both in terms of the spaces between soil aggregates and disruption of macropores formed by earthworms, insects, or roots. Conservation agriculture methods increase infiltration through minimal soil disturbance and maintenance of soil cover. Percolation is the downward movement of water to the aquifer. Water-soluble pollutants such as nitrate and some pesticides may be transported from the surface to the groundwater through percolation.

5.3.3 Evaporation and Transpiration

Liquid water evaporates to the atmosphere from soil, water, or other surfaces or by transpiration from plant tissue. The two processes combines to form evapotranspiration (ET) and can be accounted for a large portion of the water cycling through the system. Temperature, relative humidity, wind, vegetation type, soil cover, and other factors influence ET.

5.3.4 Runoff

Rainfall will initially infiltrate into the soil. When the rate of rainfall exceeds the rate at which water infiltrates into the soil, there may be some ponding and filling of surface depressions, then runoff will occur. Runoff rate plotted against time is called a hydrograph. Runoff volume is necessary for sizing storage structures such as reservoirs, as well as for estimating runoff-borne contaminant loads such as sediment. Runoff rate information is needed to size channels or pipes for conveying flow. Generally, it is neither practical nor necessary to measure the hydrograph for a particular watershed outlet resulting from a particular storm. Equations have been developed relating a watershed's time of concentration (time for water to travel from the most remote point of the watershed to the outlet) to the time to peak runoff and to the total time of runoff flow (base of the hydrograph) (Schwab et al. 1992). A simple relationship known as the Rational Method can be used to demonstrate some basic hydrologic principles. McCuen (1989) cites literature that traces the use of the method to the late 1800s.

5.4 BRIEF LITERATURE REVIEW

Watershed is a natural laboratory of hydrology. It can be defined as the area that drains the entire precipitation into a particular stream outlet. In another word it is the catchment's area from which all precipitation i.e. rainfall, as well as snow melt water, drained into a single stream. It forms naturally to dispose of the runoff as efficiently as possible. It is a natural convergent mechanism which consists of a network / branch of streamlets converging into a major stream. Studies of morphometry and hydrologic analysis on different watersheds have been carried out in many parts of the world drained into a single stream. It forms naturally to dispose the runoff as efficiently as possible. It is a natural convergent mechanism which consists of a network /branch of streamlets converging into a major stream. Studies of morphometry and hydrologic analysis on different watersheds have been carried out in many parts of the world. Relief and climate are the key determinants of running water ecosystems functioning at the basin scale (Lotspeich and Platts 1982, Frisselet al. 1986). Morphometric descriptors represent relatively simple approaches to describe basin processes and to compare basin characteristics (Mesa, 2006) and enable an enhanced understanding of the geomorphic history of a drainage basin (Strahler 1964). Drainage basin morphometric parameters can be used to describe the basin characteristics. These are basin size (stream order, stream length, stream number, and basin area), basin shape factors (circularity ratio, elongation ratio, form factor and compaction ratio), basin perimeter, bifurcation ratios, drainage density, stream frequency and drainage intensity. The risk factor of flood is indirectly related with the bifurcation ratio (Waugh 1996). Quantitative expression of drainage basin shape or outline form was made by Horton (1932) through a form factor.

5.5 BASE MAP OF THE STUDY AREA

Guwahati city is surrounded by - toward the north is the mighty river Brahmaputra and hillocks towards the south, east and west direction. Since last few year back Guwahati is facing storm water flood. The Guwahati city drainage is a serious problem. Two rivulets Bharalu (the upstream part of which is called Bahini) and Basistha, originating from the southern hill range, which is an extension of the hills of Meghalaya, run through the city of Guwahati. Both Bharalu and Basistha are the natural drainage channels for the Guwahati Metropolitan Area. The Bahini Bharalu channel has its outfall in the Brahmaputra and the Basistha channel flows into Deeper Beel, which again is connected to the Brahmaputra through a stream known as Khana Jan. Similarly, another stream called Bonda Jan in the east connects Silsako Beel with river Brahmaputra. However, the capacity of these channels has eroded in the recent times thereby proving to be inadequate to handle the storm water flows. Moreover, also to prevent the reverse flow from the Brahmaputra into Guwahati, Sluice gates had to be installed at the downstream ends of the Bharalu channel, Bonda Jan and Khona Jan, and pumps had to be installed at Bharalu sluice gate to discharge Guwahati drainage water into the Brahmaputra.

The base map of the study has been prepared from Survey of India (SOI) Toposheet 1972. The toposheet obtained from SOI has been processed in GIS environment. Figure 5.1 depicts the Base map of the study area used in the study.

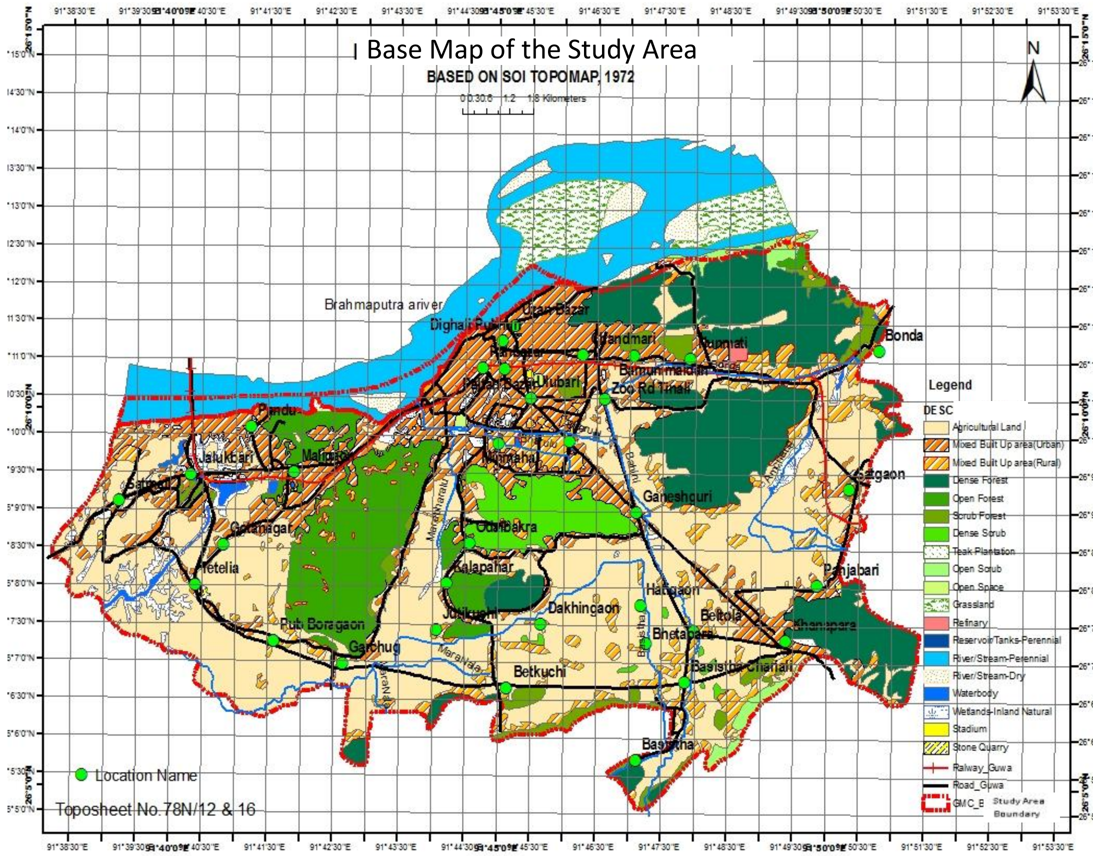

Figure 5.1: Base Map of the Study Area

5.6 DIGITAL ELEVATION MODEL (DEM)

A common task in hydrology is to delineate a watershed from a topographic map. To trace the boundary, one should start at the outlet and then draw a line away on the left bank, maintaining it always at right angles to the contour lines. (The line should not cross the drainage paths). Continue the line until it is generally above the headwaters of the stream network. Return to the outlet and repeat the procedure with a line away from the right bank. The two lines should join to produce the full watershed boundary. However, in recent years the use of GIS (Geographic Information System) has become increasingly popular and has facilitated much of the work of hydrologists. The use of DEMs (Digital Elevation Models) in particular has made watershed delineation a relatively smooth procedure.

A digital elevation model (DEM) is a digital model or 3D representation of a terrain’s surface commonly for a planet, created from the terrain elevation data. The DEM only represent the height information without any further definition of the surface. A DEM can be represented as a raster (grid of square, also known as a height map when representing elevation) or as a vector-based triangular irregular network (TIN). The TIN DEM dataset is also referred to as a primary (measured) DEM, whereas Raster DEM is referred to as a secondary (computed) DEM. The DEM could be acquired through techniques such as photogrammetry, lidar, land surveying, etc., (Li et al, 2005). DEMs are commonly built using data collected using remote sensing techniques, but they may also be built from surveying data. DEMs are used often in the geographic information systems (GIS), and are the most common bases for digitally produced relief maps. Aster DEM is released in geo-tiff format with geographic latitude /longitude coordinates and at 1arc-second (approximately 30 m) grid. The latitude-longitude coordinate of Aster DEM is referenced to the World Geodetic System 1984 (WGS 84). Figure 5.2 is the DEM of the Study area.

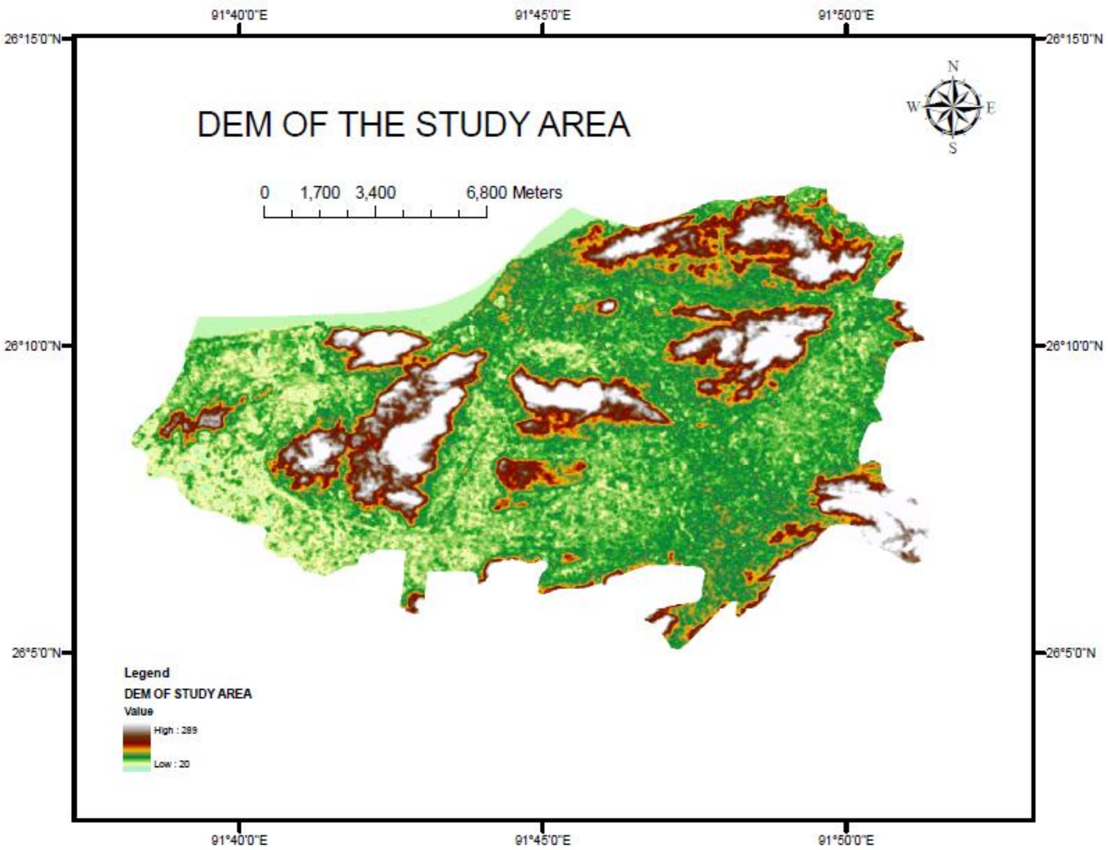

Figure 5.2: DEM of the Study Area

5.6.1 Generation of the Contour Map.

A contour line, which is also known as isoline or isopleths is an imaginary line which joins points of equal elevation. All the points of the given contour line are at the same height. It is one of the most important ways of showing the relief feature of ground surface on the map. It is two dimensional representation of the surface relief . It shows mainly the height of an area above Mean Sea Level (MSL), Fig 5.3. The contour line of the Guwahati region was generated using DEM of the study area with a 1meter interval in ArcGIS software.

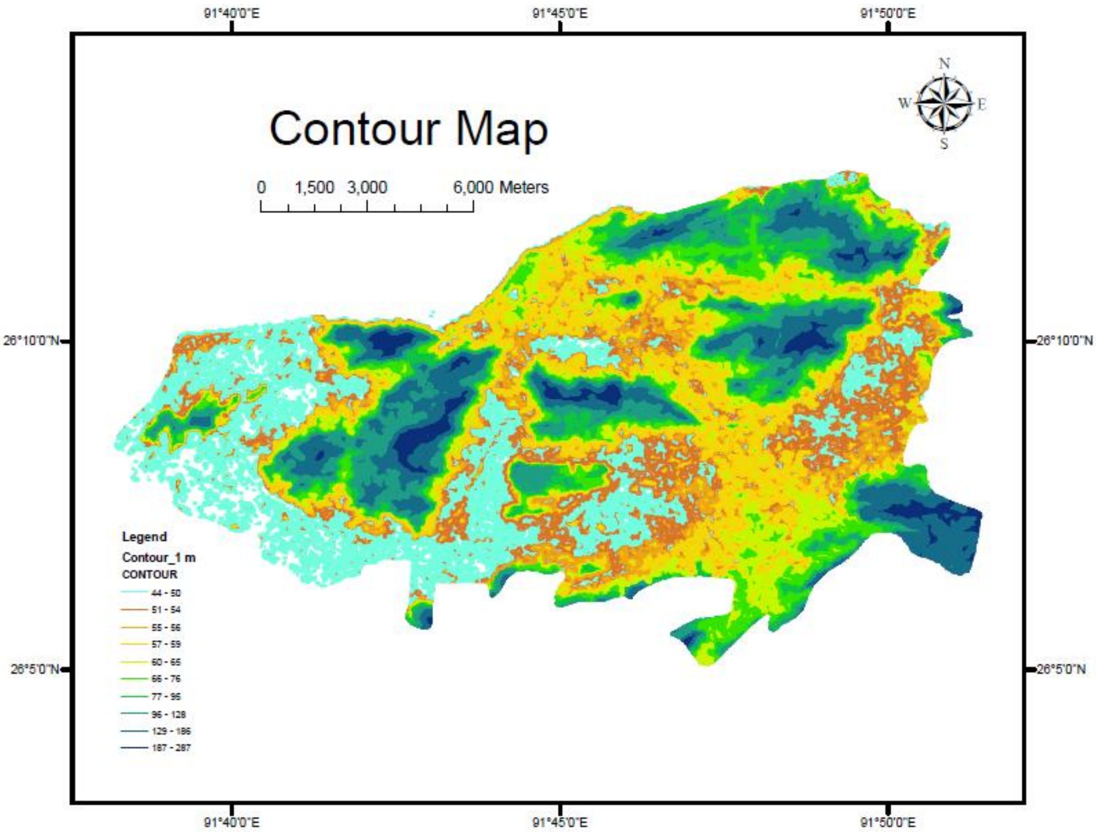

Figure 5.3: Contour Map of the Study Area

5.6.2 Generation of Slope of the study area

Slope is one of the major factors which plays an important role in identification and mapping of the flow of the water as well as of the landslide susceptibility zone. Movement of slope helps in predicting future landslide (Carrara et al., 1998). The stability of hilly terrain is highly influenced by the angle of the slope. Slope is defined as the degree of inclination of a feature relative to the horizontal plane, Fig.5.4. Most of the hills have moderate slope but without much vegetation cover. Development work carried throughout the city has resulted into instability of slopes in the region. Moreover, construction of large number of settlement over the hills without any appropriate measure has also played a crucial role in the slope failure in the region. Slope analysis is an important parameter in geomorphological studies for watershed development and important for morphometric analysis. The slope elements, in turn, are controlled by the climatomorphogenic processes in areas having rock of varying resistance (Magesh et al., 2011; Gayen et al., 2013). A slope map of the study area is calculated based on Aster DEM data using the spatial analysis tool in ArcGIS-9.3. Slope grid is identified as ‘‘the maximum rate of change in value from each cell to its neighbors’’ (Burrough, 1986). The percentage of slope in the study area watershed varies from 1% to 60% slope. Higher slope degree results in rapid runoff and increased erosion rate (potential soil loss) with less ground water recharge potential.

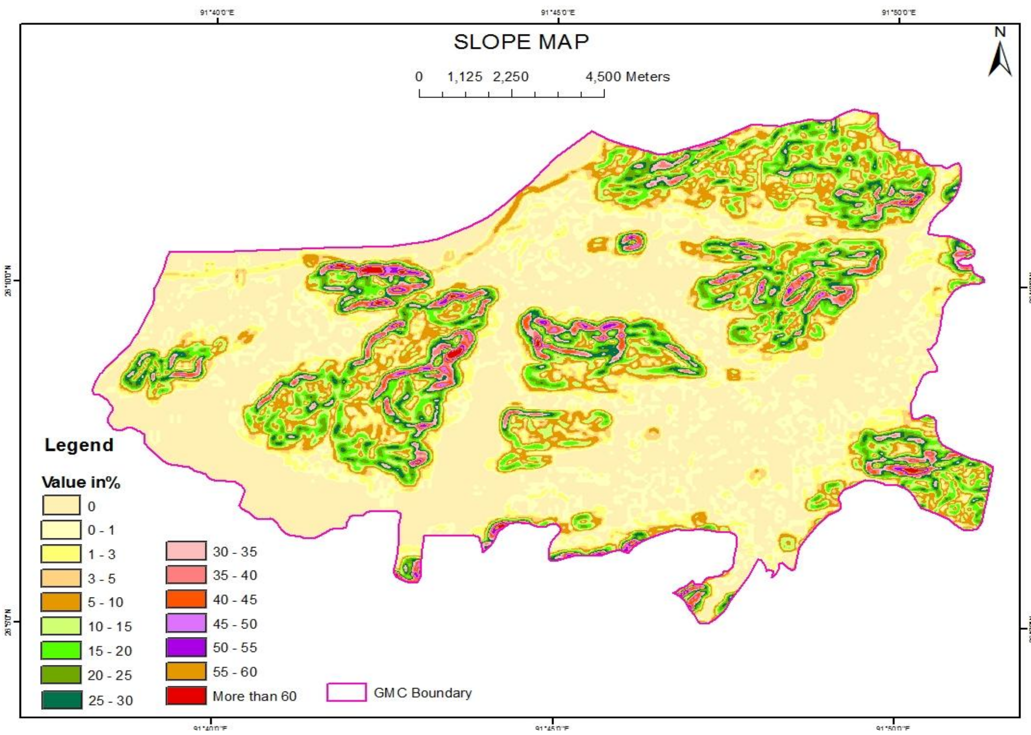

Figure 5.4: Slope Map of the Study Area

5.6.3 Generation of Slope Aspect Map

The slope aspect map shows the direction and steepness of hilly terrain slope. Slope aspect is an isoline map with selected aspect categories e.g. northeast, northwest, southeast, southwest etc. Slope aspect shows the direction a slope is facing towards. The direction of the slope in respect to the sun has a huge influence on its structural and chemical composition of the soil slope, Fig 5.5. Slope aspects are basically constructed on the basis of contour line data of the area.

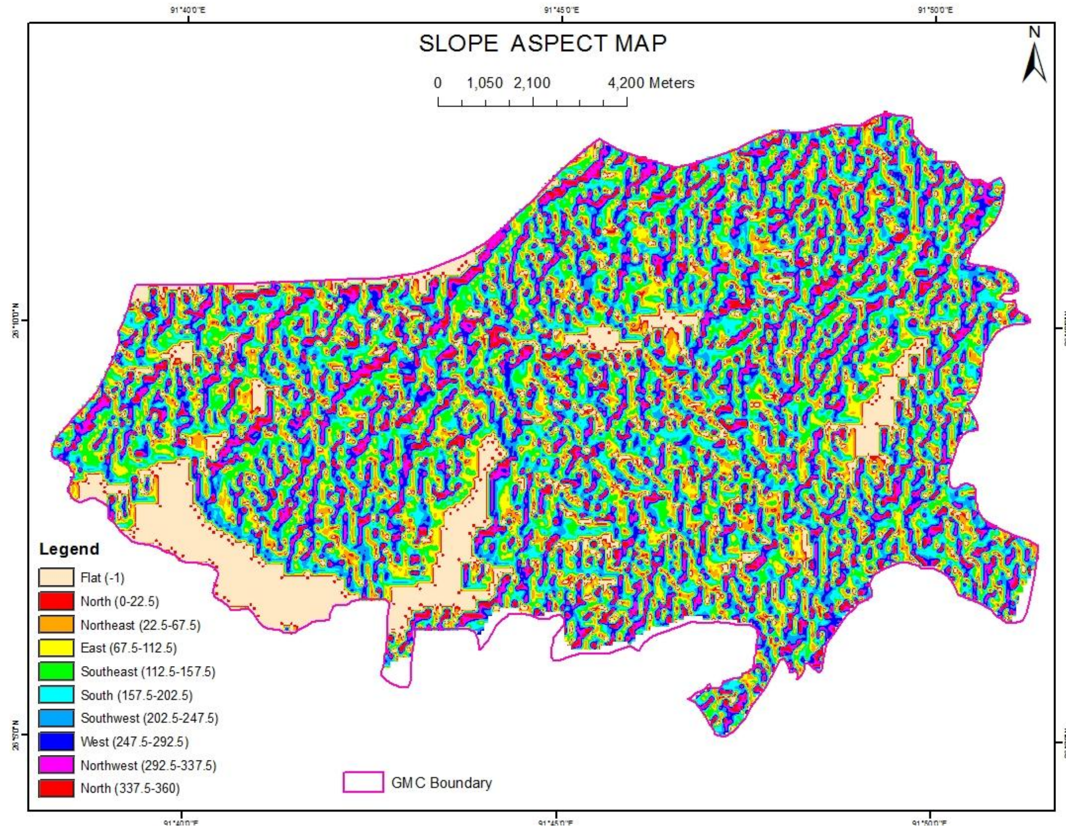

Figure 5.5: Aspect Map of the Study Area

5.7 DELINEATION OF WATERSHED OF THE STUDY AREA

The delineation of the watershed of the study area has been done under GIS environment. For this purpose, Aster DEM is processed using a GIS software ArcGIS 9.0. The DEM is given as input raster in the ArcGIS Hydrology tool under Spatial Analysts Tool extension tool in the ArcGIS software, and then is processed under GIS environment. By the geo-processed techniques the delineation of the watershed has been done. The contributing watershed area was extracted with the help of various geo-processing techniques in ArcGIS version 9.3. The DEM, the flow direction and the flow accumulation datasets are the input parameters required for the delineation of the watershed, as shown in Fig. 5.6.

