

**Evaluation of Draft Dhaka Structure Plan (2016-2035) Regarding
Drainage and Flood Management: A Case study on Turag River
and Its Contributory Area**

A Thesis

**Submitted to the Department of Disaster Engineering and Management in
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MASTER OF SCIENCE IN DISASTER AND ENVIRONMENTAL ENGINEERING

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CERTIFICATE OF APPROVAL

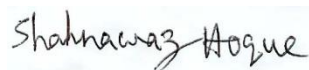
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This thesis is dedicated to my beloved Parents

Abstract

Turag river is an upper tributary of the Buriganga River and flows beside the western side of Dhaka, the capital of Bangladesh. Turag river and its flood plain plays a dominant role in flood management of Dhaka city as it assists to save Dhaka city from flooding by containing excessive flood water during inundation. From the very past, Turag and its tributaries are enriched with biodiversity and ecological resources and have provided enormous ecosystem services and functions to the society. Like other areas of Bangladesh, the settlement and livelihood pattern of people especially the farmers and fishermen community of Turag river-floodplain are adjusted with the deltaic conditions of Bangladesh. But the lives and livelihood and the settlement of the local community are about to extinct now. Encroachment and pollution and of Turag river-flood plain ecosystem have damaged the socio-economic and ecological harmony of the region. Recognizing the importance of restoring the original character of Turag river, Department of Environment (DoE) of Bangladesh declared Turag river as ‘ecologically critical area’ in 2009. The High court division of Bangladesh in 2019 passed an order by declaring Turag river a ‘living entity’ and directed concerned authorities to save it from extinction and revive its original character. Conventional flood management strategies/ practices consider flood protection as their only goal but multiple ecosystem benefits/socio-ecological dimensions of flood management approaches are overlooked. In this context, there was an urgent need to critically evaluate the policies/proposals of Dhaka Structure plan (2016-2035) and Dhaka Detailed Area Plan (2022-2035) regarding drainage and flood management of Turag river and its contributory areas from multiple ecosystem benefit approach. This study attempted to understand the status of socio-ecological considerations of flood management approaches in the study area. This study also performed hydrologic and hydrodynamic analysis through mathematical modeling to understand the hydrologic and hydraulic process of the study area and then flood mapping analysis was done to understand the impact of development pattern on the flooding pattern of the study area. Finally, the policies/proposals of Dhaka Structure plan (2016-2035) and Dhaka Detailed Area Plan (2022-2035) regarding drainage and flood management of the study area were evaluated with the output derived from the socio-ecological, hydrologic and hydrodynamic analysis. The Dhaka Structure Plan (2016-2035), the strategic plan for Dhaka prepared by RAJUK, has been approved by the Inter-ministerial Steering Committee of government dated 20 November, 2016 but gazette notification has not yet been published by the government. So, in the title of the thesis, the term ‘Draft’ before Dhaka Structure Plan (2016-2035) has been used. However,

before publishing gazette notification of the plan, the gazette notification for the next tier of the plan, i.e. the Dhaka Detailed Area Plan (DAP, 2022-2035), a detailed or local plan prepared by RAJUK, has already been published dated 23 August, 2022 following approval of the government of Bangladesh. From the field investigation, it is observed that insecurity in land ownership/ tenure rights due to threat of forced eviction is the root cause for conversion of flood plains/agricultural lands to non-agricultural uses in the region. This study finds that the percentage of amount of main flood flow zone is almost same for flood map of study model and DAP (2022-2035). But, the connectivity network, position and alignment of main flood flow zone in flood map of the study model is different from those in flood map of DAP (2022-2035) and Dhaka Structure Plan (2016-2035). Besides this, for extreme flooding event (1988), the percentage of inundation extent in study model is different from that of the DAP (2022-2035) for different flood depths. There may be some differences because boundary condition and catchment extent of model for hydrodynamic analysis are different for study model and DAP (2022-2035) although existing DEM is same for both DAP (2022-2035) and study model. This study also finds that in the flood map of DAP (2022-2035), the main flood flow zone is not connected in some areas and the position and alignment of main flood zone have been shifted in some areas from Dhaka Structure Plan (2016-2035) and Dhaka Detailed Area Plan (2010-2015). But, both in Dhaka Structure Plan (2016-2035) and Dhaka Detailed Area Plan (2010-2015), the flow path of main flood flow zone is continuous. It is observed that the flood map in DAP (2022-2035) is prepared by hydrodynamic analysis based on the existing/latest available DEM (year 2014, updated in year 2018), but no oldest available DEM is used for analysis. As existing development pattern is unplanned and existing DEM only reflects the existing scenario, so in DAP (2022-2035), flooding pattern in main flood flow zone based on existing DEM reflected the existing unplanned development pattern which is the main reason for discontinuity and shifting of the position and alignment of the main flood flow zone from the previous plan. Disconnected and changing pattern of flood plains act against conservation of flood plains and can't deliver their ecosystem services and functions. So, it is high time to restore the original character of Turag river-flood plain ecosystem so that maximum benefits/values can be captured from the restored ecosystem services and functions.

বিমূর্ত

তুরাগ নদী বুড়িগঙ্গা নদীর একটি উপনদী এবং বাংলাদেশের রাজধানী ঢাকার পশ্চিম পাশ দিয়ে প্রবাহিত। তুরাগ নদী এবং এর প্লাবনভূমি ঢাকা শহরের বন্যা ব্যবস্থাপনায় গুরুত্বপূর্ণ ভূমিকা পালন করে থাকে, কারণ এটি বন্যার সময় অতিরিক্ত পানি ধারণের মাধ্যমে ঢাকা শহরকে বন্যামুক্ত রাখতে সহায়তা করে। প্রাচীনকাল থেকেই তুরাগ এবং এর শাখানদীগুলি জীববৈচিত্র্য ও পরিবেশগত সম্পদে অনেক সমৃদ্ধ এবং সমাজের নিকট অনেক বাস্তুতান্ত্রিক পরিষেবা সরবরাহ করে থাকে। বাংলাদেশের অন্যান্য অঞ্চলের মতো, তুরাগ নদী-প্লাবনভূমি অঞ্চলের মানুষের বিশেষ করে কৃষক ও জেলে সম্প্রদায়ের বসতি ও জীবিকা নির্বাহের পদ্ধতি বাংলাদেশের ব-দ্বীপ পরিস্থিতির সাথে সামঞ্জস্যপূর্ণ। কিন্তু স্থানীয় জনগোষ্ঠীর জীবন, জীবিকা ও বসতি এখন বিলুপ্তির সম্মুখীন। তুরাগ নদী-প্লাবনভূমি বাস্তুতন্ত্রের দখল ও দূষণ এই অঞ্চলের আর্থ-সামাজিক ও পরিবেশগত সম্প্রীতিকে বিনষ্ট করেছে। তুরাগ নদীর মূল চরিত্র পুনরুদ্ধারের গুরুত্ব উপলব্ধি করে বাংলাদেশ পরিবেশ অধিদপ্তর (DoE) বিগত ২০০৯ সালে তুরাগ নদীকে 'পরিবেশগত সংকটাপন্ন এলাকা' হিসাবে ঘোষণা করে। বিগত ২০১৯ সালে বাংলাদেশের হাইকোর্ট বিভাগ তুরাগ নদীকে 'জীবন্ত' সত্ত্বা হিসেবে ঘোষণা করে একটি আদেশ জারী করে এবং এটিকে বিলুপ্তির হাত থেকে বাঁচাতে এবং এর মূল চরিত্র পুনরুজ্জীবিত করার জন্য সংশ্লিষ্ট কর্তৃপক্ষকে নির্দেশ প্রদান করে। প্রচলিত বন্যা ব্যবস্থাপনার কৌশল/অভ্যাসগুলি বন্যা থেকে সুরক্ষাকেই তাদের একমাত্র লক্ষ্য হিসাবে বিবেচনা করে কিন্তু বন্যা ব্যবস্থাপনা পদ্ধতির বহুবিধ বাস্তুতান্ত্রিক সুবিধা বিষয়ক/সামাজিক-পরিবেশগত দিকসমূহ উপেক্ষা করা হয়। এই প্রেক্ষাপটে, তুরাগ নদী এবং এর প্রভাববলয় এলাকার পানি নিষ্কাশন ও বন্যা ব্যবস্থাপনার বিষয়ে ঢাকা স্ট্রাকচার প্ল্যান (2016-2035) এবং ঢাকা ডিটেইল্ড এরিয়া প্ল্যান (2022-2035) এ উল্লেখিত নীতি/প্রস্তাবগুলিকে বহুবিধ বাস্তুতান্ত্রিক সুবিধা প্রাপ্তির দৃষ্টিকোণ থেকে মূল্যায়ন করার জরুরি প্রয়োজন ছিল। এই গবেষণায় অধ্যয়ন এলাকার বন্যা ব্যবস্থাপনা পদ্ধতির সামাজিক-বাস্তুসংস্থানগত দিকসমূহের বর্তমান পরিস্থিতি অনুধাবনের চেষ্টা করা হয়েছে। অধ্যয়ন এলাকার জলবিদ্যা ও জল গতিবিজ্ঞান প্রক্রিয়া বোঝার জন্য এই গবেষণায় গাণিতিক মডেলিংয়ের সাহায্যে জলবিদ্যা ও জল গতিবিদ্যা বিষয়ক বিশ্লেষণ করা হয়েছে এবং তারপর অধ্যয়ন এলাকার বন্যার প্রকৃতির উপর উন্নয়ন প্রকৃতির প্রভাব বোঝার জন্য বন্যা মানচিত্র বিশ্লেষণ করা হয়েছে। পরিশেষে, অধ্যয়ন এলাকার পানি নিষ্কাশন ও বন্যা ব্যবস্থাপনার বিষয়ে ঢাকা স্ট্রাকচার প্ল্যান (2016-2035) এবং ঢাকা ডিটেইল্ড এরিয়া প্ল্যান (ড্যাপ, 2022-2035) এ উল্লেখিত নীতি/প্রস্তাবগুলিকে আর্থ-সামাজিক-পরিবেশগত, জলবিদ্যা এবং জল গতিবিজ্ঞান বিষয়ক বিশ্লেষণ থেকে প্রাপ্ত ফলাফলের ভিত্তিতে মূল্যায়ন করা হয়েছে। ঢাকা স্ট্রাকচার প্ল্যান (2016-2035), রাজউক কর্তৃক প্রণীত ঢাকার একটি কৌশলগত পরিকল্পনা, যা বিগত ২০ নভেম্বর, ২০১৬ সালে বাংলাদেশ সরকার কর্তৃক অনুমোদিত হয়েছে, কিন্তু অদ্যাবধি উক্ত পরিকল্পনার গেজেট বিজ্ঞপ্তি প্রকাশিত হয়নি। তাই গবেষণা প্রতিবেদনের শিরোনামে ঢাকা স্ট্রাকচার প্ল্যান (2016-2035) এর পূর্বে 'খসড়া' শব্দটি ব্যবহার করা হয়েছে। অবশ্য উক্ত পরিকল্পনার গেজেট বিজ্ঞপ্তি প্রকাশের পূর্বেই বিগত ২৩ আগস্ট, ২০২২ তারিখে উক্ত পরিকল্পনার পরবর্তী ধাপ অর্থাৎ ঢাকা ডিটেইল্ড এরিয়া প্ল্যান (2022-2035) এর গেজেট বিজ্ঞপ্তি সরকারের অনুমোদনক্রমে প্রকাশিত হয়েছে। উল্লেখ্য, ঢাকা ডিটেইল্ড এরিয়া প্ল্যান (2022-2035) একটি বিশদ অঞ্চল ভিত্তিক বা স্থানীয় পর্যায়ে পরিকল্পনা। এই গবেষণার আওতায় অধ্যয়ন এলাকায় সরেজমিন জরিপপূর্বক দেখা যায় যে জোরপূর্বক উচ্ছেদের হুমকির কারণে জমির মালিকানার/ ভোগদখলের অধিকারের নিরাপত্তাহীনতাই অত্র অঞ্চলে প্লাবনভূমি/কৃষি জমিগুলির অকৃষি ব্যবহারে রূপান্তরের মূল কারণ। এই গবেষণায় দেখা গেছে যে ড্যাপ (2022-2035) এর বন্যা মানচিত্রে প্রধান বন্যা প্রবাহ অঞ্চলের শতকার পরিমাণ এবং গবেষণা মডেলের বন্যা মানচিত্রে প্রধান বন্যা প্রবাহ অঞ্চলের শতকার পরিমাণ প্রায় একই। কিন্তু, গবেষণা মডেলের বন্যা মানচিত্রে প্রধান বন্যা প্রবাহ অঞ্চলের সংযোগ নেটওয়ার্ক, অবস্থান, প্রাণীককরণ ড্যাপ (2022-2035) এবং ঢাকা স্ট্রাকচার প্ল্যান (2016-2035) হতে ভিন্ন। এর পাশাপাশি, প্রবল বন্যার (১৯৮৮) ক্ষেত্রে, বিভিন্ন প্লাবন গভীরতার জন্য গবেষণা মডেল হতে প্রাপ্ত প্লাবনের পরিমাণের শতকার হার এবং ড্যাপ (2022-2035) হতে প্রাপ্ত প্লাবনের পরিমাণের শতকার হার ভিন্ন। এক্ষেত্রে কিছু পার্থক্য থাকতে পারে, কারণ জল গতিবিদ্যা বিষয়ক বিশ্লেষণের ক্ষেত্রে গবেষণা মডেলের সীমানার শর্ত এবং অববাহিকা/পরিব্যাপ্তি ড্যাপ (2022-2035) হতে ভিন্ন যদিও গবেষণা 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Abbreviations and Acronyms

ADB	Asian Development Bank
BWDB	Bangladesh Water Development Board
DIT	Dacca Improvement Trust
DMDP	Dhaka Metropolitan Development Plan
DWASA	Dhaka Water supply and Sewerage Authority
GIS	Geographic Information System
RAJUK	Rajdhani Unnayan Kartripakkha
RHWL	Recorded Highest Water Level
WB	World Bank

CHAPTER 1: INTRODUCTION

1.1 Background

Bangladesh is situated on the Ganges, the Brahmaputra and the Meghna (GBM) delta, the largest Delta in the world. Bangladesh's geography is dominated by its trans boundary water resources system. Dhaka, the capital and largest city of Bangladesh, is located in the central Bangladesh at latitude 23°42'N and longitude 90°22'E on the eastern banks of the Buriganga River. The periphery of the city is encircled by the distributaries of the Brahmaputra and the Meghna River. A network of rivers connects the city with the rest of the country. The history of urban settlement in the modern Dhaka dates back to the 1st century. Over the century, Greater Dhaka has grown to a metropolitan city of approximately 16 million people (Dhaka Structure Plan, 2016-2035). Accommodating around 37% of total urban population of the country, the city has become the economic, political, administrative and cultural hub of Bangladesh (Dhaka Structure Plan, 2016-2035). A large portion of the cities enormous population belongs to poor and middle income classes. To accommodate the large and ever increasing population, rapid growth of business and industry, there has been almost uncontrolled expansion of industrial, commercial and residential activities in and around the city. However, there were some plans in the past to restrict peripheral expansion, but those did not work out well.

Flooding is a natural and common phenomenon of Greater Dhaka, i.e., Dhaka Metropolitan City Region. In Dhaka water resources are endangered due to both anthropogenic activities as well as natural phenomenon. Due to its geographic location, Dhaka city suffers from annual river flooding and frequent storm water flooding also. The illegal encroachment of rivers, flood plains, khals/canals and other wetlands and the indiscriminate dumping of domestic and industrial wastes into wetlands are hastening the drainage congestion in the city causing severe economic losses and health effects.

In its recent endeavor, RAJUK, the capital Dhaka city development authority, has prepared Dhaka Structure Plan (2016-2035) and Dhaka Detailed Area Plan (2022-2035) for Dhaka Metropolitan City Region of 1528 sq.km. Dhaka Structure Plan (2016-2035) is a strategic or policy plan which is also a higher level plan whereas Dhaka Detailed Area Plan (2022-2035) is a detailed/local level plan prepared

following the guidelines of the higher level plans, policies or programs. The Dhaka Structure Plan (2016-2035), the strategic plan for Dhaka prepared by RAJUK, has been approved by the Inter-ministerial Steering Committee of government dated 20 November, 2016 but gazette notification has not yet been published by government. So, in the title of the thesis, the term ‘Draft’ before Dhaka Structure Plan (2016-2035) has been used. But, before publishing gazette notification of the plan, the gazette notification for the next tier of the plan, i.e. the Dhaka Detailed Area Plan (DAP, 2022-2035), a detailed or local plan prepared by RAJUK, has already been published dated 23 August, 2022 following approval of the government of Bangladesh. Drainage, flood management and disaster resilience is a very important segment/component about which policies/proposals were proposed/ formulated in Dhaka Structure Plan (2016-2035) and Dhaka Detailed Area Plan (2022-2035). As this segment/component will act predominantly as the future guiding tool for development management of Dhaka, it is needed to analyze critically the approach and method of identifying and zoning of areas demarcated for flood plain area, conservation area etc. in the plan.

Turag river is the major life line and one of the major natural drainage systems in Dhaka and Gazipur districts. Pollution and illegal encroachment of Turag river-flood plain are major threats for delivering its natural hydrological functions and ecosystem services. Along both banks of the Turag River, it is seen that industries, housing developments, and other economic activities have been growing rapidly. The river is becoming narrower due to gradual encroachment on its banks, endangering its very existence. Now, it is high time to address the problem seriously not only to save Turag River with its flood plains but also to ensure numerous ecological and socio-economic benefits.

Therefore, there is a need to evaluate policies/proposals of Dhaka Structure Plan (2016-2035) and Dhaka Detailed Area Plan (2022-2035) regarding drainage and flood management of Turag river-flood plain from multiple ecosystem benefit approach in order to get directives for preparation of future plans and protection/conservation of flood plains/wetlands. The rivers and wetlands have unique function in Bangladesh alleviating disaster risk resulting from floods, water logging, drainage congestion, pollution and provide a city with clean environment and aesthetics and after all, environmental sustainability.

1.2 Objectives of the Research

The overall objective of the study is to evaluate the policies/proposals in Dhaka Structure Plan (2016-2035) and Dhaka Detailed Area Plan (DAP) (2022-2035) on drainage and flood management of Dhaka Metropolitan City Region focusing Turag river and its contributory area from multi-benefit perspective by the output derived from socio-ecological and hydrological analysis.

Specific Objectives:

- To review different plans, policies of government regarding drainage and flood management of Dhaka Metropolitan City Region.
- To analyze socio-ecological aspects of drainage and flood management strategies of Dhaka Metropolitan City Region.
- To conduct hydrological and hydrodynamic analysis (using mathematical modeling) of Turag river and its contributory area.
- To evaluate policies/proposals in Dhaka Structure Plan (2016-2035) and Dhaka Detailed Area Plan (DAP) (2022-2035) on drainage and flood management of Dhaka Metropolitan City Region from multiple ecosystem benefit approach.
- To identify potential measures for drainage and flood management of Dhaka Metropolitan City Region.

1.3 Rationale of the Study and limitations

A lot of master plans were prepared for managing growth, controlling land use and tackling urban problems like flood management, drainage improvement etc. for Dhaka Metropolitan Region from the British Indian period till date. But, no plans did function properly. The implementation status of the previous plans is insignificant. In this regard, a thorough evaluation of the Dhaka Structure Plan (2016-2035) and Dhaka Detailed Area Plan (2022-2035) is necessary which will assess the existing status of the plans, the reasons behind non-implementation of previous master plans and act as guiding tools/directives for future development plans especially in the case of flood management, drainage improvement and disaster resilience. The limitation of the study is that although some primary data were collected, the study is mainly based on secondary data.

CHAPTER 2: FLOOD MANAGEMENT APPROACHES AND TECHNIQUES IN GLOBAL AND NATIONAL CONTEXT

2.1 Introduction

Flood management has been considered as a technical or technological aspect from a very long time. Until recently, flood management was mainly associated with conventional engineering measures called “hard” engineering or “gray” infrastructure such as construction of embankments, levees, dams etc. to control runoff and flows of rivers. But it has been found that these engineering structures are not always cost effective. Relying only on the engineering solutions is increasingly being perceived as inappropriate and unsustainable in tackling extreme events due to climate change. Natural Flood Management (NFM) is a broader approach, which involves particularly with nature and considers the opportunities and benefits of flood incidents in delivering solutions. Recently, the concept of Natural Flood Management (NFM) has emerged as a good alternative to traditional gray approaches. The interventions in NFM can be completely “green” or “hybrid” (i.e. a combination of green and gray approaches). Different countries in the world have already adopted the approach of nature based solution of flood management in their respective acts, regulations, policies, and planning documents.

2.2 Flood management

The method and plan to lower the risk of flooding is called flood management. When a river overflows its banks, water floods into the floodplains, causing river flooding. There are various approaches of managing floods. Hard engineering and soft engineering are the two main categories into which flood management measures are typically separated. Both approaches have benefits and drawbacks, and the situation determines which is more suited. When significant construction work involving machinery, concrete, and building supplies is required to prevent flooding, the hard engineering method is used. It stops or lessens the impact of river processes by utilizing man-made structures. Techniques that need the least amount of construction work are used in the soft engineering method. It makes use of the surrounding natural environment to support the river's natural functions. Soft engineering methods are usually more sustainable than hard engineering methods.

2.3 Natural Flood Management (NFM)

Natural flood management (NFM) involves the use of ecosystem measures such as planting trees, re-meandering rivers, constructing dams or reservoirs to alleviate flood risk (Dadson et al., 2017; Paavola & Primmer, 2019). NFM is an example of Nature-based solution (NbS) as an umbrella concept for a range of ecosystem based approaches for addressing societal challenges (Paavola & Primmer, 2019). NFM adopts to enhance catchment based processes affected by human intervention to mitigate flood risk (Dadson et al., 2017). NFM enables Sustainable Flood Management by adopting more economically and environmentally sustainable water management and flood risks (Iacob et al., 2014; Cook et al., 2016).

Natural Flood Management (NFM) –A catchment based approach

Natural Flood Management is a major component of a catchment-based approach, by reducing the impact of floods as well as improving water quality and biodiversity. Natural flood management works best when a ‘catchment based approach’ is taken, where a plan is formulated to manage water flow throughout a river catchment.

A region of land that is encircled by hills or mountains and from which surface and subterranean water flow into rivers, streams, and other wetlands is known as a catchment. Water gravitationally flows to a catchment's lowest point. When water runs over the earth, it is referred to as surface runoff; when it seeps into the ground, it is referred to as groundwater flow. A drainage network is the system of watercourses that move sediment, water, and other materials out of a watershed. A catchment encompasses every square inch of land on the planet. Although terrain eventually influences the natural flow of water within a catchment, centuries of land management and use have altered this flow. Generally speaking, catchment regions are divided into three sections: upper, medium, and lower. Any change in a river's energy in one of these catchment areas will have an impact on the other portions. Addressing water issues in a catchment piecemeal simply causes them to spread from one place to another. A more thorough synergistic response can be developed by managing water at the catchment scale, boosting community resilience across the whole catchment area.

2.3.1 Principles of Nature-based Solution of Flood Risk Management

Principle 1: System-scale perspective

A system-wide examination of the local socioeconomic, environmental, ecological, and institutional circumstances should be the first step in implementing nature-based solutions for disaster risk reduction and climate change adaptation.

Principle 2: Risk and benefit assessment of the full range of possible measures

To measure their environmental and socioeconomic benefits, risk and benefit assessments should be conducted together. A thorough evaluation of the advantages and disadvantages of every potential course of action should be carried out, taking into account the social and environmental impacts in addition to the benefits of risk reduction.

Principle 3: Standardized performance evaluation

Quantitative criteria should be used in the design, testing, and evaluation of nature-based flood risk management strategies.

Principle 4: Integration with ecosystem conservation and restoration

Native species and existing ecosystem should be used in nature-based flood risk management strategies. These ought to adhere to fundamental conservation and restoration principles for ecosystems.

Principle 5: Adaptive management

Nature-based solutions for flood risk management require adaptive management strategies relying on long-term monitoring. This guarantees their long-term success (Source: World Bank, 2017) [21].

2.3.2 Restoring river-flood plain connectivity as a Nature-based Solution

➤ Definition of Floodplains

Floodplains are defined as geomorphic features created and impacted by river flows and sediment that support and sustain ecosystems, as well as landscape features that are regularly submerged by water from a nearby stream (Opperman et al., 2010). Floodplain ecosystems are therefore characterized by their dynamic characteristics, whereby the hydrodynamics of floodwaters traversing a complex floodplain landscape

produce fluctuating patterns of scour, deposition, and inundation as river flows rise and fall. Natural floodplains are dynamic environments that sustain some of the highest levels of biodiversity in freshwater ecosystems (Ward et al., 1999). They also offer riparian birds, fish, invertebrates, and other animals that use the habitat plenty of food sources (Sommer et al., 2001; Grosholz and Gallo, 2006; Jeffres et al., 2008; Limm and Marchetti, 2009).

Naturally occurring floodplains are the level areas next to rivers that are flooded during floods (Nanson and Croke, 1992) and formed by sediment deposition when the channel moves laterally (Marriot, 1998). Rich farmland and level terrain for building near to a transportation axis are provided by fine river sediments that are deposited on floodplains. One of the main factors influencing the river ecology is the preservation of lateral connectivity between rivers and their floodplains during flooding (Junk et al., 1989). While the floodplain provides a breeding place for river species and improves water quality through sediment deposition, nutrient and pollutant absorption, and recycling, rivers also contribute nutrients and sediment to the floodplain (Brookes and Shields, 1996). It is commonly known that floods downstream can be lessened by storing floodwater on floodplains.

➤ **Elements of Ecologically Functional Floodplains**

1. **Connectivity.** For the flow, sediment, nutrients, and organisms to be exchanged, a functional floodplain needs to be connected to its neighboring river (Amoros and Bornette, 2002).

2. **Flow regime.** From extreme low flows to rare high flows, a broad range of flow levels and events shape, sustain, and impact floodplain ecosystems (Poff et al., 1997; Whiting, 2002). Therefore, interaction with a river that maintains a flow regime with enough diversity to cover the flow levels and events that support significant floodplain processes is necessary for an ecologically functional floodplain.

3. **Spatial scale.** There are two reasons why a functional floodplain needs to have a minimum geographic extent. First and foremost, the floodplain needs to cover enough ground area to support significant dynamic processes, like erosion and deposition during major floods (Richards et al., 2002; Rohde et al., 2005). Second, for advantages to materialize (for example, management objectives), the floodplain

(either alone or in conjunction with other related floodplain sites) must cover a large enough spatial scale. (Source: Opperman et al., Jeffrey J. 2010) [9].

2.4 Global shifting towards Nature-based Solution of Flood Management/ Multi-benefit approach

Flooding is considered as one of the most destructive natural hazards in the world, causing significant harm to people and their surroundings. The extreme flooding events in terms of frequency and severity is expected to increase in the years to come because of climate change (Hirabayashi et al., 2013) and extensive practices of land-use changes in urban areas (Field et al., 2012; Thieken et al., 2016). Now, there is widespread concern that the structural solutions will not be able to handle the future extreme events. Nature-based solutions (NbS) have emerged as innovative and sustainable flood risk management strategies in response to such extreme events (Wesenbeeck et al., 2017; Jongman, 2018). Nature-based solutions (NbS) are seen as a viable adaptation strategy that offers several advantages while addressing a variety of societal issues in a sustainable manner [1].

The term NbS (Nature-based solutions) was first used by the World Bank in 2008 (MacKinnon et al., 2008) and also adopted by the International Union for Conservation of Nature (IUCN) for its 2013-2016 program (Cohen-Shacham et al., 2016). In order to promote its goal of making the European Union a leader in the implementation of NbS, the European Commission (EC) incorporated the idea into its framework program for research and innovation, known as Horizon 2020 (European Commission, 2015). The EC describes nature-based solutions as a means of addressing societal issues with nature-inspired and nature-supported solutions that are affordable, concurrently offer economic, social, and environmental advantages, and contribute to resilience (European Commission, 2015). The EC definition has a more specific priority on addressing societal challenges to co-benefits, with less emphasis on the ecology, whereas the IUCN definition focuses on restoration of the ecosystem that has been altered by human usage.

2.4.1 Lower Danube green corridor: Floodplain restoration for flood protection

Blocking off of the Danube river floodplains by dyke construction along with channelization has made flood peaks worse. Anthropogenic climate change is

expected to result in decreased water quality and more frequent flooding. When the Lower Danube Green Corridor Agreement was signed in 2000, the governments of Bulgaria, Romania, Ukraine, and Moldova committed to cooperating to create a green corridor spanning the roughly 1,000 km of the Lower Danube River. Every nation acknowledged the necessity and mutual obligation to preserve and sustainably manage the Lower Danube. By reconnecting the river to its natural flooding areas and protecting and restoring the wetlands along the river, the agreement aimed to lower the likelihood of significant flooding in areas where people live and to benefit local economies through fisheries, tourism, and other ecosystem services along the river. The initiative's current results demonstrate that the restoration initiatives have benefited local economies by diversifying livelihoods based on natural resources, improving biodiversity, and improving the natural capacity to store and release floodwaters. In order to manage the existing climate unpredictability and the anticipated effects of future climate change, it is assumed that the implemented solutions will strengthen the resilience of local societies and natural systems.

It was observed that restoration work was still ongoing in around 60,000 hectares of floodplains in the Lower Danube corridor as of 2020. By letting the river return to its natural state, dikes have been removed. The species of invasive plants have been removed. To support the natural regeneration of forests across a much greater region, 10,000 native trees have been planted on dozens of locations. Fish populations have significantly grown and several bird species have returned as a result of the restoration of natural processes.

2.4.2 'Room for the River' Program, Netherlands

In 1993 and 1995, the Dutch river region and its inhabitants had to deal with abnormally high water levels. Large areas were submerged, and 250,000 people had to be evacuated, despite the dykes prevented flood water. The 'room for the river' program became the new flood protection approach in river areas to address extraordinarily high water levels. The program's design phase began in 2006, and its completion was scheduled for 2015. The program's primary objective was to control rising river levels by decreasing flood plain levels, building flood bypasses, relocating levees, establishing water buffers, and deepening side channels. The Rhine, Meuse, Waal, and IJssel rivers were all featured in the show. At over thirty sites, steps were

taken to allow the river to safely flood. In addition to this, the actions were planned to enhance the quality of the near environment [5].

2.4.3 Nature-based Solutions in China: Financing “sponge cities” for integrated urban flood management

China is one of the world’s most highly vulnerable countries to floods.. With over 640 cities at risk of flooding and 67 percent of its population residing in flood-prone areas, China loses an estimated 1 percent of GDP annually on average because of flooding. (Xiawei Liao; Marcus J. Wishart, 2021). The level of services and climate resilience are needed to handle the increased threats that cannot be provided by traditional urban flood management techniques alone. In order to lessen the consequences of human development, cities are increasingly investigating the integration of natural and semi-natural techniques, such as built wetlands, rain gardens, green roofs, and permeable highways, to simulate natural water cycles. These are nature-based solutions that are becoming crucial instruments along the spectrum. Along the continuum of gray, green, and blue solutions, these nature-based approaches are becoming more significant instruments that can enhance disaster risk management, foster resilience, and create sustainable adaptations.

In order to capitalize on the advantages of nature-based solutions, China launched the Sponge City Initiative in 2014 for integrated urban flood management. This project combines traditional "gray" infrastructure, like concrete embankments, with green areas and "blue" systems, like wetlands. China wants to make 80 percent of its cities "sponge-like" by 2030. This will help with surface water flooding, peak runoff attenuation, urban runoff purification, and water conservation, all while enhancing the environment, public health, and economic development [7].

2.4.4 “Flood Bypasses” in the Sacramento River System in California, USA

Once expansive and productive, the floodplains of California's Central Valley are no longer able to provide vital ecological services and functions because levee construction and dam flow regulation have largely cut them off from riverine floods (Garone, 2011; Whipple et al., 2012). Only 5% of the ancient riparian habitat is thought to be remained in the Central Valley (Vaghti and Greco, 2007), mostly confined to the river's slender passageways inside vast levee complexes. In the middle

of the 19th century, the majority of the wetlands and floodplain habitats were drained and replaced with cities and farms. Because they no longer have access to the shallow, productive, slow-moving floodplain habitats that offer the best conditions for foraging, resting, spawning, and rearing, migratory birds and native fish populations have been severely impacted by the loss of habitats and disconnectivity of associated floodplains (Moyle, 2002; Moyle et al., 2007; Garone, 2011).

A network of "flood bypasses" was created to move floodwaters around communities in the Sacramento Valley, California, in response to frequent destructive floods in the 19th and early 20th centuries. In order to transport the majority of flow during major floods downstream to the Sacramento-San Joaquin Delta and then out through the San Francisco-Bay estuary to the Pacific Ocean, two broad stretches of managed floodplain (bounded by levees) in the lower Sacramento River were designated as flood bypasses (the Sutter and Yolo bypasses) (Kelley, 1998). Compared to the original floodplains, the bypass floodplains are inundated less frequently and for shorter periods of time because they are graded to swiftly drain water from the system and are only designed to flood during large floods.

2.5 Land management techniques for planned land use development

2.5.1 Land consolidation and land readjustment

The two effective land management tools that make it easier to rearrange land rights in line with the intended land use development are land consolidation and land readjustment. undoubtedly, land is a scarce but extremely valuable resource. Agricultural land, natural resource land, nature conservation land, and urban land are all in competition with one another. A balanced and sound spatial development of the conflicting land uses in many countries is urgently needed. In light of the growing demands for food, safety, and a clean environment, among other things, the Sustainable Development Goals (SDG) emphasize the necessity of balanced development (United Nations, 2015).

The Land consolidation and land readjustment tools are widely practiced in different countries of the world like Germany, Netherlands, Japan, South Korea etc.

Land Consolidation:

Uimonen (2004) defines that “land consolidation means to make a new allotment of cadastral parcels”. Sonnenberg (2002) defines “land consolidation for agricultural purposes is an activity or an instrument that is implemented in order to consolidate fragmented agricultural holdings or, in other words, to unite the scattered parcels of the distinct farms”.

Essadiki (2002) defines “Land consolidation is an operation that aims to improve land cultivation by replacing the current dispersed division of the land into numerous parcels with a new division that is larger, easier to access, and suitable for machinery cultivation.”.

By integrating the two widely accepted ideas of land consolidation into the following statement, the FAO (2008) makes clear: "Land consolidation is a term traditionally used to refer to measures to remove the effects of fragmentation by adjusting farm structures." However, the term encompasses much more than the specific but significant act of reparing land to eliminate fragmentation. Consolidation of land has historically been linked to more significant environmental, social, and economic shifts. Consequently, land consolidation has been more focused on intergraded rural development rather than only agricultural structures [4].

Land Readjustment (LR)

Land readjustment (LR) is a planning tool for managing the urban development of fringe areas, whereby a group of separate land parcels are assembled together for their unified planning, then servicing and subdividing as a single estate, with the sale of some of the new land parcels/plots to recover the costs and the redistribution of the other plots back to the landowners. (Archer, 1992).

Land readjustment is an alternative to the compulsory land acquisition technique. Landowner's participation is a necessary requirement for land readjustment scheme. All the land parcels within the boundary of the scheme are grouped together and landowners contribute an equitable portion of their lands for public facilities, utility services and functions and cost recovery purpose. Financial contribution may be an alternative to land contribution. Landowners profit more from the LR scheme's ability

to optimize site utilization by regularizing the forms of land parcels, even though they lose a minor amount of land. Following the redistribution, land rights are transferred.

The fundamental principle of the LR project is based on reassembling land parcels using a new layout plan in conjunction with the building of new infrastructure, even though the procedure varies slightly from nation to nation. External funding such as government subsidy may be needed to develop major infrastructures and facilities. Through equitable contributions and re-plotting disposition under a land readjustment technique, all landowners share in the costs and benefits of development. When nations like South Korea and Japan experienced rapid economic growth and urbanization, the land readjustment technique proved to be highly effective.

2.6 Flood Management approaches in Bangladesh context

The majority of Bangladesh is made up of deltaic plains with river floodplains, which provide the nation a distinct hydrological regime. Bangladesh only occupies 7% of the vast catchment area of the Ganges, Brahmaputra, and Meghna, three transboundary river systems. Every year, floodwaters cover over 30% of the country's land, including over 350 perennial rivers. The nation has seen four devastating floods in the past 20 years: in 2004, 2007, 2012, and 2017. The 2017 floods were particularly noteworthy, resulting in over 100,000 homes being damaged and 145 fatalities (C. Emdad Haque et al., 2019).

Bangladesh usually experiences four different types of floods: flash floods, rain-fed floods, river floods, and storm floods. The start of the monsoon in June causes the major rivers' water levels to rise as floodwater from the upstream basin areas descends. The commencement dates and precipitation characteristics of the monsoon cause major rivers to peak in different months. If floods occur in the Ganges and Brahmaputra Rivers at the same time, the central region is at much higher risk of flooding.

Since the 1950s, Bangladesh's territory has had to deal with the problems of flash floods and rivers. From physical floodwater control in the early decades to more recent public awareness campaigns, the government developed a variety of policies and program interventions in response to the difficult flood disasters. Floods are not necessarily viewed as "negative" phenomenon because Bangladesh is home to one of

the world's largest deltas, creating vast floodplains. Instead, it is seen that yearly flooding replenishes the environment, soil, and wetlands while also offering people benefits for their livelihoods. Therefore, regular floods are viewed as desirable and beneficial occurrences. As a result, the goals of Bangladesh's comprehensive flood and water management policy have focused on managing water by addressing it concurrently as a resource and a hazard.

2.6.1 Evolution and Change in Flood Control and Water Management Policies in Bangladesh

Over the past 70 years, flood control and prevention strategies have evolved in the present-day Bangladesh, encompassing both hard engineering and soft solutions. The policy-shifting tendency can be separated into three distinct phases: i) the structural phase, which lasted from 1947 to 1987; ii) the structural and nonstructural phase, which lasted from 1987 to 1995; and iii) the post-Flood Action Plan (FAP) phase, which lasted from 1995 to the present. Foreign interests and other social-ecological factors probably had an impact on these phases [3].

Structural Phase (1947 to 1987): Large- and Small-scale Engineering Schemes

After two disastrous floods in East Pakistan (now Bangladesh) in 1954 and 1955, contemporary flood management strategies were developed. The world community took notice of these two devastating occurrences. A number of commissions were funded to investigate the issue and identify potential remedies.

The East Pakistan Water and Power Development Authority (EWAPDA), now known as the Bangladesh Water Development Board (BWDB), was established in 1959 on the recommendation of the Krug Mission Report, a technical report of the United Nations Development Program (UNDP). With the assistance of the International Engineering Company, USA, a 20-year Master Plan was subsequently prepared in 1964 based on the technical study in order to safeguard riverbanks and reduce flooding through extensive engineering measures. This master plan comprised of 91 big development projects, funded by donor agencies. Building embankments along the main riverbanks, improving the channel, dredging and training the river, and creating flood bypasses or flood diversions were the objectives of these extensive development projects.

Following attaining independence in 1971, Bangladesh encountered numerous difficulties in providing food for its population of over 75 million. As a result, the flood control strategy underwent a policy change, which developed primarily from experiential learning. The management of water resources was added to flood control as an extra layer to the current policy domain in order to safeguard livelihood and food security.

Structural and Non-structural Phase (1987 to 1995): Flood Action Plan (FAP) Regime

Following devastating floods in 1987 and 1988 that cost over two billion US dollars, there was a major shift in flood control policy in the late 1980s. Policies to prevent flooding seemed to be on everyone's agenda in both domestic and international discussions. The lack of an ecologically sustainable water resource policy, according to certain quarters, was blamed for the nation's rising flood-disaster risks and fatalities.

In order to accomplish a lasting solution to floods, mainly through a structural approach, the government of Bangladesh developed the Flood Action Plan (FAP) in 1989 as part of an integrated strategy in cooperation with international agencies. The FAP was initially composed of 26 parts designed to form a comprehensive system of drainage and flood control operations. The FAP concentrated on early warning system development, flood forecasting, flood proofing, river training, and flood management. The FAP was criticized for failing to sufficiently acknowledge other cross-cutting sectors and the possible effects of structural measures on the economy and environment. In addition, the implementation procedures failed to adequately consider public opinions during the decision-making phase.

During the 1980s and 1990s, donor organizations that were crucial in establishing Bangladesh's flood and water management policy split on these topics. The donor agencies produced two schools of thought. While the United States and China backed the flood mitigation plan, the French and UNDP firmly backed the plan to build embankments along the riverbanks and train the river. Following the release of the Flood Action Plan (FAP), these discussions prevailed. Journalists, lawyers, environmentalists, and members of civil society frequently criticized the FAP for relying too heavily on engineering methods to control rivers and floodplains.

Post-FAP Phase (1995 to Present): Towards an Integrated and Participatory Flood and Water Management Policy

As climatic occurrences started to have a major impact on flood and water management policies, incremental processes expedited the shift. The defensive strategy to flood and water control was no longer the only option. Instead, during the FAP implementation phases, an integrated approach to water resources management was seen. The 1999 National Water Policy was enacted in response to this approach. By preserving the environment, this program provided a foundation for prosperity, economic expansion, and poverty eradication.

The policy framework was clearly moving in the direction of integrating structural and nonstructural measures to safeguard infrastructure, property, and people equitably from flooding. The new strategy acknowledged that the water management system required the participation of Community Based Organizations and a coordinated mechanism of all related institutions. The Bangladeshi government completed the National Water Plan in 2000 after realizing how important it was to develop the water sector. Guidelines for the coordinated execution of water and flood management activities were provided by this plan and policy framework for organizations at the regional and national levels. In order to guarantee efficient upkeep of flood control and prevention infrastructure, the Bangladesh Water Act, 2013 was later enacted by the Bangladeshi Parliament in 2013. This Act's primary objective was to establish integrated flood prevention and water resource management requirements.

Over the past 20 years, the Bangladesh government has prepared a number of cross-cutting comprehensive legislative and regulatory frameworks for disaster management, which also oversee flood control operations in the country. In 1997, the Bangladeshi government created Standing Orders on Disasters, which were revised in 2010 to prioritize disaster-risk reduction above disaster response. The goal of the National Plan for Disaster Management (2010–2015) was also to lessen the likelihood that individuals, particularly the underprivileged and impoverished, would be affected by environmental, natural, and man-made hazards. The government of Bangladesh passed the Disaster Management Act, 2012, in Parliament in order to guarantee that the roles and duties of all parties involved in disaster management are clearly defined and carried out.

CHAPTER 3: FLOOD MANAGEMENT APPROACHES IN DHAKA

3.1 Introduction

Dhaka, the capital and largest city of Bangladesh, is in the midst of The Ganges–Brahmaputra–Meghna River (GBM) Delta, bounded by the Buriganga River to the south, the Turag River to the west, the Balu and Shitalakhya rivers to the east and the Tongi khal-drainage canal to the north. At the Southernmost end, the Buriganga meets the Dhaleswari. The combined flow then meets the Sitalakhya and flows Southward to join the Meghna, the third major river of Bangladesh. Waters of the Turag, Buriganga and Balu rivers are collected by the Dhaleswari river and finally conveyed to the Bay of Bengal through the Meghna and Padma rivers. The water level of the Turag, Buriganga and Balu rivers and Tongi khal are affected not only by the discharges from the upstream rivers, but also by back water from the downstream rivers. Topographically, Dhaka is a flat land that is 2–13 meters above mean sea level, with the majority of its urbanized areas having elevation of 6 to 8 meters (Huq & Alam, 2003; Alam & Rabbani, 2007). It receives about 2000 mm of precipitation annually, with over 80% of that falling during the storm season (June to September), and it is located in the subtropical rainfall zone (Dewan et al., 2007; Dewan & Yamaguchi, 2009). Numerous lakes or canals, as well as a large number of low-lying areas that serve as retention basins during high flood water levels, make up Dhaka's drainage system to the GBM (Khan, 2006). Based on the infrastructure for flood management, Dhaka and the surrounding area are separated into Dhaka West and Dhaka East. Urbanized and protected by an embankment, Dhaka West is primarily the floodplain of the Buriganga and the Turag River. Although Dhaka East, primarily the Balu River floodplain, is rapidly becoming increasingly urbanized, it is still largely undeveloped.

Floods are a regular phenomenon in Dhaka due to the city's geographic location and climate, and their intensity is steadily rising (Dewan et al., 2007). Flooding in the city is caused by significant monsoon rains and water overflow from the nearby rivers (Alam & Rabbani, 2007). Flood risk has been reduced and the natural ecology has been maintained due to effective water retention functions of Dhaka's temporary water bodies, which store and discharge surplus water brought on by heavy rains (Khan, 2000). The natural flow and function of rivers have been significantly

impacted by human interventions like waste disposal, filling up water bodies, and encroaching on fringe areas. This has resulted in environmental degradation and a marked increase in the risk of flooding.

Dhaka's urbanization has been significantly influenced by its advantageous position. Dhaka has seen a sharp increase in both population and size since Bangladesh gained its independence in 1971. Currently, one of the world's most densely populated megacities is Dhaka. The administrative area of Dhaka is divided into Dhaka Metropolitan area (DMA) at 360 km² and the area covered by Dhaka Metropolitan Development Plan (DMDP), i.e. Greater Dhaka area at 1,528 km² (DAP, 2016-2035). Present population of Greater Dhaka region is around 16 million and projected population in 2025 for the same area is around 26 million (Dhaka Structure Plan, 2016-2035). Since independence of Bangladesh, Dhaka's urban population has grown by an estimated 4% annually, while the country's population has grown by 2.2% (World Bank, 2007). The city's growth is impacted by socioeconomic and demographic growth, which is influenced by the region's topography and geographical features (Sultana et al., 2009). At elevations between 10 and 12 meters above mean sea level, settlements were established on the higher terraces during the early stages of development. The inevitable expansion of Dhaka into the surrounding wetlands was caused by a number of factors, including ever-increasing urbanization and population growth, a lack of available high land, rising land prices, encroachment by individuals and developers, a lack of government control over development, and a lack of government maintenance and management.

3.2 Policies and legislation affecting Flood Management in Greater Dhaka

Identification and analysis of flood management approaches in greater Dhaka revealed that there is a correlation between the historical major flooding events and significant policy changes regarding flood management [6], [8], [10], [11], [12].

3.2.1 Major flood events and policy responses

3.2.1.1 1955 flood and policy response

About 35% of the East Pakistan (now Bangladesh) and 80% of the Dhaka city were submerged by the floods of 1955 (EWAPDA). The Krug mission was formulated in response to the floods that occurred in 1951 and 1955. The Krug Report is a report

that was prepared by the Krug mission. After establishment of the EPWAPDA in 1959 following recommendations of the Krug Report, the EPWAPDA along with International Engineering Company prepared the first Master Plan for Water Resources in 1964 (Ali & Liakath). The plan specifically proposed a number of drainage and flood control projects and programs in the Dhaka-North, Dhaka-South-West, and Dhaka-Narayanganj-Demra areas. The Dhaka-Narayanganj-Demra (DND) project is the only one that has been put into action.

