Journal of Bangladesh Institute of Planners ISSN 2075-9363
Vol. 9, 2016 (Printed in April 2018), pp. 59-68, © Bangladesh Institute of Planners

Incorporating Drainage Modeling with Development Plan to Reduce Climate Change Induced Water Logging in Urban Areas of Bangladesh: A Case Study of Khulna City

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Abstract

Bangladesh is considered to be one of the most vulnerable countries in the world to climate change due to its vast low laying area. The Khulna City is located in the coastal area of Bangladesh and the main natural hazard affecting the city is water logging, which is associated with rain water stagnation and lack of proper development plan. The objective of the study is to investigate the role of drainage modeling integrating with the development plan to reduce climate change induced water logging in the urban area of Bangladesh. For this study topography condition and watersheds analysis was conducted for the Khulna City. Drainage capacity of waterlogged areas was analyzed comparing drainage density map and inundation map. Drainage model preparation procedure and framework for incorporating with development plan was also developed. Low topography of Khulna City is responsible for severe water logging problem. Areas in ward 19, ward 20, ward 23, ward 24 and ward 27 have higher drainage density but are inundated frequently during heavy rainfall, because of the gaps in the development plan. Drainage modeling may help the development authority for decision making, especially on drainage and water related issues to solve the water logging problems of the study area. Other urban areas of Bangladesh may also apply such models in solving their water logging problems.

Introduction

With vast low lying areas, Bangladesh is considered as one of the most vulnerable countries in the world to climate change (ADB, The Asian Development Bank, 2010). The impacts of climate change on water logging are severe in the urban areas of Bangladesh while drainage is already a serious problem. Due to the more intensive rainfall associated climate change and delay discharge for sea level rise, low laying areas are inundated frequently in all metropolitan cities as well as other district towns and small towns. These inundations in urban areas are responsible for troubling in traffic movement, disruption of normal life, damage of roads and underground service lines, damage of household goods and infrastructures, water pollution and harm to vegetation. The city of Khulna, being located in the coastal area of Bangladesh, and influenced by tides from the Bay of

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Bengal, is highly vulnerable to climate change (Ahmed & Ghosh, 2010). The city experiences frequent water logging during the rainy season (The Asian Development Bank, August 2010). The possible increase in precipitation as a consequence of climate change coupled with inappropriate drainage planning will make the situation even worse.

Khulna is the third largest city of Bangladesh (World Bank, 2000). The city has been developed as an industrial along with an administrative center. The population of this city in 1991 was about 663340, in 1998 about 847580 (World Bank, 2000) and at present 1500689 in 2016 wherever the density is 67994 per sq. kilometer (Khulna City Corporation, 2016). Due to the increase of population the land uses have been shifted from water body and fallow lands to structures and paved lands. Previously the storm water of Khulna City had been drained out through some natural drainage like creek and canals. Due to rapid urbanization and increasing development, these natural drainage and other water retention areas have gradually been transformed into built-up areas. Some of areas are changed by narrow surface drains. Consequently, some parts of the city are inundated regularly during concentrated precipitation particularly in the late monsoon. Most of the waterlogged areas are located the Southwestern wards of Khulna City. Percentages of households affected by annual water logging vary between 90-100% in those wards. In Khulna city, 38% of households regularly experience short-term water logging (Murtaza, 2001).

Khulna City experiences about 1810 mm of rainfall annually, of which almost 80% falls during the monsoon (weatherbase, 2015). The city is more vulnerable to inundation due to heavy and unpredictable rainfall but also for its decreasing drainage capacity due to unauthorized settlements and inappropriate development plan. Khulna City Corporation has spent BDT 70.97 crore over the last two years for re-excavation of two rivers, eleven canals and reconstruction of 6.70 kilometer long drains in different areas of the city only with a view to putting an end to water-logging on the roads and highways (The Independent, 2015).But water-logging still continuously happening on roads and highways after incessant rains and create problem to the residences.