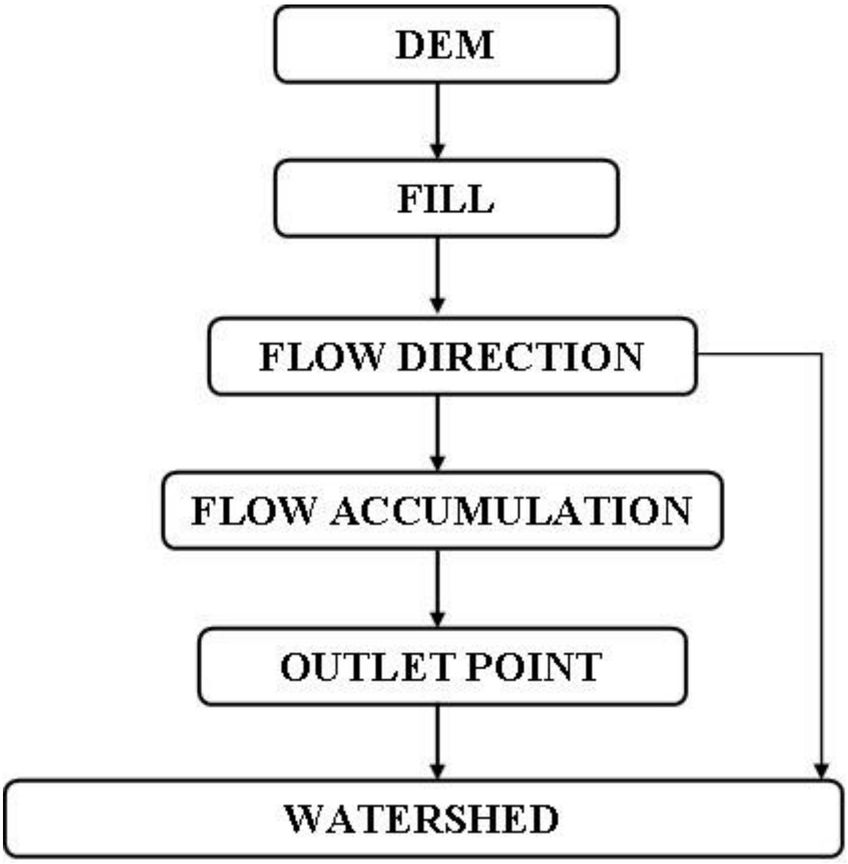

Figure 5.6: Flow Diagram of Delineation of Watershed

The main objective of this research is to implement new sound technologies or process such as remote sensing, and GIS with the help of which the determination of hydrological parameters becomes easier than the use of the traditional method. The research has focused on stream and watershed delineation and in general, the analysis is based on the topographic data. Digital Elevation Model (DEM) is generally produces by photogrammetric technique from stereo-photo pairs, stereo satellite images or interpolation of elevation data. Thus the procedures for delineating streams and watersheds from DEMs were followed in the study. A DEM of 30m resolution has been used to drive the needed hydrological parameters. The flow direction grids were computed from the DEM. And with this flow direction assigned for each DEM point, the flow accumulation for a given point has been defined as the number of DEM points whose flow paths eventually pass through that point. And using the flow accumulation and location of the watershed outlet, the watershed boundaries has been defined. The watershed boundaries are delineated from the outlets at each stream junctions. Based on the grid cells system the DEM technique can be used to provide basic input data. Flow direction, Slope and Aspect of the grids can be computed from DEM based on the terrain analysis and relative hydrological parameters determination method, (Baillard et al., 1998, 2000). Thus under GIS environment, many input parameters, such as, land slope, aspect, slope shape factor, field slope length and soil texture required are terrain based and which could be obtained directly or indirectly. In this study only a few of these parameters including flow direction, flow accumulation, land and channel slopes and water contributing area has been included.

The DEM with 30 m resolution has been processed to removes depression that cause non-contributing area to be formed in the basin. Flow direction is needed in hydrology for the determination of the paths of water movement. A grid representing flow direction is produced from the DEM. The values of grid cells in the flow direction represent a code for defining one of the eight possible directions for water to move out of that cell. The direction of this grid define a unique path leading from each cell to the DEM outlet. From the flow direction grid, the flow accumulation grid is formed and by tracing the unique downstream path of each cell, the total number upstream cells draining through each cell is calculated. Once the pit has been filled and the flow directions is known, the drainage area in units of cell is calculated by the flow accumulation. This flow accumulation grid stores the number of cells located upstreams of each cell area, equals the drainage area. Once the flow accumulation grid is formed, the stream grid is usually defines as the grid cells where the flow accumulation grid exceeds a certain threshold of the contributing area, these streams (in raster format) is vectored to form a set of stream lines. A watershed is the upslope area contributing flow to a given location. Such an area is also known as basin, catchment or contributing area. Watersheds are thus delineated from the DEM by computing the flow direction and using it in the watershed function. The watershed function uses a raster of flow direction to determine the contributing area. The pour point (outlet point) has been used with the flow accumulation threshold value to delineate the watershed. When the threshold is used a watershed, the pour points for the watershed will be the junction of a stream network derived from flow accumulation. Therefore the flow accumulation raster must be specified as well as the minimum number of cells that constitute a stream (the threshold value). Also, when a feature dataset is used to define a watershed, the features identify the pour point.

The outlet point for each watershed has been identified. This outlet point has been used to as a source to delineate the watershed boundary. Thus under the GIS environment the whole study area has been divided into 39 no of watershed shed as shown in Fig 5.7. The watershed boundary has been identified and the area of each watershed has been calculated. The watershed of the study area, (Guwahati city) contributes its water in its own drainage basin. The whole study area has been divided into five number of drainage basin. They are as follows:

1) Bharalu Basin
2) Silsako Basin
3) Basistha Basin
4) Mora Bharalu Basin
5) Foreshore Basin.

It is observed that the all the 39 no of watershed of the study area contributes it water to its own drainage basin, Fig. 5.8

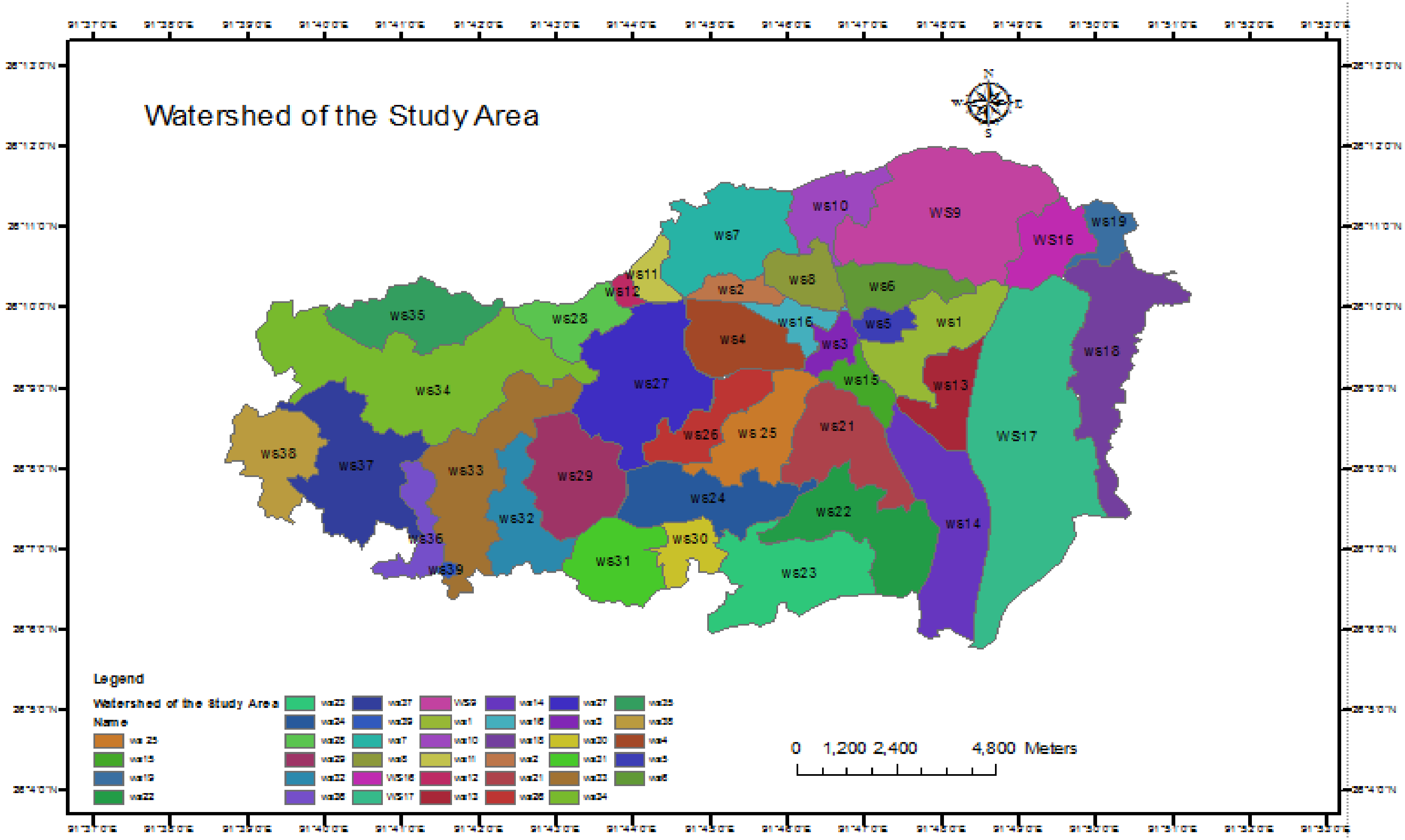

Figure 5.7: Delineated Watershed of the Study Area

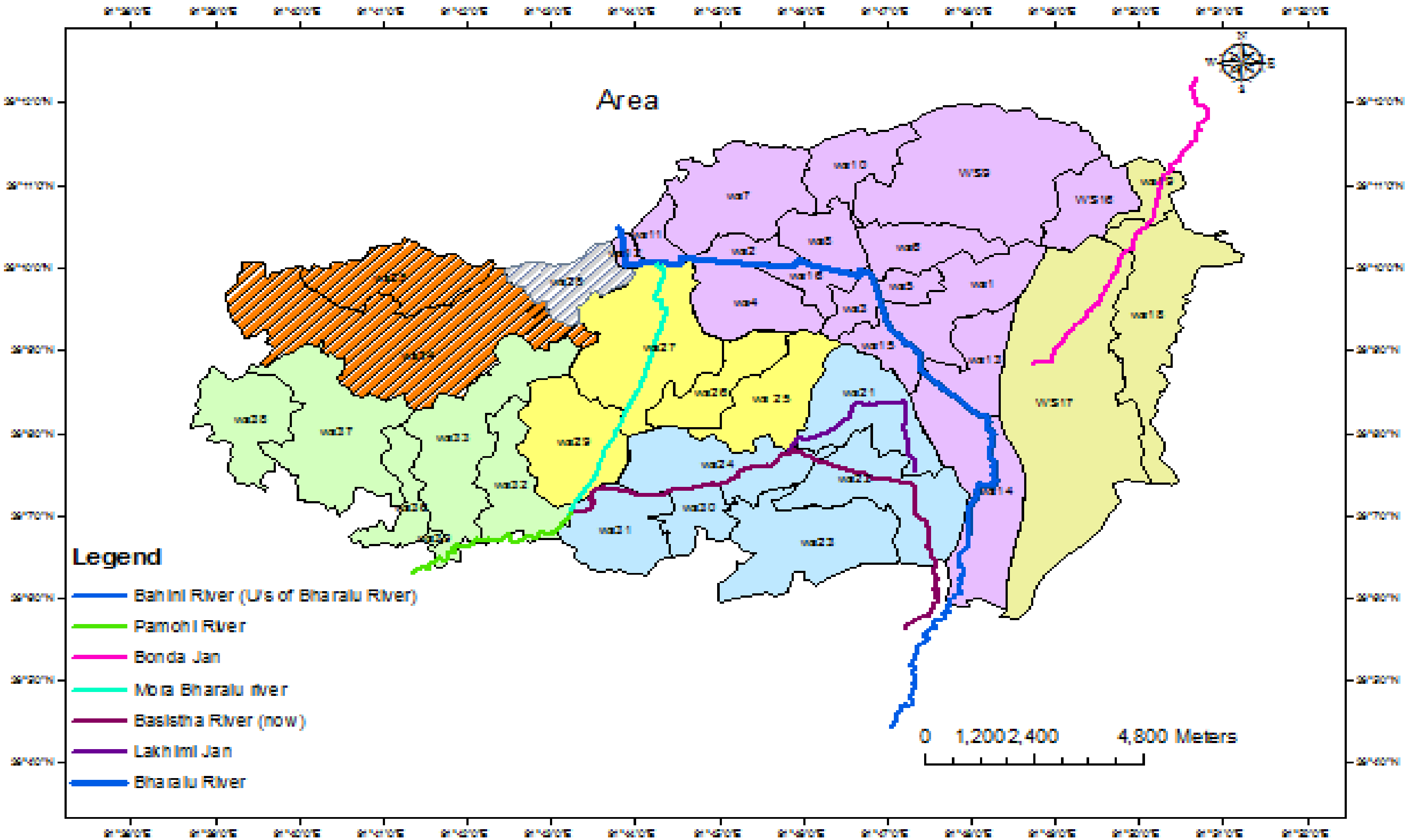

Figure 5.8: Watershed contribution to its Drainage Basin

For the research work, the watersheds contributing to the Bharalu Basin has been considered and the hydrological parameters of this watershed has been considered for further analysis of this basin to reduce the damages to be caused by the flash flooding.

5.8 BHARALU BASIN

The Bharalu basin comprises of area 52.4 sq km. to the east is the Silsako Basin, to the north lies the foreshore basin and the mighty river Brahmaputra, to the South is the NH-37 bypass and the Basistha Basin to the western part lies the Mora Bharalu Basin. It is observed that the Bharalu basin suffers flash flood during a small duration of rainfall with high intensity. This basin has important communication network, and linkage to every important office, educational institutions, hospitals, and other urban activities. With the state's capital and almost 80% of the important structures with historic importance lie within this basin. Since the flash flood creates drastic scenario, by paralyze the basin even during short duration of rainfall, thus the reason for the flash flooding has been analyses and thus the analysis for this basin has been given first priority. It is observed, 16 numbers of watershed contributes it water directly or indirectly to the Bharalu basin.

The hydrological property for this basin has been calculated under GIS environment. The watershed boundary area this basin is shown in Fig. 5.9

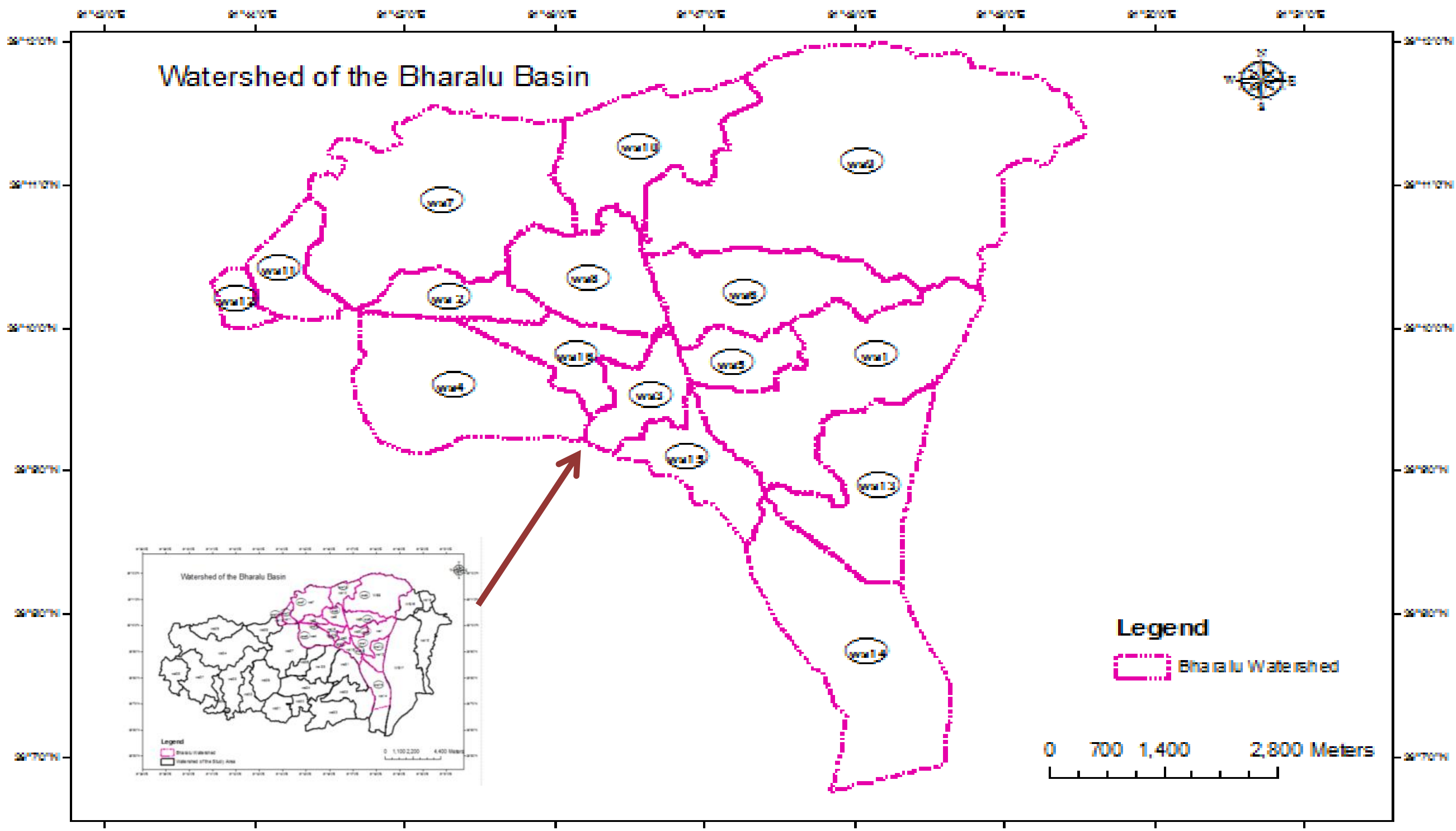

Figure 5.9: Watershed of the Bharalu Basin

All the 16 nos of watershed contributed its water individually to this basin. All these watershed are almost being developed by unplanned manner. As such these watersheds have lost its natural drainage pattern. All the surface area are being built up in an haphazard manner with no room for the natural drainage pattern. As such the flash flood has being increased day by day with the short duration of rainfall. Out of the all 16 numbers of watershed, 5 nos. of watershed i.e WS8, WS6, WS2, WS3 & WS5 faces acute flash flood problem. It is noteworthy to be mentioned that none of the watershed has a definite storm water drainage pattern and as such the surface runoff during heavy shower find no way to flow through the stream pattern and thus inundates first the low-lying areas and gradually flood the other parts of the watershed, like roads, houses, etc. The surface pattern of these watersheds has been discussed in the Chapter 6. The surface pattern has been compared with the toposheet of Survey of India, 1972 which has been geo-referenced in GIS environment and satellite image of 2011, IRS-LISS-III. The changes in the land use pattern has been observed and thus with the unplanned development, these watershed has lost its natural drainage flow.

5.9 RESULTS AND INTERPRETATION

The Bharalu basin comprises of 16 number of watershed. From the field observation and satellite image from Google Earth, it is observed that the elevation of this basin varies from 260m to 40m. It is surrounded by small hillock. Through there is the mighty river Brahmaputra flowing to the northern part of the basin, yet it is unable to discharge its water to the Brahmaputra river, it is because of it topography and terrain condition. The only outlet of this basin is the river Bharalu which discharges directly in to river at Bharalumukh. The Bharalu basin is of undulating terrain, almost 60% of its terrain lies in the elevation in the range between 48m to 52m, which can be assumes to be a flat terrain with undulating surface. The basin slope from the east to north-west. The length of the primary channel (river Bharalu) is about 14.3 km from the NH-37 bypass up to its outfall point at river Brahmaputra. The river Bharalu carries the surface runoff along with the waste water from each contributing watershed. Almost all the watersheds have some portion of hillocks and a very unplanned settlements with all kind of complex structure. There is no definite storm water conveying system in any the watershed.

5.9.1 Identification of the Low Lying and Worst Flood Affected Area:

It is observed that that flood affected and low lying area of this Bharalu Basin area are has been stated below:

1. GNB road from Guwahati Club to Silpukhuri.
2. RG Baruah road from Zoo Road Tinali to Ganeshguri.
3. GS road from Ganeshguri to Bhangagarh
4. Guwahati Club, Islampur and Hedayetpur.
5. Nabagraha road and its adjoining areas,
6. Nabin Nagar, Anil Nagar, Rajgarh, Lachit Nagar, Ambikagiri Nagar, Tarun Nagar etc,
7. Some areas of A.T. Road. Athgaon area near Kumarpara Panchali
8. Kumarpara and Machkhowa area.
9. Rehabari, Rupnagar, Birubari and Srimantapur.

Thus it is observed that whole of these locality is fully built-up and developed area. All these area has definite road network and all other land have been used for the construction purposes. It is also observed that the depression zones, low-lying area, existing water bodies which were used to storage of storm water, now at present, has been fill up for human activities. Even the hills are also encroached drastically and have reduced its forest area. These encroachments on the hills have affected the ecology of the hills and have resulted in soil erosion and landslides in some localities, during heavy downpours. It also created the sedimentation problem in the roadside drains and thus decreases the load carrying capacity of the drains. As a result during heavy down pours these drains overflows the drains and inundates the nearby locality. So here it is proposed that some preventive measure and maintenance for the surrounding hill related to soil erosion and landslide has to be taken up.

Thus with the delineation of the watershed of the Bharalu basin, the boundary and the stream of the watershed has been identified and thus the hydrological parameters can be easily determined. The hydrological parameters of the watershed has been shown in the Table 5.1

Table 5.1: Hydrological Parameters of the Watersheds of the Bharalu Basin

Watershed ID	Area in Sq.km	Highest Elevation (m)	Lowest Elevation (m)
1	4.79	270	48
2	1.20	78	42
3	1.25	179	43
4	4.13	253	40
5	1.05	188	44
6	3.00	205	44
7	6.43	180	40
8	2.35	179	42
9	12.31	223	46
10	3.11	210	41
11	1.15	87	40
12	0.43	74	40
13	2.97	169	40
14	5.21	83	51
15	1.56	175	41
16	1.46	113	40

5.10 SUMMARY

This study focused in the determination of the hydrological parameters for the peak discharge design of the watersheds of the study area and also focuses on the importance of the remote sensing and GIS techniques which are increasingly becoming an important tool in hydrology and water resources development. The possibility of rapidly combining data of different types in a GIS has led to significant increase in its use in hydrological applications. These tools can be used in hydrology through determining the watershed geometry and other map type information and providing input data that are used in hydrological simulation. DEM was used to drive the flow direction, flow accumulation, watershed boundaries, sub basins and drainage network. The derivation of such information through the using remote sensing and GIS would be very useful in storm water design, site selection and designing of water harvesting project with minimum cost, efforts and time compared to the traditional methods in addition to giving an accurate results.

CHAPTER 6

INTEGRATED GIS AND REMOTE SENSING BASED STUDY ON THE CHANGES IN LANDUSE / LAND-COVER PATTERN OF GUWAHATI CITY AND GENERAL CONSEQUENCES

6.1 INTRODUCTION

Like many other fast developing metropolitan cities, Guwahati being a premier city of the North-Eastern Indian region, has shown a rise in unplanned growth induced problems like flash flood, heavy erosion in the city hills and landslides. This issue has led not only to the loss of property but also caused loss of human life. These problems are thought to be primarily due to the change in the landuse / land cover (LULC) cover pattern of Guwahati in last few decades. In this study an attempt has also been made to examine the changes in the LULC pattern over the last few decades.

The LULC pattern is a factor which affects the runoff during storm event. This study aims to focus on the changes in the landuse pattern which has a direct impact on the climate and environment of the study area. The findings of this study will be a helpful tool for the planner and decision maker for the future expansion of the city in a sustainable and healthy manner. This study also demonstrates the application of remotely sensed satellite data to dynamical monitoring of the process of development and urbanization and the loss of arable land. Integrated technologies of remote sensing and the geographic information system (GIS) have been used to analyze the urbanization process of Guwahati City with its impact on urban flood. Spatial information was acquired from remotely sensed data, while factors responsible for urban flooding and unplanned development of the city were analyzed. The study of the LULC pattern of the study area has been carried out under GIS environment and the data set with the Survey of India (SOI) topo map of the year, 1972 and has been compared with the satellite image data of IRS LISS III.

6.2 METHODOLOGY

The LULC maps are generated from the digitized topomap of SOI 1972 and IRS LISS III satellite image of 2011. The Survey of India toposheet, 1972, is geo-referenced and processed under GIS environment using GIS software Arc GIS 9.0 to obtain the LULC of year, 1972. Similarly the satellite image of 2011 is geo-processed under GIS platform and the LULC map is generated. These maps are used to prepare the LULC to study the changes in the land cover pattern of the study area. A comparison between the LULC of 1972 with that of 2011 is then made.