Both the Krug Report and the Water Master Plan focused primarily on flood management and food security due to the significant damage to crops and populations. However, the projects' execution had a negative effect on the environment (such as forests and fisheries) as well as the water supply for homes and businesses. Natural water and sediment flows, which are necessary to sustain ecosystem services and functions, were impeded by structural interventions. In addition, water scarcity was resulted from excessive groundwater extraction (Ali & Liakath).

Dacca Master Plan 1959

Under the Town Improvement Act of 1953, the East Pakistan (now Bangladesh) government formed the Dhaka Improvement Trust (DIT) in 1956. In 1987, the DIT changed its name to the Rajdhani Unnayan Kartripakkha (RAJUK), and it became more involved in Dhaka's urban planning and road construction projects (Huq & Alam, 2003; Shafi, 2010). A consortium of British firms Minoprio & Spencely and P. W. Macfarlane prepared the first master plan of Dhaka, known as the Dacca Master Plan 1959, in 1958 over a 20-year planning period (1958 to 1978) for an area of 320 square miles (Islam, 2014). Traffic congestion in the old part of Dhaka and a lack of developable land above flood level are the two key issues identified in the plan for the city's development. The plan's primary flaws were its rigidity, inability to accommodate the city's growth, and disregard for flood control measures.

3.2.1.2 1974 flood and policy response

The 1974 flood submerged around 37% of the Bangladesh (NWP). Around 25% of the area of Dhaka was more or less impacted by the flood. This flooding event underscored the necessity for planned water resources development as well as

thorough assessment of on-going projects of the country. The Master Plan Organization (MPO) was established in 1980 as a result of the BWDB and World Bank's 1979 recommendations for the creation of a comprehensive national water plan. The MPO then went on to produce two successive national water plans (NWP-I and NWP-II) in 1986 and 1991.

Dhaka Metropolitan Area Integrated Urban Development Project (DMAIUDP)

In order to prepare a long-term development strategy for the future of Dhaka city, with flood protection as the primary focus, the Dhaka Metropolitan Area Integrated Urban Development Project (DMAIUDP) was formulated in 1981 (Kabir & Parolin, 2012). With financial assistance from the Asian Development Bank (ADB) and the United Nations Development Programme (UNDP), it was Bangladesh's first urban development strategy plan. Besides this, Planning commission with the Ministry of Planning was the executor of the plan.. However, although being a well-thought-out strategic plan, the DMAIUDP was never put into action because it lacked official institutional support.

3.2.1.3 1988 flood and policy response

1988 flood was one of the catastrophic floods in terms of severity and intensity in the history of Bangladesh. The government of Bangladesh was forced to respond right away due to the extent of the harm caused by this catastrophic flood and the international attention it received. A group was tasked with looking into the reasons behind flooding and creating a nationwide Flood Action Plan (FAP). By implementing an integrated approach that included both structural (such as embankments, sluices, pumps, and drainage networks) and non-structural (such as land use zoning/spatial planning, protecting natural canals, developing flood forecasting and warning systems, etc.) measures, FAP marked a significant departure from previous plans. However, the FAP disregarded multi-sectoral focus and failed to incorporate people's opinion.

Flood Action Plan (FAP), 1989

Following the catastrophic floods in 1988, the government of Bangladesh established a committee whose main goal was to create a plan for Dhaka's flood control. Finally, two plans (FAP 8A and FAP 8B) were formulated for the city of Dhaka as part of the Flood Action Plan (FAP). Through a long-term flood prevention program, the plans sought to offer a reasonably safe and flood-free living environment. They also sought to enhance

environmental conditions in order to support long-term, sustainable growth in Dhaka (Alam et al., 1996; Islam, 2014). The first phase of program included FAP 8B, which covered 136.5 km² of the city's western side, and the second phase considered FAP 8A, which covered approximately 118.62 km² of the city's eastern side (JICA, 1987, 1991, 1992).

Dhaka Metropolitan Development Plan (DMDP) (1995–2015)

The plan provided long term development management strategies for 20 years up to 2015 for the Dhaka Metropolitan Development Plan (DMDP) area of 1528 km² under RAJUK jurisdiction. This is a three tier plan; the first two tiers of the DMDP plan i.e. the Dhaka Structure Plan (the policy plan) and Dhaka Urban Area Plan (the interim plan) were formulated in 1995. In 1997, the government approved DMDP and gazette notification was published later on. The main objective was to prepare a multi-sectoral development plan for Dhaka Metropolitan Development Plan region where drainage and flood management is a major component. The plan incorporated the proposals of FAP 8A and FAP 8B while preparing its drainage and flood management policies. It identified Main Flood Flow and Sub flood Flow Zones along the rivers around Dhaka [15].

3.2.1.4 1998 flood and policy response

1988 flood was also one of the catastrophic floods in the history of Bangladesh. The country remained under water for sixty five days. Seventy out of ninety wards of Dhaka city were submerged for two months. The 1998 flood was more destructive than the 1988 flood. Intense development over the last 10-year period after construction of western embankment exacerbated the situation. The construction of the western embankment, which was intended to prevent west Dhaka from river flooding, increased local rainfall flooding due to unplanned conversion of agricultural lands to residential purposes with a decrease in groundwater infiltration (Muhit; Chowdhury). The 1998 flood seriously impacted the proposals of the National Water Management Plan (NWMP). NWMP incorporated proposals emphasizing integration of multiple sectors and cross-sectoral issues. The plan proposed the construction of the Dhaka Eastern embankment at the west bank of Tongi khal and Balu river, together with retention ponds and other necessary measures, appropriate urban planning and improved drainage systems.

3.2.1.5 2004 and 2007 flood and policy response

Heavy downpour for two times, one at the beginning of June, 2004 and the other at September, 2004 caused the rainfall induced flooding in Bangladesh in 2004. Another flood occurred in, due to a localized monsoon depression, resulting in three times the normal rainfall and inundating Dhaka city and the southwestern parts of the country. Besides this, two major flood occurrences were held in Bangladesh in 2007. The widespread destruction from the 2004 flood emphasized the necessity for an upgraded storm water flood management system in Dhaka. The DWASA (Dhaka Water Supply and Sewerage Authority) formulated the ‘Storm water Drainage Master Plan’ for Dhaka city in 2016. This plan recommended that, taking into account the ongoing rapid unplanned urban growth in eastern Dhaka violating the DMDP guidelines, additional measures associated with drainage had to be ensured before construction of the eastern embankment.

DMDP Detailed Area Plan (DAP) (2010-2015)

On 22 June, 2010, following its approval, an official gazette of the Detailed Area Plan (DAP) (2010-2015) as the final tier of the DMDP (1995-2015) for DMDP area was published by Bangladesh government. A land-use zoning plan with an infrastructure development plan was prepared under DAP (2010-2015). As the final tier of DMDP (1995-2015), the DAP (2010-2015) was supposed to conform to policies of the DMDP Structure Plan (1995-2015) and Urban Area Plan (1995-2005). But, in some cases DAP (2010-2015) deviated from DMDP (1995-2015) policies. As for example, in DMDP Structure Plan (1995-2015), Flood Flow Zone is divided as “Main Flood Flow Zone” and “Sub flood flow zone” following FAP guidelines and the two zones are separately demarcated in plan map. Development management policies are also different for the two types of flood zones because of their different nature and character. But, in DAP (2010-2015), the “Sub flood flow zone” is merged with the “Main Flood Flow Zone” and a single zone is shown termed as “Flood Flow Zone” [16].

Dhaka Structure Plan (2016-2035) and Dhaka Detailed Area Plan (DAP) (2022-2035)

Because Dhaka Structure Plan (1995-2015) was expired in 2015 and because of changing situation, Dhaka Structure Plan 2016-2035 was formulated in 2015 to update the Dhaka Structure Plan (1995-2015) policies under Dhaka Metropolitan Development

Plan (DMDP), which is a higher tier policy plan. Dhaka Structure Plan (1995-2015) has been approved by the government by 2016 but gazette notification has not yet been published by the government. But, before publishing gazette notification of Dhaka Structure Plan (2016-2035), the next tier of the plan, i.e. the Dhaka Detailed Area Plan (DAP, 2022-2035) was prepared and also approved and gazetted by government of Bangladesh. By reviewing the proposals of the Detailed Area Plan (DAP) 2010-2015 and in the light of the higher level plan policies and acts of government, the Dhaka Detailed Area Plan (DAP) (2022-2035) was formulated. The official gazette notification of Dhaka Detailed Area Plan 2010-2015 was published by government on 23 August, 2022.

The structural and non-structural approaches of flood management both are considered in formulating flood management policies/proposals of Dhaka Structure Plan (2016-2035) and DAP (2022-2035). But approach in delineating flood flow zone in (DAP) (2022-2035) is different from (DAP) 2010-2015 and Dhaka Structure Plan 2016-2035. In (DAP) (2022-2035), flood flow zone is not considered as land use zone rather considered as land cover and showed on land use zone map as overlay zone [17], [18], [20].

3.2.2 Review of Flooding Characteristics in Dhaka

3.2.2.1 Depth and duration of normal Flood in Dhaka City

It is found that the maximum and average flood depth of normal flooding in Dhaka city is 5.7 m and 3.0 m respectively (BWDB, 1989 and Islam, 1996). The depths of floods sometimes are being controlled by the construction activities at the local level. The depth of flooding of 1987 was 1.0 m in Uttar Khan while it was comparatively higher in Baunia and Bailjuri which is about 3.9 m in the same elevation. The value varied from north to south and east to west of Dhaka city. The primary cause for this depth of flooding condition is the favorable sources of water coming in the river and different physiographic conditions of Dhaka city. On the other hand, it is found that the minimum and average flooding duration in Dhaka City is 12 days and 32 days respectively (Md. Abu Taleb, 2012) [13], [14].

3.2.2.2 Comparison of two extreme Floods in Dhaka in 1988 and 1998

Dhaka City was severely affected by flooding in 1988, 1998 and 2004 of which the 1988 and 1998 floods were disastrous. It was estimated that about 85 percent of the city was submerged at depths ranging from 0.3 to over 4.5 meters and about 60 percent of city dwellers were affected by the 1988 flood (Huq and Alam 2003). After flooding in 1988, western embankment was constructed along the east bank of Turag and south-east bank of Buriganag River under Dhaka Integrated Flood Protection Project (DIFPP) in order to protect western part of Dhaka from river flooding. But heavy rainfall causes urban flooding in many parts of the city in 1998. In case of flooding in 1998, severity of flooding was massive than the flooding in 1988, although western embankment was existed at the time of flooding in 1998. Western embankment could not protect Dhaka during 1998 flooding because of management failure of embankment and drainage congestion in Dhaka.

Compared to the 1988 flood event, the 1998 flood event peaked much earlier. The number of days above the water level's danger level was also longer than it was during the 1988 incident. It was seen that the water level of every river surrounding the city began to increase in the third week of July 1998 and remained until the last week of September. Thus, the 1998 flood was the longest in memorable history, lasting for more than two months. Excessive transboundary influx and a lack of flood control systems in the city contributed to the 1988 flood's severity, while hydraulic leakage and heavy monsoonal rainfall were the main causes of the 1998 disaster. In addition, the 1998 flood scenario was more critical for some auxiliary variables such as poor pumping, drainage congestion, and a lack of institutional coordination (IFCDR, 1998).

Water level and duration:

1. The Turag at Mirpur (Station ID 302)

In 1998, the flood water began to rise during the second week of July, peaked on August 27 (7.97 mPWD), and remained above the danger threshold until September 24. In 1988, the water level began to decline in the third week of September after surpassing the appropriate danger point on August 24. According to the BWDB, the duration of flood level above the danger point was just 35 days in 1988, but it was 69 days in 1998.

2. The Tongi Khal at Tongi (Station ID 229)

The Tongi Khal's water level somewhat affects Dhaka's overall flooding scenario. Nonetheless, it plays a significant role in local level floods in the city's northern region. The flood level began to increase during the 1998 flood event in the second week of July, and the flood water began to retreat around the third week of September. In 1998, the duration over the danger level was 65 days, but in 1988, it was just 25 days (BWDB).

Table3.1: Comparison of Floods in Dhaka and Surroundings in different years (Days above DL)

Station	River	RHWL (m PWD)	DL (m PWD)	1988 (Days)	1998 (Days)	2004 (Days)	2007 (Days)	2020 (Days)
Demra	Balu	7.13	5.75	43	73	34	22	17
Narayanganj	Lakhya	6.93	5.5	37	71	36	21	24
Mirpur	Turag	8.35	5.95	35	69	25	26	17
Tongi	Tongi Khal	7.84	6.1	25	65	22	28	19
Taraghat	Kaliganga	10.39	8.4	48	66	21	31	27
Jagir	Dhaleswari	9.96	8.25	28	58	18	25	24
Rekabi Bazar	Dhaleswari	7.66	5.2	26	75	39	45	No flood
Nayarhat	Banshi	8.39	7.3	27	35	14	No Flood	12
Dhaka	Buriganga	7.58	6	22	57	18	No Flood	No flood

(Source: BWDB)

Table 3.2: Comparison of Floods in Dhaka and surroundings in different years (Peak Water Level)

Station	River	RHWL (m PWD)	DL (m PWD)	1988	1998	2004	2007	2020
				Peak WL (m PWD)	Peak WL (m PWD)	Peak WL (m PWD)	Peak WL (m PWD)	Peak WL (m PWD)
Demra	Balu	7.13	5.75	7.09	6.97	6.98	6.27	6.0
Narayanganj	Lakhya	6.93	5.5	6.7	6.93	6.75	6.05	5.87
Mirpur	Turag	8.35	5.95	8.35	7.97	7.29	6.62	6.5
Tongi	Tongi Khal	7.84	6.1	7.84	7.54	7.13	6.87	6.5
Taraghat	Kaliganga	10.39	8.4	10.37	10.21	9.93	9.79	9.58
Jagir	Dhaleswari	9.96	8.25	9.96	9.73	9.50	9.43	9.29
Rekabi Bazar	Dhaleswari	7.66	5.2	6.43	6.87	6.64	6.13	-
Nayarhat	Banshi	8.39	7.3	9.9	8.68	8.09	-	7.58
Dhaka	Buriganga	7.58	6	7.58	7.24	6.68	-	-

(Source: BWDB)

The table 3.1 and 3.2 show the comparison of water level and duration of Floods in Dhaka and Surrounding areas in different years (Days above DL). It was found that for the 1988 flood event, the peak water level in Turag River and Tongi Khal was 8.35 mPWD and 7.84 mPWD respectively. It was also found that for the 1998 flood event, the peak water level in Turag River and Tongi Khal was 7.97 mPWD and 7.54 mPWD respectively. The peak water level in Turag River and Tongi Khal for the 1988 flood event was the Recorded Highest Water Level (RHWL).

3.2.3 Review of Dhaka Structure Plan (2016-2035) and Detailed Area Plan (2022-2035)

3.2.3.1 Dhaka Structure Plan (2016-2035)

The Dhaka Structure Plan (2016-2035) plan was prepared under City Region Development Project (CRDP) funded by the Asian Development Bank (ADB). The Rajdhani Unnayan Karttripakkha (RAJUK) is the executing agency of the government for formulating the plan. A team of international and national consultants were engaged in this purpose. The plan formulation process was started in July 2011 and the completed in December, 2016.

- **Nature and function-** The Dhaka Structure Plan (2016-2035) provides long term strategy which spans 20 years until 2035 for the development of Dhaka Metropolitan Region (DMR). A report with multiple supporting maps and a suitable scale composite map that highlights the main strategic decisions make up the Structure Plan. It also covers the future broad functions of various strategic zones. The report outlines a wide range of sectoral policies deemed essential for achieving the plan objectives, as well as the order, amount, and direction of expected urban expansion.

Whole Dhaka Metropolitan Region (DMR) is divided into two strategic zones termed Urban Promotion Area (UPA) and Urban Control Area (UCA). Table 3.3 below shows the nature and future growth direction of Proposed Strategic Zones under Dhaka Structure Plan (2016-2035).

Table 3.3: Nature and Future Growth Direction of Proposed Strategic Zones

Strategic Zone	Location	Nature	Growth Direction
Central Urban Area (CUA)	Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC)	Established Urban Area (Local Government)	Urban Promotion Area
Outer Urban	Narayanganj and Gazipur	Established urban area	

Area (OUA)	City Corporations, Savar, Tarabo Pouroshava etc.	(Local Government)	
Growth Management Area (GMA)	Rest of the area other than CUA and OUA and all conservation areas	Developing areas	
Conservation Area	Flood flow zones, Water Retention Area, National & regional parks, Forest Area, Heritage sites, Rivers and Khals;	Environmentally sensitive areas that need protection	Urban Control Area
Agriculture Area	Agricultural zone of DAP (2010-2015)	Prime Agriculture lands	

Source: Dhaka Structure Plan (2016-2035)

➤ **Future plans and directions regarding flood management**

Objective-DH 01: To Ensure Flood Prevention

To prevent property damage and loss of life, flood protection and control are essential. It should be appropriately managed to prevent the negative hydraulic effects of flooding. The destructive consequences of flooding can be lessened with a variety of engineering and non-engineering solutions.

Policy-DH/1.1: Protection of Flood Flow Zones

The risk to human life and economic damages in flood flow zones will be controlled in order to lessen negative hydraulic consequences.

Strategic Action: - Stringent control on development in the flood flow areas.

Implementation Tools:

- It should be made sure that no construction occurs in flood plains that could limit flood flow or endanger infrastructure investment or human life.
- It will be restricted to develop land for residential, commercial, or industrial purposes, by raising the land's level through land filling.

- Feasibility study for the applicability Transfer of Development Rights (TDRs) and Marketable Development rights (MDRs) etc. as different market based tools for conservation of flood flow zones can be undertaken.
- Strict vigilance is required on violation of development proposals of the plan.
- To remove obstructions (e.g. illegal land filling and development works) in flood flow zone to ease controlled flooding.
- Legal actions should be taken against any violation of the plan.
- Permitted uses in the flood flow areas will be-
 - Facilitating different commercial, aquatic and seasonal farming programs.
 - Promoting recreational facilities.
 - Ferry terminals; and
 - Excavation of mineral deposits without causing adverse hydraulic effects.
 - Raised way/track for roads or railways will be allowed, sufficient for unobstructed flood flow.
- To establish regional cooperation for real-time data gathering and flood forecasting.
- To encourage community in organization and management of the flood proofing infrastructure.
- To develop comprehensive Action Plan for Watershed/Water Resources Management.

Implementing Agencies:- BWDB, RAJUK, LGED, and DWASA

3.2.3.2 Dhaka Detailed Area Plan (2022-2035)

➤ The principle/criteria followed in formulating land use plan proposals

UN Habitat describes the current zoning regulations and their implications in its “Planning Sustainable Cities: Global Report on Human Settlements 2009” as follows:

“The major problem with urban modernism and master planning is that they are unable to adapt to the bulk of people’s lifestyles in fast expanding, informal cities, which inevitably leads to social and physical marginalization. It is nearly unlikely that residents in such situations could adhere to zoning regulations designed for more

affluent European towns. There are two conceivable outcomes in this situation. First, the system is strictly enforced, making it possible for those who cannot afford to follow the zoning regulations rely on illegal informal settlements in peri-urban areas. Otherwise, the municipality might not be able to carry out the regulation. The local governments themselves are causing environmental risks and social and spatial marginalization by enacting unsuitable rules and regulations. Instead of appreciating and enhancing the social capital that is typically developed in impoverished or low-income regions, the issue is a concern with the physical look of cities.”

UN Habitat in the same policy report gives the following instructions on how to overcome this management problem:

“...Land-use management or zoning systems must be changed to allow for a wider mix of land uses and urban forms, more flexible land-use classifications like informal settlements, and performance-based criteria for approving land-use change instead of use-based criteria.”.

The key concept of performance-based criteria is- the structure use is not as important as the impacts of that use, rather the impacts made on its surroundings which are more relevant. If anyone thinks about why usually some uses are considered as nuisance for the city, it can be understood that they create certain negative impacts; such as noise pollution, overcrowding etc. Now if anyone eliminates these effects or at least brings it down to a minimum level then the nature of the use of the building does not matter at all. Shifting from Use-based criteria to Performance-based criteria means, it will be fixed that how much impact people will be allowed to create instead of fixing which type of use people can do in their building. That is to say, on the whole, Performance-based criteria refers to going back to the root cause of land use zoning why it was started, i.e. control of negative impact or nuisance.

It is mentioned in DAP (2022-2035) that actually a significant evolution is occurring worldwide in the idea of land use zoning and policies. All the above-mentioned contexts have been considered in the proposal for building development management directives in DAP (2022-2035).

➤ **Approach of land use management zoning for protection and preservation of environmental and other sensitive areas**

Considering the implementation and effectiveness of the strategy of the previous Detailed Area Plan (2010-2015), it is seen that the protection and conservation of environmental, flood and other sensitive areas are in a critical situation. These areas include forests, agricultural areas, floodplains, etc. In such areas, the desired solution is to apply the law applicable to common / public property such as protected forests, canals, etc. However, the main challenge is to preserve the areas that are privately owned. The reason is that change in the use of these lands is basically an economic phenomenon. These undeveloped areas are usually the center of interest for entrepreneurs due to their low land value. And the economic power in this regard is so strong that it is almost impossible to deal with such economic power with just a map of the land use zone identified in the plan.

In this context, direct measurement of land use management zoning has been maintained but various types of indirect measures have been used to control and manage sensitive areas. Since economic power is involved in the process of land use change, efforts have been made to take into account the economic regulators involved in imposing any control, especially economic losses.

The direct methods include approval of construction in sensitive areas under appropriate conditions such as imposition of construction conditions in forest or agriculture, imposition of conditions on land elevation change such as imposition of restrictions on change of surface in main watershed areas etc. Indirect methods include fixing the base price of land, application of transfer of development rights, etc. In other words, it has been proposed to apply various strategies to avoid possible financial loss due to imposition of control over land use. Indigenous people in the area who are usually evicted from the area due to changes in land use can play an important role in strengthening their economic status. So that they are not forced to transfer land ownership at a nominal price due to fragile economic conditions.

➤ **Proposals and instructions on floodplain management**

1. Background

The floodplain areas of Dhaka metropolitan area have been identified under the Detailed Area Plan Detailed Area Plan (2022-2035). But the definition and approaches of delineating of flood flow zones and flood plains is different in Detailed Area Plan (2022-2035). In this case, data obtained from mathematical survey and survey report conducted by Bangladesh Department of Geological Survey and Federal Institute for Geoscience and Natural Resources, Germany (BGR), Geo-Information for Urban Development, Bangladesh, November, 2016 has been taken into consideration for identifying floodplains around Dhaka metropolitan Area.

In various previous plans (FAP-8A, DMDP) the floodplain areas of Dhaka were identified as floodplain areas and thereby control was imposed on development activities. But research conducted under the Detailed Area Plan (2022-2035) has shown that land development has taken place in flood plain areas without considering the various policies regarding development control. However, the purpose of imposing these controls was overlooked i.e. to preserve the areas, so that the flood flow is controlled, uncontrolled land development does not increase the destructive power of floods and the security of life and property of the common man is not at risk. Two deficiencies were observed in the identification of floodplain areas in the previous plans:

- The velocity of the water flow has not been taken into account in the identification of floodplain areas and no precise criteria have been determined as to what changes the water flow may change and what the consequences may be if settlements are built.
- Although there is talk of building settlements that are compatible with water flow in the identified floodplain areas, not enough explanations have been presented. However, after controlling the floods by constructing dams around Dhaka, the level of land development has been determined for the development of land inside the dam, in which case the issue of building settlements compatible with the flow of water is no longer relevant.

In previous development management plans (DMDP, DAP 2010-2015) land use in floodplain areas was referred to as 'floodplain area' but in fact land use in these areas is historically agricultural. The land use of floodplain areas is stated as agriculture in the master plan of FAP-8A; but later and even other contemporary surveys and reports have shown the floodplain area as a land use. In these cases, the economic use of land in determining land use and with it the financial dependence, security, capability of the various indigenous professionals who depend on them, including the land owner and the farmer; Above all, the issue of their fortunes has not been brought to the fore and only the policy of conservation has been given priority. As a result, this policy of unilateral conservation without considering the socio-economic realities of the floodplain region has proved ineffective in later times (Source: DAP, 2022-2035).

2. Conservation of flood plains and agricultural areas: intentions and realities

Two key issues worked as a key driver behind the transition of the land use from agriculture to urbanization, despite the controls imposed in the DAP 2010-2015:

- Increasing agricultural production in floodplain areas and/ or various flood control infrastructures designed to protect the city, construction of unplanned roads, bridges and culverts in the name of development have disrupted the normal flow of floods and disrupted agricultural productivity. As a result, the cost of production in agriculture has increased and the interest in agriculture is declining. As a result, the landowners and the farming community in these areas are becoming economically weak. In this situation, the restrictions imposed under various schemes have deprived the landowners living in the floodplain areas of the opportunity to improve their lot in any way other than agriculture. In this situation, these people in financial crisis are being forced to change their hands by selling land ownership to the rich and powerful of the society. Subsequently, in the interest of these rich and powerful people, on large scale unplanned land development is being done in the floodplain areas by violating or changing the law (Source: DAP, 2022-2035).

Although the various development activities currently underway in Dhaka and its environs is on rise , as a result peoples defensive costs are increasing in the face of

changes in the environment, ecology, biodiversity and socio-economic conditions of the floodplain and the average region. These defensive costs include:

- Costs of environmental change:
 - ✓ Increased costs in agriculture subject to changes in the natural features of floodplains.
 - ✓ Costs due to depletion of fisheries subject to changes in the natural features of the floodplain.
- Increased cost of living due to ecological change.
- Increased medical costs subject to contamination and pollution.
- Increased infrastructure construction and maintenance costs subject to increased risk of natural disasters.
- Increased security costs subject to the possibility of man-made disasters.
-

Whether the development activities carried out in an area will improve the lot of the common man will depend on the difference between the increased purchasing power of the people under the influence of the development activities and the imposed self-defense costs. If both the purchasing power and expenditure of an individual increase after developmental activities, then the seemingly increased purchasing power does not in fact play any role in the overall well-being of the people. Therefore, the idea of the overall well-being of people of all classes and professions especially the professional communities based on local nature and environment needs to be taken as the main basis behind the planning of any developmental activity.

One thing that is clear that in the current trend of development, the indigenous people of these floodplain areas, i.e. farmers and people of other professions indirectly involved in agriculture, have gradually become detached from agriculture and are gradually being evicted from their homeland. In addition, although there is no direct role in land use change, it needs to be stated here:

- Unplanned construction of roads, bridges and culverts in the name of increasing agricultural production and development of various flood control infrastructures designed to protect the city first endangered the floodplain fishing community.

- Floodplains serve as a place for fish to roam, breed, and search for food. But such developmental activities prevent the free movement of floodplain fish. As a result, the fishing in the rivers and canals has decreased and the fishing dependent fishing community has become economically incapacitated.
- Later, under the supervision of the influential people of these rivers and canals, fish farming spread and the control of fish production passed into the hands of the influential people of the area.
- As a result, over time, the fishing community in these areas is becoming increasingly refugee and forced to choose livelihoods where there is no application of their hereditary professional skills.

The farming and fishing communities and other professional people dependent on them are the aborigines of the floodplain. Their innate natural knowledge, which has been nurtured and cultivated for generations, has played a role in retaining the natural features of the region. These include:

- **Basic strategies for floodplain housing:**
 - ✓ Land development strategy through excavation.
 - ✓ Tree planting techniques for vita and habitat conservation.
- Road and bridge construction techniques.
- Strategies to maintain the productivity of agricultural land.

These strategies are influenced and guided by the principle of coexistence with nature and flooding, which is the long-experienced knowledge of people living in floodplains. Through this, Dhaka and the whole of the delta-inhabited Bengal region has been ensuring fair and sustainable use of the natural resources of this region for thousands of years. When these people are evicted from their place of birth, the floodplain area, the natural features of the floodplain area will change and as a result the land use will change and urbanization will continue which is normal. It is not possible to slow down these changes or retain the original natural features of these areas by imposing any unrealistic regulatory policy, especially when the current development strategy is not at all consistent with the special features of the floodplain.

Keeping this reality in mind, development management policies have been formulated in the Detailed Area Plan (2022-2035) (Source: DAP, 2022-2035).

3. Flood plain and agricultural area management principles

Considering the context of the Detailed Area Plan (2022-2035), the following issues have been specially considered in the formulation of development management policies for flood basin areas:

- The floodplain area is actually land cover, not land use and it is part of the floodplain realizing this reality.
- Conserve the ecosystem and biodiversity of the floodplain area and protect the environment by moving away from the tendency to protect the floodplain area only considering the benefits of flood control and drainage.
- Realizing the fact that the displacement of the aboriginal people in the floodplain region is the main regulator behind the destruction of the natural features of these areas and strengthening their economic base to prevent this process of displacement
- Realizing the fact that development work in floodplain areas should be conducted in the light of the principle of coexistence with floods.
- Ensuring development consistent with the geo-natural features of Dhaka and its adjoining areas in overall development
- Identification of capacity of RAJUK for the implementation of Detailed Area Plan 2022-2035

In the light of these issues, hydrological research activities have been conducted in the Detailed Area Plan (2022-2035) to formulate policies. Principles adopted for development management subject to the results of research conducted in the light of hydrology and in line with the concept of high leverage point of change adopted in the Detailed Area Plan (2022-2035):

- Instead of floodplain areas, overall ‘floodplain’ protection strategies need to be selected.

- Strategies need to be chosen to protect the socio-economic security and economic independence of the people in the floodplain areas.
- In the case of development, it is necessary to select development strategies by limiting the possibility of man-made disasters.
- In the case of land development or agricultural development, development strategies need to be formulated so that technical and engineering activities do not destroy the natural features of the floodplain.
- Strategies need to be devised to control the defensive costs imposed due to development activities.

➤ **Development management guidelines in the light of hydrology**

Flood free area

Mathematical studies under the Detailed Area Plan (2022-2035) and general experience show that areas in the average area of Bhawal and Madhupur are not affected by river flooding and are shown as flood-free average areas. All areas above the average area and most areas of medium height are identified within this area. In the average area there is forest land as well as agricultural land. In these areas -

- Land use: Mainly non-agricultural
- Land Ownership: Privately owned in agriculture and housing. Khas land in the case of forests.

Flood plain area

The term floodplain area will be used instead of floodplain area in the DAP (2022-2035) for the purpose of understanding the special significance of floodplain area in planning. A major reason for this is that the need for conservation of previously identified floodplain areas has been limited to the realization of the need for flood control and drainage in various plans and general conversations. By definition, floodplain areas have been formed over a long period of time with the help of riverine sediments. However, in the DAP (2022-2035), the possibility of increasing the fertility of the land through siltation has also been considered significant in identifying floodplain areas. As a result, the relatively low-lying areas covered by the

average area and some medium elevated areas have also been identified as floodplain areas based on the probability of flooding.

Common features of this region include:

- Floods caused by heavy rains
- Very suitable for agriculture and fisheries as it is formed by riverine silt; Canals, rivers, beels, reservoirs and wetlands fall under this area.

Floodplain areas are mainly divided into two parts based on water permeability, water depth, velocity and frequency:

- i. Flood Flow area
 - a. Main Flood Flow
 - b. General Flood Flow
- ii. General Flood Plain

Main Flood Flow:

Areas of floodplain areas where water permeability, depth, velocity and frequency are observed have been identified as major watershed basins. Areas that are flooded most of the time to some extent are part of the main watershed basin. If development activities are conducted in violation of the rules mentioned in the Detailed Area Plan (2022-2035), disaster will be caused.

General Flood Flow:

Areas where only the extent, depth and velocity of water are observed in the floodplain area are identified as normal watershed basins. Under the Detailed Area Plan (2022-2035), the watershed area identified as a general watershed basin area based on the extent, depth and current velocity of the 1988 flood based on the results of a two-dimensional mathematical study conducted to determine the nature of riverine flooding. Although the floods are not normal, the amount of damage will increase if the necessary measures are not taken in case of large-scale floods.

General Flood Plain

Areas where only water permeability and depth are observed in floodplain areas are identified as normal floodplains. It is a relatively higher part of the floodplain, where:

- During the monsoon season excess water overflows and accumulates.
- When the water recedes at the end of the monsoon, this excess water returns to the river and is connected to the main stream.
- During water entry and exit, the direction of flow is almost perpendicular to the main flow of the river (upstream to downstream).
- Due to riverine silt, this area is very suitable for agriculture and crops are not wasted without unusual floods.
- The common river basin area serves as a breeding ground for fish and a source of food.
- Land Ownership: Mainly privately owned

Rivers are not usually flooded here. Although it was submerged in the floods of 1988, there was no current or even less.

Floodplain areas have been identified under the Detailed Area Plan (2022-2035) and development management policies have been presented in these areas. The Detailed Area Plan (2022-2035) sets out the policy in the context of the floodplain and determines the need for management in floodplain development activities. It is recommended to allow building/ structure only in common watershed areas subject to special conditions considering the epoch-making concept of building a relationship with water and land rather than considering the floodplain area as an isolated entity. On the other hand, ground level improvement has been banned in the main watershed areas.

The Dig and Mound policy of digging reservoirs will be applicable to the area in the following ways:

a. Main Flood Flow:

- ❖ Upgrading the ground floor is prohibited

b. General Flood Flow:

Subject to land use approval, only public interest projects in general watershed areas - infrastructure or civic amenities can be undertaken by fulfilling the following conditions.

- ❖ If the amount of land applied is 2 bighas or more for individual applicant, 1 bigha or more for institutional applicant (government / autonomous / non-government organization) dig and mound method will be applicable for land development.
- ❖ The Dig and Mound method will also apply to any ‘large/ special building/ structure’.

c. General floodplain area:

- ❖ Dig and Mound method will be applicable for land development if the amount of land applied in general floodplain is 2 acres or more for individual applicant, 1 acre or more for institutional applicant (government/autonomous/non-government organization).

d. Flood-free Areas:

- ❖ Dig and Mound method will be applicable for land development if the amount of land applied is 2 acres or more for individual applicant, 1 acre or more for institutional applicant (government/ autonomous/ non-government organization).
- ❖ The Dig and Mound method will also apply to any ‘large/ special building/ structure’
- ❖ Water catchment area can be conserved in various ways such as- gardens, play grounds; deep / shallow reservoirs etc. and its number may be one or more.

3.2.4 Review of relevant acts

1. Bangladesh Environment Conservation Act, 1995 (amended 2010)

In order to preserve and enhance environmental standards as well as to regulate and lessen environmental pollution, the Bangladesh Environment Conservation Act, 1995 (amended in 2010) was passed in the Parliament of Bangladesh in 1995 (GoB, 1995). The government designates an area as ecologically critical if it faces threats to ecological protection, as per the Bangladesh Environment protection Act of 1995. In the event that an accident or other unanticipated incident releases pollutants into the environment, the person who caused the incident is accountable for taking action to reduce the pollution. Following the directives of the act, The Bangladesh Environment Conservation Rules, 1997 (amended in 2023) and Ecologically Critical

Area Management Rules, 2016 were formulated and gazetted by the Government of Bangladesh.

2. The Metropolitan, Divisional and Municipal areas' Playground, Open space, Park and Natural water body Conservation Act, 2000

This act is a landmark for the conservation of water body, park and playground in metropolitan, divisional and municipal city areas. This legal instrument protects environmentally sensitive areas prohibiting any type of construction in the environmentally sensitive areas. According to this act, any kind of alteration to playground, open space, park and natural water body/reservoir is not allowed. Any kind of alteration is prohibited and treated as punishable offence.

3. Bangladesh Water Act, 2013

The Bangladesh Water Act, 2013 was promulgated as part of the implementation of the National Water Policy, 1999, for the integrated management and development, skilled and effective use, conservation and maintenance of water resources of the country. According to this Act, the Government shall form a National Water Resources Council (NWRC), which perform as the policy maker through the executive committee of NWRC and the Water Resources Planning Organization (WARPO) will be the secretariat of this council.

According to this Act, any person can use surface water of natural water bodies for domestic purposes and agricultural use. In order to reduce the detrimental impacts and increase the benefit of the social, economic and environmental condition, the Act also emphasized on sustainable use of water for urban areas and agricultural purpose. Use of rainwater, balanced use of surface and ground water may be good options for supplying water to urban areas. The water also has to be protected from the pollution from wastes and hazardous substances. Wetland designated for water flow and bird habitat should not be allowed for drainage projects. The Act mentions that in any case, biodiversity, aquatic environment and fisheries should be important considerations for development of Project. A number of punitive measures have been suggested in the Act for violation of any of the clauses or directives. For example- using water for any purposes other than the one prescribed in the Act; encroaching upon or polluting the water resources; changing the flow path of canals etc.

CHAPTER 4: MATERIALS AND METHODOLOGY

4.1 Introduction

Drainage and Flooding of a river is dependent on the hydrologic and hydraulic processes along a river and its floodplain. Studying the hydrologic and hydraulic behaviors of rivers presents significant challenges due to the intricate relationship between the movement of water and the shifting of sediments. The hydrologic activities within a river system encompass the distribution and flow of water, reacting to precipitation, interacting with subterranean water sources, and adapting to the cyclical changes in water levels. The river's hydrologic pattern is shaped by the climate, the physical landscape, and human land utilization within its catchment area. On the other hand, hydraulic processes are concerned with the fundamental laws that dictate water movement through the river's course. This encompasses the river's ability to transport water, the dynamics of sediment movement, and the creation of distinct riverine structures such as twists, sediment bars, and expansive floodplains.

Conventional drainage and flood management strategies are concerned with hydrologic and hydraulic processes only but social and ecological considerations are not integrated in the flood management strategies. There has been a paradigm shift of flood management strategies in different countries of the world from solely flood protection approach to multiple ecosystem benefit approach. To understand the drainage and flood management of the study area following steps were followed and documented in following sections of the report.

4.2 Outline of Methodology/Experimental Design:

The methodology followed for the study is presented below

- i) Literature review (review of national and international journal, books, papers, reports, government plans and documents)
- ii) Selection of study area
- iii) Data collection: Primary and secondary data were collected. Primary data were collected through field work at sample locations/questioner survey/interviews/consultation/focus group discussion/Participatory Rapid Appraisal (PRA) etc., Secondary data i.e. topographic data (DEM etc.), water level data, rainfall data, cross section data of the

river/ canal, river and canal network, discharge data, evaporation data, DAP physical feature survey data, land use/land cover data were collected from different organizations such as WDB, RAJUK, IWM etc. Land price data at sample locations, Ownership/records of rights of land/property data such as deed agreement, mutation/parcha, land/property tax of selected respondents were collected from local land office/sub-registry office. Both qualitative and quantitative data were collected.

- iv) Data Analysis: Qualitative Data Analysis, Quantitative/Statistical Data Analysis-Regression statistics etc. Hydrological Modeling using software HEC-HMS, Hydrodynamic Modeling-1 D and 2D hydraulic modeling with using software HEC-RAS, Flood mapping analysis using GIS software 10.3
- v) Result Analysis

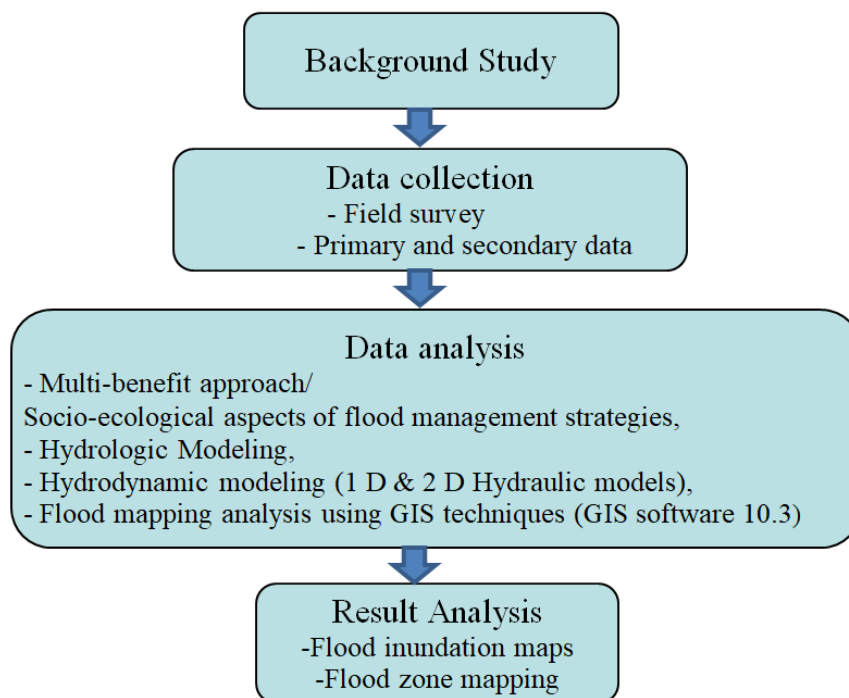


Fig 4.1: Flow chart of Methodology/Experimental Design

4.3 Selection and description of the study area

The study area covers a total of 29,973 acre (121.29 square kilometer) of Dhaka (Savar upazilla) and Gazipur district, about 35 kilometers of the Turag River as an area of investigation. This area lies between 23°74' - 23°88' north latitude and 90°34' - 90°40' east longitude. About 20 km length of the Turag river particularly from Gabtoli Aminbazar bridge to Tongi Bridge is adjacent to Dhaka City. The Turag River originated from the Bangshi River (lower) at Khaliakhor upazilla under Gazipur district. Turag River is divided into two parts at the point of Birulia Union of Savar upazilla under Dhaka district.

The average width of Turag River is about 0.12 km covering water body of about 276 ha during dry season whereas the amount of water body is 500 ha during rainy season (BWDB, 2004). The Fig. 4.2, Fig. 4.3, Fig. 4.4, Fig. 4.4.1 in the following section show the map of the study area boundary, the study area location showing river networks, the location of the study area on Dhaka Detailed Area Plan map and the location of study area on Google image respectively. Table 4.1 shows the list of Mouzas (administrative/cadastral unit) within the study area.