In this situation incorporating proper drainage capacity analysis through mathematical urban drainage modeling with development plan is essential for the Khulna City. The mathematical drainage model will help to take decision for reducing water logging in city area as well as reduce the unusual cost of development authority for unplanned constructions. Using a drainage model different water logging areas can be identified for different extent of climate change that helps find the specific reason of water logging in a specific area. So incorporation drainage modeling with development plan will help the development authorities to take decision for reducing the water logging in urban area of Bangladesh. The comprehensive objectives of the study is to investigate the role of drainage modeling integrating with development plan to reduce climate change induced water logging in urban areas of Bangladesh.

Relations of Climate Change, Water logging and Drainage Modeling

Climate change is a change in the usual weather found in a place (NASA, 2014). Climate change is an alteration in the pattern of climate over a long period of time, and may be due to a combination of natural and human induced causes (Allison, 2010). The climate

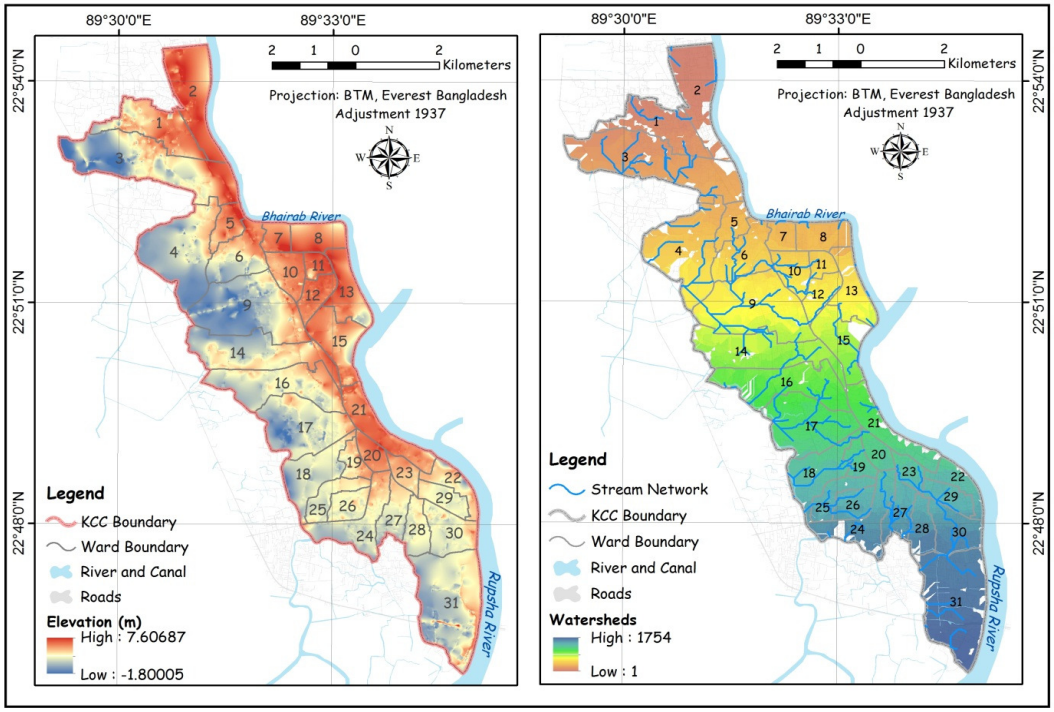
of the world is habitually changing progressively as a result occurrence of frequent intensive rainfall is increasing in rainy season. For the heavy rainfall the volume of run-off water increases and due to sea level rising high amount of surface water cannot infiltrate in the soil. When the quantity of run-off water increases the burden on drainage system also increases. In this situation urban drainage system fails to manage the flow and volume of additional run-off water and cause water logging in the urban area. Urban water logging is inundation that happens in a relatively short period of time and can inundate an area with several feet of water (Oblack, 2016). The inundation of property in a built environment, particularly in more densely populated areas, caused by rainfall overwhelming the capacity of drainage systems, such as storm sewers (Winters, 2015). Water logging is responsible for losing of property (i.e. building, road, structure, service line etc.), time and money. It is not only the event of inundating but the secondary effect of exposure to infection also has its toll in terms of human suffering, loss of livelihood and, in extreme cases, loss of life (National Disaster Management Authority Government of India, 2016). Urban built-up areas need to be drained to remove the logged surface run-off water. Traditionally this has been achieved by using underground pipe systems designed for managing water quantity (flows and volumes), to prevent flooding locally by conveying the water away as quickly as possible (Susdrain, 2012). So the managing capacity of a drainage system for both flows and volumes of water can be termed drainage capacity. Mathematical urban drainage modeling is one of the suitable processes to investigate the drainage capacity that can also help to take decision for reducing the impact of water logging on human life and property. By urban drainage modeling various inundation maps for different climate change scenarios can be generated which helps to prepare proper development plan for reducing the water logging problem. This mathematical simulation model can be used as an effective tool for all water resource projects in the urban area.