6.2.1 Landuse / Landcover (LULC) Pattern of the Study Area

The LULC maps are very useful for identifying the different pattern of land. It is most important in analyses of the developments of the land, indication of the vegetative cover, settlements, overall imperviousness of land, deforestation or vice-versa in relation to change in landuse pattern of the study area over a different period. The LULC map of the year 1972 is shown in Fig.6. 1and the distributed area of the LULC pattern is illustrated with the pie diagram in Fig. 6.2

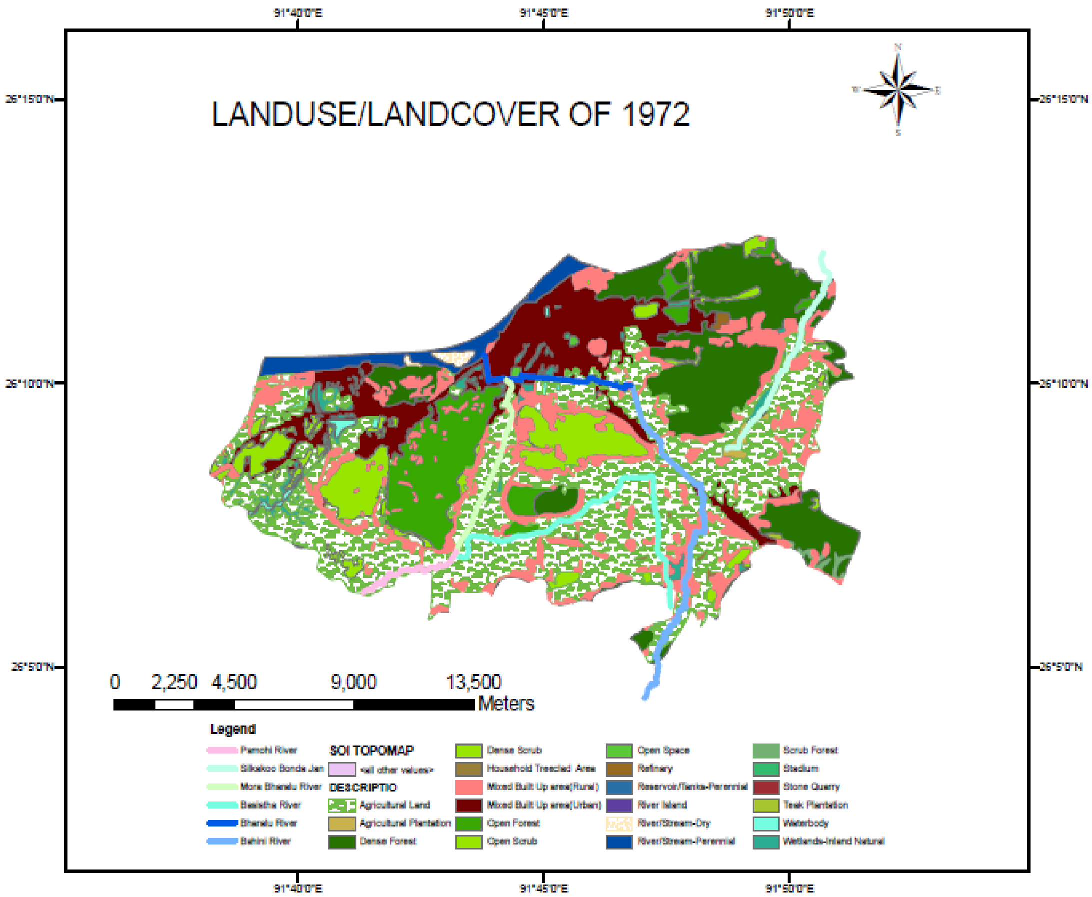

Figure 6.1: Land Use Land Cover Map of the study area in the year 1972

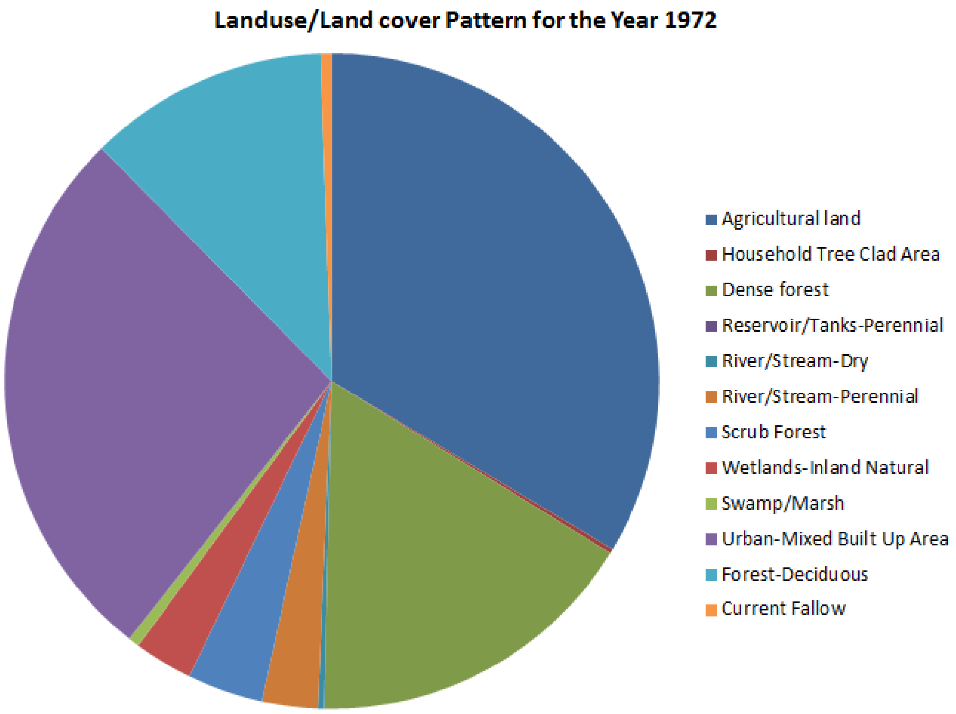

Figure 6.2: Shows percentage of land use /land cover for the year 1972

LULC map for the year 2011 is generated and is shown in Fig. 6.3 and the distributed area of the LULC pattern is shown in the pie diagram in Fig. 6.4.

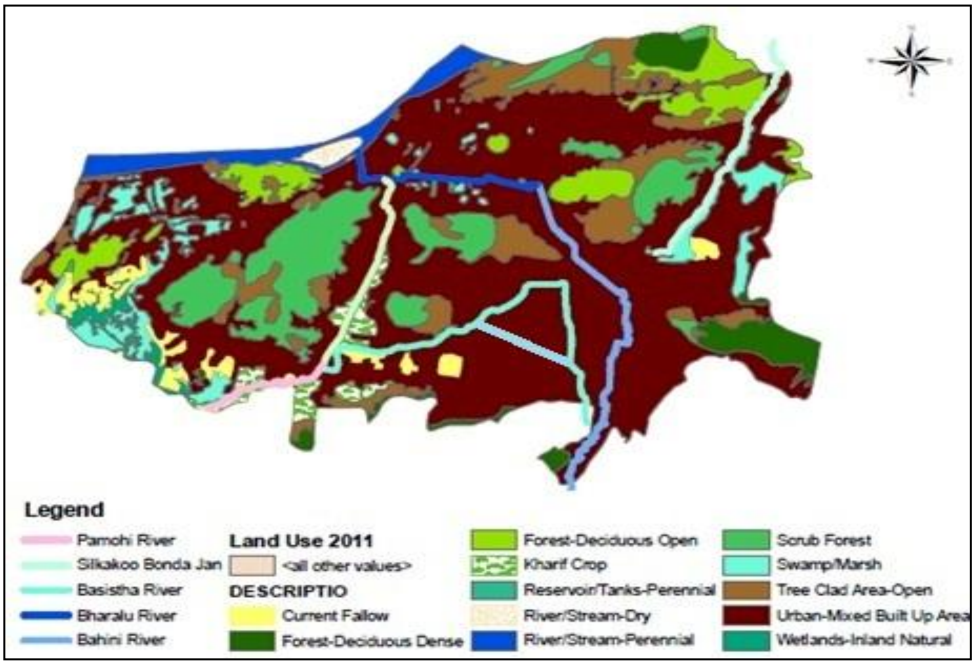

Figure 6.3: LULC Map of Guwahati for the year 2011

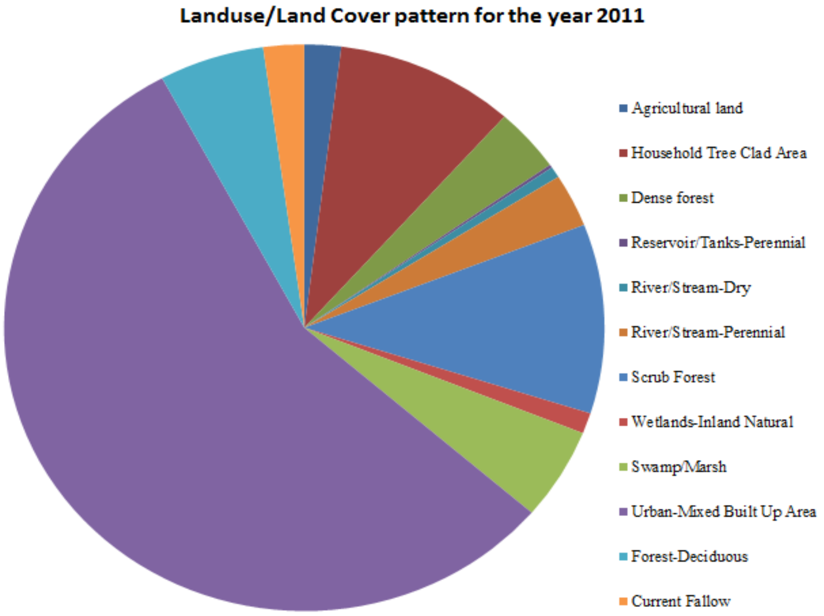

Figure 6.4: Percentage of land use /land cover for the year 2011

6.3 ANALYSIS AND RESULT

LULC maps and the Pi-Diagrams of Fig. 6.1 through Fig .6.4, clearly indicates the changes in the LULC pattern of Guwahati. A clear comparison of Landuse/ Land Cover between 1972 and 2011 is shown in Fig. 6.5. It is observed that the agricultural land in 2011 has reduced compared to that in 1972. On the otherhand the built -up area has increased There has been drastic changes in the forest cover , swampy or marshy lands as well.

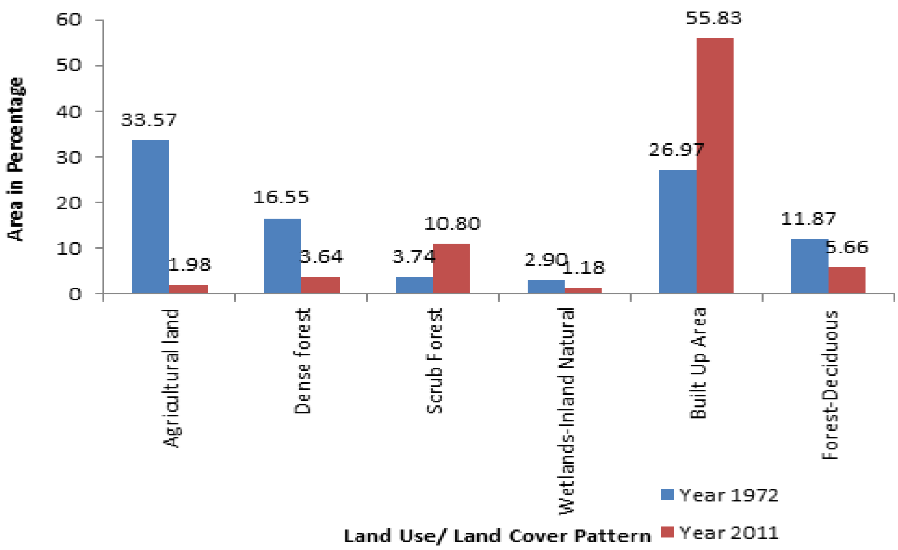

Figure 6.5: Comparison of the LULC pattern of 1972 and 2011

The significant change in the landuse pattern may be attributed to the unplanned rapid development of Guwahati, which can be corroborated by the following-

i) Increase in population

Their has been a phenomenal growth in the population in Guwahati. As per census report of 1971, Guwahati had a population of only 123783 where as 2011 census report recorded a population of 963429, which is 778.3% growth with reference to 1972, Fig. 6.6

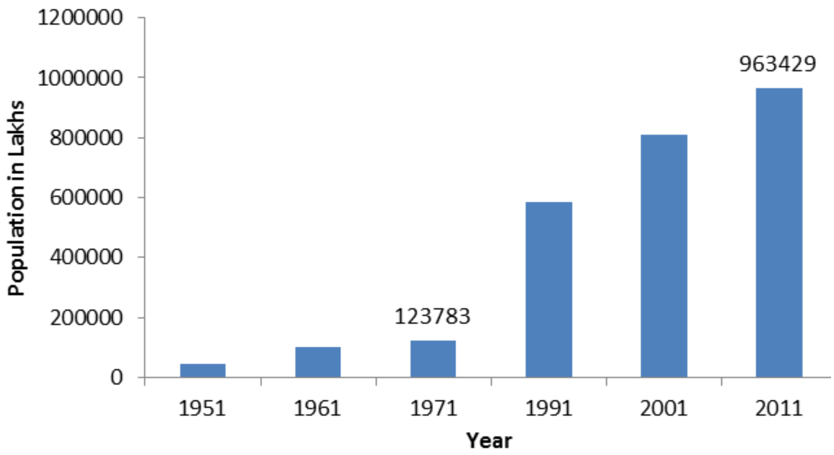

Figure 6.6: Increasing Trend in Population

(Source: Census Report of India)

ii) Increase in the Built-up area

Fig. 6.7 clearly demonstrates that built-up residential area of Guwahati has increased from 4.8 sq.kM in 1971 upto 87.48 sq.kM in 2001. The increase in the population has led to the increase in the Built-up residential area.

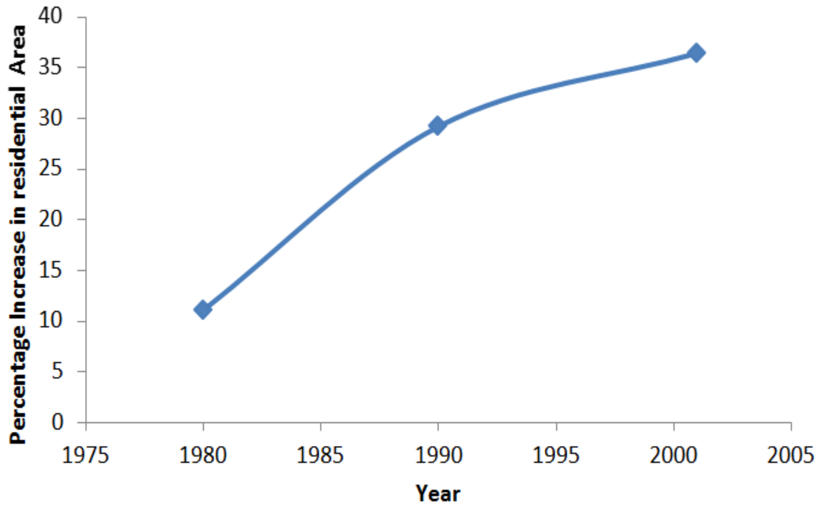

Figure 6.7: Increasing Trend in Built-Up Area

iii) Increase in the Hill area settlement

The increasing trend in the population of Guwahati has also given rise to human settlement in the hill areas of the city and thus, in turn has led to the decrease of the dense and deciduous forest area. As per one survey in 2011(AC Nielson, 2011), the GMC area comprises of 16 hills on which a total of 65,894 households reside. The Guwahati Slum Policy of 2009 identified about 24 hill settlements, having a population of 5,380 households, as slums. (Source, GMC Slum Policy Report, 2009).

6.4 GENERAL CONSEQUENSES

As a result of the above mentioned factors, the general consequences on Guwahati may be easily explained.

i) Increase in the surface runoff and decrease in the ground water infiltration

Due to the increase in the impervious surface , there is frequent occurrence of the flash flood in the Guwahati. As such due to the increase in the population growth, built up area has incresed, a decrease in the agricultural and open land.

ii) Increase in the extreme rainfall events

Due to the changes in the LULC pattern, specially changes in the forest and agricular area, which are the natural landscape and the hydrology of the area depends upon these factors. So changes in these factor directly disturbs the natural hydrology. Figure 6.8, depics the increae trend in the extreme rainfall event, and due to the increase in the extreme event, the chances of flash flood is also increased.

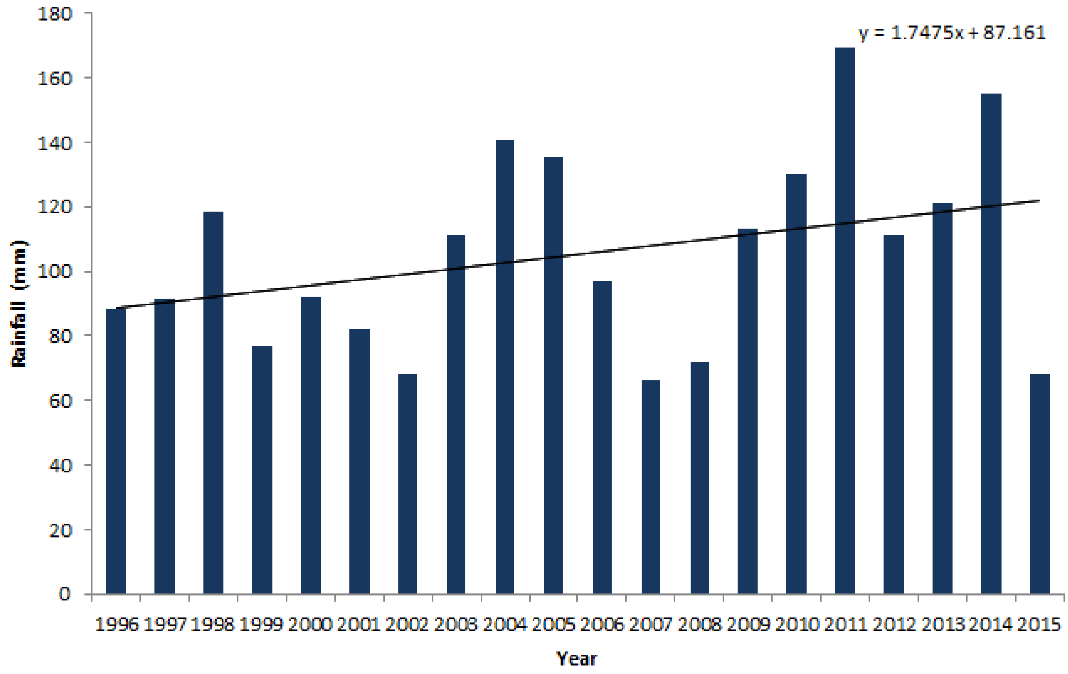

Figure 6.8: Increasing Trend in Extreme Rainfall Events

(Source: RMC, Guwahati)

iii) Hill erosions and Landslides

From Fig.5 the decrease in the Scrub Forest and Forest Deciduous area, and the increase in the built-up area are the factor for the hill erosions and the landslide problem in the Guwahati city. The cutting of hills and deforestation also decreases the interception and infiltration rate during rainfall and thus increase the surface runoff. In the recent years there being many landslide cases in the Guwahati city, which has taken more than 60 lives in the last decades. it is also observed, deforestation of the hills creates soil erosion which is a major cause of sedimentation in the foothill including the clogging of the channel or drains in its neighborhood. The deforestation is a major factor for the flooding because it fails to intercept the rainfall and decrease the infiltration rate thus increases the runoff during a storm event.

6.5 SUMMARY

The aim of this study is to assess the LULC pattern of the study area and its environmental impact. As can be seen from the analysis and result it is evident that the LULC pattern of the study area has undergone a drastic change. And the growth of urbanization has been increased in unplanned manner and which is directly or indirecly related to the problem of flash flood and other related hazard landslide and erosion of the study area.

CHAPTER 7

GENERATION OF INTENSITY DURATION FREQUENCY CURVE USING SHORT DURATION RAINFALL DATA FOR DIFFERENT RETURN PERIOD FOR GUWAHATI CITY.

7.1 INTRODUCTION

Estimation of Peak Flood Discharge for the desired return period is a pre-requisite for planning, design, and management of hydraulic structures like storm water drains, barrages, dams, spillways, bridges, etc. One of the objectives of the present study is to develop an IDF Curve for the Guwahati city by using the Gumbel's Extreme Value distribution and to generate an IDF curve and estimate the rainfall intensity for any duration and any return period. Short duration rainfall data for the year 1990 to 2014 has been collected from Indian Meteorological Department. This model is developed to predict precipitation depth for various return period storms. The derived precipitation depth is utilized for generation of intensity duration frequency curve having different return periods.

In the past, many researchers have developed IDF curves for different regions of the world. Bell (1969) generated IDF curves for certain areas of U.S.S.R; Al-Sheikh (1985) has developed IDF relations for Saudi Arabia. Al-Khalaf (1997) has conducted a study for generating short-duration, high-intensity rainfall in Saudi Arabia using IDF studies. Koutsoyiannis (1998) has suggested the construction of IDF curves using data from recording as well as non-recording stations. Elsebaie (2012) generated IDF relationship for two regions in Saudi Arabia. Ogarekpe (2014) has generated IDF relationships for Calabar Metropolis, South-Nigeria.

Al-Khalaf (1997) suggested that IDF relationships are area specific. Development of IDF relationships largely involves the knowledge of the underlying distribution. There are commonly used distributions in IDF, and other similar other studies include Gumbel, Generalised Extreme Value, Pearson Type III and Log Pearson Type III distributions (Al-Dokhayel, 1986; Dupont and Allen, 2000; Hadadin, 2005; Nhat et al. , 2006 and AlHassoun, 2011). The present chapter attempts on the generation of IDF curves and relationships for the study area using the Gumbel's Extreme Value distributions.

7.2 APPLICATION OF IDF CURVE IN URBAN DRAINAGE DESIGN

Storm sewers make up the majority of the constructed urban drainage system. In the design of storm sewers, the rational method is commonly used to estimate the peak flows resulting from storms of specific return periods. The rational method is expressed as,

$$Q = C\ i\ A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 7.6$$

Where, Q = Discharge

C = runoff coefficient

i = intensity of rainfall of chosen return period for a duration equaling the time of concentration of the catchment; and

A = area of the catchment.

Average rainfall intensities for durations of 5 min to several hours are needed in estimating design flows for urban drainage systems. As seen the only unknown part in this Eq. 7.6 the intensity of the rainfall which can be easily derived from the constructed IDF curves with any level of significance.

7.3 RAINFALL REGIME OF THE STUDY AREA

Guwahati city falls within the area comprising of the northern and north-eastern India as well as adjoining parts of Nepal, Bangladesh, and North Myanmar. In this part, the rainfall generally occurs in the months of monsoon, i.e., from June to September while the months from November to February are generally dry with occasional winter rains. It has been observed that the following four meteorological conditions are mainly responsible for heavy rainfall and subsequent floods:

a) Movement of a monsoon trough to the northeast of the Bay of Bengal to the sub-basin
b) Shifts of the monsoon trough to the north from its normal position.
c) Formation and movement of lowlands or land depressions over North-East India.
d) Circulation of cyclonic upper air over North-East India.

The annual rainfall in Guwahati was on average 1,681 mm from 2008 to 2012 (*Source: IMD Monthly Rainfall data from 2008 to 2012*). Of this amount, 63% of the rain fell during the monsoon months (June to September), 31% during the pre-monsoon months (March to May), 5% during the post-monsoon months (October to November), and 1% during winter (December to February). Hence, approximately 94% of total annual rainfall occurred during the wettest seven months (March to September).

7.4 OBJECTIVE & DATA COLLECTION

This chapter aims to establish a relationship between the intensity, duration, and frequency of rainfall and use it to assess the probability of intensity of the rainfall in the future for a given duration of time. For this study, hourly daily rainfall data from period 1990 to 2014 has been collected from Regional Meteorological Center, (RMC), Guwahati and Intensity duration frequency curve is generated using these data. The rainfall intensity-duration-frequency (IDF) relationship is one of the most commonly used hydrological tools in departments like water resources engineering, planning, designing and operating of water resource projects, or the protection of various engineering projects (e.g. highways, etc.) against floods. They describe the relationship between mean precipitation intensity and frequency of occurrence (the inverse of the return period) for different time intervals of a given duration. These intervals over which the precipitation intensity is averaged are called durations. The intensity,i, is time rate of precipitation, that is, depth per unit time (mm/hr). The average intensity is commonly used and can be expressed as Eq. 7.1

$$i = P/D \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7.1)$$

Where, P is the rainfall depth (mm or in) and D is the duration, usually in hours. The frequency is usually expressed in terms of the return period, T, which is the average length of time between precipitation events that equal or exceed the design magnitude.

