ANALYZING THE TRANSFORMATION OF PRE AND POST-DEVELOPMENT WETLAND AREAS IN PURBACHAL NEW TOWN, BANGLADESH

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1 ABSTRACT

Dhaka, the capital city of Bangladesh, is one of the fastest-growing metropolitan regions in the world. Around 18 km away from Dhaka, Purbachal satellite city was planned in 1995 to solve the ever-increasing need for housing. Purbachal is the largest planned township in Bangladesh, with an area of over 25 square kilometers. Historically a low-lying wetland, Purbachal has gone through a rapid transformation in past decades. This study investigates the transformation of wetland areas in Purbachal New Town using Supervised Classification for Land Use and Land Cover (LULC) Change and Water Flow and Watershed Analysis. The study Investigates whether the new developments in the Purbachal New Town followed a natural topography or was drastically modified from its natural conditions. The result shows wetlands around the new town have been filled in to create new developable land. As a result, the existing water flow patterns drastically altered, making the satellite city susceptible to flooding. By combining geospatial modeling with impact simulation, the study demonstrated a feedback process that facilitates the development of sustainable design strategies. The study's outcomes will guide the formulation of an alternative city planning process aided by Geodesign tools and the establishment of a systematic urban planning approach for this region guided by the natural land transformation analysis to create cities where people will be able to live in harmony with nature.

1.1 Keywords:

Wetland transformation, remote sensing, watershed analysis, GIS

2 INTRODUCTION

2.1 Site Location

Bangladesh is a country in South Asia located east of India on the Bay of Bengal (Figure 1). Roughly two-thirds of the country is constituted of the deltaic plain of the Padma (Ganges [Ganga]) and Jamuna (Brahmaputra) rivers. The landscape is a predominately flat plain of recent alluvium, except for small higher areas in the Barind and Madhupur Tract. The capital city of Bangladesh is Dhaka. Purbachal New Town is around 18 km away from Dhaka, situated in Rupganj Upazila of Narayanganj District and Kaliganj Upazila of Gazipur District. Purbachal New Town is in three administrative districts, Dhaka, Narayanganj, and Gazipur. Bangladesh is a riverine country, and all the major cities, towns, and commercial centers are located on the bank of rivers. Purbachal is also not an exception. The area is in eastern-central Bangladesh between large floodplains of Brahmaputra and terraces. Purbachal is situated at the confluence of the Shitalakhya and Balu rivers. The Balu and Sitalakkhya Rivers are on the west and east sides of the new town.