Topography and Watersheds Analysis of the Study Area

Bangladesh is one of the most vulnerable countries due to climate change and the impacts of climate change are severe in the Southwest regions (i.e. Khulna) of Bangladesh. The land of Khulna area is flat and poorly drained due to being deltaic plain. The whole Khulna City Corporation area is approximately 2.5m above the mean sea level. Such low topography of the city is responsible for severe water logging problem.

Topographical condition of the study area was exposed using Digital Elevation Model (DEM) prepared through elevation of spot values. The Digital Elevation Model (DEM) of the study area was shown in Figure 1(A). It was observed that the maximum ground level was 7.60687 meters and the minimum ground level was -1.80005 meters from the mean sea level. The average ground level of the study area was not far from the mean sea level. So it can be said that the study area was vulnerable due to climate change (i.e. sea level rise and rainfall increasing). It can also be said that low ground level can be one of the causes of water logging in the study area. The adjacent areas of the Rupsha River and Bhairab River were higher than additional part of the study area. It can protect the city from the water of river but in the time heavy rainfall it can be a burden for flowing out the logged water from the city to the Rivers. So it can be summarized according to Digital Elevation Model that the study area is in risk for water logging. Proper alignment and capacity of drainage network can help to reduce the water logging problem in the city.

Figure 1(B) showed the stream link for the study area. It was generated through stream network raster data generated from Digital Elevation Model (DEM). Stream links were the natural drainage flow of the study area. In the Figure 1(B) few stream links were seen and most of the links were connected to the boundary. Mainly the linked carried water from the higher ground level to lower ground level. In the study area links carried water from wards and discharge it in the outside of the study area. So any development or natural change can affect the natural flows and generate water logging in the study area. The number and length of stream links in the study area were few and the positions of the stream links were not also spread through the whole ward. No stream links were directly connected to the river which was also the reason of water logging in the study area.



