Assessment of Climate Change Related Impacts and Adaptation Measures for the Road Transport Sector of Bangladesh

A Project Report Submitted

by

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CERTIFICATE OF APPROVAL

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CHAPTER 1
INTRODUCTION

1.1 GENERAL

It is broadly recognized that Bangladesh is highly vulnerable to climate change related impacts. Indeed, it has been argued that Bangladesh, as a country, may suffer the most severe impacts from climate change (MOEF, 2009). Bangladesh is highly climate vulnerable, because it is low-lying, located on the Bay of Bengal in the delta of the Ganges, Brahmaputra and Meghna and is very densely populated. Its national economy strongly depends on agriculture and natural resources that are sensitive to climate change and sea level rise (Koudstaal and Ahmed, 1999). The geographic position of the country is giving effective monsoon to the people's life, on one hand, and the catastrophic disasters like tropical cyclones, storm surges, floods, droughts and erosion, on the other. These disasters cause huge loss of lives and properties and impede the development activities. While Bangladesh is already experiencing these disasters, in the foreseeable future, the country is likely to be affected by the long lasting and global scale human-made disaster, i.e. the climate change and the sea level rise (CCSLR) (Ali, 2000). Bangladesh is a signatory to United Nations Framework Convention on Climate Change (UNFCCC). In 1992, the Government of Bangladesh had signed the UNFCCC in Rio de Janeiro and ratified the Climate Convention in April 1994. To better prepare the country for dealing with these climate change impacts, pragmatic planning is needed based on authentic data and analyses from scientific studies.

Transport is the life of a country and choices on transit options are fundamental decisions about a country's future growth and development. An efficient transportation system increases accessibility and improves quality of life. The Bangladesh economy is burdened by major transportation constraints resulting from a combination of factors - physical, developmental and institutional-cum-policy framework-related, which lead to lower efficiency, higher transport costs, and more significantly, "transport unreliability" with major adverse consequence for the economy and environment. Beyond global concerns like climate change, transport impacts on the daily lives of people.

1.2 BACKGROUND OF THE STUDY

Bangladesh is one of the most densely populated countries in the world, with over 755 people per square km. With its high population density, low level of development, and low lying deltaic mass, Bangladesh has already been facing a number of natural and manmade problems. Natural hazards like cyclones, floods, droughts and socio-economic problems such as poverty, low literacy, poor health delivery systems, high unemployment are some of them. In the future Bangladesh may also have to face adverse impacts of development across its border -which among other, are expected to reduced availability of water during the dry season; and has to deal with impacts of climate change and sea level rise. The following features of Bangladesh are alarming with respect to climate change vulnerability:

- Two-thirds of the country is less than 5 meters above sea level;
- Bangladesh is very vulnerable to Tropical Cyclone and, in low-lying coastal areas, to tidal flooding during storms;
- 17.5 % of the land will disappear and 10 to 20 million people could become environmental refugee by 2050; and
- Bangladesh is susceptible to river and rainwater flooding, and according to UNDP, the sixth most vulnerable country to floods.

The UNDP has identified Bangladesh to be the most vulnerable country in the world to tropical cyclones and the sixth most vulnerable country to floods (see Table 1.1).

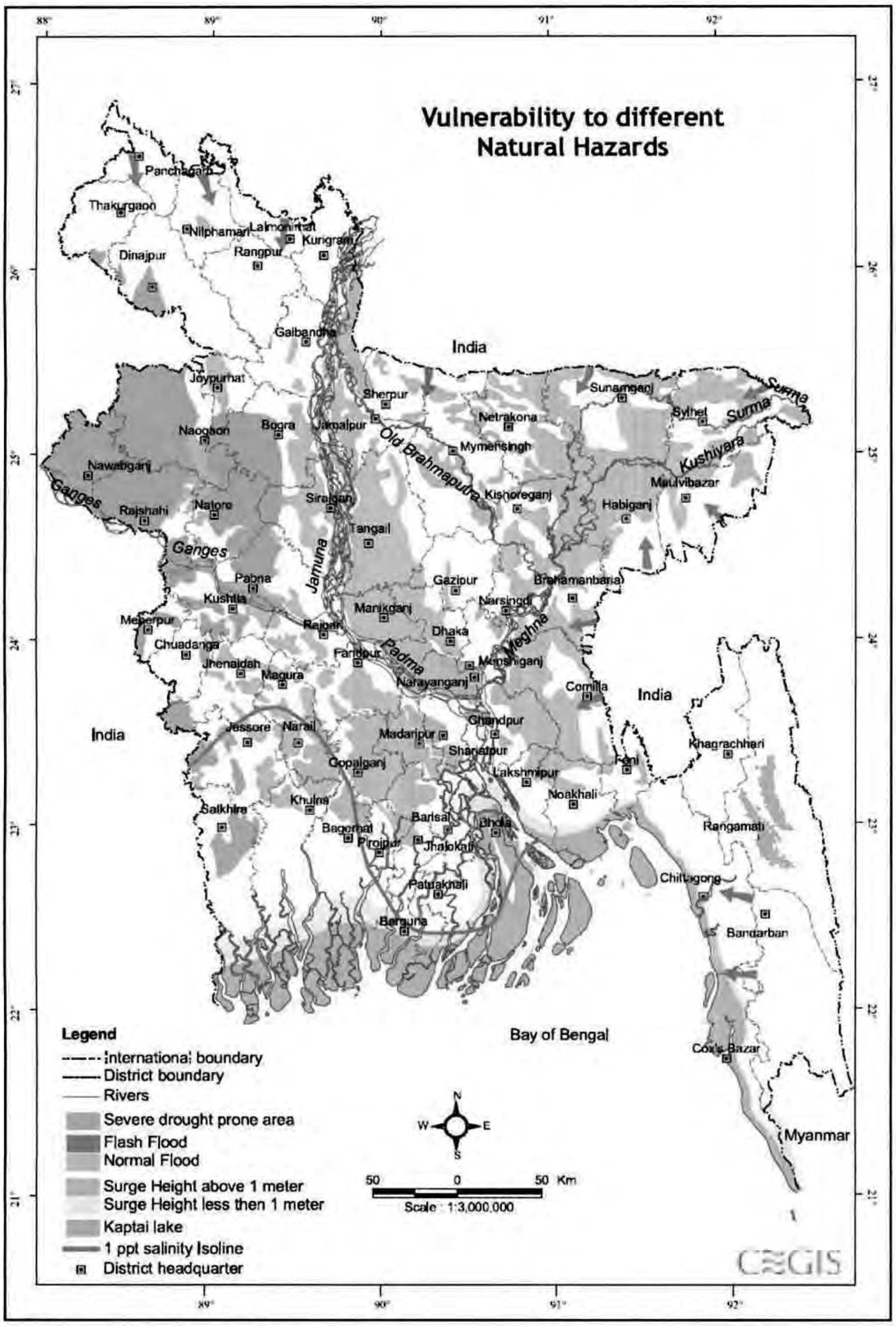
Table 1.1: Most vulnerable countries to floods or cyclones

Most vulnerable countries to floods or cyclones (Deaths/100,000 people exposed to floods or cyclones)					
	Floods			Tropical cyclones	
1.	Venezuela	4.9	1.	Bangladesh	32.1
2.	Afghanistan	4.3	2.	India	20.2
3.	Pakistan	2.2	3.	Philippines	8.3
4.	China	1.4	4.	Honduras	7.3
5.	India	1.2	5.	Vietnam	5.5
6.	Bangladesh	1.1	6.	China	2.8

* Of major flood-affected countries reporting an average of over 200 deaths/year.

Source: UNDP (2004), A Global Report: Reducing Disaster Risk: A Challenge for Development
http://www.undp.org/bcpr

Being susceptible to natural hazards like floods, tropical cyclones, storm surges, droughts, heat waves, etc., effective climate change adaptations are urgently required. The regions of the country affected by the different hazards are shown in Fig. 1.1.



Source: CEGIS, Dhaka.

Figure 1-1: Areas vulnerable to different hazards in Bangladesh

In light with the above discussion, it is also clear that climate change can have direct and indirect impacts on the Food Security, Social Protection and Health, Rural and Urban Infrastructure, Agriculture and Water Resources, Livestock and Fisheries, Industries, Livelihoods and overall life of the people of Bangladesh. One of the major impacts would be on ROAD INFRASTRUCTURE, which is especially vulnerable to these changes due to the nature of the terrain and shortage of fund to build sustainable infrastructure. Flood flow discharge and rainfall changes can alter moisture balances and influence road embankment and pavement deterioration. In addition, temperature can affect the aging of bitumen resulting in an increase in cracking of the surface chip seal, with a consequent loss of waterproofing. The result is that surface water can enter the pavement causing potholes and fairly rapid los of surface condition. More frequent reseal treatments will ameliorate the problem, but at a cost to road agencies. Increased intensity of strong hurricanes would lead to more evacuations, damages, transportation interruptions, and a greater probability of infrastructure failure.

Bangladesh is likely to experience the following major impacts in the future due to climate change:

- Flooding of Rivers and Canals;
- Increase in mean Temperature;
- Mean Sea level Rise;
- Changes in mean precipitation;
- Increase in storm frequency and severity; and
- Increase in precipitation intensity and storm surges.

Due to the above mentioned weather event, the following impacts are anticipated:

- Inundation and flooding of coastal and inland infrastructure (road embankment);
- Reduced navigational clearance of bridges, making these bridges non-functional;
- Increased flow of water through culverts;
- Changes in transportation demand;
- Change in length and quality of construction season; and
- Damages to structures

New infrastructure need to be designed and constructed considering the possible impacts of climate change. For existing infrastructure, modification (e.g., raising embankment), relocation (e.g., to meet changed transportation demand), retrofitting structures with appropriate protection, reconstruction over same alignment and changing of maintenance practice might be possible correction measures. For new infrastructure, the following issues should be addressed:

- Change in design practice (e.g., new design should incorporate probable rise of sea level over the estimated design life of the infrastructure.); and
- Use different construction materials that can sustain elevated temperatures and flooding.

Impacts of climate change is not considered in planning process of Road sector of Bangladesh and even recently formulated Road Master Plan for next 25 years did not consider probable climate change effect. Another important cause of concern is that there is no detailed inventory of Roads and Bridge infrastructure, which are vulnerable to climate change.

Considering the possible impact of climate change in Bangladesh, studies are urgently needed on impact identification, remedial measures and adaptation in facing the challenges of climate change in transport infrastructure sector. At the same time, an inventory of potentially vulnerable Roads and Bridges of Roads and Highways Road Network needs to be developed. This would create the foundation for future detailed studies on impact of climate change on transport infrastructure and for devising and implementing various adaptation programs.

1.3 OBJECTIVES OF THE STUDY

The specific objectives of the proposed study are:

1) To identify areas that are likely to undergo inundation due to sea level rise (under different scenarios) and during storm surges in the coastal areas.
2) To make an inventory of the roads and bridges that are susceptible to climate change impact.
3) To assess the sustainability of recently approved Road Master Plan for Bangladesh.

4) To recommend adaptation measures for coping with possible climate change impacts on transport infrastructure of the country.

1.4 LIMITATIONS OF THE STUDY

The objective of this study is to find out the vulnerable transport networks i.e. roads, highways, culverts and bridges with respect to Climate Change related impacts especially due to sea level rise, flood and inundations along the coastal areas of Bangladesh. Due to time and fund constraint, and absence of adequate secondary data, the research scope was limited to the following factors:

i) Climate Change related impacts were measured only for road transport sector because of its large modal share to the transportation demand, facilities and infrastructure;
ii) Moreover, only Roads and Highway elevations were considered to assess vulnerability against Climatic Events; bridge or culvert locations were not considered in the study. However, any findings and recommendations from this research study for any specific road must go in line with the presence of bridge and culverts along the alignment;
iii) Due to shortage of secondary data and time and fund constraints in generating primary data to find out the crest level of finished roads, Google Earth® software has been used to extract data and info regarding Reduced Level (RL) of the road. Data taken from the software may differ slightly from the actual scenario;
iv) The research study was conducted only for the coastal areas in Bangladesh, as coastal areas are experiencing innumerous and fatal climatic events. Due to time constraint, study area was limited to three districts in the coastal zones. In line with the objective of the study Satkhira, Khulna and Bagherhat were selected for the study, as these districts are vulnerable with respect to Climate Change Impacts; and
v) In the analysis, South West Regional Model developed by Institute of Water Modeling (IWM) was used, which considers temperature changes, precipitation, inundation, river discharges, tidal surges with variation, etc., but not the Cyclonic or Storm effects which often causes much devastation to the life of people and environment.

1.5 OUTLINE OF THE REPORT

This project report consists of six chapters. The contents of the chapters are as follows:

Chapter 1 includes general introduction, salient features and objectives of the study. Background of the study is also presented in in this chapter.

Chapter 2 presents literature review and review of similar previous studies.

Chapter 3 contains the approach and methodology. The procedure that has been followed in this work is presented with relevant references here. A brief description of the theory and the method of analysis are also included in this chapter.

Chapter 4 presents the important results and discussion. The major findings of the work are also presented in this chapter.

Chapter 5 contains the adaptation strategies and measures in combating the climate challenge and focus on the adequacy and effectiveness of the RHD Master Plan as well as NAPA.

Chapter 6 presents the major conclusions and recommendations of this research study.

CHAPTER 2
REVIEW OF LITERATURE

2.1 GENERAL

Rapid change in the global climate is not a nature driven phenomenon; human induced changes in the global climate and the associated sea level rise are now widely recognized by scientists. The Intergovernmental Panel on Climate Change (IPCC) concluded that "the balance of evidence suggests a discernible human influence on global climate". The exact magnitude of the changes in the global climate is still uncertain and subject of worldwide scientific studies. It is broadly recognized that Bangladesh is very vulnerable to these changes. Bangladesh has a climate-dependent economy. This country has historically been wrecked by numerous natural hazards like flooding, severe tropical cyclones and associated storm surges, drought and earthquakes, flash flooding, tornados and river-bank erosion. Climate change is a recent but silently growing member joining this already large family of disasters in Bangladesh. It was envisaged in late 1990s that global climatic change could exacerbate some of the physical consequences of natural hazards (Warrick and Ahmad, 1996). According to the Third Assessment Report of IPCC, South Asia is the most vulnerable region of the world to climate change impacts (McCarthy et al., 2001). Observing the repetitive attack of natural disasters over Bangladesh, it has internationally been argued that Bangladesh, as a country, may suffer the most severe impacts from climate change. The international community also recognizes that Bangladesh ranks high in the list of most vulnerable countries on earth.

Bangladesh's high vulnerability to climate change is due to a number of hydrological, geological and socio-economic factors. Geographical location in South Asia, flat deltaic topography with very low elevation, extreme climate variability which is governed by monsoon resulting in acute temporal and spatial distribution of water, high population density, high poverty incidence, climate-dependent crop agriculture etc. make up the utterly volatile regime of vulnerability. A review on Bangladesh disaster and public finance (Benson and Clay, 2002) remarked that the effects of rising sea-level on low-lying coastal areas, where there is elevation in progress and in interacting with high flood levels, were clearly complex and uncertain. It is, therefore, most important to understand its vulnerability in terms of population and sectors at risk. Climate change phenomena like temperature rise; sea-level rise, erosion, precipitation, drought etc. impact the primary variables like physical, biological and human systems. These, in turn, impact the secondary variables like aquatic, terrestrial and marine environments. Its final incidence falls upon the various economic sectors like agriculture, livestock, poultry, wildlife, livelihood and health, affecting GDP of the economy.