7.5 APPROACH

The first step of constructing the IDF curve for a given region is to assess the local rainfall data and determine the maximum rainfall depth associated with each year. The maximum rainfall depth has been found for the different duration of rainfall, and descriptive statistical analysis is done for each duration. The mean and standard deviation are determined as functions of duration. One for the mean depth of rainfall, μ, as a function of the duration of the rainfall and the other one as the standard deviation (σ) of the depth of rainfall. Then a Probability Distribution Function (PDF) or a Cumulative Distribution Function (CDF) is fitted to each group, which comprises of the data values for a specific duration. It is possible to relate the maximum rainfall intensity for each time interval with the corresponding return period from the cumulative distribution function. For a return period (T), its corresponding cumulative frequency (F) is expressed as Eq. 7.2

$$F = 1 - \frac{1}{T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7.2)$$

Once a cumulative frequency is known, the maximum rainfall intensity is determined using Gumbel's Extreme Value distribution.

7.5.1 Gumbel's Extreme Value Distribution.

As described by Chow (1951), the frequency distribution functions applicable in hydrologically related studies can be expressed by the Eq. 7.3 known as the general equation of the hydrologic frequency analysis. The frequency analysis using frequency factors has been explained below.

The magnitude (X_T) of a hydrologic event may be represented as the mean, μ, plus the departure ΔX_T of the variate from the mean , Figure. 7.1,

$$X_T = \mu + \Delta X_T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7.3)$$

The departure ΔX may be taken as equal to the product of the standard deviation σ and a frequency factor K_T; that is, $\Delta X_T = K_T\,\sigma$. The departure ΔX_T and the frequency factor K_T are functions of the return period and the type of probability distribution to be used in the analysis. Therefore, the Eq. 7.3 may be expressed shown, Eq. 7.4

$$X_T = \mu + K_T\,\sigma \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7.4)$$

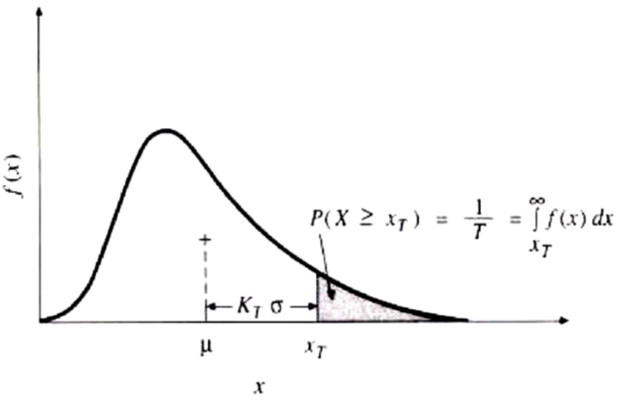

Figure 7.1: The magnitude of an extreme event X_T expressed as a deviation $K_T\,\sigma$ from the mean μ, where K_T is called the frequency factor.

7.6 IDF Empirical Equation

IDF empirical equation is the equation that estimates the maximum rainfall intensity for the different duration and return period. There are different procedures and formulas which have been proposed in the literature (Bell, 1969; Rambabu et al, 1979, Chen 1983; Aron et al. 1987; Kouthyari and Garde, 1992). IDF is a mathematical relationship between the rainfall intensity, i, the duration, t_d, and the return period, T. In this study empirical Eq. 7.5 is used

$$i=a*(t_d)^{-c} \qquad (7.5)$$

Where i is the rainfall intensity in mm/hr.

t_d is the duration in minutes.

a & c are the fitting parameters.

7.7 RESULTS AND DISCUSSION

The probability distribution method is carried out to determine the rainfall and their corresponding return period. Thus, various short duration rainfalls like 5, 10, 15, 30, 60 and120 min were estimated from this evaluated rainfall intensity for different return period, as shown in Table 7.1.

Table 7.1: Rainfall intensity for different return period

Duration (min)	Return Period (Years)					
	2	5	10	25	50	100
	Rainfall Intensity, (i) for Different Reriod, (mm/hr)					
15	84.00	105.63	119.74	137.84	151.24	163.70
30	76.63	92.81	103.36	116.90	126.92	136.24
60	62.73	79.96	91.20	105.62	116.30	126.22
120	28.64	40.39	48.05	57.89	65.17	71.94
360	9.75	16.18	20.37	25.75	29.73	33.44
1440	4.17	5.11	5.73	6.51	7.10	7.64

By using the rainfall intensity from the Table 7.1, for various durations, intensity duration frequency curve is plotted for various return periods.

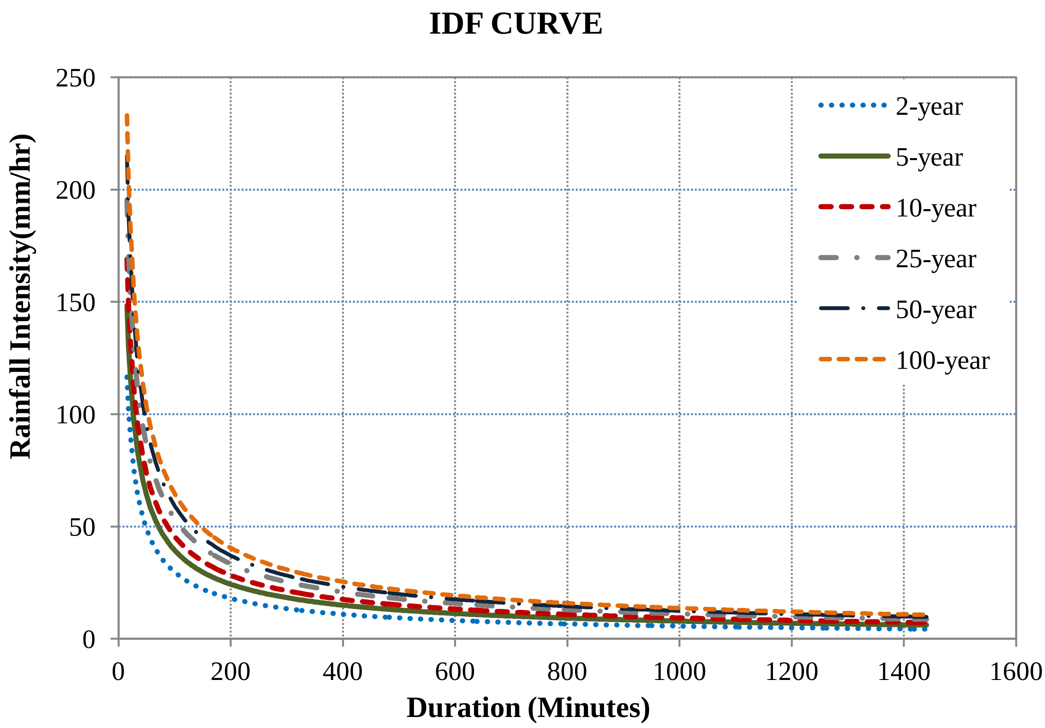

Figure 7.2: Intensity duration frequency curve in Normal paper

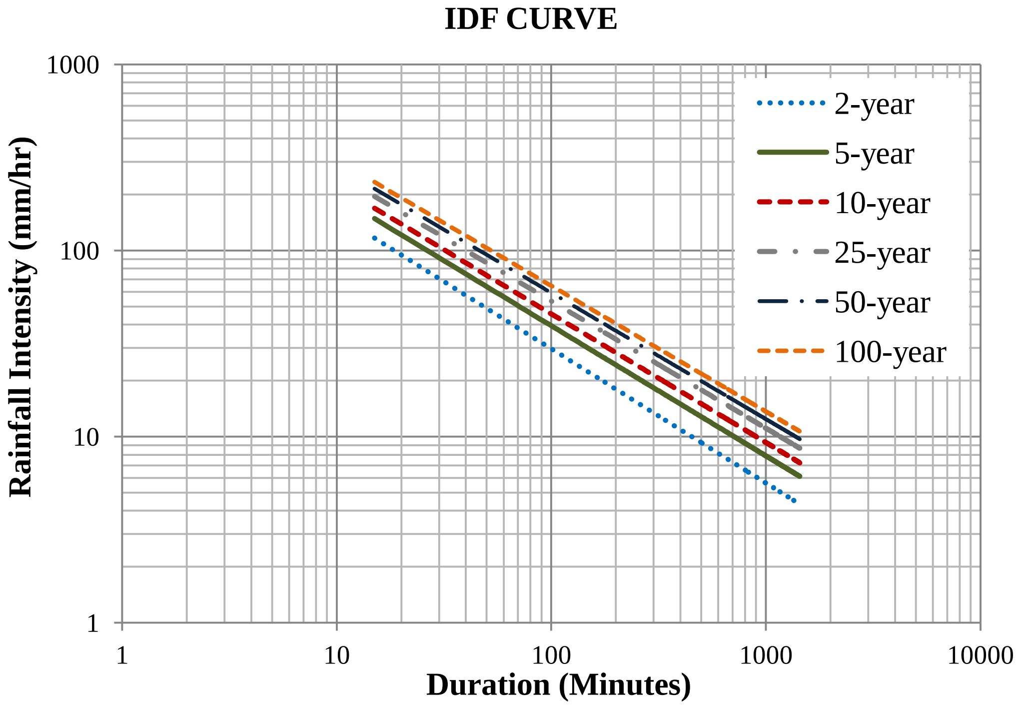

Figure 7.3: Intensity duration frequency curve in log paper

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Figure 7.3 shows that while plotting in log paper, Intensity duration frequency diagram is a straight line of decreasing intensity with duration.

Table 7.2: Rainfall IDF Empirical Equation for respective return period

Intensity, I (mm/hr)	**$i=a*(t_d)^{-c}$, t_d= duration (minutes)**		**Correlation Coefficient, R^2**
Return Period, T (years)	**a**	**c**	
2	821.43	0.721	0.9600
5	983.80	0.699	0.9589
10	1095.40	0.690	0.9534
25	1241.30	0.683	0.9457
50	1350.40	0.679	0.9403
100	1452.30	0.676	0.9375

7.8 SUMMARY

This study will help the hydrologist and engineers in planning and design of water resources projects and to estimate the rainfall the rainfall intensity for any specific return period in Guwahati city in short time and more easily. Hence, the present study, therefore, has developed a useful design data for water resources development project especially for urban drainage management for Guwahati city.

CHAPTER 8

ESTIMATION OF RUNOFF FOR THE WATERSHED AND DRAINAGE DESIGN

8.1 INTRODUCTION

This chapter aims to discuss the estimation of the direct surface runoff for a storm event of different return period. For the estimation of the surface runoff, the rational formula has been used. The runoff coefficient for the watershed has been calculated as per the surface condition. The rainfall intensity is used from the IDF curve. The existing drainage is checked for the adequacy of the cross-sectional area to carry the surface runoff. The excess runoff volume is managed to make the study area free from flooding. Then finally the resection of the existing channel and resection of the detention or storage tank for the volume of runoff for heavy downpour in a short duration storm event.

8.2 RUNOFF

When a storm occurs, a portion of rainfall infiltrates into the ground, and some portion gets evaporated. The rest flows as a thin sheet of water over the land which is termed as overland flow. If there is a relatively impermeable stratum in the subsoil, the infiltrating water moves laterally in the surface soil and joins the stream flow which is termed as underflow or sub-surface flow or interflow. If there is no impending layer in the subsoil, the infiltrating water percolates into the ground as deep seepage and builds up the ground water table (GWT or phreatic surface). The term direct runoff is used to include the overland flow and the interflow. The direct runoff results from the occurrence of an immediately preceding storm while the ground water contribution, which takes days to reach the stream, in all probability, has no direct relation with the immediately preceding storm. The ground water flows into the stream would continue even if there had been no storm immediately preceding. It is for this region it is termed as base flow in the hydrograph analysis.

When overland flows starts due to a storm event, some portion of the runoff infiltrates and some potion gets evaporated, the part of the runoff which cannot infiltrate or flows freely on the impervious surface inundating the low-lying area. This excess portion of the runoff create havoc in the inundating area.

8.3 FACTORS AFFECTING SURFACE RUNOFF IN A WATERSHED

The various factors which affects the runoff from a watershed depends upon the following characteristics

1) Storm Characteristics
2) Meteorological Characteristics
3) Watershed characteristics
4) Storage characteristic

It is observed that low intensity of storms over longer spells contributes to ground water storage and produces relatively less runoff. A high-intensity storm or smaller area covered by it increases the runoff since losses like infiltration and evaporation are less.

The practice of storm water management has evolved significantly over the last twenty years and is focused primarily on flood and erosion control. Flash floods being a natural phenomenon, total elimination or control of floods is neither practically possible nor economically viable. Hence, flood management aims at providing a reasonable degree of protection against flood damage at economic costs and preserves the environment.

Structural measures include storage reservoirs, flood embankments, drainage channels, anti-erosion works, channel improvement works, detention basins and non-structural measures include flood forecasting, flood plain zoning, flood proofing, disaster preparedness, etc, (Needhidasa. S, et al, 2013). A good and efficient storm water management approach is very much required at the moment all over the world especially in developing countries like India. The idea of efficient storm water management is based on the requirement to protect the health of the public, welfare and safety of the public, conservation of water, need to strive for sustainable environment etc. Basic considerations in a storm water catch basin design are functional requirements, technical requirements, and social and economic considerations, (Dieter, 2013) . Urban drainage includes two types of fluids viz.

wastewater and storm water (Butler and Davies, 2000). Waste water is that which is generated after the use for life support, process from industry and needs to be collected and transported without causing any hazardous issues. Whereas storm water is the runoff which caused due to precipitation. Both storm water as well as waste water needs to be considered for the drainage system planning and design.

8.4 SURFACE RUNOFF AND ITS CHARACTERISTICS

Surface runoff is water, from rain, snowmelt, or other sources, that flows over the land surface, and is a major component of the water cycle. When runoff flows along the ground, it can pick up soil contaminants such as petroleum, pesticides, or fertilizers that become discharge or overland flow. Urbanization increases the surface runoff, by creating more impervious surfaces such as pavement and buildings do not allow percolation of the water down through the soil to the aquifer. Increased runoff reduces groundwater recharge, thus lowering the water table and making droughts worse who depend on water wells. The peak rate, volume, and timing of runoff are important characteristics in the planning and design of storm water management practice. Runoff rate and volume generally increase after urbanization and this development alters the characteristics of runoff. If the downstream channel capacity is exceeded, flood will occur over the floodplain, another related problem is channel erosion which depends on runoff rate and its duration. Thus, urbanization not only increases runoff rate and volume but also their frequency and frequency of runoff rate has a direct impact on erosion and sediment transport of river channel. Runoff from non-urban areas carries eroded sediments, nutrients from natural and/or agricultural sources, bacteria from animal droppings, and pesticides and herbicides from agricultural practices. After urbanization, runoff carries solids particles from automobile wear and tear, dust and dirt, and winter sand, nutrients from residential fertilizers, metals such zinc, copper, and lead, hydrocarbons leaching from asphalt pavement materials, spilled oils and chemicals, and bacteria from domestic animals. This change of runoff quality causes a general degradation of water quality in the receiving waters

8.5 LITERATURE REVIEW

The unit hydrograph, a method for estimating storm runoff, was proposed by Sherman in 1932 and since then it has been considered as a significant concept. Runoff is one of the most important hydrologic variables used in most of the water resources applications. Reliable prediction of quantity and rate of runoff from land surface into streams and river have been difficult and time consuming task especially for un-gauged watersheds. However this information is needed in dealing with many watershed development and management problems (Kumar et.al., 1991). Conventional models for prediction of river discharge require considerable hydrological and meteorological data. Several factors like land use pattern, soil types, slope, character of rainfall etc. control runoff character. So, collection of these data is expensive, time consuming and a difficult process. Remote sensing technology can augment the conventional methods to a great extent in rainfall/runoff studies (Pandey & Sahu, 2002, Zhan & Huang, 2004). The role of remote sensing in runoff calculation is generally to provide a source of input data or as an aid for estimating equation coefficients and model parameters. Experience has shown that satellite data can be interpreted to derive thematic information on land use, soil, vegetation, drainage, etc which, combined with conventionally measured climatic parameters (precipitation, temperature etc) and topographic parameters height, contour, slope, provide the necessary inputs to the rainfall-runoff models. The information extracted from remote sensing and other sources can be stored as a geo-referenced data base in geographical information system (GIS). The system provides efficient tools for data input into data base, retrieval of selected data items for further processing and software modules which can analyze/ manipulate the retrieved data in order to generate desired information on specific form.

8.6 DRAINAGE SYSTEM PRINCIPLES AND METHODOLOGIES FOR RUNOFF ESTIMATION

A storm drainage system is a system receiving, conveying, and controlling storm water runoff in response to precipitation and snowmelt. Such systems include: ditches, culverts, swales, subsurface interceptor drains, roadways, curb and gutters, catch basins, manholes, pipes, attenuation ponds and service lateral lines. It is designed to convey runoff from frequent storms (e.g., up to 2 or 5 year storms). The main purpose of this system is to minimize storm water ponding at intersections and pedestrian crossings which may cause inconvenience to both pedestrians and motorists so it is also called the convenience system. The major drainage system comprises the natural streams and valleys and man-made streets, channels and ponds. The main aim for the purpose is to essentially eliminate the risk of loss of life and property damage due to flash flooding. In the past there have been many methodologies developed, to estimate the total runoff volume, the peak rate runoff and the run off hydrograph from land surfaces under a variety of conditions like runoff curve number method, small storm hydrology method, infiltration model methods etc. for earlier stages and Rational method, SCS method, modified Rational method in present stages, as discussed here.

The methodology followed here is based on Rational method, which is adopted widely, however laborious effort are required to ensure that the few input data required for rational method is accurate.

8.6.1 Rational Method

Rational method was first used in 1889 developed by Emil Kuichling. The rational method is the oldest method still probably the most widely used method for design of storm drains. The idea behind the rational method is that if a rainfall of intensity 'i' begins instantaneously and continues indefinitely, the rate of runoff will increase until the time of concentration 'tc', when the entire watershed is contributing to flow at the outlet. The product of rainfall intensity 'i' and watershed area 'A' is the inflow rate of the system, iA, and the ratio of this rate to the rate of peak discharge Q (which occurs at time tc) is termed the runoff coefficient C. The following Fig. 8.1 is the hydrograph for rational method.

This is expressed in the rational formula as in Eq. 8.1.

$$Q = C\,i\,A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8.1)$$

In Urban areas, the drainage area usually consists of sub areas or sub-catchments of different surface characteristics. As a result a composite analysis is required that must account for the various surface characteristics. 'A' denotes the area of the sub catchments and 'C' denotes the runoff coefficients of each watershed. The peak runoff is then computed by summing the Q of individual watershed. The assumptions associated with the rational method are:

1. The computed peak rate of runoff at the outlet point is a function of the average rainfall rate during the time of concentration, i.e., the peak discharge does not result from a more intense storm of a shorter duration, during which only a portion of the watershed is contributing to runoff at the outlet.
2. The time of concentration employed is the time for runoff to become established and flow from the most remote part of the drainage area to the inflow point of the sewer being designed.
3. Rainfall intensity is constant throughout the storm duration.

8.6.1.1 Limitations

The Rational Method is an adequate method for approximating the peak rate and total volume of runoff from a design rainstorm in a given catchment. The greatest drawback to the Rational Method is that it normally provides only one point on the runoff hydrograph. When the areas become complex and where sub-catchments come together, the Rational Method will tend to overestimate the actual flow, which results in oversizing of drainage facilities. The Rational Method provides no direct information needed to route hydrographs through the drainage facilities. One reason the Rational Method is limited to small areas is that good design practice requires the routing of hydrographs for larger catchments to achieve an economic design.

Another disadvantage of the Rational Method is that with typical design procedures one normally assumes that all of the design flow is collected at the design point and that there is no water running overland to the next design point. However, this is not the fault of the Rational Method but of the design procedure.

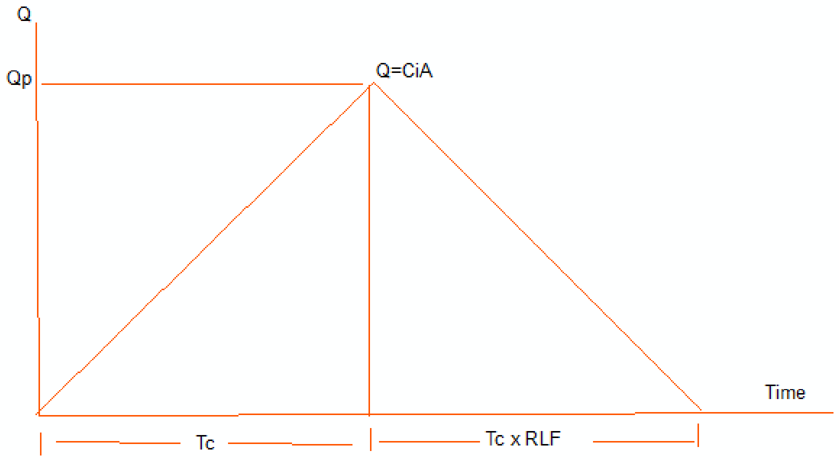

Figure 8.1: Hydrograph for Rational Method

From the parameters of the rational formula only the area ‘A’ can be precisely defined by measuring the area of the sub-catchment. The intensity ‘i’ for the sub-catchment depends on the analysis of point rainfall data, time of concentration etc. The most cumbersome process is the estimation of runoff coefficient ‘C’ which comprises so many characteristics on the sub-catchment like land use pattern, antecedent precipitation, soil moisture, infiltration, ground slope, surface and depression storage, shape of the drainage area , over land flow velocity etc and this coefficient can vary with time also. One of the most the most serious limitations of the rational method is that it does not take into consideration the real storm pattern. Thus the time variation of the rate of rainfall and the variation in area and velocity contributing the flow are therefore not accounted.

8.6.2 Soil Conservation Service (SCS) Runoff Method

The SCS method was developed by U.S Soil Conservation Service. This method estimated the volume and peak of the runoff for a 24-hr design storm. This method can be used for both urban and non-urban small watersheds. This method requires the determination of the runoff curve number, CN for the drainage basin, which is a function of the soil and surface characteristics and land use. Soil characteristics that are associated with each group as follows:

Group A: Deep sand, deep loess, and aggregated silts.

Group B: Clay loams, shallow loess, sandy loam

Group C: Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay.

The SCS method uses a dimensionless unit hydrograph and drainage inputs to determine flow volumes and peak discharges.

SCS runoff equation is given below (Eq. 8.2)

$$Q= \frac{(P-Ia)^2}{(P-Ia+S)} \quad \text{...(8.2)}$$

Where

Q = Runoff,

P = Rainfall

S = Potential maximum retention after runoff begins,

I_a = Initial abstraction

8.6.3 Modified Rational Method

The Modified rational method is an extension of the rational method for rainfalls lasting longer than the time of concentration and the hydrograph for the same is shown in the Fig.8.2. This method was developed so that the concepts of the rational method could be used to develop hydrographs for storage design, rather than just flood peak discharges for storm sewer design. The modified rational method can be used for the preliminary design of detention storage for watersheds of up to 20 to 30 acres.

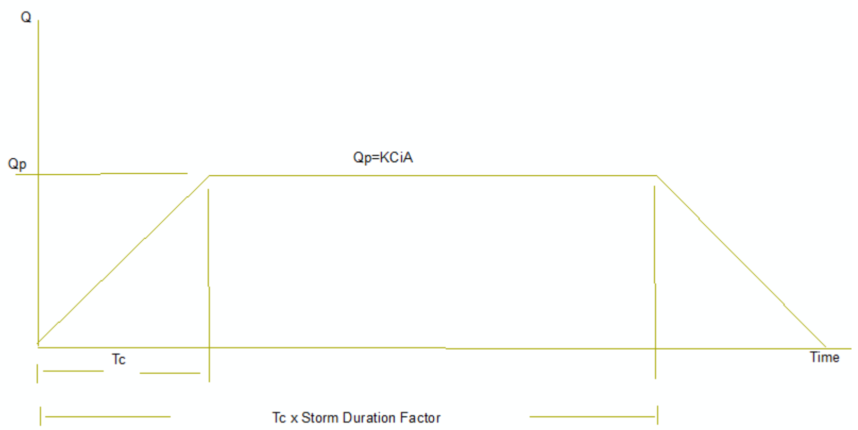

Figure 8.2: Hydrograph for Modified Rational Method

Various techniques and methodologies have been developed to design the storm water in the past. The usage of Rational method and the definition of parameters and its calculation have been clearly discussed in the drainage criteria manual of the city of Winnipeg, (James, 1997). Estimation of the storm water using rational method and the comparison of the same using SCS and modified rational method has been depicted clearly in the course Manual of PDH engineers The advantages of rational methods, it shortfalls, methods to find out the time of concentration, guidelines for finding runoff coefficients, etc. were clearly discussed. Steven et. al. (2000) describes the necessity of proper and efficient urban drainage system. It compares the drainage systems of the past and present, which without any doubt points to the fact that for a healthy environment especially in cities the proper design and planning of the drainage systems are inevitable. Theodore G. Cleveland et al, (2011), has described the use of Rational method and modified rational method in general for the Texas City. It has also described the applicable area of the Modified rational method over rational method. Francesco & Goivanni (2010) has described the Curve Number procedure, which is largely used world-wide because of ease of application, and it allows to estimate the volume of direct runoff for a given rainfall event by means of a single parameter, CN, which represents the basin infiltration storage depending on soil types, land cover, and land use.

