URBAN DEVELOPMENT DIRECTORATE (UDD)
Ministry of Housing and Public Works
Government of the People's Republic of Bangladesh

PREPARATION OF PAYRA-KUAKATA COMPREHENSIVE PLAN FOCUSING ON ECOTOURISM

Report on the Efficiency of Existing Drainage System and Land Use Planning Guidelines considering Hydrological Situation of the Project Area

June 2022

Institute of Water and Flood Management

Bureau of Research, Testing and Consultation
Bangladesh University of Engineering and Technology

Contents

1 INTRODUCTION

1.1 Background

Kuakata, locally known as Sagar Kannya (Daughter of the Sea) is a sea beach of rare scenic beauty on the southernmost tip of Bangladesh. The most important attraction of the beach is that one can see both sunrise and sunset from some of its locations. Situated 320 km from DHAKA and 70 km from the PATUAKHALIdistrict headquarters, Kuakata is part of the Latachapli union of KALAPARAupazila. The best way to reach Kuakata from Dhaka is to first travel to BARISAL by road, water, or air, and then to take the bus or boat/launch for the destination. The Bangladesh Road Transport Corporation introduced a direct bus service from Dhaka to Kuakata via Barisal.

The name Kuakata originated from Kua-Well dug on the sea shore by the early Rakhine settlers in quest of collecting drinking water, who landed on the Kuakata coast after being expelled from Arakan by Mughals. Afterward, it has become a tradition of digging Kua-Well in the neighborhood of Rakhine homestead for the collection of water for drinking purposes and general use. The beach at Kuakata is 18 km long and 3 km wide. This sandy beach slopes into the BAY OF BENGAL. Other attractions at Kuakata include blue sky, a huge expanse of water, the evergreen forest in surrounding areas, rows of coconut trees, boats of many different kinds and their colorful sails, and surfing waves. The main tourist season is in winter but all over the year, tourists visit this place.

Kuakata is truly a virgin beach-a sanctuary for migratory winter birds, a series of coconut trees, a sandy beach of the blue bay, and a feast for the eye. Forest, boats plying in the Bay of Bengal with colorful sails, fishing, towering cliffs, surfing waves everything here touches every visitor's heart. The unique customs and costumes of the 'Rakhine' tribal families and Buddhist Temple of about a hundred years old indicate the ancient tradition and cultural heritage, which are objects of great pleasure. Kuakata is the place of pilgrimage for the Hindus and Buddhist communities. Many people visiting Kuakata find interest in the Buddhist temples located at nearby places such as Keranipara, Misripara and Amkholapara, while many others find the place interesting because of the unique customs and traditions of the Rakhine community. Kuakata is also a place of pilgrimage for Hindus and Buddhists. Devotees arrive here during the festivals of Rash Purnima and MaghiPurnima. A major ritual on these occasions is dipping in the holy waters of Kuakata. Visitors also enjoy the traditional fairs organized to mark these celebrations.

The study area consists of seven Upazilas in Barguna and Patuakhali Districts namely Patharghata, Amtali, Taltali and Barguna Sadar Upazilas of Barguna District and Galachipa, Kalapara and Rangabali Upazilas of Patuakhali District (Figure 1.1). The coastal plains of Bangladesh are subject to tidal inundation twice a day by the semi-diurnal tide originating from the Bay of Bengal. During the low flow season, the tide penetrates far inland. The whole area is predominantly under tidal influence throughout the year. The area has been formed by a sedimentary deposit in the recent geologic time by the Ganges-Brahmaputra system. The area is highly vulnerable due to hydrological hazards especially monsoon floods and coastal floods. Coastal floods can arise from tidal floods as well as storm surge-induced floods. The area is also vulnerable due to extreme precipitation, especially during cyclones that occur during the pre-monsoon and post-monsoon periods. The extreme precipitation and storm surges can cause drainage problems in the area as well.