Transportation is essential to our well-being. Bangladesh needs a reliable, safe and sustainable transportation system to connect our communities, and to connect us with our trading partners. Transportation industries account for approximately 5% of its gross domestic product, and employ more than 20,00,000 people. However, these statistics vastly understate the importance of transportation in this country because of the fact that private cars and trucks account for a large proportion of both passenger and freight movements. Overall, it is difficult to overestimate the importance of transportation to Bangladeshi life. It has been estimated that the road system alone has an asset value approaching 1,00,000 Crore BDT.

Assessing the vulnerability of transportation in Bangladesh to climate change is an important step toward ensuring a safe, efficient and resilient transportation system in the decades ahead. Transportation in Bangladesh remains sensitive to a number of weather-related hazards. Future climate change of the magnitude projected for the present century by the Intergovernmental Panel on Climate Change (IPCC), specifically an increase in global mean annual temperature of 1.4–5.8°C, would have both positive and negative impacts on Bangladesh's transportation infrastructure and operations. These impacts would be caused by changes in temperature and precipitation, extreme climate events (including severe storms), and water level changes in oceans and rivers.

2.2 CLIMATE CHANGE RISK TO BANGLADESH

Bangladesh suffers from many climate dependent natural hazards, such as: riverine and coastal floods, riverbank erosion, tropical cyclones and droughts. The 1998 riverine flood, one of the worst this century inundated two-thirds of the country, damaged crops, physical infrastructure and assets of over US$ 2.5 billion and caused hundreds of deaths and hundreds of thousands of cases of diarrhea. Devastating incidence named SIDR in November 2007, which had arrived as a Category- 4 Super Cyclone with peak winds at

250 km/hr. A preliminary assessment of UNDP shows that approximately 4.7 million people and a further 2.6 million people (most of them the poorest of the poor) living on 30 of Bangladesh's 64 districts were affected by the storm mainly within the coastal regions of Barisal and Khulna. Apart from this, the country is known for its high sensitivity to natural calamities. According to the third assessment report of IPCC, South Asia is the most vulnerable region of the world (McCarthy et al., 2001) and the international community also recognizes that Bangladesh ranks high in the list of most vulnerable countries on earth (Ahmed, 2006). The case of Bangladesh is unique in the sense that: unlike other vulnerable island countries, this country will eventually face the multidimensional manifestations of climate change (e.g. flood, cyclone, sea level rise, drainage congestion, salinity, drought etc (WB, 2000). Researchers (Ahmed and Haque, 2002; Ahmed, 2006) have identified a number of hydro-geological and socio-economic factors responsible for Bangladesh's high vulnerability as listed below:

- Its geographical location in South Asia
- Its flat deltaic topography with very low elevation
- Its extreme climatic variability that is governed by monsoon and which results in acute
- Water distribution over space and time
- Its high population density and poverty incidence; and
- Its majority of population being dependent upon crop agriculture, which is highly influenced by climatic variability and change

Other than this, burdened by social and economic problems such as low levels of literacy, poor health delivery systems, low per capita income and high unemployment, Bangladesh faces many difficulties in achieving sustainable development (WB, 2000).

2.3 CLIMATE CHANGE VARIABILITY: HYDRO MORPHOLOGICAL ASPECTS

Geographically Bangladesh is located on the Bengal Basin between $20^0$34' to $26^0$38' North latitude and $88^0$01' to $92^0$42' East longitude. It is bordered on the west, north and east by India, on the south-east Myanmar and on the south by the Bay of Bengal. The country occupies and area if 147,570 sq. km (BBS, 2005). A network of river originated in the eastern Himalayas –The Ganges, The Brahmaputra, and the Meghna (GBM)- their tributaries and distributaries crisscross the floodplain flow over the country. Bangladesh has around 700 km of coastline from the Sundarbans to Teknaf and its prominent deltaic geophysical characteristics have made it one of the most water related disaster prone countries within the world. Bangladesh is endowed with both surface and groundwater resources and on a per capita basis it has one of the highest quantum available in the world (Ahmed, 2006). Its surface water system is dominated mainly by the GBM rivers, covering about 7% of the surface of the country and constituting a huge outfall only second to that of the Amazon system. Combined discharge of the rivers into the Bay of Bengal is about 142 thousand cubic meters per second at peak periods. It is estimated in average year availability if surface water flows is 1,350 billion cubic meters (BCM), of which 85% of the water flows to the Bay of Bengal (Rahman et al., 1990) carrying a huge amount of Himalayan and GBM flood plain sediments as building blocks of the landmass of the delta.

2.3.1 Temperature and Precipitation Change

Past and present climate trends and variability in the South East Asia are generally characterized by increasing surface air temperature, which is more pronounced during winter than in summer. IPCC-IV has reported that an increasing trend of about 1°C in May and 0.5°C in November has been observed during the 14-year period from 1985 to 1998 in Bangladesh (Mirza and Dixit, 1997; Khan et. al.. 2000; Mirza, 2002). They have also reported decadal rainfall anomalies above long-term averages since 1960s. Since climate change is a dynamic phenomenon, changes will occur over time, and implications will only understood in future, it is not possible 'to define a changing climate' that might occur 'within a definite period in future'.

In early 1990s, several attempts have been made to generate climate change scenarios by the use of available General Circulation Models (GCM). The BUP-CEARS-CRU (1994) study reported 0.50C to 2.00C rise in temperature by the year 2030 under the 'business as usual' scenario of IPCC. The same Modeling effort estimated 10 to 15% rise in average monsoon rainfall by the year 2030. ADB (1994) study also made use of four GCMs: CSIR09, CCC, GFDLH and UKMOH. The high estimating GFDL model (GFDLH) projected 59% higher rainfall in South Asian monsoon with a corresponding withdrawal of dry monsoon rainfall by 6%. Modeling outputs of IPCC IS92a showed a rise in temperature of 0.3^0C and 1.5^0C for 2010 and 2070 respectively. But the above-mentioned Modeling outputs have not tried validation of GCM outputs for Bangladesh.

Another major attempt has been made to generate a model-driven climate change scenario under the 'Climate Change Country Studies Programme' (Ahmed et. al., 1996; Asaduzzaman et. al., 1997 and Huq et. al., 1998). A number of GCMs (CCCM, GFDL, GF01) have been used and the outputs if the three GCMs for the 1990 base year were validated against long-term 'climate normal', as provided in published report (FAO-UNDP, 1988). Applying the same methodology, Ahmed and Alam (1998) reproduced the climate change scenarios, which have been used for a number of subsequent national assessments. Their outputs of the GCM exercise using GFD 01 transient model is given in Table 2.1.

Table 2-1: Temperature and Precipitation Outputs of the GCM using GFD 01 Transient Model by Ahmed and Alam (1998)

Year	Average Temperature			Temperature Increase			Average Precipitation			Precipitation Increase		
	W	M	Ave	W	M	Ave	W	M	Ave	W	M	Ave
	(°C)			(°C)			mm/month			mm/month		
1990	19.9	28.7	25.7	0.0	0.0	0.0	12	418	179	0	0	0
2030	21.4	29.4	27.0	1.3	0.7	1.3	18	465	189	6	47	10
2075	22.0	30.4	28.3	2.1	1.7	2.6	00	530	207	-12	112	28

Agarwala et. al. (2003) has used another ensemble of a dozen GCMs, which were driven by MAGICC model using SCENGEN database. The core findings have been found consistent with the findings of Ahmed and Alam (1998). The output is shown below:

Table 2-2: Findings of Agarwala et. al. (2003) on Temperature and Precipitation

Year	Temperature Change in °C Mean (Standard deviation)			Precipitation Increase Mean (Standard deviation)		
	Annual	DJF	JJA	Annual	DJF	JJA
2030	1.0 (0.11)	1.1 (0.18)	0.8 (0.16)	3.8 (2.3)	-1.2 (12.56)	+4.7 (3.17)
2050	1.4 (0.16)	1.6 (0.26)	1.1 (0.23)	+5.6 (3.33)	-1.7 (18.15)	+6.8 (4.58)
2100	2.4 (0.28)	2.7 (0.46)	1.9 (0.40)	+9.7 (5.8)	-3.0 (31.6)	+11.8 (7.97)

(DJF represents the months of December, January and February, usually the winter months. JJA represents the months of June, July and August, the monsoon months)

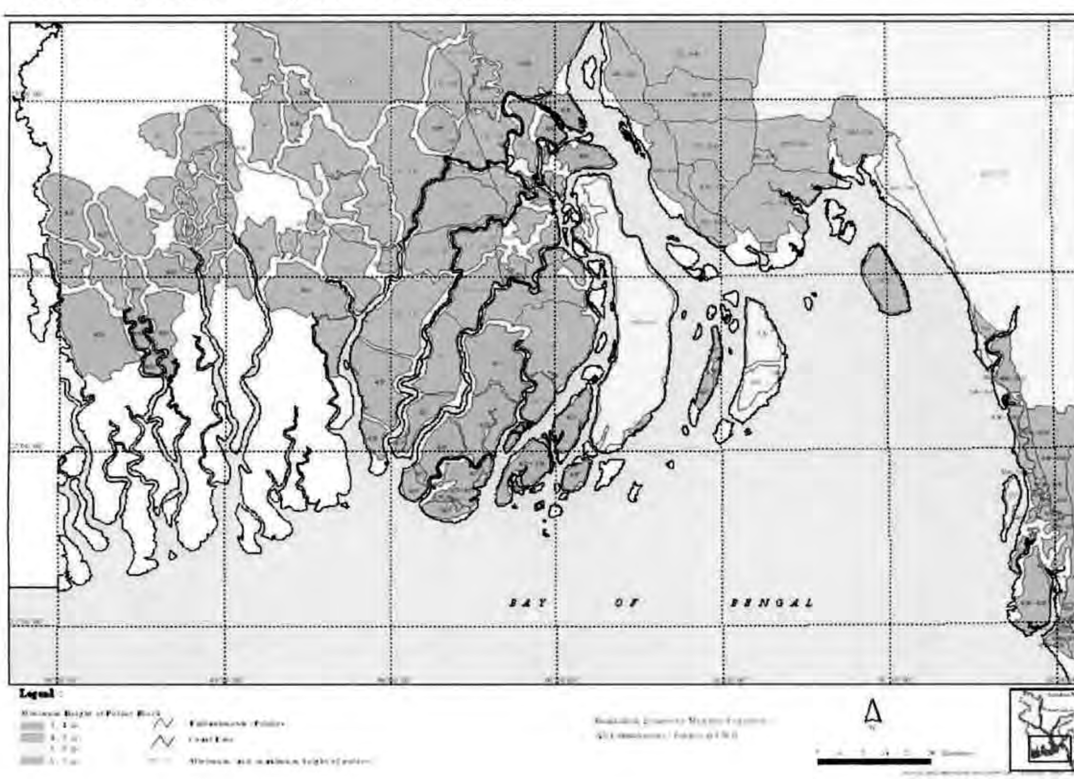
Another attempt has been made by NAPA (GoB, 2005) and they have adopted the results obtained by Agrawal et al. (2003) for changes in temperature and modified the results of Agrawal et al. (2003) regarding changes in precipitation (Table 2.3).

Table 2-3: Change in Temperature and Precipitation by NAPA (GoB, 2005)

Year	Temperature Change in ºC Mean (Standard deviation)			Precipitation Increase Mean (Standard deviation)		
	Annual	DJF	JJA	Annual	DJF	JJA
2030	1.0	1.1	0.8	5	-2	6
2050	1.4	1.6	1.1	6	-5	8
2100	2.4	2.7	1.9	10	-10	12

2.3.2 Sea level rise

Bangladesh has 710 km long coastline. The landward distance of the delineated coastal zone from the shore is between 30 and 195 km whereas the exposed coast is between 37 and 57 km. Other part of the country has an elevation of less than 10 meters above sea level. With the exception of the Chittagong Hill Tracts in the southeast and the Modhupur tract in the central region, the country is located in the floodplains of three main rivers namely Ganges, Brahmaputra and Meghna.



(Source: CEGIS)

Figure 2-1: Coastal region of Bangladesh

The coastal zone is low-lying with 62% of the land have an elevation of up to 3 metres and 86% up to 5 metres. The Bay of Bengal is a northern extended arm of the Indian Ocean. In the north of Bay of Bengal, Swatch of No Ground, a submarine canyon present at 25 km south of the western coastline of Bangladesh (Mohal et. al., 2006).

A number of previously published studies examined the potential impacts of climate change on Bangladesh (e.g., Qureshi and Hobbie, 1994; Huq et al., 1996; Warrick and Ahmad, 1996; Huq, Karim, Asaduzzaman and F. Mahtab eds. 1998), assuming certain changes in the climate and corresponding sea level rise. Islam (2001) identified some of the changes in global mean sea level induced by several processes on different time and space scales. The processes include glacio-isostatic rebound, oceanographic, atmospheric, and tectonic effects. Eustatic sea level variation is associated with the volume change of seawater and relative sea level rise can be different due to local uplift and subsidence. Sea level rise due to sedimentation, although significant near river deltas, is negligible on a global scale. Sea level rise (SLR) on a short time scale (several years) is associated with El Nino/ Southern oscillations. IPCC-IV study has referred to various researchers who have reported that in the coastal areas of Asia, the current rate of SLR (1 to 3mm/yr) is marginally greater than the global average. In addition to this, the rate of sea level rise of 3.1 mm/yr as reported over the past decade has been accelerated relative to the long-term average taken over the 20th century as a whole (1.7 to 2.4 mm/yr). Future climate change scenarios research by a pilot study of Department of Environment mentioned (DOE, 1993) a potential future sea level rise for Bangladesh is 30-50 cm by 2050. An increasing tendency in sea level rise from west to east along the coast has also been observed. Ahmed and Alam (1998) has projected the SLR value for the year 2030 and 2050, which have been constructed by using general circulation models (GCM) that was superimposed on long-term climatic patterns over ten locations in Bangladesh. Their estimate was one-meter change of sea level by the middle of 21st century; it combines a 90 cm rise in sea level and about 10 cm local rise due to subsidence. The SAARC Meteorological Research Centre (SMRC) analysed sea level changes of 22 years historical tide data at three tide gauge locations in the coast of Bangladesh. The study revealed that the rate of sea level rise during last 22 years is many fold higher than the mean rate of global sea level rise over 100 years. SMRC projected figures of sea level rise are 18 cm, 30cm and 60 cm for the year 2030, 2050 and 2100 respectively (Table 2.4). National Adaptation

Programme for Action (GoB, 2005) Team is fully compliant with the Third Assessment Report (TAR) regarding probable SLR, which indicates that the global sea level rise is 9 cm to 88 cm from 1999 to 2100. Another notable study by Mohal et. al (2006) is also agreeable with the IPCC-III prediction and their result shows that, in the year 2100 at 88 cm SLR, about 11% area (4,107 km2, as shown in Figure 2.2) of the coastal zone will be inundated in addition to the inundated area in the year 2000 under same upstream flows. But it should be noted that the IPCC rates of change of sea level are only indicative and accurate predictions could not be made due to inherent weaknesses of the models. In addition to this, there is a wide range of variation concerning the extent of such changes in the above-mentioned and other literatures (Yohe and Schlesinger, 1998; Greenpeace, 1999).