(A) **(B)**

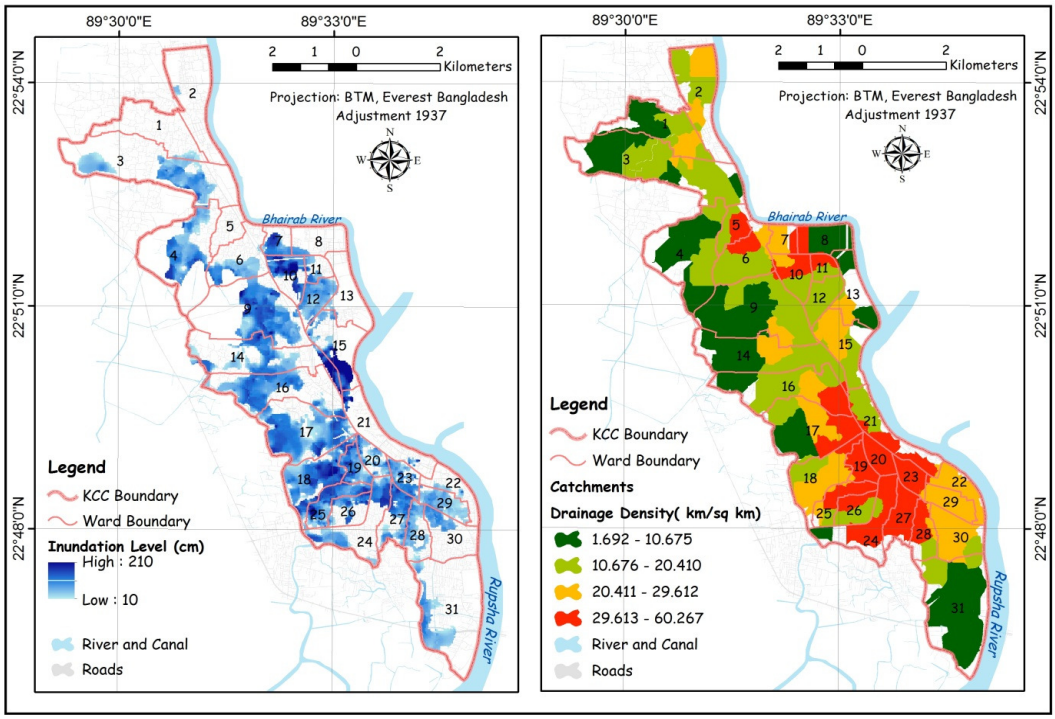
Source: Map was prepared by Authors (A) using KDA spot values and (B) using Watersheds Analysis, 2016

Figure 1: (A) Digital Elevation Model (DEM), (B) Watersheds with Stream Link of Khulna City Corporation

Drainage basin or catchments area were referring to an area of drainage that contributes water to common outlets. In the Figure 1(B) catchments for the study area were shown. The total numbers of catchments in the study area were 1754. Catchment area was defined through the stream link. Some catchments were absent adjacent the study area boundary for lack of stream link. It was also observed that the areas were not connected to stream link so these parts can be logged by water during heavy rainfall. Less number of catchments as well as less number of outfalls in the study area may be one of the causes of the water logging in the study area.

Drainage Capacity Analysis

Using the inundation map shown in Figure 2(A) the waterlogged areas were identified in the study area. Drainage density map shown in Figure 2(A) was also prepared for analyzing the drainage capacity of waterlogged areas.



(A) **(B)**

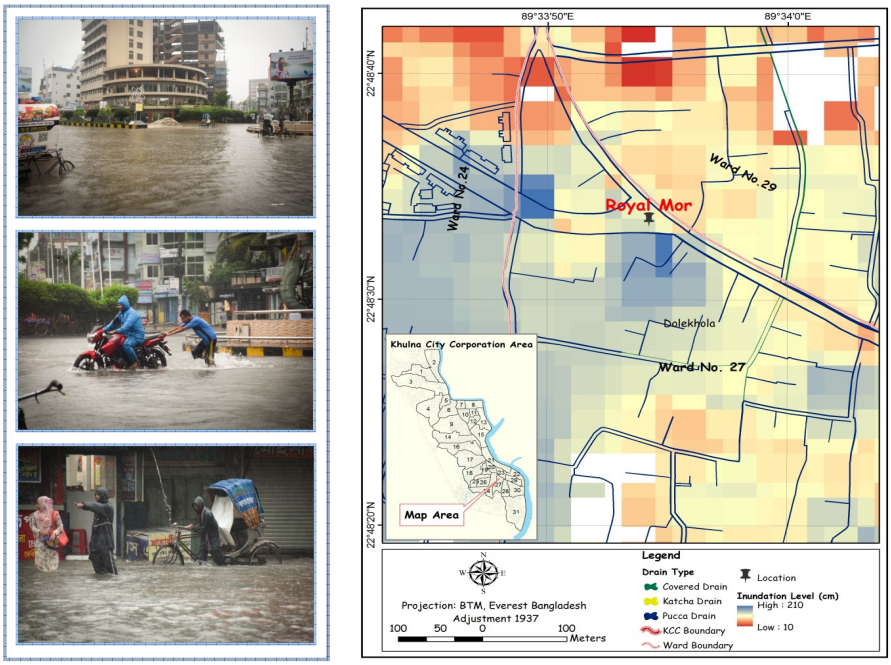
Source: Map was prepared by Authors: (A) The Asian Development Bank, 2010, and (B) Khulna City Corporation, 2016