Table 4.1 List of Mouzas (administrative/cadastral unit) within the study area

Mouza	Upazila	Thana	District
Abdullahpur	Uttara	Cantonment	Dhaka
Akran	Savar	Savar	Dhaka
Ashutia	turag	Turag	Dhaka
Ati Chandgaon	Savar	Savar	Dhaka
Bagnibari	Savar	Savar	Dhaka
Banagram	Savar Upazila	Savar	Dhaka
Bara Ashulia	Savar Upazila	Savar	Dhaka
Bara Kakar	Savar Upazila	Savar	Dhaka
Bara Paragaon	Savar Upazila	Savar	Dhaka
Begunbari	Savar Upazila	Savar	Dhaka

Mouza	Upazila	Thana	District
Bhatulia	Turag	Turag	Dhaka
Bhomka	Savar Upazila	Savar	Dhaka
Bighatpatti	Savar Upazila	Savar	Dhaka
Biralia	Savar Upazila	Savar	Dhaka
Chakulia	Savar Upazila	Savar	Dhaka
Chandgaon	Savar Upazila	Savar	Dhaka
Chaubaria	Savar Upazila	Savar	Dhaka
Chhota Kakar	Savar Upazila	Savar	Dhaka
Dampara	Savar Upazila	Savar	Dhaka
Deul	Savar Upazila	Savar	Dhaka
Dewanbari	Savar Upazila	Savar	Dhaka
Dhanaid	Savar Upazila	Savar	Dhaka
Dhananjaypur	Savar Upazila	Savar	Dhaka
Dhaur	Mirpur	Turag	Dhaka
Diakhali	Savar Upazila	Savar	Dhaka
Gauripur	Savar Upazila	Savar	Dhaka
Goran Chotbari	Mirpur	Turag	Dhaka
Gram Bhatulia	Mirpur	Turag	Dhaka
Ichharkandi	Savar Upazila	Savar	Dhaka
Isakabad	Savar Upazila	Savar	Dhaka
Jiraba	Savar Upazila	Savar	Dhaka
Kumar_Khoda	Savar Upazila	Savar	Dhaka
Mana Santosh	Savar Upazila	Savar	Dhaka

Mouza	Upazila	Thana	District
Mosta Para	Savar Upazila	Savar	Dhaka
Nawaber Bagh	Mirpur	Mirpur	Dhaka
Pipulia	Savar Upazila	Savar	Dhaka
Rudrapur	Savar Upazila	Savar	Dhaka
Saipara	Savar Upazila	Savar	Dhaka
Samair	Savar Upazila	Savar	Dhaka
Sarulia	Savar Upazila	Savar	Dhaka
Taiyabpur	Savar Upazila	Savar	Dhaka
Tajpur	Savar Upazila	Savar	Dhaka
Uttar Datta Para	Savar Upazila	Savar	Dhaka
Uttar Kaundia	Savar Upazila	Savar	Dhaka
Uttar Ulumora	Savar Upazila	Savar	Dhaka
Arispur	Gazipur Sadar	Tongi	Gazipur
Auch Para	Gazipur Sadar	Tongi	Gazipur
Bade Palasona	Gazipur Sadar	Tongi	Gazipur
Baimail	Gazipur Sadar	Savar	Gazipur
Bakral	Gazipur Sadar	Tongi	Gazipur
Basan	Gazipur Sadar	Joydebpur	Gazipur
Bhadam	Gazipur Sadar	Tongi	Gazipur
Bhadam	Gazipur Sadar	Tongi	Gazipur
Bharari Para	Gazipur Sadar	Tongi	Gazipur
Chak Bhadam	Gazipur Sadar	Tongi	Gazipur
Chand Para	Gazipur Sadar	Joydebpur	Gazipur

Mouza	Upazila	Thana	District
Chandra	Gazipur Sadar	Tongi	Gazipur
Darail	Gazipur Sadar	Tongi	Gazipur
Daulatpur	Gazipur Sadar	Tongi	Gazipur
Gachha	Gazipur Sadar	Tongi	Gazipur
Gusulia	Gazipur Sadar	Tongi	Gazipur
Gutia	Gazipur Sadar	Tongi	Gazipur
Islampur	Gazipur Sadar	Joydebpur	Gazipur
Jamaldia	Gazipur Sadar	Tongi	Gazipur
Kadda Nandul	Gazipur Sadar	Joydebpur	Gazipur
Kakil Sataish	Gazipur Sadar	Tongi	Gazipur
Kasimpur	Gazipur Sadar	Savar	Gazipur
Mahisher Tek	Gazipur Sadar	Tongi	Gazipur
Mirpur	Gazipur Sadar	Savar	Gazipur
Mudi Para	Gazipur Sadar	Tongi	Gazipur
Naojuri	Gazipur Sadar	Joydebpur	Gazipur
Palasana	Gazipur Sadar	Tongi	Gazipur
Purba Souldubi	Gazipur Sadar	Savar	Gazipur
Sarupaitali	Gazipur Sadar	Savar	Gazipur
Satish	Gazipur Sadar	Tongi	Gazipur
Surabari	Gazipur Sadar	Gazipur Sadar	Gazipur
Tongi	Gazipur Sadar	Tongi	Gazipur

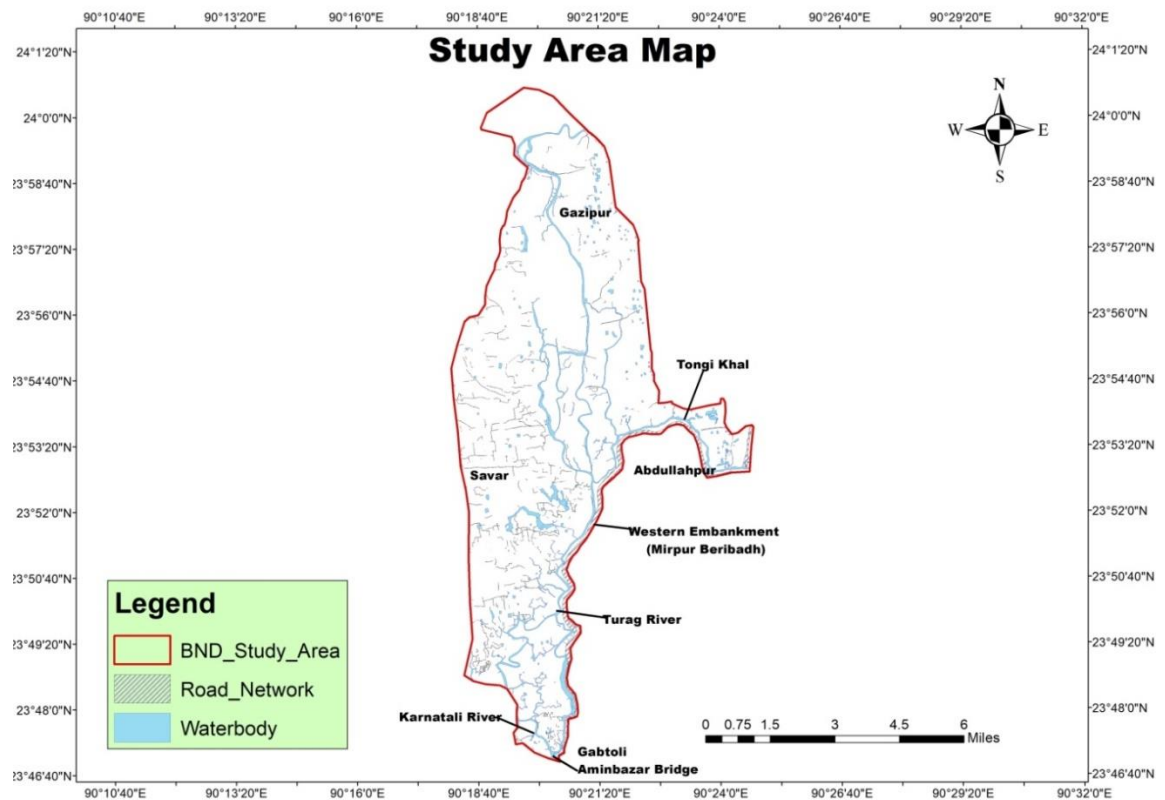


Figure 4.2: Study Area Boundary: Turag River and Its Contributory Area

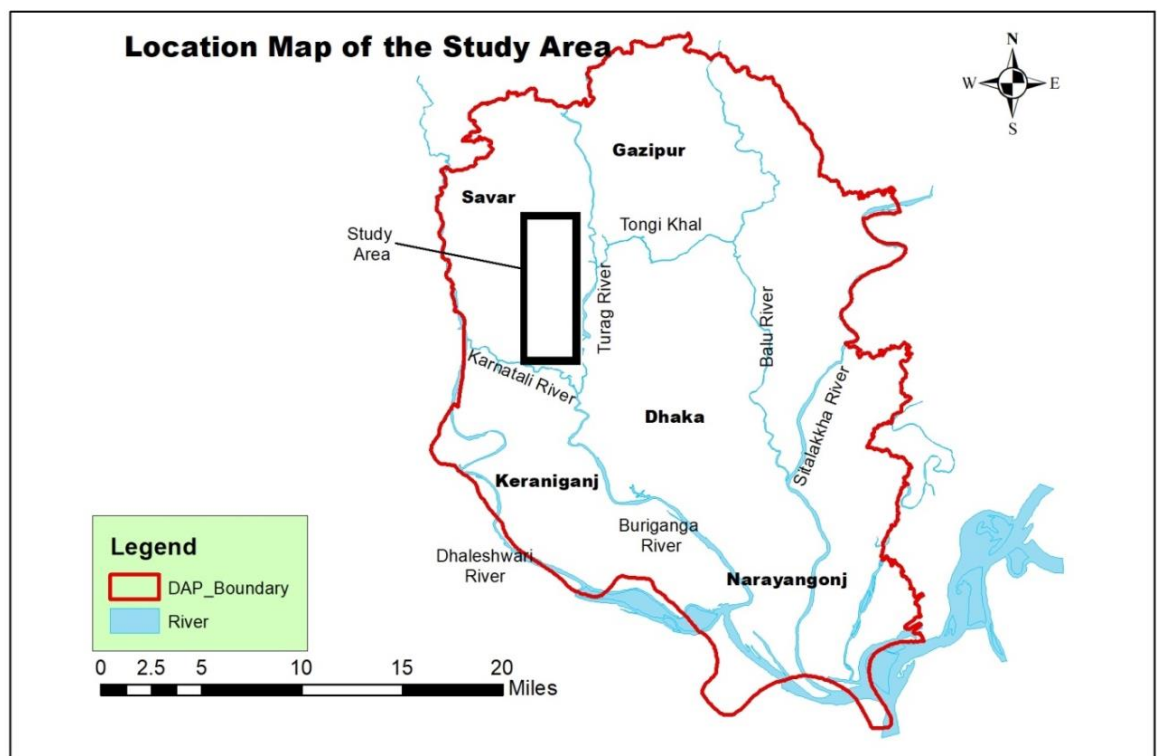


Figure 4.3: Location map of the study area showing hydrological (river) networks

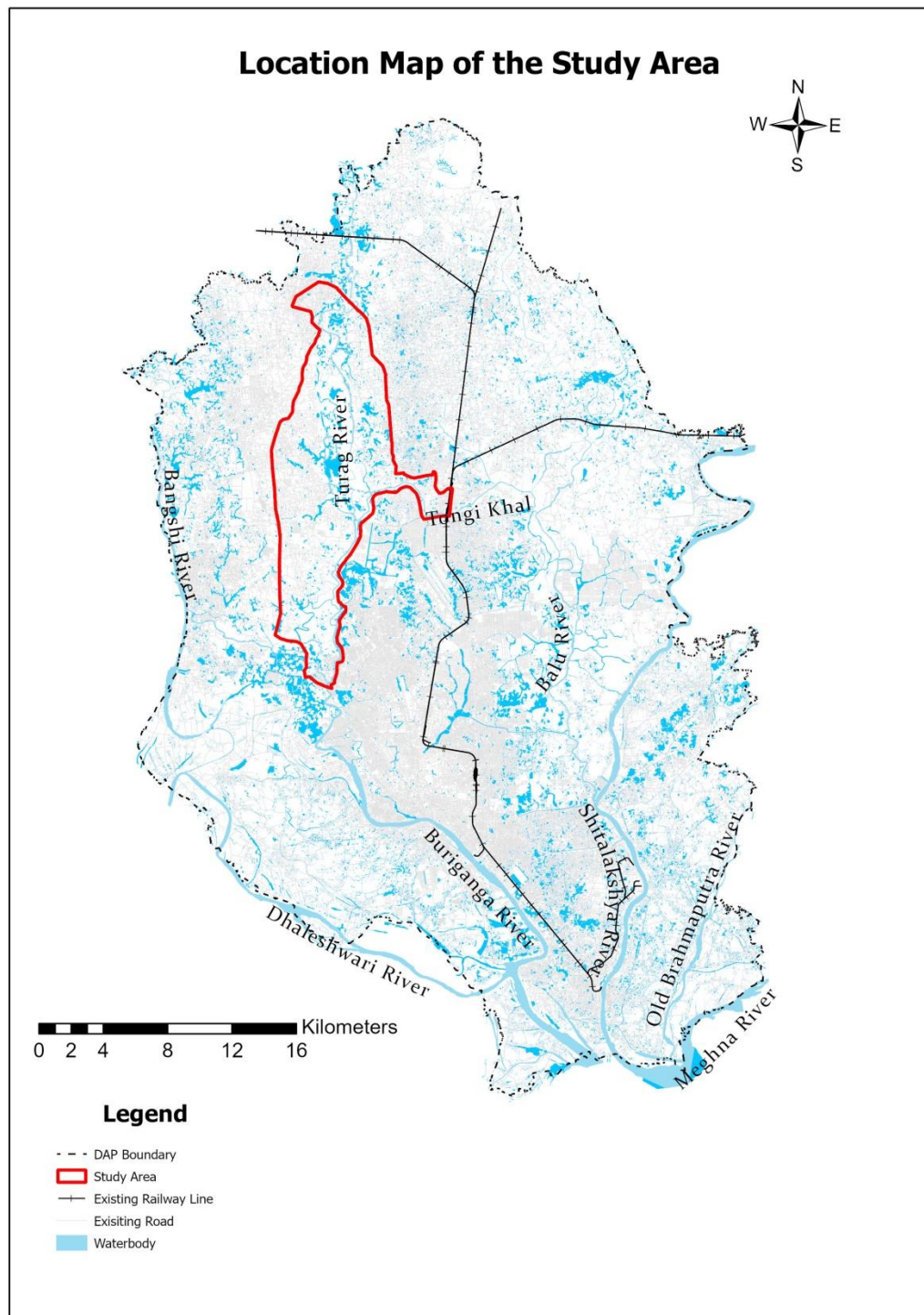


Fig 4.4: Location of the study area on Dhaka Detailed Area plan (DAP) Map

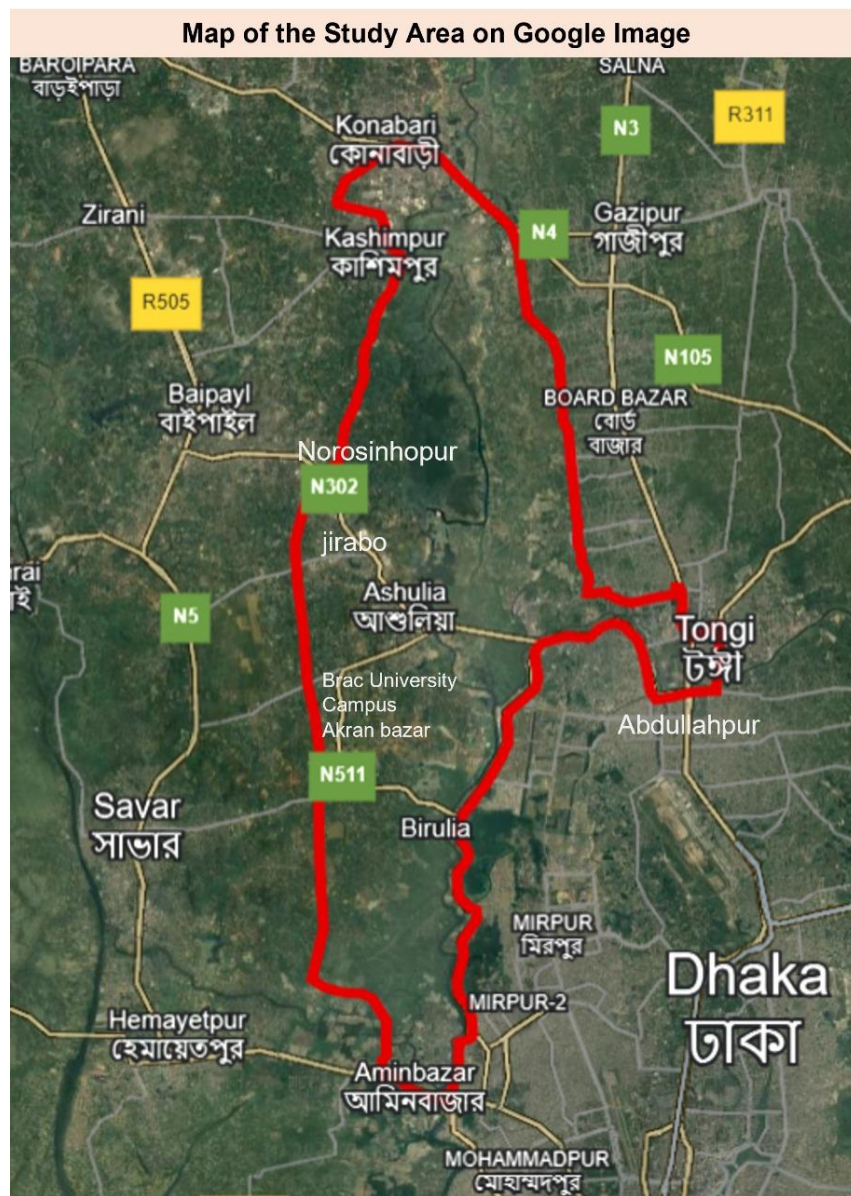


Fig 4.5: Study Area map on Google image

4.3.1 Hydro-Morphology of Turag river

Hydrology of Turag River

The basin of the Turag River is nearly semi-funnel shaped and the river flows from north to south within the basin. The rivers' catchment is located on the central and southern part of the Madhupur tract. Water flow increases and overflows the flood plain at both sides of the river at monsoon period. The river becomes polluted from the nearby industries during dry season or low flow period which is very important phenomenon for the river. Water level fluctuates between about 1 m to 2 m from January to April. (Uddin, 2005).

Morphology of Turag River

The Turag River is an irregular meander type and **Thalweg shifting river**. The sinuosity of the river is 1.50, which indicates the river's meandering property rather than straight line. Thalweg shifting and significant bed level changes of Turag river have been identified by analyzing the morphological cross sections of the river for the year 2005, 2010, 2014 (Fig. 4.4.2) which indicates the intervention of river flood plains (Sazzad, 2018). Table 4.2 represents the major hydro-morphological features of Turag river. Fig. 4.4.2 shows the cross sections of Turag river near Mirpur in 2005, 2010 and 2014.

Table 4.2: Major Hydro-morphological features of Turag River

Physical description	Nature	Meandering, gradient 2cm/km
	Bank level	Left 2.67 m to 5.92 m, right 4.210 to 368 m
	Bed level	-0.748 to -12541 m,
	Catchment area	1024 sq km
Discharge/ River Flow	Seasonal	
	Dry period	124 cusec,
	Monsoon period	1136 cu sec
	Tidal effect	Downstream Tidal, upstream non-tidal

(Source: Sazzad, 2018)

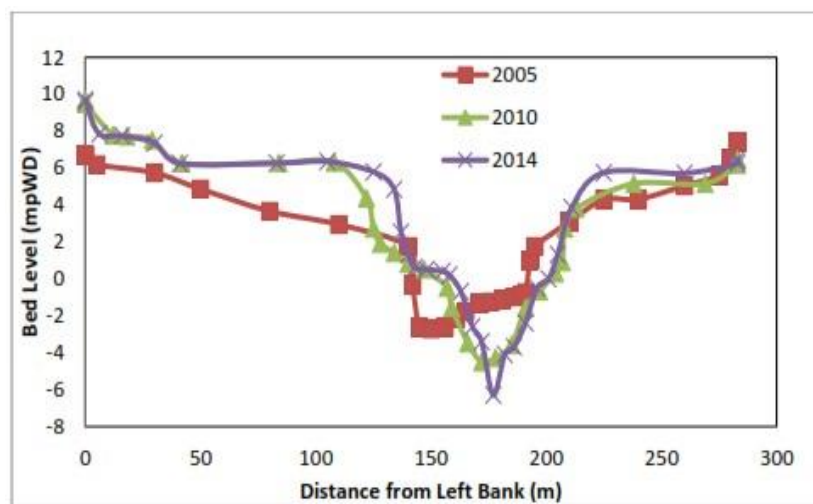


Fig: 4.6 Cross sections of Turag River near Mirpur showing flood plain interventions
(Source: Sazzad, 2018)

4.3.2 Field observation and basic survey

To understand the hydrological system and socio-ecological context of flood management approaches of the study area, relevant primary and secondary data were collected. Primary data were collected both by field observation/investigation and interviews/discussion with different sections/diverse groups of people of different genders in the locality such as land/property owners, tenants, farmers, fishermen, villagers, shopkeepers, industrial workers, community organizations with a structured questionnaire. A total of 35 individual respondents were interviewed. Secondary data were collected from literature review and different government and non-government organizations such as RAJUK, WDB, IWM, Sub-registry office, AC (land) office etc. Survey period was from January, 2020 to December, 2023.

Physical feature and Topographic (DEM) data prepared under Dhaka Detailed Area plan (DAP) 2022-2035 were collected from RAJUK for the study area and verified/crosschecked for sample locations. Land filling/encroachment sites and pollution hotspots (point/non-point sources) were identified. Information related to land price, land demand, land availability and land size, land quality, compensation benefits, occupational changes, types of crops were collected. Information related to forced eviction were collected from communicating with the representative of former land owners, especially with the representatives of farmers and fishermen communities in Kaundia, Birulia, Rustompur of Savar upazilla whose livelihood mainly depend on the availability of local resources. Information about the frequency of extreme weather events like heavy rainfall and flooding and flood depth were also collected from field investigation.



Fig 4.7: Industrial effluents pollute Tongi Khal and adjacent vegetation at Uttarkhan, Dhaka



Fig 4.8: Illegal sand filling/encroachment of flood flow zones adjacent to the west bank of Turag river at Birulia, Savar

4.4 Socio-Ecological aspects of Flood Management approaches in the Study Area

Conventional flood management strategies/ practices consider flood protection as its only goal. Multi-benefit/socio-ecological dimensions of flood management approaches are overlooked. The following section describes the status of socio-ecological considerations of flood management approaches in the study area.

4.4.1 Major challenges and threats for conservation of Turag river-flood plain ecosystem in the study area

Challenge 1: Population growth and in-migration

Major driving forces for population growth and in-migration in the study area include rapid urbanization and industrialization, transport network expansion, employment opportunities, increased housing demand, low land value and low living cost. The Turag River and its floodplains are impacted both directly and indirectly by population growth. For example, by releasing sewage into the river, residents along the Turag River are contaminating the water. In a similar vein, land grabbers are encroaching on the river and its floodplains in order to build homes and other facilities that impede the Turag River's natural flow.

Challenge 2: Urbanization and industrialization

After 1990, rapid industrialization due to industrial explosion in the garments industry has led to the rapid urbanization in the study area. The urbanization process has resulted in the extinction of agricultural lands with high value agriculture, decreased soil fertility and increased production costs leading to the loss of agricultural production. As a result, marginal farmers sell their agricultural lands and migrate to the nearby cities. Occupational pattern has also been changed with migration from farming to non-farming activities such as industrial or construction activities etc. Major effects of urbanization are loss of wetlands due to landfilling, encroachments of rivers and canals etc. Therefore, due to urbanization and industrialization existence of river and its floodplains are under threat.

Threat 1: Illegal sand filling and encroachment

West bank of Turag river is not cordoned by embankment. But land development activities are going on indiscriminately along the west bank of Turag river which is a major threat for the existence of Turag river and its contributory areas. Defying the High Court's order, many land grabbers, sand traders, housing estate agencies/companies are

continuously encroaching the foreshore and flood plains of the Turag river on its western side and erecting retaining walls, structures/establishments etc. Turag river is shrinking day by day. Besides this, floodplains in the west of Turag river are being encroached by tons of brickfields with towering chimneys to satisfy the rapid urbanization in and around Dhaka city. The entire stretch of the foreshore of the Turag river at its east bank along Dhaka western embankment between Shinnirtek, Mirpur to Kamarpara, Uttara via Birulia and Dhour Bridge has been filled up with sands dumped by dozens of dredgers working day and night.

Threat 2: Pollution

Increasing pollution with rapid industrialization has been observed in the study area. Industrial growth occurred on the bank of Turag river after establishment of Tongi BSCIC (Bangladesh Small and Cottage Industries Corporation) Industrial Estate in 1964 at Tongi, Gazipur district situated in north-east of the study area. At the time of establishment, the industrial estate was designed to accommodate only small and cottage industries which are mainly non-polluting. But, after 1990 the industrial pattern was changed tremendously due to transformation from small and cottage industries to heavy manufacturing industries especially in garments manufacturing in the industrial estate. During the early 90s many garments industries were established in the industrial estate due to rapid industrial booming of the garments industry in Bangladesh. Many industries have been grown up at the bank of Turag River during last decade and a great number of new scattered industries are continuously increasing. But, the waste management system has outpaced the industrial booming of the area. Many industries in operation have no ETPs (Effluent Treatment Plant) and BSCIC also has not developed any CETP (Central Effluent Treatment Plant) in the Industrial Estate. Untreated industrial wastes are thrown into the river water. Besides this, the construction materials and residual pesticides, fertilizers, herbicides and insecticides have been mixed into the river water. Locals dump wastes into the river water. It was observed that riverside people use the river water for swimming, washing, bathing and boating purposes. All the activities result in environmental pollution.

4.4.2 Bangladesh government initiatives to restore Turag river-floodplain ecosystem

High court Judgment

The High Court division of Bangladesh ordered the government of Bangladesh to draw boundaries around the original territory of the four rivers that surround Dhaka: Buriganga, Turag, Balu, and Shitalakhya. The main purpose was to restore the river areas to their natural state and safeguard them from grabbing and pollution. The ruling was delivered in June 2009. The court had also ordered the government to declare the four rivers 'ecologically critical areas'.

The Department of Environment (DoE), Bangladesh in September, 2009 declared the above four rivers Ecologically Critical Areas (ECAs) under Section 5 of the Bangladesh Environment Conservation (EC) Act, 1995. In 2016, the Bangladesh government framed the Ecologically Critical Areas (ECA) Management Rules, 2016 as part of implementing the directives of the Bangladesh EC Act, 1995. According to the ECA Management rules, 2016, any kind of development work that threatens the existence of biodiversity and ecology in the ECAs is prohibited. The High Court Division (HCD) of Bangladesh also issued a historic ruling in February, 2019 awarding all rivers "legal personhood," hence establishing legal protection for all rivers in Bangladesh. But the High court's judgment of two times to save Turag River from encroachment and pollution was violated practically. It has been seen that land grabbing, encroachment and pollution are still unabated and unstoppable in the study area.

Government Initiatives

The Bangladesh Inland Water Transport Authority (BIWTA) has been constructing demarcation pillars along the Rivers Buriganga, Turag, Balu and Shitalakhya since 2014 after a combined survey and measurement by several ministries, to prevent unauthorized and illegal possession on the banks of the four rivers. The River and Delta Research Centre (RDRC) of Bangladesh has conducted research on determining the accuracy of demarcation pillars set by BIWTA along the bank of the River Buriganga and Turag and published a report on January, 2021 which found

irregularities in the installation of the demarcation pillars on both bank of the Turag River [19].



Fig 4.9: A submerged RCC demarcation pillar of Turag river boundary

Consequences of Turag's boundary demarcation by RCC pillars and walkways

It was seen that thick RCC (Reinforced Cement Concrete) demarcation pillars along the both bank of Turag river were installed by BIWTA. Some demarcation pillars were submerged into the water, only top of the pillars was seen. Besides this, newly constructed walkways by BIWTA in some areas along the both bank of Turag river was seen.

It has been observed that demarcation of river boundary by constructing RCC pillars and walkways has negative consequences although the demarcation pillars and walkways are constructed rightly in many places following actual river boundary. Because, in case of Turag river, only the boundary of the river but not the boundary of its flood plain is being demarcated. It was found that demarcation of boundary pillars of Turag river provoked many land grabbers to start gobbling up the lands adjacent to the river boundary which are flood plains with massive earth filling. The boundary pillars and walkways have developed a sense among the people that they can't do any kind of development work inside river's boundary but outside river's boundary they have right to develop their own land although being floodplains. Actually, boundary of flood plain of the river is necessary to be demarcated. Because, rivers and

floodplains should not be treated separate entity rather they are single entity. To save river, restoration of its flood plain is also necessary.

Besides this, in case of submerging pillars into water there are possibilities of accident during boat or vessel movement by collision between the boat or vessel and the pillars.

Enforcement

Sometimes government officials from RAJUK and BIWTA conduct eviction drives against the land grabbers but their actions are not effective to stop land grabbing because their actions are limited and piecemeal type and are not taken as regular basis.

4.4.3 Impacts of anthropogenic activities on Turag-river Flood plain Ecosystem

Table 4.3: Impacts of anthropogenic activities on Turag-river Flood plain Ecosystem

Types of Benefit	Impacts
Direct Values	
Fisheries	The fishery of the Turag River plays a very vital role in alleviating poverty and providing food to the poor fishing community adjacent to Turag River. But, livelihood status of the fishing communities is not satisfactory. Fishermen villages are mostly located in inaccessible areas beyond modern communication systems. The fishing community as a whole is very poor and one of the most disadvantaged group in the society like other areas of Bangladesh. They have no other income generating activities except fishing, which cannot be carried out throughout the year. Scarcity of dry season water and pollution pose the threat to fisheries production in the study area. Fish quality with fish production has been largely hampered. Fish habitat and fish production with diverse nature might be lost permanently if pollution and illegal filling of wetlands/low lying areas can't be stopped right now. Besides

	this, the fishing communities and villages are at great risk of extinction with the loss of their occupation.
Agriculture	Farmers irrigate their agricultural land from Turag River through numerous canal networks in the dry season. The major portion of the western bank of the Turag river especially from Bhachotra of Savar Thana to Machimpur of Tongi is dominated by agricultural land use specially rice cultivation. But, recently crop production has been decreased drastically because of decreased agricultural land, soil/water pollution, illegal land filling, loss of soil fertility etc.
Pasture	The non-inundated area is greatly used as pasture land which will be impacted.
Transportation	As waterway provides easier and cheap means of transport, it is still seen passengers and goods carrying boats/vessels moving/plying on Turag river. But existing water transport system of Turag river is not as vibrant as before because of some impediments in boat/vessel movement, such as siltation, reduced navigability, reduced flow/current, deteriorated water quality and odor due to river pollution, shrinking of river due to sand filling and solid waste dumping etc. Especially in the dry season, Turag's water level goes down and boats are not able to ply on the river. Because of not resolving these impediments, the government initiative for introduction of circular waterway system around Dhaka was failed. If the impediments are not resolved, water based transportation will be hampered a lot with the livelihood of boatman and other dependent people on the sector.
Cultural Services (Recreational, Aesthetic,	➤ The Turag River flows through the study area with many beels or natural depressions on western side of the river. During rainy season, the floodwaters spill over the

Spiritual, Educational)	riverbanks through canals connecting the adjacent beels turning them into a large watershed. People from Dhaka city and outside region come to enjoy the scenic beauty of the river and its flood plains. The river Turag works as natural freshener of polluted air of Dhaka City. The river provides recreational facilities to the people from a very long time like supporting river resorts, boat racing. ➤ The Bishwa Ijtema, the second biggest Islamic congregation after the Hajj, is an annual gathering adjacent to the Turag River in Tongi, gazipur and attracts millions of Muslims annually from different countries of the world. ➤ If pollution and other anthropogenic activities can't be stopped right now, many outdoor recreational activities which have economic values- like fishing, hunting, camping, wildlife watching and boating-all the functions will be hampered to a great extent.
Indirect Values	
Regulating services (Flood control, water purification, climate regulation, soil erosion control)	Government spends a large amount of money each year to manage floods by adopting some structural measures but identifying and protecting/ restoring the natural flood plain area can reduce the consequences of flooding i.e. loss of life and properties and thereby can reduce repetitive economic losses to society and increase savings.
Water quality	Floodplains serve as natural filters when they are flooded, eliminating extra silt and nutrients like phosphorus and nitrogen that can lower water quality and raise treatment expenses. However, shifting land use patterns from flood plains to urban areas deteriorates water quality, intensifies the effects of flooding, and jeopardizes fish and wildlife habitat.

Aquifer recharge	Water flow is slowed outside of a river's main course, giving it more time to sink into the ground and replenish subterranean water sources, often known as aquifers, which are the main source of drinking water for nearby populations and for crop irrigation.
Existence values	
Terrestrial Ecosystem	Terrestrial ecosystems are found on land and are characterized by factors such as soil, topography, and climate (temperature, precipitation, etc.). Deforestation, urbanization and infrastructure development have largely damaged the terrestrial ecosystem and vegetation of the study area.
Wetland Ecosystem	Wetland ecosystem is influenced by factors such as water depth, flow rate, salinity, and light penetration. River bed, ecology, morphology and navigable channels are being destroyed as a result of sand-extraction from the riverbed which has a large impact on the above factors. Wetland ecosystem would be interrupted due to interventions.
Wildlife Habitat and Biodiversity	Floodplain forests and marshlands are among the richest habitats for wildlife, both in terms of diversity and numbers. Those would be interrupted due to interventions.

4.4.4 Major impacts of construction of Dhaka western embankment along the east bank of Turag river

The Dhaka western embankment along the east bank of Turag river was constructed in 1990. The northern section of the embankment from Uttara to Mirpur is designed to provide protection from a 100-year flood, with crest elevation of 8.2 m. The embankment had cut off the flood plains on the eastern side of the Turag river. No embankment has been constructed yet along the western bank of the Turag river. After construction of Dhaka western embankment along the east bank of Turag river, new ecosystem had been developed both inside and outside of the embankment. There had been tremendous

effects of construction of Dhaka western embankment on both inside (flood free) and outside (flood prone) of the embankment. In most of the cases, all the impacts are positive for the residents inside the embankment than that outside the embankment [2].

Levee effect: Residents living in houses protected by structural interventions (flood embankment) might “develop a false sense of security” leading to “disastrous impacts” in case of a breach of the structure (Louis Berger International, 1991). This case is true for Dhaka as it was seen that after construction of Dhaka western embankment, rapid infill development started rapidly within the embankment. Property value was also increased simultaneously. But the development within the embankment was not planned following government plans, policies, rules and regulations. Low lying retention ponds/ waterbodies/ natural drainage channels within the embankment were filled up by a large amount. Proper maintenance work of the embankment was not taken also. Residents were not totally aware about taking adaptive measures to future flooding events. The consequence is that inside part of the embankment experienced severe losses of flooding in 1998 and 2004 although the area was made flood protected by embankment.

4.4.4.1 Effects on Economy

Occupation:

Generally, the residents inside the embankment have shifted their occupation in construction, transportation, and other higher income generating activities from fishing and agriculture than the residents outside the embankment. The reason behind this is that after construction of the embankment, massive infill development was started inside the embankment and inside area was provided with major civic, urban infrastructure and facilities supported by the master plan/development plan of Dhaka, which paved the way for more economic opportunities than the outside. Furthermore, many residents outside the embankment have lost their employment and become poorer due to river/wetland pollution and encroachment and some shifted to other lower income generating activities like day-laborer, home worker from fishing and agriculture.

Income and expenditure:

After construction of the embankment, average income of the residents inside the embankment has been increased than that outside while average expenditure has been increased for both sides of the embankment. But before construction of the embankment,

there was coherence between income and expenditure of the residents both inside and outside of the embankment.

4.4.4.2 Effects on Environment

Pollution:

Inside the embankment, both point and non-point sources of industrial and household garbage are produced. These wastes are transported to the low-lying fringe areas by surface runoff. Prior to the embankment's construction, Dhaka City was supplied by a network of khals, or natural drainage canals that collected waste water from the entire city and released it into neighboring rivers via a variety of disposal locations. In this instance, the river flow might use its assimilative capacity for purification of the wastes and carrying the wastes to the downstream areas. However, the canal or drainage system does not operate as intended because of haphazard growth inside the embankment. Both point and non-point sources of household and industrial wastes are responsible for pollution of rivers, flood plains, khals or beels outside the embankment. The situation is very severe now due to encroachment of rivers and flood plains by illegal land grabbers and industrialists ignoring the government acts, rules and regulations.

4.4.4.3 Effects on Settlement Pattern

Due to the flood-free character of the inner part, new construction boom has been started in the inner part immediately after the construction of the embankment. Both land demand and land price has been increased extremely in the inner part than the outer part. In some parts of the inner part, land price per katha is more than thirty times higher than that of the outer part. Presently, most of the area of the inner part are built-up. As the outer part is more flood prone, the effects on settlement pattern on it is less than that of the inner part and so, vast tract of land in the outer part is vacant. Although, the outer part is flood prone, there is a tremendous pressure for conversion of agricultural use to housing, industry or other non-agricultural uses in the outer part. Recently, Illegal sand filling, encroachment, coercive possession of others land by taking chance of the government's ineffective measures have exacerbated the situation in the outer part of the embankment.

4.4.4.4 Effects on Land Losers due to land acquisition

It was found that the rate of compensation value for the lands acquired for construction of Dhaka western embankment was very low than the actual market value of the land at that time. The ratio between the actual market value and the rate of compensation paid varied from 2 to 6 times.

4.4.5 Factors contributing to the socio-ecological changes

Expected future land use:

There are two types of land/property owners in the study area- i) local owners-those who are the local people and resides on the locality, some of whom got ownership through inheritance and others through purchasing lands and ii) outside owners- those who are the owners from outside of the locality and bought the land/property from local people mainly for residential/industrial purposes and those who represent mainly rich classes/powerful sections of the society. In interviewing the respondents, it was found that about 15% of the total was the local owners and about 85% of the total was the owners from outside. Out of the owners from outside who bought agricultural lands, about 98% has bought the agricultural land having intention to use the land as residential/industrial purposes in future. Some part of the land owned by outside owners have already developed or converted to urban areas in a scattered way. But, a large tract of the land owned by outside owners are still being used as agricultural purposes by the help of rented farmers because the land owners think that the present situation is not conducive for residential or industrial development due to infrastructure unavailability, financial shortage etc. but some years later, they intend to convert their land use as residential or industrial purposes. The outside owners also have a perception that their land is more secured and they can't be evicted.

Demand of land and land price:

In the investigation it was found that after the year 1990, a huge transformation took place in the ownership pattern in the north-west region of the study area due to industrial explosion. Demand for residential and industrial land increased by a large amount. To fulfill the demand for residential and industrial lands, conversion of agricultural lands to non-agricultural uses increased and agricultural lands started to decrease at a faster rate

than the previous record although there is no flood protection embankment in the west bank of the Turag river. Present situation is very worse because of massive unplanned and scattered development in the flood plains of the study area. Land price is one of the indicators for the increasing land demand. When land demand is increased, land price is also increased. Figure 4.4, 4.4.1, 4.4.2 describe the land price scenario of the study area.

Table 4.4: Land price in Borokakor Mouza (BDT/katha)

Land use type	Price in government register (mouza rate)	Local market price (2023)	Ratio (market price to mouza rate)
Residential land	2,72,000	1,50000-8,50000	0.5 to 3times

Source: Sub-registry office and field survey

Table 4.5: Change of land price (market rate) in Borokakor Mouza (BDT/katha)

Land use type	Price (1998)	Price (2021)	Price (2023)	Increment ratio (1998-2023)
Residential land	3000-12000	1,00000-3,50000	1,50000-8,50000	6500 times (avg.)

Source: Field survey

Table 4.6: Future expected price of agricultural land in Savar (BDT/katha)

Parcel of Land (agriculture)	Market price (per katha) of agricultural land (2020)	Expected price (per katha) of the land (2025) as residential use	Expected Price Increase (per katha)
A	2.5 lakh BDT	5.5 lakh BDT	3 lakh BDT
B	1.75 lakh BDT	4.5 lakh BDT	2.75 lakh BDT

Parcel of Land (agriculture)	Market price (per katha) of agricultural land (2020)	Expected price (per katha) of the land (2025) as residential use	Expected Price Increase (per katha)
C	1.5 lakh BDT	4 lakh BDT	2.5 lakh BDT
D	1.25 lakh BDT	3.5 lakh BDT	2.25 lakh BDT
E	1.5 lakh BDT	3.5 lakh BDT	2 lakh BDT
Average Price	1.7 lakh BDT	4.2 lakh BDT	2.5 lakh BDT

Source: Field Survey at different locations in Savar (2020)

Land holding Size

The large parcels of land are being divided into small pieces/parts by transferring ownership for several times over time. It was observed that in Bororkakor Mouza, Savar, a small land parcel of landholding size of 2 decimal was purchased in 2023 which was the small part of a large sized land of 2 bigha in 1990 which divided later for five times. Land fragmentation is inevitable, because land prices are increasing with time with increasing demand but people has less capacity to buy large sized lands. Sometimes, people are bound to sell/transfer their own lands because of overcoming financial crisis. In case of inherited land/property, the ownership is transferred to the ancestors by the death of forefathers and land is divided into parts.

4.4.6 ROOT CAUSE FOR CONVERSION OF FLOOD PLAINS AND AGRICULTURAL LANDS TO URBAN USES

Insecurity in land ownership/tenure rights

It was observed that the insecure land ownership/tenure rights is the major determinant for conversion of flood plains and agricultural lands to urban uses i.e. residential and industrial uses. Insecurity in land ownership/tenure rights is the loss/lack of the right of the individuals or groups to effective protection by the state from involuntary removal from their land or residence. It is a situation or state faced by the owner/s of land/property in flood plains/agricultural zones as a result of the following factors:

- Fear to lose legal right to own/use a land/property due to threat of forced eviction.
- Very low economic return because of pollution and other anthropogenic activities compared to the return from non-agricultural uses
- Absence of government incentives/support for increasing economic return from agricultural lands/flood plains.

Although construction of Dhaka western embankment has led to the rapid infill development inside the embankment, but it is not the major driving force for development in that area. It is difficult to discern a significant difference between the patterns of development and adaptation inside the embankment from those of the unprotected area to the outside. It appears that tenure security has a far greater impact on residents' likelihood of adopting adaptation measure to their development works than their position on inside or the other of the embankment. It was observed from the field investigation that the residents did not considerably invest in adapting their structures to decrease flood impacts because of the threat of eviction in both inside and outside of the embankment. Threat of eviction is a form of tenure insecurity which is in the root of the concept of political ecology which tends to underscore how capitalism-driven social exclusion and marginalization can push the least powerful groups/classes to the most hazardous environments (Collins, 2010; Pelling, 1999). Political ecology concept is strengthened by incorporating the concept of facilitation which indicates how privileged/powerful groups are provided institutional support for their private gain to exploit environmental opportunities associated with hazardous places, contributing to injurious social and ecological consequences.

It was observed that tenure security governs urban development in both sides of the embankment. The residents of informal settlements i.e. slums or squatters are very much vulnerable to threat of eviction from both public and private sectors in the inner side. The situation is very severe in the outer side, because not only the tenants but also the owners of many land/property can't enjoy their legal right to use their own land. Land grabbers are engaged in encroachment and illegal sand filling activities of other people's land without getting their consent. Sometimes they compel the land owners to transfer/sell their land/property at a very lower rate below than market price through forceful eviction or coercive/deceitful techniques. Sometimes owners of agricultural lands, which act as natural retention to mitigate flood risk, can't practice agriculture in their own land due to pollution from adjacent industrial effluents. Eventually, the agricultural lands lose their productive capacity and owners of agricultural lands can't get proper return from their land and become bound to sell their land to the vested quarters. In most of the cases, the agricultural lands are sold for housing/residential or industrial purposes. But, it is irony that land grabbers/powerful groups are enjoying their land of possession as they wish. Sometimes, they develop housing estates with infrastructure facilities in flood plains or agricultural lands neglecting government acts, rules and regulations. They tend to become secure, as they just transfer the risk and vulnerability to other insecure areas, the people of which are powerless and have no voice to protest. The actions from government side to prevent those illegal activities are seen by taking sporadic eviction programs but these are not enough. Sometimes government officials are compromised with the evil intention of the vested groups. Sometimes, government plans, policies or acts also protect the interest of the powerful groups ignoring the majority peoples' opinion.

4.5 Hydrological Analysis

4.5.1 Purpose of Hydrologic Analysis

To understand the entire hydrological process of West Turag Basin including precipitation pattern, intensity and frequency, response to precipitation events (both short duration rainfall event & long term continuous event) at outfall, amount of loss due to infiltration & percolation, surface runoff volume, contribution of tributaries in main channel etc. a hydrological analysis is usually performed by simulating using hydrological modeling software like HEC-HMS, SWAT, SWMM, SWMHYMO, OTTHYMO etc.. For this particular study, hydrological analysis has been performed by developing an event-based hydrologic model using HEC-HMS (Version 4.11).

4.5.2 Description of Modeling Software

HEC-HMS is a software developed by the US Army Corps of Engineers. The Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers developed HEC-HMS software to simulate the complete hydrologic processes of dendritic watershed systems. The software can be used to simulate infiltration, runoff generation, and flow routing. HEC-HMS can simulate evapotranspiration, snowmelt, and soil moisture variation processes for continuous modeling. Advanced functions have been built into this software for gridded runoff simulation, model optimization, streamflow forecasting, depth-area reduction, model uncertainty assessment, erosion and sediment transportation analysis, and water quality assessment.

Comprehensive features have been integrated into the HEC-HMS work environment, allowing database establishment, data entry, hydrologic simulation, and results reporting. The friendly graphical user interface enables the seamless movement of the different parts of the software. The simulation results generated by HEC-HMS can be stored in HEC-DSS (Data Storage System). The HEC-DSS data files can be applied with other software for various hydrologic analyses, such as water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation. The different steps of hydrologic model development have been described in the following sections.

4.5.3 Approached Methodology

For the hydrologic analysis of West Turag River, a background study has been conducted, which consists of the description of the project background, study area and history of flooding, pointing out the objectives and the scope of the study. Following the background study, data was collected and processed accordingly. Data collection and processing includes collecting and processing Digital Elevation Model (DEM), hydrometric, soil, land use, and land cover data. Then, using HEC-HMS, a hydrologic model was developed. During the development of the hydrologic model, watershed delineation, subbasin characterization and parameterization and meteorological model development have been done, respectively. Also, the limitation of the hydrologic model was included in the study. The simulated model has been utilized to generate flow for the hydraulic model. The overall approaches and methodologies for developing hydrologic model to delineate the flood zone mapping of the West Turag river have been shown in Figure 4.10.

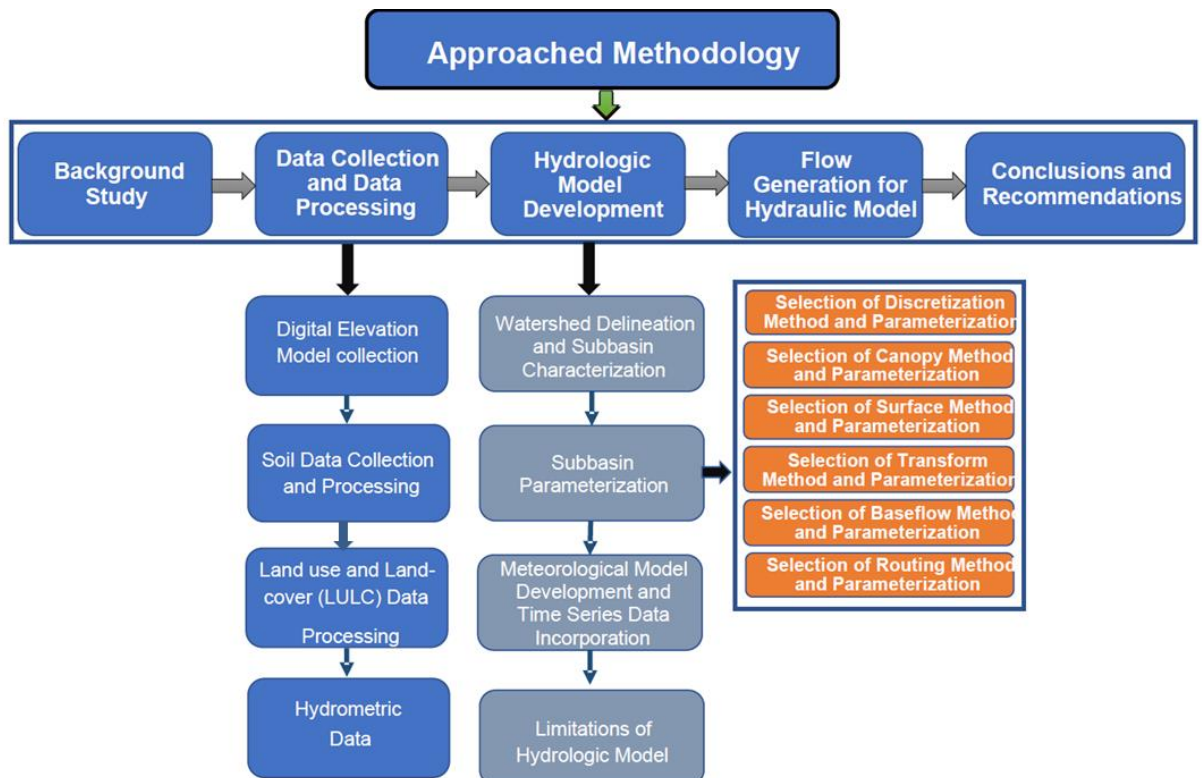


Figure 4.10: Flow chart of Approached Methodology for the Hydrologic Model in West Turag River Floodplain

4.5.4 Data Collection and Data Processing

The following types of data were collected and used primarily to develop hydrologic model:

1. Hydrometeorology of the study area (i.e., precipitation data)
2. Hydrogeology of the study area (i.e., Soil Data)
3. Land Use of the study area (i.e., Land-use and Land-cover Data)
4. Miscellaneous data (associated with the Canopy storage, surface storage, etc.)

A brief description of each of the data types is given in the following subsections.

4.5.4.1 Soil Data Collection and Processing

The soil data for the study area was collected from the “THE DIGITAL SOIL MAP OF THE WORLD” prepared by the FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (Version 3.6, completed January 2003). Across the study area, 2 units of soil layer were found. **Figure 4.11** illustrates the spatial distribution of the soil layers across the delineated watershed.