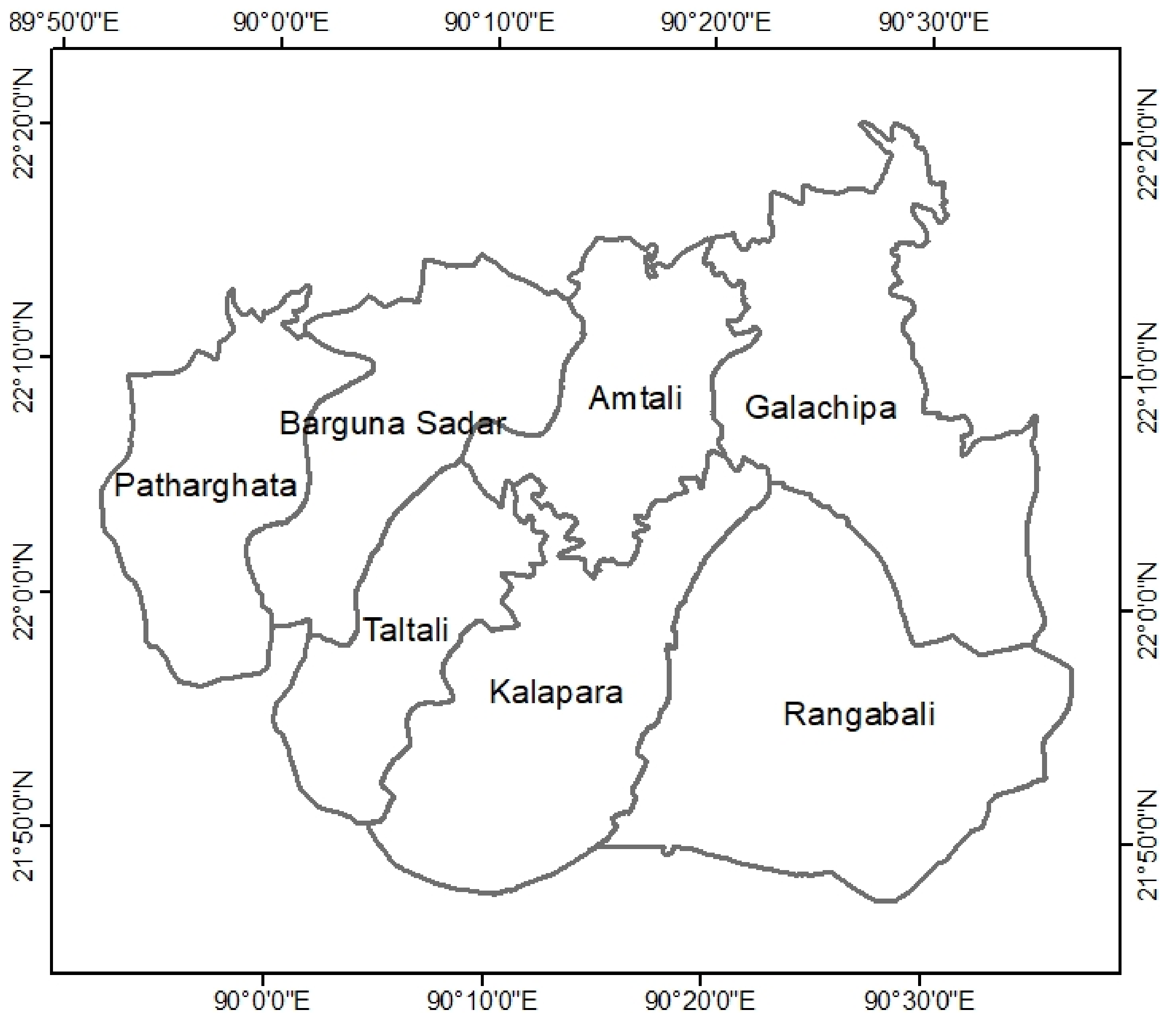


Figure 1.1: Project area showing seven Upazilas in Barguna and Patuakhali Districts.

1.2 Objectives of the Study

The objective of the project is to optimize coastal resources and activities for the sustenance of marginal people. The coastal activities and resources are very important to the economy and life of the people of Bangladesh whose living conditions are inextricably linked to the productivity and sustainability of the coastal zone. There is no long-term Holistic Development Plan for the coastal zone. The coastal zone needs to be integrated with the mainstream development process of the country. So, an interdisciplinary development planning approach is urgent to optimize the livelihood of the coastal zone. The Physical development planning problems, that need attention, are as follows:

(i) Translation of outputs from the upper-tier plan at Regional Plan to integrate coastal zone with the mainstream development process of the country.

(i) Assess functional and land use requirements for a Regional Plan in an area with hazard vulnerability.

(ii) Formulate Strategic Development Plan for Regional Plan considering functional and land use requirement with hazard vulnerability.

(iv) Formulation of urban area plan and action plan at the local level

1.3 Scope of Work

(i) To study sub-regional water resource systems;

(ii) To study the efficiency of the existing drainage system;

(iii) To prepare land use planning guidelines considering the hydrological situation of the project area;

(iv) To make a study on hydrological hazards of the area and prepare guidelines for hazard mitigation;

(v) to prepare flood prediction model of long, medium and short term (100, 50, 20, 5 and 2.33 year period) for Project area;

(vi) Formulate a regional drainage plan (retention areas, pumping station, etc.)

(vii) Any other related job assigned by the PD.

1.4 Approach and Methodology

Drainage and flood management are important considerations for assessing the development prospect of the project site. The hydrological assessment would be based on flood level analysis as well as drainage analysis. The flood analysis would focus on the estimation of the design flood level. The analysis involves the frequency analysis with different probability distribution functions for the selected design return period.

As the area lies in the coastal region facing the Bay of Bengal, the area is highly vulnerable due to hydrological hazards especially monsoon floods and coastal floods. Coastal floods can arise from tidal floods as well as storm surge-induced floods. The hydrological assessment would be based on flood level analysis as well as drainage analysis. The flood analysis would focus on the estimation of the design flood level. The analysis involves the frequency analysis with different probability distribution functions for the selected design return period. The historical data on annual peak water levels are used for the purpose. The water level data of the gage station nearest to the project site would be collected from the Bangladesh Water development Board. These data would be used to assess the extent of inundation due to floods. For flood inundation analysis, the topographic data in the form of a digital elevation model (DEM) would be required.

The area is also vulnerable due to extreme precipitation, especially during cyclones that occur during the pre-monsoon and post-monsoon periods. The extreme precipitation and storm surges can cause drainage problems in the area as well. The drainage analysis would require the estimation of design rainfall. The rainfall analysis involves the determination of intensity-duration-frequency (IDF) curves and the development of hyetographs. The IDF curves and hyetographs are used for rainfall-runoff analysis to estimate peak runoff rates. The IDF curves are used for rainfall-runoff analysis by the rational method. The rainfall intensity used is for a duration equal to the time of concentration. The time of concentration is the time required for a drop of water falling on the most remote part of the drainage basin to reach the basin outlet.

The gage station nearest to the project site is located at Khepupara and Patuakhali and is maintained by Meteorological Department (BMD). This station measures only daily rainfall. The daily rainfall data is available since 1974. These data would be processed and analyzed for developing IDF curves and hyetographs. The Extreme Value Type I (Gumbel) distribution would be used for the development of IDF curves for the different return periods. For flood inundation and drainage analysis, the topographic data in the form of a digital elevation model (DEM) would be required.