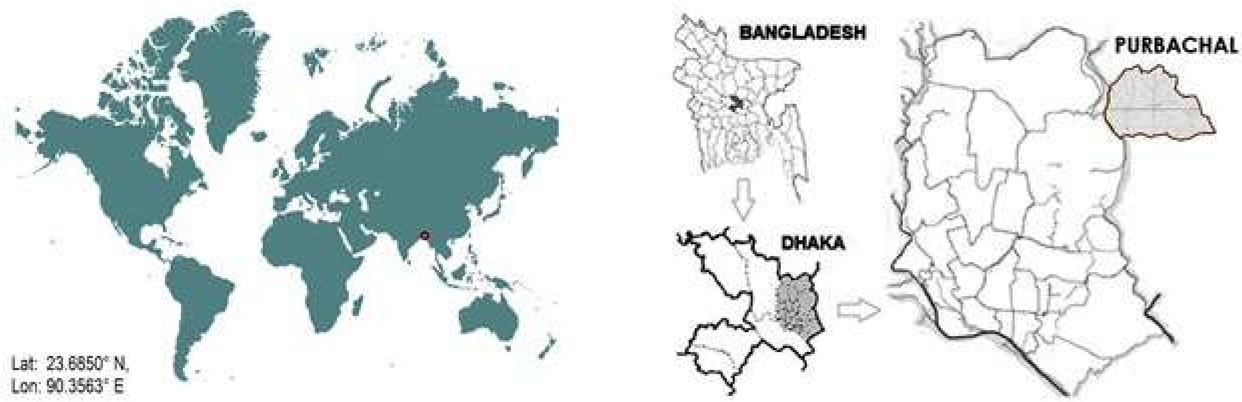

Figure 1. Geographical location of Purbachal New Town

2.2 Historical Background

From a provincial headquarters during the 14th century, Dhaka has gone through a major transformation to become the economic center of Bangladesh. The physical and environmental features largely contributed to the growth of the city (Khan, 2000). But due to rapid urbanization, human-induced changes have adversely transformed the city's natural landscape (Dewan et al., 2007). The development of Dhaka can be traced back to the 12th century AD (Mowla, 2012). Due to the strategic location to command water routes, the first urbanization of Dhaka started in the Old Natural Levees due to its suitable land elevation (Khan, 2000). In the later period, Dhaka developed gradually. But after the independence in 1971, rapid unplanned urbanization was followed that resulted in the interruption of the city's natural drainage system. Being situated in a flat plane, most of the urban areas of Dhaka have an elevation between 6-8m above sea level. Being situated in a subtropical monsoon climate, Dhaka receives around 2000 mm of annual rainfall. As a result, historically, rivers, canals, and water bodies used to play a vital role in everyday urban life (Mowla, 2010). But since the early '90s, the uncontrolled urban development in low-lying areas made the city vulnerable to urban flooding. Moreover, due to changing pattern of climate, the chances of extreme rainfall events have increased (Ahammed et al., 2014). This resulted in a reduced storm lag time and consequently increasing flood peaks (Khan, 2000). Dhaka, being a low-lying area, is surrounded by rivers and flood plains; hence the amount of developable land in Dhaka city was limited. During the late '90s, the city ran out of land that was suitable for future development. Infill and growth of residential neighborhoods put several infrastructural constraints. City authorities started searching for solutions in the fringe areas to house the ever-increasing population.

Planning and design of the satellite town was primarily the responsibility of Rajdhani Unnayan Kartripakkha (RAJUK), the capital development authority. In 1995, the plan to develop the largest satellite town in Bangladesh was undertaken. The 6,150 acres project area was divided into 30 sectors (Dhaka Structure Plan, 2015) with a 300-meter-wide highway to ensure fast connectivity with the capital city, Dhaka.

One of the main objectives of the new master plan was to maintain the balance of the environment by proper urbanization by creating an environment-friendly and sustainable atmosphere. But the plan mainly focused on creating developable land and maximizing residential plots. By doing so, the new plans for Purbachal overlooked the previous Dhaka Metropolitan Development Plan 1995-2015. A significant portion of the proposed town was within the main flood flow area (Figure 2). Soon the area once dominated by agricultural landscape started to transform rapidly.