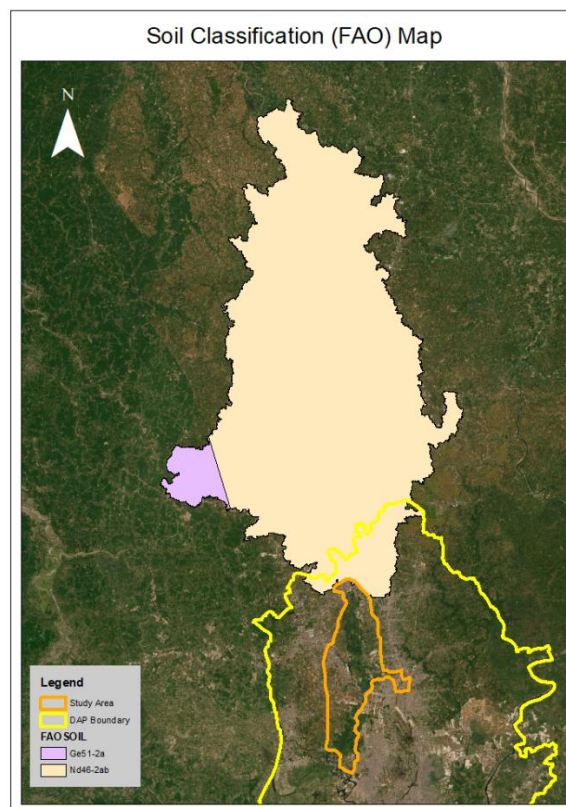


Figure 4.11: Spatial Distribution of the Soil Layer (Dominant) across the Delineated Watershed

4.5.4.2 Land-use and Land Cover (LULC) Data Collection and Processing

The Environmental Systems Research Institute (ESRI) global land use land cover (LULC) map, derived from ESA Sentinel-2 imagery at 10m resolution, was used as land-use and Land cover data. This LULC was developed by the Impact Observatory (IO) with the ESRI and in partnership with Microsoft AI for Earth. The dominant LULC type across the delineated watershed has been illustrated in Figure 4.12.

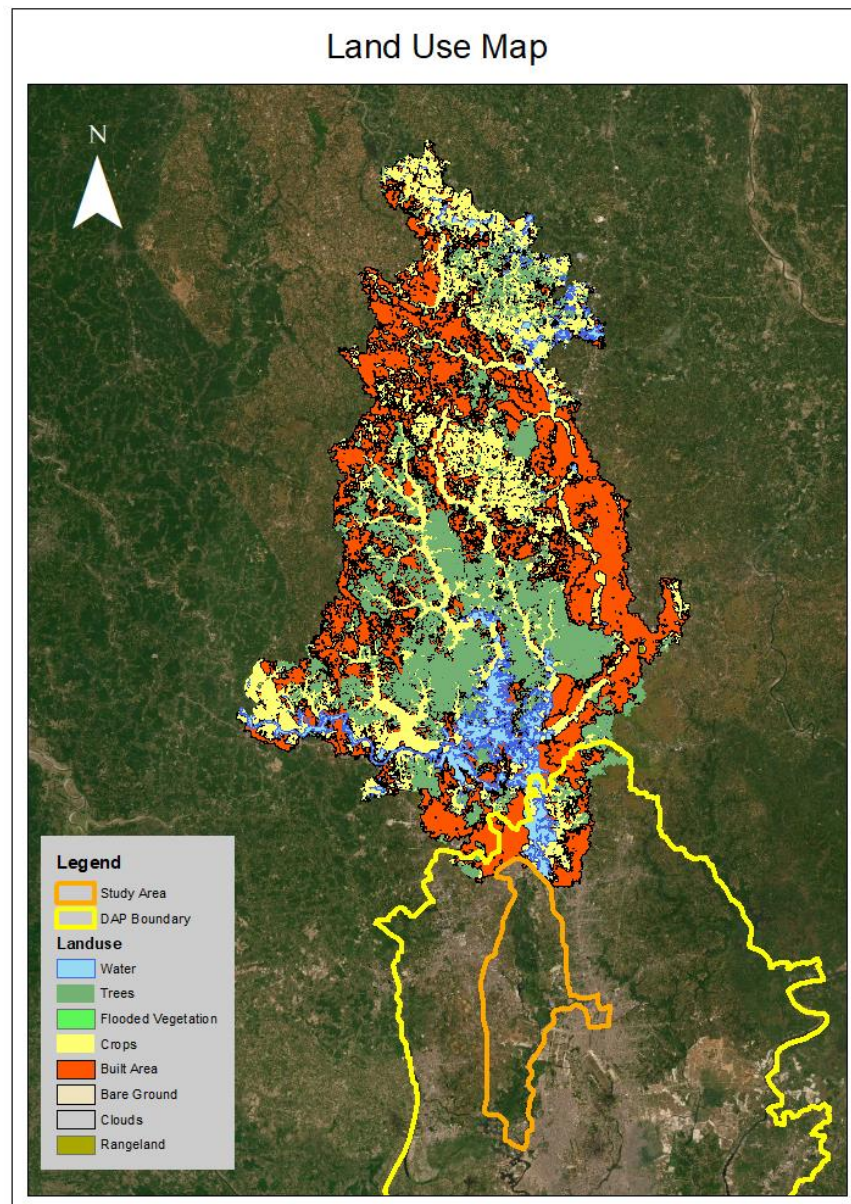


Figure 4.12: Land-use and Land-cover (LULC) map of the Delineated Watershed

Meteorological Data

The meteorological data used in this study has been collected from BMD (Bangladesh Meteorological Department). The daily time series data was collected from 1987 to 2019 for rainfall of Tangail Station. Daily Normal Maximum Temperature time series data was also collected from 1987 to 2019 from BMD. Also, Daily Maximum Temperature of 1988 for Tangail Station has been collected from BMD.

4.5.5 Hydrologic Model Development

4.5.5.1 Watershed Delineation

Purpose of this analysis is to facilitate Hydrodynamic Simulation for this study area by generating flows coming from Gollar Khal, Mokosh Bill, Beltoly, Shalda & Labandaha River sub-watersheds to Turag/Bangshi River. Tributary flows simulated by this model will be used as internal boundary condition of 2D Hydrodynamic Model.

To delineate the contributing catchment area of each tributaries of West Turag river, watershed has been delineated using HEC-GeoHMS, a pre-processing tool that is an extension of ArcGIS software. In this regard, cells which drain from a minimum drainage area of 4 km² were considered a part of the stream network. The delineated watershed has a total of 9 subbasins. Figure 4.13 illustrates the delineated watershed, reach network and subbasins.

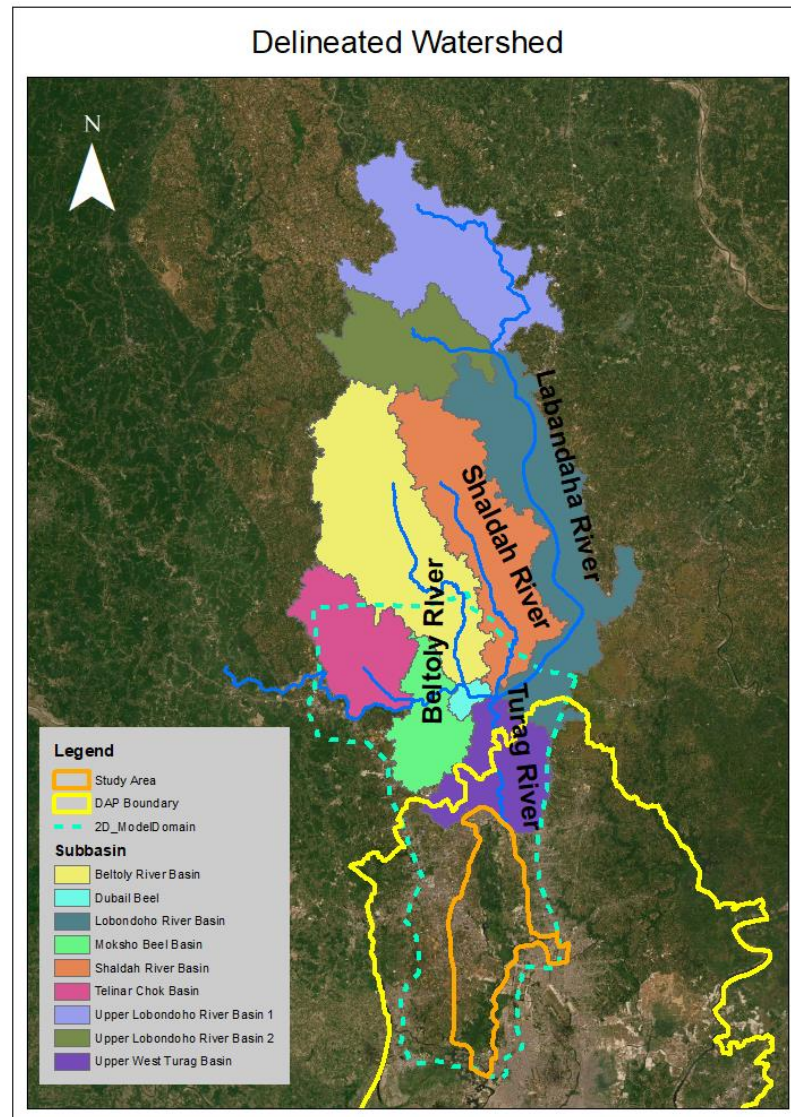


Figure 4.13: Delineated watershed, reach network, and subbasins

Description of delineated basins

Figure 4.13 illustrates delineated reaches and their contributing 9 nos. basin areas. West Turag is mainly fed by rainfall runoff from three (3) rivers naming Beltoly River, Shaldah River & Labadaha River. To observe rainfall runoff from these 3 rivers into Turag river, hydrologic analysis of these connected subbasins has been performed for this study. Purpose of this analysis is to use hydrological model simulated flow hydrograph for various return periods of these three (3) rivers at their respective outlet junction in Turag river as internal boundary condition of 2D hydrodynamic model.

Hydrologic element creation & Schematization of Basin Connection

After the delineated subbasin and reaches imported into HEC-HMS layout, hydrologic elements such as Junctions, Sinks & Outlet has been created and basin connection has been schematized in HEC-HMS. Figure 4.14 illustrates Basin connection and elements in HEC-HMS layout.

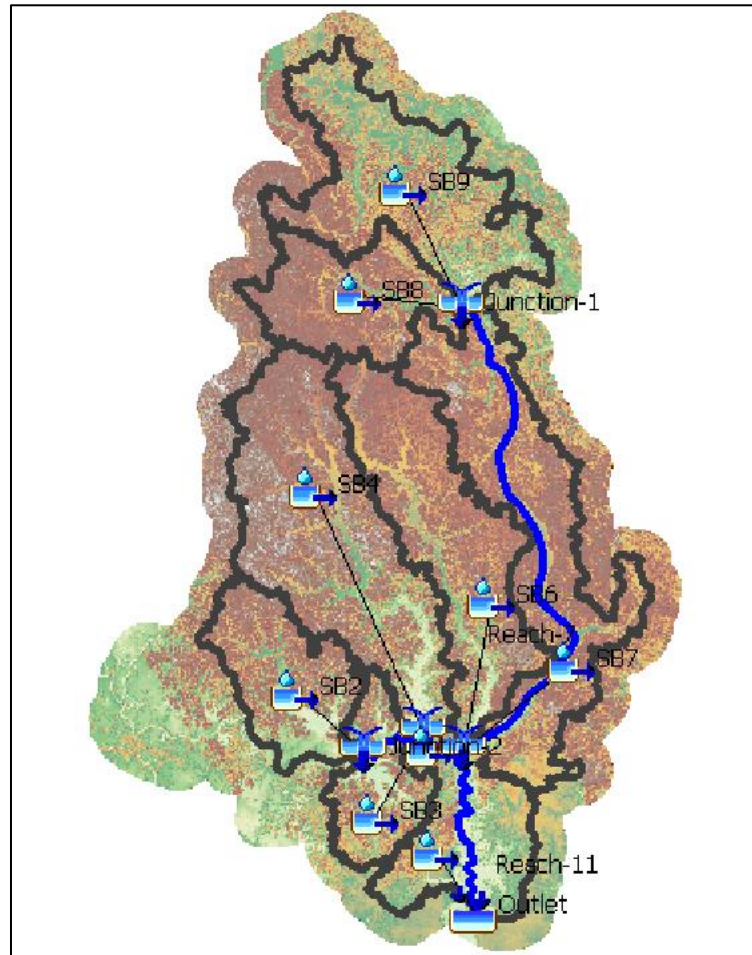


Figure 4.14: Basin connection and elements in HEC-HMS layout

In summary basin and element connection is as follows:

- i. SB2 Basin (Telina Basin) flows to Junction 2 on Turag River
- ii. Junction 2 flows through Reach 9 (Turag River) to Junction 3 where flow from Beltoli River Basin (SB4) & Moksho Beel Basin (SB3) meets
- iii. SB9 & SB8 (Upper Lobondaha River Basin 1 & 2) basin flows to Junction-1 and flows through Labandaha River (Reach 7) to Junction 4 and also SB7 Basin (Labandaha River Basin) flows to Junction-4
- iv. Junction 3 flows through Reach 4 (Turag River) to Junction 4 where flows

from Shaldah River (SB6), Labandaha River (Reach 7) & Dubail Beel Basin (SB5) meets

- v. Juntion 4 flows through Reach 11 (Turag River) to outlet carrying all flows from upstream and also Upper west Turag basin flow (SB10) meets at Outlet.

Subbasin & Reaches Characteristics

Different sub-basin and reach characteristics are described below. Table 4.7 lists the subbasin characteristics of the delineated sub-basins and Table 4.8 lists reach characteristics such as reach length and slope.

Longest Flow-path Length and Slope

The distance between the subbasin outlet to the most hydraulically remote point upstream within a subbasin has been identified as the longest flow-path length, and average slope of the flow path has been identified as the slope of the longest flow path.

10-85 Flow-path Length and Slope

The 10-85 flow paths is measured starting from the point ten percent of the total length of the longest flow path and ends at a point representing eighty-five percent of the total length. Both lengths and slopes of the 10-85 flow paths are provided in the subbasins. The 10-85 slope is often more representative of flow-path slopes as a whole within the watershed, as it is not affected by the more extreme upstream elevations.

Basin Slope (S)

In HEC-GeoHMS, basin slope represents the average slope of an entire subbasin. The algorithm scans each elevation raster value within the subbasin and computes its slope using the maximum scanned elevation difference for the surrounding eight neighbors. The algorithm considers the north, east, south, west, and diagonal neighbors equally. The basin slope output is an average of all the computed slope values in the subbasin.

Elongation Ratio (El)

The elongation ratio is a dimensionless ratio used to categorize the general shape of a subbasin. It is a ratio between the diameter of a circle with same area as the subbasin and the basin length. Elongation ratio values typically range from 0.2 to 1.0, with lower values representing elongated basins and values close to 1.0 representing circular basins. The equation that was used for determining the elongation ratio for each subbasin has been given below.

$$Elongation\ Ratio = \frac{2}{Basin\ Length} * \sqrt{\frac{Area\ of\ the\ Subbasin}{\pi}}$$

The length of the longest flow path is considered as the Basin Length in this equation.

Table 4.7: Sub-basin Characteristics

Name	Area (Sq.Km)	Basin Slope (m/m)	Longest Flow Path (km)	Longest Flow Path (m/m)	10-85 Flow- path Length (km)	10-85 Flow- path Slope (m/m)	Elongation (EL)
SB9	178.63	0.06959	47.74044	0.00040	35.80533	0.00017	0.31589
SB8	104.50	0.06373	27.47821	0.00079	20.60866	0.00060	0.41978
SB4	239.55	0.07852	46.44634	0.00051	34.83475	0.00039	0.37601
SB2	96.736	0.07441	22.68440	0.00078	17.01330	0.00048	0.48924
SB3	68.194	0.07719	21.08487	0.00102	15.81365	0.00059	0.44193
SB7	223.99	0.05519	35.01151	0.00050	26.25863	0.00028	0.48235
SB6	179.50	0.06423	43.44267	0.00041	32.58200	0.00038	0.34799
SB5	8.9992	0.07930	7.23142	0.00227	5.42356	0.00119	0.46809
SB10	93.249	0.04465	24.72659	0.00054	18.54494	0.00039	0.44067

Table 4.8: Reach Characteristics

Reach Name	Length (m)	Slope (m/m)
Reach-9	7.40652	0.00001
Reach-4	4.07350	0.00012
Reach-7	42.60080	0.00009
Reach-11	17.10891	0.00002
Reach-9	7.40652	0.00001
Reach-4	4.07350	0.00012
Reach-7	42.60080	0.00009

4.5.5.2 Sub-basin Parameterization

1. Selection of Canopy Method and Parameterization

Canopy Method: Simple Canopy method was selected for the basin model for simplification.

Initial Storage (%): Initial Storage of the canopy was assumed to be 10% for all the subbasins initially. However, usually during a sensitivity analysis, the catchment response for initial canopy storage of 0%, 5%, 10%, and 20% resulted in negligible variation to peak discharge. Thus, the value of 10% initial canopy storage is found to be justified.

Maximum Canopy Storage (mm): Initially, several literatures were reviewed to approximate the maximum canopy storage of the subbasins, and accordingly, a maximum canopy storage range of 1.5 mm to 2.5 mm was found to be appropriate for base simulation and sensitivity analysis. However, in order to get more refined maximum canopy storage values, Table 4.9 was generated, in accordance with the land-use and land-cover type (ESRI), based on adaptations of literature (Verbeiren, Nguyen, Wirion, & Batelaan, 2016). The ESRI LULC was used here for simplification purposes. Afterward, percentages of each LULC type in each of the subbasins were generated, and Weighted Average was taken to determine the composite maximum canopy storage for each subbasin.

Table 4.9: Maximum Canopy Storage Look-up values according with LULC Type

Land-use Land Cover Type	Maximum Canopy Storage
Water	0
Trees	2
Flooded Vegetation	1
Crops	2
Built Area	0.5
Bare Ground	0
Rangeland	1.5
Water	0

Crop-co-efficient: Crop co-efficient value of 1.0 was used for a simplified assumption.

Uptake Method: The simple uptake method was undertaken for the model. However, usually during a sensitivity analysis, it is observed that both the simple uptake method and tension reduction uptake method yield to the similar peak value (e.g., adaptation is not sensitive).

Evapotranspiration: Wet and Dry Periods

The selected parameter values of the Canopy Model have been illustrated in Table 4.10.

Table 4.10: Selected parameter values of the Canopy Model

Subbasin	Initial Storage (%)	Max Storage (mm)	Crop Coefficient	Evapotranspiration	Uptake Method
SB9	10	1.35	1.0	Wet and Dry Periods	Simple
SB8	10	1.99	1.0	Wet and Dry Periods	Simple
SB4	10	1.36	1.0	Wet and Dry Periods	Simple
SB2	10	1.22	1.0	Wet and Dry Periods	Simple
SB3	10	1.03	1.0	Wet and Dry Periods	Simple
SB7	10	1.00	1.0	Wet and Dry Periods	Simple
SB6	10	1.46	1.0	Wet and Dry Periods	Simple
SB5	10	0.64	1.0	Wet and Dry Periods	Simple
SB10	10	0.85	1.0	Wet and Dry Periods	Simple

2. Selection of Surface Method and Parameters

Method: Simple Surface method was selected for the basin model for simplification.

Initial Storage: Initial surface storage was assumed to be 10% for all the subbasins and was justified by the sensitivity analysis.

Maximum Surface Storage (%): In accordance with the findings of the “*Design and Construction of Urban Stormwater Management Systems*”, Table 4.11 was used as a look-up table for the maximum surface storage value in each land-use and land-cover type (ASCE, 1992). Afterward, the percentage of each LULC type in each of the subbasins was generated, and the weighted average was taken to determine the composite maximum surface storage for each subbasin. The ESRI LULC was used to calculate this parameter for simplification purposes.

Table 4.11: Maximum Surface Storage Look-up values in each LULC Type

Land-use Land Cover Type	Maximum Surface Storage (mm)
Water	0
Trees	7.5
Flooded Vegetation	4
Crops	7
Built Area	1.5
Bare Ground	2
Rangeland	5
Water	0

The selected parameter values of the Surface Model have been illustrated in Table 4.12.

Table 4.12: Selected parameter values of the Surface Model

Subbasin	Initial Storage (%)	Max Storage (mm)
SB9	10	4.75
SB8	10	7.03
SB4	10	4.88
SB2	10	4.28
SB3	10	3.65
SB7	10	3.43
SB6	10	5.20
SB5	10	2.27
SB10	10	2.88

3. Selection of Loss Method and Parameterization

Method: Deficit and Constant method was selected as the Loss method. This method is commonly used in continuous hydrologic models.

Initial Deficit (mm): The initial deficit is the initial condition for the method. It indicates the amount of water that is required to saturate the soil layer to the maximum storage. Initially, the values of the initial deficit for each subbasin have been estimated using the LULC type and Hydrologic Soil Group.

Maximum Storage (mm): The maximum storage specifies the amount of water the soil layer can hold, specified as a depth. Values of the parameter were determined based on the hydrologic soil group, land use, and hydrologic condition of the watershed. Land use and land cover types were reclassified into smaller groups of land use/cover. The Hydrologic Soil Group (A, B, C & D) of the watershed was combined with the reclassified land use/cover to create a composite land use-soil texture called Hydrologic Response Unit (HRU) map. This map and its index were applied to determine the following soil property parameters - maximum deficit. Table 4.13 was used as a maximum storage look-up value.

Table 4.13: Maximum Storage Look-up Value

Land use Land-cover (LULC) Type	LU Identifier	Hydrologic Soil Group (HSG)			
		A	B	C	D
		Maximum Storage			
Aggregate (bare soil and paved area combination)	HUM	190	195	200	210
Bare Grounds	AGP	85	130	175	210
Bare ground/Agricultural Area	AGC	85	130	175	210
Built Areas	RHS	85	130	175	210
Crops	AGC	85	130	175	210

Land use Land-cover (LULC) Type	LU Identifier	Hydrologic Soil Group (HSG)			
		A	B	C	D
		Maximum Storage			
Field	PRK	85	130	175	210
Field/Bare ground	PRK	85	130	175	210
Impervious Area with Bare Grounds and Plants	HUM	190	195	200	210
Impervious/Built Area	RHS	85	130	175	210
Meadow	FOR	85	130	175	210
Open Space with < 50% grass cover	AGP	85	130	175	210
Residential Houses	RES	85	130	175	210
Shrub	PRK	85	130	175	210
Streets and Roads	HWY	210	210	210	210
Trees	FOR	85	130	175	210
Trees and plants	FOR	85	130	175	210
Urban and Residential Areas	RHS	85	130	175	210
Water	WAT	195	200	210	220
Wetland	WET	110	150	185	210
Wetland (Canopy Dominated)	WET	110	150	185	210

Constant Rate (mm/hr): The constant rate defines the infiltration rate when the soil layer is saturated. Values of the constant rate were estimated using the hydraulic conductivity of each soil texture which was taken from USACE EM 1110-2-1417, 1982 paper authored by Rawls et al., after unit conversion. Table 4.14 was used as a constant rate look-up value.

Table 4.14: Constant Rate Look-up Value

Soil Texture	Texture Abbreviation	Hydraulic Conductivity (in/hr)	Hydraulic Conductivity(mm/hr)
C	Clay	0.01	0.254
CL	Clay Loam	0.04	1.016
FS	Fine Sand	3.775	95.885
FSL	Fine Sandy Loam	0.355	9.017
GL	Gravelly Loam	0.48	12.192
GLS	Gravelly Loamy Sand	2.91	73.914
GS	Gravelly Sand	5.505	139.827
GSL	Gravelly Sandy Loam	0.605	15.367
L	Loam	0.13	3.302
LCS	Loamy Clay Sand	0.73	18.542
LFS	Loamy Fine Sand	1.105	28.067
LS	Loamy Sand	1.18	29.972
LVFS	Loamy Very Fine Sand	0.855	21.717
ORG	Organic	0.01	0.254
S	Sand	4.64	117.856
SICL	Silty Clay Loam	0.04	1.016
SIL	Silty Loam	0.26	6.604
SL	Sandy Loam	0.43	10.922
VA	Variable	0.917826087	23.31278261
VAR	Variable	0.917826087	23.31278261
VFSL	Very Fine Sandy Loam	0.28	7.112

Imperviousness (%): The percentage of ‘Built Area’ in each of the subbasins was considered as imperviousness (%). The ESRI LULC built area was used in this regard for simplification.

The selected parameter values of the Loss Model have been illustrated in Table 4.15.

Table 4.15: Selected parameter values of the Loss Model

Subbasin	Initial Deficit (mm)	Max Storage (mm)	Constant Rate (mm/hr)	Impervious (%)
SB9	50	175.55	3.3	33.3
SB8	50	175.13	3.3	66.2
SB4	50	176.90	3.3	35.4
SB2	50	175.32	3.3	50.8
SB3	50	181.51	3.3	39.8
SB7	50	175.51	3.3	64.33
SB6	50	176.13	3.3	31.43
SB5	50	191.38	3.3	28.3
SB10	50	181.53	3.3	51.96

4. Selection of Transform Method and Parameterization

Method: Clark Unit Hydrograph

Time of Concentration: The time of concentration for the subbasins was determined using the Technical Release 55 (TR-55) method. The method has been described in a detailed manner in “*Urban Hydrology for Small Watersheds, TR-55*” (USDA, 1986). This method computes the time of concentration as the total travel time required for sheet flow, shallow concentrated flow, and open channel flow.

Travel time (T_t) between two points is determined using the following relationship:

$$T_t = \frac{l}{3600V} \dots\dots\dots(i)$$

T_t = Travel Time (hour)

l = Flow length (ft)

V = Average velocity (ft/s)

Again, the total time of concentration for each subbasin is determined from the following relation.

$$\text{Time of Concentration } (T_c) = \text{Travel Time for Sheet Flow} + \text{Travel Time for Shallow Concentrated Flow} + \text{Travel Time for Open Channel Flow} \dots\dots\dots(ii)$$

Determination of Travel Time for Sheet Flow

The travel time required for the sheet flow has been determined from the following equation.

$$T_{\text{sheet Flow}} = \frac{0.007 \times (nl)^{0.8}}{P_2^{0.5} \times S^{0.4}} \dots\dots\dots(iii)$$

Where,

$T_{\text{sheet Flow}}$ = Travel Time for Sheet Flow (hour)

n = Manning's Roughness Co – efficient

l = Flow Length of Sheet Flow (ft)

P_2 = 2 – year, 24 – hour rainfall (in)

S = Slope of Land Surface (ft/ft)

In this equation, Manning's roughness coefficient grid for sheet flow was generated by adapting specified values against each LULC type, as per the recommendation of the “Urban Hydrology for Small Watersheds, TR-55”.

Determination of Travel Time for Shallow Concentrated Flow

The shallow concentrated flow velocity was determined for the paved and unpaved area of each subbasin separately, using the following two equations, as per the recommendations from Appendix F of the document “Urban Hydrology for Small Watersheds, TR-55.”

$$V_{\text{unpaved}} = 16.1345 \times S^{0.5} \dots\dots\dots(iv)$$

and,

$$V_{\text{paved}} = 20.3282 \times S^{0.5} \dots\dots\dots(v)$$

Where, $V_{unpaved}$ = Velocity of flow at the Upvaed area

V_{paved} = Velocity of flow at the paved area

S = Watercourse Slope for the Shallow Concentrated Flow (ft/ft) ,

The value of S was determined from the HEC-GeoHMS processing.

Determination of Travel Time for Open Channel Flow

Manning's equation (Equation vi) is used for determining the open channel flow velocity. Afterward, using equation (i), the travel time for the open channel flow was determined.

$$V_{OCF} = \frac{1.49}{n} \times R^{\frac{2}{3}} \times S^{0.5} \dots\dots\dots (vi)$$

Where,

V_{OCF} = Open Channle Flow Velocity (ft/ s)

n = Manning's Roughness Co – efficient

R = Hydraulic radius (ft)

S = Channel Slope (ft/ft)

Computation of Travel Time according to TR-55 method is illustrated in the table 4.16.

Table 4.16: Computation of Travel Time according to TR-55 method

Subbasin	SB9	SB8	SB4	SB2	SB3	SB7	SB6	SB5	SB10
Sheet Flow Characteristics									
Manning's Roughness Coefficient	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Flow Length (ft)	99.99 99	99.99 99	99.99 99	100.0 001	100.0 001	100.0 001	100	100	100.0 001
Two-Year 24-hour Rainfall (in)	4.895 27823 4	4.895 27823 4	4.895 27823 4	4.895 27823 4	4.895 27823 4	4.895 27823 4	4.895 27823 4	4.895 27823 4	4.895 27823 4
Land Slope (ft/ft)	0.090 3	0.037 8	0.030 3	0.072	0.069 5	0.036 9	0.022 4	0.159	0.058 8
Sheet Flow Tt (hr)	0.11	0.15	0.17	0.12	0.12	0.16	0.19	0.09	0.13
Shallow Concentrated Flow Characteristics									

Surface Description (1 - unpaved, 2 - paved)	1	1	1	1	1	1	1	1	1
Flow Length (ft)	51341 .7974	36554 .8811	56939 .9889	33665 .6449	50347 .95	39612 .2571	13773 .891	43882 .8953	64089 .7089
Watercourse Slope (ft/ft)	0.000 9	0.001 4	0.001 2	0.001 7	0.001 1	0.000 8	0.003 6	0.000 7	0.000 6
Average Velocity - computed (ft/s)	0.48	0.60	0.56	0.67	0.54	0.46	0.97	0.43	0.40
Shallow Concentrated Flow Tt (hr)	29.46	16.82	28.30	14.06	26.14	24.11	3.95	28.56	45.05
Channel Flow Characteristics									
Cross-sectional Flow Area (ft ²)	20	20	20	20	20	20	20	20	20
Wetted Perimeter (ft)	20	20	20	20	20	20	20	20	20
Hydraulic Radius - computed (ft)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Channel Slope (ft/ft)	0.000 5	0.000 2	0.000 4	0.000 4	0.000 5	0.000 4	0.000 2	0.000 4	0.000 2
Manning's Roughness Coefficient	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Average Velocity - computed (ft/s)	1.11	0.70	0.99	0.99	1.11	0.99	0.70	0.99	0.70
Flow Length (ft)	32534 .9404	12244 8.473 1	18461 .1867	68173 .2079	21051 .1042	89923 .2511	9968. 2744	94307 .4015	86045 .3139
Channel Flow Tt (hr)	8.14	48.43	5.16	19.06	5.27	25.15	3.94	26.37	34.03
Watershed Time of travel (hr)	37.71	65.40	33.63	33.24	31.52	49.41	8.08	55.01	79.20

Storage Co-efficient:

HEC-HMS refers to the 'Dam Safety Study in Pennsylvania' and then suggests estimating the storage coefficient (R) using the relation $R / (T_c + R) = 0.65$. However, since this synthetic relationship can vary based on the watershed characteristics, initial

consideration was made considering $R / (T_c + R) = \text{Constant } (x)$. The relationship can be rewritten as follows:

$$R = \frac{x}{1-x} \times T_c \dots\dots\dots(vii)$$

The selected parameter values of the Transform Model have been illustrated in Table 4.17.

Table 4.17: Selected parameter values of the Transform Model

Subbasin	Time of Concentration (HR)	Storage Co-efficient (HR)	Time Area Method
SB9	37.71	70.03	Default
SB8	65.40	121.46	Default
SB4	33.63	62.46	Default
SB2	33.24	61.73	Default
SB3	31.52	58.54	Default
SB7	49.41	91.77	Default
SB6	8.08	15.01	Default
SB5	55.01	102.17	Default
SB10	79.20	147.1	Default

5. Selection of Routing Method and Parameterization

Method: The Muskingum-Cunge routing method was selected.

Initial Type: Discharge/Inflow.

Length and Slope: Derived from the HEC-GeoHMS processing.

Manning's Roughness Co-efficient (n): The average value of channel roughness ($n = 0.025$) was considered across all the reaches for simplification.

Index Method and Index Flow: The flow index method was selected. The index flow was approximated as per the recommendations of the HEC-HMS manual, and the approximation was justified after sensitivity analysis.

Channel Shape, Width, and Side Slope: Trapezoidal channel was considered for estimation. The width and side slope were approximated from previous experiences and model DTM (Digital Terrain Model) analysis. However, each adaptation was justified following sensitivity analysis.

The selected parameter values of the Routing Model have been illustrated in Table 4.18.

Table 4.18: Selected parameter values of the Routing Model

Reach	Initial Type	Length (m)	Slope (m/m)	Manning's n	Space-Time Method	Index Method	Index Flow (m ³ /s)	Shape	Width (m)	Side Slope (xH:1V)
Reach-9	Discharge = Inflow	7406.52	0.00002	0.025	Auto DX Auto DT	Flow	60	Trapezoid	50	5
Reach-4	Discharge = Inflow	4073.50	0.00012	0.025	Auto DX Auto DT	Flow	60	Trapezoid	50	5
Reach-7	Discharge = Inflow	42600.80	0.00010	0.025	Auto DX Auto DT	Flow	60	Trapezoid	50	5
Reach-11	Discharge = Inflow	17108.91	0.00001	0.025	Auto DX Auto DT	Flow	60	Trapezoid	50	5

6. Selection of Baseflow Method and Parameterization

Method: Linear Reservoir

The subbasins in the continuous model also include a “Baseflow” groundwater component. The model applies a linear reservoir baseflow method for simulating the groundwater flow. The linear reservoir method with two layers computes the

recession of baseflow after a storm event. Infiltration computed by the loss method is connected as the inflow to the linear reservoir. In the continuous model, the initial baseflow of each basin was specified as a volume per area per time. To perform baseflow computation, parameters including groundwater storage coefficient and the number of groundwater reservoir need to be specified. The groundwater storage coefficient is the time constant for the linear reservoir in each layer. The number of groundwater storage reservoirs controls the number of sequential reservoirs that the groundwater is routing through. It affects any attenuation of groundwater.

The selected parameter values of the Base flow model have been illustrated in Table 4.19.

Table 4.19: Selected parameter values of the Base flow model

Sub basin	Number of Layers	Initial Type	GW 1 Flow Type	GW 1 Initial (m ³ /s km ²)	GW1 Fraction	GW1 Coefficient (hr)	GW1 Reservoirs	GW2 Flow Type	GW 2 Initial (m ³ /s km ²)	GW2 Fraction	GW2 Coefficient (hr)	GW2 Reservoirs
SB9	2	Discharge Per Area	Base flow	0	0.5	113.13	1	Base flow	0.015	0.5	377.1	1
SB8	2	Discharge Per Area	Base flow	0	0.5	196.2	1	Base flow	0.015	0.5	654	1
SB4	2	Discharge Per Area	Base flow	0	0.5	100.89	1	Base flow	0.015	0.5	336.3	1
SB2	2	Discharge Per Area	Base flow	0	0.5	99.72	1	Base flow	0.015	0.5	332.4	1
SB3	2	Discharge Per Area	Base flow	0	0.5	94.56	1	Base flow	0.015	0.5	315.2	1
SB7	2	Discharge	Base	0	0.5	148.23	1	Base	0.015	0.5	494.1	1

		Per Area	flow					flow				
SB6	2	Disch arge Per Area	Base flow	0	0.5	24.24	1	Base flow	0.015	0.5	80.8	1
SB5	2	Disch arge Per Area	Base flow	0	0.5	165.03	1	Base flow	0.015	0.5	550.1	1
SB10	2	Disch arge Per Area	Base flow	0	0.5	237.6	1	Base flow	0.015	0.5	792	1

4.5.6 Meteorological Model Development and Time-Series Data Incorporation

4.5.6.1 Precipitation

Daily cumulative rainfall depth data was collected from Tangail station of Bangladesh Meteorological Department (BMD). Frequency analysis (Gumbel Method) of Daily rainfall data of Tangail station (1987-2019) was performed to determine 2.33- and 100-year return period flow. Also, Daily cumulative rainfall depth data of 1988 has been collected to generated flows. Figure 4.15, 4.16 and 4.17 illustrates the adapted annual rainfall depths for 2.33- year return period, 100-year return period and year 1988.

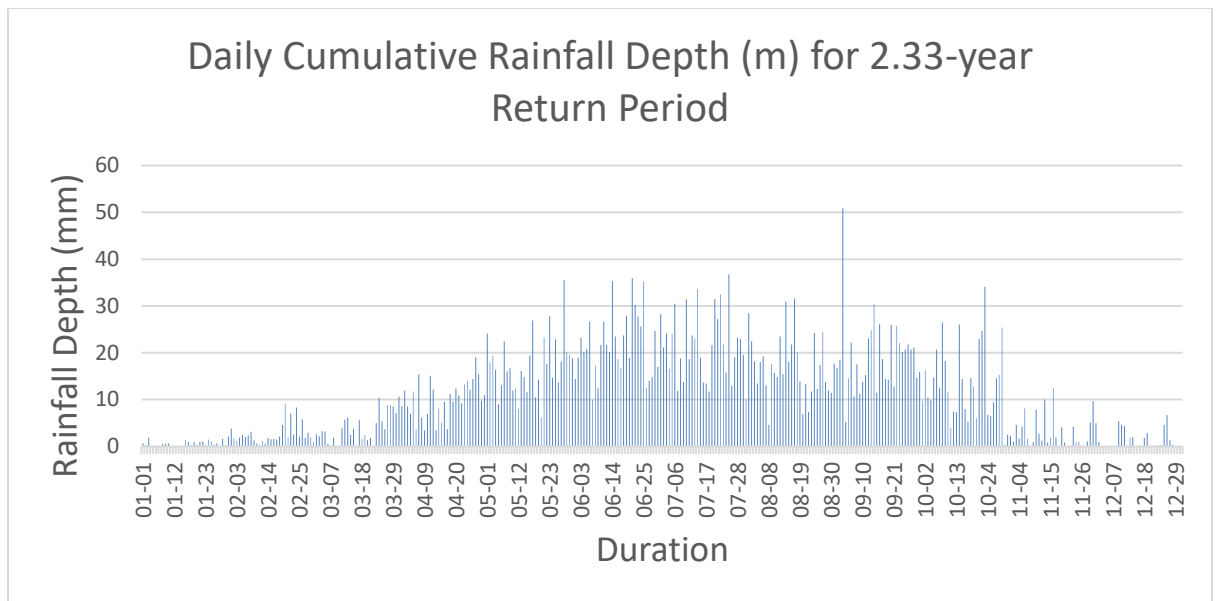


Figure 4.15: Daily cumulative Rainfall Depth (m) for 2.33-year Return Period

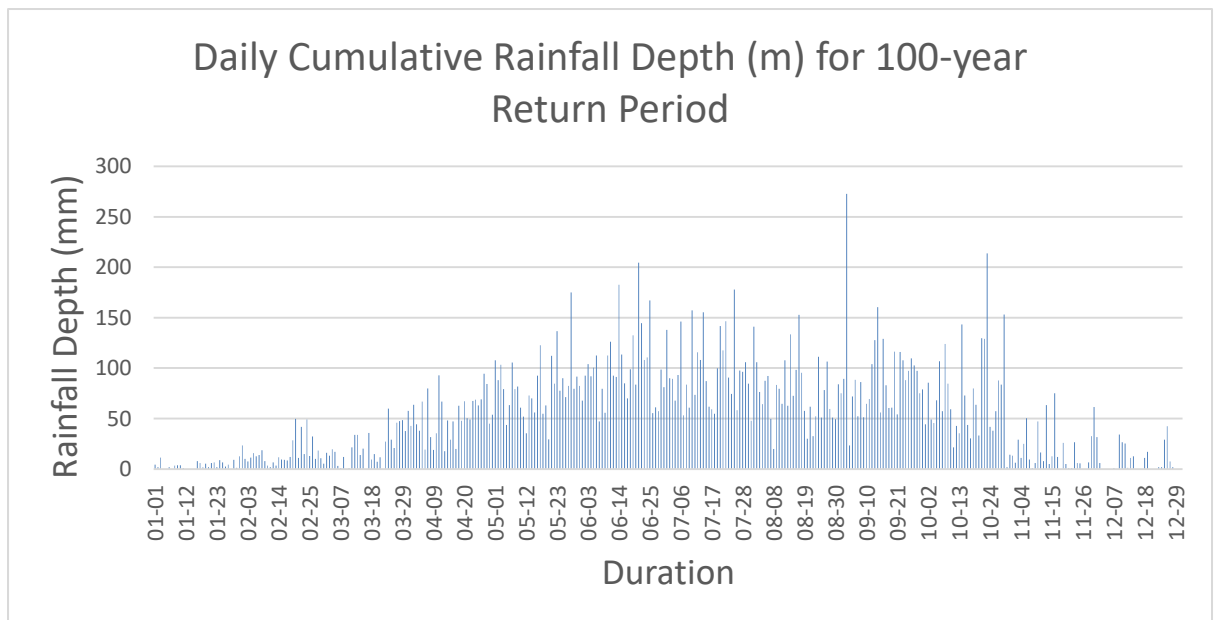


Figure 4.16: Daily cumulative Rainfall Depth (m) for 100-year Return Period

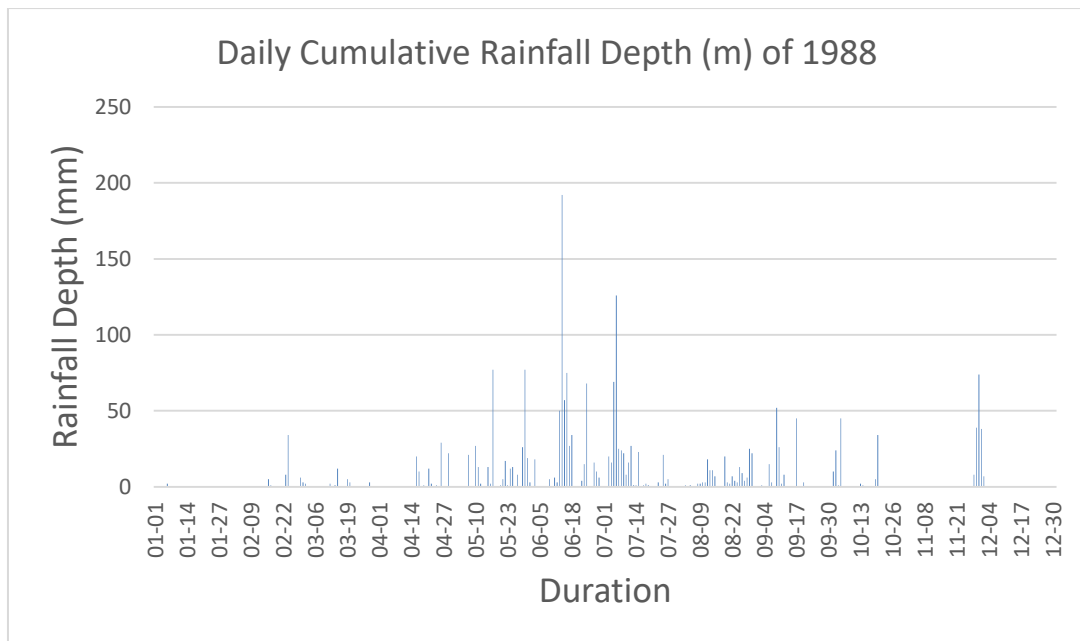


Figure 4.17: Daily cumulative Rainfall Depth (m) of 1988

4.5.6.2 Air Temperature

Daily Normal Maximum Temperature data (Year) of Tangail BMD Data has been collected and used for the meteorological model. Also daily maximum temperature for 1988 has also been used.

Figure 4.18 and 4.19 illustrates the daily normal maximum temperature data and daily maximum temperature over 1988 data.

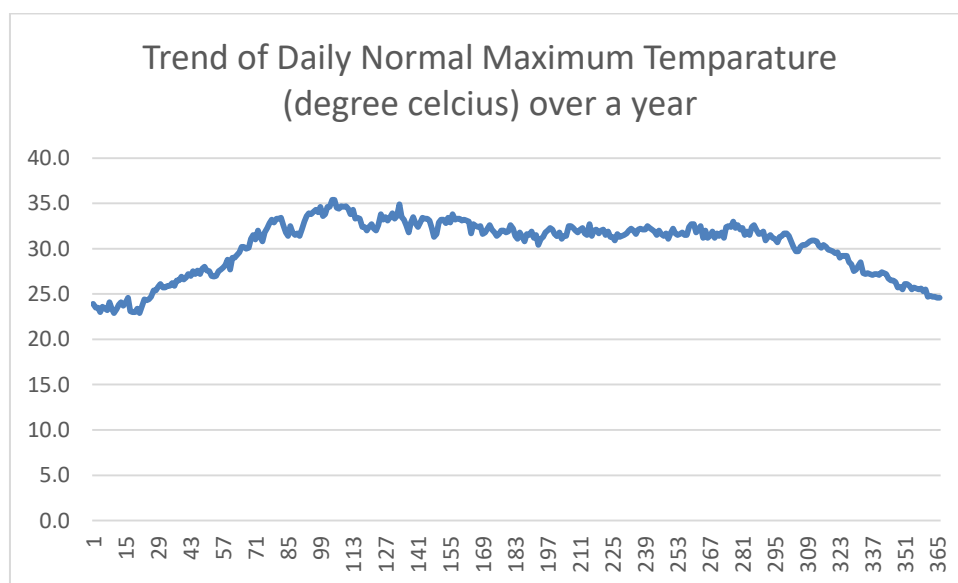


Figure 4.18: Daily normal maximum temperature

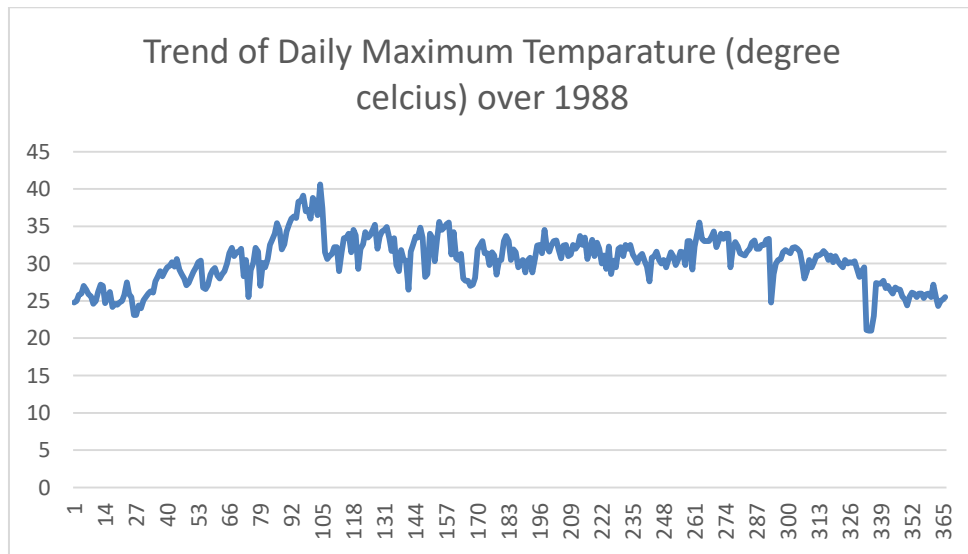


Figure 4.19: Daily maximum temperature over 1988

4.5.6.3 Selection of Evapotranspiration Method

Method: Hamon method was used to incorporate Evapotranspiration into the model. For this purpose, daily temperature data was incorporated into time series data for a year. For any continuous hydrologic model using HEC-HMS, selecting the appropriate evapotranspiration method is crucial. As part of this study, other methods like Annual Evapotranspiration, Hargreaves Method, Priestley Taylor method, Penman Monteith Method, Monthly average methods was explored and due to limitations of meteorological data for this basin, Hamon method was selected because this method is a temperature-only method. It Estimates potential evapotranspiration (PET) based on temperature data. It is simple and suitable for areas with limited data and does not require additional meteorological inputs. Accordingly, Hamon coefficient (mm/g/m³) has been calculated for each basin and for this model, it has been calculated 0.1651.