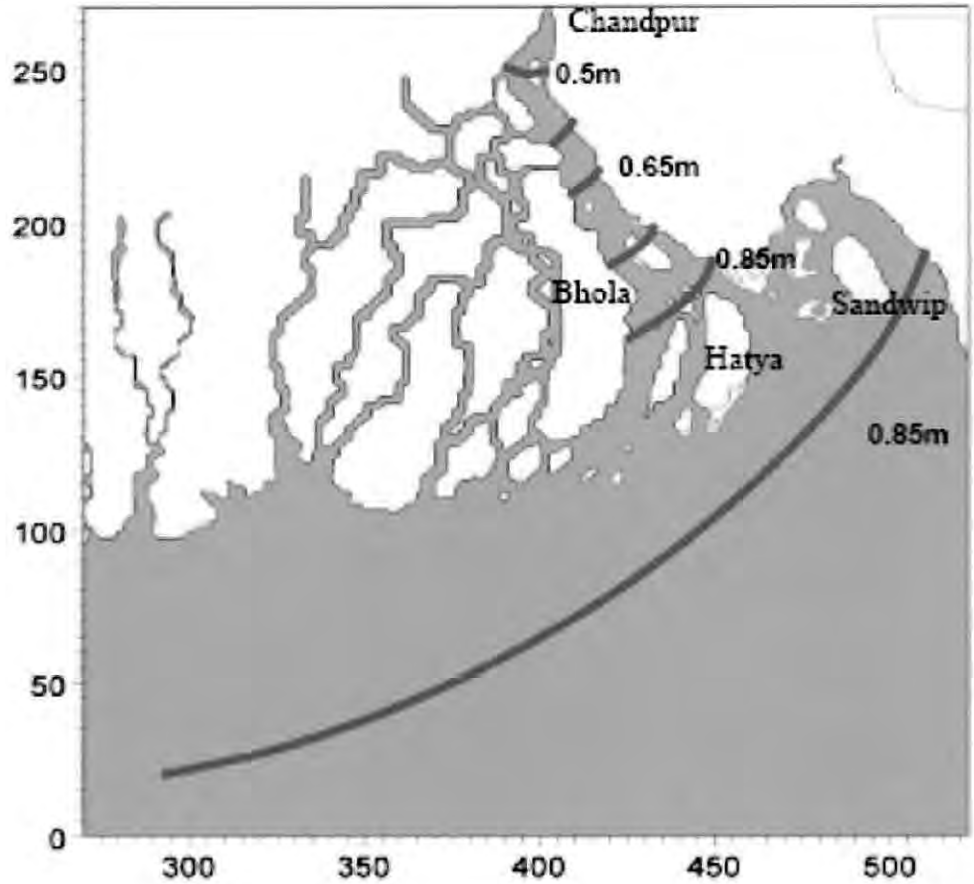


Figure 2-2: Probable depth of flooding in the coastal Region

Direct rainfall and river runoff water may be significant factors in short-term changes (seasonal) in sea level along some coasts. Rainfall and runoff water contribute significantly to producing the 100 cm sea level variation seen in the Bay of Bengal. The seasonal sea level changes in the Bay is remarkable and one of the highest in the world. Due to its funnel shaped geometry the maximum seasonal variation can be seen along the northeast coast of the Bay. Along Chittagong coast the annual variation is 1.18m. In the Bay of Bengal during the last 9,000 years, five periods of marine transgressions, each followed by regression, have been recorded. A maximum relative sea level rise rate of 3.65mm/yr-1 has been estimated between 6315 and 5915 years BP; the average rate for the Bengal basin, during the Holocene, was 1.07 mm/yr-1. The focus of this study is on examining the needs and possibilities for addressing adaptation. The aim is to reduce Bangladesh' vulnerability to climate change and sea level rise impacts, and enhance the country's potential for sustainable development.

Impacts of changes in climate and sea levels should not be considered in isolation from other exogenous changes, such as: subsidence of the coastal area and developments in upstream (shared) river basins. For example, increased salt water intrusion in the coastal zone of Bangladesh will result from a combination of reduced river flows from upstream basins and sea level rise. Effectiveness of adaptation measures should be weighed against the relative importance of these other exogenous changes.

Table 2.4: Considerations of Climatic factors in different years

Year	Temperature change (^0C) mean		Precipitation change (%) mean		Sea level rise (cm)		
	Monsoon season	Dry season	Monsoon season	Dry season	SMRC	NAPA scenario	3rd IPCC (upper range)
2030	0.8	1.1	+6.0	-2.0	18	14	14
2050	1.1	1.6	+8.0	-5.0	30	32	32
2100	1.9	2.7	+12.0	-10.0	60	88	88

2.3.3 Cyclones and Storm Surges

The coastal areas of Bangladesh and the Bay of Bengal are located at the tip of northern Indian Ocean, which has the shape of an inverted funnel, and the Bay itself is quite shallow. The area is frequently hit by severe cyclonic storms, generating long wave tidal surges. These surges are amplified when they traverse shallow waters, and have a disastrous effect on the coastal areas of Bangladesh (WB 2000). Recent studies indicate that the frequency and intensity of tropical cyclones originating in the Pacific have increased over the last few decades (Fan and Li, 2005). In contrast, cyclones originating from the Bay of Bengal and Arabian Sea have been noted to decrease since 1970 but the intensity has increased (Lal, 2001). This statement is very much compliant with the recent attack of cyclone SIDR in Bangladesh. Cyclone Sidr hit the South West Bangladesh coast during the evening of the 15 Nov. 2007. The storm arrived as a Category-4 Super Cyclone with peak winds at 250 kms. per hour. Sidr continued to travel in a North-North East Direction, affecting parts of Central Bangladesh, where it was subsequently downgraded into a Category-3 cyclone. Approximately 30 of Bangladesh's 64 districts were affected by the storm mainly within the administrative divisions of Barisal and Khulna (UNDP 2007).

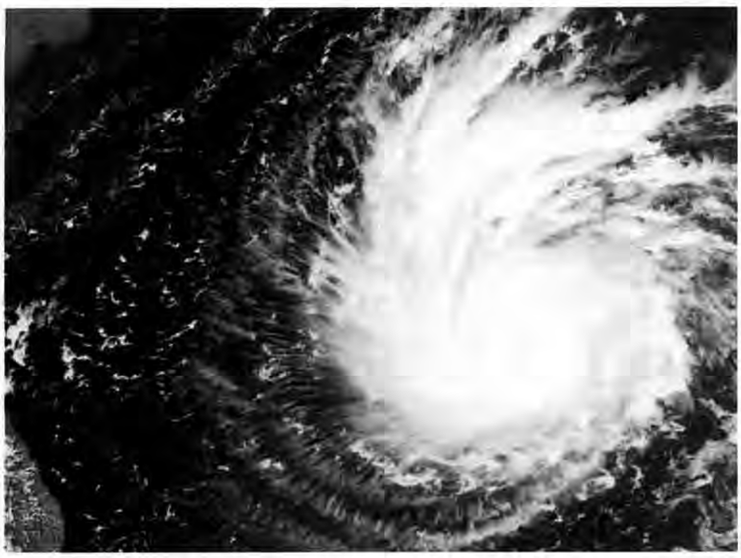
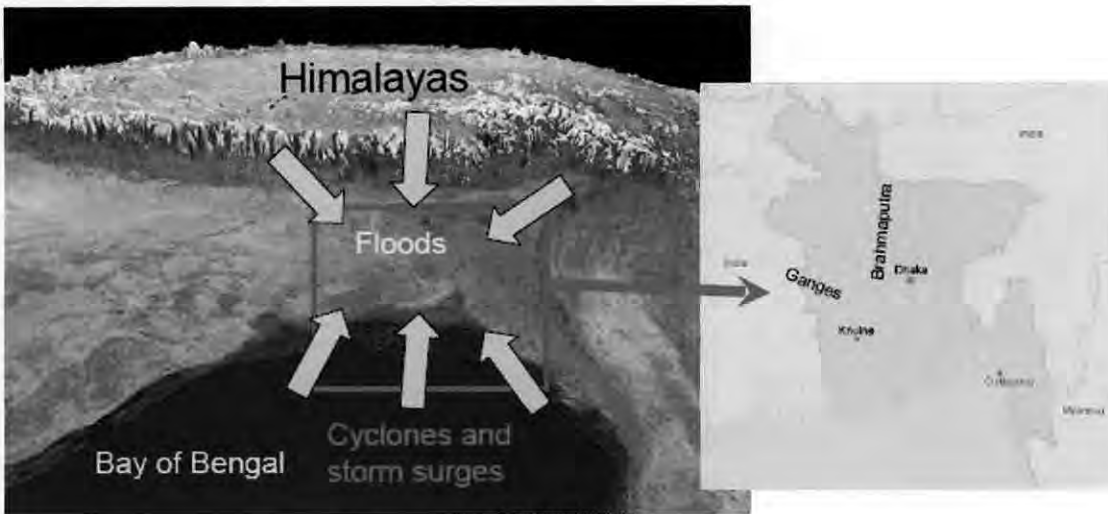


Figure 2-3: Pathway of Cyclone Sidr 2007 (Source: NASA)

In Bangladesh, cyclones are observed twice a year: during late April and early May (early summer), and between late October and early November (late autumn/fall). A storm surge during a cyclone inundates coastal areas and offshore islands, which causes most of the loss of life and property. Information on storm surge height is very scarce in Bangladesh. Available literature provides a range of 1.5 to 9.0 meter high storm surges during various severe cyclones (Haider et al., 1991). However, a SMRC report shows the surge height for 1876 cyclone was 13.6 m at Bakerganj and the surge height for 1970 cyclone was 10m. Locations of these surge heights are not known. Therefore, it is difficult to compare maximum wind speed and corresponding surge heights. Displacement of water surface during a cyclonic storm surge also depends on the height of tide, which is a function of lunar attraction and wind-factor. There is considerable difference in tide-height depending on the season and position of the moon relative to the sun.



Source: USGS

Figure 2-4: Climatic Sandwich (effect of flood and cyclones)

Another important factor is the path of cyclones. Due to its geographic location, cyclones hitting the Khulna region in the southwest have comparatively lower storm surges than those hitting the Meghna estuary. The paths of a few recent cyclones that hit Bangladesh are shown. These include the recent SIDR path and other historical incidences up to 1997 cyclone.

2.3.4 Cross-boundary River Flows

The country's geographical location, high dependence on the GBM regional hydrology, spatial and temporal distribution of water resources-all contribute to the high degree of susceptibility of Bangladesh to water related extreme events (Ahmed et. al., 1998a). Bangladesh has been sharing a total of 54 Trans-boundary Rivers, which are mostly originated from Himalayan glaciers located on upper riparian countries. Himalayan glaciers cover about three million hectares or 17% of the mountain area as compared to 2.2% in the Swiss Alps. They form the largest body of ice outside the polar caps and are the source of water for the innumerable rivers that flow across the Indo-Gangetic plains. Himalayan glacial snowfields store about 12,000 kml of freshwater. About 15,000 Himalayan glaciers form a unique reservoir which supports perennial rivers such as the Indus, Ganga and Brahmaputra which, in turn, are the lifeline of millions of people in South Asian countries like Pakistan, Nepal, Bhutan, India and Bangladesh. The Gangetic basin alone is home to 500 million people, about 10% of the total human population in the region (IPCC-IV).

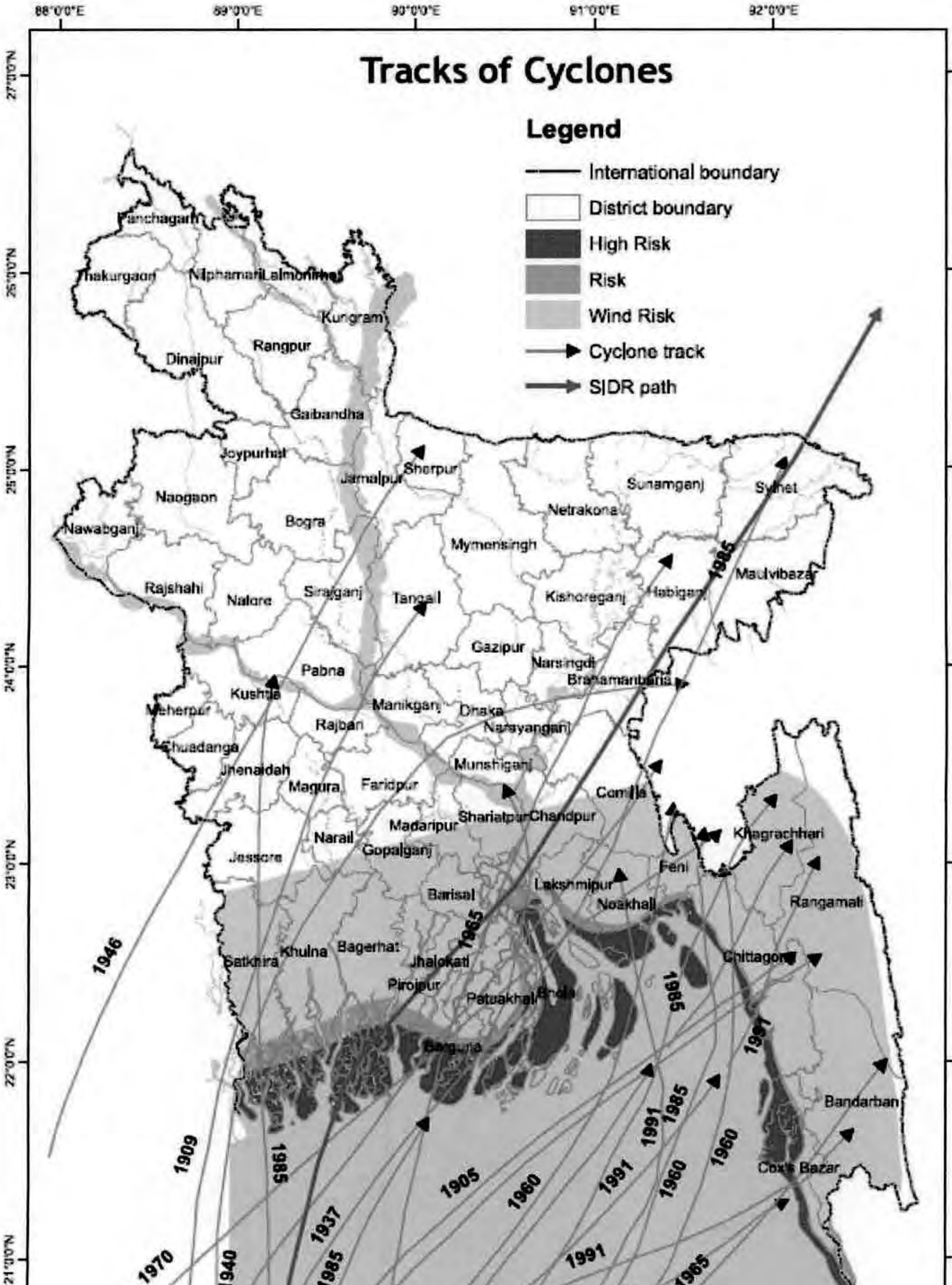


Figure 2-5: Tracks of Cyclones over last 50 years

It is expected that climate change induced alterations in temperature would affect the timing and rate of snow melt in the upper Himalayan reaches. Recent study shows that glaciers in the Himalaya are receding faster than in any other part of the world and, if the present rate continues, the likelihood of them disappearing by the year 2035 and perhaps sooner is very high if the Earth keeps warming at the current rate. Its total area will likely shrink from the present 500,000 to 100,000 kM2 by the year 2035 (WWF, 2005). As a result, the hydrological aspects of the eastern Himalayan rivers and the Ganges-Brahmaputra-Meghna(GBM) river basins could change significantly. Bangladesh is the common lower riparian for all these cross-boundary rivers. In December 1996, the governments of Bangladesh and India came to an agreement on sharing the low Ganges flows. Discussions on sharing of Cross-boundary River flows need to include contingencies for changes in runoff, and demand due to climate change.