Figure 2: (A) Inundation Level, (B) Drainage Density of Khulna City Corporation

It can be said that the poor drainage capacity was one of the reasons of water logging in some part of especially for the ward 31 ward 14 and ward 17. According to inundation map and drainage density map the areas having higher drainage density as well as drainage capacity have also high and moderate level of inundation. In ward 19, ward 20, ward 23, ward 24 and ward 27 the length of drainage network were more but this part of the city were inundated frequently during intensive rainfall. The roads were inundated frequently during the heavy rainfall and the life lines of the people were troubled due to the water logging in the study area. Development authority's initiatives were failed to reduce the water logging due to lack of proper drainage planning in most of the parts of the city. If drainage modeling was incorporated with development plan different scenario of precipitation can be analyzed easily without construction cost. Mathematical drainage model can also help the development authority to take proper decision in preparation of development plan as well as reduce water logging problem in the study area.

Extent of Water logging with Existing Drainage Network

One specific area (i.e. Royal Mor) having extremely inundation level was analyzed considering existing drainage system. In Figure 3(A) drainage network in Royal Mor at Northern part of Ward No. 27 was shown. In this part the drainage network was better but high inundation was seen during the intensive rainfall. Improper alignment of drains and lack of proper implementation of development plan can be the cause of water logging in this part. In Figure 3(B) condition of Royal Mor one of the important part of Khulna City during intensive rainfall were shown by the photographs. According to the photographs disruption of traffic movement and disruption of normal life of the city resident due to water logging was clarified. This part of the study area has much improved pucca drains but impact of water logging was severe due to proper drainage plan. Drainage modeling should be an effective tool for analyzing the required drainage capacity and alignment for this part of the study area to reduce the impact of water logging.



(A) (B)

Source: Map was prepared by Authors (A) through The Asian Development Bank, 2010 and Khulna City Corporation, 2016 and (B) Photographs were taken by Authors, 21 August, 2016

Figure 3: (A) Existing Drainage Network with Inundation Level, and (B) Condition during Intensive Rainfall in Royal Mor Area, Khulna City Corporation.

Procedure of Drainage Model Preparation

Hydrological simulation model should be formulated to estimate the inundation level using hydrological modeling software (i.e. Mike Urban, HEC-RAS etc.). Output of the

model will be discharge in each outlet and maximum discharge of each outlet should be used for generating the inundation map.

Probable Inputs for Model

a) Different Catchment Area: Catchment area for runoff will be delineated according to the elevation of ground surface using DEM and Arc Hydro tools in ArcGIS. Raster analysis will be performed to generate flow direction, flow accumulation, stream definition, stream segmentation, and watershed delineation. For preparing the simulation model delineated catchments should be edited and processed. Some parameters for each catchment should be also defined shown in Table 1.

b) Nodes: The intersection points of the drains and ends of the drains are defined as nodes. Each node was given some parameters shown in Table 1. Ground levels of all nodes will be calculated according to Digital Elevation Model (DEM). Diameters of each node will be assumed according to the connecting drains width.

c) Link: Connections of nodes through the existing drainage network will be identified as link. Parameters for link are also shown in Table 1. Lengths for each link should be calculated and widths will be assumed according to the width of drains. Connected nodes for each link will also identified as from node in the upstream and to node at downstream.

d) Rainfall Events: For this type of study previously daily/ three hourly precipitations event should be used. The precipitation event should start from zero rainfall and ended at zero rainfall.