4.5.7 Model Simulation & Flow Generation for Hydraulic Model

The continuous hydrologic model has been simulated with 2.33- and 100-year return period daily rainfall data. Simulation resulted in flow hydrographs in Subbasin, Channels, Junctions and Outlet which has been used as External/Internal boundary condition of 2D Hydrodynamic Model simulated for 2.33- and 100-year return period scenarios. Figure 4.20 illustrates the Graphical User Interface of HEC-HMS Simulation.

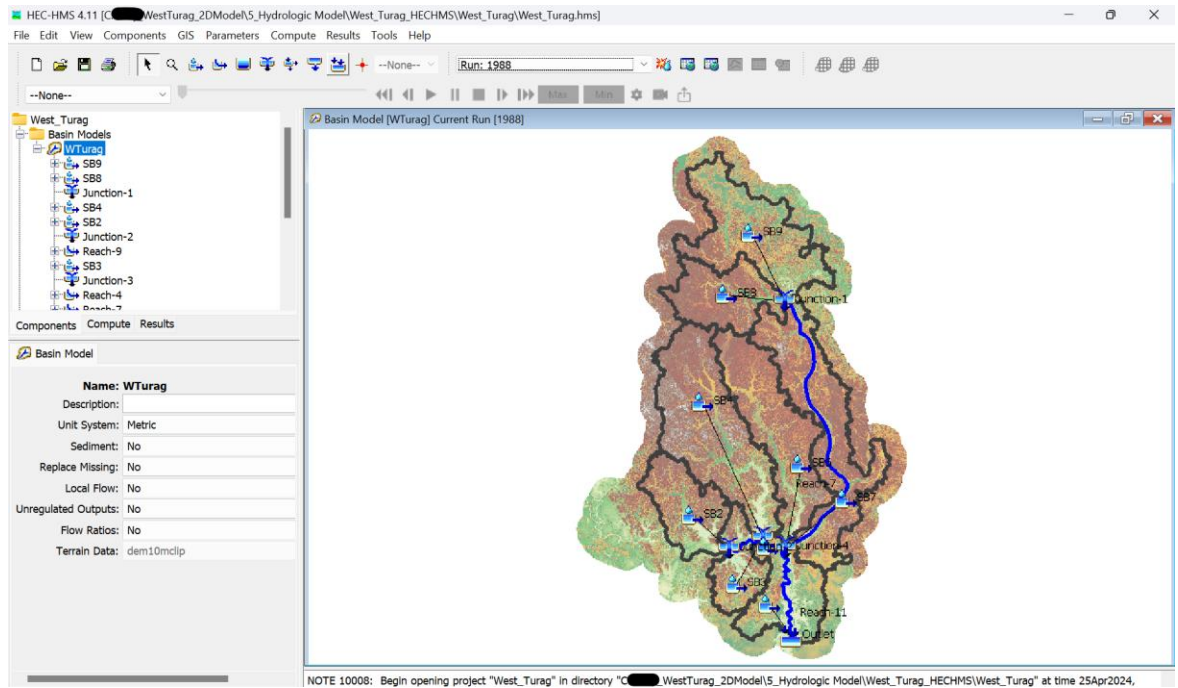


Figure 4.20: Graphical User Interface of HEC-HMS Simulation

Hydrologic Model Output

A 2D Hydrodynamic Model is being developed using HEC-RAS software to generate different flood flow zone maps. The HEC-RAS model makes use of discharge as an upstream boundary condition. The HEC-HMS model has been used to generate flows for several inlets/junctions within the watershed at this stage. Figure 4.21 illustrates the locations of identified inlets and junctions for the flow generation.

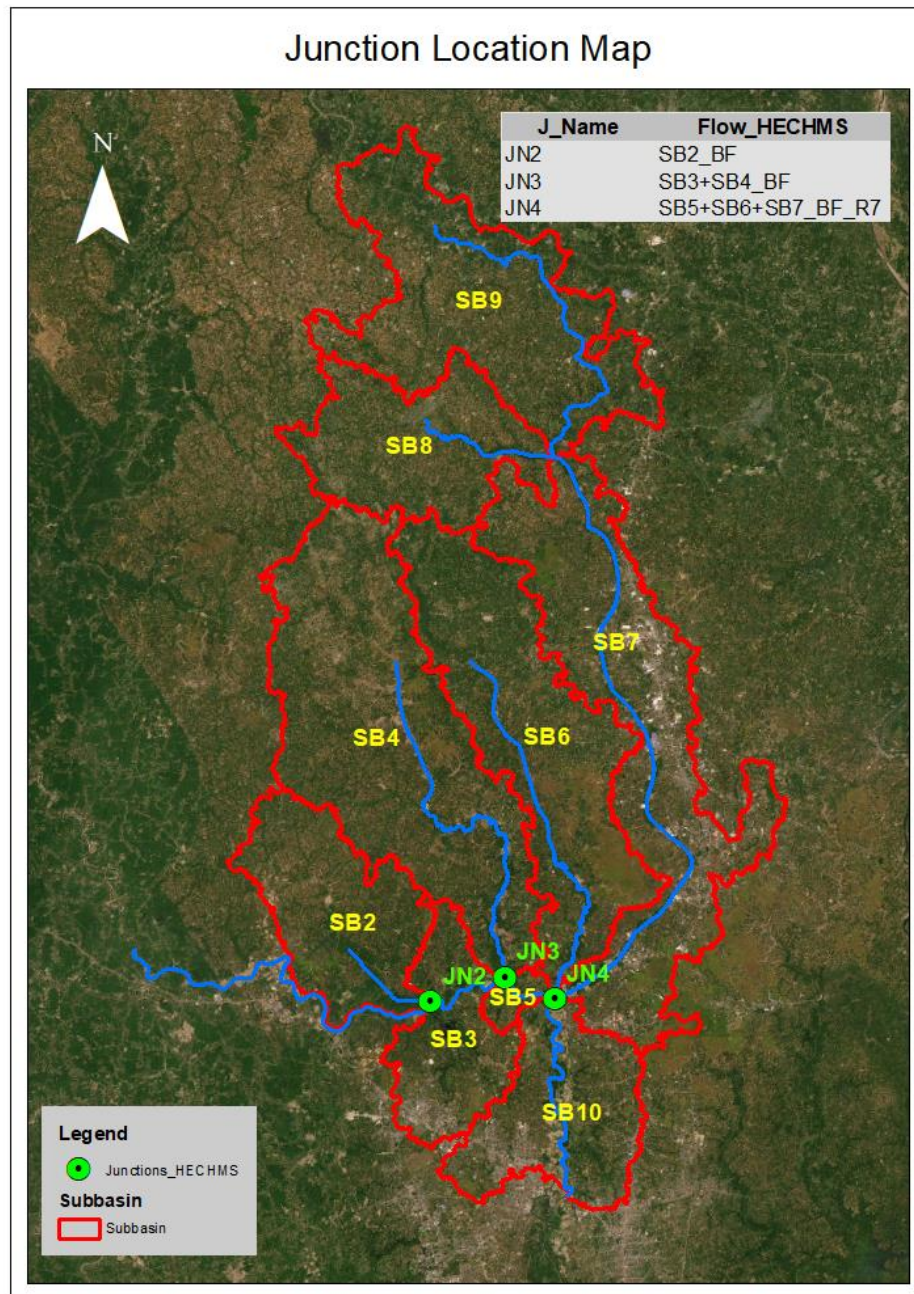


Figure 4.21: The locations of identified inlets and junctions for the flow generation

The value of the generated flow (cumec) at each inlet and junction has been demonstrated in following graphs from *Figure 4.22 to 4.30*:

Junction-2

Flow Hydrograph at JN2 (Flow from SB2) from 2.33-year Return Period Simulation

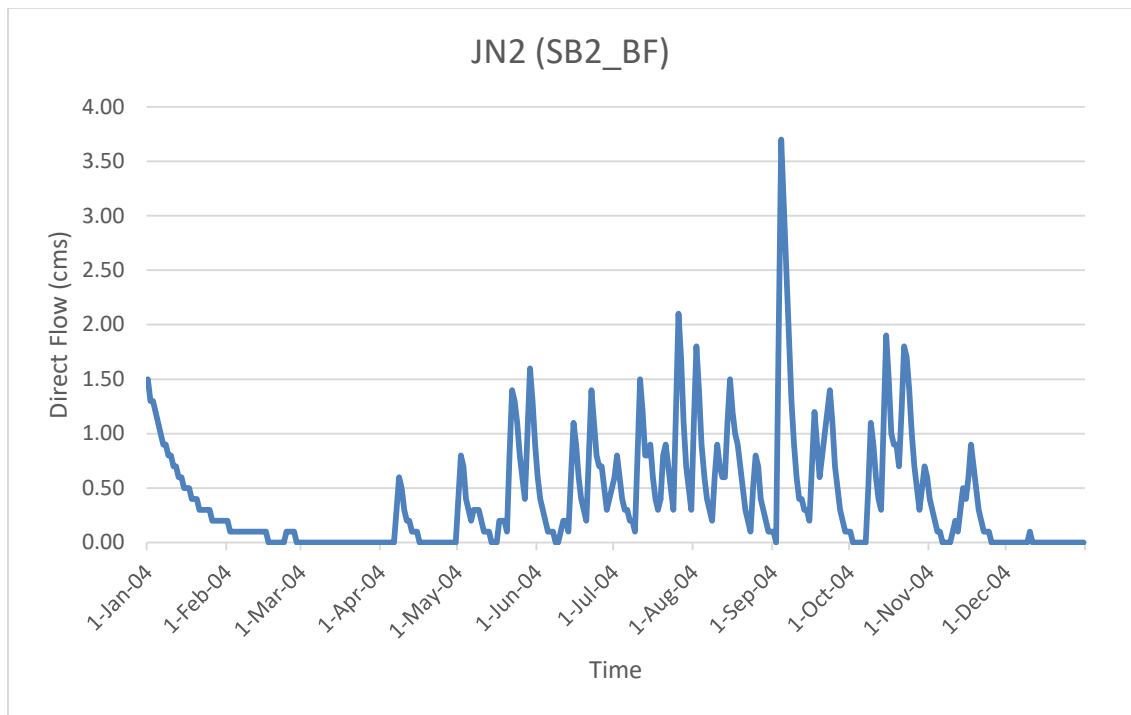


Figure 4.22: Flow Hydrograph at JN2 (Flow from SB2) from 2.33-year RP Simulation

Flow Hydrograph at JN2 (Flow from SB2) from 100-year Return Period Simulation

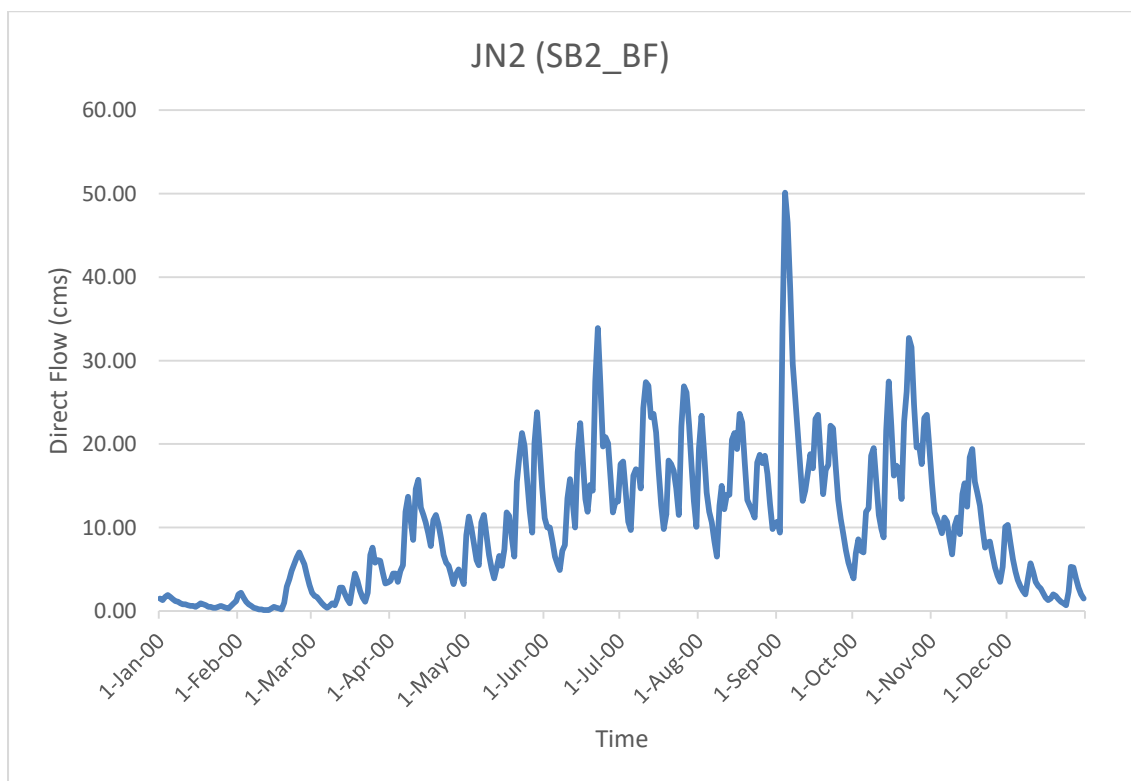


Figure 4.23: Flow Hydrograph at JN2 (Flow from SB2) from 100-year RP Simulation

Flow Hydrograph at JN2 (Flow from SB2) from 1988 Simulation

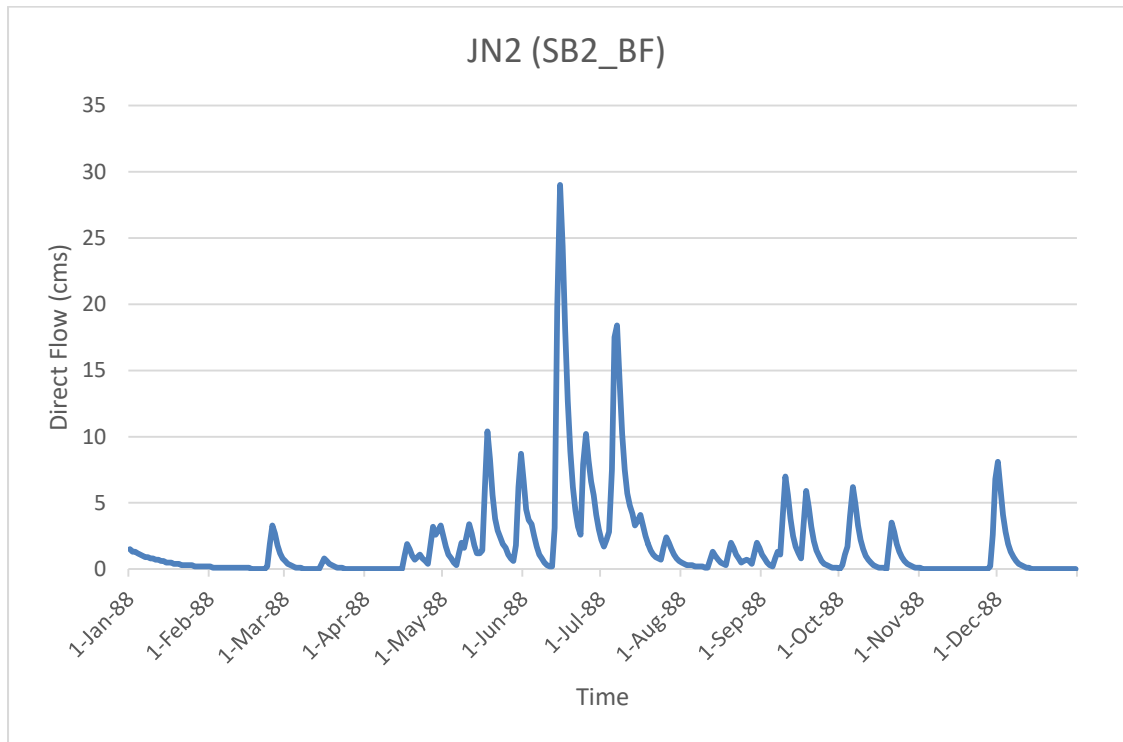


Figure 4.24: Flow Hydrograph at JN2 (Flow from SB2) from 1988 Simulation

Junction 3

Flow Hydrograph at JN3 (Flow from SB3 & SB4) from 2.33-year Return Period Simulation

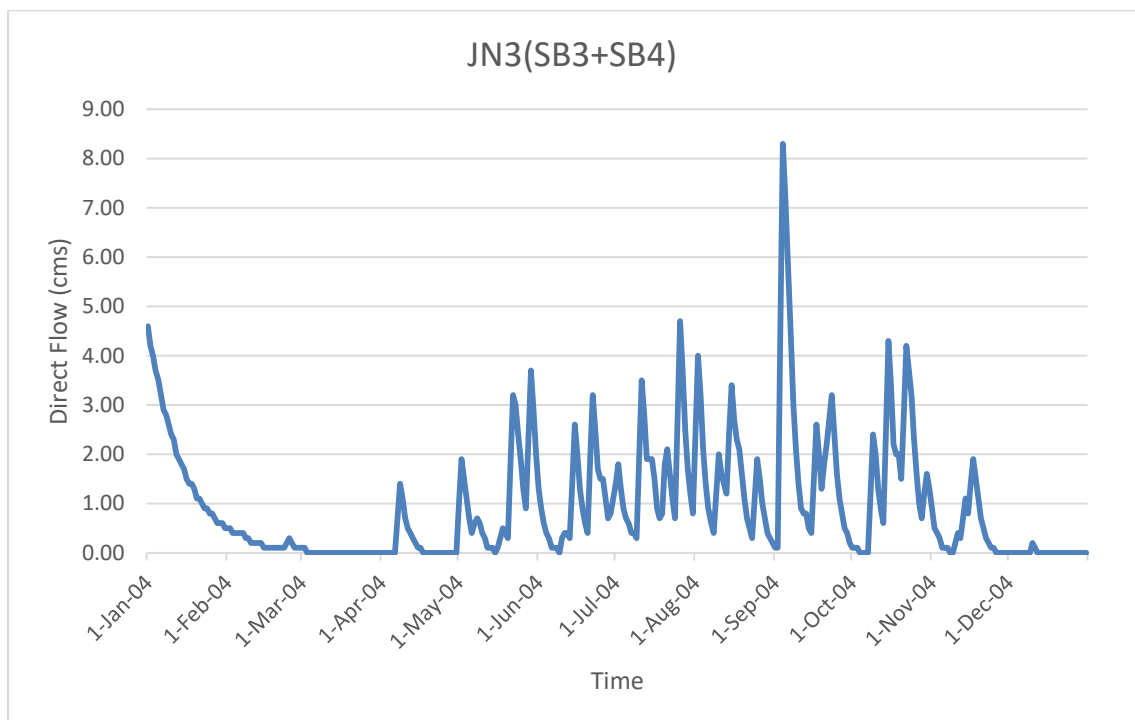


Figure 4.25: Flow Hydrograph at JN3 (Flow from SB3 & SB4) from 2.33-year R Simulation

Flow Hydrograph at JN3 (Flow from SB3 & SB4) from 100-year Return Period Simulation

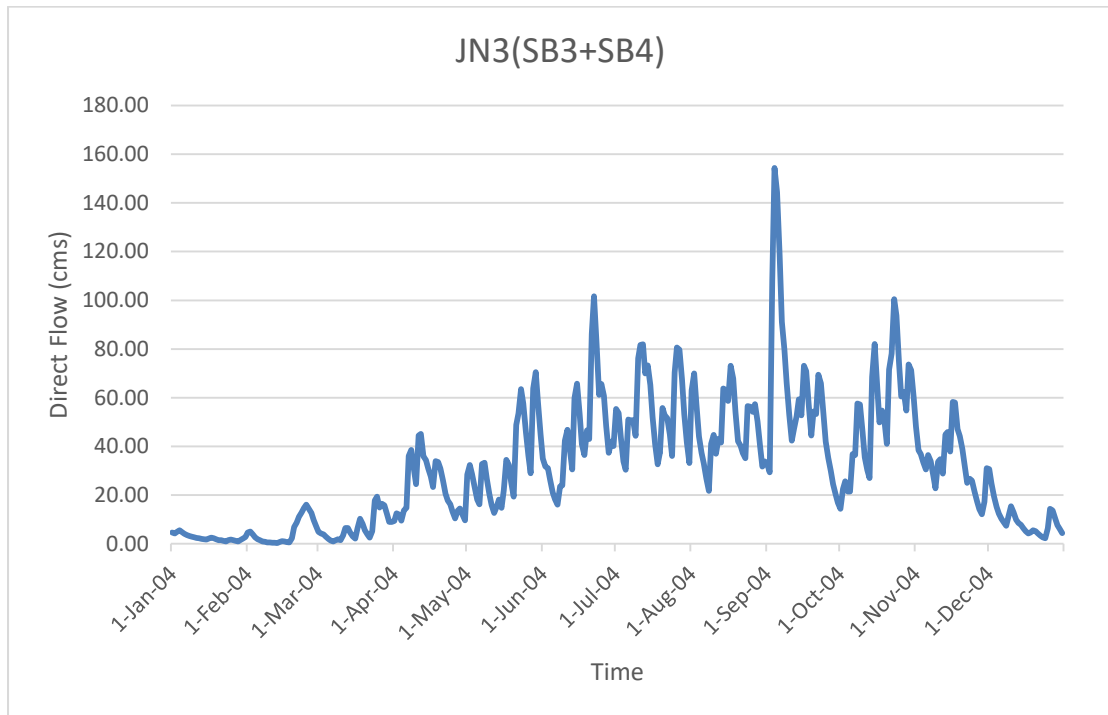


Figure 4.26: Flow Hydrograph at JN3 (Flow from SB3 & SB4) from 100-year Return Period Simulation

Flow Hydrograph at JN3 (Flow from SB3 & SB4) for 1988 Simulation

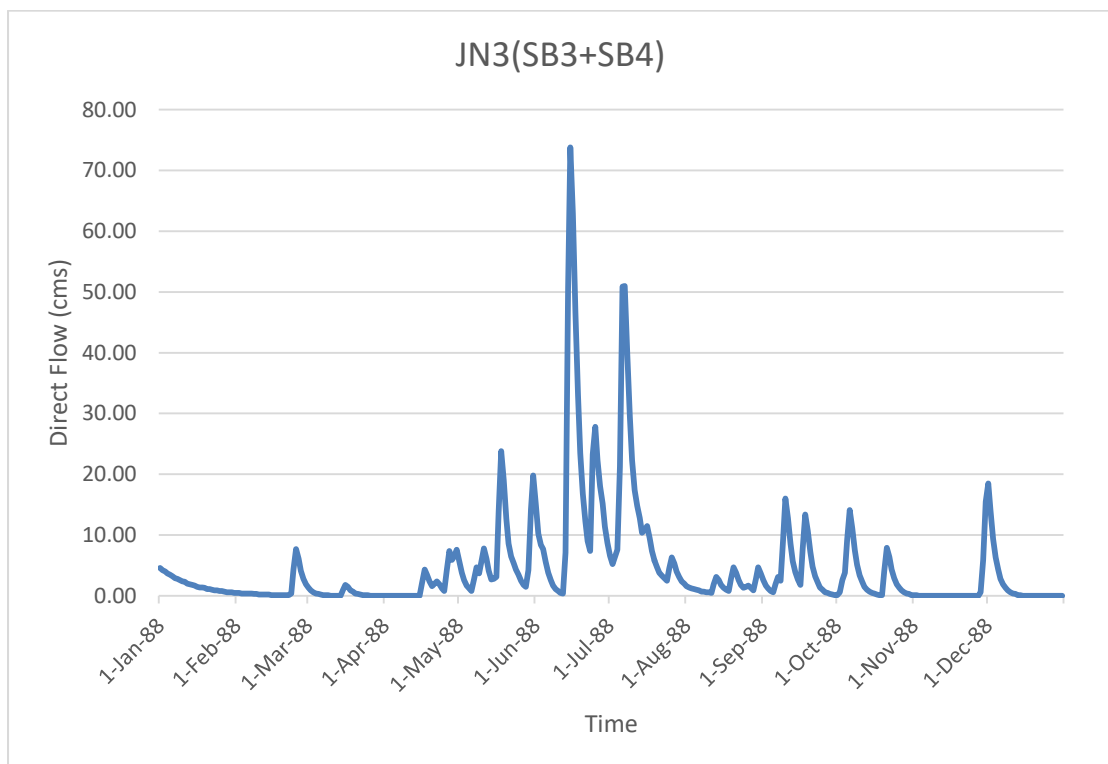


Figure 4.27: Flow Hydrograph at JN3 (Flow from SB3 & SB4) for 1988 Simulation

Junction 4

Flow Hydrograph at JN4 (Flow from SB5, SB6, SB7 & Reach 7) from 2.33-year Return Period Simulation

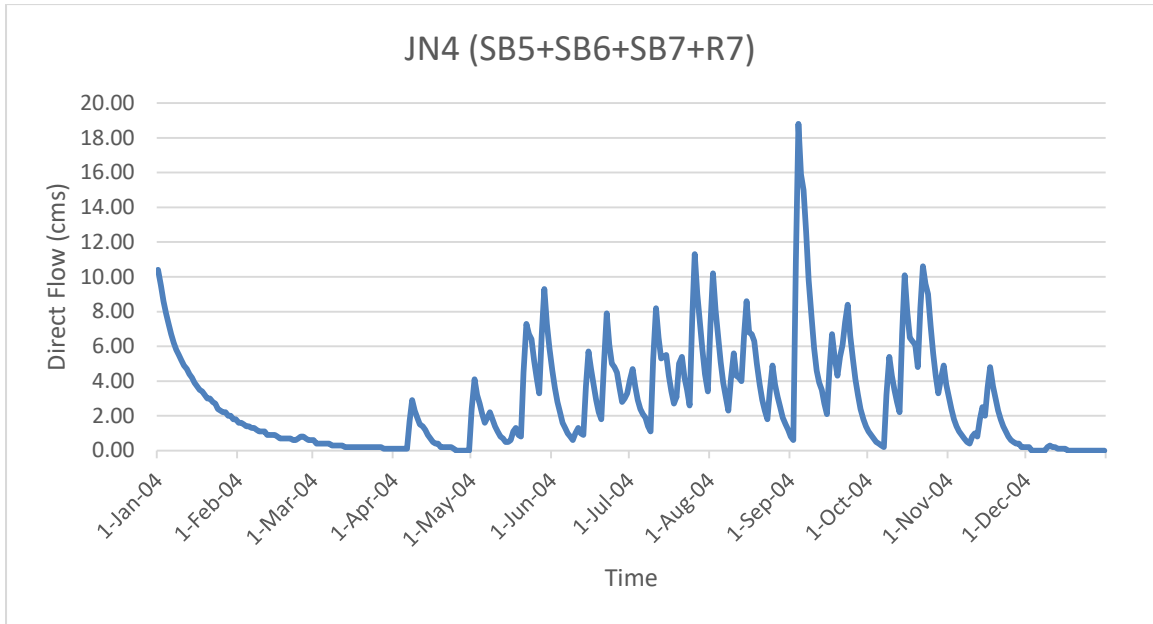


Figure 4.28: Flow Hydrograph at JN4 (Flow from SB5, SB6, SB7 & Reach 7) from 2.33-year Return Period Simulation

Flow Hydrograph at JN4 (Flow from SB5, SB6, SB7 & Reach 7) from 100-year Return Period Simulation

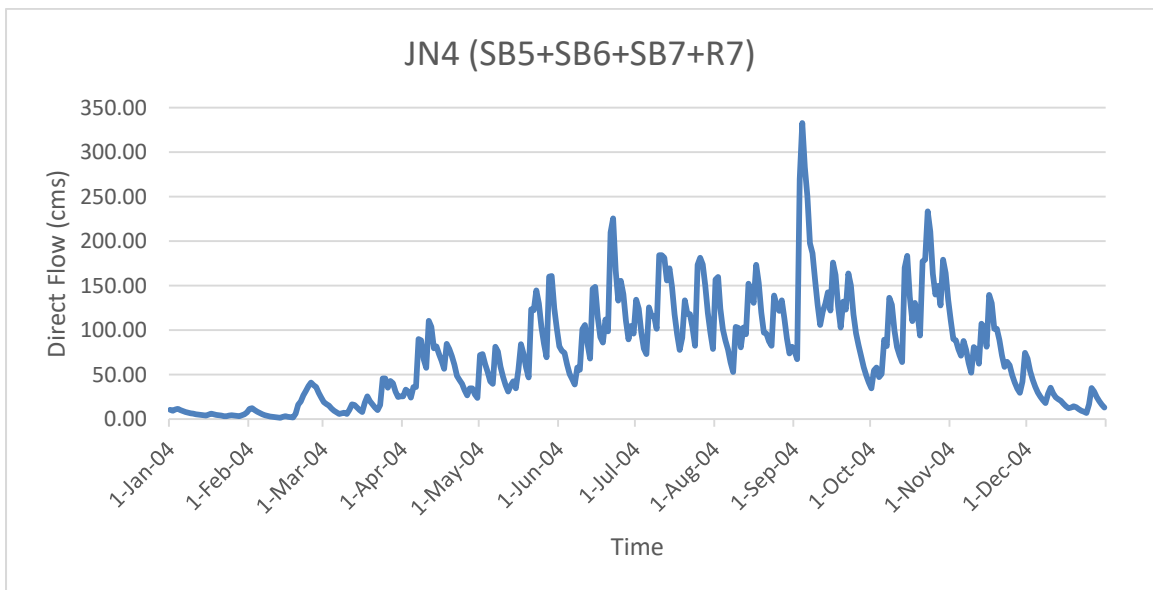


Figure 4.29: Flow Hydrograph at JN4 (Flow from SB5, SB6, SB7 & Reach 7) from 100-year Return Period Simulation

Flow Hydrograph at JN4 (Flow from SB5, SB6, SB7 & Reach 7) from 1988 Simulation

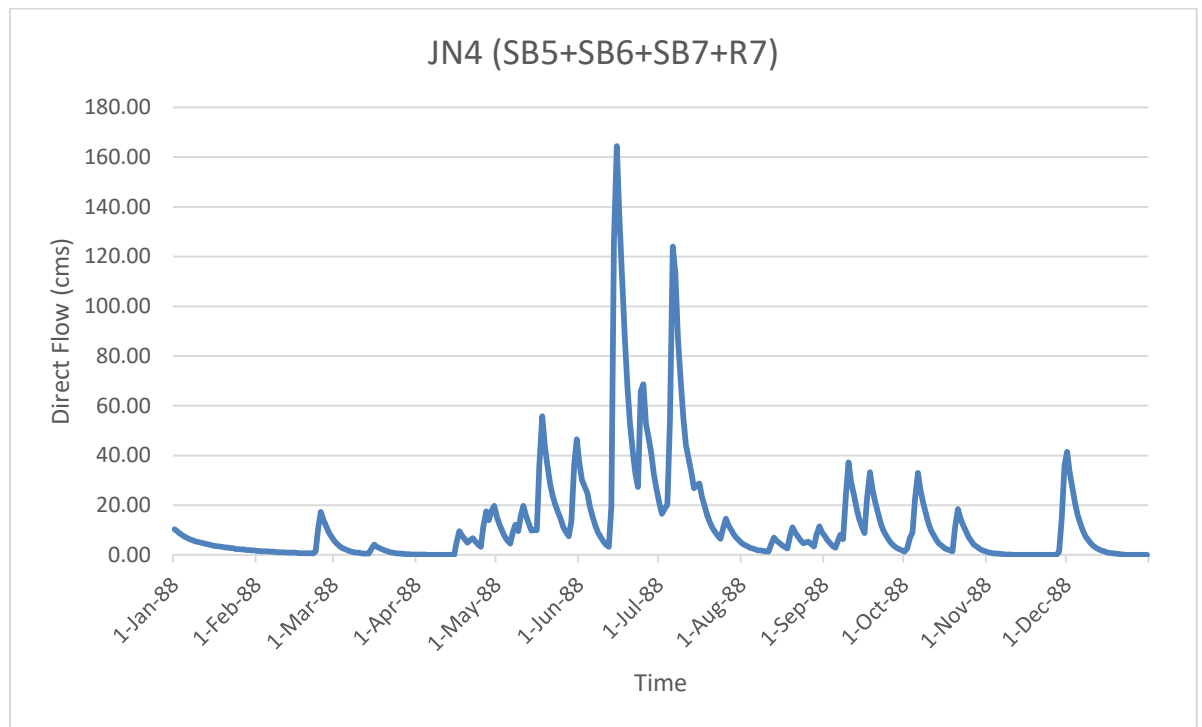


Figure 4.30: Flow Hydrograph at JN4 (Flow from SB5, SB6, SB7 & Reach 7) from 1988 Simulation

4.6 HYDRODYNAMIC ANALYSIS

4.6.1 Model Selection

Overview of HEC-RAS

HEC-RAS is a software for one-dimension or two-dimension simulations of the evolution of a flood, which could have a steady or an unsteady flow rate, sediment transport, change of the riverbed, etc. The name 'HEC-RAS' derived from the creators of the software: Hydrologic Engineering Center, which stands as a subdivision of the Institute of Water Resources, U.S Army Corps of Engineers (HEC), and "RAS" is an acronym for "River Analysis System". The software itself has four main river analysis possibilities: the constant flow rate at the surface of a considered river profile; simulation of an unsteady flow of water; calculations of the sediment transport and modifications of the riverbed; and analysis of the water quality (U.S. Corps of Engineers, 2003, Tate et al. 1999). It is a widely used tool to model 1D flow

simulation and provides graphical results. Inundation mapping is accomplished in the HEC-RAS Mapper portion of the software and Tabular output is also available. The model result can be post-processed using SMS software to obtain and map detailed results. When the length-to-width ratio is larger than 3:1, a 1D hydraulic model can provide fairly good results (UK Environment Agency, 2009). More detailed information about HEC-RAS can be obtained from the websites: <http://www.hec.usace.army.mil/software/hec-ras/>.

4.6.2 Development of 1D Hydrodynamic Model of the study area

4.6.2.1 Data Collection and Processing

The study has been carried out based on available secondary data along with primary data. Both hydro-meteorological data and geo-spatial data have been collected from different sources to accomplish the study.

4.6.2.2 Primary Data Collection

Required data has been collected from the field visit of the study area and focus group discussion. The main purpose of the field visit was to observe the situation of Turag River and associated Khals especially hydraulic connectivity, siltation, and encroachment activities. Topographic data collected from secondary source has also been cross-checked and updated from field visit.

4.6.2.3 Secondary Data Collection

Required data for the study purpose include water level, discharge, river cross section, land terrain/Digital Elevation Model (DEM), topographic and land use. Rainfall data has been collected from database of Bangladesh Water Development Board (BWDB) and Bangladesh Meteorological Department (BMD). Water level (03 stations) data has been collected from database of BWDB. Discharge records (03 stations) has been collected from database of BWDB. Cross-sections of Turag river and associated khals has been collected from database of BWDB. Land terrain data/DEM data has been collected from database of RAJUK. Topographic/Physical feature survey and Land use data has been collected from RAJUK.

4.6.2.4 Hydrodynamic (HD) Model Setup

Hec-RAS 5.0.7 software has been used for the study. The hydrodynamic model setup comprises schematization of the river network, selecting boundary conditions, input of cross section data, input boundary data and friction parameters (Manning's n). The following sections discuss the steps of hydrodynamic model setup.

4.6.2.5 Hydrodynamic Model Inputs

i. Boundary conditions

The Hydrodynamic (HD) model for the study area comprises two upstream boundaries which are Kaliakoir, Gazipur on the Turag River (SW301), Tongi, Gazipur on the Tongi Khal (SW299) and one downstream boundary at Mirpur on the Turag River (SW302). Daily discharge data for the upstream boundary at Kaliakoir, Gazipur on the Turag River (SW301) and Daily tidal water level data for the upstream boundary at Tongi, Gazipur on the Tongi Khal (SW299) and one downstream boundary at Mirpur on the Turag River (SW302) has been utilized as the boundary condition.

ii. Cross sections

A total number of one hundred and fifty cross sections have been used in the HD model for the study area. These cross sections were collected from different sources like BWDB, IWM etc.

4.6.2.6 Model Simulation

The developed Hydrodynamic (1D) and overland (2D) flow models have been used for the study. The model has been simulated for water level, water depth and discharge. The model simulation has been carried out to fulfill the objectives and to cover the extreme events for river flooding. In this regard, the frequency analysis results have been used to identify the extreme events.

Flood Frequency analysis: Frequency analysis was conducted for the study area using Log-normal distribution and the Gumbel distribution method. The analysis was done considering the 2.33, 20, 50 and 100 years return period of flood. For the three

stations SW301 (discharge), SW302 (water level) and SW299 (water level), return period was calculated. Maximum water level and discharge data from 1980 to 2009 were considered for this analysis.

Data collected from BWDB for stations as listed above have been analyzed for daily basis using Extreme Value Distribution Type 1 (EVI) which is also known as Gumbel's Distribution. Deriving frequency factor (K_T) using Chow's (1951) expression:

$$K_T = -\frac{\sqrt{6}}{\pi} \left[0.5772 + \ln \left\{ \ln \left(\frac{T}{T-1} \right) \right\} \right] \text{----- (1)}$$

Computation of analyzed data has been done for return periods of 2.33, 20, 50 and 100 years using following equation:

$$y_T = \bar{y} + K_T s_y \text{----- (2)}$$

Table 4.20: Flood Frequency Analysis

Station	Year (Return Period)	2.33	20.00	50.00	100.00
SW299(WL), mPWD	Log-normal distribution	5.99	8.77	9.76	10.47
	Gumbel Distribution	5.86	7.87	8.65	9.23
Station	Year (Return Period)	2.33	20.00	50.00	100.00
SW302(WL), mPWD	Log-normal distribution	6.22	7.51	7.92	8.20
	Gumbel Distribution	6.13	7.66	8.25	8.70
Station	Year (Return Period)	2.33	20.00	50.00	100.00
SW301(Q), cumec	Log-normal distribution	618.00	1225.68	1486.21	1687.97
	Gumbel Distribution	642.12	1368.16	1651.02	1862.98

1D model: A Hec-RAS 1D model was developed for the study area. Discharge data were provided for SW301 and water level data were provided for SW299 and SW302.

Model Calibration and Validation: Once model setup is completed, it has been calibrated and validated against observed data to determine its ability to reproduce the actual phenomena observed in the field. The resistance parameter is the major controlling calibration parameter for the hydrodynamic model. **Manning's 'n'** has been chosen as resistance parameter for the Model. After calibration, the model has been validated with another set of observed data different from model calibration. In the present study, the model was calibrated using the data for the year 2009 and the model was validated using the data for 2011.

Calibration at Kaliakoir Station

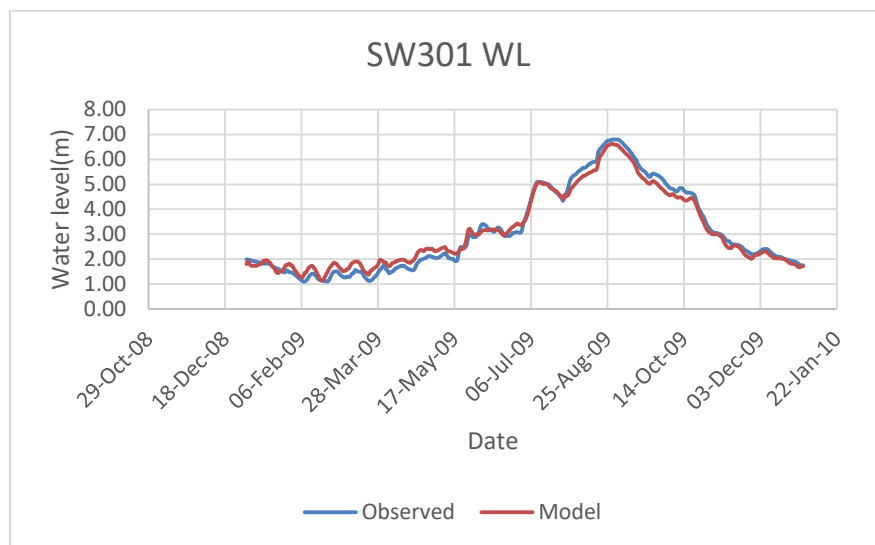


Fig 4.31: Observed and simulated water levels for calibration period at Kaliakoir station

Calibration at Mirpur station

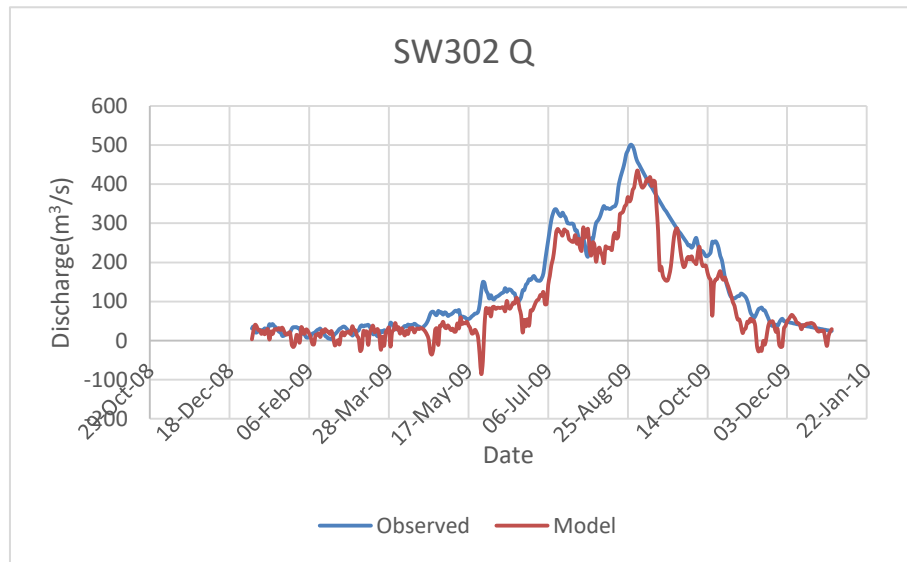


Fig 4.32: Observed and simulated water levels for calibration period at Mirpur station on the Turag River

Validation at Kaliakoir station

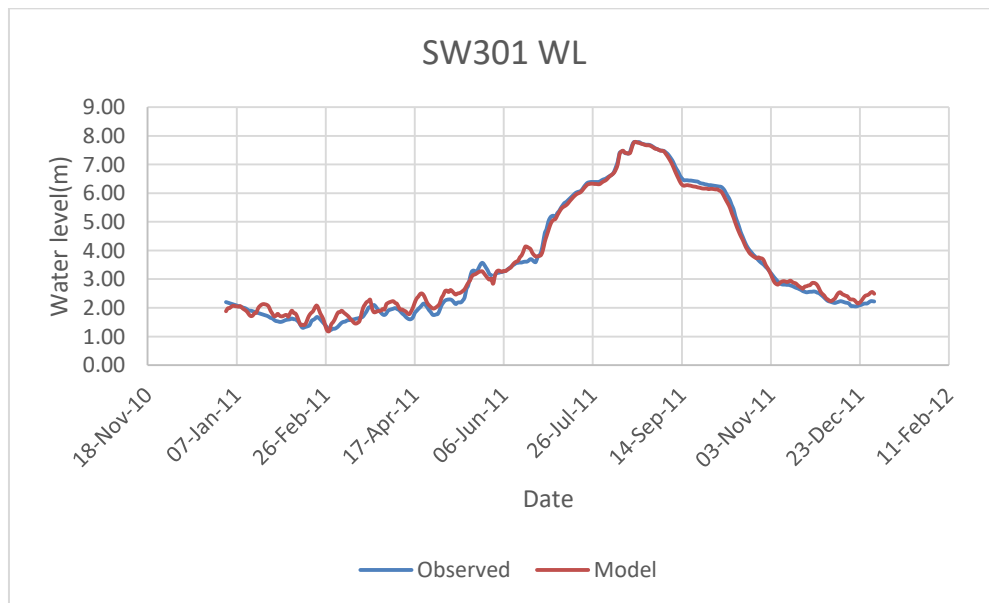


Fig 4.33: Observed and simulated water levels for validation period at Kaliakoir station

Validation at Mirpur station on the Turag River

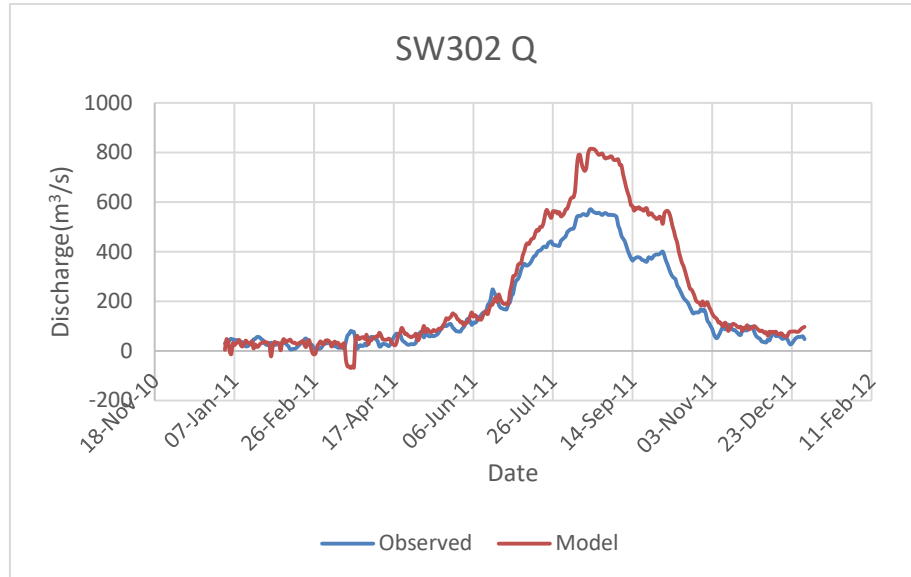


Fig. 4.34: Observed and simulated water levels for validation period at Mirpur station on the Turag River

The statistical comparison of observed and simulated water levels and discharge data showed that the model performs very well for both calibration and validation periods.

4.6.3 Development of 2D Hydrodynamic Model of the study area

4.6.3.1 Selection of Hydraulic Model

A two-dimensional hydrodynamic model has been developed as part of this study using HEC-RAS (Version 6.4.1) Modeling software. HEC-RAS is a software for one-dimensional or two-dimensional simulations of the evolution of a flood, which could have a steady or an unsteady flow rate, sediment transport, change of the riverbed etc. The flow obtained for different return period events from the hydrologic model has been incorporated into the hydrodynamic model.