2.3.5 Flooding

The most common water-related natural hazard in a deltaic floodplain such as Bangladesh is flood. Flooding in Bangladesh is the result of complex series of factors. Ahmed (2006) has identified four major types of flood in this country, viz. in country rainfall floods, flash floods in the eastern hill basin, major river floods, and the floods caused by tidal storm surges during cyclones. Of these four types, river flood is of the greatest concern to the people. Analysis of past floods suggests that, about 26 percent of the country is subject to annual flooding and an additional 42 percent is at risk of floods with varied intensity (Ahmed and Mirza, 1998). Table 2.4 shows the major floods in Bangladesh over the last 25 years and summarizes their impacts.

The projected increase in rainfall during monsoon would be reflected in the flow regimes of the rivers of Bangladesh. Increased flooding and drainage congestion, therefore, are the expected consequences of increased rainfall from a warmer and wetter condition. A 10 percent increase in monsoon precipitation in Bangladesh could increase runoff depth by 18 to 22 percent, resulting in a sevenfold increase in the probability of an extremely wet year (Qureshi and Hobbie, 1994). Since it is found that monsoon precipitation will increase by 11 and 20 percent, surface runoff will increase in the order of 20 to 45 percent, respectively (Ahmed and Alam, 1998). They also reported that, by the year 2030, an additional 14.3 percent of the country will become extremely vulnerable to floods, while the already flood vulnerable areas will face higher levels of flooding. It is also reported that, even if the banks of the major rivers are embanked, more non-flooded areas will undergo flooding by the year 2075.

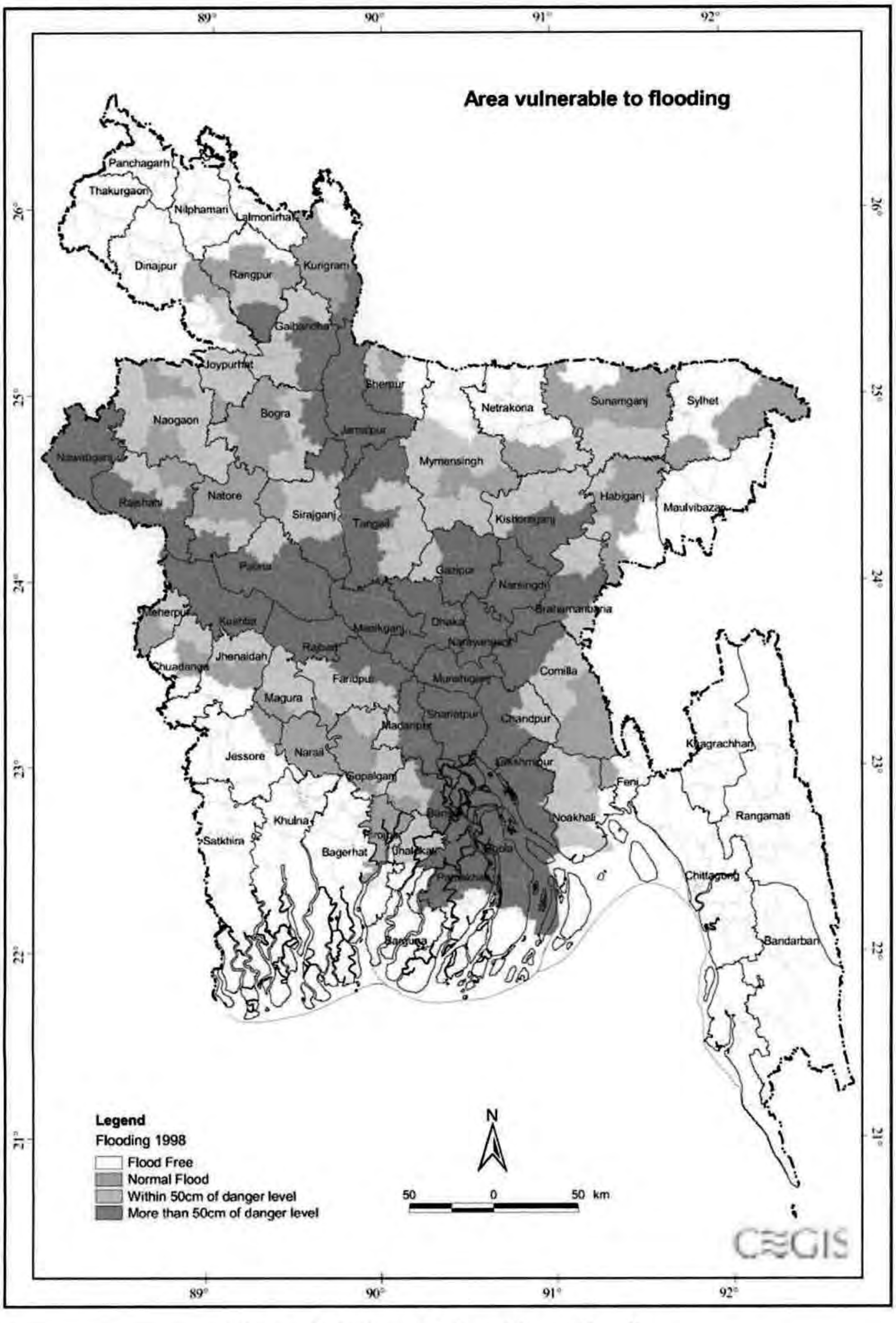


Figure 2-6: Area Vulnerable to Flooding

Furthermore, rise in sea level along the coastal belt would not only inundate low-lying areas along the coast, it would also create a favorable condition for saline waters to overtop the flood protecting coastal embankments, especially when induced by strong winds (CEGIS, 2006). Breach of existing coastal embankments will also inundate land with saline waters. Mirza and Dixit (1997) estimated that a 2°C warming combined with a 10 percent increase in precipitation would increase runoff in the GBM Rivers by 19, 13, and 11 percent respectively. Increased depth of flooding will be pronounced in the lowlands and depressions in the Faridpur, southwest Dhaka, Rajshahi-Pabna, Comilla, and Sylhet-Mymensingh greater districts.

Table 2.4: Serious flood in last 25 years

Event	Impact
1984 flood	Inundated over 50,000 sq. km, estimated damage US$ 378 million
1987 flood	Inundated over 50, 000 sq. km, estimated damage US$ 1 billion, 2,055 deaths
1988 flood	Inundated 61% of the country estimated damage US$ 1.2 billion, more than 45 million homeless, between 2,000-6,500 deaths
1998 flood	Inundated nearly 100,000 sq. km., rendered 30 million people homeless, damaged 500,000 homes, heavy loss to infrastructure, estimated damage US$ 2.8 billion, 1,100 deaths
2004 flood	Inundation 38%, damage US$ 6.6 billion, affected nearly 3.8 million people. Estimated damage over $2 billion, 700 deaths
2007 flood	Inundated 32,000 sq. km, over 85,000 houses destroyed and almost 1 million damaged, approximately 1.2 million acres of crops destroyed or partially damaged, estimated damage over $1 billion, 649 deaths

Sources: Government of Bangladesh (2005) National Adaptation Programme of Action , Ministry of Environment and Forests, Dhaka and Government of Bangladesh (2007) 'Consolidated Damage and Loss Assessment, Lessons Learnt from the Flood 2007 and Future Action Plan', Disaster Management Bureau, Dhaka.

2.3.6 Drainage Congestion and Sediments

Flooding would be exacerbated by climate change induced sea level rise, which would limit runoff discharge due to enhanced backwater effect, as was seen in the floods of 1998 (Ahmed and Mirza, 1998). Moreover, due to prolonged discharge of floodwaters; the rate of sedimentation will increase. As a result, both the riverbed and the bed of the adjacent floodplains will rise leading to further drainage congestion, and possibly more intense flooding in the following years. Such a cyclic course of events would intensify flood problem in the already flood prone areas of the country. Major sources of the sediments carried by the region's rivers are in the upstream areas in India, China, Nepal, and Bhutan and the average annual sediment load that passes through the country to the Bay of Bengal ranges between 0.5 billion to 1.8 billion tons (Ahmed, 2006). Increased rainfall runoff in the vast GBM region, comprising a total catchment area of 1.41 Mkm2, also contributes to enhanced sediment flows along the GBM river systems. Sediments generally originate in the mountainous areas. In recent years, increased deforestation in the mountains has exposed topsoil, and eventually might have increased the sediment load in the rivers (Goswarni, 1985). This is likely to increase the rate of bed level rise in the channels and the floodplains. Moreover, instead of fertile silt, if infertile sand or coarse sediments are deposited with flooding of the Brahmaputra, it will severely reduce productivity of the top soil. Climate change induced higher sedimentation rates will, therefore, have serious social and economic implications for the future.

2.3.7 Low River Flows and Salinity Ingress

In a normal hydrological cycle, rivers suffer from low flow conditions when there is no appreciable rainfall runoff. Lower precipitation in combination with higher evaporation will lead to increased withdrawal of surface water. Low flow conditions of the rivers will be subsequently accentuated. This will also reduce the cross-boundary river flows, and the availability of fresh water for irrigation, livestock and people. Typically low flow condition starts to occur in the post monsoon period and continues till early April, March being the critical month. During low flow surface salinity penetrates further inland due to lack of adequate flushing.

Under climate change scenarios low flow conditions are likely to aggravate with the possibility of withdrawal of appreciable rainfall in winter (Ahmed et al., 1998a). The southwestern parts of the country will be particularly vulnerable, since the region depends on freshwater flows along the Ganges and its major distributaries, Gorai. People in the southwestern region have expressed their concerns regarding increasing salinity (RVCC, 2003). Study from Mohal et. al. (2006) almost complied with the same finding that was derived from mathematical Modeling. They found that as sea level continues to raise, the associated effects of permanent inundation is likely to increase the salinity near coastal areas. The world heritage and declared Ramsar site Sundarban will be hugely affected by the salinity ingress. Actually, the Sundarbans has already been affected due to reduced freshwater flows through Ganges river system over the last few decades particularly during the dry season. This has led to a definite inward intrusion of the salinity front causing the different species of plants and animals to be adversely affected. Increased salt-water intrusion is considered as one of the causes of top dying of Sundari trees.

The impact of sea level rise will further intrude the saline water to landward. Sea level rise of 32 cm will intrude 10 to 20 ppt salinity level more in the Sundrabans. The rate of salt-water intrusion will also affect the ability of the ecosystem to adapt (Mohal et.al, 2006). Bangladesh NAPA document has also highlighted the concerns regarding salinity ingress, especially for the southwestern region (GOB, 2005).

2.3.8 Droughts

Bangladesh will also be at higher risk from droughts. High index of aridity in winter, especially in the western parts of the country may be compensated by increased withdrawal from the surface water sources. If that is the case, despite the minimum flow in the Ganges as provided by the Ganges Water Sharing Treaty (GOB-GOI, 1996) it would be extremely difficult to provide adequate freshwater flows in the downstream of the Ganges dependent areas, particularly during the dry season. The issue of drought has also been reiterated in the Bangladesh NAPA document.

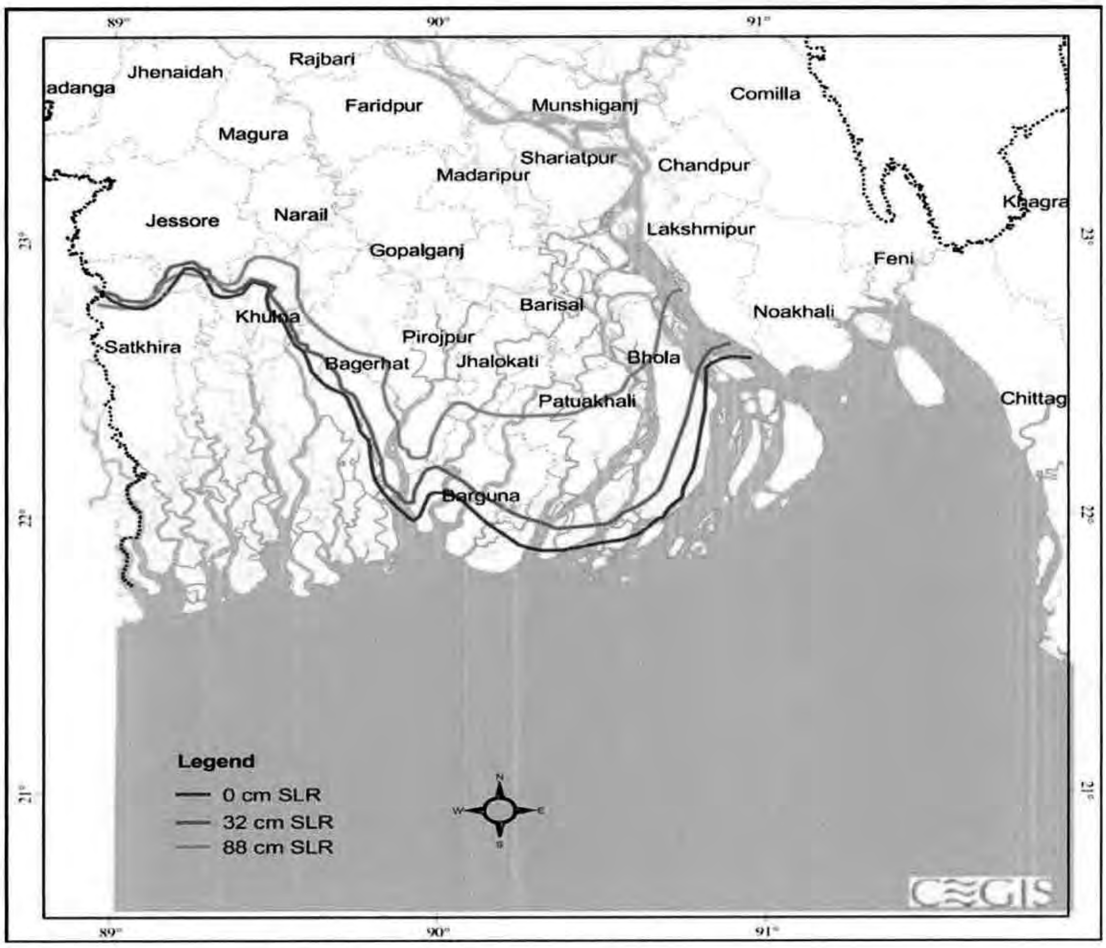


Figure 2-7: Sea Level Rise at Southern Areas

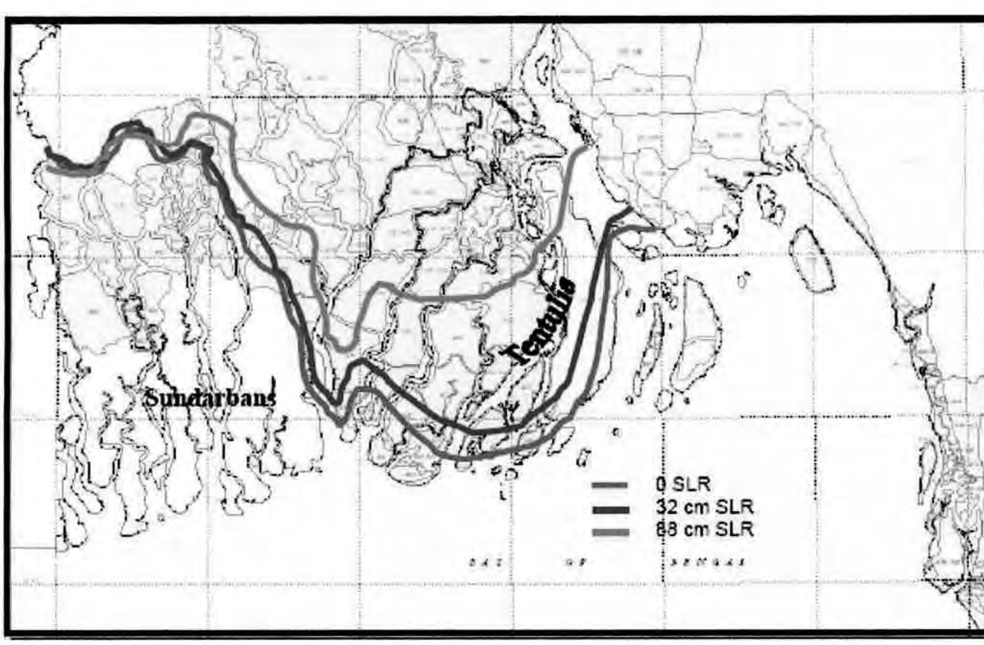


Figure 2-8: Line of equal salinity (5 pm) for different sea level rise during the dry season. (Source: Mohal et. al., 2006)

2.3.9 River Erosion and Accretion

Rivers in Bangladesh are morphologically highly dynamic. The main rivers are braided, and forms islands or char in between the braiding channels. These chars, of which many are inhabited, "move with the flows" and are extremely sensitive to changes in the river conditions. Erosion processes are highly unpredictable, and not compensated by accretion. These processes also have dramatic consequences in the lives of people living in those areas.