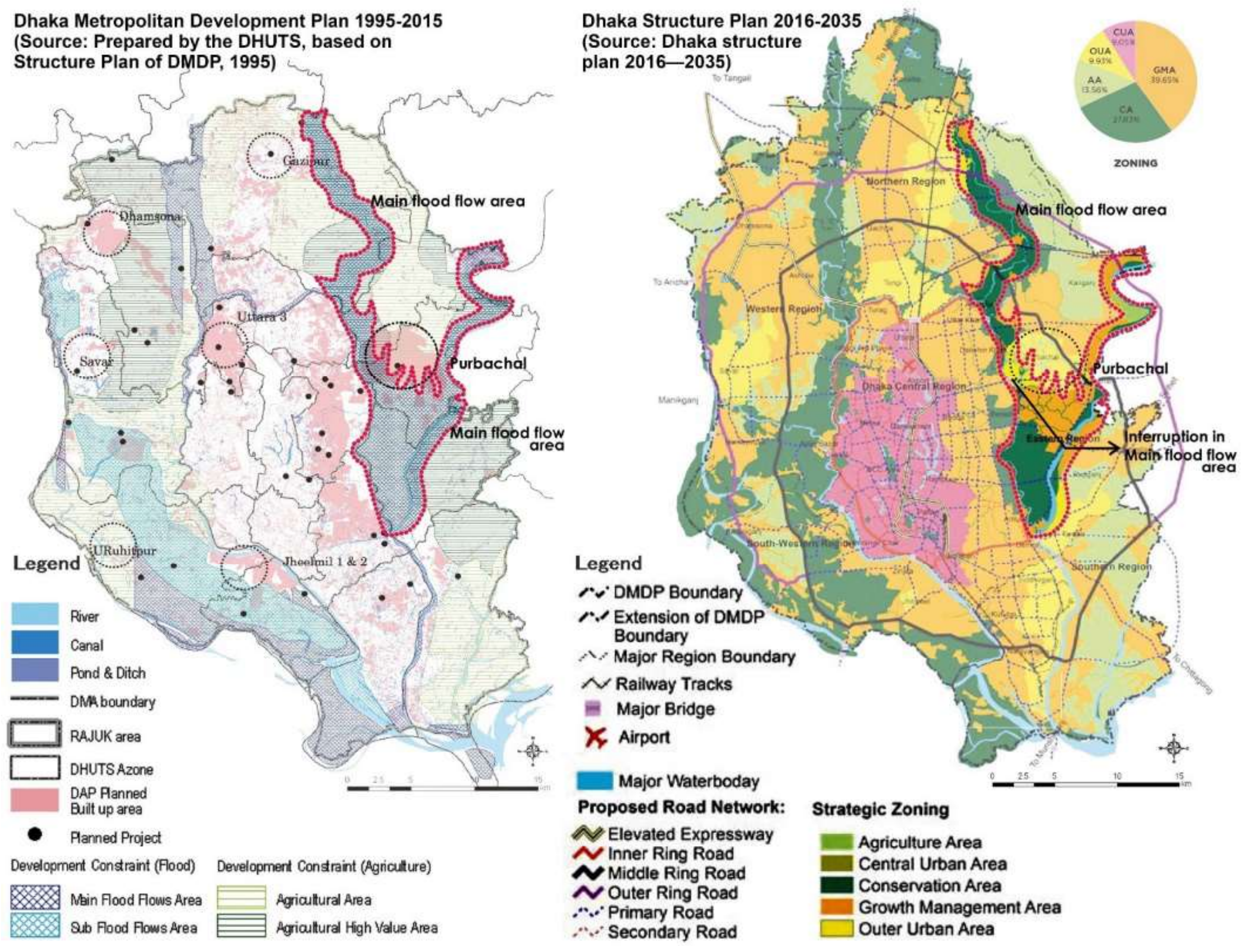

Figure 2: Conversion of areas within main flood flow zone Into Growth Management and Outer Urban Areas

Due to anthropogenic climate change, the frequency and intensity of extreme weather events like floods might increase globally. Dhaka City is recognized internationally as a hot spot for flood risk (Gain et al., 2015). The majority of channels and water bodies of the city have been filled up to create developable lands (Datta & Mandal, 2017). As a result, even moderate rainfall causes urban flooding in certain areas of the city. The low-lying wetlands around Dhaka are subjected to annual flooding and act as a water retention zone. During each monsoon, the wetlands get inundated, creating a low-lying ecosystem with unique flora and fauna. These wetlands are also vital for replenishing the groundwater table. A lowering water table could increase the rate of land subsidence. But unfortunately, a significant portion of these wetlands has been lost during the development of Purbachal New Town. As a result, severe land subsidence is occurring in Dhaka (Erkens et al., 2015). The main flood flow areas around Dhaka historically protected the city from flood events. In 2021, most of the proposed areas within the master plan have been filled up, and road construction work is ongoing on these areas. Although much of the wetlands are filled up, there is still scope to save some existing ones and restore some of the lost wetlands.

2.3 Study Questions and Objectives

The study aims to answer the followings questions:

- What percentage of wetland has been lost since the development of Purbachal?
- How has the water flow pattern changed due to wetland transformation?
- How will changing the relationship between natural factors affect the future urban environment of Purbachal?
- Is there a way to develop the area without hampering the natural landform pattern?
- Is it possible to re-establish the deep structures (Spirn, 2014) inherent in the landscape to strengthen the relationship between the natural factors?

The study has three main objectives:

- Objective 1: Identification of natural land transformation pattern
- Objective 2: Analyze the impact of anthropogenic disturbance of the natural landscape
- Objective 3: Demonstrating the application of land cover and flow analysis as tools to analyze pre and post-development flows.

The study's main objective is to create a development plan to enhance economic growth while ensuring the protection of the environment to create a sustainable society (Farr, 2011).

3 METHODS

To study the adverse effect of human-induced land transformation, many researchers have used Remote Sensing (RS) techniques to trace the transformation pattern of a city from pre-urbanization periods to the current situation. The study combines Remote Sensing (RS) with a Geographic information system (GIS) to develop a framework for intelligent, holistic geospatial design (Figure 3). The study was divided into three main phases:

1. Land Use and Land Cover (LULC) Analysis: In the first phase, the changing urban LULC condition of Purbachal was analyzed to understand the geospatial structure (Flaxman, 2010) of the region.

2. Water Flow and Watershed Analysis: In the second phase, watershed analysis was done to identify the water flow characteristics and watershed boundaries of Purbachal New Town.

3. Result Analysis: In the third stage, the geo-hydrological aspects of Purbachal were analyzed.

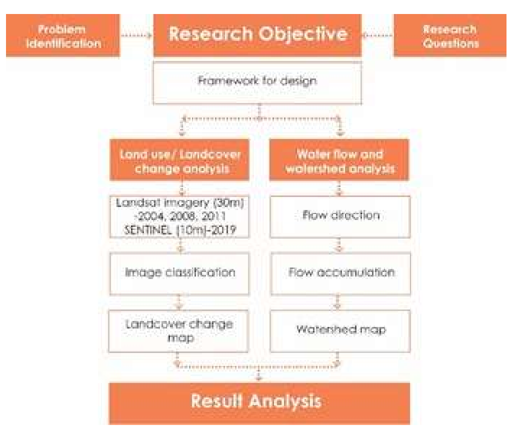

Figure 3: Study Procedure Flowchart

3.1 Derivation of Land Cover Maps

The main source used in producing land use maps was Landsat images. Ahmed et al. (2013) mainly used Landsat images acquired from 1989, 1999, and 2009. On the other hand, Dewan & Yamaguchi (2009) and Khan (2000) used a combination of Landsat images with SPOT and aerial photography to compare pre and post-land development typologies. Landsat MMS band 7 (0.8-1.1um) is particularly useful for analyzing the flood delineation, but some studies also suggested using TM band 7 with Band 4 in combination (Dewan & Yamaguchi 2009).