4.6.3.2 Model Domain

The HEC-RAS 2D model domain encompasses an approximate 650 sq.km of the area encompassing a total watercourse length of 80 kilometers of Turag River and its tributaries. The lateral extent of the hydraulic model domain was selected considering the maximum flooding extent of the study area for the flood of 1988. Figure 4.35 shows the model domain for the 2D hydraulic model.

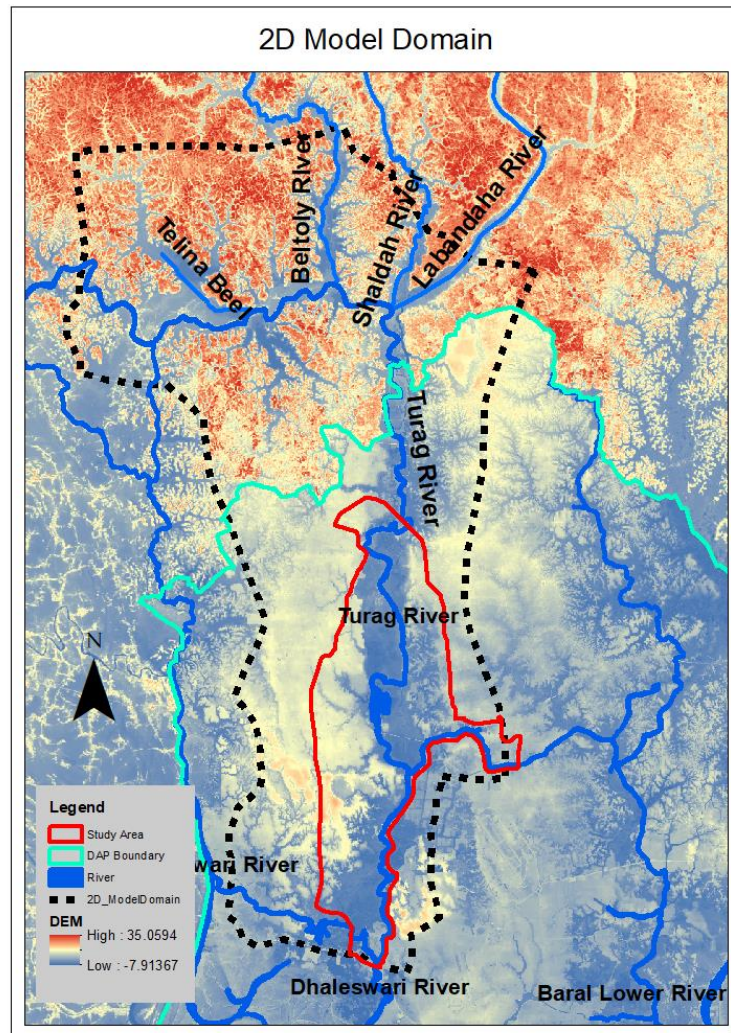


Figure 4.35: The model domain for the 2D hydraulic model

4.6.3.3 Model Mesh

The Mesh for the hydrodynamic model was prepared using Surface-water Modelling System (SMS-13.1) software. The mesh has boundary-fitting flexible mesh with different sizes depending on land use and land cover, size and shape of buildings/structures, and dimensions of hydraulic structures. SMS Map Module was applied to create the map coverage with the conceptual domain and polygons and to define the structured and unstructured mesh. The map coverage was converted to 2D meshes/grids. The model meshes have a fine resolution for areas where the model needs to accurately characterize hydraulic, hydrodynamic, and flood flows. The model has refined mesh in the main channel and coarse mesh in the flood plains.

Figure 4.36 represents a preview of the generated mesh of the study area and Figure 4.37 represents a zoomed preview of the hydraulic model mesh.

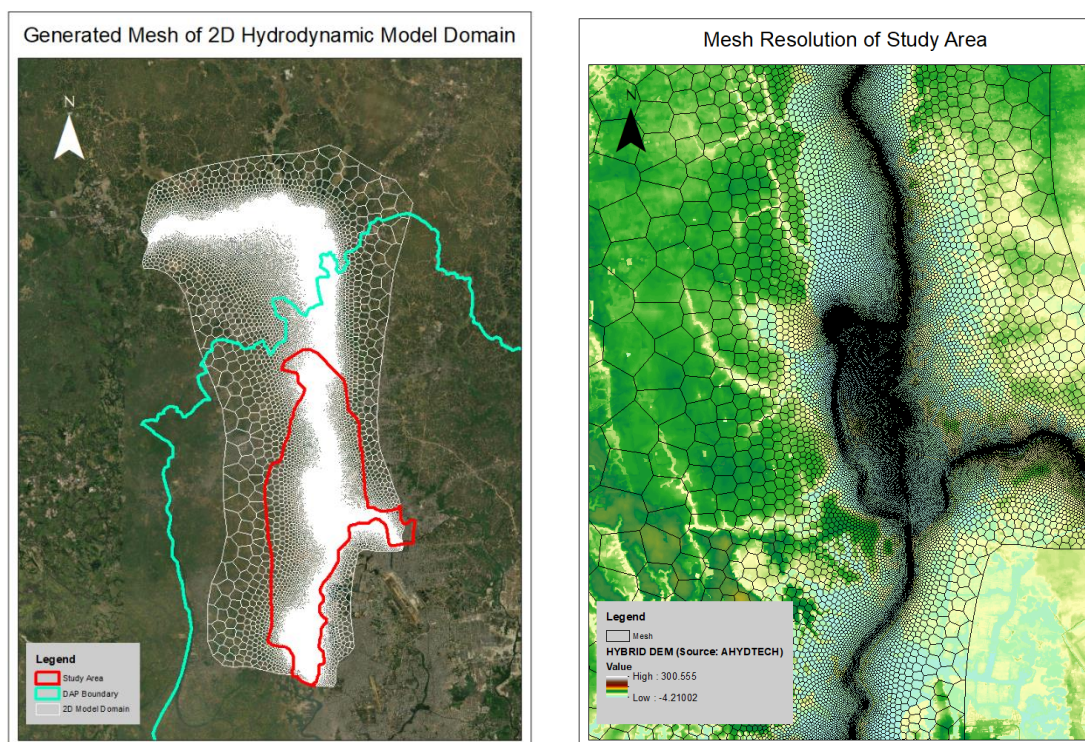


Figure 4.36: A preview of the generated mesh of the study area

Figure 4.37: Zoomed preview of the hydraulic model mesh

4.6.3.4 Model Topography

i. Digital Elevation Model (DEM)

The DEM has been used for the overland flow analysis (flooding extent and depth). A 10m X 10m DEM map (2014) of DMDP DAP area, later updated in 2018 for newly filled-up land elevation and river bathymetry, has been collected from RAJUK. But the RAJUK's DEM only covers DMDP DAP area but for this study, 2D model domain extends up to Kaliakoir. So, an extended hybrid DEM (10m x 10m) has been collected from AHYDTECH Water Resources (BD) Ltd. AHYDTECH prepared hybrid DEM (10m x 10m) using several GIS, Machine Learning & Remote Sensing

Technique by SNAP toolbox, developed by European Space Agency (ESA). It has been processed and down sampled on basis of latest dry period Sentinel-1 image and corrected using thousands of ground truth data retrieved from Survey of Bangladesh (SoB) benchmark. Figure 4.6.8 shows the Digital Elevation Model (DEM) map of the 2D domain area.

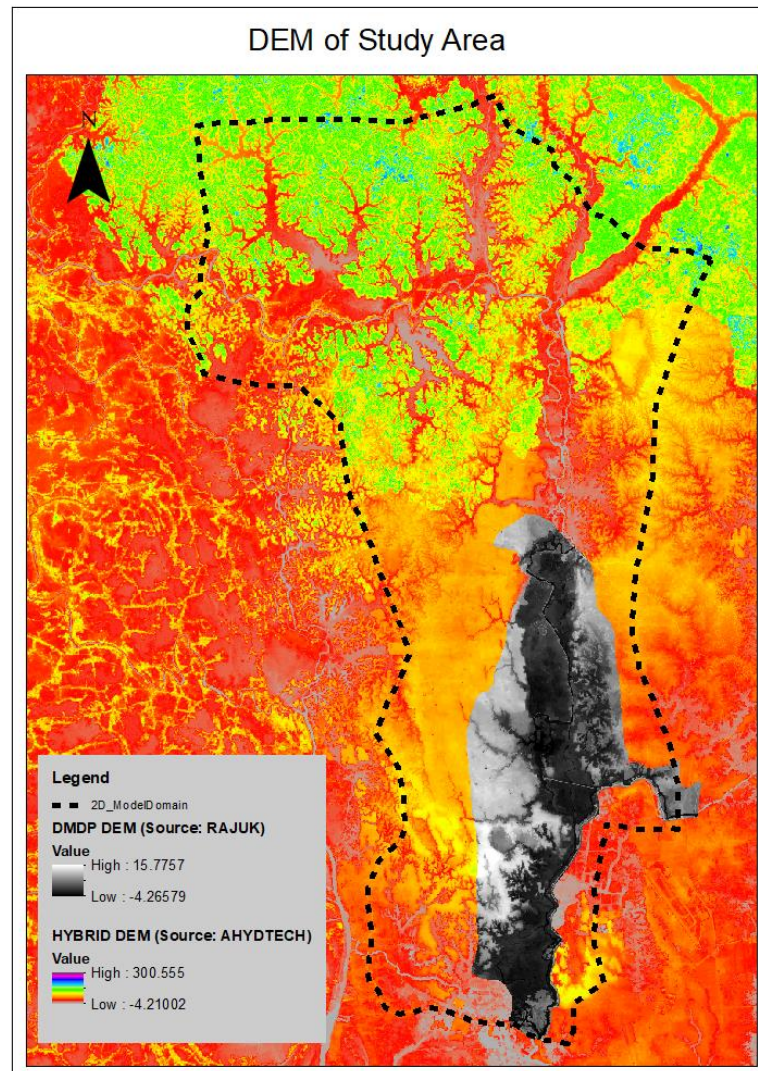


Fig 4.38: Digital Elevation Model (DEM) map of the 2D domain area

The following source of DEM has been used for preparing the hybrid DEM: (i) FABDEM (Forest And Buildings removed Copernicus 30m DEM), by University of Bristol (ii) SRTM 30m DEM (iii) RAJUK's 10m DEM (2014) corrected with river bathymetry (2018). The hybrid DEM contains river bathymetry.

ii. Terrain in RAS-Mapper

This refined dataset was applied for the 2D hydraulic model development and the floodplain mapping using HEC-RAS 2D. The Geospatial capabilities available in HEC-RAS were used to prepare a terrain file to associate the geometry files. The fined resolution DTM was called into RAS-Mapper and a Terrain was created in RAS-Mapper interphase. Figure 4.39 illustrates the created-RAS-Terrain that accounts for the vertical components in the HEC-RAS Geometry.

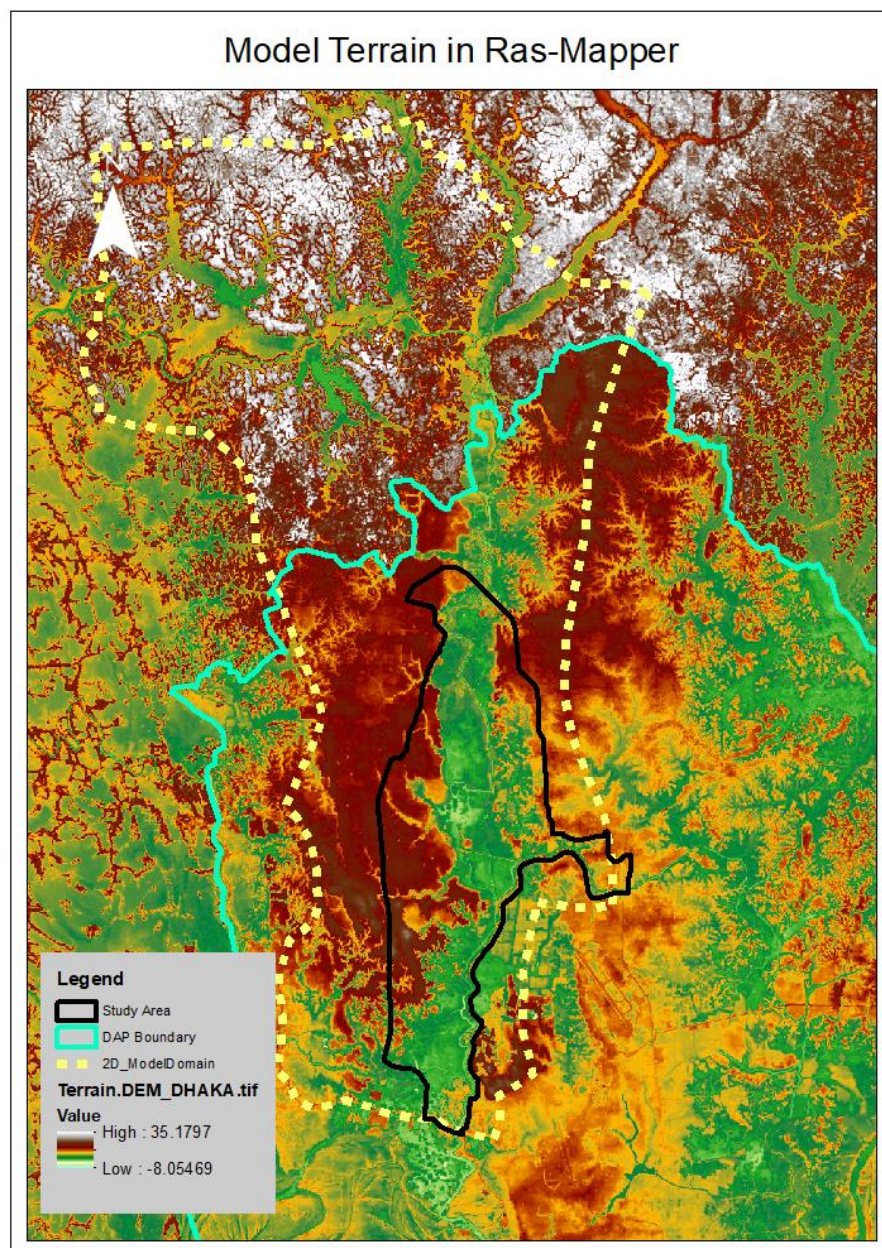


Figure 4.39: Model terrain in RAS-Mapper

4.6.3.5 2D Hydrodynamic Model Inputs

i. Boundary Condition

Upstream Boundary Condition (Flow)

In this study, data from two (2) different sources was incorporated as boundary condition at upstream location for the hydrodynamic model.

- (a) The first kind is derived by frequency analysis (Gumbel Distribution) of observed annual hydrograph of the hydrometric gauge station **SW-301 (Kaliakoir)** for **2.33-year and 100-year return period** using data from **1987-2019**. Also, observed annual hydrograph of 1988 for the hydrometric gauge station **SW-301 (Kaliakoir)** has been assigned. Figure 4.40 illustrates the comparison of observed flow hydrographs (2.33 & 100 year Return Period and 1988) at upstream boundary condition (SW301).

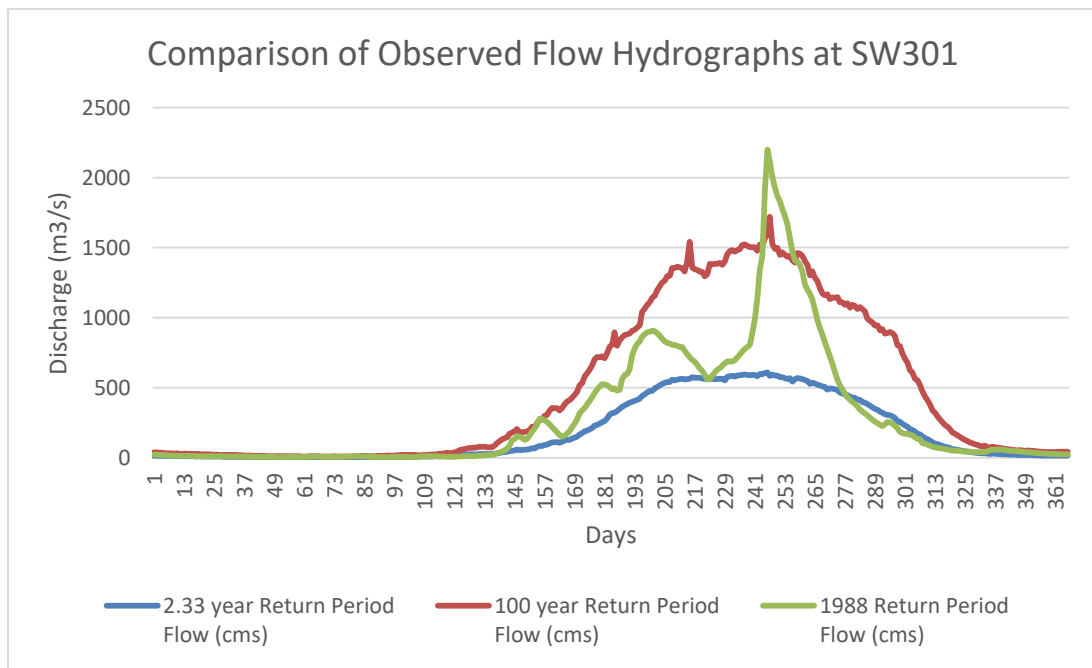


Figure 4.40: *Comparison of Observed Flow Hydrographs (2.33 & 100 year Return Period and 1988) at U/S Boundary Condition (SW301)*

- (b) The second kind is the simulated data for intermittent reaches obtained from the hydrologic model for 2.33-year and 100-year return period. The hydrologic model developed using HEC-HMS to simulate the 2.33-Year, 100-

Year return period and 1988 rainfall event to generate flow hydrographs at different locations.

Both observed and simulated flow hydrographs were incorporated into the 2D HEC-RAS model as “Internal and External Flow Boundary Conditions”.

Downstream Boundary Condition (Water Level)

Stage hydrographs for 2.33-year, 100-year return periods and 1988 have been used in the downstream external boundary condition location. The downstream boundary condition has been introduced in two locations. The stage hydrographs have been developed by performing frequency analysis (Gumbel Distribution) on observed daily water level of SW299 (Tongi) and SW302 (Mirpur) for 2.33-year and 100-year return period for data period 1987-2019. Figure 4.41 & 4.42 illustrates the comparison of observed stage hydrographs (2.33 & 100 year Return Period and 1988) at downstream boundary condition at SW299 and SW 302 respectively.

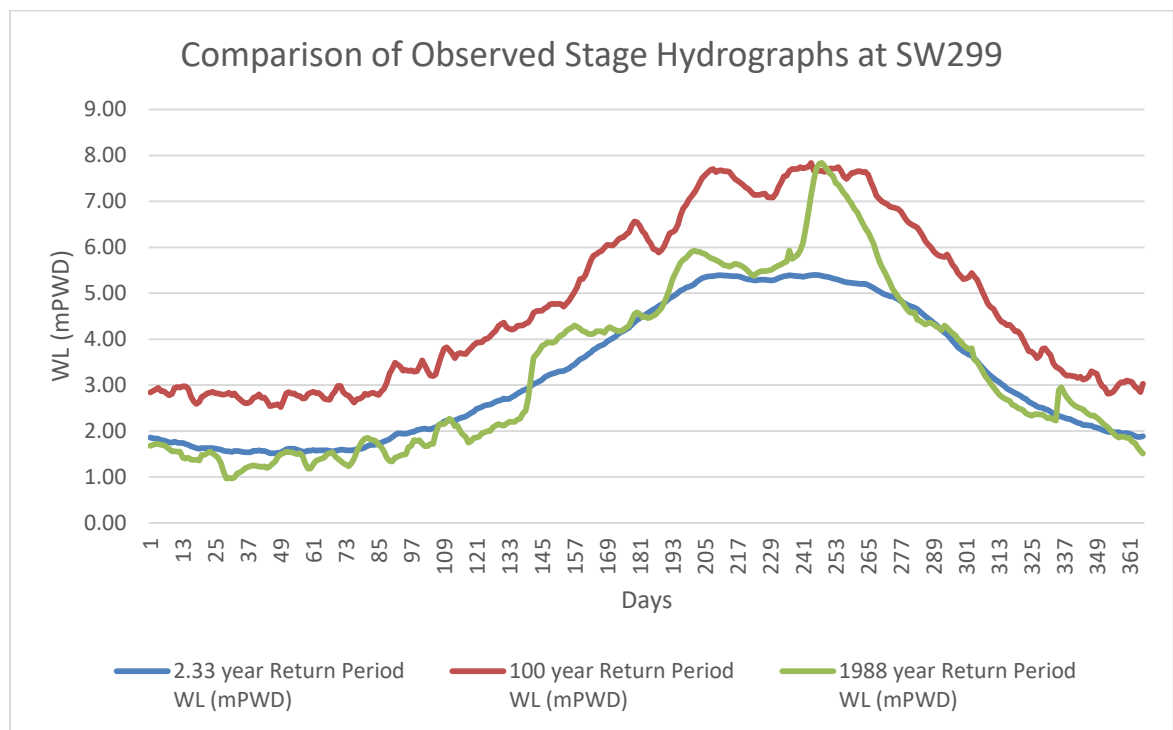


Figure 4.41: Comparison of Observed Stage Hydrographs (2.33 & 100 year Return Period and 1988) at D/S Boundary Condition (SW299)

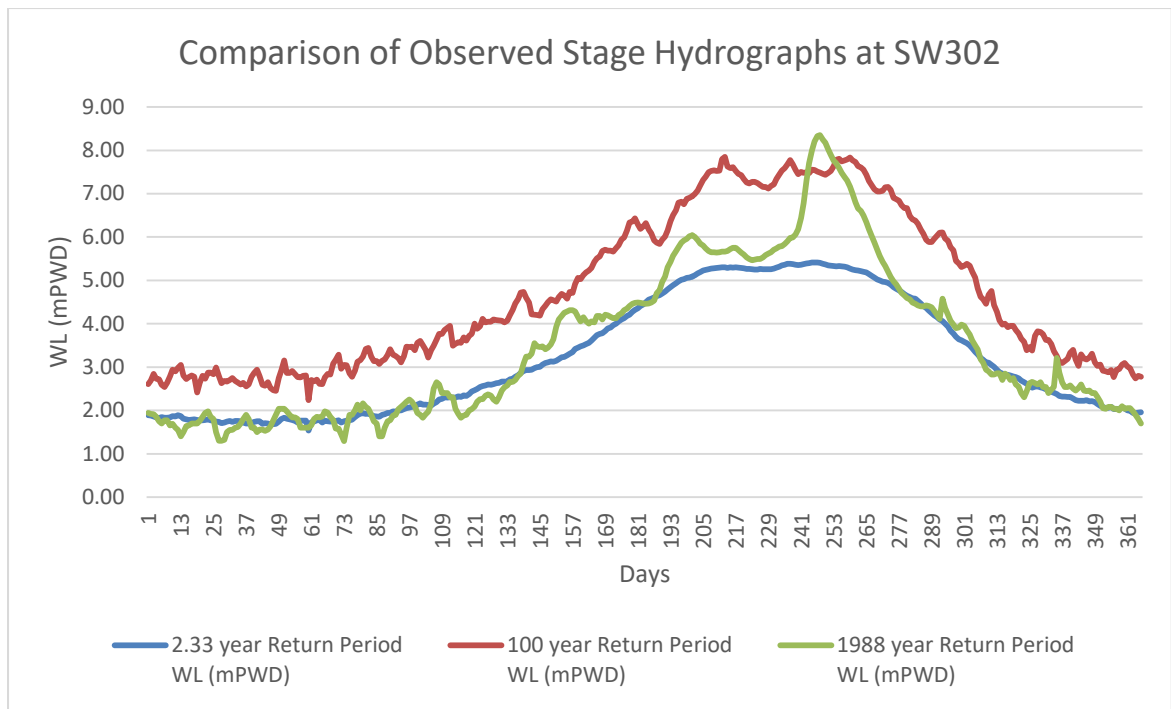


Figure 4.42: Comparison of Observed Stage Hydrographs (2.33 & 100 year Return Period and 1988) at D/S Boundary Condition (SW302)

Figure 4.43 illustrates the location of boundary condition along the study reach and Table 4.21 lists the connection between simulated flow from HEC-HMS model and internal boundary condition locations of 2D HEC-RAS model. The HEC-RAS External-Internal boundary conditions are named ‘Junctions’.

Table 4.21: Link between HEC-HMS Flow hydrographs and HEC-RAS Model External & Internal Boundary Condition

SL No.	HEC-RAS Junction	HEC-HMS Flow Hydrograph Name	Boundary Condition Type
1	SW301	Observed Flow at Kaliakoir	Flow (External)
2	JN2	Sub-basin flow of SB2	Flow (Internal)
3	JN3	Sub-basin flow of SB3 & SB4	Flow (Internal)
4	JN4	Sub-basin flow of SB5, SB6, SB7 & Routing flow of Reach 7	Flow (Internal)

5	SW299	Observed Water level at Tongi	Water Level (External)
6	SW302	Observed Water level at Mirpur	Water Level (External)

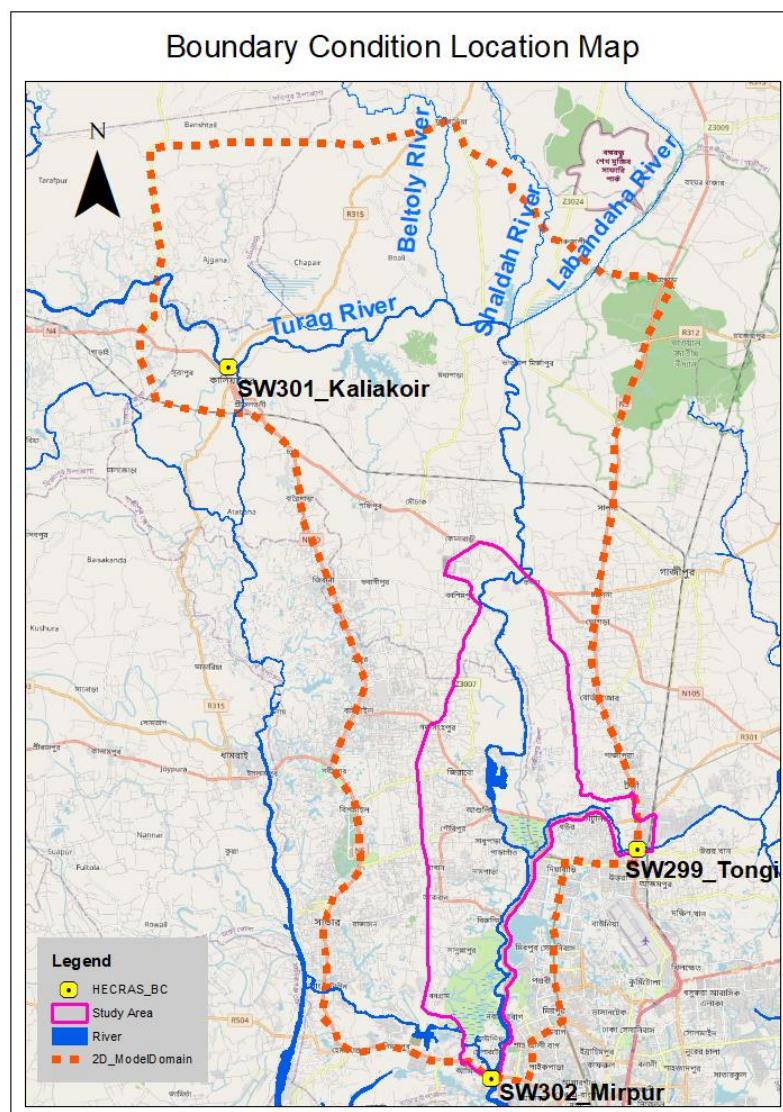


Figure 4.43: The location of boundary condition along the study reach

Figure 4.44 to Figure 4.46 below illustrate the flow Hydrographs incorporated in the model at different upstream and internal boundary locations for both return periods and Figure 4.47 to Figure 4.52 below illustrate the stage hydrographs incorporated in the model at downstream external boundary location.

Flow Hydrograph at U/S Boundary Condition (SW301)

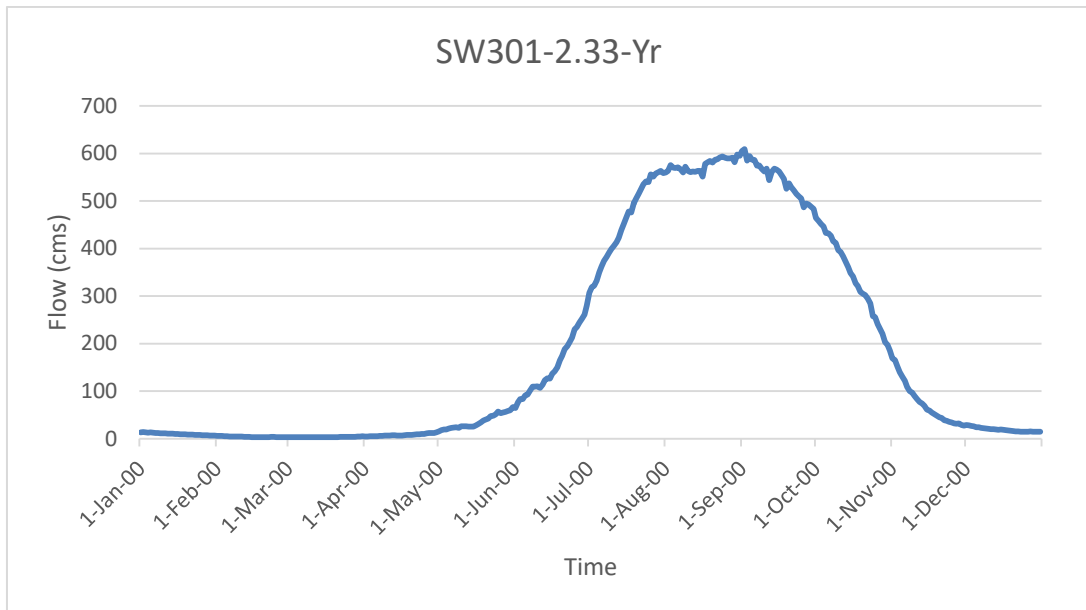


Figure 4.44: Annual Flow Hydrograph incorporated at SW-301 for 2.33-year return period

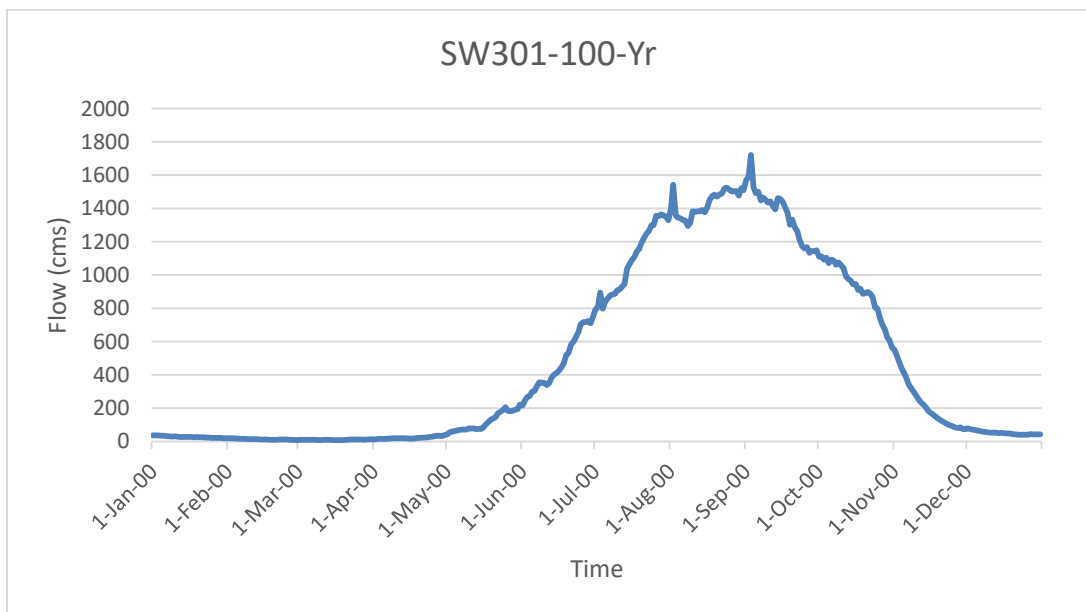


Figure 4.45: Annual Flow Hydrograph incorporated at SW301 for 100-year return period

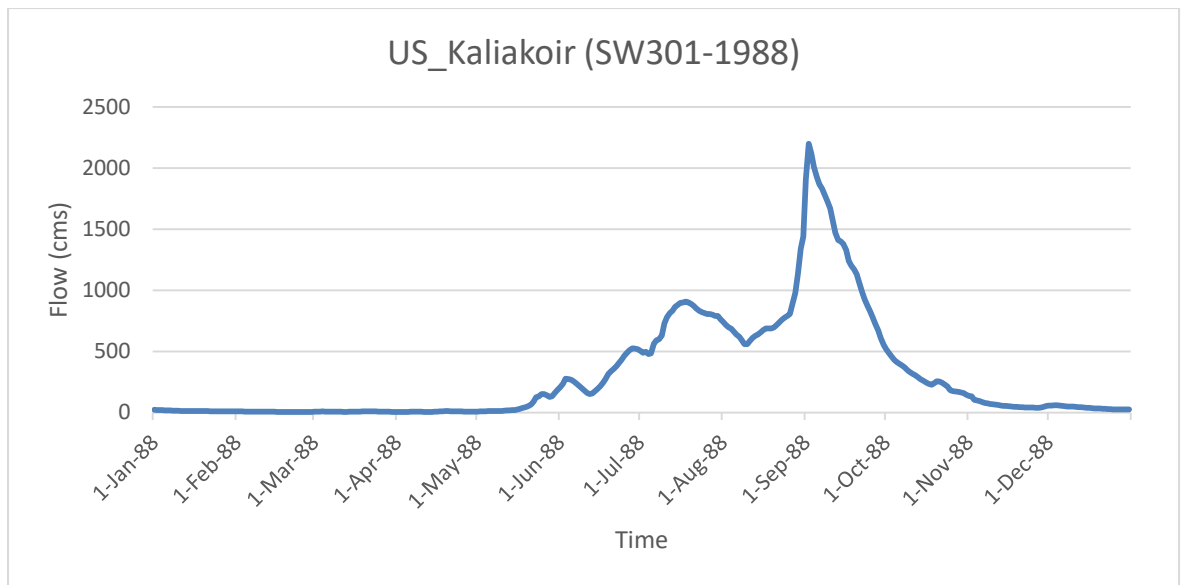


Figure 4.46: Annual Flow Hydrograph incorporated at SW301 for 1988

Stage Hydrograph at D/S Boundary Condition (SW299 & SW302)

SW299

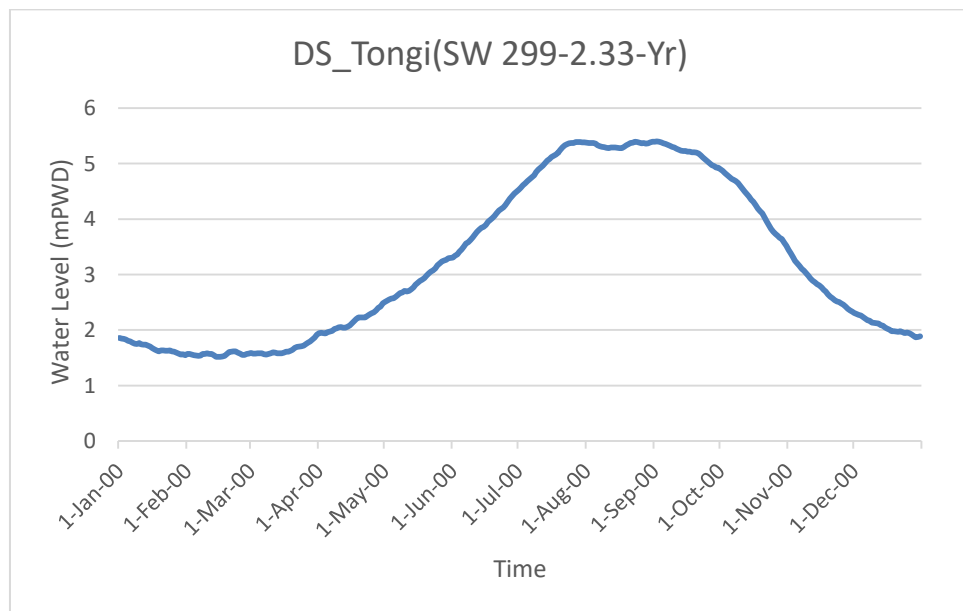


Figure 4.47: Annual Stage Hydrograph incorporated at DS_Tongi from SW-299 for 2.33-year return period

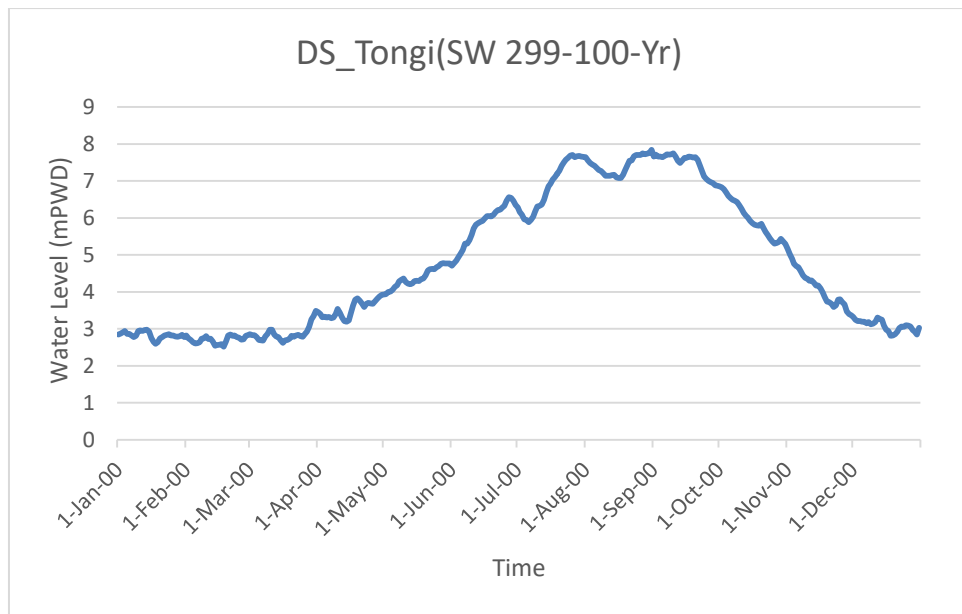


Figure 4.48: Annual Stage Hydrograph incorporated at DS_Tongi from SW-299 for 100-year return period

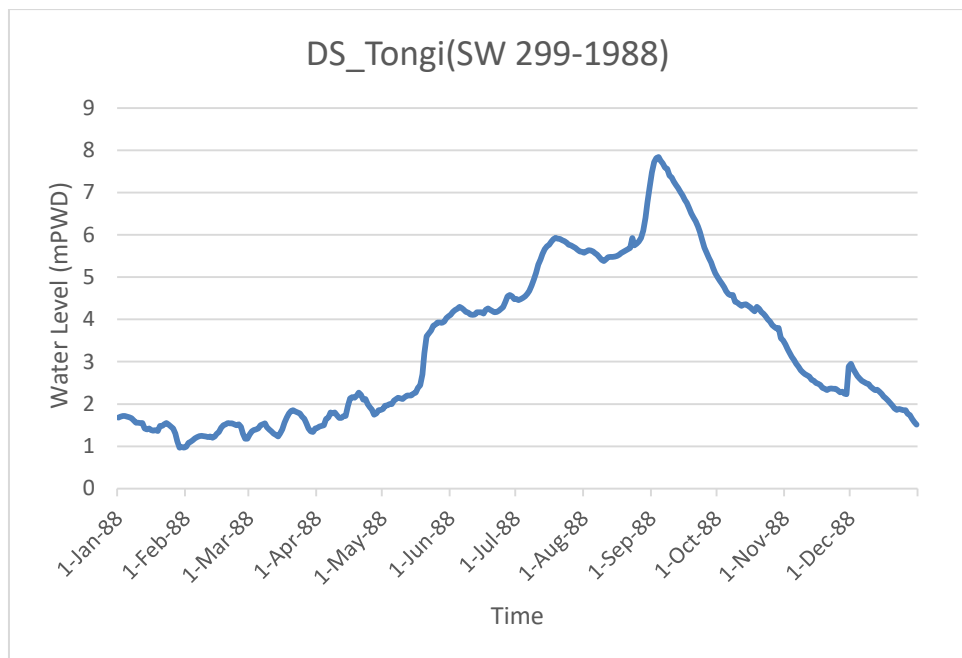


Figure 4.49: Annual Stage Hydrograph incorporated at DS_Tongi from SW-299 for 1988

SW302

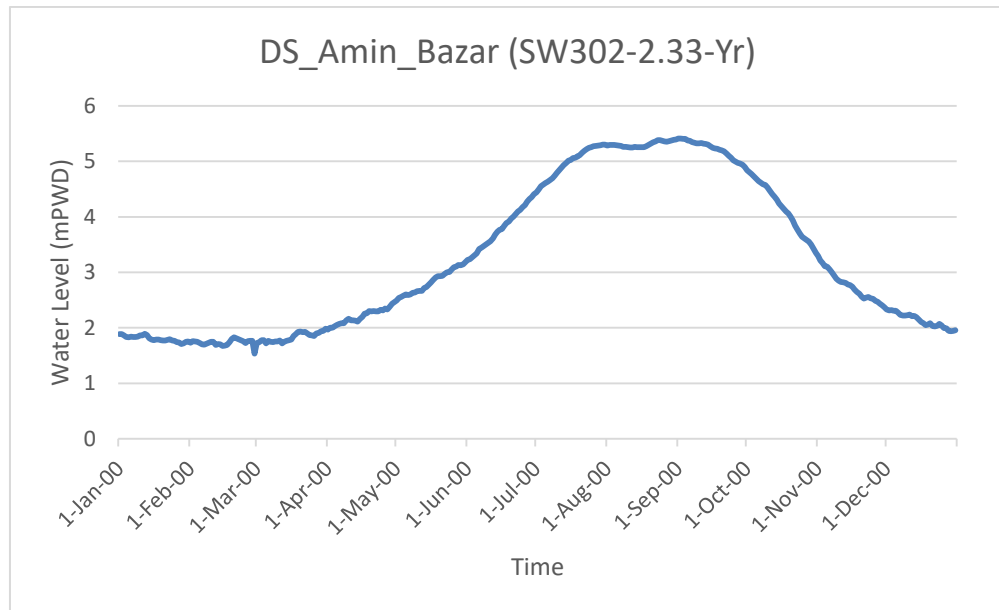


Figure 4.50: Annual Stage Hydrograph incorporated at DS_Amin_Bazar from SW-302 for 2.33-year return period

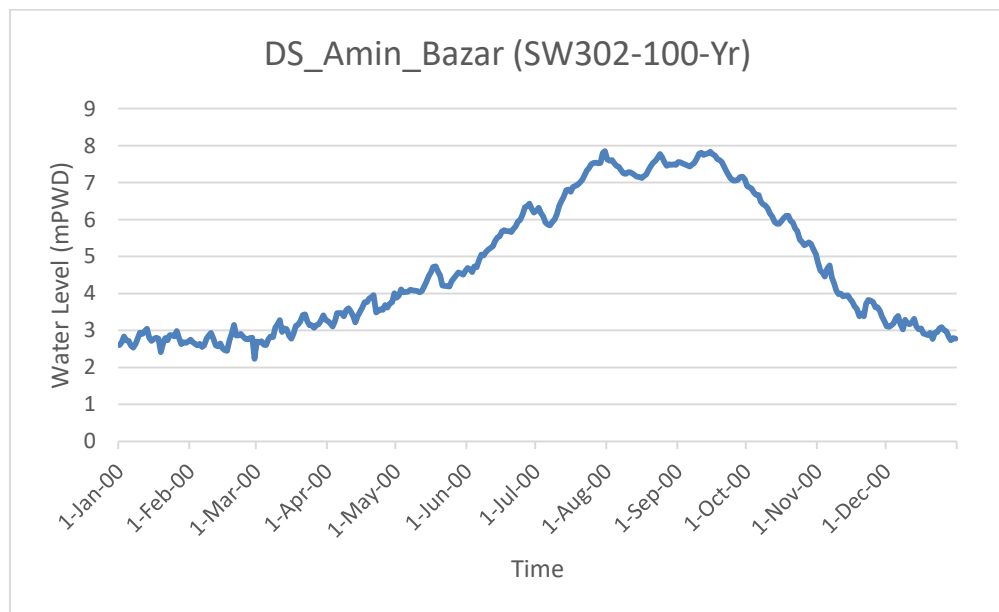


Figure 4.51: Annual Stage Hydrograph incorporated at DS_Amin_Bazar from SW-302 for 100-year return period

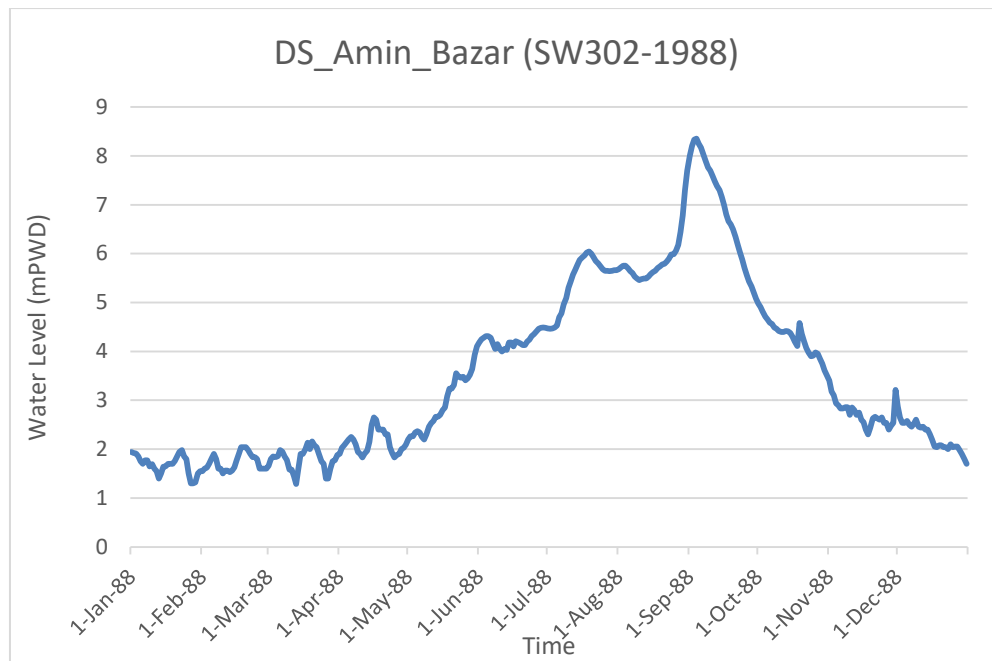


Figure 4.52: Annual Stage Hydrograph incorporated at DS_Amin_Bazar from SW-302 for 1988

ii. *Manning's Roughness Coefficient*

Manning's n coefficient reflects hydraulic resistance for flow in a watercourse and flood plain. Roughness in the main channel is usually lower than that in the flood plain. It also varies in the floodplain depending on the type of land use/land cover. For use of roughness into the HEC-RAS model, the classified land use/cover data along with their Manning's roughness values, according to the HEC-RAS manual, were incorporated into the model grid. Thus, a roughness raster file was created covering the whole model domain for the 2D HEC-RAS modeling. The Manning's roughness values used in this study for each type of land use/cover has been listed in Table 4.22.