2 EFFICIENCY OF EXISTING DRAINAGE SYSTEM IN THE PROJECT AREA

2.1 Introduction

Rapid urbanization contributes to the increase of impervious areas which in return increases stormwater runoff peak and volumes. Rapid urbanization leads to intense land-use change and an increase in impervious surfaces (Guan et al., 2015). The increased runoff volumes and peak flows associated with faster response time result in urban flood risks (Zhou, 2014). In order to assess the efficiency of the existing drainage system, rainfall-runoff analysis is required.

2.2 Characteristics of Rainfall in the Study Areas

There are two rain gage stations in the project area namely Khepupara and Patuakhali. The rain gauge stations are maintained by Bangladesh Water Development Board. The mean annual rainfall in Khepupara and Patuakhali is 2607 mm and 2492 mm, respectively which are higher than the national average of 2300 mm. Annual rainfall shows considerable variability from year to year. The rainfall also varies considerably within a year (Figures 2.1 and 2.2), with 82% and 83% of rainfall occurring within the five months from May to September in Khepupara and Patuakhali, respectively. The mean annual one-day precipitation in Khepupara is 185 mm. Table 2.1 shows the rainfall statistics in the project area.

Table 2.1 Rainfall statistics in the project area

Parameter	Khepupara	Patuakhali
Total	2607	2492
Mean	217	208
Max	594	511
Min	6	6
Rainfall in May-Sep	2137	2061
% Rainfall in May-Sep	82%	83%

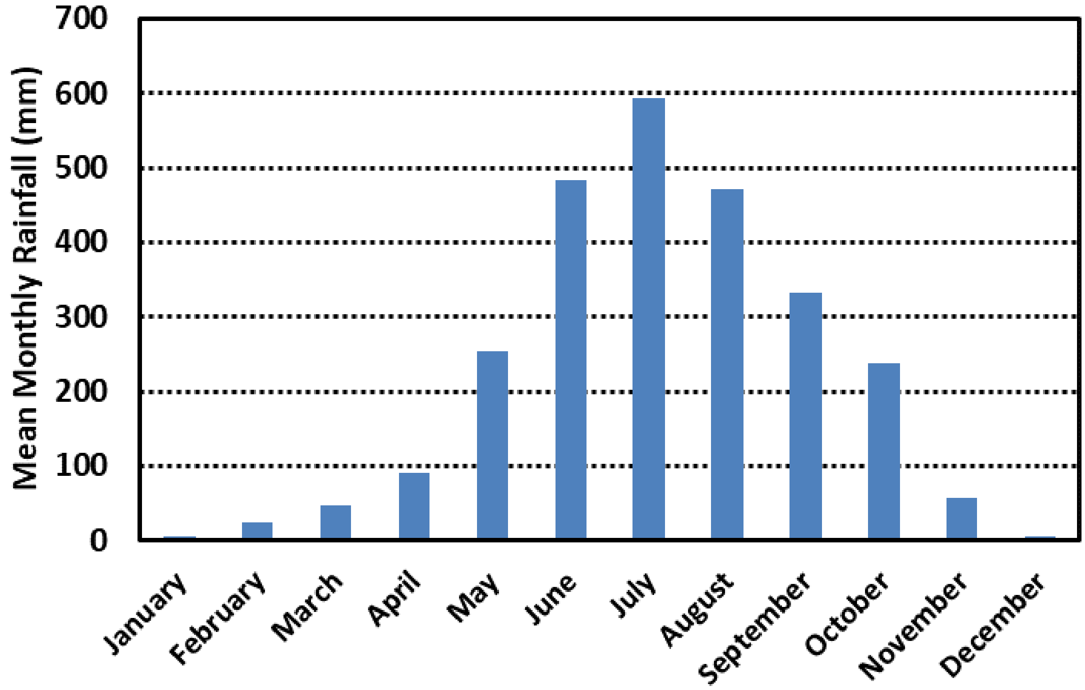


Figure 2.1: Distribution of mean monthly rainfall at Khepupara.

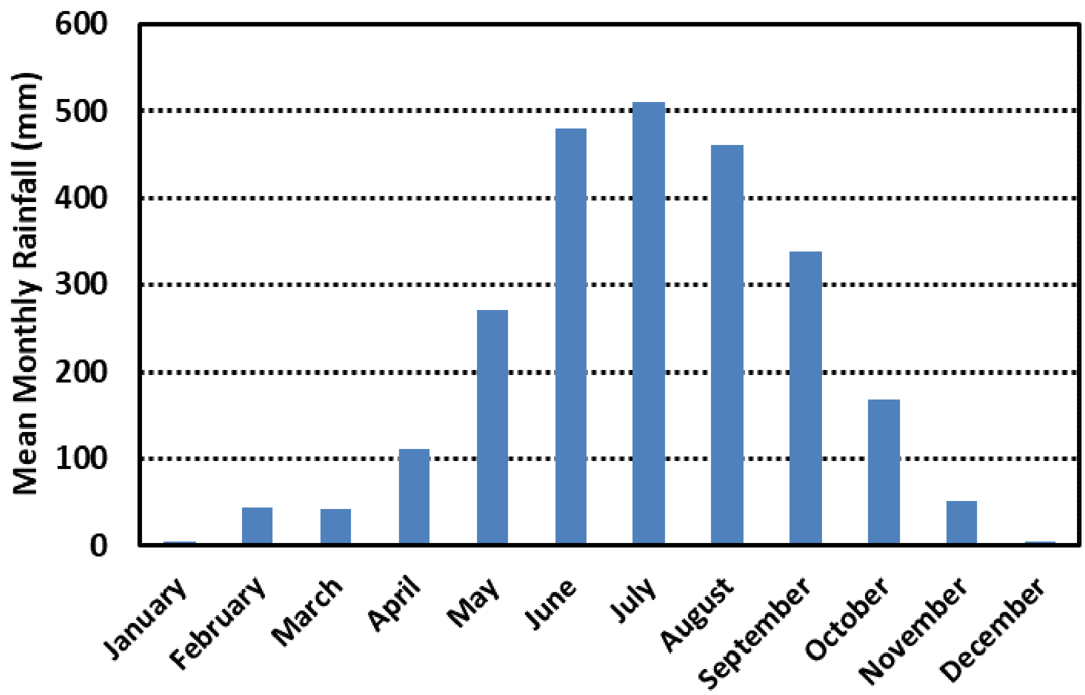


Figure 2.2: Distribution of mean monthly rainfall at Patuakhali.