3.2 Data classification

The maximum likelihood classification method was used for the statistical characterizations of this study. The statistical characterizations were followed by the digitization of the training sites (Ahmed et al., 2012). Maximum likelihood classification is a type of supervised classification that assumes the statistics for each class in each band are normally distributed. The algorithm used for this classification calculates the probability of a given pixel belonging to a specific class. Dewan & Yamaguchi (2009) also used the supervised Maximum likelihood classification method. Each pixel is assigned to the highest probability class; hence, the name is Maximum likelihood classification. No training data used had a pixel size less than 280, and the greatest pixel size used was 7800. A common problem faced during the study was classifying landcover with Mixed Pixels due to the heterogeneous nature of the urban land cover.

3.3 Data Analysis in the context of Bangladesh

Anthropogenic causes have been the main driving factor for natural habitat destruction around the world. With the increasing population and rapid urbanization, cities in the developing world face the worst impact of changes in urban land use and land cover (LULC). Dewan et al. (2009) assessed the impact of rapid urbanization on land use/cover changes in the Greater Dhaka region of Bangladesh. Landsat data (MSS, TM, and ETM+) images from 1975 to 2003 were analyzed to assess the changing LULC conditions of the Greater Dhaka region. A ground truth map was prepared with fieldwork data collected from 200 reference points using a global positioning system (GPS). A supervised maximum likelihood classification (MLC) algorithm was used for satellite image classification. With the use of Geographic Information System (GIS) and Remote Sensing (RS), this study followed a similar procedure to evaluate the spatial and temporal dynamics of LULC.

3.4 Accuracy assessment

Accuracy assessment is perhaps the most important part of validating the results. The basics of error evaluation are to use an independent source to check the validity of the classification for each of the classes chosen for the study. The basic rules for the classification are:

1. The accuracy evaluation should be carried out with testing data that is not the same as those used to train the classifier.
2. There should be many test pixels – ideally several hundred.
3. The test pixels should be randomly placed.
4. Each class should have a minimum number of test pixels.
5. The ground reference data should be obtained independently from the data used for classification.

Typically, in remote sensing, two different types of accuracy are used: user's accuracy and producer's accuracy.

3.5 User's Accuracy

The user's accuracy is used to assess the reliability of the maps produced in the study. It predicts the chances that what is shown in the map can be accurately found in the actual condition. The user's accuracy is used to establish the level of trust one can have to a class designated on the map.

Errors of commission (if expressed as a percentage) = 100% - User’s Accuracy

3.6 Producer's Accuracy

The producer's accuracy is used to assess what proportion of class has been identified correctly in the classification. It describes the chances of a pixel in an image belonging to a class is labeled in that class or not. The user's accuracy is used to establish the level of trust that areas on the map that are NOT labeled a certain class are indeed not that class.

Errors of omission (if expressed as a percentage) = 100%- Producer's accuracy

3.7 Kappa Statistics

The kappa statistics are used to explain whether the results obtained in the study are the outcome of a random chance or not. Kappa penalizes for guessing and always reduces the overall accuracy. All the reviewed studies conducted accuracy assessments. In most cases, the MSS images produced were the least accurate due to the core's spatial resolution (Dewan & Yamaguchi, 2009). The mapping accuracy ranged between 85-90%, with kappa statistics around 0.80 (Ahmed et al., 2013).

3.8 Scope and Limitations of using Remote Sensing

The combination of using RS with GIS can play a vital role in developing future planning strategies. Using RS is a comparatively cost-effective method instead of using ground-based traditional survey methods (Ahmed et al., 2013). For research carried out in developing nations like Bangladesh, RS techniques are particularly useful. With RS, it is relatively easy to collect data and analyze them for a vast area within a short period (Dewan & Yamaguchi 2009). This may result in making decisions faster to come up with the changing environment.

On the other hand, RS has its problems too. The main problem of using RS is the availability of data and the difference in the type of data. In many places of the world, high-resolution images might not be available. In most of the studies, data from many different sources and scales were used, creating many problems in the analysis phase. For the classification, due to the heterogeneous nature of the urban surface, mixed pixels were a common problem while working with Landsat Data. The Wetland class easily gets merged with the low land class due to the similar reflectance properties. Wetland and low land categories also got mixed up with cultivated lads (Dewan & Yamaguchi 2009). But despite these problems, the accuracy of the maps was satisfactory in all the studies reviewed, and the accuracy of RS classification can be further improved by using rule-based techniques and combining with GIS tools.

3.9 Flow Direction Analysis

The flow direction is one of the keys to deriving the hydrologic characteristics of an area. The flow direction map is used to derive hydrologic characteristics of terrain. The flow direction map shows the water flow direction within and around the site. This process creates a raster of flow direction from each cell to its steepest downslope neighboring cells. Eight numbers represent the eight cardinal directions. The values for each direction from the center are the following: (North=64, North-East=128. East=1, South-East=2, South=4, South-West=8, West-16, and North-West=32). So, for example, if water flows from a cell to the south direction, the flow direction would be coded as 4 and so on.