8.7 DESIGN CRITERIA FOR ESTIMATION OF RUNOFF OF THE WATERSHED FOR THE BHARALU BASIN

The Rational method has been used to design the drains in the study area. The available data of rainfall records has been analyzed, the intensity of rainfall has been taken from IDF curves (Chapter 7). The quantity of runoff was worked out using the Eq. (8.3).

$$Q = C\ i\ A \qquad (8.3)$$

Where, Q = Run off

i = Intensity of rain fall

A = Area

C = Coefficient of runoff.

The coefficient of Runoff, C, has been considered as per topography, slope and nature of the soil in the study area the value of 'C' has been assessed and depending upon the surface condition it has been interpreted in both the way, under GIS environment and ground reality. For calculating the C value for a heterogeneous land cover, weighted C value (C) has been used, (refer to the Chapter 6). The land use/land cover pattern of the watershed has been classified and with utmost care the value of runoff coefficient has been assigned and is based on available literature (Sarma et al 2005; Iowa, 2008) and is given in Table 8.1.

Table 8.1: Runoff Coefficient (C) factor for different land covers

Land Cover	Runoff Coefficient, C
Urban Mixed built-up area	0.9
Tree clad area	0.3
Forest Deciduous Dense	0.2
Forest Deciduous	0.3
Scrub Forest	0.5
Rive / waterbodies / marshyland	0

Manning's formula, Eq. 8.4, has been used to design the drains.

$$Q = A \times 1/n \times R^{2/3} \times S^{½} \qquad \text{……………………………(8.4)}$$

Where, Q = Runoff

A = area of the section

n = Manning's constant

R = hydraulic mean depth

S = bed slope

Moreover, considering the type of the material for the fair condition Manning's constant has been considered as 0.015, and minimum velocity is considered as 0.8m/s.

Time of Concentration: For calculation the time of Concentration, the Kirpich formula has been used, Eq. (8.5).

$$t_i = 0.0195 \times L^{0.77} \times S^{-0.385} \qquad \text{…………………………….. (8.5)}$$

Where, t_i = Time of concentration in minute

L = Length of flow in m

S = Slope

Travel time, $t_v = v/t$, where v= minimum velocity in m/sec and t= time in min

The final time of concentration has been considered as the

$$t_t = t_i + t_v \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (8.6)$$

8.8 ESTIMATION OF PEAK DISCHARGE OF THE WATERSHED

Figure 8.3, depicts the methodology involve for the design of the drains.

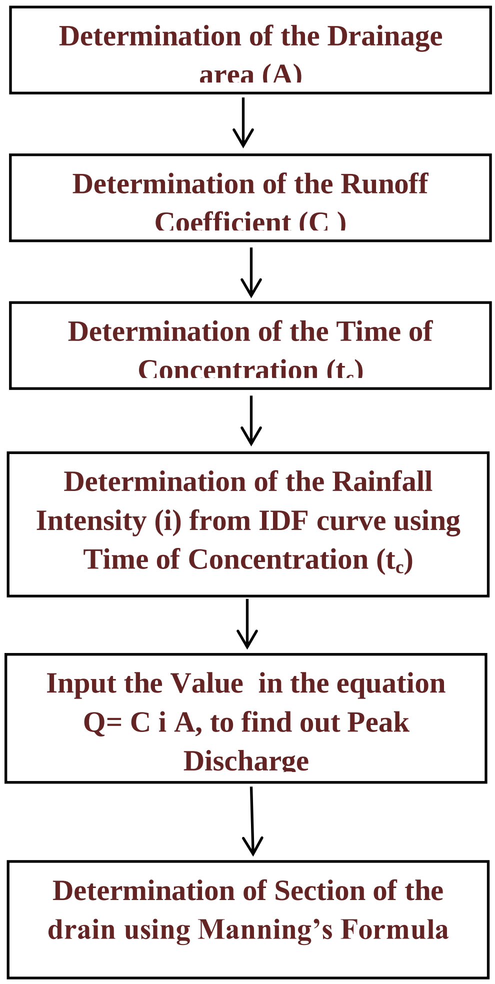

Figure 8.3: Diagram Depicting Methodology for Runoff Estimation and Design Section

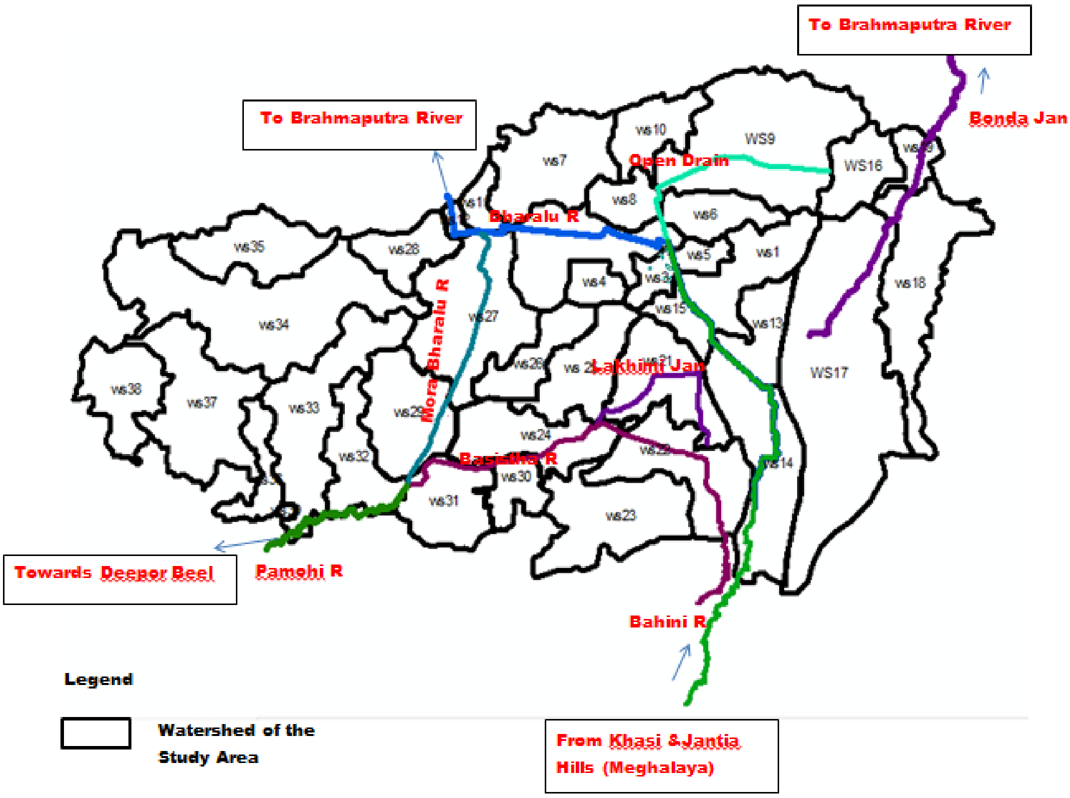

Figure 8.4: Watershed of the Study Area.

The watershed of the study area contributes its water to its own drainage basin, Fig 8.4. For the estimation of the runoff, the Bharalu Basin has been considered. It is observed that 16 number of watershed contributes its water directly or indirectly to this basin, as shown in Fig 8.5. The hydrological parameters of these watersheds have been shown in the Table 5.1, Chapter 5 Clause 5.8.

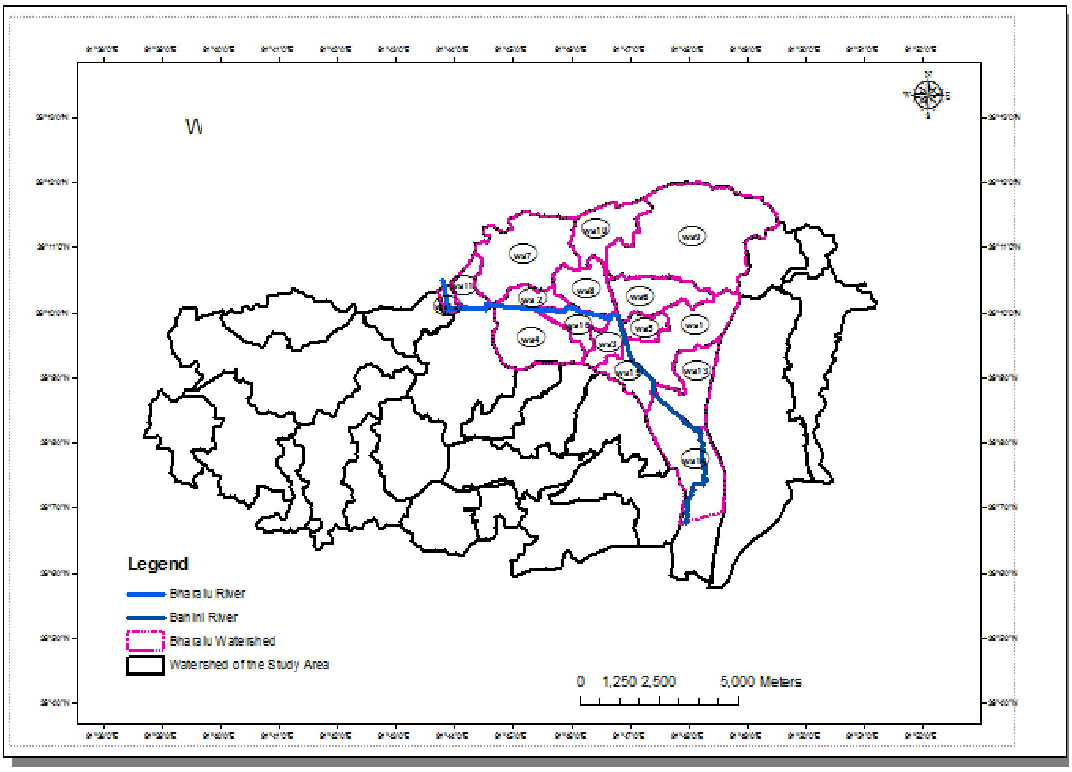

Figure 8.5: Watersheds of the Bharalu Basin

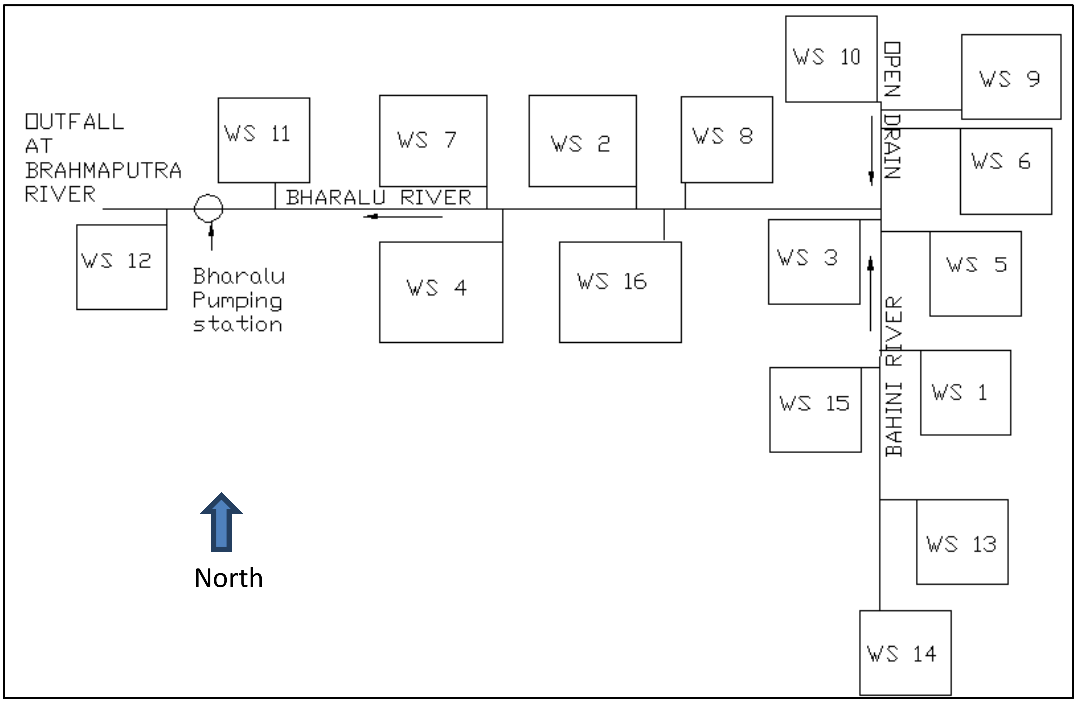

Figure 8.6: Line diagram representation of the Watershed for the Bharalu Basin

8.9 DRAINAGE DESIGN

The methodology for the design of drain is explained in section 8.9.1 with the help of a worked out example for watershed WS 2.

8.9.1 Estimation of Runoff for Watershed WS 2

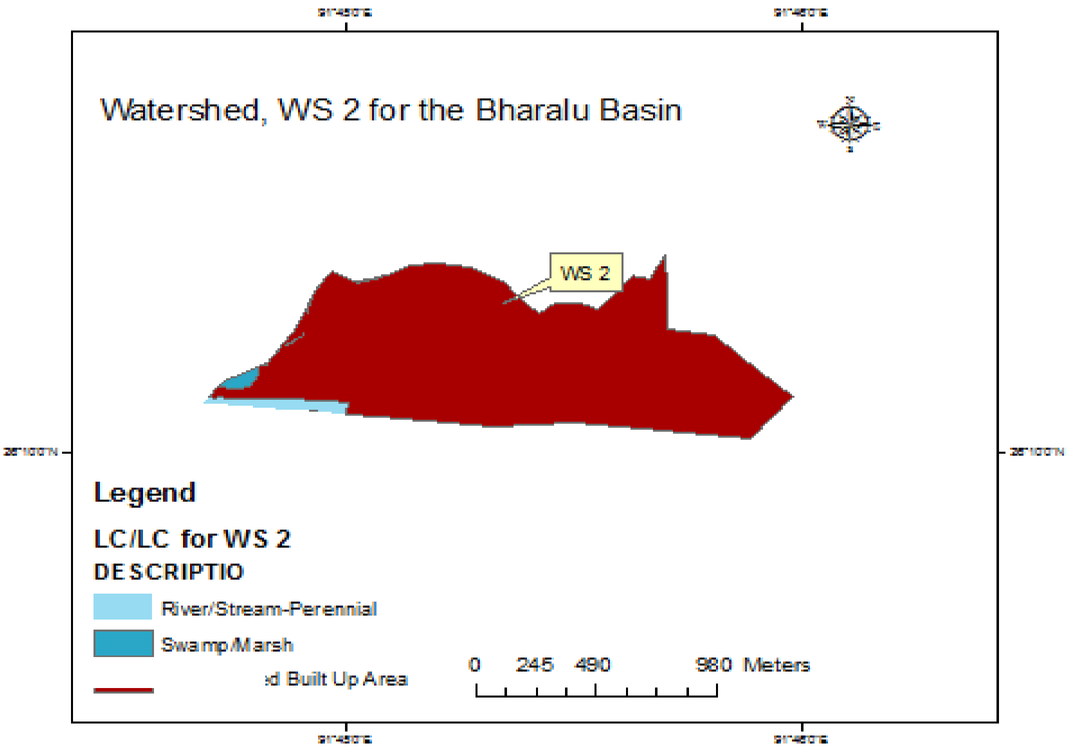

Figure 8.7: Watershed, WS 2 of the Bharalu Basin

For estimation of runoff for the watershed, WS 2, Fig, 8.7 , Eq. 8.1 has been used,

Q= 0.28 CIA

Ares of the watershed, WS 2, A= 1.2 Sq. km.

Calculation of time of concentration, Kirpich formula, t_i , from Eq. 8.5

$$t_i = 0.0195 \text{ x } L^{0.77} \text{ x}^{S\ -0.385}$$

Where L = 500m, S= 0.036

t_i = 8.40 min

Length of the channel = 1148.41 m, therefore $t_v = \frac{L}{V*60} = \frac{1148.41}{0.8*60}$ = 23.93 min

Thus time of concentration = $t_c = t_i + t_v$,from Eq. 8.6.

= 32.3 min

Considering a storm event of 2-year return period, from IDF curve (from Chapter 6) for a storm event of 2-year return period, for duration t_c = 32.3 min,

Rainfall Intensity, i = 67.0 mm/hr

For the runoff coefficient determination, the land cover land use pattern has been considered as in Table 8.2.,by using weighted area method.

Table 8.2: Coefficient of Runoff for WS-2

WS -2				
Land cover	**Area, A (sq m)**	**Coefficient of runoff (C)**	**CA**	**$C_{weighted}$**
River/Stream-Perennial	22413.07	0.00	0.00	0.88
Swamp/Marsh	8571.55	0.00	0.00	
Urban-Mixed Built Up Area	1170428.37	0.90	1053385.53	
	1201413.00		1053385.53	

From Table 8.2, Runoff Coefficient, C = 0.88

Putting these value in Eq. 8.1

Runoff discharge for WS 2, Q = 0.28 CiA = 0.28 x 0.88 x 67.0 x 1.2

= 19.76 m^3/sec

Similarly, the runoff of the entire watershed for the Bharalu basin has been estimated accordingly. The estimation of the peak runoff of the individual watershed for 2-year and 5-year return period has been shown in Table 8.3 & Table 8.4 respectively. The discharge for the 16 individual watershed of the Bharalu basin has been represented by the Line Diagram in Fig 8.8 and Fig. 8.9, for the storm event for 2-year and 5-year return period respectively.

Table 8.3: Estimation of runoff of the watershed for the storm event of 2-year return period for Bharalu Basin

Watershed ID	Section		Watershed Area (sq km)	Length (m)	Urban Mixed Built up area	Tree Clad Area	Forest Deciduous Dense	Forest Deciduous open	Scrub Forest	Reservoir/Tank perennial	River/Stream Perennial	Swamp/Marshy land	Length of overland flow (meter)	Difference of elevation, H (meter)	Inlet time, t_i (as per Kirpich formula) (minutes)	Time of flow, t_v (minutes)	Time of concentration (t_c) = $t_i + t_v$ (minutes)	Intensity of rainfall (i) from IDF the curve in mm/hr (2-yr RP)	Runoff Coefficient, C						C weighted	Discharge, Q= 0.28 x CiA, m^3/s
	From point 1	To point 2																	Urban Mixed builtup area = 0.9	Tree Clad Area = 0.30	Forest Deciduious Dense = 0.20	Forest Deciduious = 0.30	Scurb Forest = 0.50	River/Tank/waterbodies/ Marshyland =0		
WS 1	WS1-1	WS1-2	4.79	1857.1	1.58	1.39	0.00	1.08	0.732	0.00	0.00	0.00	2000	196	16.60	38.69	55.3	45.5	1.42	0.4	0.00	0.32	0.37	0.00	0.53	32.23
WS 2	WS2-1	WS2-2	1.20	1148.4	1.17	0.00	0.00	0.00	0.00	0.00	0.02	0.01	500	18	8.40	23.93	32.3	67.0	1.05	0.0	0.00	0.00	0.00	0.00	0.88	19.76
WS 3	WS3-1	WS3-2	1.25	978.11	0.97	0.27	0.00	0.00	0.00	0.00	0.00	0.00	885	113	8.00	20.38	28.4	73.6	0.88	0.1	0.00	0.00	0.00	0.00	0.77	19.75
WS 4	WS4-1	WS4-2	4.13	1513.6	2.09	0.38	0	0	1.21	0.13	0.01	0.29	1500	208	11.64	31.53	43.2	54.4	1.88	0.1	0.00	0.00	0.61	0.00	0.63	39.60
WS 5	WS5-1	WS5-2	1.05	860.23	0.37	0.31	0	0.68	0	0	0	0	740	71	7.79	17.92	25.7	79.1	0.33	0.1	0.00	0.20	0.00	0.00	0.60	13.95
WS 6	WS6-1	WS6-2	3.00	1513.4	1.862	0	0	0.517	0.29	0	0	0	2000	143	18.75	31.53	50.3	48.7	1.68	0.0	0.00	0.16	0.15	0.00	0.66	26.97
WS 7	WS7-1	WS7-2	6.43	2070.5	5.692	0.19	0	0	0	0.15	4E-04	0.279	1937	124	19.09	43.14	62.2	41.8	5.12	0.1	0.00	0.00	0.00	0.00	0.81	60.62
WS 8	WS8-1	WS8-2	2.35	1285.3	2.101	0	0	0.189	0	0.032	0	0.019	230	80	1.93	26.78	28.7	73.0	1.89	0.0	0.00	0.06	0.00	0.00	0.83	39.81

Table 8.3: Estimation of runoff of the watershed for the storm event of 2-year return period for Bharalu Basin (continued)

Watershed ID	Section		Watershed Area (sq km)	Length (m)	Urban Mixed Built up area	Tree Clad Area	Forest Deciduous Dense	Forest Deciduous open	Scrub Forest	Reservoir/Tank perennial	River/Stream Perennial	Swamp/Marshy land	Length of overland flow (meter)	Difference of elevation, H (meter)	Inlet time, t_i (as per Kirpich formula) (minutes)	Time of flow, t_v (minutes)	Time of concentration (t_c) $= t_i + t_v$ (minutes)	Intensity of rainfall (i) from IDF the curve in mm/hr (2-yr RP)	Runoff Coefficient, C						C weighted	Discharge, Q= 0.28 x CiA, m^3/s
	From point 1	To point 2																	Urban Mixed builtup area = 0.9	Tree Clad Area = 0.30	Forest Deciduious Dense = 0.2	Forest Deciduious = 0.30	Scurb Forest = 0.50	River/Tank/waterbodies/ Marshyland =0		
WS 9	WS9-1	WS9-2	12.31	3562.4	7.191	3.146	0.013	1.3242	0.574	0	0	0.025	2310	166	20.91	74.22	95.1	30.8	6.47	0.9	0.00	0.40	0.29	0.00	0.66	69.83
WS 10	WS10-1	WS10-2	3.11	1232.4	2.188	0.768	0	0.059	0.092	0	0	0	1000	144	8.40	25.68	34.1	64.5	1.97	0.2	0.00	0.02	0.05	0.00	0.73	40.89
WS 11	WS11-1	WS11-2	1.15	1137.4	0.91	0	0	0.1172	0	0	0.012	0.103	650	30	9.34	23.70	33.0	66.0	0.82	0.0	0.00	0.04	0.00	0.00	0.74	15.78
WS 12	WS12-1	WS12-2	0.43	464.27	0.342	0	0	0	0	0	0.083	0	500	14	9.25	9.67	18.9	98.6	0.31	0.0	0.00	0.00	0.00	0.00	0.72	8.50
WS 13	WS13-1	WS13-2	2.97	1647.9	1.858	0.931	0	0	0.161	0	0	0	1500	114	14.67	34.33	49.0	49.6	1.67	0.3	0.00	0.00	0.08	0.00	0.68	28.25
WS 14	WS14-1	WS14-2	5.21	3240.5	5.21	0	0	0	0	0	0	0			5.00	67.51	72.5	37.4	4.69	0.0	0.00	0.00	0.00	0.00	0.90	49.14
WS 15	WS15-1	WS15-2	1.56	667.77	1.118	0.437	0	0	0	0	0	0	360	116	2.80	13.91	16.7	107.8	1.01	0.1	0.00	0.00	0.00	0.00	0.73	34.33
WS 16	WS16-1	WS16-2	1.46	971.97	1.371	0.021	0	0	0	0.023	0	0.035	820	58	9.47	20.25	29.7	71.2	1.23	0.0	0.00	0.00	0.00	0.00	0.85	24.73