2.4 TRANSPORT INFRASTRUCTURE IN BANGLADESH: CLIMATE VULNERABILITIES

Transportation industries account for approximately 7% of its gross domestic product, and employ more than 20,00,000 people. Overall, it is difficult to overestimate the importance of transportation to Bangladeshi life. It has been estimated that the road system alone has an asset value approaching 1,00,000 Crore BDT. Assessing the vulnerability of transportation in Bangladesh to climate change is an important step toward ensuring a safe, efficient and resilient transportation system in the decades ahead. Transportation in Bangladesh remains sensitive to a number of weather-related hazards. Future climate change of the magnitude projected for the present century by the Intergovernmental Panel on Climate Change (IPCC), specifically an increase in global mean annual temperature of 1.4–5.8°C, would have both positive and negative impacts on Bangladesh's transportation infrastructure and operations. These impacts would be caused by changes in temperature and precipitation, extreme climate events (including severe storms), and water level changes in oceans and rivers. The main sensitivities of Bangladesh's transportation system to such changes are summarized in Figure 2.9.

Expected Changes in Climatic Variables

Increase in mean temperature
Sea level rise

Change in temperature extremes (increase in summer, decrease in winter)
Changes in mean precipitation

Increase in storm frequency and severity
Increase in precipitation intensity

Low Moderate High
Confidence Level[a]

Potential Impacts on Transportation Infrastructure and Systems

National Impacts

- Inundation and flooding of coastal and inland infrastructure (road embankment)
- Reducing navigational clearance of bridges and making these bridges non-functional.
- Increased flow of water through culverts
- Changes in Transportation demand
- Change in length and quality of construction season
- Damages to Structures
- Impacts on health and safety (e.g., accidents, access to services)
- Changes in fuel efficiencies and payloads.

Northern Part of Bangladesh

- Changes to the maintenance and design practices
- Changes in Transportation Demand
- Change in length and quality of construction season
- Impacts on health and safety (e.g., accidents, access to services)
- Changes in fuel efficiencies and payloads.

Southern Part of Bangladesh

- Inundation and flooding of coastal and inland infrastructure (road embankment)
- Reducing navigational clearance of bridges and making these bridges non-functional.
- Increased flow of water through culverts
- Changes in Transportation demand
- Change in length and quality of construction season
- Damages to Structures
- Impacts on health and safety (e.g., accidents, access to services)
- Changes in fuel efficiencies and payloads.
- Changes in monsoon maintenance costs for surface transport.
- Changes to maintenance and design practices

Figure 2-3: Climate Sensitivities of Bangladesh's Transportation System

2.5 IMPACT ON ROADS AND HIGHWAYS

Floods, especially the high intensity floods, often devastate physical infrastructure such as road networks, educational centers, market places, administrative buildings, etc (Nizamuddin et al., 2001; Siddiqi, 1997; Siddique and Chowdhury, 2000). Among this, a large road and highway network is crisscrossing the whole Bangladesh like veins, most of it traversing through the flood plains of the country. The Roads and Highways Department (RHD) is responsible for a huge number of assets in the form of roads, bridges and culverts. Protecting and maintaining about 20,798 kilometers of roads and 14,712 bridges and culverts with an estimated asset value of TK 727,000 Million is of prime importance for the national economy. Table 2.5 shows major climatic parameters and corresponding potential impacts and vulnerable infrastructure and design parameters.

Table 2.5: Potential impacts and vulnerable infrastructure and design parameters of major climatic parameters

Climate events	**Potential impacts**	**Vulnerable Infrastructure and Design parameters**
Temperature	The extended warm weather would affect pavement deterioration due to melting of bitumen, heating and thermal expansion of bridges and buckling of joints of steel structures. Decrease in temperature would affect toad transport operation as well as snow and ice removal costs including salts used.	**Pavement**: Camber. Stiff bitumen to withstand heat or workable in winter, Soil moisture and maintenance planning **Steel bridges**: Selection of material, Corrosion protection
Rainfall:	The increase in winter precipitation would affect drainage capacities, road pavement, driving condition and visibility. Increase in intensity of summer precipitation would create floods; affect drainage, bridges affecting waterways and clearance, damage pavement and affect road, damage bridges foundation due to scoring. Rainfall would trigger landslides and mudslides could create road blocks.	**Bridges and culverts**: Flood estimation, return period, design discharge High flood level, Free board (clearance above High Flood Level), Length of waterway, Design load, wind load. Foundation, river and bank protection . Corrosion protection, **Drains:** Discharge estimation, size and shape of drain, drain slope **Mountainous road:** Slope protection work, Subsurface drains, catch drains **Pavement**: camber, frequent maintenance, design
Storms and storm surges:	Rainfall and winds associated with cyclone would create flooding, inundation and affect road transport. Disrupt traffic and safety and emergency evacuation operations; affect traffic boards and information signs.	**Road signs:** Wind load, Structural design, Foundation, Corrosion protection
Sea level rise	Rise in sea level would affect the coastal roads there may be need to realign or abandon the roads in the affected areas.	**Coastal Road:** Protection wall, Warning signs, Realignment, Edge strengthening

Deluge of 1998 rendered most parts of Dhaka inaccessible by motorized vehicles, while the flood waters of 1988 penetrated the runways of Dhaka International Airport and disconnected it for about 11 days from the rest of the world. The telecommunication network was torn off during the cyclone of 1991 and the entire coastal belt was disconnected for weeks. Historical records show that the roads, which were raised above the 1988/1998 flood-level, suffered minimum damage in the 2004 floods. After the 1988 flood, for example, national highways such as the Dhaka-Chittagong, Dhaka-Mawa-Khulna, Dhaka-Sylhet and Dhaka-Aricha highways were raised by 1 to 1.5

meters above HFL. As a result, these highways suffered no significant damages during the 2004 flood. Flood loss potentials to roads infrastructure have been huge. In the 1998 and 2004 flood, for example, the direct damage to roads sector is estimated as TK 15,272 and TK 10,031 Million, accounting for 15 and 9 per cent of the total damage respectively. The situation is expected to be deteriorating in the days to come, with the increased extent and intensity of flooding due to potential climate change and sea level rise in future. Hence, it is important to develop CLIMATE CHANGE PROOFING SYSTEMS as a response to natural disasters, in designated flood risk zones, to protect life, property and vital infrastructure such as roads.

Climate change induced high intensity events pose huge threats to existing physical infrastructure. From a Report of BRTC-BUET in 2005, damage to national highways due to flood alone is estimated at 1,011 and 3,315 kilometers by the year 2030 and 2050, respectively. The corresponding damage to embankments is estimated at 4,271 and 13,996 kilometers by the year 2030 and 2050, respectively. The aggregated damage figures for health centres and hospitals due to floods, cyclones, sea-level rise and salinity intrusion is estimated at 1,682 and 5,212, respectively, for the above two time horizons (BRTC-BUET, 2005). In this regard, removal of impediments of drainage (dredging/re-excavation of choked rivers/khals; drainage canals), construction of drainage structures (culverts, bridges, and regulators), rehabilitation of structures such as roads, embankments etc. should be considered as adaptation measures towards facilitating drainage and reduce flood-related vulnerability (Ahmed et al., 1998a, Ahmed, 2005; Faruque and Ali, 2005). In view of urban flooding, this option will remain as an important adaptation option despite the high cost of its implementation. In increasingly Flood Vulnerable Areas (FVA), efforts should be made for CLIMATE CHANGE PROOFING SYSTEMS of infrastructure, as deemed necessary (Faruque and Ali, 2005).

2.6 CLIMATE CHANGE MODELING: ROAD TRANSPORT SECTOR

In Bangladesh there are major three types of roads according to the RHD classification such as, (a) National Highway—which connects Divisions and important cities and ports with the capital city, Dhaka; (b) Regional Highways—which connects division centers with division head quarters; (c) Zilla road— which connects districts with Upazilas and

(d) Other are rural roads which connects Upazila with Unions and other growth centers. Table 2.6 shows lengths of different classes of roads.

Table 2.6: Lengths of different classes of roads in Bangladesh

Road Length by Classification		
National Highway	=	3,507.51 Km
Regional Highway	=	4,118.72 Km
Zilla Road	=	13,251.42 Km
Total Road Length	=	20,877.65 Km
Road Length by Surface Type according to latest survey		
Bituminous	=	16,766.06 Km
HBB	=	653.02 Km
Earth	=	563.38 Km
Cement Concrete (CC)	=	2.44 Km
Cement Blocks	=	0.37 Km
Total Paved Road Length	=	17,332.25 Km
Total Unpaved Road Length	=	653.02 Km
Total Surveyed Road Length	=	17,985.27 Km
Length of Road Not Surveyed	=	2,892.38 Km

(Source: RHD Road Condition Survey 2008)

The roads make obstructions to overland flows especially during recession time of flood. The roads are designed using elevation of flood with different recurrence depending on types. National, Regional Highways and Zilla road area usually designed for 30, 20 and 10 year return period of maximum floods.

2.7 SUMMARY

Previous studies to identify potential impacts of Climate Change on Transport Infrastructure (Roads and Bridges) were identified and quantified as a whole depending upon the road classification of Bangladesh Road Network. But location specific quantifiable and qualitative identification of climate change hazards have not been done any study. Though having a list of limitations, this research was undertaken to identify the impact level on the transport infrastructure in the coastal area of Bangladesh. An inventory of the roads which are susceptible to the impacts of climate change in the coastal areas have been prepared.

CHAPTER 3
APPROACH AND METHODOLOGY

3.1 STUDY AREA

The objective of this study was to assess the vulnerability of transport networks i.e. roads and highways with respect to climate change related impacts especially due to sea level rise, floods and inundations in the coastal areas of Bangladesh. Due to time and fund constraints, the study was limited to the following issues:

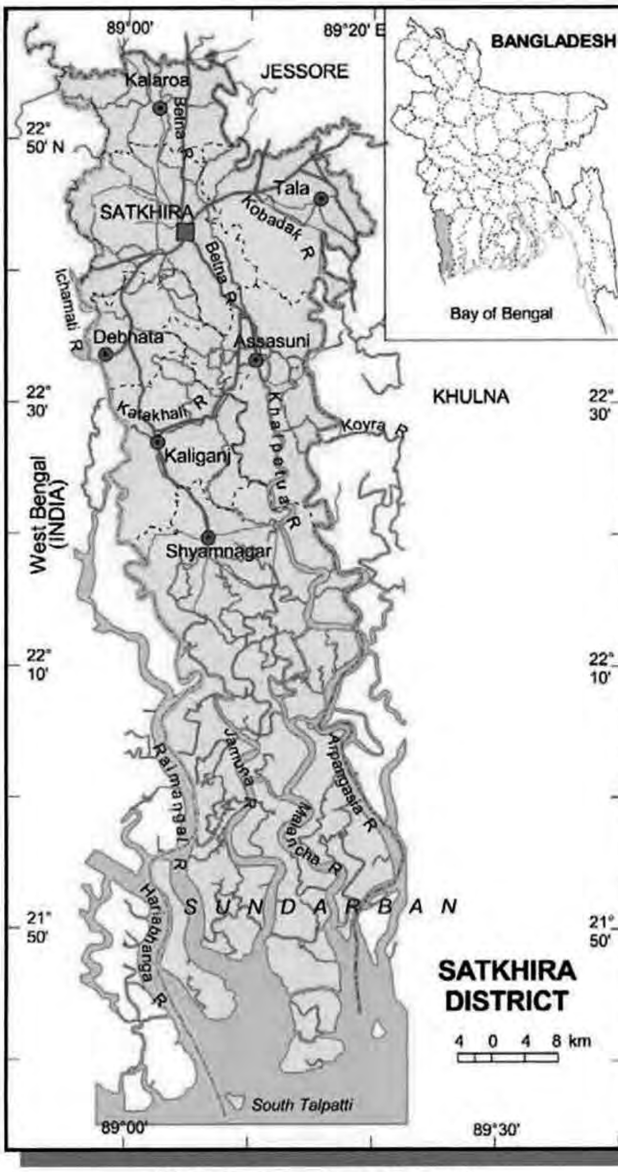
i) Climate Change related impacts were measured only for road transport sector because of its large modal share to the transportation demand, facilities and infrastructure;
ii) The study was conducted for three selected coastal areas (Satkhira, Khulna and Bagherhat) in Bangladesh, as coastal areas are experiencing innumerous and fatal climatic events.
iii) In the study, crest level of the roads belonging to only the Roads and Highways Department (RHD) were taken into consideration for assessing inundation.

3.2 DESCRIPTION OF THE STUDY AREA

Three districts were considered for the inundation modeling - Satkhira, Khulna and Bagherhat. These three districts are crisscrossed by a lot of rivers where ebb-tidal effects are pre-dominant. Bay of Bengal has bounded the southern portion of those districts and almost 50-60% of the districts fall within the Largest Mangrove Forest- Sundarban. Generally, the roads of RHD are built over the polders which were constructed to protect the districts from high tide.