2.3 Rainfall Analyses

The rainfall data in Bangladesh are primarily measured by Bangladesh Meteorological Department (BMD) and Bangladesh Water Development Board (BWDB). The nearest rainfall gage station to the study site is located in Sreemangal and is maintained by BMD. The rainfall data of BMD in Khepupara station is available since 1953. In order to estimate the design rainfall, statistical techniques, through a process called frequency analysis, are used to estimate the probability of the occurrence of a given rainfall event for the selected recurrence interval or return period. The recurrence interval is based on the probability that the given event will be equaled or exceeded in any given year. Rainfall recurrence interval is based on both the magnitude and the duration of a rainfall event.

The rainfall analysis results in developing Intensity-Duration-Frequency (IDF) curves. These curves are required for the design of urban drainage works, e.g., storm sewers and retention ponds. Probability distribution functions (PDFs) are used for frequency analysis to develop the IDF curves. The best-fitted PDF is determined based on the goodness-of-fit test. The best-fitted PDF is used to develop IDF curves from which the design rainfall intensity for the selected return period and duration can be obtained.

Runoff analysis is carried out for estimating the peak runoff of rate which is required for designing the drainage requirement of the study site. The peak runoff rate would be estimated by the Rational Method. The Rational Method, also known as the Rational Formula, represents an empirical relationship between rainfall intensity, drainage area and runoff coefficient. The rainfall intensity is read out from the IDF curves corresponding to the duration of rainfall which is equal to the time of concentration. The time of concentration is the time required for a drop of water falling on the most remote part of the drainage basin to reach the basin outlet. The time of concentration would be determined by the Kirpich equation. The peak runoff rate would be needed for the drainage design such as the size of the storm sewer, retention pond and pumping station. The required size of the storm sewer to convey the peak runoff would be designed by Manning's equation.

2.3.1 Development of IDF Curves

The IDF curves are used for rainfall-runoff analysis by the rational method. The rational method, also known as the rational formula, is an empirical relation, expressed as

$$Q = CIA/360 \tag{2.1}$$

Where Q = peak discharge in m^3/s,
C = a dimensionless runoff coefficient whose value depends on hydrologic characteristics of the drainage area,
I = rainfall intensity in mm/hr for a duration equal to or greater than the time of concentration of the drainage basin, and

A = area of the drainage basin in acres.

The rainfall intensity used is for a duration equal to the time of concentration. The time of concentration is the time required for a drop of water falling on the most remote part of the drainage basin to reach the basin outlet. The time of concentration can be determined by Kirpich equation as

$$t_c = 0.00032L^{0.77}S^{-0.385} \tag{2.2}$$

Where, t_c = time of concentration (hr)

L = maximum length of travel of water (m)

S = slope equal to H/L, where H is the difference in elevation between the remotest point on the basin and the outlet (m).

The hyetographs are used as input in the rainfall-runoff model for estimating the peak runoff rate.

2.3.2 Development of IDF Curves for Long Duration Rainfall

The nearest daily rainfall data (station Khepupara) for Galachipa and Amtali municipalities have been collected from Bangladesh Meteorological Department (BMD). This station measures only daily rainfall. The data covers from 1974 to 2010 for Khepupara station. These data have been processed and analyzed for developing IDF curves and hyetographs. The Extreme Value Type I (Gumbel) distribution has been used for the development of IDF curves for the different return periods. The yearly maximum rainfall data for different durations have been derived from daily rainfall data. These derived data have been sued for developing IDF curves by fitting Gumbel distribution for long-duration rainfall as can be seen in Figure 2.3.

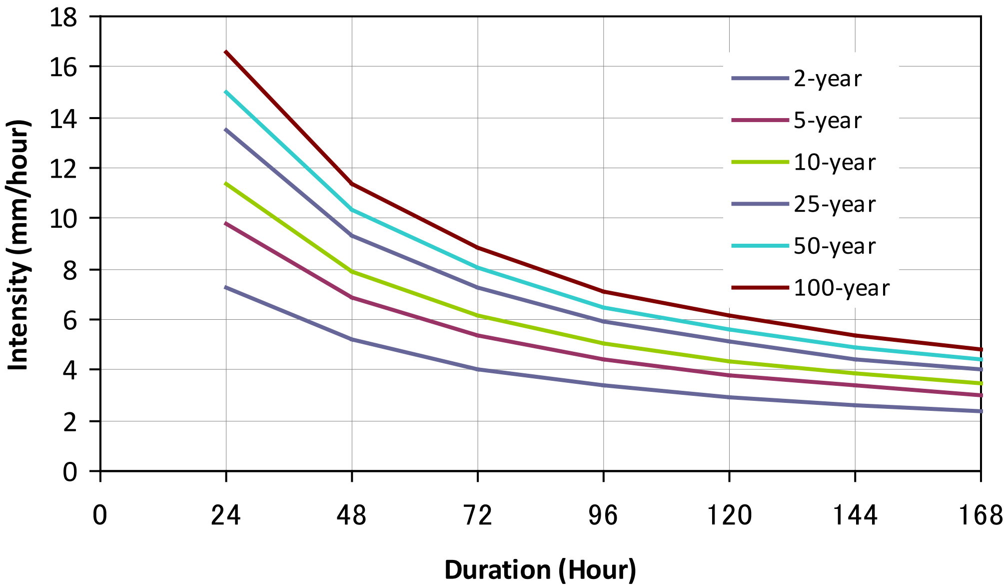


Figure 2.3: IDF curves for long-duration rainfall at Khepupara.