According to Qin et al., (2007), in the Multiple Flow Direction (MFD) algorithm, partitions flow from a cell to all downslope neighboring cells. A flow-partition exponent is derived from an adaptive approach based on local topography conditions. This method is used to determine the fraction of flow draining to all downslope neighbors. By choosing to 'force all edge cells to flow outward' in the flow direction command, it was assured that the process creates a path from every cell to another cell. So, all cells at the edge of the surface raster will flow outward from that surface raster.

The flow direction grid created from the filled elevation surface provides One Directional values, which are assigned based upon the path that water would likely take based upon the elevation values in eight different directions from that cell.

3.10 Watershed Analysis

A Watershed is the part of the land within which water flows down through streams or canals and drains into a larger water body like a river, lake, or sea. Watershed edges are derived from the topography of an area. Watershed analyses were done to identify the water flow characteristics and watershed boundaries of the surrounding areas of Purbachal New Town. For this purpose, GIS-based analysis tools were used. A geographic information system (GIS) applies geographic science with various tools to collect data and map them systematically to create analysis and represent the spatial or geographic information of an area. GIS applications are tools that allow users to create queries regarding the topographical characteristics of an area, analyze spatial information to generate hydrological context, edit data in maps, and present the results of all these operations as water flow paths and watershed boundaries.

Watershed boundaries with well-defined edges make up a fundamental unit for landscape planning. Developing the delineated watershed is the final step of the watershed analysis. There are three main procedures to create the watersheds, including targeted areas in a stream as pour points, watersheds by stream segment, and off-stream delineation. For this study, the Watersheds by stream segment method was used. This method uses a stream network to generate corresponding watershed boundaries. The number and size of watersheds depend on the density of the stream network. For example, a denser stream network will result in many small watershed boundaries.

The first step is to create a stream link grid that gives a unique identifier to each stream segment where a segment is defined as the water flow on a single line between junctions. The Stream Link command creates a one-to-one relationship between each stream segment a catchment with it. This assigns unique values to each of the raster sections.

Next, the flow direction raster is used as the input for the Watershed command. From the one-to-one relationship between the stream segments, Watershed boundaries were identified. The result of this analysis is watersheds that correspond with each of the stream segments.

By moving the segment Watersheds below the stream link grid and changing their display properties to the unique categorical legend, pre and post-development watershed boundaries of Purbachal New Town were generated.

The watershed analysis offers an understanding of the watershed environment, which plays an important role in guiding the design decision-making process. Understanding the water flow mechanism of an area helps identify suitable locations for future development and categorizes areas that might be susceptible to different levels of flooding. Results from the watershed analysis can be crucial to develop ecologically sustainable planning guidelines by determining environmental needs to assist ecosystem functions. Through watershed analysis of the Purbachal New Town and surrounding areas, different areas were classified based on their inherent watershed characteristics.

4 RESULTS

4.1 Supervised Classification of Pre-development Landform

A supervised classification was carried out to create an accurate land cover map. For the accuracy statement, the number of samples needed to evaluate the classification accuracy for classification of 8 classes, 90% confidence, and 10% precision was estimated. The multinomial distribution method was followed to calculate the sample size (Jensen, 2016). By using Equalized Random distribution parameters, 142 points were generated. Next, the points were interpreted for their land class, and an accuracy report was generated. From the confusion matrix, it can be observed that the land cover class Grass' and Structure' was wrongly classified in some cases, and therefore had a lower user's accuracy.

Table 1. Accuracy Statement of pre-development landform Supervised classification.

Producer's Accuracy	Percentage	User's Accuracy	Percentage
Shallow water	93.3 %	Shallow water	100.0 %
Tree	96.6 %	Tree	100.0 %
Grass	50.0 %	Grass	44.4 %
Structure	100.0 %	Structure	50.0 %
Semi wet	100.0 %	Semi wet	57.9 %
Bare land	79.4 %	Bare land	93.1 %
Sand	60.0 %	Sand	100.0 %
Water	88.9 %	Water	100.0 %

Table 2. Accuracy Statistics and Landform Percentage of pre-development landform.

Statistics		Landform	Area (ha)	Percentage
N=	142	Shallow Water	1101.24	8.2 %
d=	125	Tree	4729.14	35.3 %
q=	4820	Grass	435.15	3.2 %
		Structure	905.13	6.8 %
Kappa Estimation	84.3 %	Sami-Wet	3555.45	26.6 %
		Bare land	1981.35	14.8 %
Overall accuracy	88.0 %	Sand	194.67	1.5 %
		Water	487.62	3.6 %
Foody 1992 statistic	65.8 %	Total	13389.75	100 %

From the accuracy statement in Table 1, it is observed that the classification worked well in most of the landforms. From Table 2, we can see the kappa statistics was 84.3, which suggested that the map was not a result of random classification. The overall map accuracy was 88. The map performed quite well in identifying the trees and bare land and differentiated between areas of shallow water and water.