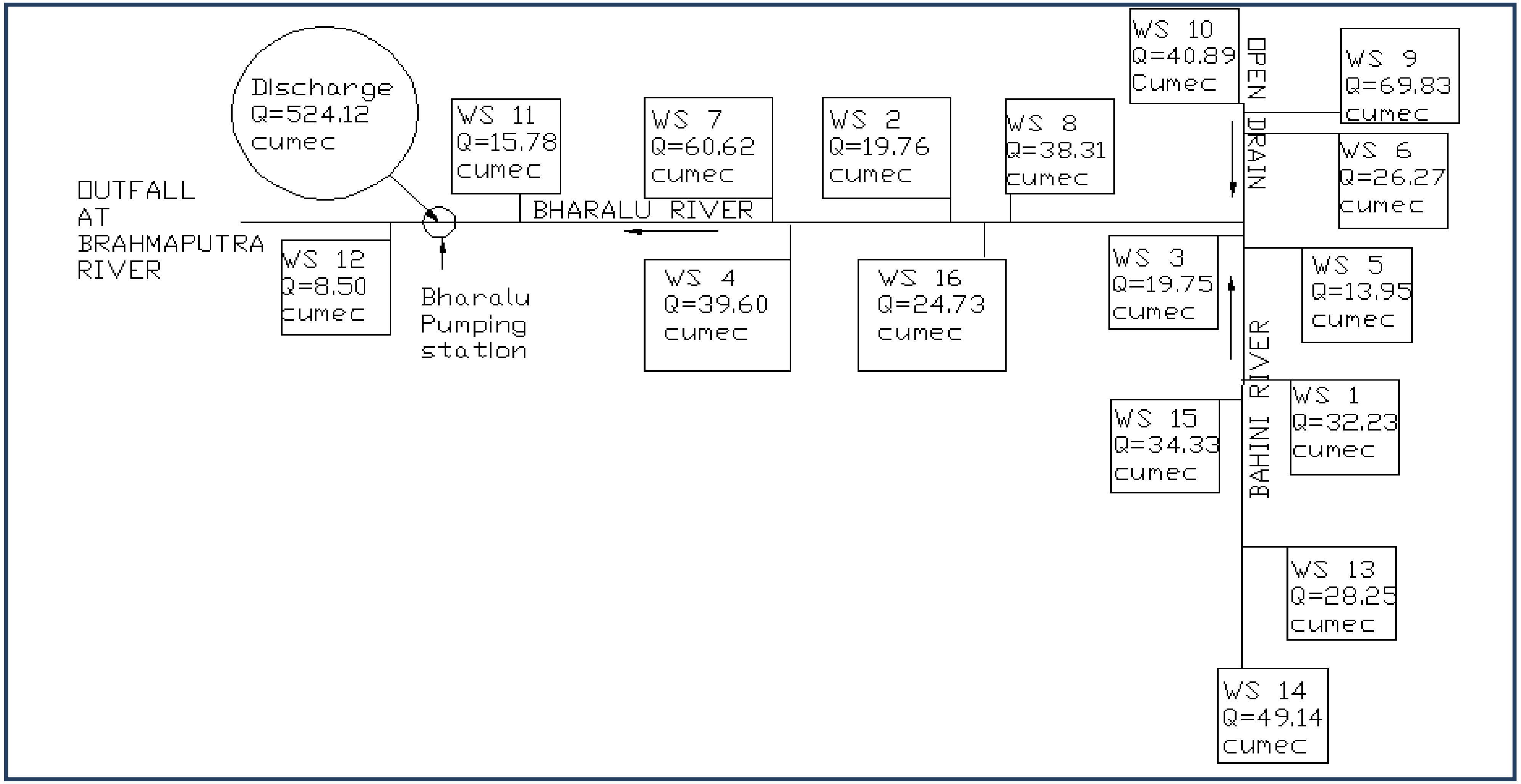

Figure 8.8: Line Diagram representation with discharge for a storm event of 2-year return period for Bharalu Basin

Table 8.4: Estimation of runoff of the watershed for the storm event of 5-year return period for Bharalu Basin

Watershed ID	Section		Watershed Area (sq km)	Length (m)	Urban Mixed Built up area	Tree Clad Area	Forest Deciduous Dense	Forest Deciduous open	Scrub Forest	Reservoir/Tank perennial	River/Stream Perennial	Swamp/Marshy land	Length of overland flow (meter)	Difference of elevation, H (meter)	Inlet time, t_i (as per Kirpich formula) (minutes)	Time of flow, t_v (minutes)	Time of concentration (t_c) = $t_i + t_v$ (minutes)	Intensity of rainfall (i) from IDF the curve in mm/hr (5-yr RP)	Runoff Coefficient, C						C weighted	Discharge, Q= 0.28 x CiA, m^3/s
	From point 1	To point 2																	Urban Mixed builtup area = 0.9	Tree Clad Area = 0.30	Forest Deciduious Dense = 0.2	Forest Deciduious = 0.30	Scurb Forest = 0.50	River/Tank/waterbodies/ Marshyland =0		
WS 1	WS1-1	WS1-2	4.79	1857.12	1.58	1.39	0.00	1.08	0.73	0.00	0.00	0.00	2000	196	16.60	38.69	55.3	59.5	1.42	0.4	0.00	0.32	0.37	0.00	0.53	42.15
WS 2	WS2-1	WS2-2	1.20	1148.41	1.17	0.00	0.00	0.00	0.00	0.00	0.02	0.01	500	18	8.40	23.93	32.3	86.6	1.05	0.0	0.00	0.00	0.00	0.00	0.88	25.54
WS 3	WS3-1	WS3-2	1.25	978.11	0.97	0.27	0.00	0.00	0.00	0.00	0.00	0.00	885	113	8.00	20.38	28.4	94.9	0.88	0.1	0.00	0.00	0.00	0.00	0.77	25.45
WS 4	WS4-1	WS4-2	4.13	1513.59	2.09	0.38	0.00	0.00	1.21	0.13	0.01	0.29	1500	208	11.64	31.53	43.2	70.8	1.88	0.1	0.00	0.00	0.61	0.00	0.63	51.51
WS 5	WS5-1	WS5-2	1.05	860.23	0.37	0.31	0.00	0.68	0.00	0.00	0.00	0.00	740	71	7.79	17.92	25.7	101.7	0.33	0.1	0.00	0.20	0.00	0.00	0.60	17.93
WS 6	WS6-1	WS6-2	3.00	1513.37	1.86	0.00	0.00	0.52	0.29	0.00	0.00	0.00	2000	143	18.75	31.53	50.3	63.6	1.68	0.0	0.00	0.16	0.15	0.00	0.66	35.19
WS 7	WS7-1	WS7-2	6.43	2070.53	5.69	0.19	0.00	0.00	0.00	0.15	0.00	0.28	1937	124	19.09	43.14	62.2	54.8	5.12	0.1	0.00	0.00	0.00	0.00	0.81	79.48
WS 8	WS8-1	WS8-2	2.35	1285.27	2.10	0.00	0.00	0.19	0.00	0.03	0.00	0.02	230	80	1.93	26.78	28.7	94.1	1.89	0.0	0.00	0.06	0.00	0.00	0.83	51.32

Table 8.4: Estimation of runoff of the watershed for the storm event of 5-year return period for Bharalu Basin (continued)

Watershed ID	Section		Watershed Area (sq km)	Length (m)	Urban Mixed Built up area	Tree Clad Area	Forest Deciduous Dense	Forest Deciduous open	Scrub Forest	Reservoir/Tank perennial	River/Stream Perennial	Swamp/Marshy land	Length of overland flow (meter)	Difference of elevation, H (meter)	Inlet time, t_i (as per Kirpich formula) (minutes)	Time of flow, t_v (minutes)	Time of concentration (t_c) = $t_i + t_v$ (minutes)	Intensity of rainfall (i) from IDF the curve in mm/hr (5-yr RP)	Runoff Coefficient, C						C weighted	Discharge, Q= 0.28 x CiA, m^3/s
	From point 1	To point 2																	Urban Mixed builtup area = 0.9	Tree Clad Area = 0.30	Forest Deciduious Dense = 0.2	Forest Deciduious = 0.30	Scurb Forest = 0.50	River/Tank/waterbodies/ Marshyland =0		
WS 9	WS9-1	WS9-2	12.3	3562.4	7.19	3.15	0.01	1.32	0.57	0.00	0.00	0.02	2310	166	20.91	74.22	95.1	40.7	6.47	0.9	0.00	0.40	0.29	0.00	0.66	92.42
WS 10	WS10-1	WS10-2	3.11	1232.43	2.19	0.77	0.00	0.06	0.09	0.00	0.00	0.00	1000	144	8.40	25.68	34.1	83.5	1.97	0.2	0.00	0.02	0.05	0.00	0.73	52.91
WS 11	WS11-1	WS11-2	1.15	1137.37	0.91	0.00	0.00	0.12	0.00	0.00	0.01	0.10	650	30	9.34	23.70	33.0	85.3	0.82	0.0	0.00	0.04	0.00	0.00	0.74	20.40
WS 12	WS12-1	WS12-2	0.43	464.27	0.34	0.00	0.00	0.00	0.00	0.00	0.08	0.00	500	14	9.25	9.67	18.9	125.9	0.31	0.0	0.00	0.00	0.00	0.00	0.72	10.85
WS 13	WS13-1	WS13-2	2.97	1647.89	1.86	0.93	0.00	0.00	0.16	0.00	0.00	0.00	1500	114	14.67	34.33	49.0	64.8	1.67	0.3	0.00	0.00	0.08	0.00	0.68	36.85
WS 14	WS14-1	WS14-2	5.21	3240.5	5.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	67.51	72.5	49.2	4.69	0.0	0.00	0.00	0.00	0.00	0.90	64.65
WS 15	WS15-1	WS15-2	1.56	667.77	1.12	0.44	0.00	0.00	0.00	0.00	0.00	0.00	360	116	2.80	13.91	16.7	137.3	1.01	0.1	0.00	0.00	0.00	0.00	0.73	43.73
WS 16	WS16-1	WS16-2	1.46	971.97	1.37	0.02	0.00	0.00	0.00	0.02	0.00	0.04	820	58	9.47	20.25	29.7	91.8	1.23	0.0	0.00	0.00	0.00	0.00	0.85	31.90

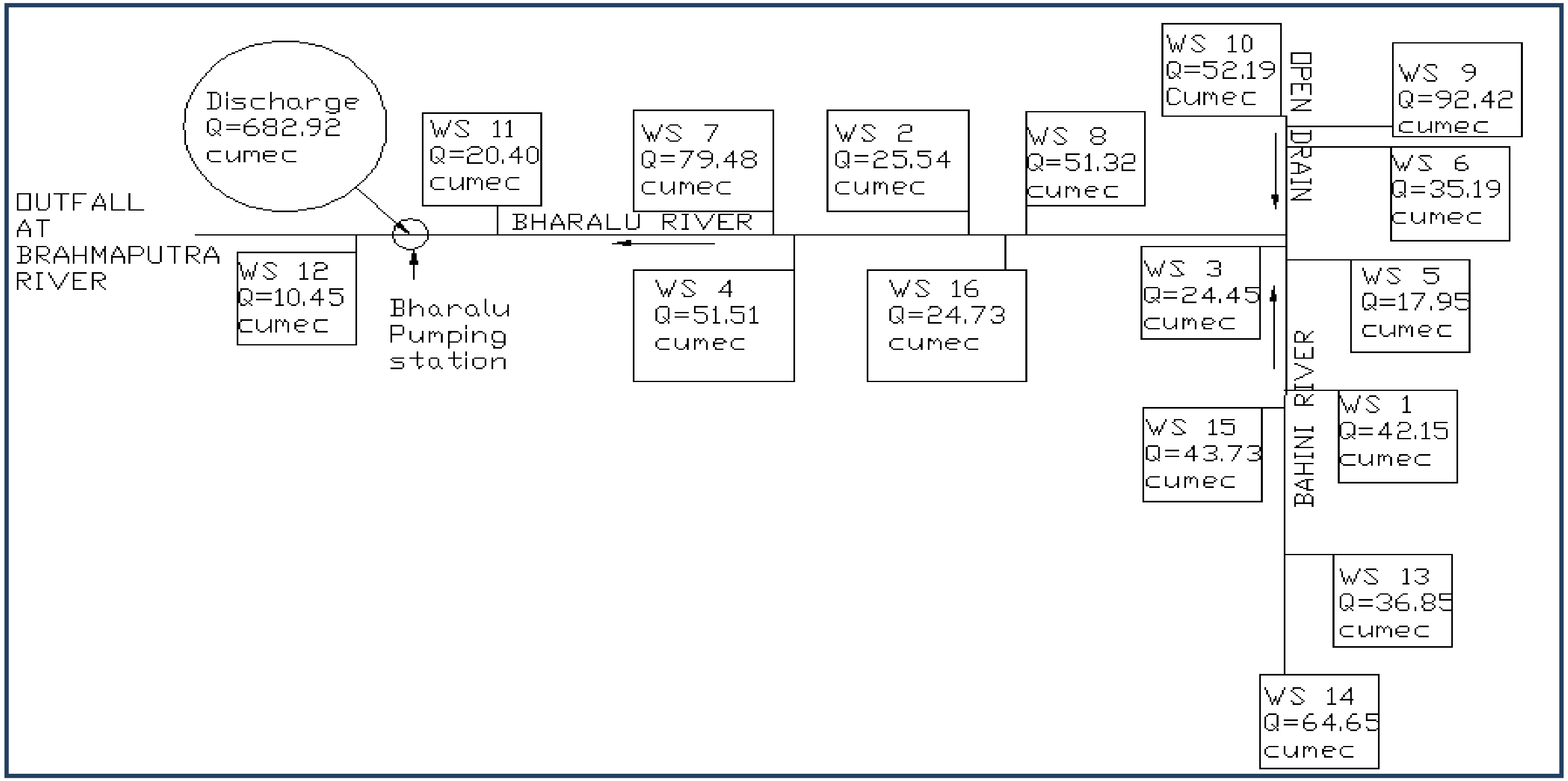

Figure 8.9: Line Diagram representations with discharge for a storm event of 5-year return period for Bharalu Basin

From the Table 8.4 and Table 8.5, it is observed that for the 2 year return period the peak discharge at the outfall point near the sluice gate at the Bharalu river is 524.12 m^3/sec and if 5 year return period is considered the peak discharge would be 682.92 m^3/sec. Thus there is an increase of 23.25% of runoff in the near future and had a tendency to increase more in future.

Thus to discharge these runoff, the design section of the capacity for the peak discharge has been done. The Fig, 8.3 shows the methodology for the designing the section. Design Section for the Watershed, WS 2, considering a rectangular section, as shown in Fig 8.10,

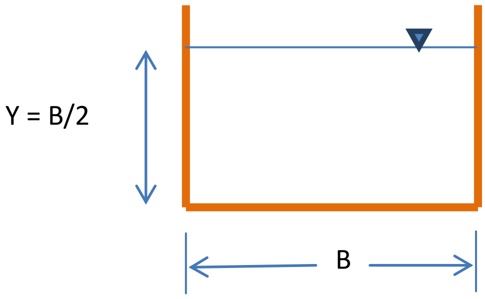

Figure 8.10: Rectangular section for the Watershed, WS 2

Assuming, Width of the Channel = B in m

Depth of the Channel = Y=B/2 in m

Area = A = B x B/2 in m^2

Wetted perimeter = P in m

Hydraulic Radius = R = A/ P = B/4

Using Manning's equation, Eq. 8.4, considering the Manning's coefficient, n=0.015

$$V = 1/n \times R^{2/3} \times S^{1/2} = (1/0.015) \times (B/4)^{2/3} \times S^{1/2}$$

Area required, A = Q / V

$$B \times B/2 = 19.76 / \{(1/0.015) \times (B/4)^{2/3} \times 0.0087^{1/2}\}$$

$$B = 2.8 \text{ m}$$

$$\text{Since Depth, } Y = B/2 = 1.4 \text{ m}$$

The Design section for the watershed WS 2 is 4 m^2. Thus the Design section for the watershed of the Bharalu Basin has been shown in Table 8.5.

Table 8.5: Design Section for a storm event of 2-year return period of the watershed of the Bharalu Basin

Drainage Design for the Watershed of the Bharalu Basin																				
Ref		Peak Discharge of watershed	Length	G.L		Proposed Size		Cross Sectional Area	Wetted perimeter	A/P	$R^{2/3}$	Slope	Velocity	Carrying capacity (Q)	I.L		Actual size of drain			Check
From Point1	To Point 2			U/S	D/S	Depth (D)	Width (B)	(A)	(P)	R		(S)			U/S	D/S	Depth		Width	q/Q should not be greater than 1
																	U/S	D/S		
		m^3/s	(m)	m	m	(m)	(m)	(m^2)	(m)	(m)			(m/s)	(m^3/s)	m	m	(m)	(m)	(m)	
WS1-1	WS1-2	32.23	1857.12	60.00	50.50	2.00	3.75	7.500	7.75	0.97	0.98	0.0051	4.67	34.99	58.00	48.50	2.00	2.00	3.75	0.92
WS2-1	WS2-2	19.76	1148.41	60.00	50.00	1.50	2.75	4.125	5.75	0.72	0.80	0.0087	4.99	20.56	58.50	48.50	1.50	1.50	2.75	0.96
WS3-1	WS3-2	19.75	978.11	60.00	50.50	1.75	2.25	3.938	5.75	0.68	0.78	0.0097	5.10	20.10	58.25	48.75	1.75	1.75	2.25	0.98
WS4-1	WS4-2	39.60	1513.59	52.00	50.50	3.50	4.50	15.750	11.50	1.37	1.23	0.0010	2.59	40.76	48.50	47.00	3.50	3.50	4.50	0.97
WS5-1	WS5-2	13.95	860.23	60.00	50.50	1.50	2.00	3.000	5.00	0.60	0.71	0.0110	4.98	14.95	58.50	49.00	1.50	1.50	2.00	0.93
WS6-1	WS6-2	26.97	1513.37	62.00	50.50	1.75	3.25	5.688	6.75	0.84	0.89	0.0076	5.18	29.49	60.25	48.75	1.75	1.75	3.25	0.91
WS7-1	WS7-2	60.62	2070.53	56.00	50.50	3.50	4.50	15.750	11.50	1.37	1.23	0.0027	4.24	66.74	52.50	47.00	3.50	3.50	4.50	0.91
WS8-1	WS8-2	39.81	1285.27	60.00	50.50	2.50	3.00	7.500	8.00	0.94	0.96	0.0074	5.49	41.18	57.50	48.00	2.50	2.50	3.00	0.97
WS9-1	WS9-2	69.83	3562.4	57.00	50.50	4.00	5.00	20.000	13.00	1.54	1.33	0.0018	3.80	75.90	53.00	46.50	4.00	4.00	5.00	0.92
WS10-1	WS10-2	40.89	1232.43	66.00	50.50	1.75	3.50	6.125	7.00	0.88	0.91	0.0126	6.84	41.89	64.25	48.75	1.75	1.75	3.50	0.98
WS11-1	WS11-2	15.78	1137.37	57.00	50.50	1.75	2.50	4.375	6.00	0.73	0.81	0.0057	4.08	17.86	55.25	48.75	1.75	1.75	2.50	0.88
WS12-1	WS12-2	8.50	464.27	60.00	50.50	1.00	2.00	2.000	4.00	0.50	0.63	0.0205	6.01	12.02	59.00	49.50	1.00	1.00	2.00	0.71
WS13-1	WS13-2	28.25	1647.89	55.00	50.50	2.50	3.50	8.750	8.50	1.03	1.02	0.0027	3.55	31.08	52.50	48.00	2.50	2.50	3.50	0.91
WS14-1	WS14-2	49.14	3240.5	60.00	50.50	3.25	4.00	13.000	10.50	1.24	1.15	0.0029	4.16	54.11	56.75	47.25	3.25	3.25	4.00	0.91
WS15-1	WS15-2	34.33	667.77	57.00	50.50	2.00	3.00	6.000	7.00	0.86	0.90	0.0097	5.94	35.61	55.00	48.50	2.00	2.00	3.00	0.96
WS16-1	WS16-2	24.73	971.97	55.00	49.50	2.00	3.00	6.000	7.00	0.86	0.90	0.0057	4.53	27.15	53.00	47.50	2.00	2.00	3.00	0.91

8.10 EXISTING DRAINAGE SYSTEM OF THE BHARALU BASIN

As mentioned earlier, the river Bharalu acts as the primary drainage channel to carry the entire water from its drainage area with all 16 watersheds and discharge it to the mighty river Brahmaputra at Bharalumukh. The upper stretch of this river is known as the river Bahini. The development of these watersheds has been done in a very unsystematic and in an unplanned manner. The developing process of these watersheds has been still going on without any scope for the storm water management and thus the hill area, plain area, the water bodies as well as the forest area has been degraded day by with the human activities in the name of urbanization. Moreover, the settlement in the hills and along the stream has been ever increasing day by day. This settlement has been clearly observed in the landuse/landcover pattern as discussed in the earlier Chapter 5. Thus it has been felt necessary to examine the discharge carrying capacity of the existing drainage system and compare the section with the design section.

Adequacy of the existing channel, the river Bharalu is considered as the primary channel, the present discharge carrying capacity of this channel is as shown.

As the width of the channel is not uniform throughout it stretches, considering its width at different stretches along the channel, effective average width of the channel = 16m

Depth of the channel = 1.75m

Flow velocity of the river = 0.8 m/sec

Discharge carrying capacity = Area x velocity

=16x1.75x 0.8

= 22.4 m^3 /sec

It is observed from the Fig, 8.4, the discharge required for the storm event of 2-year return period is 524.12 m^3/sec and at present the discharge capacity of the Bharalu river is 22.4 m^3 /sec. Thus it can be proved that the primary channel is inadequate to discharge the surface runoff to be generated for the storm event of 2-year return period in the worst scenario.

Table 8.7: Comparison of the adequacy of existing channel section with the design section of the watershed in the Bharalu basin.

Sl No	Watershed ID	Design Section (m^2)	Existing Section (m^2)	Remarks
1	WS 1	7.500	6	Inadequate
2	WS 2	4.125	4	Inadequate
3	WS 3	3.938	4	Adequate
4	WS 4	15.750	6	Inadequate
5	WS 5	3.000	6	Inadequate
6	WS 6	5.688	4	Inadequate
7	WS 7	15.750	9	Inadequate
8	WS 8	7.500	6	Inadequate
9	WS 9	20.000	10	Inadequate
10	WS 10	6.125	6	Inadequate
11	WS 11	4.375	3.5	Inadequate
12	WS 12	2.000	4	Inadequate
13	WS 13	8.750	6	Inadequate
14	WS 14	13.000	10	Inadequate
15	WS 15	6.000	6	Adequate
16	WS16	6.000	4	Inadequate

From the Table 8.7, it has been observed that the, 90% of the existing channel are inadequate and required a larger section with respect to its original sizes with reference to the design section.

8.11 RESULTS AND INTERPRETATION

From the above analysis, it has been observed that the section of the primary drains as well the existing drains of the watershed between the Bharalu basin is inadequate is carry the surface runoff of the storm event of 2-year return period for the worst condition.

The present section of the primary drain can discharge only 22.4m ^{3}/sec where the section has to be designed for the discharge of 524.12 m 3/sec. The discharge of such high amount out runoff, it not possible to resection the primary drain due to the physical state of the availability land and other ancillary constraint. Thus to some extent, the Bharalu section can be re-sectioned, which can reduce the discharge demand of the surface runoff and manage the peak discharge some remedial storm water management measure has to be adopted.

8.12 SUMMARY

Thus from the above analysis, it can be stated that the flash flood is due to the inadequate drainage system in the study area. It has been observed neither the primary, not the secondary drains are adequate to tackle the short duration heavy shower. These are no provision for the storm water management schemes in the developing processes of the watershed as such the growth and development is being grown in the name of urbanization in a very unscientific way. This it has become very necessary to take a step for the storm water drainage network system and if not taken up then the whole study area, will have to face threat of life and property in the near future.

CHAPTER 9

FLASH FLOOD / SUBMERGENCE SCENARIO FOR VARIOUS RAINFALL INTENSITY AND DURATION USING GEOGRAPHIC INFORMATION SYSTEM

9.1 INTRODUCTION

The elevation information, represented in computers as elevation data in a digital format, which is called Digital Elevation Models (DEM). Thus a DEM is a computerized representation of the Earths relief. Different formats exist, among the most usual are Triangulated Irregular Networks (TIN), regular grids, contour lines and scattered data points. A DEM is usually described either by a wire frame model or an image matrix in which the value of each pixel is associated with a specific topographic height. DEM are in combination with other spatial data, an important database for topography-related analyses or 3D video animations (e.g. fly-through). Different geo-referenced 3 dimensional products can be derived and complemented by a coordinate system and presented in a 2D-map projection or as a 3D perspective view In India, 12% land of the total geographical area is flood prone. A flood occurs typically during monsoon mainly due to heavy rain and due to inadequacy carrying capacity of the channel sections, in the past few years, Guwahati city had experienced flash flood and which has caused greater damage to life and property. This flash flood event had resulted killing people and damage to the property thus paralyzing the whole urban function within short duration rainfall. For the present work DEM of the study area (Bharalu Basin) the city is generated by digitizing contour of the city at 1m interval than Geographical Information system is used to identify probable submergence area of the various zones. In order to identify the probable submergence, the intensity of rainfall from IDF curve has been used irrespective of the return period and water level at a different level. The submergence has been assumed to vary linearly (which may not be the case in actual), but if so, the probably submerged area can be identified is such heavy intensity of rainfall occurs in near future. Thus this work focused as a flood warning system so that the people under the probably submerged area can be informed and can get ready or be prepared to tackle such threat from nature. The application of DEM and GIS environment had creates the digital database which can be stored and monitor the watershed and also helps as a tool for the future planning in carving the landscape of the watershed.