2.3.4 Development of IDF Curves for Short Duration Rainfall

The IDF curves for short-duration rainfall (less than 3 hours) have been developed by fitting a non-linear least-square line of the following type.

$$I = \frac{A}{(t+B)^C} \qquad (2.3)$$

Where, I = rainfall intensity

t = rainfall duration and

A, B, and C = coefficients

The IDF curves developed for short-duration rainfall at Khepupara by fitting Eq. (3) are shown in Figure 2.4.

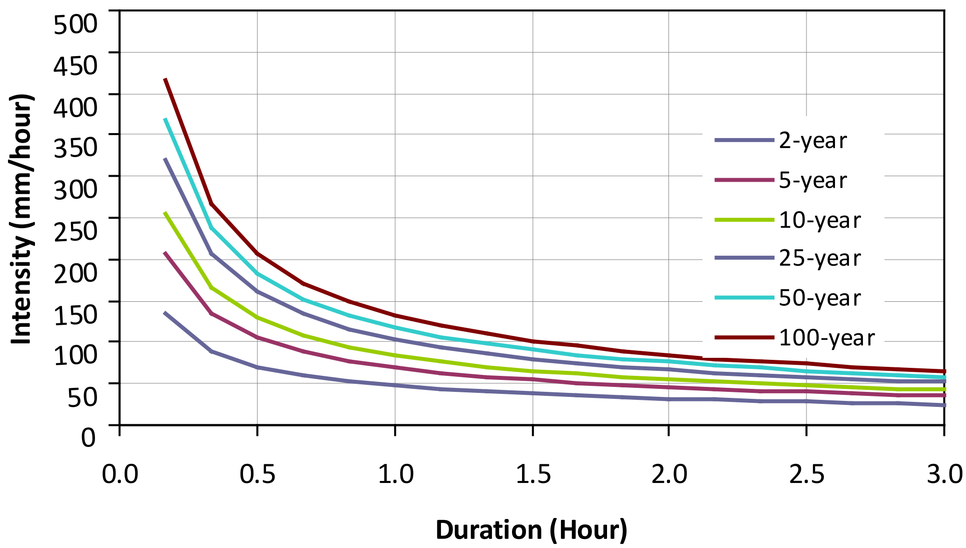


Figure 2.4: IDF curves for short duration rainfall at Khepupara.

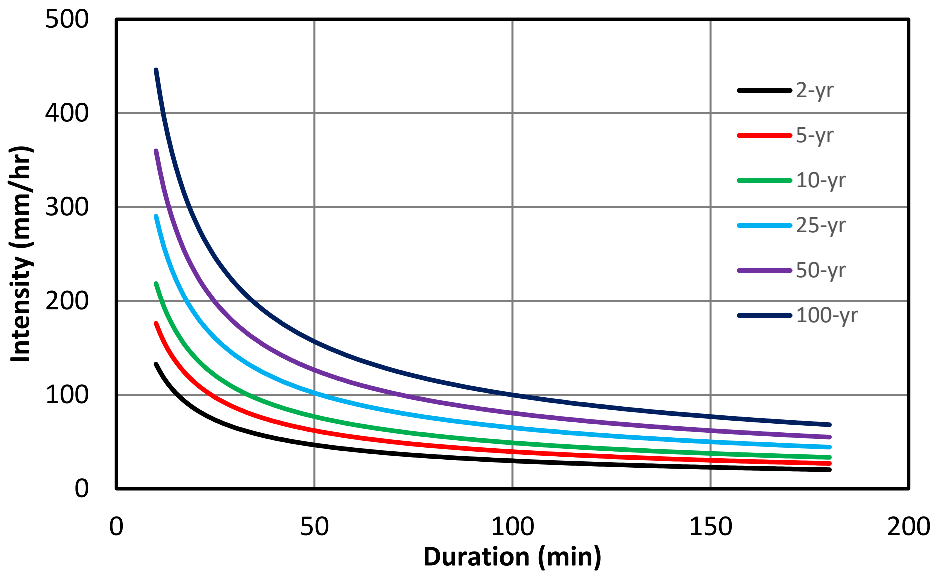


Figure 2.5: Fitted IDF curves for short duration rainfall at Khepupara.

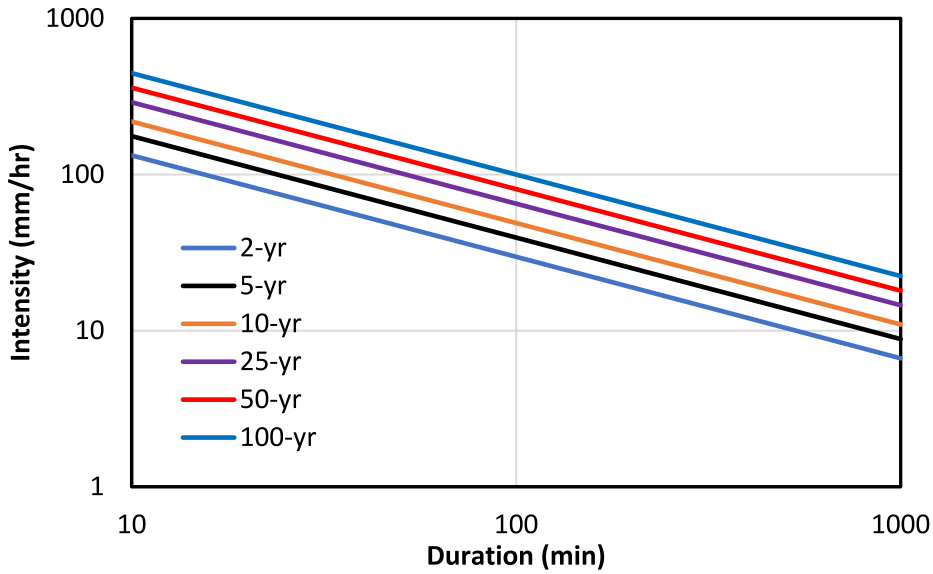


Figure 2.6: Log-log plots of the fitted IDF curves for short-duration rainfall at Khepupara.