Table 4.22: Manning's Roughness Values Used in Hydrodynamic Model

LULC Type	Manning's 'n' Value
Water	0.025
Trees	0.1
Flooded Vegetation	0.05
Crops	0.035
Built Area	0.08
Bare Ground	0.023
Clouds	0.025

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Results

5.1.1 2D Model Simulation & Hydraulic Analysis

For this study, DAP (2022-2035) guidelines was followed to do hydraulic analysis and to produce inundation mapping products.

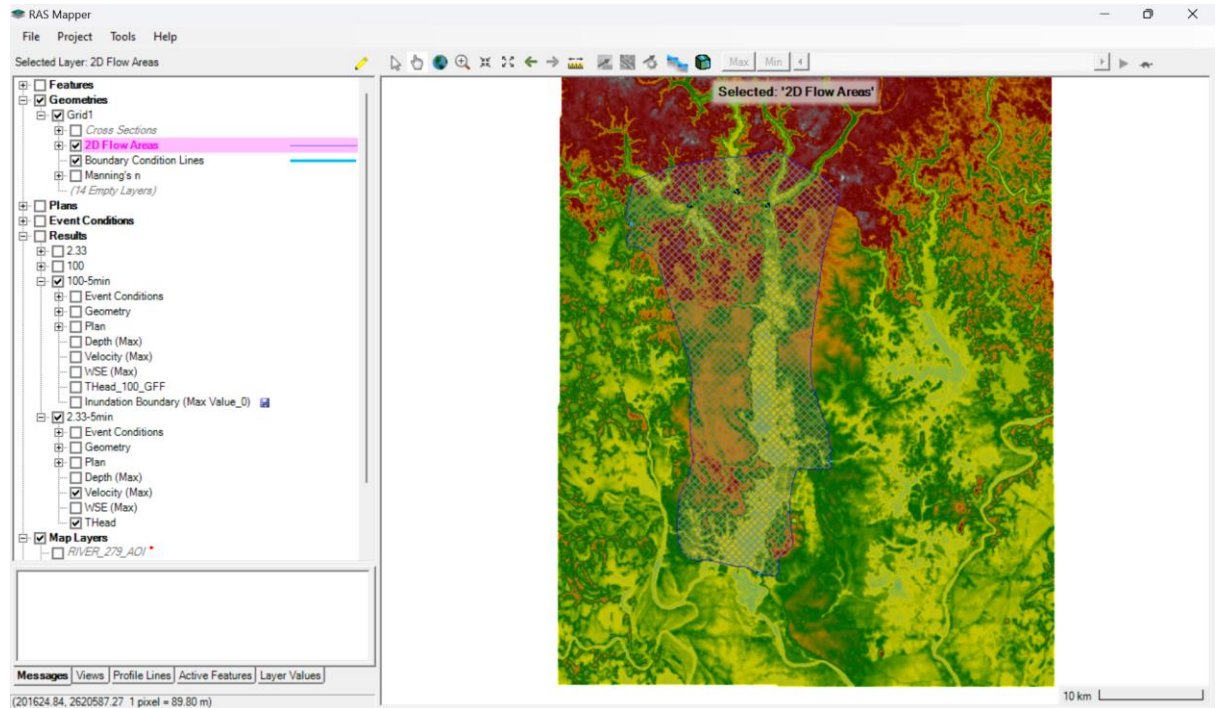


Figure 5.1: Graphical User Interface of RAS Mapper – HEC-RAS 6.4

This study has prepared the flood inundation maps for 2.33 year, 100 year & 1988 return period yearlong event. The results are depicted in the section below:

5.1.1.1 Inundation Mapping

To formulate policies and guidelines of Development Management in Detailed Area Plan (DAP) (2022-2035), hydrological and hydrodynamic analysis of riverine flood has been performed using a two dimensional mathematical model. Accordingly, flood affected area has been identified from different flood year situations. The DAP flood map is based on total energy head calculation [Total head (E) = Gravimetric head (Z + h) + Velocity head ($v^2/2g$)].

Following area has been identified from flood affected map:

- a) Flood free area
- b) Flood plain area

a) Flood free area

Mathematical studies and general experience show that areas in the average area of Bhawal and Madhupur that are not affected by river flooding under the Detailed Area Plan (2022-2035) and are flood-free average areas. All areas above the average area and most areas of medium height are identified within this area.

b) Floodplain area

Floodplain areas have been formed over a long period of time with the help of riverine sediments. However, in the DAP (2022-2035), the possibility of increasing the fertility of the land through siltation has also been considered significant in identifying floodplain areas. As a result, the relatively low-lying areas covered by the average area and some medium elevated areas have also been identified as floodplain areas based on the probability of flooding.

Floodplain areas are mainly divided into two parts based on water inundation extent, water depth, velocity and frequency:

i) Flood Flow area

- Main Flood Flow
- General Flood Flow

ii) General Flood Plain

i. Flood Flow area

Main Flood Flow:

Areas of floodplain areas where water inundation extent, depth, velocity and frequency are observed have been identified as major watershed basins. Areas that are flooded most of the time to some extent are part of the main watershed basin. In DAP (2022-2035), any location with a flood depth above or equal to 3.7 m is considered as the main flood flow zone from an output of average flooding (i.e. equaling the magnitude of 2.33 years return period). But in this study, any location with a flood

depth above or equal to 3.0 m is considered as the main flood flow zone from an output of average flooding (i.e. equaling the magnitude of 2.33 years return period) (Figure 5.2), as it was observed that the average/normal flood depth in Dhaka city is 3.0 m.

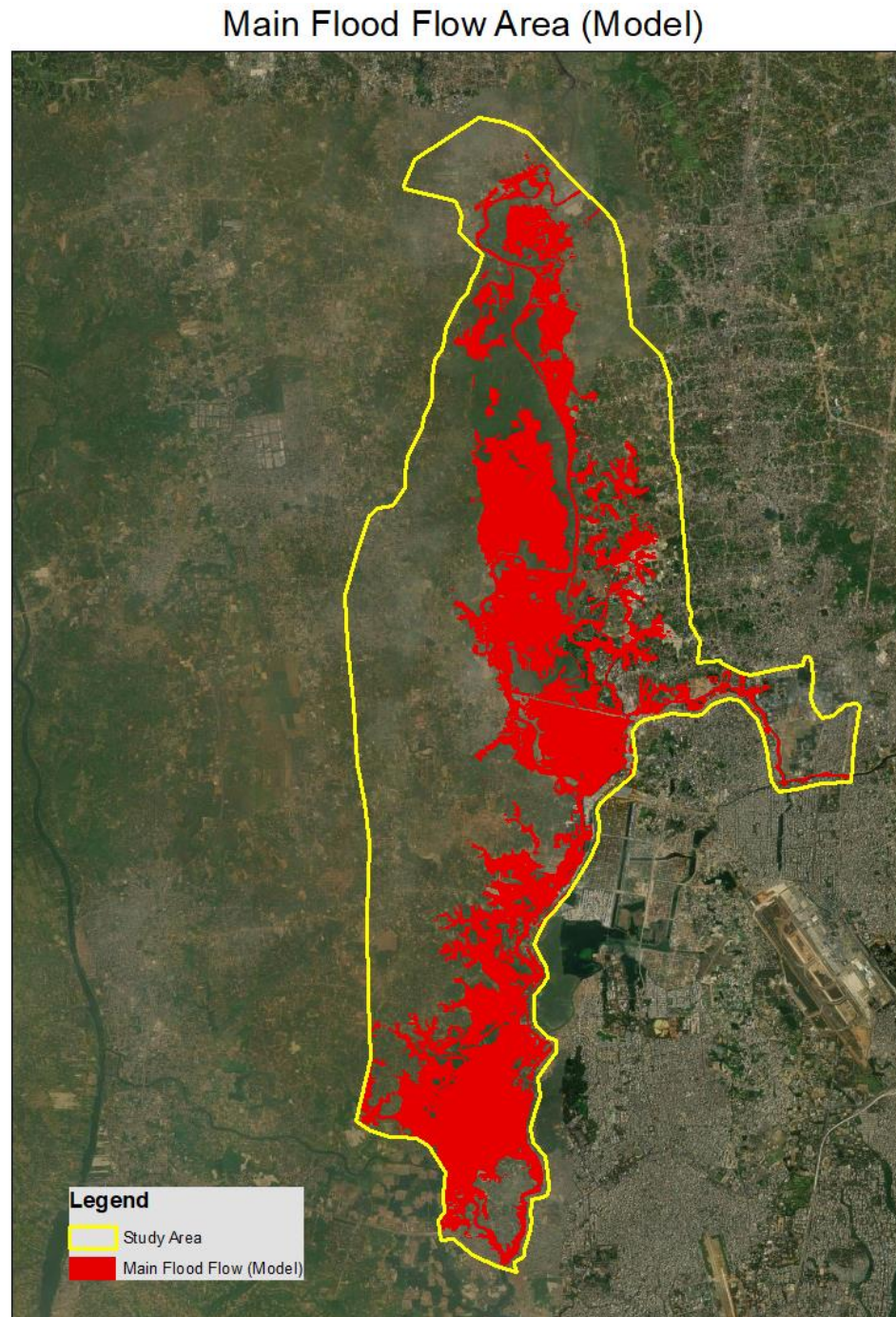


Figure 5.2: Main Flood Flow Area (Model)

General Flood Flow:

Areas where only the extent, depth and velocity of water are observed in the floodplain area are identified as normal watershed basins. Under the Detailed Area Plan (2022-2035), the watershed area identified as a general watershed basin area based on the extent, depth and current velocity of the 1988 flood based on the results of a two-dimensional mathematical study conducted to determine the nature of riverine flooding. Any location with a total head above or equal to 3.7 m is considered as the general flood flow zone by considering the 1988 flood (a 100-year return period flood) (Figure 5.3).

General Flood Flow Area (Model)

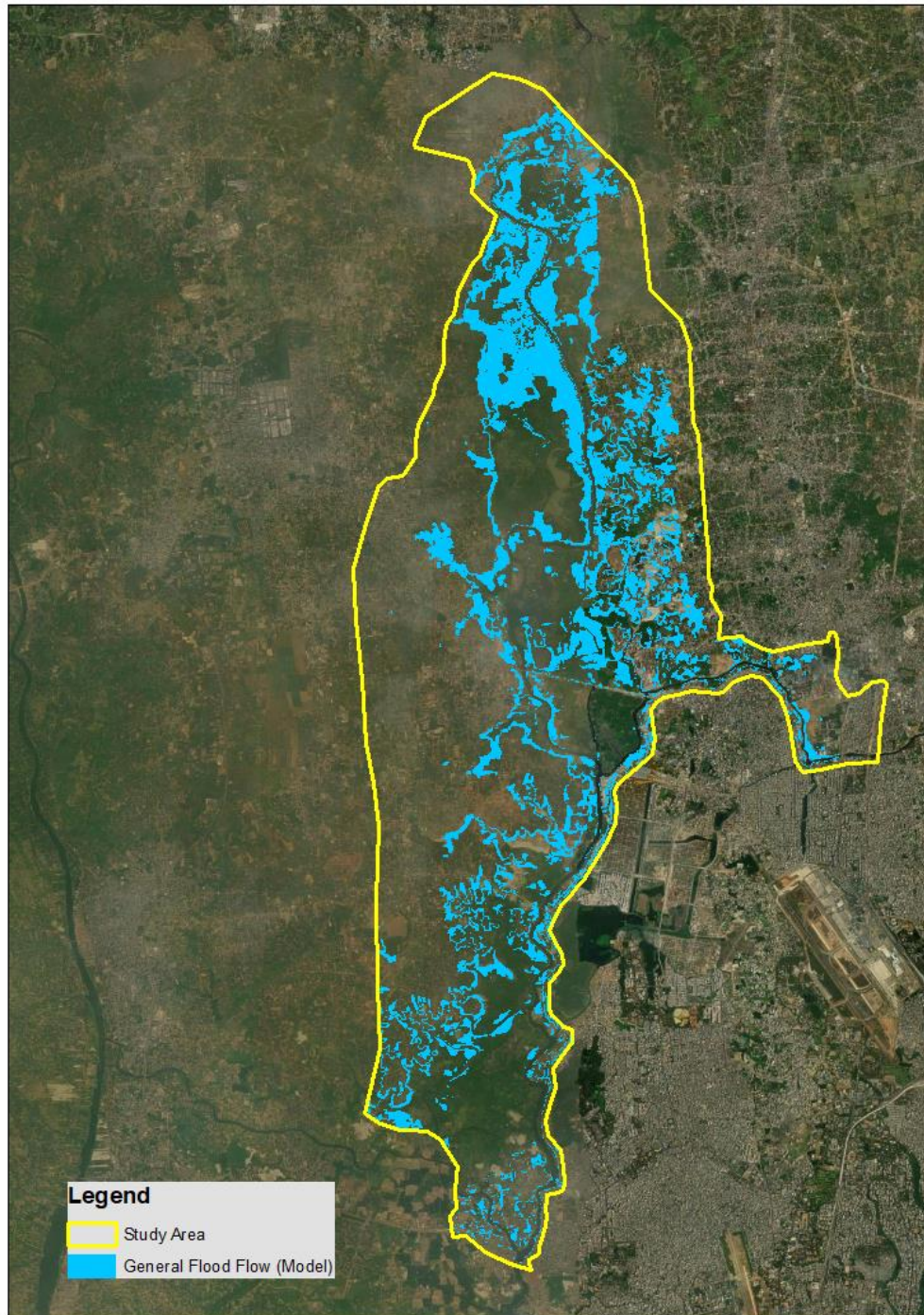


Figure 5.3: General Flood Flow Area (Model)

ii. *General Flood Plain*

The second is the general floodplain area. Areas where only water permeability and depth are observed in floodplain areas are identified as normal floodplains. It is a relatively higher part of the floodplain (**Figure 5.4**), where:

- During the monsoon season excess water overflows and accumulates.
- When the water recedes at the end of the monsoon, this excess water returns to the river and is connected to the main stream.
- During water entry and exit, the direction of flow is almost perpendicular to the main flow of the river (upstream to downstream).

General Flood Plain Area (Model)

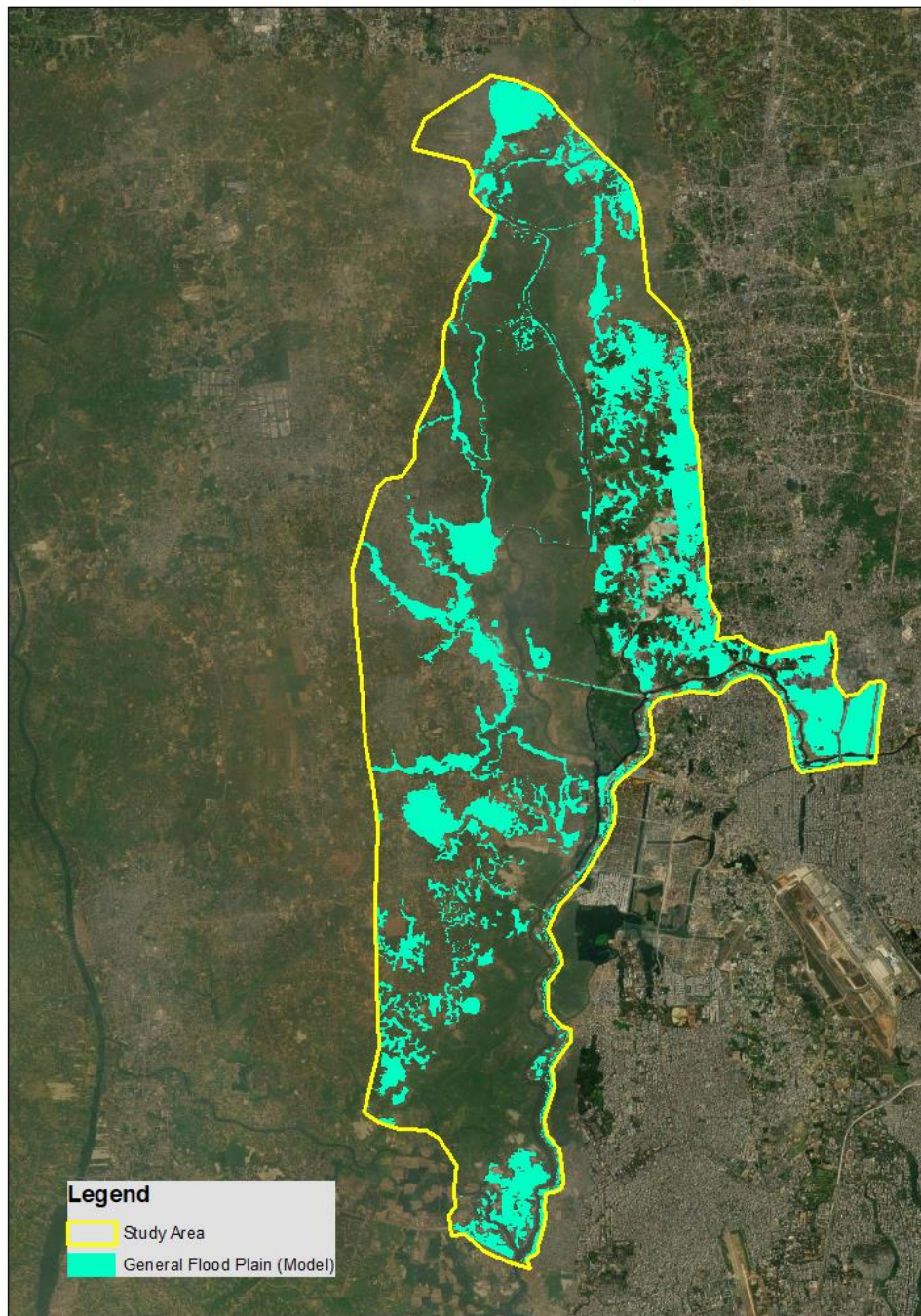


Figure 5.4: General Flood Plain Area (Model)

Rivers are not usually flooded here. Although it was submerged in the floods of 1988, there was no current or even less. Floodplain area = inundated area considering the 1988 flood (a 100-year return period flood).

General Flood Flow => 3.7 m Total head of 1988 flood- Main Flood Flow

General Flood Plain = 1988 Flood Extent- (Main Flood Flow + General Flood Flow)

Model Generate Flood Overlay Map

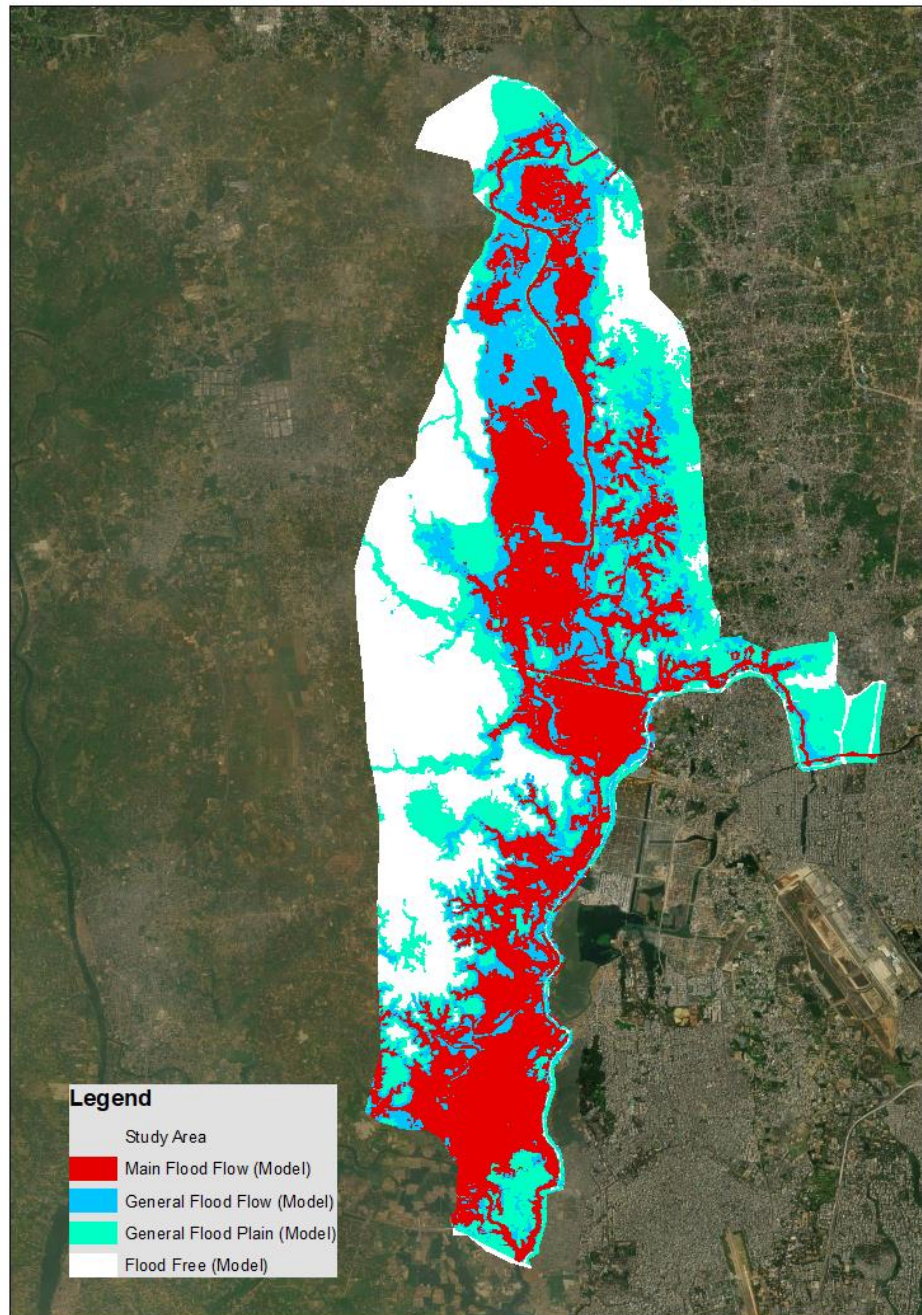


Figure 5.5: Model Generated Flood Overlay Map

DAP (2022-2035) Flood Overlay Map

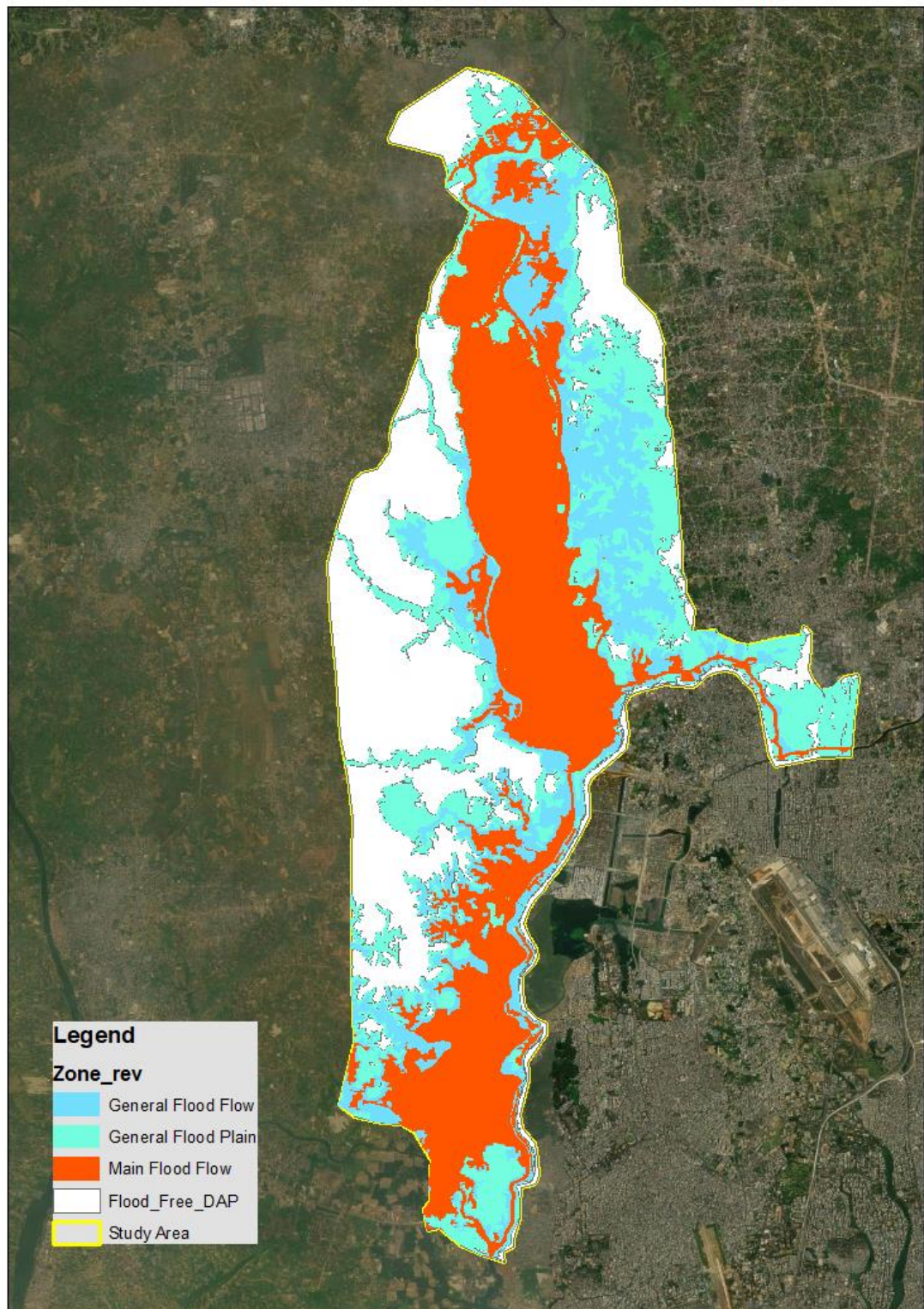


Figure 5.6: Proposed Flood Overlay Map of DAP (2022-2035)

Comparison Map between Model Generated and
DAP (2022 - 2035) Proposed Main Flood Flow Area

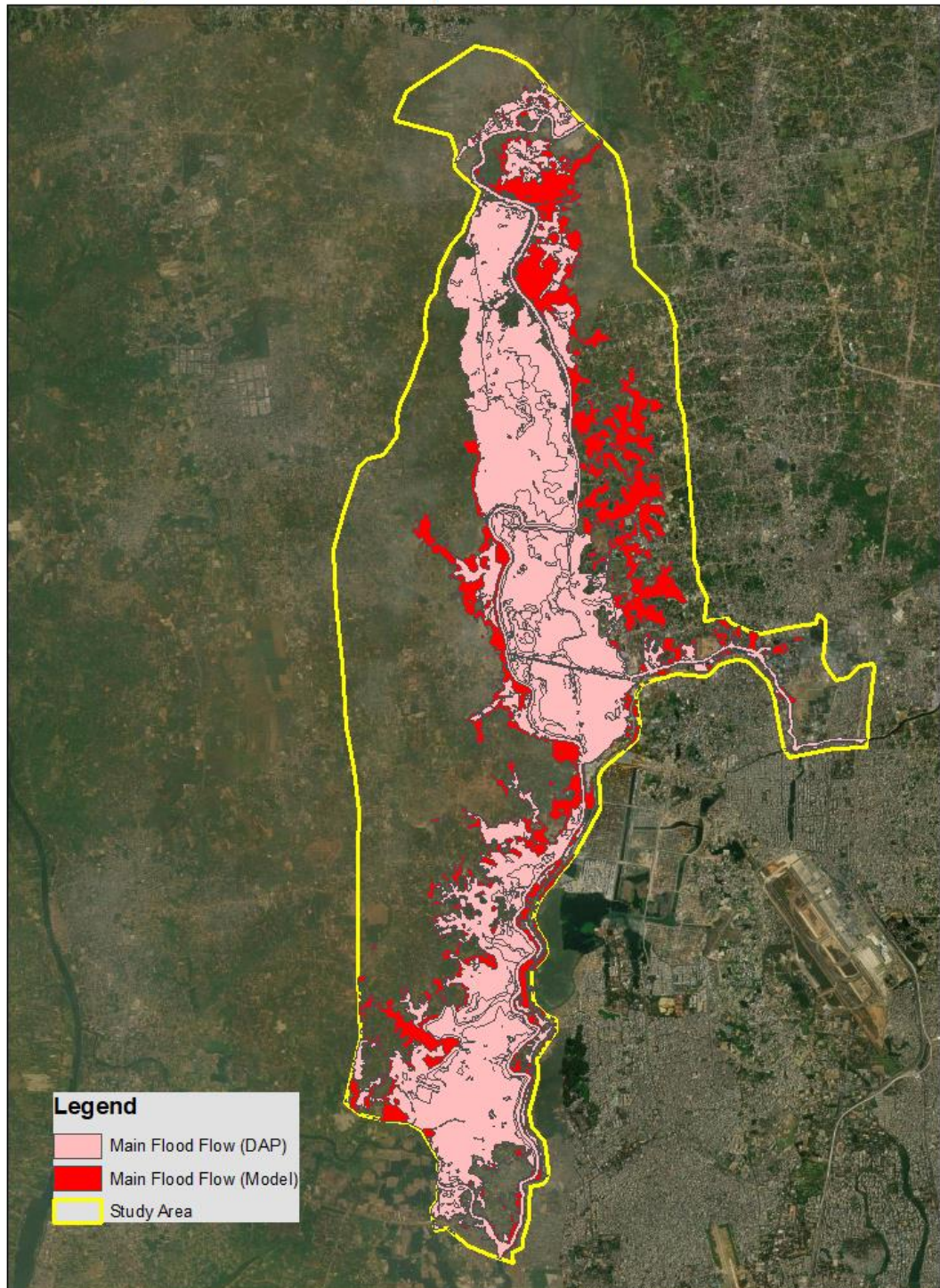


**Figure 5.7: Comparison of Model Generated Main Flood Flow area Maps and
DAP (2022-2035) Proposed Main Flood Flow Area**

Comparison Map between Model Generated &
DAP (2022- 2035) Proposed General Flood Flow Area

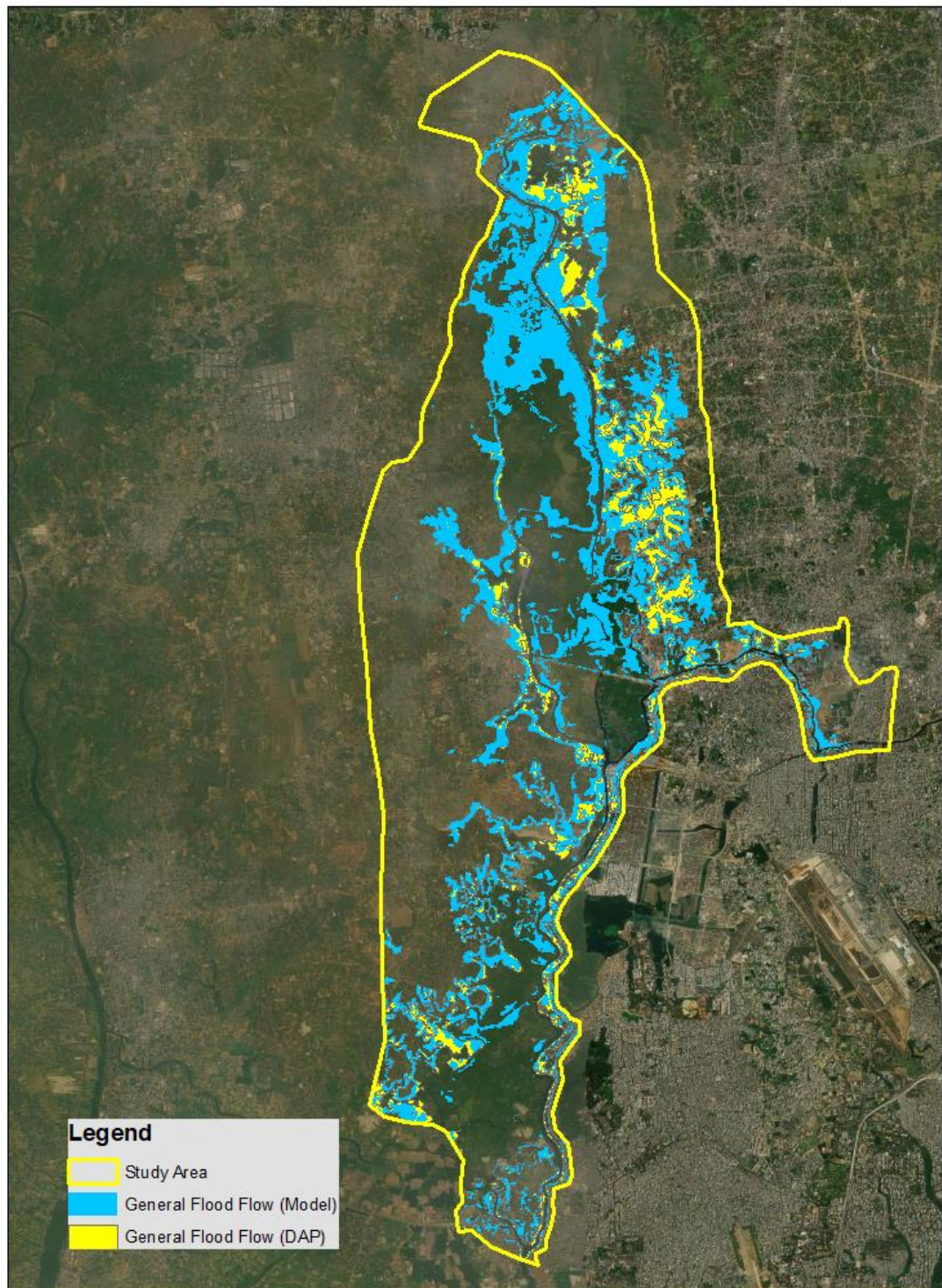


Figure 5.8: Comparison of Model Generated General Flood Flow area Maps and DAP (2022-2035) Proposed General Flood Flow Area

Comparison Map between Model Generated &
DAP (2022 - 2035) Proposed General Flood Plain Area

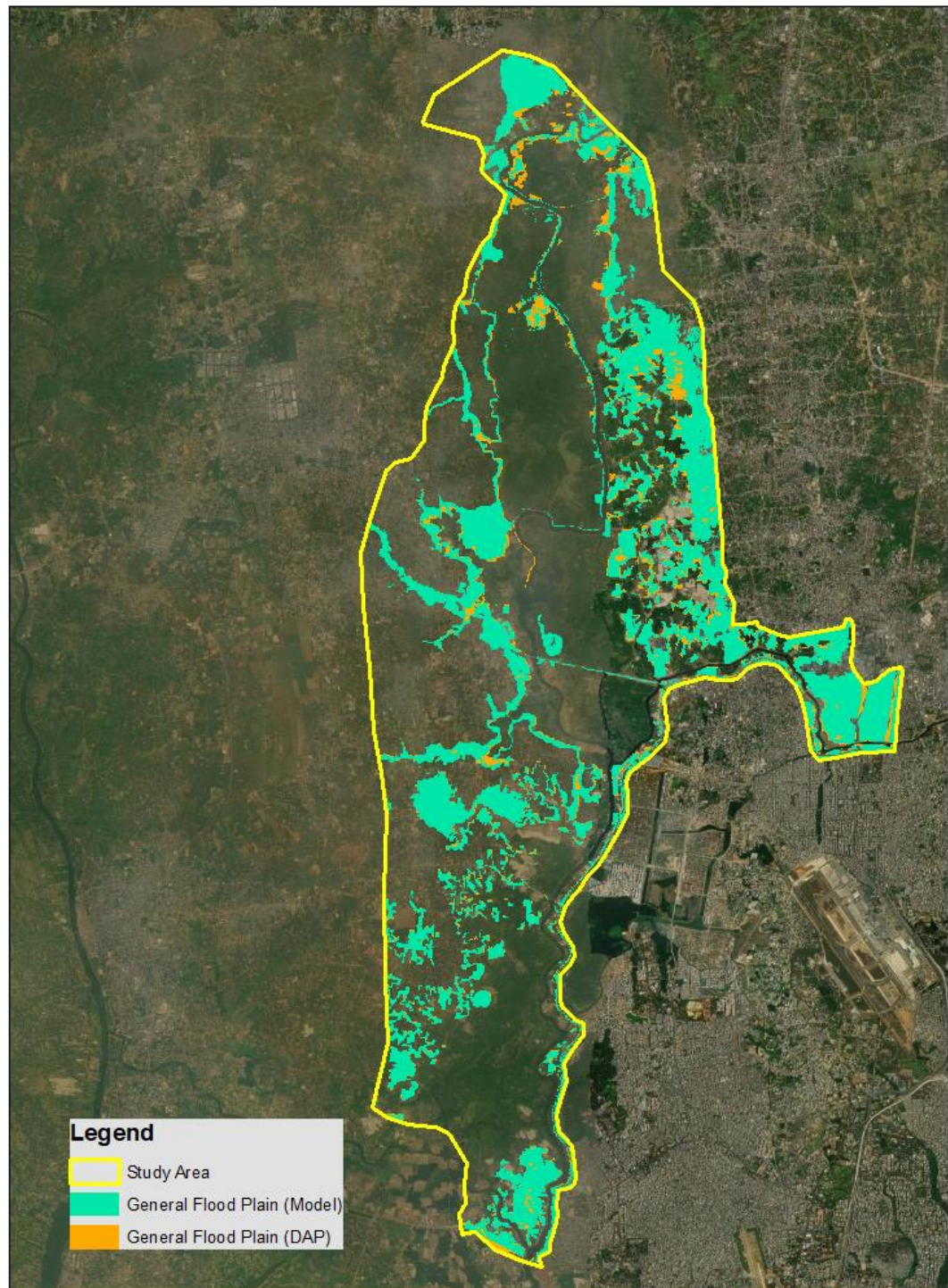


Figure 5.9: Comparison of Model Generated General Flood Plain area Maps and DAP (2022-2035) Proposed General Flood Plain Area

Table 5.1: Comparison of Flood overlay areas between Model Generated Flood and DAP (2022-2035) Porposed Flood

Flood Overlay Area		Model Generated Flood		DAP (2022-2035) Proposed Flood	
		Area (sqkm)	Percentage	Area (sqkm)	Percentage
Flood Free Area		32.17	26.46	36.62	30.10
Flood Plain Area		89.39	73.54	85.03	69.90
i) Flood Flow Area	Main Flood Flow	38.30	31.51	39.63	32.58
	General Flood Flow	23.27	19.14	19.48	16.01
ii) General Flood Plain Area		27.82	22.89	25.93	21.31
Total		121.56	100	121.65	100

Figure 5.5, 5.6, 5.7, 5.8, 5.9 shows the comparison map of Flood overlay areas between Model Generated Flood and DAP (2022-2035) Proposed Flood and Table 5.1 shows the comparison of Flood overlay areas between Model Generated Flood and DAP (2022-2035) Proposed Flood. Table 5.1 shows that the percentage of main flood flow area in Model Generated and DAP (2022-2035) proposed is 31.51% and 32.58% respectively.

5.1.1.2 Relation between Elevation of DEM & Model Generated Flood Overlay Areas

The total Floodplain in study areas is found to cover about 89.39 sq.km where about 38.30 sq.km (31.51 %) area of -3.73 – 7.14 mPWD elevation zone falls under Main Flood Flow area and 23.27 sq.km (19.14%) and 27.82 sq.km (22.89%) of -3.8 - 6.95 mPWD and 0.1 – 12.09 mPWD elevation zones falls under General Flood Flow Area & General Floodplain Area respectively. The total Flood free in study area is found to cover about 32.17 sq.km with an elevation of -0.23 to 16.23 mPWD heights which mostly covers high land of Savar (Figure 5.10, 5.11).

1988 Flooded Terrain Map (Model)

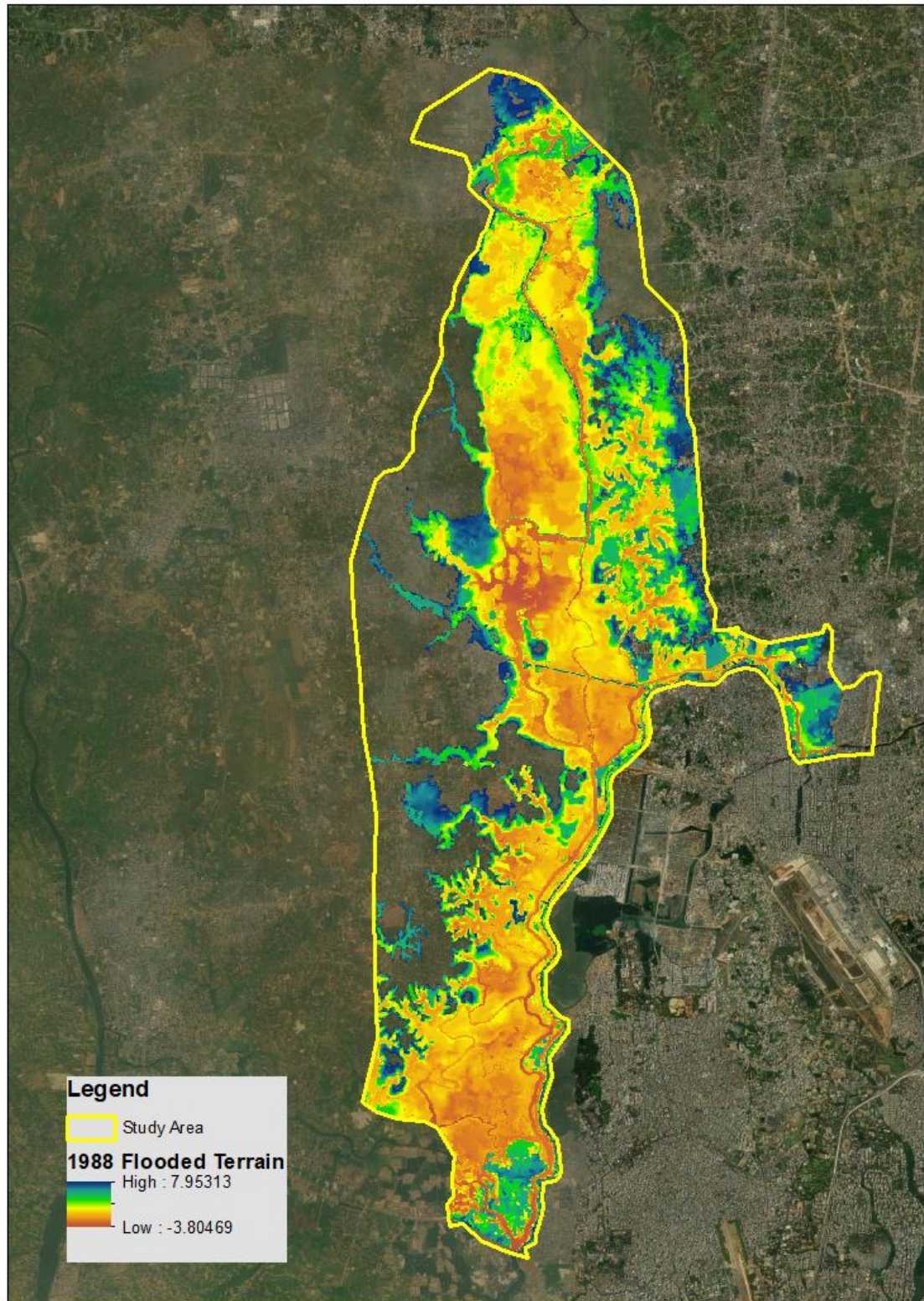


Figure 5.10: Relation between Elevation of DEM & Classified Flood Depth for 1988 Flood

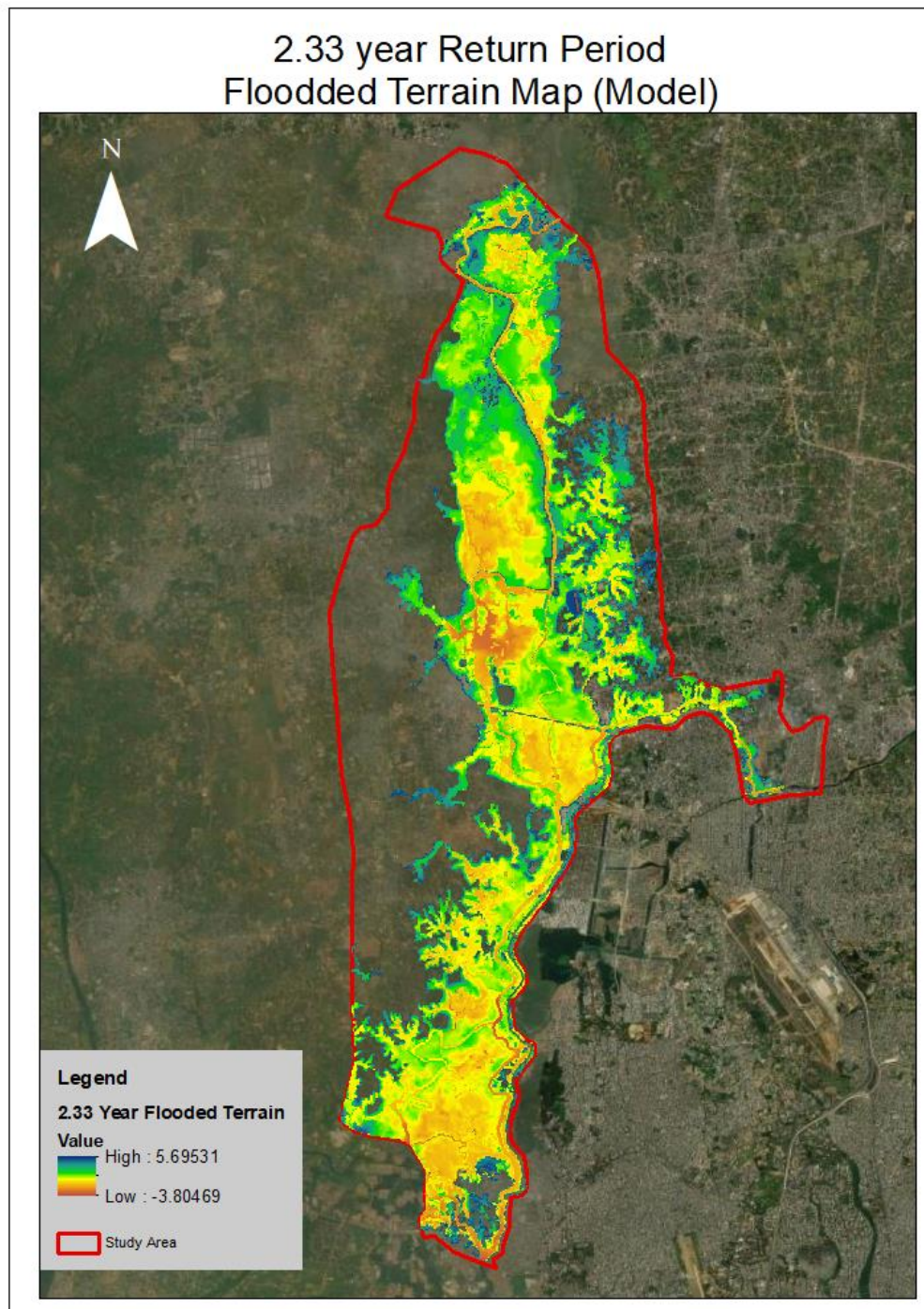


Figure 5.11: 2.33 year return period flooded terrain map

The total flooded areas of normal flood (2.33 year flood) in and around study area is found to cover about 66.75 km² where about 36.1 percent of the submerged area is under low land with an elevation of -3.8 to 5.7 mPWD heights. For the severe floods of 1988, about 14.01 sq.km (16.5 %) area of 5.69 – 7.95 mPWD elevation zone is found to be gone under flood water in study area and 11.97 sq.km (14.11%) and 58.87 km² (69.37%)

of 4.19 - 6.15 mPWD and -3.8 - 4.33 mPWD elevation zones are found to be gone under flood water respectively. In total, about 84.87 sq. km. of about 69.77% of area of the study area is found to be affected by this severe inundation of 1988 (Figure 5.10, 5.11).