3.2.1 Satkhira

Satkhira District (Khulna division) with an area of 3858.33 sq km, is a south west bordered district of Bangladesh (Fig. 3.1). It is bounded by Jessore district to the north, the Bay of Bengal to the south, Khulna district to the east, Pargana district of West Bengal to the west. Annual average temperature is maximum 35.5°C, minimum 12.5°C; annual rainfall is 1710 mm. The soil of the district is alluvial floodplain. Main rivers are Kobadak, Sonai, Kholpatua, Morischap, Raimangal, Hariabhanga, ichamati, Betrabati and Kalindi-Jamuna.

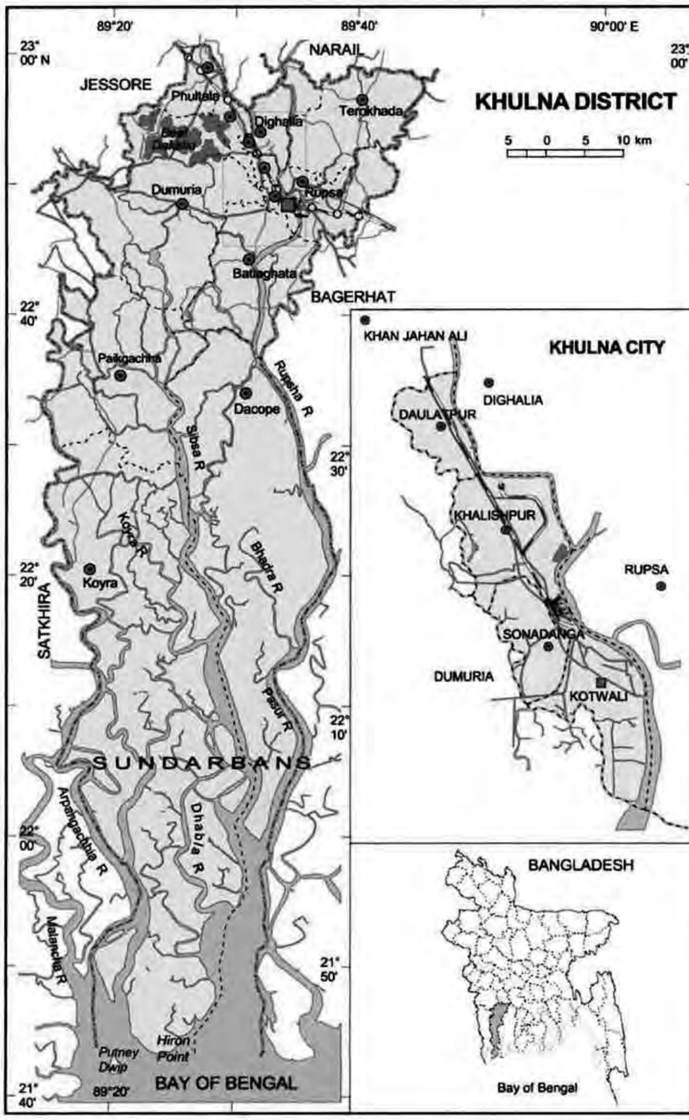


(Source: banglapedia.org)

Figure 3-1: Administrative Map of Satkhira District

3.2.2 Khulna

Khulna District (Khulna division) with an area of 4394.46 sq km, is bounded by Jessore and Narail districts on the north, the Bay of Bengal on the south, Bagerhat district on the east, Satkhira district on the west (Fig. 3.2). Annual average temperature is 35.5°C and lowest 12.5°C; annual rainfall is 1710 mm. The main rivers are Rupsa-Pasur, Bhairab, Shibsha, Dharla, Bhadra, Ball, and Kobadak.

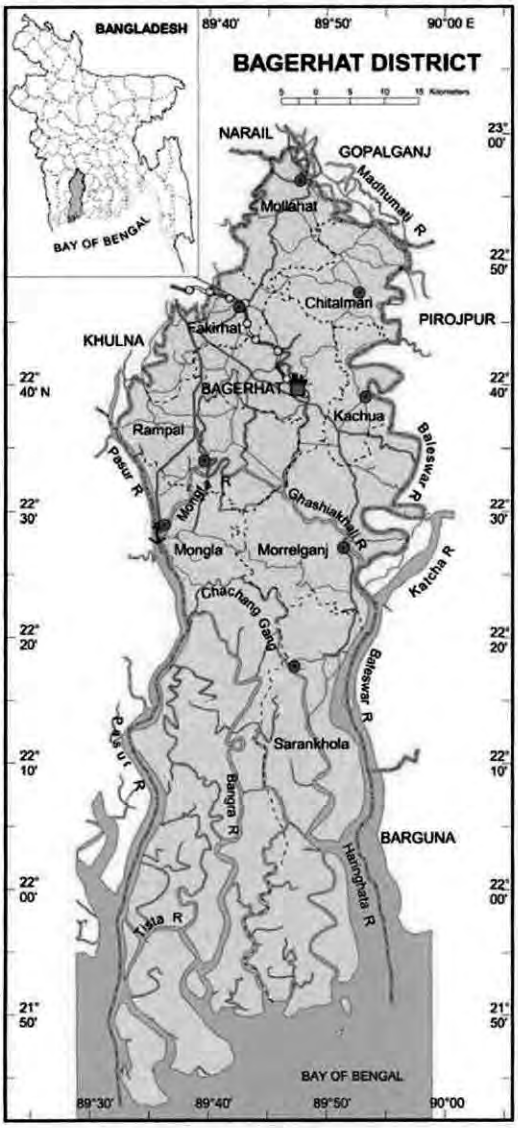


(Source: banglapedia.org)

Figure 3-2: Administrative Map of Khulna District

3.2.3 Bagherhat

Bagerhat District (Khulna division) with an area of 3959.11 sq km, is bounded by Gopalganj and Narail districts on the north, Bay of Bengal on the south, Gopalganj, Pirojpur and Barguna districts on the east and Khulna district on the west (Fig. 3.3). Annual average maximum temperature is 33.5°C and minimum 12.5°C. Annual rainfall is 1710 mm. Main rivers are Panguchi, Daratana, madhumati, pasur, Haringhata, Mongla, Baleswar, Bangra and Goshairkhali.



(Source: banglapedia.org)

Figure 3-3: Administrative Map of Bagherhat District

3.3 RIVER SYTEM

Most of the rivers of the region are dominated by the tide. Many rivers, particularly those in the southern part, carry very little fresh water flow, but instead act as tidal channels for tides originating in the Bay of Bengal. The southern rivers mainly comprise tidal estuary systems, the largest being the Jamuna, Malancha, Pussur-Sibsa, Baleswar. There are huge numbers of small tidal channels, which interconnect these large rivers. The tidal channel network is particularly complex in the Sundarbans Mangrove Forest in the far southwest corner of the region. Fresh water inflows into this area are mainly by the Gorai River, which is an off-take of the Ganges, and also by numerous smaller off-takes from the Lower Meghna River.

3.3.1 Nabaganga – Chitra - Bhairab System

Nabaganga River is one of the offshoots of the Mathabhanga River. The river originates near the Chuadanga town. Flowing eastward the river receives the Kumar at Magura and the Chitra at Narail. Then it flows southward to meet the Bhairab River. In the past, the Nabaganga was a distributary of the Ichamati, but later its head was silted up and the river became a tributary of the Bhairab. The Nabaganga River has non-tidal characteristics at the upstream and tidal characteristics at the downstream. The upstream part of this river has become discontinued, especially during dry period due to earthen dams constructed by local people.

Chitra River originates from the lower part of Chuadanga and Darsana. It runs about 170 km southeast through Darsana, Kaliganj, Jessore, Salikha and Kalia upazilas and joins with the Nabaganga in Gazirhat of Narail district. Afterwards the joint flow falls into the Bhairab River in Daulatpur upazila of Khulna district. In the past, the Chitra was an offshoot of the Ichamati, but it turned into a distributary of the Nabaganga due to siltation at its mouth. The river is heavily silted up and not navigable from its original point to Salikha. From Salikha to Gazirhat, it is under tidal influence and the range of the tide is about one meter. The river is navigable and a launch route from Khulna runs along its course. An embankment along its left bank from Rathdanga to Gazirhat has been constructed under a flood control drainage and irrigation project.

Bhairab River is an important river in the moribund delta area. Its name means 'the terrible' and attests to the size it had reached when the main volume of the Ganges was carried by it. At present the main stream is not navigable beyond Bagherpara upazila (Jessore district). It has two main branches, the Ichamati (Khulna-Ichamati) and the Kobadak. Part of the Khulna-Ichamati is in India and part in Satkhira district of Bangladesh, and so it forms the boundary between the two countries. The river is known by several names along its course. Downstream from Kaliganj to Kaikhali it is the Kalindi and the Raymangal from where it has become a large estuarine river. It splits into two, with the western arm named Hariabhanga and the eastern arm retaining the original name. Downstream from Kaikhali, the river is referred to as the Khulna-Ichamati while in the south it is the Raymangal-Hariabhanga. The total length of the Bhairab is about 250 km. In the monsoon, the Ganges feeds it, but in the dry season it becomes dry. Its lower course remains navigable throughout the year and is influenced by tides. Khulna and Jessore towns stand on the bank of this river. In the past, the Bhairab greatly influenced development of settlements and culture in these two towns.

3.3.2 Kobadak River

Kobadak River was transformed into 'Kapotaksha' [Kapotaksa] (meaning the 'pigeon-eyed') in Sanskrit. The river Ichamati branched into two streams at Darshana in Kushtia district. One flowing southeast is known as the Bhairab. At the south of Kotchandpur, an offshoot branches out from the Bhairab and flowing south meets with the Shibsa near Paikgachha in Khulna district. This offshoot of the Bhairab is the Kobadak. From the monsoon the river receives only the local rainwater and percolated water and loses its navigability at most places. In summer, the river almost dries up near Jhikargachha. The high levee near Tala upazila indicates that once upon a time the river might have had a width of 750m, but it is now only about 170m; but at Chandkhali the figure is about 300m. The river was about to die, but the Bangladesh Water Development Board maintains a flow from the Ganges by pumping, providing irrigation to its buffer area in the Ganges-Kobadak irrigation project (G-K Project).

3.3.3 Rupsa- Passur River

The Pasur River is a continuation of the Rupsa, which is formed of the union of the Bhairab and Atrai rivers. At present, much of its water is from the Gorai diverted through the Nabaganga. From near Batiaghata upazila, the Rupsa changes its name to Kazibacha, which is given up near Chalna in favour of Pasur. Near the Mongla port, the Pasur receives Mongla river, and near the forest outpost at Chandpai it receives the Mirgamari cross-channel from Bhola, both on the left bank. On the right bank the Manki, Dhaki and Bhadra are connected with the Shibsa system. In the lower delta, the Rupsa-Pasur is second only to the Meghna in size. Many cross-channels connect it with the systems on either side. A large cross-channel connects it with the Morzal at the head of its estuary. East of the Sela the next largest river is Bhola, which begins as a small channel where the Bhairab becomes the Keora tributary of the Baleshwar. Bhola falls into the Haringhata estuary of Baleshwar. The Baleshwar, which is a continuation of the Gorai-Madhumati, has played a very important role in building up the Mature Delta. The Bagerhat and Pirojpur districts depend upon it for the annual deposit of silt. Floodwaters kept the seawater from reaching beyond the Bogi at the edge of the Sundarbans, but with the diversion of the Gorai into the Pasur, the river is decaying. The flow was sufficient to make the forests of freshwater nature grow within 16 km of the sea. At the point of its junction with the Bhola, it widens out to 6 km to form one of the sources of the huge Haringhata estuary, which also receives the flows of the Bishkhali and the Burishwar and so reaches a maximum width of 19 km. The Rupsa-Pasur is about 142 km long and the entire course is under tidal influence.

3.3.4 Baleswar River

The Baleshwar River is located in the southern part of Bangladesh, covering three districts Bagherhat, Pirojpur and Barguna. It borders the largest mangrove forest in the world, in the Sundarbans delta. During cyclone Sidr 2007 and Aila 2009, Baleswar River drenched both the banks in full brim. Huge economic losses occurred during those events.

3.3.5 Kholpetua River

The Kholpetua River is one of the important rivers in the hydraulic system in Satkhira. It has both tidal and non-tidal behavior. The upstream boundary of this river is at Taherpur and on the non-tidal part at Taherpur and Jhekorgacha. During dry season, it behaves as a non-tidal river because during dry period people use to construct cross dam for storing water for cultivation, due to this obstruction the water cannot flow freely and water level rises unusually.

3.3.6 Betna - Morirchap - Labangabati System

Betna-Morichap River system drains local runoff to the Bay through Kholpetua-Kobadak river system.

3.4 ENVIRONMENTAL PARAMETERS

3.4.1 Soil Types

The soil in the south western coastal region is basically full of alluvium, as the whole area acts as a large floodplain. Table 3.1 shows the soil types of the study areas.

Table 3-1: Soil types in the study Area

General Soil Types	District
Flood Plain Soils	
Calcareous alluvium	Khulna, Satkhira, Bagerhat
Acid Sulphate Soil	Khulna, Satkhira, Bagerhat
Peat	Khulna, Bagerhat
Non-calcareous Grey Floodplain Soil	Bagerhat
Calcareous Grey Floodplain Soil	Khulna, Satkhira, Bagerhat
Non-calcareous Dark Grey Floodplain Soil	Khulna, Satkhira, Bagerhat
Calcareous Dark Grey Floodplain Soil	Khulna, Satkhira, Bagerhat
Calcareous Brown Floodplain Soil	Khulna, Satkhira, Bagerhat
Non-calcareous Brown Floodplain Soil	Satkhira

(Source: Compendium of Environmental Statistics of Bangladesh 2005 by BBS)

3.4.2 Land Area

A large number of major long rivers are crisscrossing the three districts covered in this study. An average of 24.5% of total land area of these districts has been found to be rivers; most of them are tributaries of major rivers (Table 3.2).

Table 3-2: Land Area and the River Areas

District	Settlement (ha)	River (ha)	Total
Khulna	30002	14457	32%
Satkhira	32299	8638	20.6%
Bagerhat	38886	10614	20.9%
Total	101187	33709	Avg- 24.5%

(Source: Compendium of Environmental Statistics of Bangladesh 2005 by BBS)

3.4.3 Main Rivers According to Length

Garai which turns into Modhumati and Baleswar in the downstream is the largest river in this region following the popular Kobadak River (Table 3.3); these two rivers actually feed the total agricultural water and also contain the shrimp culture in the locality.

Table 3-3: Land Area and the River Areas

Name of the Rivers	km
Garai-Modhumati-Baleswar	371
Kobadak	259
Bhadra	193
Betna-Kholpotua	191
Bhairab	159
Rupsa-Pasur	141

(Source: Compendium of Environmental Statistics of Bangladesh 2005 by BBS)

Tide Variation at Selected river Stations

Tidal variation of the rivers is significant and this variation is the reason for the existence of the Sundarban area. These variations of tide prompt many agricultural farmers to convert their land for shrimp culture. All the major highways are located nearby or beside these rivers.

3.5 METHODOLOGY

3.5.1 Geographic Information System- GIS

Geographic Information System (GIS) is the science and technology for preservation, management, analysis and presentation of geographic and other spatially referenced data. It deals with the information about feature, phenomenon and processes on and in the earth such as physical environment, natural and manmade resources, their use and change thereof. GIS has become one of the modern tools to live up to and beyond its early expectation. It has spread from the centers of advanced technology to the emerging worlds and remote corners of our planet to places.