2.3.5 Development of Hyetographs

The hyetographs have been developed by the alternating block method. It is a simple way of developing hyetographs from the IDF curve. The design hyetograph produced by this method specifies the rainfall depth occurring in n successive time intervals of duration Δt over a total duration $T_d = n\Delta t$. After selecting the design return period, the intensity is read from the IDF curve for each of the duration Δt, $2\Delta t$, $3\Delta t$, …, and the corresponding rainfall depth is found as the product of intensity and duration. By taking differences between successive rainfall depth values, the amount of rainfall to be added for each additional unit of time Δt is found. These increments, or blocks, are recorded into a time sequence with the maximum intensity occurring at the center of the required duration T_d and the remaining block arranged in descending order alternatively to the right and left of the central block to form the design hyetograph. The design hyetographs developed for 2-, 5-, 10-, 25-, 50- and 100-year return periods are shown in Table 2.2.

Table 2.2: Design hyetographs for different return periods at Khepupara

Duration (min)	Rainfall (mm)					
	2-year	5-year	10-year	25-year	50-year	100-year
10	2.40	3.24	3.80	4.49	5.00	5.51
20	2.72	3.69	4.33	5.13	5.72	6.31
30	3.17	4.34	5.11	6.08	6.79	7.50

40	3.93	5.43	6.42	7.67	8.59	9.51
50	5.55	7.80	9.28	11.16	12.55	13.93
60	22.29	34.32	42.61	53.31	61.36	69.43
70	7.55	10.76	12.89	15.59	17.60	19.59
80	4.55	6.34	7.51	9.00	10.10	11.19
90	3.50	4.81	5.67	6.75	7.56	8.35
100	2.92	3.98	4.68	5.55	6.20	6.84
110	2.55	3.45	4.04	4.78	5.33	5.88
120	2.28	3.07	3.59	4.24	4.72	5.20

2.4 Urban Flooding and Drainage Issues in the Project Area

As mentioned earlier that the project area comprises seven Upazilas. Galachipa Upazila of Patuakhali and Amtali Upazila of Barguna are two of them. AECOM (2013) conducted a study on urban drainage modeling for three selected coastal towns of Bangladesh considering climate change. Two of the three towns were Galachipa and Amtali. There is a polder surrounding Galachipa Pourashava. However, the Pourashava Complex itself has been constructed outside of the Polder. It is a matter of concern that Pourashava Complex is remaining unprotected. In fact, one-third area of Galachipa Upazila is not yet protected by polder from future disasters like AILA and SIDR. The Ramnabad River is shifting away from its present position leaving away a lot of space for Galachipa Upazila to be extended further and a lot of settlements have been developed in the newly developed area. The present polder functioned quite well and people and properties were saved during past SIDR and AILA events. The embankment height of the polder was about 30 cm higher than the storm surge height during the disasters. However, people suffered from in-polder drainage congestion. The residential area of blocks 4, 5, 6, 7 and 8 of Galachipa Pourashava usually suffers from drainage congestion during rains and needs to clear the drainage network using its own local technologies.

The main drainage network and its existing condition are not in good condition. The drainage system got reduced in both horizontal and vertical dimensions in the city area. Encroachment and siltation have turned the large canal into almost a non-distinguishable small drain, through which once plied upon local launches and country boats. At present, the drain is clogged with market garbage, water hyacinth, etc. Once it was a natural drainage system, but now is blocked at several points and later construction of the polder by BWDB turned it fully blocked. These locations are to be opened up again to make the drain more effective and to drain water towards the Ramnabad River. There is one closed junction for blocks 4, 5, 6, 7 and 8 which needs to open to eliminate drainage congestion during rain events.

At the outfall of the Mujib Nagar to Arambagh Khal, there exists one vent Sluice Gate. The sluice gate drains water to the Ramnabad River. The existing sluice gate is to be modified for a larger drainage opening. This point is to discharge the drain water from the proposed improved main drainage under construction. Several drainage canals are under construction with a vertical wall. Photograph 2.1 shows the Shantibag Sluice Gate No. 3 towards Galachipa Pourashava while Photograph 2.2 shows Galachipa Khal in the market area logged with garbage.

Photograph 2.1: Shantibag Sluice Gate No. 3 towards Galachipa Pourashava

Photograph 2.2: Galachipa Khal in the market area logged with garbage.

The Amtali Pourashava is protected by a polder. But during SIDR, the entire Amtali was over flooded and three people are reported to die at Basaki Sluice Gate over the Basaki drainage canal. 7 people died in another location during the SIDR event. Amtali Pourashava has a large water body and runs through the Pourashava. It functions as a storage reservoir during rain or other extreme events. Two main roads cum bundhs run through the water body in two locations. In one location, the water body has been filled up with sand. The newly filled-up area is prepared for use of EID Ghah. But no drainage provision has been considered yet. The challenge is that again a drainage canal is to be excavated along the border of the filled-up land to connect the existing water body to the outfall of the culvert towards the Paira (Buriswar). The provision for a drainage canal could be kept during the filling up of the existing water body. The existing large water body is an asset for the people of Amtai Pourashava.