9.2 SUBMERGENCE AND DIGITAL ELEVATION MODELS

When rain occurs, the surface runoff wants to find its way to the conveying system through its gravity. However, due to the urbanization and unplanned growth of the landscape the surface runoff gets accumulated in the depression zones and increases in the water level with the increase in the duration of rainfall and the rainfall intensity. Thus the low-lying zones of the watershed get submerged and increase the level of submergence accordingly. Environmental issues are of vital importance for human life on the earth. The Digital Elevation Model or DEM or 3D information of the topography of the surface helps in understanding out the vulnerable environment and secure a more sustainable management and used together with other spatial data, image data in Geographic Information System (GIS), for instance (Dhrubesh, et al., 2015). A GIS is an information system designed to acquire, process, store and thus display data referenced by spatial or geographical coordinates (Rolf A. de, 2001). In a sense, a GIS acts as a higher order map, being both a database system with specific capabilities for spatially referenced data as well as a set of operation for processing and analyzing the data, (Sulebak, J.R., 2000). The DEM provides a basic spatial reference system to the GIS data sets. The image or vector information can automatically be draped over and integrated with the DEM for more advances analysis. It has been observed that the flash flood is an increasing problem in the study area (Guwahati city), especially in the Bharalu basin, where 16 numbers of watershed contribute its water in this basin. Since past few years the increasing trend in the flash flood has created havoc in the low lying area as well as has taken lives and has caused huge damages to the properties. There is no storm water management system in the study area. To identify the probable submergences area, the level of the low lying area has been investigated, considering the level 48m above MSL to the dead storage for the low-lying area.

9.3 STUDY AREA

The Bharalu Basin lies within the Guwahati city. The main channel, the river Bharalu carries the surface water from all 16 watersheds. The whole basin is being developed in a very haphazard way. And thus with the growth of construction activities in the name of development and urbanization has decreased the storage capacity for the storm water. As such, during short spell with high intensity, the city gets submerged with the flash flood and triggers threat to life and property.

9.4 METHODOLOGY

The methodology involves shown in Fig 9.1.

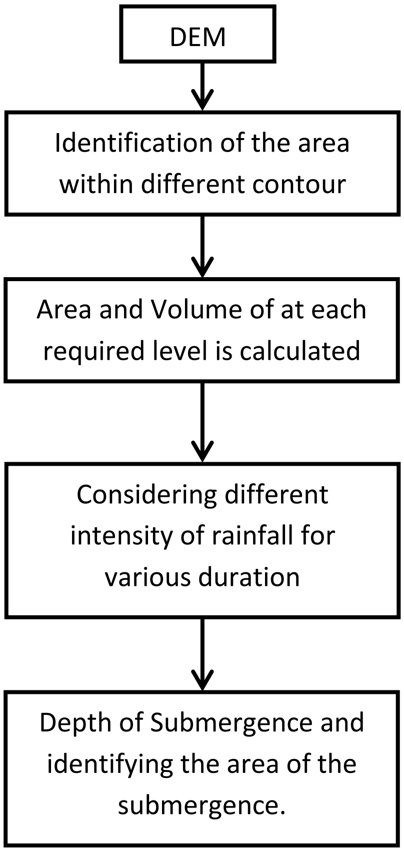

Figure 9.1: Overview of the Methodology

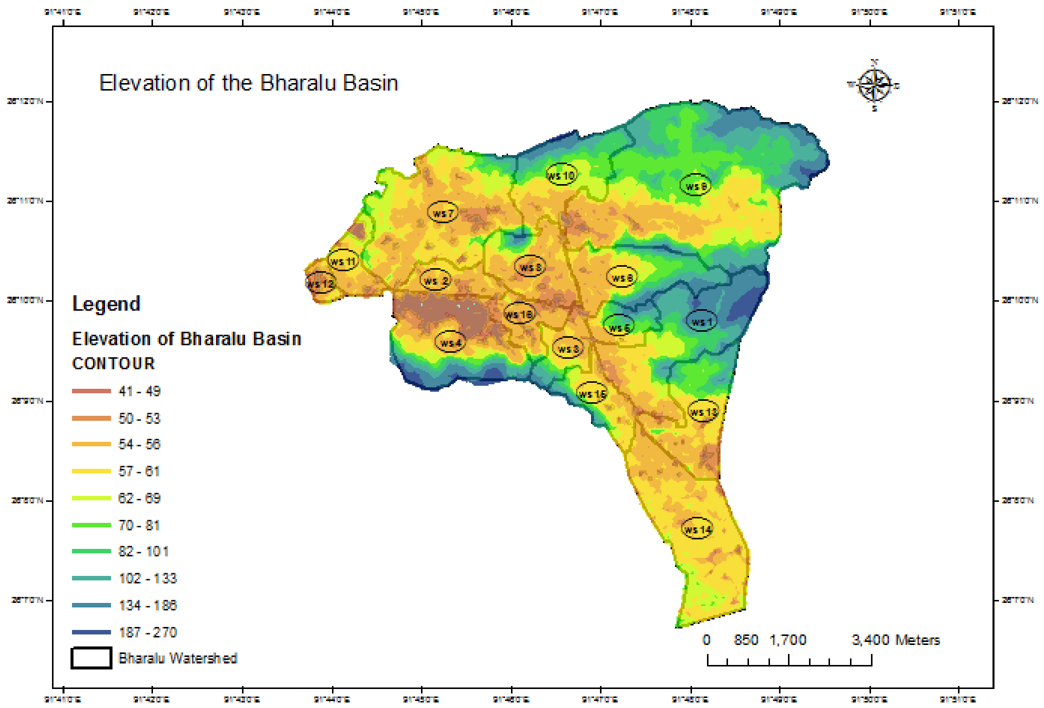

Figure 9.2: Elevation of the Study Area

9.5 ANALYSIS FOR SUBMERGENCE

To find the level of the submergence of the basin, the contour level at 48m, 49m & 50m has been considered. The area under these levels has been calculated. The volume of each level has been calculated using the trapezoidal rule methods.

Consider 48 m level above MSL to be the dead storage of the Bharalu Basin, as shown in Fig. 9.3 and assuming linear variation, the increase in the height of submergence with respect to level has been calculated.

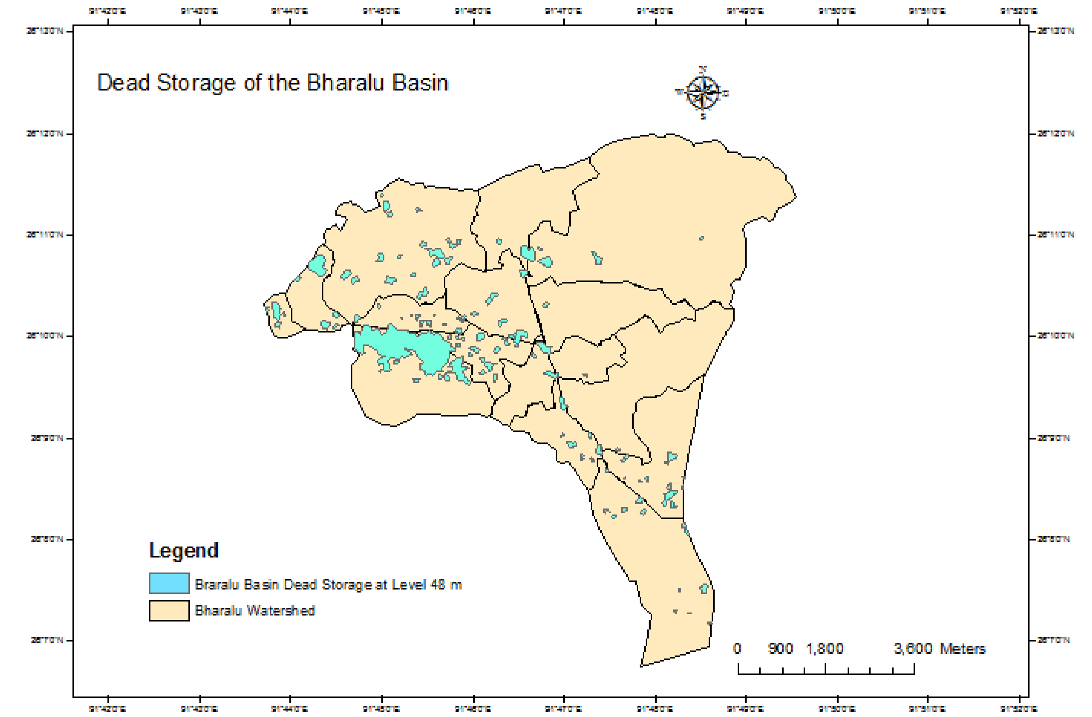

Figure 9.3: Dead Storage of the Bharalu Basin

The area under the 48 meters contour has been found to be 2525199 m^2 and for the contour 49 meter and 50 meters as 2870167 $m^2$and 4408551 m^2, Table 9.1

Table 9.1 Area and Volume under different levels

Contour (m)		Area (m^2)	Volume (m^3)	
A_1	48	2242513.83	Volume (V_1) between 48m & 49m	1348841.5
A_2	49	2505531.95		
A_3	50	3778746.23	Volume(V_2) between 49m & 50m	1819679.5

The area of the Bharalu basin is 52.4 Sq.km. It is observed that 4.27% of the total area is under 48m level. Similarly 4.78% and 7.21 % of the total area is under 49 meters and 50 meters contour, Fig 9.4

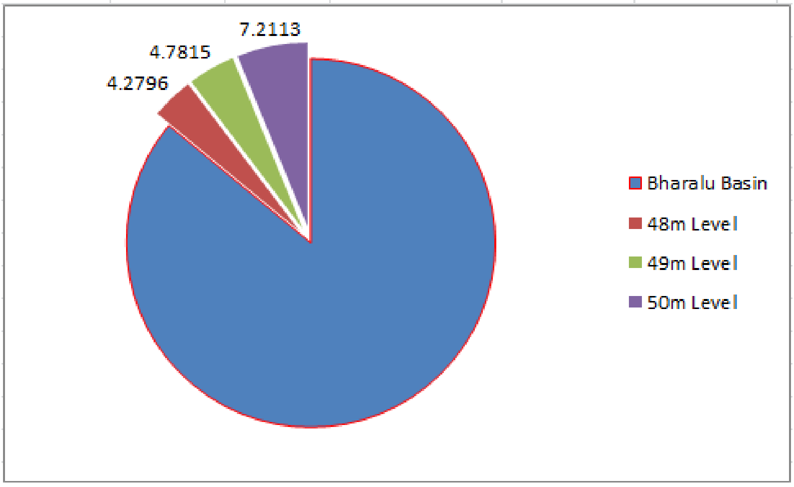

Figure 9.4: Percentage of Area w.r.t. Different Contour Level.

The volume between 48meters and 49 meters level and between 49meters and 50meters has been calculated with the Trapezoidal rule formula. The contour interval is 1m. Table 9.2 shows the volume for different contours.

9.5.1. Calculation for Spill over Volume.

For the prediction of spill over from one level to another, considering an intensity of rainfall of 90 mm/hr for different duration for the entire Bharalu basin and assuming all the conveyance system of the basin working sufficiently, the volume of surface runoff spill over from one level to another is shown in Table 9.2

Table 9.2a: Volume of spill over for 50mm/hr intensity for different duration.

Contour Level (m)	Rainfall intensity (mm/hr)	Duration in min	Depth of rainfall (mm)	Effective Area of whole Bharalu Basin (considering C), Sq km	Volume of runoff (Vr), Generated, =Effective Area x depth, in Cum	Volume of Contour, Vc , Cum	Vr/Vc	Spillover volume in cum	Remarks
49	50	15	12.50	38.252	478150	1348842	0.3545	-870692	Vr / Vc > 1 represents submergence
	50	30	25.00	38.252	956300	1348842	0.7090	-392542	
	50	45	37.50	38.252	1434450	1348842	1.0635	85608	
	50	60	50.00	38.252	1912600	1348842	1.4180	563759	
	50	120	100.00	38.252	3825200	1348842	2.8359	2476359	

For 50mm/hr rainfall for 15 min to 30 min then no spill over takes place. However, with the same intensity of 50mm/hr, if it rains for 45 min, 60min or 120min then there will be spill over with a volume of 85608 m^3, 563759 m^3& 2476359 m^3 respectively, Table 9.2 a

Similarly for 60mm/hr, 80mm/hr and 90mm/hr of rainfall intensity, the spill over volume has been presented in Table 9.2b, Table 9.2c and Table 9.2d.

Table: 9.2b: Volume of spill over for 60 mm/hr intensity for different duration.

Contour Level (m)	Rainfall intensity (mm/hr)	Duration in min	Depth of rainfall (mm)	Effective Area of whole Bharalu Basin (considering C), Sq km	Volume of runoff (Vr), Generated, =Effective Area x depth, in Cum	Volume of Contour, Vc , Cum	Vr/Vc	Spillover volume in cum	Remarks
49	60	15	15	38.252	573780	1348842	0.4254	-775062	Vr / Vc > 1 represents submergence
	60	30	30	38.252	1147560	1348842	0.8508	-201282	
	60	45	45	38.252	1721340	1348842	1.2762	372499	
	60	60	60	38.252	2295120	1348842	1.7015	946279	
	60	120	120	38.252	4590240	1348842	3.4031	3241399	

Table 9.2c Volume of spill over for 80 mm/hr intensity for different duration

Contour Level (m)	Rainfall intensity (mm/hr)	Duration in min	Depth of rainfall (mm)	Effective Area of whole Bharalu Basin (considering C), Sq km	Volume of runoff (Vr), Generated, =Effective Area x depth, in Cum	Volume of Contour, Vc , Cum	Vr/Vc	Spillover volume in cum	Remarks
49	80	15	20	38.252	765040	1348842	0.5672	-583802	Vr / Vc > 1 represents submergence
	80	30	40	38.252	1530080	1348842	1.1344	181239	
	80	45	60	38.252	2295120	1348842	1.7015	946279	
	80	60	80	38.252	3060160	1348842	2.2687	1711319	
	80	120	160	38.252	6120320	1348842	4.5375	4771479	

Table 9.2d Volume of spill over for 90 mm/hr intensity for different duration

Contour Level (m)	Rainfall intensity (mm/hr)	Duration in min	Depth of rainfall (mm)	Effective Area of whole Bharalu Basin (considering C), Sq km	Volume of runoff (Vr), Generated, =Effective Area x depth, in Cum	Volume of Contour, Vc , Cum	Vr/Vc	Spillover volume in cum	Remarks
49	90	15	22.50	38.252	860670	1348842	0.6381	-488172	Vr / Vc > 1 represents submergence
	90	30	45.00	38.252	1721340	1348842	1.2762	372499	
	90	45	67.50	38.252	2582010	1348842	1.9142	1233169	
	90	60	90.00	38.252	3442680	1348842	2.5523	2093839	
	90	120	180.00	38.252	6885360	1348842	5.1046	5536519	

9.5.2. Calculation for Submergence Depth.

Calculation for the depth of submergence has been done by the following Eq. 9.2

Considering the area of the 48m level, 49m level, and 50m level as A_1, A_2 and A_3 respectively. Similarly, the volume between 48m to 49m level and between 49m to 50m level as V_1 and V_2 , values to be considered from Table 9.1.

For a storm event of 90mm/hr intensity of rainfall for 60minutes duration,

Runoff generated =V_r = 3442680 m^3 from Table 9.2(d)

And Volume between 48m49m level V_1= 1348841.5 m^3 from Table 9.1

Here $V_r > V_1$the level of water will be above 49m level but below 50m level

Assuming linear variability,

Let the water above 49m level = h_1, Contour Interval, H = 1 m

Total Submergence Depth, h_s= 49 + h_1…………………………………………..(9.1)

Assuming linear variability,

$$V_1+[\{A_2+(\frac{A3-A2}{H}x\,h_1)+A_2\}\frac{1}{2}]\,x\,h_1=V_r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9.2)$$

⇨ $h_1 = 0.708$ m

Substituting the 'h_1' value in Eq. 9.1,

Thus the submergence depth above 49m level, h_s= 0.708m

Similarly for the same intensity of rainfall for the duration of 120 min, the depth of submergence above 49m level = 1.577m.

9.6 RESULT AND INTERPRETATION

From the above analysis, it is observed that, if 90mm/hr intensity of rainfall occur for a duration of 60min, it will submerge the area under the 49 m to 50 m contour with depth of submergence of 0.708m above 49 m, and if the same intensity of rainfall occurs for 120min duration, the depth of submergence will be 1.577m. Table 9.3 depicts the depth of submergence and the area that will get inundated from the different intensity of rainfall event.

Table 9.3Depth of Submergence for different intensity of rainfall

Intensity of rainfall (mm/hr)	Duration of the rainfall event (min)	Contour level (m)	Rise of Water level above 49m level (m)
50	60	49	0.2130
50	120	49	0.8180
60	60	49	0.3470
60	60	49	1.0260
80	30	49	0.0710
80	45	49	0.3470
80	60	49	0.5940
80	120	49	1.4040
90	60	49	0.7080
90	120	49	1.5770

The Fig 9.5 and Fig 9.6show the inundated areas to occur for a storm event of the 90mm/hr of rainfall intensity for 60minute and 120-minute duration. Similarly, storm event for different intensity for a different duration, the depth of submergence can be calculated and thus the area to be inundated can be predict and thus to be inundated area can be kept vigilance or investigate and as such would be prepared for such storm events.

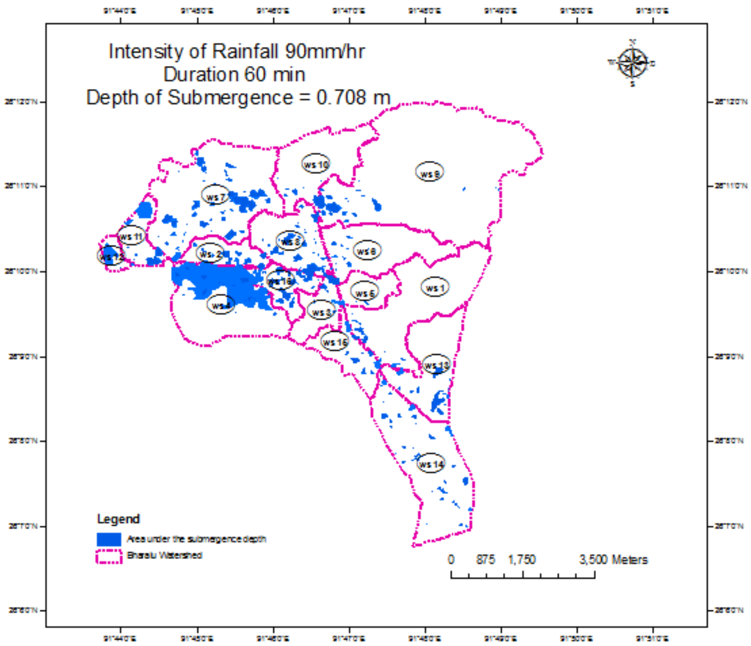

Figure 9.5: Submergence Area for Depth of Submergence at 0.708m

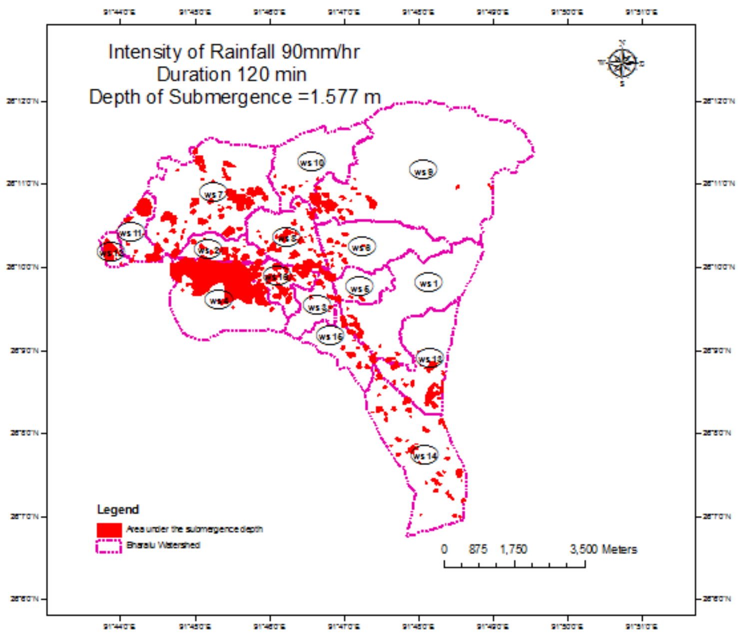

Figure 9.6: Submergence Area for Depth of Submergence at 1.577m

9.7 SUMMARY

The DEM and GIS, plays a very vital role in the present day flood scenario. It is capable of depicting the scenario of the flood affected area. The DEM acts as the platform for the terrain height analysis, which had proven to indicate the inundation area with relationship to the submergence. The use of GIS provides supplementary data in Hydrology for analysis and make easy to interpret and to understand flood phenomenon and its characteristic. DEM can be used effectively for the simulation to get a complete model of the area. The analysis of the submergence with respect to the rainfall intensity with the different duration of time for the study area can predict the area to be inundated for a specific pattern of rainfall. It has also been observed from the analyssi that with the same intensity, i.e., 90mm/hr for different duration of time the depth of submergence increase accordingly from 0.708m for 60 min duration and 1.577m for 120 min.

CHAPTER 10

REMEDIAL MEASURES AND OTHER MANAGEMENT MEASURES FOR LONG RUN SUSTAINABILITY

10.1 INTRODUCTION

In order to suggest measures to tackle the flash flood problem, a holistic approach incorporating all the factors responsible for the problem must be taken into account. Attempt is made to address the important factors pertaining to the flash flood problem of Guwahati and corresponding remedial steps are discussed in the following sub-sections. It is also tried to demonstrate how with the combination of various alternatives the flash flood problem of Guwahati can be solved completely.

10.1.1 Efficient Drainage Network

It has been observed that Guwahati lacks a proper scientifically designed drainage network, either in the hill areas or in the plain areas of the city. Because of absence of a proper drainage network in the hill areas of Guwahati, runoff resulting from the rains finds their way haphazardly through the soil surface giving rise to erosion of the surficial soil. In many cases prolonged surface flow over steep soil surfaces even give rise to landslides/ debris-slides. Such a debris-slide may even block natural streams partially or completely causing flash flood in the upstream sides. Huge amount of erosion and debris-slides ultimately has a toll on the drains in the downstream side in terms of siltation and in turn reduction in the effective cross sectional area of these drains. Calculation of required effective cross-sectional area of the main drains for each watershed of Bharalu basin has been demonstrated in Chapter 8. In the same line, the feeder drains also can be designed based on the same watershed management approach, for micro watersheds within each watershed in the hill area. A network of feeder drains and main drains designed by watershed management approach outlined above in the hill areas of Guwahati city will help in reducing silt load in the city drains in plain areas.

It has also been shown in the previous sections that city drains in the plain areas are not adequate enough for carrying the runoff water during monsoon period. Creation of dedicated storm water drains in addition to roadside drains is likely to reduce city flash floods. In the Bharalu basin, Bharalu River is the main outlet channel for its entire basin, into river Brahmaputra. However, the present Bharalu cross section is found to be quite inadequate to carry out runoff from its entire basin. Although there exists a limitation for deepening river Bharalu, for natural gravity flow from Bharalu into Brahmaputra River, it is found that some amount of deepening is still possible. Re-sectioning of the primary drains/rivulets like Bharalu, Mora Bharalu & Basistha river is believed to reduce the flash flood problem of Guwahati significantly. An analysis showing re-sectioning of the river Bharalu, from the Bhangagarh (Point A) to the Bharalu Sluice gate at Shantipur, (Point B) is presented. The length of this stretch between Point A and Point B is 6 kms. approximately (Fig. 10.1). Figure 10.2 shows the proposed cross-section of Bharalu river.