GIS uses spatial data which normally can be placed on a map. Non-spatial data is not location specific but can be used with GIS. GIS performs many integrated functions. GIS accepts data from multiple sources which can be in a variety of formats. Data types include maps, images, digital products, global positioning system, text data and tabular data. This is a special strength of GIS that few other technologies share. GIS coupled with remote sensing inputs can play a significant role in monitoring and management of the natural resources. GIS is implicated with accumulation of analysis and illustration of spatial and non spatial data in order to contribute information of desirability of planners and decision makers as well as researchers.

3.5.2 South West Regional Model

In this study, an important model developed by Institute of Water Modelling (IWM) was used for the modeling purpose. The model outputs from different locations were taken for the comparison with road crest level data. The South West Region Model (SWRM) is one of the six regional models of Bangladesh developed at the Institute of Water Modelling (IWM). Development of the SWRM was initiated in December 1989 and the data collection started in April 1990. The present model was created towards the end of SWSMP-II, when two smaller sub-regional models covering the South Central and South West regions were merged to a single model.

During Phase-III of SWSMP, the SWRM was extended to cover the Sundarbans Mangrove Forest for a study carried out by FAO/UNDP. Cross sections in the morphologically active areas west of Khulna were updated with surveys carried out by IWM. Before present validation, the SWRM has been validated for hydrological years 1995-96, 1996-97, 1997-98 1998-99 and 1999-00, 2000-01, 2001-02, 2002-03 and 2003-04 and 2004-05. The present validation of SWRM has been carried out using the hydrological data of 2005-06 and 2006 monsoon period. The following parameters are considered in the model- Rainfall, Sea Level Rise, Evapo-transpiration, Abstraction, Ground water depth, Water level gauging and Discharge.

The South West Region Model (SWRM) covers the entire area lying to the south of the Ganges and west of the Meghna estuary. The SWRM is bounded on the north by the Ganges and the Padma River, on the east by the Lower Meghna and Shahabazpur River, on the west by the Indian border and on the south by the Bay of Bengal (Drawing SWRM-01). The regional model covers approximately 37,330 km^2 area and the length of rivers/channels is around 5,600 km. Most of the rivers of the southwest area of Bangladesh are dominated by tide. Many rivers, particularly those in the southern part, carry very little fresh water flow, but instead act as tidal channels for tides originating in the Bay of Bengal. The southern rivers mainly comprise tidal estuary systems, the largest being the Jamuna, Malancha, Pussur-Sibsa, Baleswar, Lohalia and Tentulia. There are huge numbers of small tidal channels, which interconnect these large rivers. The tidal channel network is particularly complex in the Sundarbans Mangrove Forest in the far southwest corner of the region. In the northern part of the model, the main non-tidal river systems comprise of the Gorai, Arial Khan and Upper Meghna. Fresh water inflows into this area are mainly by the Gorai River, which is an off-take of the Ganges, and also by numerous smaller off-takes from the Lower Meghna River.

3.6 PREPARATION OF THE VULNERABILITY MAPS

Water level data (inundation) collected from the South West Regional Model output and the GIS map comprising the values of inundation are overlaid in the ArcView GIS® to prepare vulnerability map with respect to the RHD's Road Maintenance Management System (RMMS).

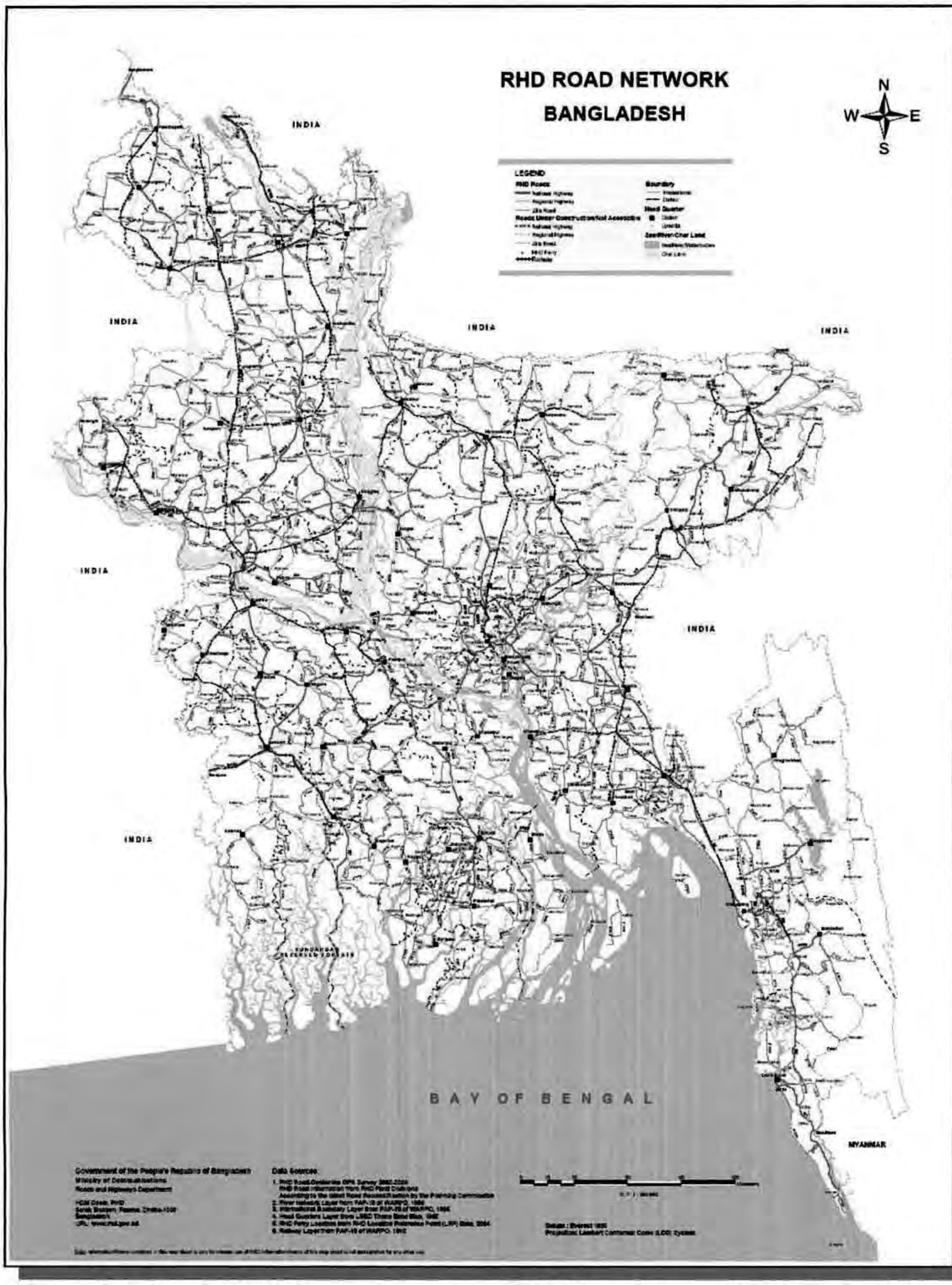


Figure 3-4: Roads & Highways Department GIS Map (Source- HDM Circle, RHD)

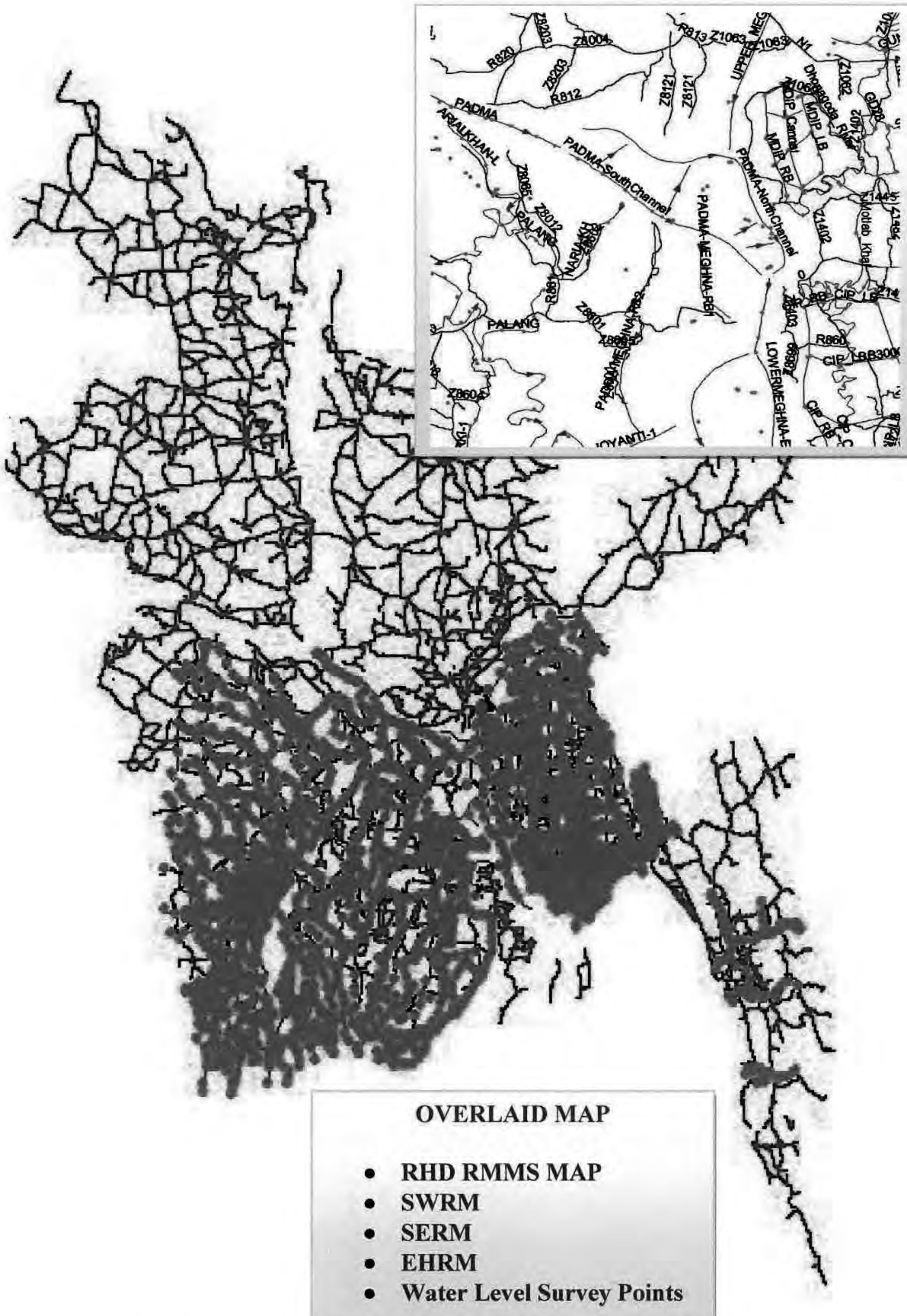
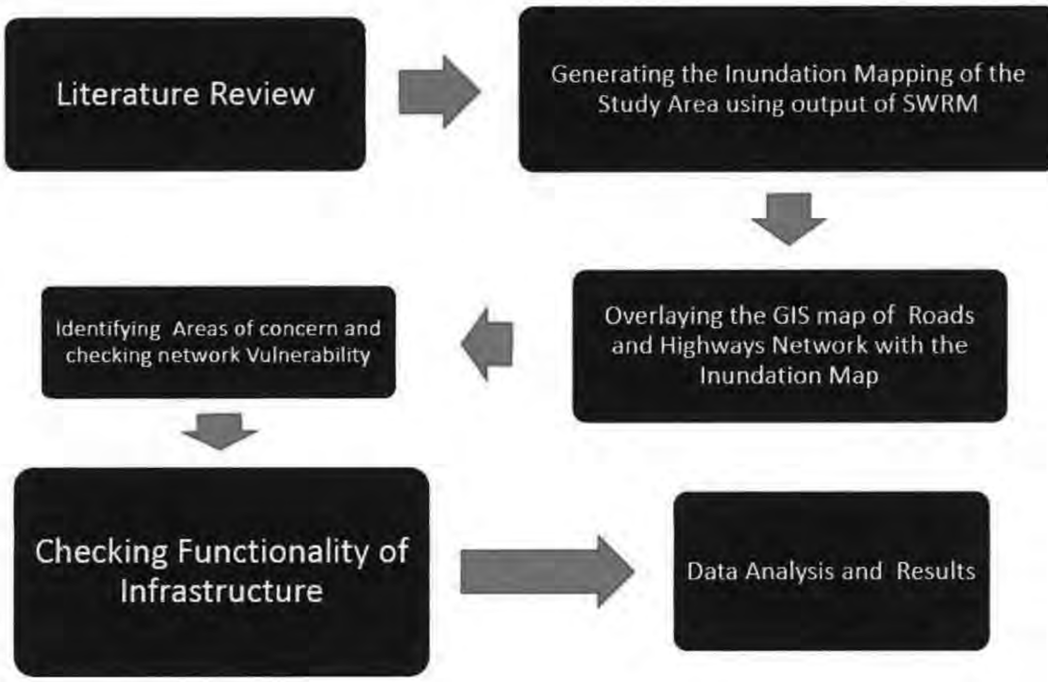


Figure 3-5: Overlay of RHD RMMS and SWRM Model Map

A brief description of the methodology to be followed in conducting the study is given below:



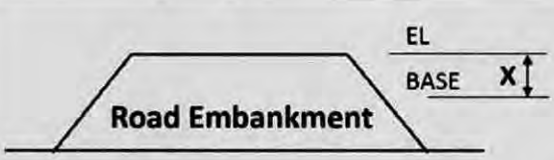
Literature Review: A range of literature is available related to climate change impacts on transport infrastructure. Detailed studies with similar nature were conducted in U.S.A, U.K., Australia, Finland and Middle East Countries. Available relevant literature was reviewed to identify the important issues and concerns in the context of Bangladesh.

Preparation/Collection of Geo-referenced Inundation Map and Map Overlay: Through Atmospheric-Ocean General Circulation Model, sea level rise in the vicinity of coastal areas of Bangladesh was predicted and that was incorporated in the South West Regional Model and an inundation map was prepared, which shows the areas under risk of inundation due to flood, temperature and precipitation variation, drought effect, sea level rise etc. under Climate Change A2 scenario as devised by IPCC.

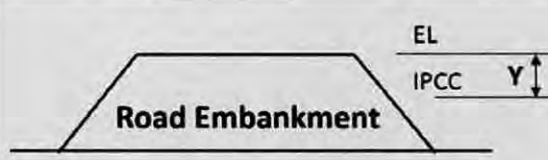
From Institute of Water Modelling (IWM), the water level station location with water level data for base scenario (1998 flood) and IPCC 2080 scenario was collected; those layers of GIS based data have been overlaid with the RHD Road GIS layer for comparison. In the pavement design of RHD roads, a depth of one meter freeboard (Difference between Formation Level and Highest Flood Level- HFL) is generally considered to avoid drainage problems and climate hazards. In the assessment of vulnerability of roads, the elevation of road crest level was compared with water level data (for base year and IPCC 2080 predictions). The criteria presented in Table 3.4 were used for assessment of vulnerability. For assessment of "present vulnerability", roads with crest elevation > 1.5 m above base year (1998) water level, have been categorized as "comparatively safe". On the other hand roads with crest level equal to or below the 1998 water level have been categorized as "very risky". Similarly, for assessment of future vulnerability, roads with crest elevation > 1.5 m above the IPCC 2080 water level, have been categorized as "comparatively safe". Details are shown in Table 3.4.