4.2 Supervised Classification of Post-development Landform

By using Equalized Random distribution parameters, 120 points were generated. Next, the points were interpreted for their land class, and an accuracy report was generated. From the confusion matrix, it can be observed that like the pre-development map, the land cover class 'Grass' and 'Structure' was wrongly classified in some cases, and therefore had a lower user's accuracy.

Table 3. Accuracy Statement of post-development landform Supervised classification.

Producer's Accuracy	Percentage	User’s Accuracy	Percentage
Shallow water	90.0 %	Shallow water	69.2 %
Tree	81.3 %	Tree	76.5 %
Grass	66.7 %	Grass	53.3 %
Structure	88.9 %	Structure	53.3 %
Semi wet	75.0 %	Semi wet	100.0 %
Bare land	75.0 %	Bare land	100.0 %
Sand	93.8 %	Sand	100.0 %
Water	88.2 %	Water	100.0 %

Table 4. Accuracy Statistics and Landform Percentage of post-development landform.

Statistics		Landform	Area (ha)	Percentage
N=	120	Shallow Water	86.44	0.6 %
d=	98	Tree	3084.57	22.7 %
q=	1812	Grass	2487.47	18.3 %
		Structure	3549.98	26.1 %
Kappa Estimation	79.0 %	Sami-Wet	1280.94	9.4 %
		Bare land	2439.44	17.9 %
Overall accuracy	81.7 %	Sand	339.07	2.5 %
		Water	331.69	2.4 %
Foody 1992 statistic	61.1 %	Total	13599.6	100 %

From the accuracy statement in Table 3, it is observed that the classification worked well in most of the landforms. The kappa statistics was 79.0 in Table 4, which suggested that the map was not a result of random classification. The overall map accuracy was 81.7. The post-development map had lower accuracy and a lower kappa value but still performed quite well in identifying semi-wetland areas, trees, and bare land.

4.3 Result Comparison

By comparing the Pre-development and Post-development landcover map of Purbachal New Town within its administrative boundary, we can see that the landcover has been drastically modified in the last sixteen years. All wetland categories have decreased significantly. The amount of shallow water decreased from 8.2 % to only 0.6 %. The amount of semi-wetland also decreased from 26.6 % to 9.4 %. On the other hand, Grass cover increased from 3.2 % to 18.3 %, indicating newly filled areas (Figure 4).

As wetlands were converted into developable land, the amount of structure increased from 6.8 % from the pre-development stage in 2004 to 26.1 % to the post-development stage in 2020. According to the water reservoir conservation Act 2000, areas with flowing water and the land which retains the rainwater are defined as 'Natural wetland.' This includes rivers, canals, beels (a type of shallow waterbody), ponds, streams, fountains, and flood flow lands. These wetlands should be protected and preserved according to this law. But unfortunately, RAJUK, the capital development authority itself, has violated this law.

From the 2020 post-development land cover map, we can also see large patches of sand around the Purbachal New Town administrative boundary (Figure 4). This suggests that wetlands around the town are still getting filled up with sand. Illegal land encroachment must be stopped to prevent further ecological disturbance, and initiatives should be taken to recover the lost wetlands in and around the Purbachal New Town.

4.4 Water Flow and Watershed Analysis Result

By analyzing the pre-development flow direction map, the western part of the site has a large area where water is flowing towards the south (Figure 5). The water flows from the patches of relatively higher ground to the adjacent river on the east or towards the wetland on the west, and the general flow direction is towards the south.

In contrast, the post-development flow direction map clearly shows the drastic change in the water flow pattern. The area on the western side of the site has been filled up, interrupting the natural flow direction. As a result of this, water is diverted into different directions, causing flood risk for newly developed areas as well as the existing eastern part of Dhaka city.