5.1.1.3 Flood Phasing Map

2.33 year Return Period Flood Depth Classification Map

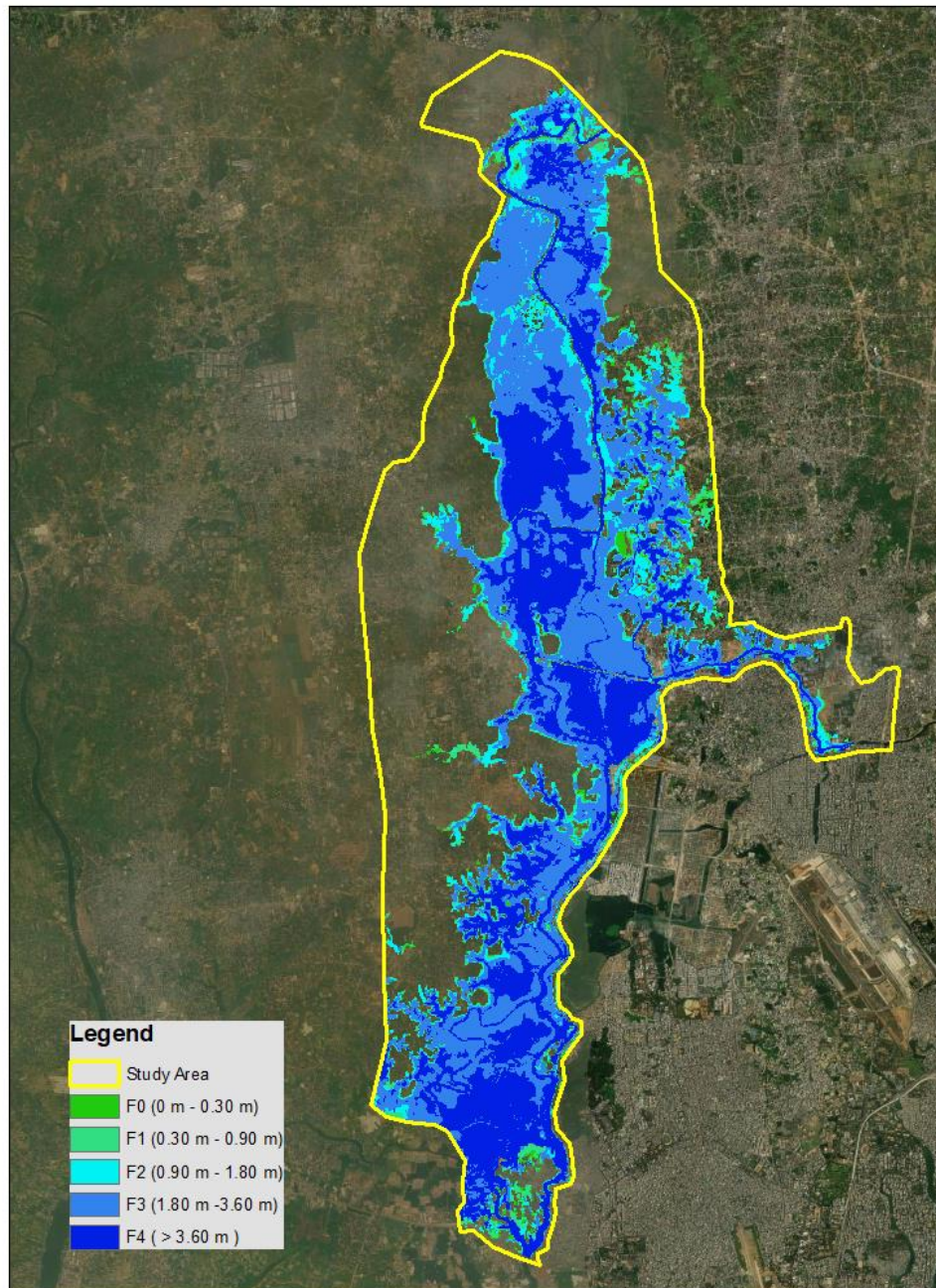


Figure 5.12: Model Generated 2.33 year Return Period Flood Depth Classification Map

1988 Flood Depth Classification Map

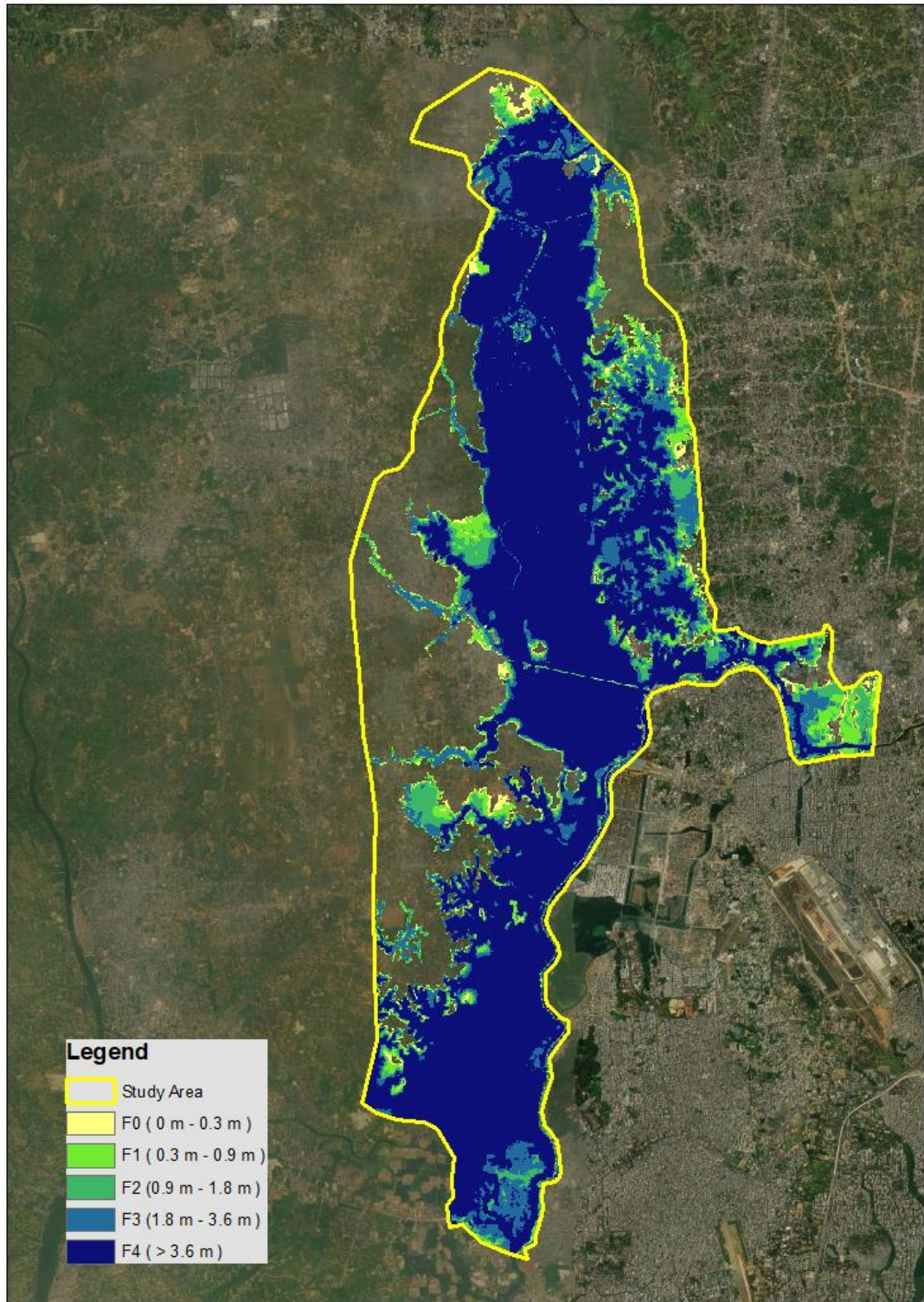


Figure 5.13: Model Generated 1988 (equivalent to 100 years Return Period) Flood Depth Classification Map

Table 5.2: Comparison of Classified Flood Depth Extent for different flood scenarios (Model)

Flood Classification	% of Inundation Extent	
	2.33 year	1988 (equivalent to 100 year)
F0 (0m – 0.3m)	2.80	2.79
F1 (0.3m – 0.9m)	5.76	5.90
F2 (0.9m – 1.8m)	10.17	7.82
F3 (1.8m – 3.6m)	45.17	14.12
F4 (> 3.6m)	36.10	69.37

DAP (2022 - 2035) Proposed
1988 Flood Depth Classification Map

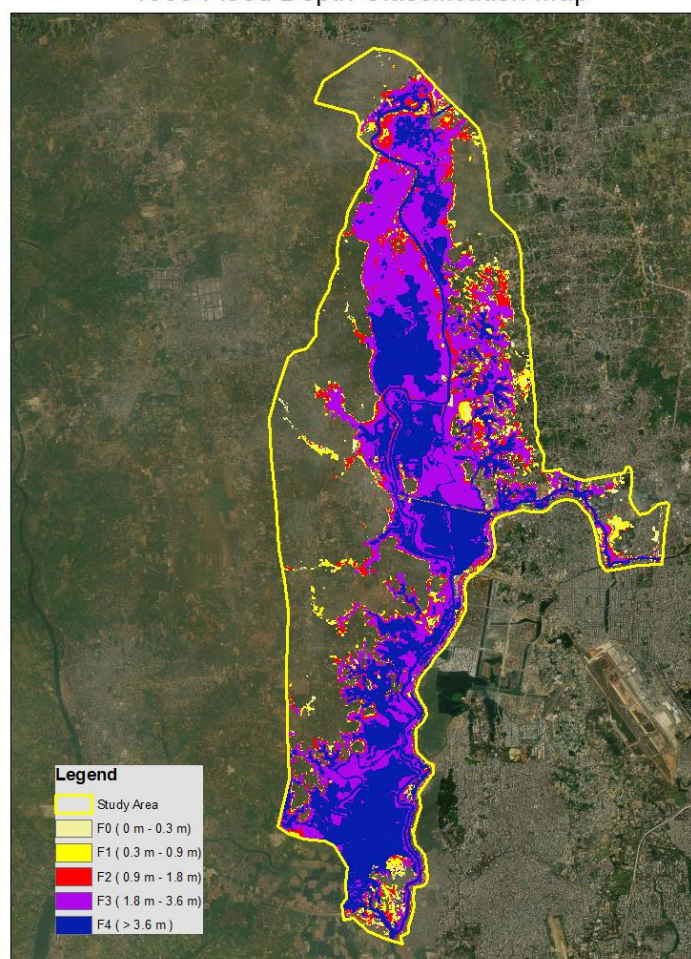


Figure 5.14: DAP (2022-2035) Proposed 1988 Flood Depth Classification Map

Table 5.3: Comparison of Classified Flood Depth Extent between Model Generated 1988 Flood and DAP (2022-2035) Proposed 1988 Flood

Flood Classification	% of Inundation Extent	
	1988 Flood (Model)	1988 Flood (DAP)
F0 (0m – 0.3m)	2.79	3.14
F1 (0.3m – 0.9m)	5.90	6.06
F2 (0.9m – 1.8m)	7.82	9.22
F3 (1.8m – 3.6m)	14.12	38.91
F4 (> 3.6m)	69.37	42.64

The Figure 5.12, 5.13 and table 5.2 show that with the extreme flooding events, the inundation extent/ area increases for deeper flood depth in Model. The Figure 5.14 and Table 5.3 show that for the extreme flooding events (1988), the inundation extent/ area increases with deeper flood depths both in Model and in DAP (2022-2035). But, for extreme flooding event (1988), the percentage of inundation extent in study model is different than that of the DAP (2022-2035) for different flood depths. It was shown that the percentage of inundation extent for deeper flood depth (> 3.6m) in Model (69.37%) is higher than that of the DAP (2022-2035) (42.64%) for extreme flooding event (1988).

5.1.1.4 Comparison of Model Generated Flood Flow with DAP (2010-2015), Dhaka Structure Plan (2016-2035) and DAP (2022-2035) Proposed Flood

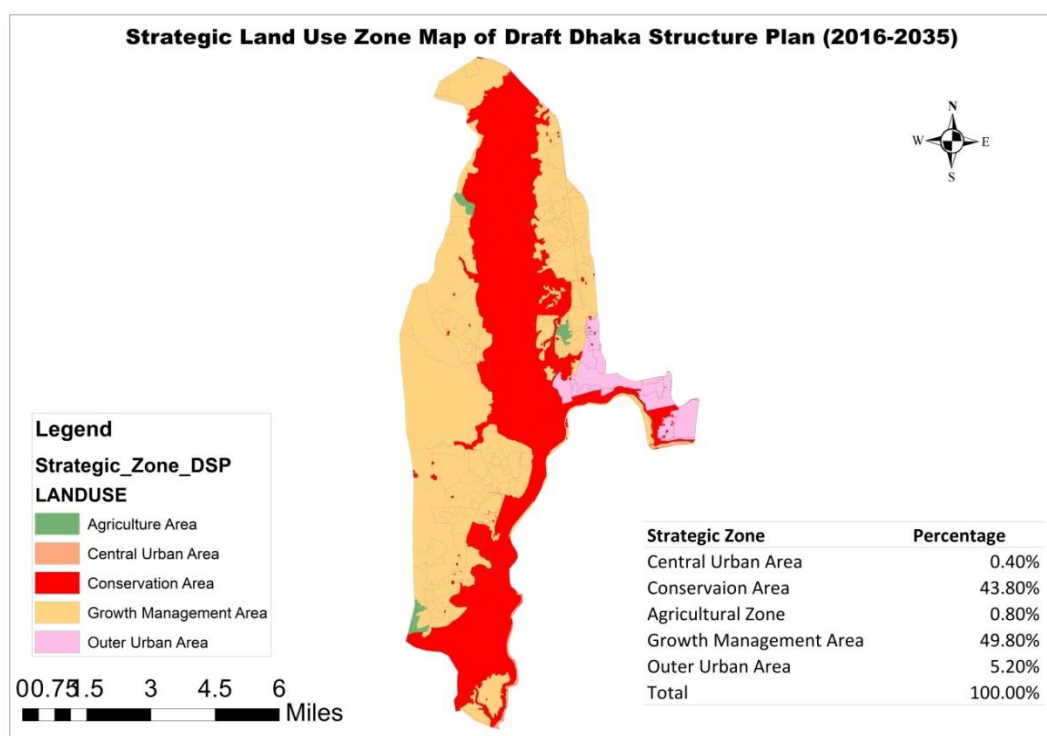


Figure 5.15: Strategic Land use zone Map of Dhaka Structure Plan (2016-2035)

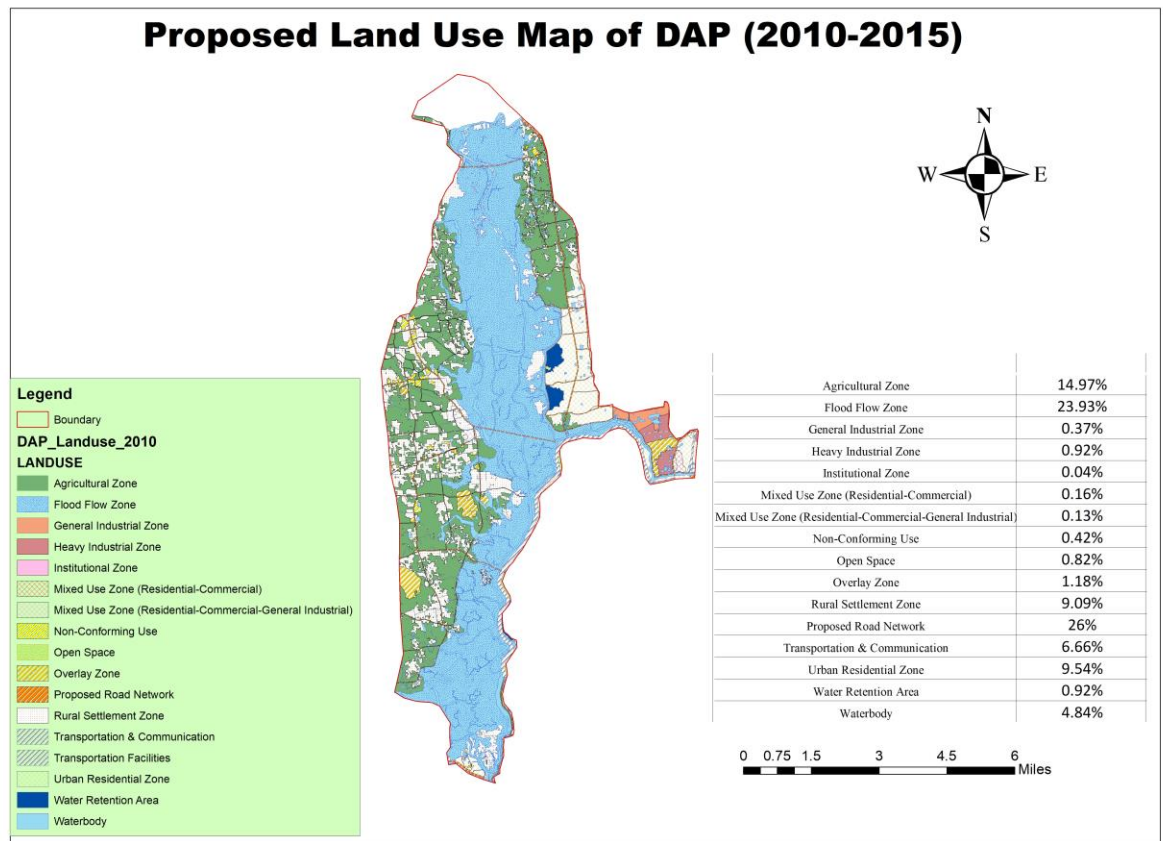


Figure 5.16: Proposed Land use Map of DAP (2010-2015)

Table 5.4: Comparison of Model Generated Flood with DAP (2010-2035) Proposed, Structure Plan (2016-2035) Proposed and DAP (2022-2035) Proposed Flood

Flood Overlay Area		Model Generated	DAP (2010-2015) Proposed	Structure Plan (2016-2035) Proposed	DAP (2022- 2035) Proposed
		(% of Total)	(% of Total)	(% of Total)	(% of Total)
Flood Flow Area (Flood Flow Zone, River, Water body, Water Retention	i) Main Flood Flow (Conservation Area)	31.51	29.69	43.80	32.58
	ii) General Flood Flow	19.14	-	-	16.01

Area)	(Only Infrastructure/ civic amenities Permitted Conditionally)				
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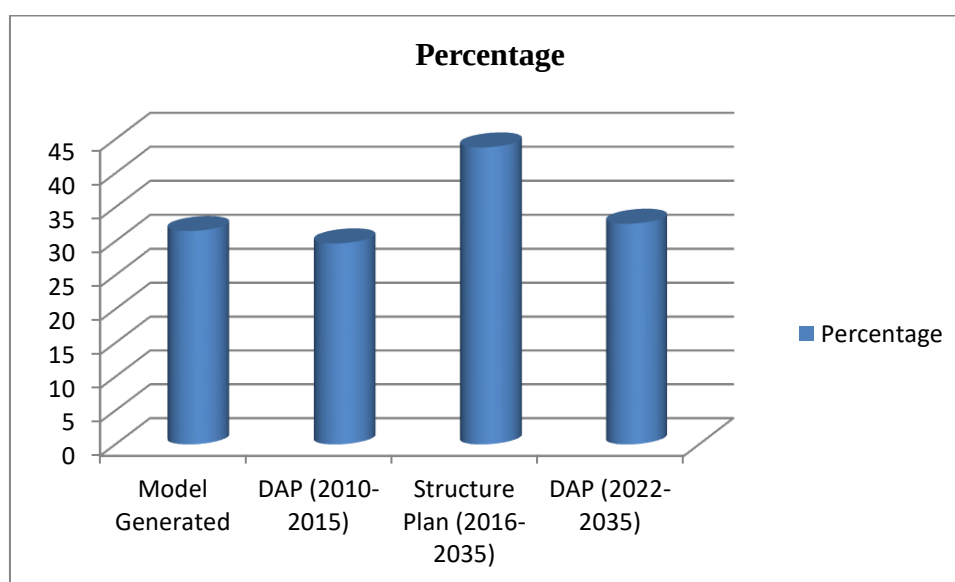


Figure 5.17: Comparison of Percentage of Main Flood Flow area (Conservation Area) in Model generated and three successive plan proposals

From the figure 5.15, 5.16, 5.17 and Table 5.4, it is shown that the percentage of main flood flow area (conservation area) in Model Generated, DAP (2010-2015) proposed, Structure Plan (2016-2035) proposed and DAP (2022-2035) proposed is 31.51%, 29.69%, 43.80% and 32.58% respectively.

5.2 Discussion

The policies/proposals of Dhaka Structure Plan (2016-2035) and Detailed Area Plan (DAP) (2022-2035) on Drainage and Flood Management of the study area were critically evaluated from the multi-benefit approach with the outputs/results derived from hydrological and hydrodynamic analysis. The findings of the evaluation are described below.

5.2.1 The flood flow zone is divided as Main flood flow zone and General flood flow zone in DAP (2022-2035). *The flood zone considering floods at normal/average flooding event (2.33 year return period) is termed as Main flood flow zone and the flood zone considering floods at extreme flooding event (100 year return period) is termed as General flood flow zone.* Main flood flow zone is conservation zone; no land filling/construction activity is permitted in the zone whereas only infrastructure/civic amenities are permitted in the General flood flow zone according to the development management guidelines of DAP (2022-2035). This approach to flood zone in DAP (2022-2035) is similar to that of the Dhaka Structure Plan (1995-2015), where the flood flow zone is divided as main flood flow zone and sub flood flow zone but different from the Dhaka Detailed Area Plan (DAP, 2010-2015) and Dhaka Structure Plan (2016-2035), where there are no divisions of flood flow zones. In Dhaka Detailed Area Plan (DAP, 2010-2015), main flood flow zone and sub flood flow zone are merged into a single zone namely flood flow zone and in Dhaka Structure Plan (2016-2035), there is also a single zone regarding flood flow zone namely conservation zone. No development is permitted in flood flow zone/conservation zone according to the development management guidelines of the two plans.

5.2.2 It is found that the percentage of main flood flow zone in DAP (2022-2035) (32.58%) is close to the percentage of main flood flow zone derived from the study model simulation (31.51%). But, the connectivity network, position and alignment of main flood flow zone in flood map of the study model is different from those in flood map of DAP (2022-2035) and Dhaka Structure Plan (2016-2035). Besides this, for extreme flooding event (1988), the percentage of inundation extent in study model is different from that of the DAP (2022-2035) for different flood depths. There may be some differences because boundary condition and catchment extent of model for hydrodynamic analysis are different for study model and DAP (2022-2035). In DAP (2022-2035), water level has been used as boundary condition but in study model, both water level and discharge has been used as boundary condition although base DEM is same for both DAP (2022-2035) and study model. Also, catchment extent in DAP (2022-2035) is larger than in the study model.

It is also found that the percentage of main flood flow zone in DAP (2022-2035) (32.58%) is greater than the percentage of the flood flow zone in DAP (2010-2015) (29.69%). It seems apparently good that the latest plan (DAP, 2022-2035) has more/ larger amount of main flood flow zone than the previous plan (DAP, 2010-2015) but it is less likely to conserve a small portion of main flood flow zone of DAP (2022-2035) because of the following errors in delineating main flood flow zone of DAP (2022-2035).

- **The main flood flow zone is not connected in some areas.** Some island like and irregular or zigzag shaped lands with higher elevation have been demarcated within main flood zone and shown as general flood flow zone/ general flood plain area where some form of development activities are permitted according to plan. It was observed that in most of the cases those lands were elevated/ developed by sand filling but not belonged to old settlements/villages. If development permission is given on those lands according to the plan and development starts in a full swing, then the negative impact of the development will be extended to the surrounding flood flow zone areas and it is difficult to conserve the flood flow zone.

It was also observed that in case of DAP (2010-2015) and Dhaka Structure Plan (2016-2035), the flow path of the flood flow zone/conservation zone was continuous and connected.

- The position and alignment of main flood zone have been shifted from the previous plan in some areas. The position and alignment of main flood zone of DAP (2022-2035) have been shifted in some areas from Dhaka Structure Plan (2016-2035) and Dhaka Detailed Area Plan (2010-2015). Some areas which were not included as flood flow zone in DAP (2010-2015) were demarcated as main flood flow zone in DAP (2022-2035). Whereas, some areas which were included as flood flow zone in DAP (2010-2015) were not included as main flood flow zone in DAP (2022-2035). If the position and alignment of main flood flow zone of a river under a plan become changed/ shifted from the previous plan, then the plan loses its acceptability in moral and legal grounds and people are unwilling to follow the plan which goes against the conservation of the flood flow zone.

5.2.3 It was observed that the flood plain overly map in DAP (2022-2035) had been prepared by hydro-dynamic analysis based on the existing/latest available DEM (year 2014, updated in year 2018 by field verification). The area which were not converted to urban uses and found low lying/depressions during survey/DEM preparation stage, were demarcated as main flood flow zone in DAP (2022-2035) whereas the area which were low lying areas/depressions before but converted to urban uses later and found high land during survey/DEM preparation stage, were demarcated as flood free/general flood flow/general flood plain where some form of development activities are permitted according to the plan. As DEM is the discrete representation of land surface elevation, so the DEM considered for hydro-dynamic analysis in DAP (2022-2035), represented the existing ground elevation which reflected the existing development pattern also. As existing development pattern was unplanned and existing DEM only reflected the existing scenario, so flooding pattern in main flood flow zone in DAP (2022-2035) based on existing DEM reflected the existing unplanned development pattern which is the main reason for discontinuity and shifting of the position and alignment of the main flood flow zone from the previous plan.

The flood plain overlay map that reflected the existing scenario/unplanned development pattern shouldn't have been followed in DAP (2022-2035). Existing scenario/unplanned development pattern was the outcome of the unauthorized development practices due to contravening plan guidelines. If unauthorized activities are exempted/ regularized through plans without compensation it is hardly possible to be conserved a small portion of main flood zone in future.

An oldest available DEM of the study area should have been considered as standard DEM for hydro dynamic analysis of DAP (2022-2035). As existing land development scenario is always changing with time, if proposed flood flow zone of a plan is prepared based on existing DEM, then the amount, position and alignment of the proposed flood flow zone of the plan must be changed from the previous plan that will go against conservation of the flood flow zone. The following scenarios should have been taken into consideration for preparation of proposed main flood flow zone in DAP (2022-2035).

- i) **Scenario-1: Floods at normal/average flooding event (2.33 year return period) based on a standard/oldest available DEM.** An oldest available DEM as standard DEM should have been considered for hydro dynamic analysis when flood flow Zone of Turag River was in its pristine/original condition (without occupation). Besides this, it is better to consider the standard/oldest available DEM after 1990, as Dhaka western embankment was constructed in 1990 and the ecosystem of the surrounding areas was changed after 1990 by the impact of the embankment.
- ii) **Scenario-2: Floods at normal/average flooding event (2.33 year return period) based on existing/latest available DEM.**
- iii) **Scenario-3: Floods at normal/average flooding event (2.33 year return period) based on existing/latest available DEM with modifications by analyzing DEM of scenatio-1 and scenario-2.** As for example, in case of considering ground elevation of a developed land with illegal sand filling, the original low elevation of the land before sand filled should be considered.

5.2.4 If existing unplanned/scattered pattern of development is continued, then some form of structural interventions will be necessitated in future to safeguard the developed portion from flooding. As for example, embankment along the west bank of Turag River may be required to be constructed. It was observed from the field investigation and hydro dynamic analysis that the structural intervention to mitigate flood risk such as embankment construction can't reduce volume of water rather shifts flooding problem from one place to another. Besides this, it is economically infeasible to construct embankments on both sides of all the rivers.

Structural intervention also limits the natural hydrological functions/ benefits of flood flow zones such as storing excess floodwaters, improving water quality, providing habitat for fish during inundation and supporting a multitude of cultural services.

5.2.5 From the field investigation under the present study, it was observed that insecurity in land ownership/ tenure rights due to threat of forced eviction was the root cause for the irreversible conversion of flood plains/agricultural lands to non-agricultural uses in the region. From the sample survey it was found that most of the land owners (85%) were the

outside owners who came from outside of the locality and represented mainly the elite classes. Out of the owners from outside who bought agricultural lands, majority of them (98%) had bought the agricultural land having intention to use the land as residential/industrial purposes in future. The unwillingness of the outside land owners to conserve their lands as flood plains/agricultural uses acts as restraining forces for conserving flood plains.

5.2.6 Bangladesh government declared Turag River with three other Rivers around Dhaka city as ecologically critical area in 2009 after a High court judgment of 2009 to restore Turag River in its original state. Another High court judgment was also delivered in 2019 to declare Turag River with all other rivers of Bangladesh as a legal/juristic person or a living being to save the river from illegal encroachment and pollution. But, the two judgments of High court were violated. Illegal encroachment and pollution can't be controlled although those activities are prohibited by the laws of government like-Playgrounds, park, open space and water bodies conservation act, 2000, Environmental conservation Act, 1995 (amended 2010), Bangladesh Water Act, 2013, Ecologically Critical Area Conservation Rules, 2016 etc.

A river and its flood plain are not separate entity rather they should be treated as single entity and be connected for each other's survival. Disconnected and changing pattern of flood plains can't deliver their ecosystem services and functions. A river-flood plain ecosystem, if conserved, delivers innumerable ecosystem services/benefits (use or non-use, direct or indirect, tangible or intangible) and adds values (ecological/environmental, socio-cultural, spiritual, aesthetic and recreational, economical etc.) to the national/local economy of the country. For example, huge savings of government money for avoiding investment for structural measures because of natural flood protection (ecological services/functions). But most of the time ecosystem services/benefits are not noticeable and people are not aware about the ecosystem services/benefits and their associated values. If a river-flood plain ecosystem is conserved in its original state, then it is possible to be captured the values of the ecosystem services and benefits to their maximum capacity.

It was observed from the study that flood flow zones/flood plains are used as dry season agriculture. But agricultural activities are not considered as profitable as housing or industrial development. Price of agricultural land goes up only when there

is any development initiative adjacent to the agricultural land. Market price of agricultural land is determined/measured by its direct use value only such as productivity, profitability etc. of agricultural uses. As indirect use values are immense and are ignored in estimation, so the market price of agricultural land is always far below than its actual value. Still now, there has been no system developed for estimating/quantifying the actual value (monthly/annual direct and indirect value) of flood plains/agricultural lands. Although Flood plains/agricultural lands add innumerable values (direct and indirect) to the economy of the country but locals, who play vital role in value addition get a very insignificant portion of it. It is also irony that although national or local economy is benefited a lot from the ecosystem services, but incentives or financial assistances from Government side to protect/boost up the local economy dependent on local resources (agriculture etc.) are very insignificant. At the same time, the elite sections of the society having intention to maximize profit are taking the chance of the miserable condition of the local people and are engaged in some illegal/deceitful practices and thereby destroying the socio-ecological structure of the locality.

5.2.7 Up to 10% building coverage is permitted for any parcel of agricultural land according to DAP (2022-2035) which contradicts with the National land use policy (2001) of Bangladesh. This type of development approach encourages scattered or unplanned development and is threatening for food security. In course of time, vast tract of agricultural land will be converted to urban areas because development works wouldn't be confined in the permitted area (i.e. 10%) only if demand increases. Infrastructure demands will necessitate exceeding the limit. Eventually, rest of the agricultural lands will lose their fertility/productive capacity due to pollution from scattered settlements and other anthropogenic activities and will not capable to deliver their ecosystem services. The land management tools proposed in Dhaka Structure Plan (2016-2035) and DAP (2022-2035) like land consolidation and land readjustment approach for conservation of agricultural land/flood plains needs to be applied as new concept for Dhaka.

5.2.8 The technique of creating local retention/detention ponds during land development through Dig and mound method of settlement pattern has been adopted in DAP (2022-2035). According to DAP (2022-2035), Dig and Mound method will be

applicable for land development if the amount of land applied is 2 bighas or more for individual applicant and 1 bigha or more for institutional applicant in General Flood Flow Area; if the amount of land applied is 2 acres or more for individual applicant and 1 acre or more for institutional applicant in General floodplain and Flood-free Area. But, if the land size is below 2 bigha for individual applicant in General Flood Flow Area and below 2 acre for individual applicant in General floodplain and Flood-free Area, Dig and Mound method is not applicable. It means that Dig and Mound method is not applicable for land development of small sized lands (< 2 bigha) according to DAP (2022-2035). Due to land fragmentation over time, as most of the lands in the study area are very small in size with respect to land ownership/rights, the approach followed in DAP (2022-2035) for creating local retention ponds through Dig and Mound method during land development of large sized lands (> 2 bigha), is not effective.

Over thousands of years, people living in Bengal delta learned how to live with rivers and adjusted their lives to the deltaic conditions of the land. In settling on flood plains, the people of Bengal delta always sought out high patches of land to construct dwellings and used the rest for farming. When such high patches were not available, they dug ditches and used the excavated earth to elevate the land and constructed houses thereon. This is the ‘Dig and Mound’ method of settlement pattern. Numerous ponds, beels and dighis which one can still see in Bengal delta, were created through this method. But presently, as most of the landholding size with respect to land ownership is very small in the study area like other areas of Bengal delta, so local retention ponds at individual level are hardly creating by this approach.

DAP (2022-2035) didn’t identify the locations of proposed local retention/detention ponds at mouza plot (records of land rights) level. Area based action plan of government was required to be prepared to identify locations of proposed local retention/detention ponds but it was not taken. In the circumstances, Government intervention is necessary to take necessary measures for identification and conservation of proposed/new local level retention/detention ponds.

CHAPTER 6: CONCLUSION

6.1 Key Findings:

- 1) The percentage of main flood flow zone in DAP (2022-2035) (32.58%) is close to the percentage of main flood flow zone derived from the study model simulation (31.51%). But, the connectivity network, position and alignment of main flood flow zone in flood map of the study model is different from those in flood map of DAP (2022-2035) and Dhaka Structure Plan (2016-2035). For extreme flooding event (1988), the percentage of inundation extent in study model is different from that of the DAP (2022-2035) for different flood depths.
- 2) In the flood map of DAP (2022-2035), the main flood flow zone is not connected in some areas and the position and alignment of main flood zone have been shifted in some areas from Dhaka Structure Plan (2016-2035) and Dhaka Detailed Area Plan (2010-2015). But, both in Dhaka Structure Plan (2016-2035) and Dhaka Detailed Area Plan (2010-2015), the flow path of main flood flow zone is connected and continuous.
- 3) Flood plain overly map in DAP (2022-2035) had been prepared by hydro-dynamic analysis based on the existing/latest available DEM (year 2014, updated in year 2018 by field verification), But, no past/oldest available DEM before the existing/latest DEM was used for hydro-dynamic analysis in DAP (2022-2035). As existing development pattern was unplanned and existing DEM only reflected the existing scenario, so flooding pattern in main flood flow zone in DAP (2022-2035) based on existing DEM reflected the existing unplanned development pattern which is the main reason for discontinuity and shifting of the position and alignment of the main flood flow zone from the previous plan.
- 4) It was observed that insecurity in land ownership/ tenure rights due to threat of forced eviction was the root cause for the irreversible conversion of flood plains/agricultural lands to non-agricultural uses in the region.
- 5) Flood plains/agricultural lands add innumerable values to the local or national economy of the country but most of the time people are not aware of those values. Especially indirect values are not noticeable. Price of flood plain/agricultural land is determined/ measured by its direct use value only. Till now, there has been no

system developed for estimating/quantifying the actual value (direct and indirect value) of the flood plains/agricultural lands. Although national/local economy is benefitted from the added values (direct and indirect) of the flood plains/agricultural lands but locals, who play vital role in the value addition, get a very insignificant portion of it and lack all kind of administrative, financial and legal support from the government side.

- 6) Dig and Mound method is not applicable as a condition for permitting land development of small sized lands (< 2 bigha) according to DAP (2022-2035). Due to land fragmentation over time, as most of the lands in the study area are very small in size with respect to land ownership/rights, the approach followed in DAP (2022-2035) for creating local retention ponds through Dig and Mound method during land development of large sized lands (> 2 bigha), is not effective.

6.2 Recommendations:

Some recommendations are summarized below which need to be considered in adopting plans/policies/programs/projects of government and private organizations regarding drainage and flood management.

- 1) The principle of ‘least resistance’ approach should be followed for road and infrastructure development in flood plains. Construction of roads and embankments in flood plains obstruct free passage of water and therefore aggravate flooding condition. So, Development of road and other infrastructure should be avoided in the flood plains but in case of no other alternatives available, development of road and other infrastructure should be done through viaduct.
- 2) Embankment approach to flood control should be avoided. Embankments don’t reduce total volume of water. They just transfers flooding problem from one place to another. They save lives of a community at the cost of lives of other community.
- 3) The appropriate flood control approach is to open up as much space as possible to accommodate river overflow. This follows from simple arithmetic: given the volume of water and gradient, the height of flooding decreases proportionately with the increase of area over which water can spread. This is a strategy of not flood prevention but of flood mitigation. This approach is based on the principle

of living with floods and getting benefit from them.

- 4) The approach of delineating proposed main flood flow zone in DAP (2022-2035) by hydro-dynamic analysis based on only existing/latest available DEM without considering any previous DEM before existing DEM is not justifiable. Because, existing DEM only reflects the existing scenario, so flooding pattern in main flood flow zone based on existing DEM will also reflect the existing scenario. In case of existing unauthorized development, this approach does not consider the negative impacts of unauthorized development rather legitimizes it. Flood map by hydro-dynamic analysis based on existing/ latest DEM may be considered as one scenario. But, hydro-dynamic analysis for delineating main flood flow zone should be based on analyzing at least two DEMs, one- an oldest/previous available DEM considered as standard DEM of the period when flood plain occupation was at a minimum level and the other-the existing or latest DEM.
- 5) Flood management strategies should be taken in such a way that flood protection will not be the only goal rather multiple ecosystem benefit approach should be considered. It should be kept in mind that flood protection is one of the enormous ecosystem services and benefits.
- 6) Conservation of flood plain delivers enormous ecosystem services and benefits to the society and adds tons of values to the economy but most of the ecosystem services and benefits, as for example carbon sequestration, are not visible to the general people although they exists and are not quantified in economic terms. Besides this, although tons of values are added to the local/national economy from conservation but locals/marginal people don't get the benefits of the added values. In this situation, Government should provide sufficient financial, legal and administrative support/protection to the locals/marginal people so that they can boost up their economy by utilizing/managing valuable local natural resources (such as farming, fishing etc.) to their maximum capacity. By this approach, the livelihood and economy of the local people will be secured and at the same time ecosystem/floodplain conservation will be done.
- 7) It is necessary to adopt land pooling/readjustment approach for development of peripheral areas especially when public funds are not adequate for compulsory purchase and provision of infrastructure.

- 8) Clustering or consolidation (compact township) is a powerful land management instrument where scattered or fragmented land holdings are agglomerated that allows for the improvement of the agricultural holdings or rural settlements with increasing their economic and social efficiency. Such approach may be helpful in several ways.
- ❖ Much of agricultural land will be available when the traditionally dispersed rural landscape transforms into compact form.
 - ❖ If these are concentrated rather than widely scattered, it will be simpler to raise the ground level and protect homes from flooding or inundation.
 - ❖ Consolidation reduces impediments to water flow in the floodplain. Flood protection resources such as huge money needed for construction of embankment can subsequently be saved and the natural ecology of the delta can be restored.
 - ❖ It is much easier, economic, and land-saving for provision of infrastructure such as road connectivity when settlements are consolidated than when dispersed.
 - ❖ Finally, consolidation may be helpful in planning and organizing collective efforts on the part of the residents such as flood shelter.
- 9) In order to facilitate Dig and mound method of settlement pattern, Area based Action plan is required to be taken by government to determine location/boundary of required proposed local retention/detention ponds and to take measures to create and conserve the local retention ponds.
- 10) To save Turag river-flood plain from gradual extinction, a project for restoration of Turag river-flood plain ecosystem is required to be taken immediately by government in a holistic approach. Under the proposed project the following major tasks need to be considered:

Tasks:

- ❖ All private lands in the designated Conservation zone in Dhaka Structure Plan (2016-2035) have to be acquired by government to facilitate restoration. After acquisition, all lands have to be leased out to the local community/co-

operatives on condition that they will restore and utilize ecosystem services and functions (such as farming, fishing, eco-tourism etc.) to get maximum benefits from them. Government should assist local community to form different co-operatives such as farmers' cooperative, fishermen cooperative etc. so that they become organized and can't be exploited. The project must restore and secure the livelihood of the local community especially the marginalized farmers and fishermen. Uninterrupted flood flow path should be ensured and for this, encroachments or land filling obstructing flood flow should be removed.

- ❖ To take measures to control pollution of Turag river-flood plains. To relocate haphazard and polluting industries to the designated Economic zone or Industrial zone in DAP (2022-2035).
 - ❖ Compact Township in different locations of the study area should be implemented. All existing communities have to be accommodated within the township. Existing rural settlement areas should be considered for Compact Township. The Compact Township should be implemented through land readjustment technique and no compulsory land acquisition initiatives should be taken within the Township. Besides this, all developments must be confined within the township and no development/ construction outside the compact township should be allowed.
 - ❖ For cost recovery of the project, any kind of site and service scheme or housing development within the conservation zone/main flood flow zone should be prohibited.
- 11) Improving environmental flow and riparian ecosystem development, as well as altering geomorphology to promote habitat, are the best methods that may be used in the Turag River region to restore its ecosystem.
 - 12) Mitigation of water pollution requires enforcement by the concerned authority for the industries to establish and operate Effluent treatment plant (ETP) and Sewage Treatment Plant (STP) for clean disposal of wastes.
 - 13) Eco-environmental Compensation Fees should be levied on the persons/organizations responsible for environmental degradation.

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Appendix

[Household Survey Questionnaire]

[N.B.: This questionnaire is only for academic purposes. All the information collected under the MSc Eng. Thesis Work entitled “EVALUATION OF DRAFT DHAKA STRUCTURE PLAN (2016-2035) REGARDING DRAINAGE AND FLOOD MANAGEMENT: A CASE STUDY ON TURAG RIVER AND ITS CONTRIBUTORY AREA”.]

Mouza/Location Name.....Thana.....		District.....
Name.....		Age.....
Gender:	☐ Male ☐ Female	Family member:
Employment status:	☐ Employed ☐	☐ Unemployed
Level of education	☐ No Education ☐ Primary Level ☐ High school/college ☐ Bachelor ☐ University ☐ Others	
Land ownership pattern	☐ Owner ☐ Tenant	
Type of House/ Structure	☐ Pucca ☐ Semi pucca ☐ Kutchha ☐ Jhupri	

1. What is the primary occupation of your household?

☐ Crop Production	☐ Home worker
☐ Business	☐ Manufacturing/Industrial worker
☐ Livestock production	☐ Day laborer

☐ Fishing	☐ Others
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2. Have your primary household occupation been changed over last 30-40 years?
Please indicate the shift in occupation over time.

3. What is the monthly income of your household? Please indicate.

4. What is the present local market price of land for different land use types such as residential/ commercial/ industrial/ agricultural use of your locality? Please indicate.

5. How have you gained/acquired ownership of your land (if the interviewee is land owner)? Please indicate.

6. What is the present use and local market price and the future expected use and price of your land (if the interviewee is land owner)? Please indicate.

7. What is the land holding size in terms of ownership rights and possession? Please indicate.

8. What are the different resources, the sources of the resources and the different categories of people who collect those resources of your locality? Please indicate.

9. Does government or any other organizations provide any fund or incentives to the local community to maintain their economic activity dependent on local resources? Please indicate.

10. What are the different negative/restraining forces for exercising land/property ownership/tenure rights in your locality? Please specify.

11. What are the different sources of pollution? Please indicate.

12. What are the impacts of illegal land filling or pollution in your locality? Please indicate.

13. Do government agencies provide any legal or administrative support to the local community in case of insecurity due to forced eviction or illegal occupation/possession of land by vested quarters? Please specify.

14. In case of acquiring private lands by government, are proper compensation and rehabilitation measures taken by government? Please indicate.

15. What is the likelihood of flooding in your locality? Please indicate.

16. What is the maximum duration of staying flood water (in days) during flooding? Please indicate.

17. What is the water level for regular/normal flooding in your locality? Please indicate.

18. What strategies will be suitable for the potential flood risk reduction? Please indicate.

19. Which plants and animals have disappeared from your locality in the recent past? Please indicate.

Thanks for Your Cordial Cooperation

.....

Signature of the Interviewer

.....

Signature of the Interviewee