Table 1: Parameters for Inputs of Drainage Model

Catchments	Nodes	Link
Unique ID	Unique ID	Unique Name
Area of each Catchment	Ground Levels	Length
Coordinates of Centroids	Coordinate of Nodes	Width
Percentages of Imperviousness	Diameters of Each Node	From node
Time of Concentration	Invert Level	To node

Preparation of Model

At the first nodes will be imported from ArcGIS data to hydrological modeling software environment with its different parameters. Catchments will be also imported with parameters and nodes will be connected with the catchments. Link data file will be also imported in hydrological modeling software with parameters. For the study hydrological model named MOUSE Time-Area (TA) will be used and different parameter value should be used for the model parameters (i.e. time-area coefficient, type of time area curve, reduction factor etc.). Outlets for all networks should be identified and precipitation event will be also imported through boundary items. Finally, simulations will be run for the rainfall event and result should be used for analysis.

Model Application

Output of the model will be discharge in each node. Using the maximum discharge value a raster surface will be development through interpolation. Inundation map should be prepared using subtract Digital Elevation Model (DEM) from this discharge surface through ArcGIS. Waterlogged areas will be also identified in the study area using the inundation map. Drainage capacity of waterlogged areas should be analyzed comparing drainage density map and inundation map.

Incorporating Drainage Modeling in Development Plan

Water logging is one of the serious problems in the Khulna City as well as other urban area of Bangladesh due to climate change and rapid urbanization. The development authorities were taking numerous initiatives to reduce the extent of water logging on property and life line of the city people. Most of the time the initiatives were failed and day by day the problem become severe for the city area. In the time of preparing development plans no drainage capacity was analyzed that may be one of the causes of failing development authorities' initiatives for reducing in water logging. To cope up water logging proper drainage modeling should be mandatory in urban areas of Bangladesh. It can be said that drainage modeling will be incorporated with development plan helping to analysis the actual drainage capacity as well as taking decision of authority for reducing the extent of water logging in urban areas of Bangladesh. Overall framework of drainage modeling was shown in Figure 4.

Step 1: Increasing the Drainage Capacity

According to drainage model major waterlogged area will be identified in the city. Consistent with existing drainage network and field observation drainage capacity should be increased (i.e. increasing depth, increasing width, construction of new drains etc.) in the model for waterlogged part of study area. Then the model will be simulated again and waterlogged areas will be identified again. If the waterlogged areas will be reduced by increasing the drainage capacity it should be incorporated in the development plan for implementation. At the end of the step, if water logging areas are not reduced according to the result next steps should be followed.

Step 2: Providing Proper Alignments of Drainage System

Due to poor alignment of the drains water can be overflowed during rain and caused water logging. Proper alignment and sloping of drainage system should be provided according the elevation of ground surface in the model. The water collection system should be from tertiary drain to secondary drain and finally to primary drains. Then the model will be simulated again and waterlogged areas will be identified again. If the waterlogged areas will be reduced by providing proper alignment of drains it should be incorporated in the development plan for implementation. At the end of the step if water logging areas are not reduced according to the result next steps should be followed.