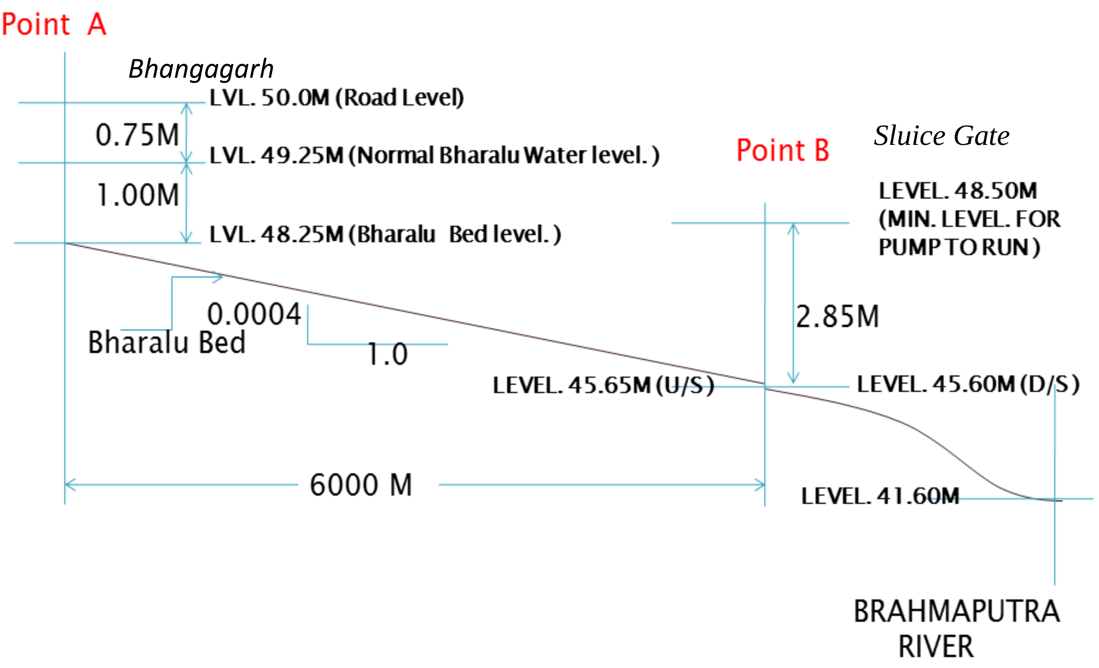

Figure 10.1: Existing Section of the river Bharalu

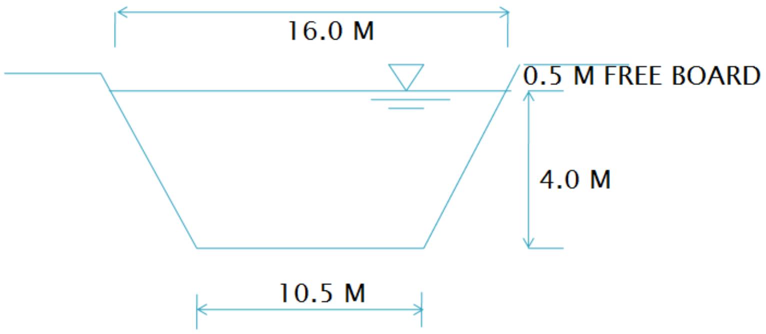

Figure 10.2 : Re-Section of the river Bharalu

Figure 10.3 shows the existing as well as the proposed bed slope of Bharalu along the stretch considered.

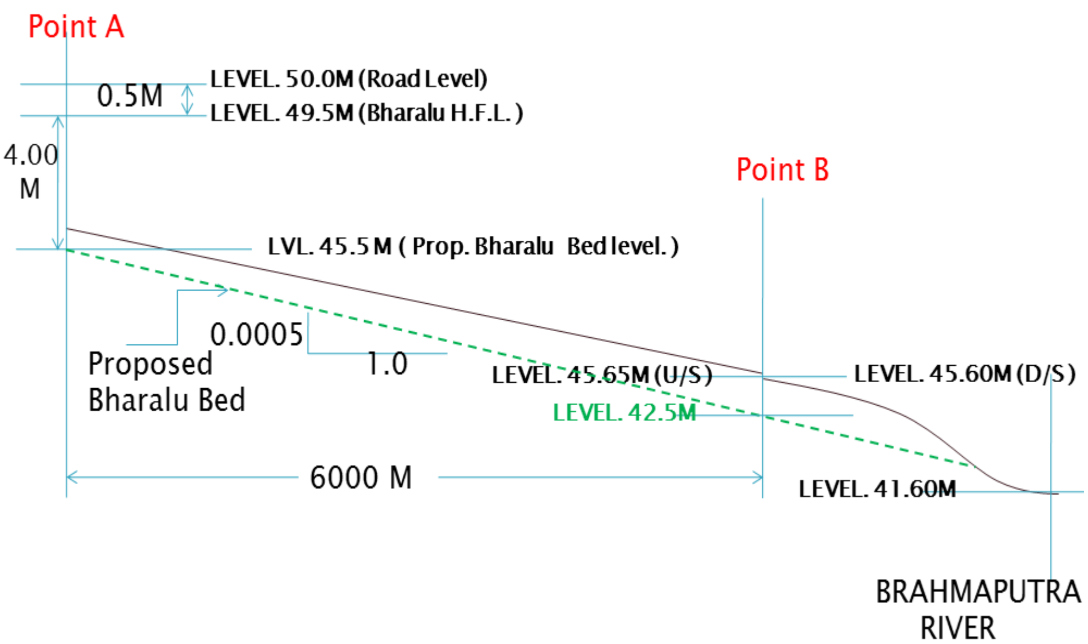

Figure 10.3: Proposed section of the river Bharalu

Considering,	Effective top width of the Bharalu river	=	16m
	Effective Bottom width of the Bharalu river	=	10.5m
	For bed slope of 0.0005 : 1 , Flow velocity	=	1.37m/sec

Maximum discharge for the proposed section = 4 x (16 + 10.5)/2 x 1.37

= 72.61 m^3/sec

Thus with the proposed section, (Fig 10.2 and Fig10.3) the Bharalu can discharge 72.61 m^3/sec. However, it is observed for a storm event of the 2-year return period, the maximum peak discharge at Sluice Gate (point B) is 524.12 m^3/sec, (refer to Chapter 8, Figure 8.4). Therefore, it is observed that mere re-sectioning the Bharalu channel is not the only solution to the stormwater flooding. Other effective measures to be taken along with the above are discussed in the following sub-sections.

10.1.2 Increasing Retention Capacity of Existing Storage Reservoirs

Guwahati naturally has many Beels and Ponds such as Sola Beel, Silsako Beel etc. (Refer Chapter 3, Cl. 3.2.1). These water retention basins are capable of holding a huge volume of water. However, during monsoon, after two-three rainfall, these beels become almost filled up and cannot hold any more water. Sluice-gates and pumping out (at a later time) system may be implemented after every storm event, to prepare these ponds and the beels to accept and store runoff from the next rainfall event. By this process, the time of concentration for different watersheds may be varied and the flash flood problem can be minimized. A critical analysis is carried out to examine the additional retention capacity generated by preparing these beels to accept storm water.

a) **Sola Beel**: After every storm event, by setting up a suitable pumping mechanism, the Sola beel can be prepared to accept at least 3.0m of storm water.

   Length of Sola beel = 1075m

   Width = 70m

   Depth of water level at Sola beel to be maintained at 3m.

   Volume of water it will retain = 225750 cum

   Thus it can hold 11.80 % of the total runoff generated.

b) Silsako Beel:

   Considering an effective area of 1.5 sq km and preparing it to accept storm water up to a depth of 0.4m

   Volume of water it can retain = 600000cum

   Thus it can hold 31.37 % of the total runoff generated.

10.1.3 Creating Additional Retention Basin

Guwahati still has many open areas where additional reservoirs can be constructed. By creating additional retention area, surface runoff can be controlled not to concentrate at a point at the same time. Rainwater harvesting and creation of dry sumps in every household of Guwahati city plays a major role in minimizing the city flash flood problem. A critical analysis of the Rainwater Harvesting is presented here.

Bharalu has a catchment area of 52.4 sq. kms, A study of the existing building footprint within this area reveals that 15% is covered by building roofs, Fig 10.4.

Considering surface runoff generated from a storm event 50mm/hr intensity for 60 minutes in the entire Bharalu basin, surface runoff generated is 1912600 cum., (refer Table 9.2 a, Chapter 9)

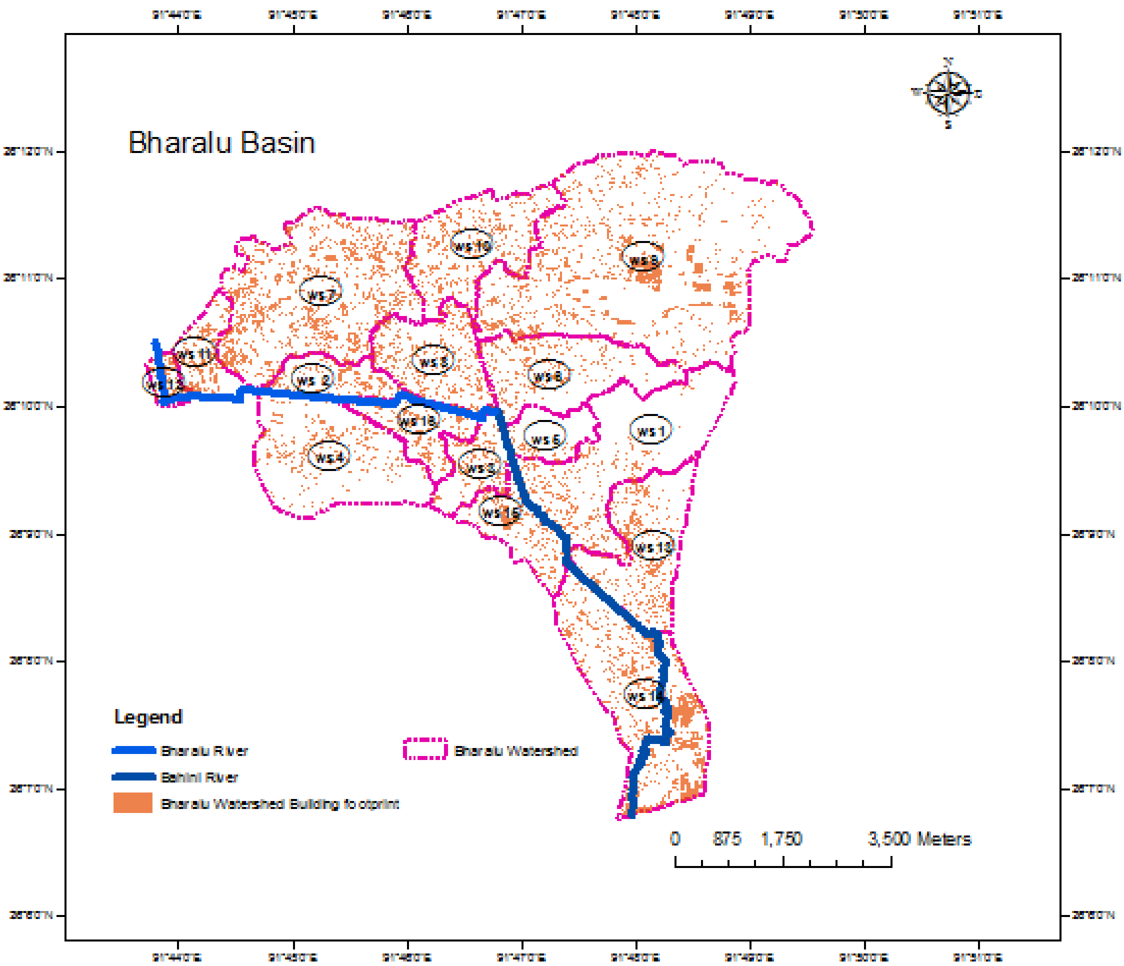

Figure 10.4: Building Footprint of the Bharalu Basin

Considering 80% of building roof to have the provision of collecting rainwater from its roof area, i.e., of area 5972824 sq m with a depth of 15 cm by either using collected rainwater for its own house hold purpose or by making arrangement to infiltrate into the ground by provision of Dry sumps, a volume of 895924 cum of storm water can be retained.
Thus it can hold 46.84 % of the total runoff generated.

By adopting the measures discussed in Cl. 10.1.2 and Cl. 10.1.3 above, it is possible to retain a total volume of runoff water = 895924 + 225750+600000 = 1721674 cum
Hence net volume of storm water generated = 1912600-1721674 = 190926 cum.
Considering a storm event of 50mm/hr. intensity of rainfall for 60 min duration, after imposing the above storm water retention measures, at point B (Fig. 10.4), Bharalu channel requires a discharge capacity of 53.04 m^3/sec, whereas the proposed section of the Bharalu channel, is able to discharge = 72.61m^3/sec (Ref. Cl. 10.1.1)

Thus by implementing the above it can be observed that 46.84% of the surface runoff generated can be stored by Building roof within Bharalu basin, 37.31 % of the storm water can be managed by diverting the water to Silsako beel and 11.80% can be retained by Sola Beel within the Bharalu basin and thus load for the discharge capacity of Bharalu can be reduced and as observed, only 3.99% of the stormwater has to be discharged by the Bharalu river for the aforesaid storm event. Bharalu, if resectioning is done as per the designed section, is quite capacble of carrying this small amount of runoff flow through it.

10.1.4 Taking care of Heavy Silting in the drains.

For a sustainable solution to the flash flood problem, it is to be seen that drains and channels and rivulets donot get silted up after a spell of a rainfall event. A critical analysis is carried out in one catchment drain to study the silt generated by erosion. By invoking the Universal Soil Loss Equation (USLE) method (Equation 10.1), theoretical value of soil loss is calculated. A rectangular drain (feeder drain) of section 1.8 m x 0.45 m is considered with the tributary area of 1.2 sq km, (296.52 acres)

The Universal soil loss equation is given as in Eq. 10.1

$$\mathbf{A = R \times K \times LS \times C \times P} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10.1)$$

A represents the potential long term average annual soil loss in tons per acre per year. This is the amount, which is compared to the 'tolerable soil loss' limits.

R is the rainfall and runoff factor by geographic location. The greater the intensity and duration of the rain storm, the higher the erosion potential.

K is the soil erodability factor. It is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Texture is the principal factor affecting K, but structure organic matter and permeability also contribute.

LS is the slope length-gradient factor. It represents a ratio of the soil loss under given conditions to that at a site with the standard slope steepness of 9% and slope length of 72.6 feet. The steeper and longer the slope the higher is the risk for erosion.

C is the crop/vegetation and management factor. It is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. The C factor is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss from continuously fallow and tilled land.

P is the support practice factor. It reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. The P factor represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope.

Determination of R factor:

From Table10.1,(Ref. ANNEXURE-1) we have,

R factor for Delhi (India) = 90

Determination of K factor:

The soil samples collected from the upstream area were found to be mainly fine sandy samples, with small amounts of silts and clays. (Ref. Annexure –II, for the laboratory test results)

Therefore from Table10.2 (Ref. ANNEXURE-I), we assume an average value of **K as 0.225**

Determination of LS factor:

$$LS = [0.065 + 0.0456(\text{slope}) + 0.006541(\text{slope})^2] \times (\text{slope length} \div \text{const.})^{NN}$$

Where,

Slope = slope steepness (%)

Slope length = length of slope (ft.)

Constant = 72.5 Imperial or 22.1 metric

NN is obtained from Table 10.4 (Ref. ANNEXURE-I),

Calculation of slope steepness:

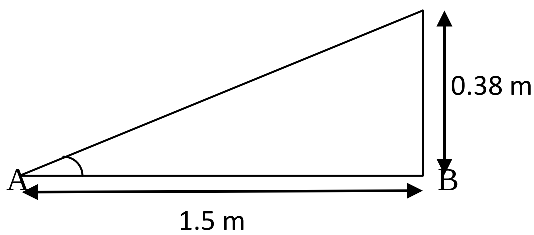

Figure 10.1

From Δ ABC, (Fig 10.1)

$\tan \theta = 0.38/ 1.5$

$= 0.253$

Slope is given by $\tan \theta = 0.253$

$\therefore$ Angle of the slope = $\tan^{-1} \theta$

$= \tan^{-1} 0.253$

$= 14.216^{o}$

Slope steepness (%) = $(0.38/1.5) \times 100$ %

= 25.3 %

This angle is taken at the area of steepest slope area and hence it can be considered as the peak slope angle since the hill slope is not uniform and consists of up and down slopes, including flat areas also. The mean slope angle of the area is considered

The mean slope angle is calculated as= $\frac{1}{2} \times (0^{o}+14.216^{o})$

$= 7.108^{o}$

Therefore the mean slope steepness (%) is considered =12.65%

Slope length: The overall slope length of the considered hill is taken as 1200 feet

Value of NN:

Value of NN is taken as 0.5from Table 10.4 (Ref. ANNEXURE-I)

Value of C:

Value of C is taken as 22.1 (metric)

From equation (iii),

$LS = [0.065 + 0.0456(\text{slope}) + 0.006541(\text{slope})^2] \times (\text{slope length} \div \text{const.})^{NN}$

$= [0.065+0.045(12.65) +0.006541(12.65)^2] \times (1200 \div 22.1)^{0.5}$

$= 12.443$

Determination of C factor:

From Table 10.5 (ANNEXURE-I), considering hay and pasture type of crop we have,

Crop factor = 0.02

Again from Table 10.6 (ANNEXURE-I), considering no tillage, we have,

Tillage factor, T = 0.25

Thus, we have C factor, $C = 0.02 \times 0.25$

$= 0.005$

Determination of P factor:

From Table 10.7 (ANNEXURE-I), considering up and down slope we have

P factor = 1

Now from Equation 10.1,

$A = R\times K \times LS \times C \times P$

$= 100 \times 0.225 \times 12.443\times 0.005\times 1$

$= 1.399$ tons/acre/year

Therefore, for the total catchment area of 296.52 acres,

We have,

Total soil loss from the catchment area = 1.339×296.52

= 414.83 tons/year

Considering RIDGE TILLAGE:

From table 10.6 (ANNEXURE-I), we have Tillage factor = 0.35

$\therefore$ C factor = 0.02×0.35

$= 0.007$

Using Equation-

$A = R \times K \times LS \times C \times P$

$= 100 \times 0.225 \times 12.443 \times 0.007 \times 1$

$= 1.959$ tons/acre/year

Total soil loss from the catchment area = 1.959×296.52

= 580.88 tons/year

= 1.6tons/day

From the above calculations the total soil loss from the catchment area in tons per acre per year is found out to be less than 3. As per Table 10.8 (ANNEXURE-I), this value corresponds to Soil Erosion Class – 'Very Low' and is within the tolerable soil loss rate.

Although, the theoretical soil loss is 1.6 ton/day by using Universal Soil Loss Equation with tillage, an actual measurement for 8 hours immediately after a smart rainfall event recorded 5 tons of soil as soil loss, i.e. soil loss has been found to be 15 ton/day.

The increase in the soil loss indicates that the field soil loss is not due to natural erosion (even with tillage). The significant difference between the expected and the actual field observation may be attributed to anthropogenic activities, such as dumping of loosely cut hill soil into natural channels during rain. Some remedial measures include-

i) Erosion protection in the hills
ii) Silt trap in appropriate location
iii) Strict administrative control and banning hill cutting completely, ban on throwing polythene, garbage, etc., into drains/rivulets etc.
iv)

10.2 SUMMARY

Although there are a few primary factors which are mainly responsible for aggravating the flash flood problem of Guwahati, only one or two remedial measures are not likely to solve the problem completely. A holistic approach comprising of all the remedial measures as mentioned above can only solve the flash flood problem of Guwahati. They are-

1 Ponds or beels meant for retention of storm water must be kept prepared for the next storm.

2 Borsola beel should be kept prepared to take 3.0m of storm water into it.

3 Silsako beel should be prepared to accept a storm flow up to at least 0.4m.

4 Roof-Top rainwater harvesting should be done in at least 80% of the households of Guwahati keeping a provision to hold water up to at least 15cm. These retained storm water either can be used for household or other activities or can be directly infiltrated into the ground to dry sumps for recharge of groundwater.

5 Erosion in the hills are found to be primarily anthropogenic in nature. To prevent erosion in the Guwahati hillocks following measures may be helpful-

i. Installation of silt fence barrier surrounding every household in the hills
ii. Provision of erosion control mats in soil surfaces without grass cover
iii. Provision of contour drains in hill area along with other drains.

CHAPTER 11

CONCLUSIONS AND SCOPE FOR FURTHER RESEARCH

12.1 SUMMARY

A detailed and in depth integrated remote sensing and GIS based study on urban storm water flooding in Guwahati carried out in this research work reveals various factors which contribute to the Guwahati flash flood problem. The study highlights the generalized approach for analyzing the city flash flood problem and designing probable solutions to this problem. Whereas more intricate solutions are also likely to exist, the mandatory measures which must be taken for sustainable solution to the Guwahati. Flash flood have been identified and suggested.

12.2 CONCLUSIONS

Major conclusions and findings of the research work are as follows:

1) Guwahati has 19 hillocks and rainwater falling on these hillocks, when flows into plain areas of the city causes flash flooding in certain areas, especially, in the city low lying areas of the city with R.L. 50m or slightly more.
2) Landuse pattern of Guwahati has changed drastically from 1971, when the capital of Assam was shifted from Shillong, Meghalaya to Guwahati as the temporary capital of Assam. There was further accelerated Land use Land cover change in Guwahati when Guwahati was declared as the permanent capital of Assam in 2002. Significant changes in landuse pattern by way of growth in the human settlement, haphazard construction activity, by filling up the low lying area, shrinking /extinction of water-bodies is thought to be the main root cause of the Guwahati Flash Flood.
3) Guwahati does not have a dedicated storm water drainage network. Though the plain areas have some natural and artificial drains, hill area in particular completely lacks a network of the storm water drains.
4) For research work Guwahati has been divided into 39 watersheds. For Bharalu Basin, it has been observed the existing main drains of most of these watersheds are not adequate even for a rainfall event of 2-year return period.

Designed and required sections of these main drains for the Bharalu basin has been suggested. Similar approach can also be adopted to the other basins namely the Basistha, Mora Bharalu, Silsako basin and Foreshore basin to calculate adequate cross-sections of main drains of each basin. Sectional areas of other secondary drains leading to the main drains also can be designed the similar approach and considering more micro-watershed of each watershed.

5) A critical examination of the adequacy of the Bharalu river cross-section which is the sole outlet for the entire Bharalu basin catering to about 29% of entire Guwahati considered is found to much smaller than its requisite section. Considering permanent structure in the adjacent vicinity on both bank of the river thereby restricting widening of the Bharalu river to certain limit and also considering the present bed level of the river Brahmaputra at Bharalu outfall point, possible resection of the Bharalu River has been calculated.
6) It has been observed that even re-sectioning of Bharalu does not take out entire runoff generated after an extreme rainfall event to the River Brahmaputra, and therefore, along with re-sectioning, other measures are also identified for a complete solution of Guwahati Flash Flood problem.
7) A study of the building roof area of Bharalu Basin, Guwahati and a scientific rainwater harvesting at least in 80% of the roof area shows that there will be a decrease in the surface runoff by 46.84 %. Excess water drained into dry sump will not only decrease the surface runoff but also will increase ground water recharge.
8) Silt generated due to erosion, especially in the Guwahati hillocks clog the drains, thereby blocking glow of rainwater through them. An analysis of amount of silt generated due to the erosion considering tillage and comparison with the actual recorded value of silt generated shows that actual silt generation is more than 9 times the theoretical prediction. This indicates anthropogenic activities like loosening hill soil and/or dumping cut soil from hillocks on to the natural streams in the hill areas during monsoon. This is

attributed as the main reason for the huge amount of silt load in the city drains.

9) Some other measures to control erosion for long term sustenance and flash flood free Guwahati is also suggested.
10) An attempt to generate flood submergence data of Guwahati city, identified the areas experiencing submergence as well as depth of submergence for a given rainfall intensity for a given duration. It is observed that a 50mm/hr intensity rainfall for 45 minutes shall cause inundation of more than 80 cm in certain areas of the city.

12.3 SCOPE FOR FURTHER RESEARCH

Based on the results and analysis, experiences gained during field visit, and interaction with the section of local people and other related departments, the following recommendation for the further study is put forward.

1) Flood inundation mapping in watershed-wise, in a number of years, in the whole city may be done to delineate flood affected area. Such an analysis is needed to be succeeded by another study aiming at possible risk zone mapping so as to make people aware.
2) A complete inventory of subsidiary surface water bodies like wetland, marshy land, and other streams may be carried out. Moreover, studies for adequate conservation of all these water bodies need to be carried out since they act as flood ponds or storm water reservoir at the basin scale. This is particularly important at monsoon peak as the Brahmaputra river fails to receive tributary water during this period.
3) A more elaborate study of the watershed under micro-level study with all the secondary and tertiary network with the main drainage network may be studied to attain further complete solution to the storm- water flooding in the Guwahati city for healthy and sustainable living environment.