There is a drainage canal named Basaki that runs towards the Paira (Buriswar). The Basaki drainage canal has a Sluice Gate at its outfall. The condition of the Basaki drainage canal is quite good. Small country boats ply through the canal. The Basaki is the main drainage canal for the Pourashava area. The Challenge includes the further strengthening of the Sluice Gate. A recreational lake is under construction close to the BWDB Sluice Gate to Paira River. The BWDB Sluice Gate is connected with the existing large water body by a narrow drainage canal. The BWDB Sluice Gate regulates the drainage flow towards the river Paira (Buriswar) as well as from the Paira side.

The existing polder and adjacent people are prone to the SIDR effect. Several people died during SIDR as their settlements were very close to or outside of the polder and storm surges hit them at the outset of the SIDR. Some secondary drainage canals are under construction with a vertical wing. Challenge is vertical wing wall is to be considered for many drains needed for the Pourashava. Photograph 2.3 shows an existing large water body, part of which was filled up at Amtali Pourashava while Photograph 2.4 shows an existing culvert on-road cum bundh through the large water body at Amtali Pourashava.

Photograph 2.3: Existing large water body, part of which was filled up at Amtali Pourashava.

Photograph 2.4: Existing culvert on-road cum bundh through the large water body at Amtali Pourashava.

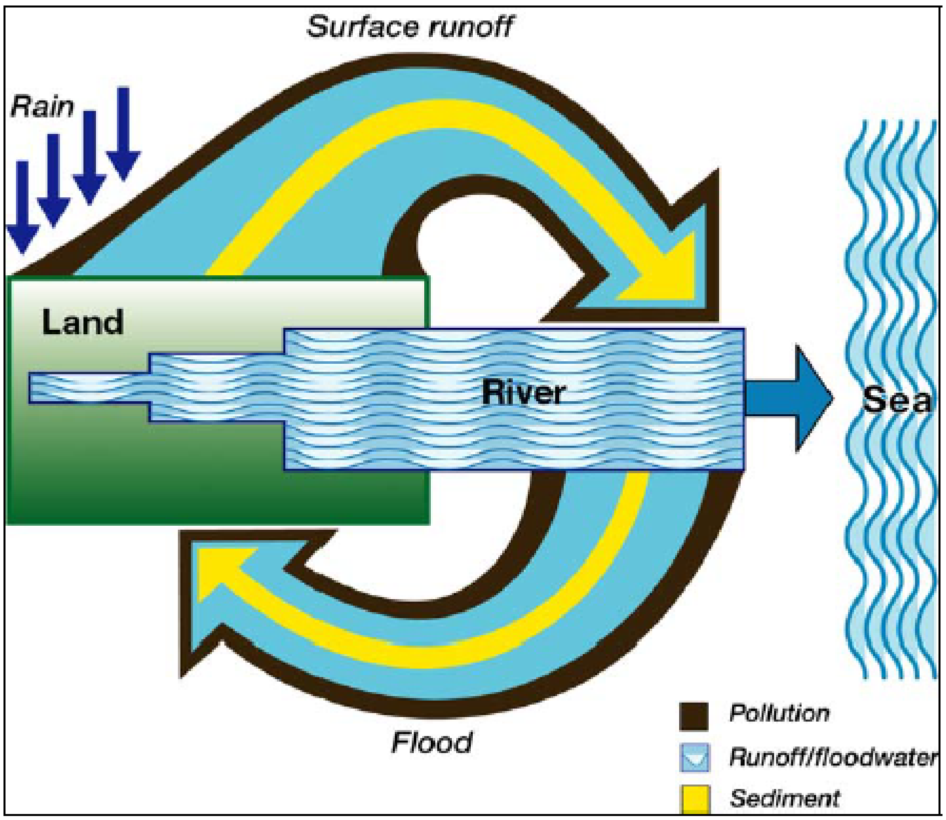
3 LAND USE PLANNING GUIDELINES CONSIDERING HYDROLOGICAL SITUATION OF THE PROJECT AREA

3.1 Introduction

While the contribution of those flood-liable lands and the flood protection infrastructure to socio-economic development needs to be recognized, the growing risks to the development process have become evident over the past decades in numerous examples of large-scale flooding with serious economic consequences. Flood risk in its most essential form is the product of the probability of a particular flood event times the consequence that event would have. In another form, flood risk is described as a function of the flood hazard (probability of occurrence of a particular flood event), the exposure of human activity to the flood (flood damage potential) and the specific vulnerability of the community affected by the flood (WMO, 2007). The land use planning is vitally important in a floodplain country like Bangladesh where 80% of her land is floodplain.

3.2 Interactions between the Land and Water Environment

River basins are dynamic systems constituted by a complex arrangement of fluxes between the land and water environment. Surface runoff carries sediments, nutrients and pollutants from the land through the river system, and flooding occurs in the floodplains as illustrated in Figure 3.1. It is important to note that those fluxes are varying over time and space. Natural geomorphologic processes influence those fluxes to vary degrees. For instance, natural phenomena such as landslides can have a significant influence on the sediment loads of adjacent water courses. Those sediments are deposited in the drainage systems, reducing the conveyance capacity of the channel and thus increasing the likelihood of flooding. Human alterations of the catchment area can significantly contribute to changes to all those processes through large-scale land use changes and land-use practices.



(Source: APFM, 2004)

Figure 3.1: Interaction between land and water environment.