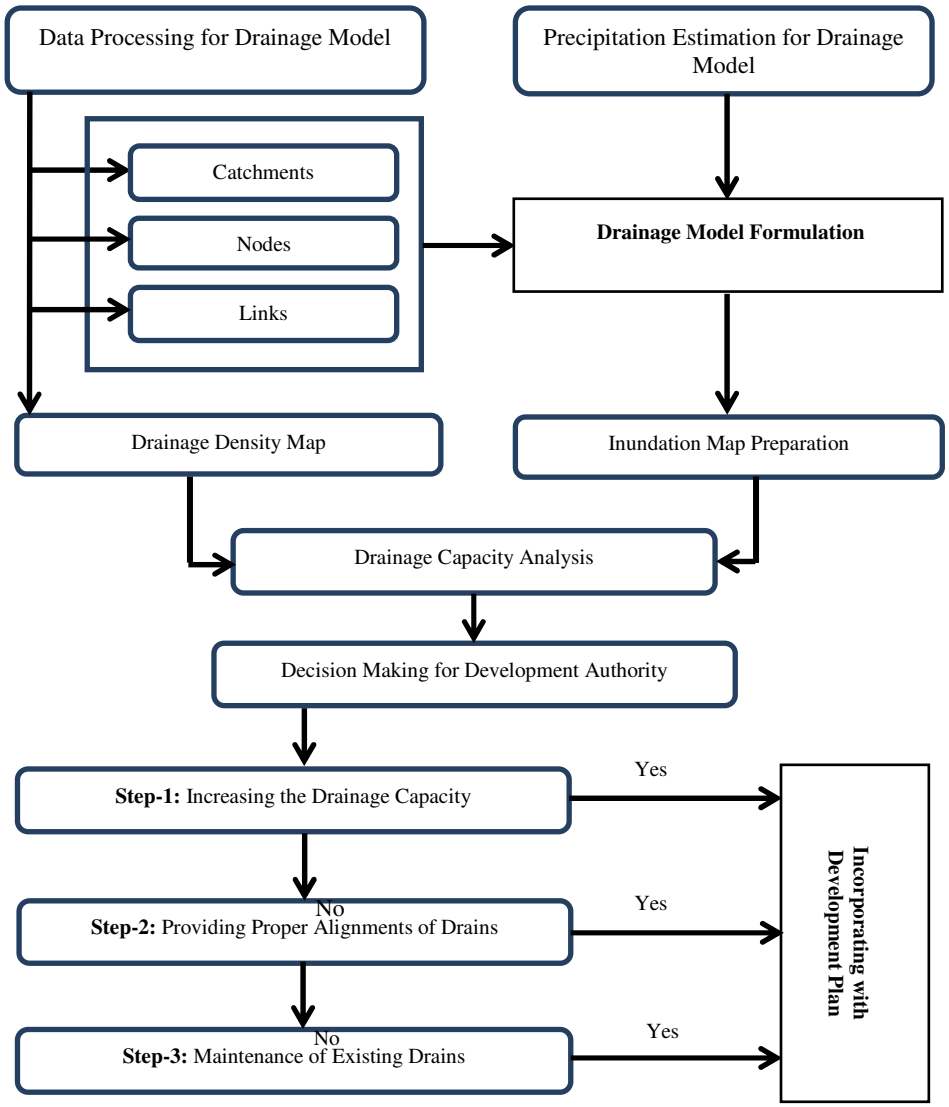


Figure 4: Framework for Preparing Drainage Modeling and Incorporating with Development Plan

Step 3: Maintenance of Existing Drainage System

When Step-1 and Step-2 can't reduce inundation in the study field observation should be used. Most of the uncovered drains can be congested by polybag, plastic bottle and household waste. This blockage of drainage network may one of the major causes of water logging. More over construction materials also blocked the drainage network. It is incorporate in development plan that to cover the uncovered drains. By covering the drains people ward can't dump the household waste in the drains as a result drainage network will be able to carry the logged water. When drains will be covered one major challenge will be also generated as cleaning and maintenance the drain. Maintenance and cleaning point at the junctions should also be identified.

Conclusion

Topographic condition is one of the causes of water logging in Khulna City. Ward 19, ward 20, ward 23, ward 24 and ward 27 have more drainage density, but become inundated frequently during intensive rainfall due to gaps in development plan. Drainage modeling will reduce the additional cost of development authority for construction of unusual structures.

According to the drainage modeling water logging areas can be find out that help to identify the possible cause of water logging in that specific part of study area. Drainage capacity analysis through mathematical drainage modeling will help to development authority for decision making process of proper and efficient implementation of drainage and other water resource projects in the study area as well as in the urban areas of Bangladesh. It is recommended that drainage modeling should be incorporated with the development plan to reduce urban water logging. The research suggests for further studies related to drainage capacity, water logging and urban inundation in the urban areas of Bangladesh.

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