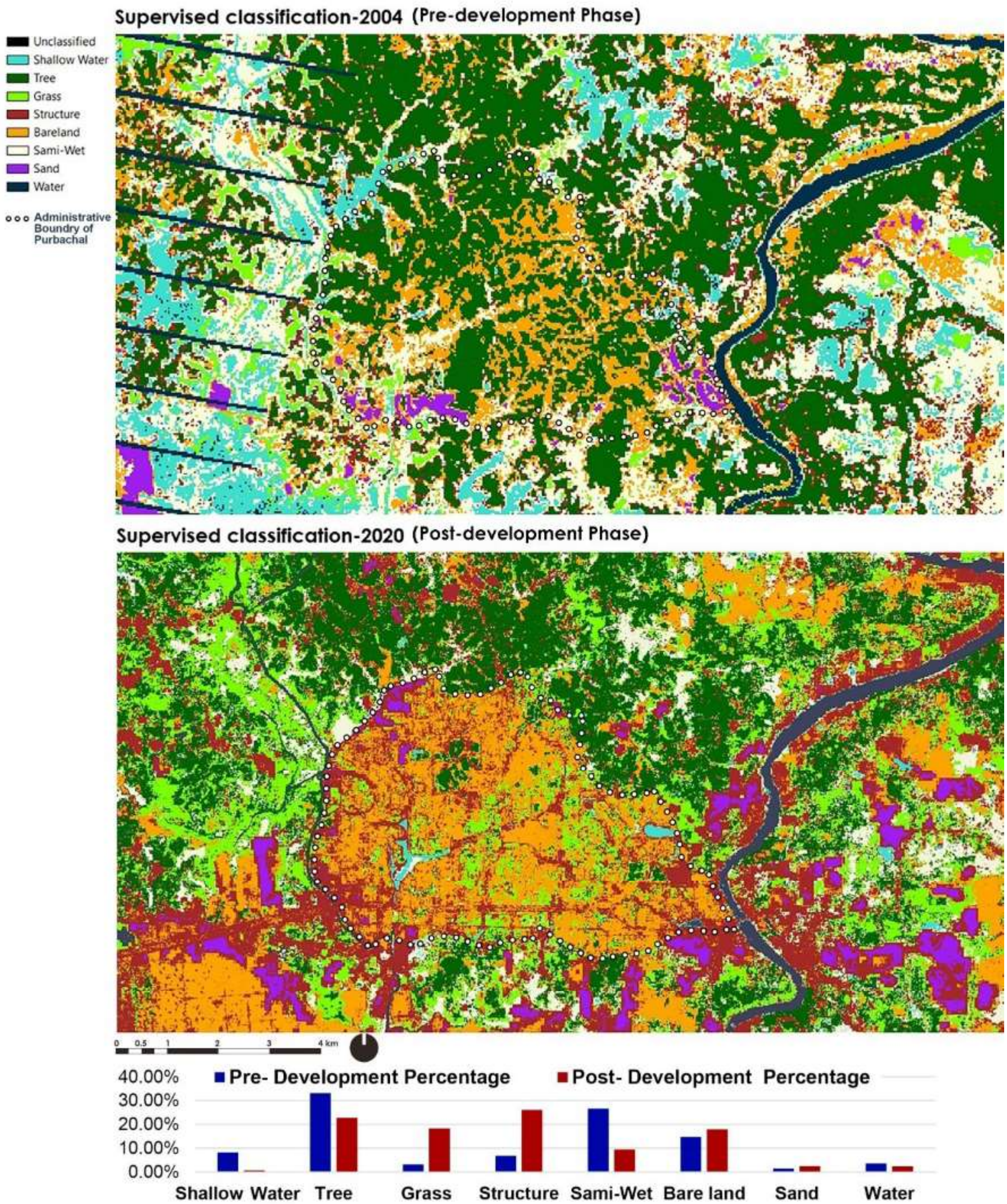

Figure 4. Comparison between Pre-development and Post-development landcover map of Purbachal New Town