3.3 Impacts of Land Use on Flood Hazards

With increasing human alteration and development of the catchment area, the runoff generation process is changed, especially through decreasing the infiltration capacity of the soil and the change of soil cover.1 This has led to concern over the role human alterations of the catchments play in increasing flood hazards. For example, a commonly repeated element of media coverage and political initiatives on floods has been that large-scale deforestation leads to increased flood hazards. It needs, however, to be borne in mind that while this may hold under certain circumstances, such as in small urbanized catchments, it does not imply that through employing a conservation agenda for certain types of land uses, floods can be prevented, in particular on larger scales. The flood formation process is influenced by various other factors - for large-scale floods especially the geomorphology of the catchment area, and preceding rainfall conditions.

15 Hydrological responses to rainfall strongly depend on local characteristics of soil, such as water storage capacity and infiltration rates. The type and density of vegetation cover and land-use characteristics are also important to understanding hydrologic response to rainfall. Environmental degradation coupled with uncontrolled urban development in high-risk zones, such as historical inundation plains and at the base of mountain ranges, leads to an increased vulnerability of those communities on the floodplains to catastrophic events.

3.4 Effect of Specific Development Interventions on Flood Hazards

Large-scale earthworks with infrastructure, industrial and residential areas. For water resources, development barrages or dams may be constructed in the upper reaches of a water course. Depending on the topography of the area this in case leads to the diversion of water into a neighboring catchment and may increase the flood hazard there. Similarly, if an elevated road traverses a floodplain it can substantially obstruct the flow of the floodwaters. Depending on the size of the river and the expected flood flows usually bridges or culverts are constructed to traverse the river channel and the immediately adjacent floodplain. However, construction cost considerations usually prohibit extending bridges or culverts to cover a wider stretch of the floodplain traverse. This particularly becomes a problem where parallel river channels form during flood conditions that have not been accounted for in the design of such cross drainage works.

3.5 Impact of Land Use on Flood Damage Potential

The location of economic values on floodplains or the investment into floodplain areas has played a major role in the development history of most countries. Depending on the availability of some level of flood defense, the overall economic output from floodplain areas can be significantly higher than in other areas. This also is evident from the high population densities floodplains have attracted over time. With growing economies and the emergence of wealthier societies, the damage potential from flooding is constantly rising. Flood damage potential can be defined as the extent of possible damage in a given flood hazard area3. This means that the benefits derived from the floodplains are provided at a risk, i.e. the risk of having to bear flood damage. This flood damage can come in various forms to buildings, goods, crops, infrastructure, or the environment. 4 By taking decisions on land-use and on placing such values on land liable to flooding humans have an influence on the flood damage potential. Therefore, in modern flood management approaches land-use planning and regulation play a vital role in controlling the flood damage potential to acceptable levels.

28 In this context it seems important to consider that society through political processes and individual choice has to take decisions on the level of a flood risk it is willing to accept. Those choices are sometimes explicitly formulated in form of policy documents, laws or similar instruments. However, in most cases, the choice is implicit, e.g. by deciding the location of a particular development, or by providing insurance cover to certain developments in flood-prone areas. It is argued here that those implicit choices are too often taken without awareness of the prevailing flood risks. This is the actual problem that has led in case of unreasonable increases in damage potential, especially where reasonable and less risk-prone alternatives may have existed. This trend can be observed in various countries, not only confined to developing countries that may lack the means to undertake flood risk assessments. The overall flood management policy should therefore point in a direction where implicit and explicit choices are possible under the awareness of prevailing flood risks and where those risks must be considered in the decision-making process.

3.6 Land Use Planning Guidelines

The field of public policy that is referred to as "Land use planning" in this paper has various corresponding terms which are sometimes used interchangeably. Some of these are Regional planning, Town and country planning, Urban planning, or Spatial planning. Depending on the country and the context where the term has used the meaning of the term varies. The overarching theme in all those terms, however, refers to ensuring that land is used in the most efficient way to serve society in achieving its economic, social and environmental goals. Usually, this is undertaken in an environment of competing uses. As such land use planning is a balancing act. With a reference to flood management that balancing act can be centrally illustrated in the ongoing debate characterized by the two paradigms "space for development" and "space for water/rivers". The operational instrument to guide this process is land use plans.

Depending on the stage of development in a society and its political priorities, various other sectoral development plans may be of interest in flood management due to their relation to flood risks:

Industrial Development: Flood risk consideration in planning industrial developments is essential to provide sustainability to business operations and to control flood damage potential. These also address control of pollution and the spread of hazardous substances due to flooding of industrial premises.

Agriculture Development/ Poverty Reduction: Heavily relies on floodplain areas due to the readily available fertile soil and water resources. At the same time, agricultural practices can influence runoff generation, infiltration processes and sediment yield.

Water Resources Management: Flood risks form a central component of water resources management plans to ensure the effective use of flood waters and safeguard the functioning of the water system during floods.

Transport and Communication Development: location and structural design of those infrastructure elements need to be planned in full awareness of flood hazard areas and the possibility of hampering infrastructure impacting on the hydrological processes and flood magnitudes.

REFERENCES

APFM (Associated Programme on Flood Management), 2004, Integrated flood management concept paper, APFM Technical Document No.1, second edition (Geneva: Associated Programme on Flood Management, World Meteorological Organization).

Guan, M., Sillanpää, N., & Koivusalo, H. (2015). Modelling and assessment of hydrological changes in a developing urban catchment. Hydrological Processes, 29(13), 2880–2894. https://doi.org/10.1002/hyp.10410.

WMO (World Meteorological Organization), 2007, The Role of Land-Use Planning in Flood Management: A Tool for Integrated Flood Management, Associated Programme on Flood Management, World Meteorological Organization.

Zhou, Q. (2014). A Review of Sustainable Urban Drainage Systems Considering the Climate Change and Urbanization Impacts. Water, 6(4), 976–992. https://doi.org/10.3390/w6040976.