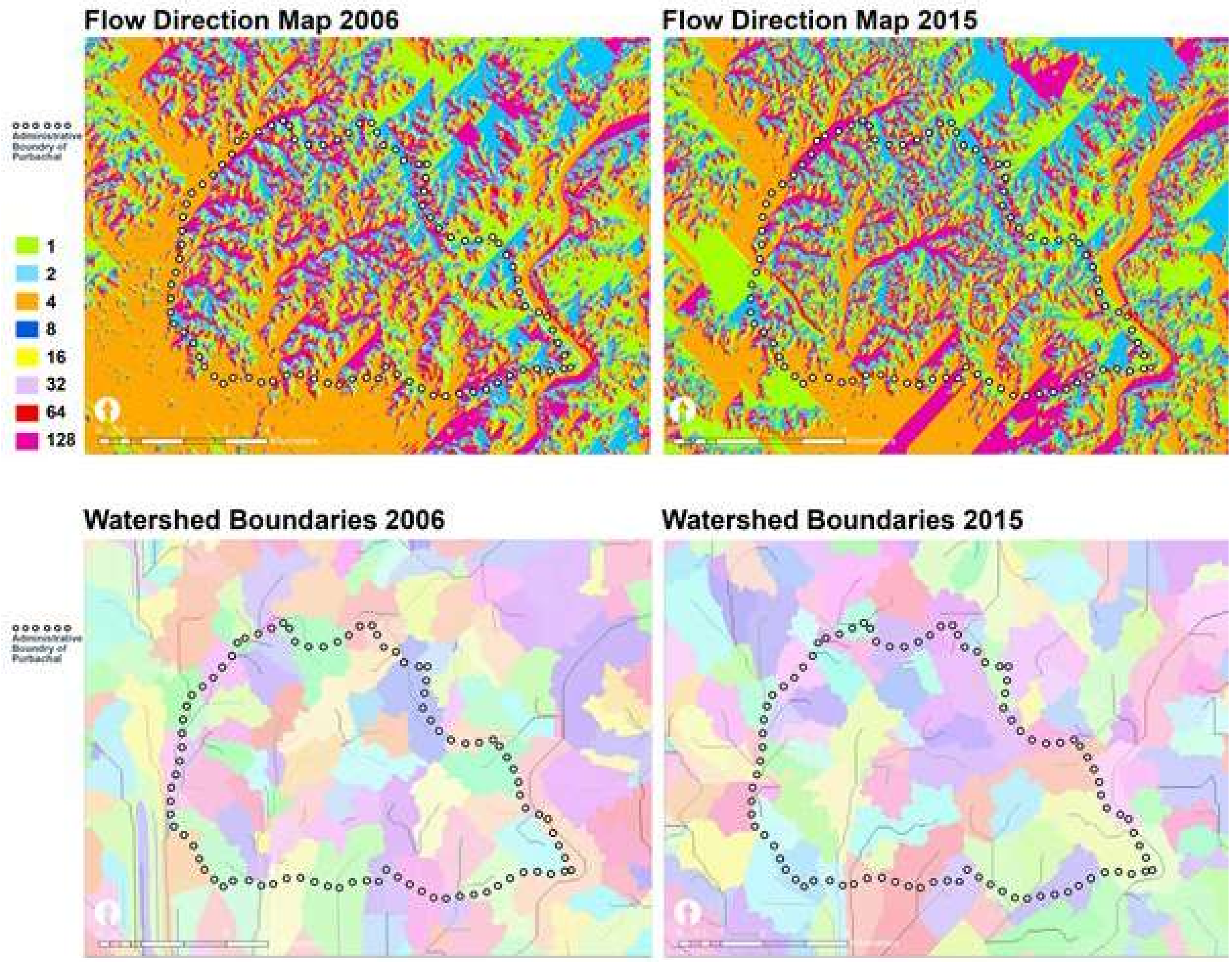

Figure 5. Water Flow and Watershed Boundaries Comparison

By analyzing the watershed boundaries of Purbachal New Town, a major change in the watershed can be observed (Figure 5). Due to filling up low lands, the post-development flow direction map clearly shows the drastic change in the water flow pattern. The area on the western side of the site has been filled up, which interrupted the natural flow direction. This can create flood risk for newly developed areas as well as the existing eastern part of Dhaka city.

5 DISCUSSION

More than half of the world's population now lives in cities, making humanity a predominantly urban species for the first time in its history. This trend is expected to continue. By 2050, with the urban population more than doubling its current size, nearly 7 of 10 people in the world will live in cities (Cohen, 2003). It is important to develop sustainable development strategies to make future cities environment-friendly (Calthorpe, 2010). The impact of cities on the world's resources is, in fact, disproportionate to their share of the population. Urban activities are estimated to account for some 67% of total energy consumption and 70% of greenhouse gas emissions (Tanaka, 2010). Similar dominance of the global demand for resources can be observed in urban consumption of freshwater, wood, and other raw materials.

Cities around the world are struggling to provide resources to sustain the huge influx of urban population. Therefore, cities should develop sustainable planning strategies to meet this ever-growing demand for resources. This is much more important in the case of developing countries like Bangladesh.

So, it is vital to develop planning strategies based on the understanding of natural landscape patterns. From the land use and land cover (LULC) maps, it is evident that despite being surrounded by low-lying areas, there are lands that can be potentially developed for commercial and residential purposes in Purbachal. From the Pre-development LULC map, it is observed that there were patches of high lands in Purbachal where the land was relatively free from annual flooding.

Instead of implementing a superimposed grid system that requires extensive cuts and fills to modify the existing landform dramatically, the new town plan should have followed the natural topography by creating a harmonious design that maximizes the use of flood-free lands for residential districts and housing infrastructure, commercial, and administrative districts. The low-lying natural areas could have served as a buffer to protect the city from annual and major flooding events. This type of planning strategy could have protected the city from potential flooding as well as preserved the flood flow areas to minimize the flood hazard of Dhaka city, which is further downstream. By minimizing cut and fill, the risk of soil liquefaction could also have been minimized.

6 CONCLUSION

The low-lying areas around the Purbachal play a crucial role in protecting Dhaka from major flooding. The surrounding wetlands support a wide range of agricultural activities, fish cultivation. A variety of natural vegetation in this area has created a unique ecosystem. The current masterplan of Purbachal altered this ecosystem and increased the risk of flooding and land subsidence. This study revealed how the landform and water flow of an area could be drastically altered when a topdown approach is implemented without properly analyzing the existing topography and hydrological conditions.

The process of analyzing natural landscape patterns in the context of Bangladesh has been demonstrated in this study. This can result in a new approach to urban development particularly suited for low-lying areas in Bangladesh. By analyzing the geo-hydrological aspects, a realistic city planning process suited for the context of Bangladesh can be formulated. By integrating natural ecosystems with urban planning, future cities will be able better equipped to face the challenges of climate change. The future resilient cities should not fight with the natural adversaries to survive, but it should generate a collaborative understanding with natural elements.

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