Table 3.4: Criteria used for assessment of vulnerability

Present Vulnerability			Future Vulnerability		
X = Existing Road Crest Level –Base Year (1998) Water Level Data			Y = Existing Road Crest Level – IPCC 2080 Water Level Data		
$X \leq 0$	↓	Very Risky- need urgent adaptation measure	$Y \leq 0$	↓	Very Risky- need urgent adaptation measure
$1 \geq X > 0$	↘	At Risk of Inundation	$1 \geq Y > 0$	↘	At Risk of Inundation
$1.5 \geq X > 1$	↗	Moderate Risk- Possibility of Inundation	$1.5 \geq Y > 1$	↗	Moderate Risk- Possibility of Inundation
$X > 1.5$	↑	Comparatively Safe	$Y > 1.5$	↑	Comparatively Safe



X = Existing Road Crest Level (EL) – Base Year Water Level Data (BASE)



Y = Existing Road Crest Level (EL) – IPCC 2080 Water Level Data (IPCC)

From Google Earth the elevation data was taken where the unit of crest level is expressed in MSL (Mean Sea Level). On the contrary, water level data of the SWR Model is reported as m (PWD). The PWD datum is 0.46 m below the Mean Sea Level (MSL) datum. In this study, the SWR elevation data have been converted to MSL. For cross checking the appropriateness of using Google Earth application in extracting elevation information, measured elevation data at two points near Maghbazar were compared with elevation data derived from Google; the results though differ appreciably (see Fig. 3.6), appears to be acceptable for the type of application made in this study.

LOCATION	GOOGLE RESULT
Location 1: Kazi Nazrul Islam Avenue (beside Hotel Sonargaon), Coordinates (UTM): X=46234364.5502; Y=2628773.7326 Elevation: 7.500 m (PWD) / **7.96 m MSL**	 **Elevation Found (Average): 8.23 m MSL**
Location 2: Diversion Road (near FDC intersection) Coordinates (UTM): X=46235109.367; Y=2629253.595 Elevation: 7.000 m (PWD) **7.46 m MSL**	 **Elevation Found (Average): 7.93 m MSL**

Figure 3.6: Comparison between measured elevation with those derived from Google

From the above mentioned activity, vulnerable roads and bridges have been identified and they were checked for functionality for the corresponding climate change impacts and effects. These were also prioritized and were listed with respect to traffic volume, road classification and economic importance. In addition, adaptation measures for each transport infrastructure have been identified and reviewed.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 GENERAL

According to RHD, roads are classified as National Highway, Regional Highway and Zilla Roads. These different types of roads are constructed all over the country to connect the capital, divisional headquarters, district headquarters, upazilla headquarters, growth centers, land ports, sea ports, harbors etc. In this study, road crest level elevation extracted from Google and key data from the Road Maintenance Management System (RMMS) of RHD have been compared with the inundation data (water level) from the SWRM of IWM. The comparison has been made for roads in three coastal areas of Bangladesh - Satkhira, Khulna and Bagherhat, which are already facing climate challenges like storms, cyclones, floods, high precipitation, high tidal surge etc. This section provides an assessment of the vulnerability of roads and highways to inundation in the study areas; the vulnerability to inundation has been assessed based on the difference between the existing road level and the water level in the base year (1998) and predicted water in 2080.

4.2 VULNERABILITY OF ROADS AND HIGHWAYS

This section provides an assessment of the vulnerability of roads and highways to inundation. In the vulnerability maps presented in this section, 'Ch'- indicates Chainage, 'Base'- indicates measured level of flood water (in m MSL) during 1998 (base year), 'IPCC'- indicates flood water level (in m MSL) predicted for 2080, considering climate change and sea level rise while 'EL'- indicates elevation of existing road level (in m MSL) derived from Google Earth. In this study, probable length of damaged road has been identified from analysis of the overlaid GIS map and Google Map. From the RHD Maintenance Circle, value of the ongoing maintenance work (in lac BDT) in the specific road location were incorporated to find out initiatives and implementation measures taken to improvise the condition of road.

4.2.1 STUDY AREA-1: SATKHIRA

Regional Highway- R765

Regional Highway R765 connects Navaron of Jessore to Satkhira district headquarters. The length of the total road is about 41.96 km and the rate of traffic flow through this road is medium (AADT- 7625). Table 4.1 shows the major features of the regional highway R765. It is one of the important highways in south-western region, and connects two remote districts Jessore and Satkhira. It connects bazaar places of Jessore, Navaron and Trimohoni of Satkhira. Along this road, a portion named Jhaudanga close to Betna River has been found to be vulnerable to inundation which falls in the upazilla Kalaroa. Table 4.2 shows the vulnerability of R765 to inundation at four selected points.

Table 4-1: Basic Data and Characteristics of Regional Highway R765

Road No.	R765					
Road Name	Navaran-Illishpur- Satkhira road					
Road Classification	Regional Highway					
Length (km)	41.96	Start	Navaron, Jessore		End	Satkhira
Traffic (AADT)	7625	Bridges	-		Ferry	-
Average Width (m)	5.5	LRP	2	Probable Length of Damage (km)		3.50
Value of Ongoing RHD Maintenance	3462.4 Lac BDT					

Table 4-2: Assessment of vulnerability of R765

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4
R765	41.96	Navaron	Satkhira (Trimohini)	1. BETNA Ch- 15045 Base- 5.14 IPCC- 5.142 EL- 12.2	2. BETNA-EXT Ch- 22567.50 Base- 5.122 IPCC- 5.124 EL- 10.7	3. BETNA Ch- 8000 Base- 5.012 IPCC- 5.015 EL- 9.15	4. BETNA Ch- 37500 Base- 3.932 IPCC- 3.996 EL- 5.183
			BASE	5.14	5.122	5.012	3.932
			IPCC	5.142	5.124	5.015	3.996
			EL	12.2	10.7	9.15	5.183
			EL-BASE= X	7.06	5.578	4.138	1.251
			EL-IPCC = Y	7.058	5.576	4.135	1.187

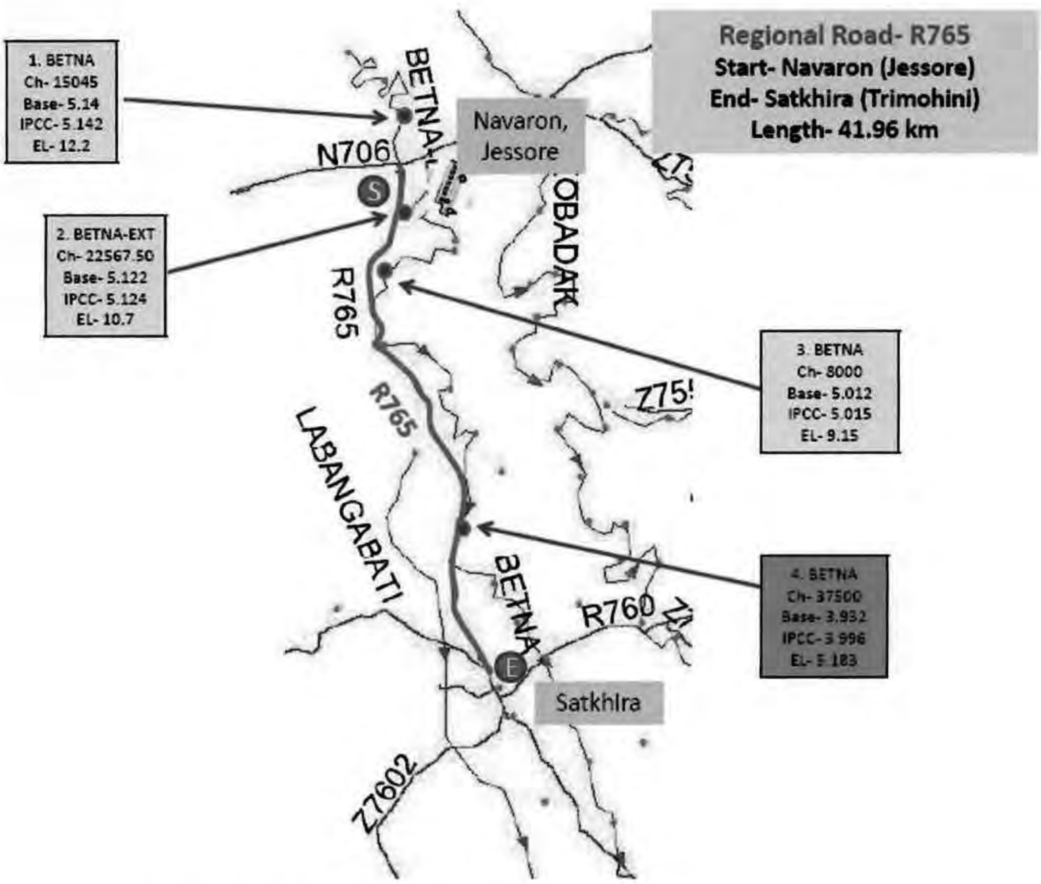


Figure 4-1: Vulnerability Map of Regional Highway R765

Figure 4.1 shows the vulnerability map of R765, it shows that parts of the road in Jessore district are at significantly higher elevation compared to water level in base year (1998) and that predicted for 2080.

However, towards the south end of the highway i.e. in Satkhira, the elevation of R765 is much lower at Betna point which is located at close proximity of the Betna River, at Chainage 37500, the difference in elevation between existing road crest level and predicted (2080) level +1.187m only. This portion of around 3-4 km is at risk of inundation and need periodic maintenance through raising the formation level of the road. Figure 4.2 shows the vulnerable location of the R765 on a Google image.

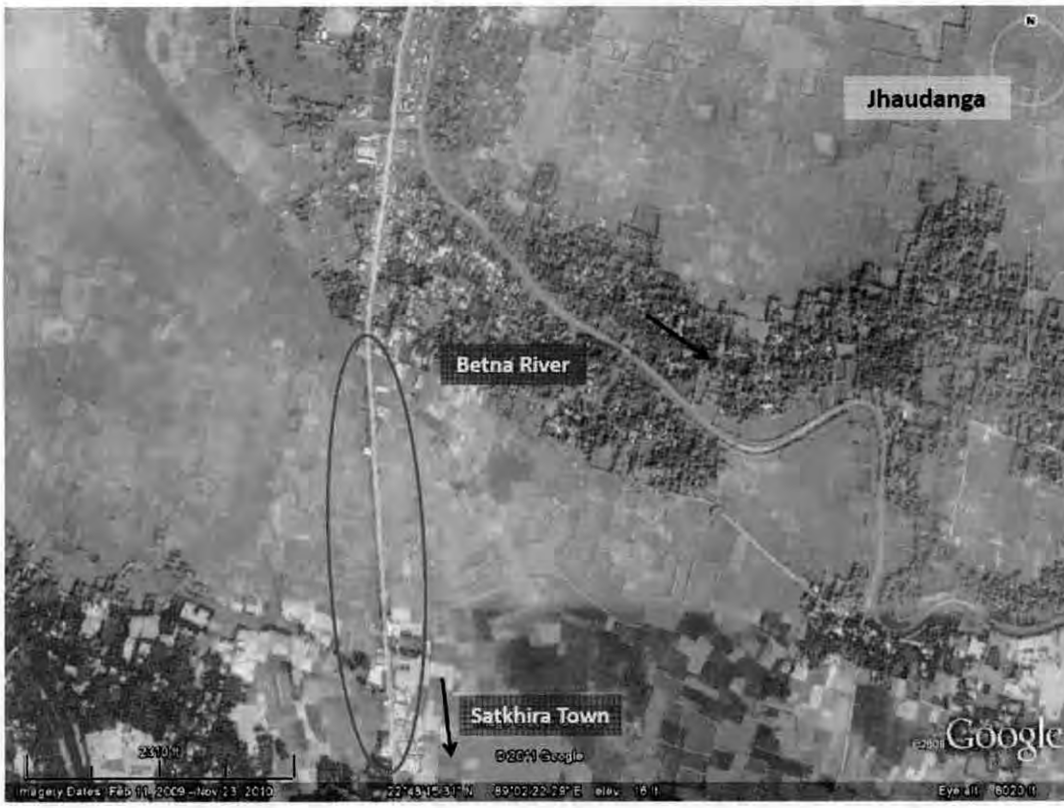


Figure 4-2: Google Image showing vulnerable areas of R765 close to the Satkhira town

Regional Highway R760

Regional Highway R760 is one of the major important highways in south-western region, connecting two remote districts Jessore and Satkhira via Chuknagar. The most important characteristics of this portion of the road is that it crosses almost 6-7 rivers/ khals transversely making impediment to the natural flow of the rivers/ khals. Table 4.3 shows the basic characteristics of R760. Table 4.4 shows the vulnerability of R760 to inundation at ten selected points.

Table 4-3: Basic Data and Characteristics of Regional Highway R760

Road No.	R760				
Road Name	Khulna-Chuknagar-Satkhira Road				
Road Classification	Regional Highway				
Length (km)	58.75	Start	Khulna (power house)	End	Satkhira (Laboni More)
Traffic (AADT)	7685	Bridges	22	Ferry	-
Average Width (m)	6.05	LRP	143	Probable Length of Damage (km)	6.8
Value of Ongoing Maintenance	441.28 Lac BDT				

Table 4-4: Assessment of vulnerability of R760

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4	Point ID5
R760	58.75	Khulna (power house)	Satkhira (Laboni More)	1. Rupsha Ch- 4999.0 Base- 2.847 IPCC- 4.054 EL- 5.85	2. Rupsha Ch- 0.0 Base- 2.878 IPCC- 4.136 EL- 5.8	3. Hatia Ch- 4200.0 Base- 0.835 IPCC- 1.706 EL- 3.96	4. U-Solmari Ch- 9150.0 Base- 1.359 IPCC- 1.963 EL- 2.74	5. Teka Heri Teli Geng Ch- 19309.0 Base- 2.178 IPCC- 3.288 EL- 5.48
			BASE	2.847	2.878	0.835	1.359	2.178
			IPCC	4.054	4.136	1.706	1.963	3.288
			EL	5.85	5.8	3.96	2.74	5.48
			EL-BASE= X	↑ 3.003	↑ 2.922	↑ 3.125	↗ 1.381	↑ 3.302
			EL-IPCC = Y	↑ 1.796	↑ 1.664	↑ 2.254	↘ 0.777	↑ 2.192

Point ID6	Point ID7	Point ID8	Point ID9	Point ID10
6. U-Bhadra Ch- 19449 Base- 2.807 IPCC- 3.843 EL- 3.96	7. KOBADAK Ch- 122998 Base- 4.177 IPCC- 4.256 EL- 8.54	8.. KOBADAK Ch- 126877 Base- 3.873 IPCC- 4.024 EL- 7.01	9. BETNA Ch- 54000 Base- 3.2 IPCC- 3.559 EL- 4.57	10. Labangabati Ch- 8750 Base- 2.187 IPCC- 3.107 EL- 9.15
2.807	4.177	3.873	3.2	2.187
3.843	4.256	4.024	3.559	3.107
3.96	8.54	7.01	4.57	9.15
↗ 1.153	↑ 4.363	↑ 3.137	↗ 1.37	↑ 6.963
↘ 0.117	↑ 4.284	↑ 2.986	↗ 1.011	↑ 6.043

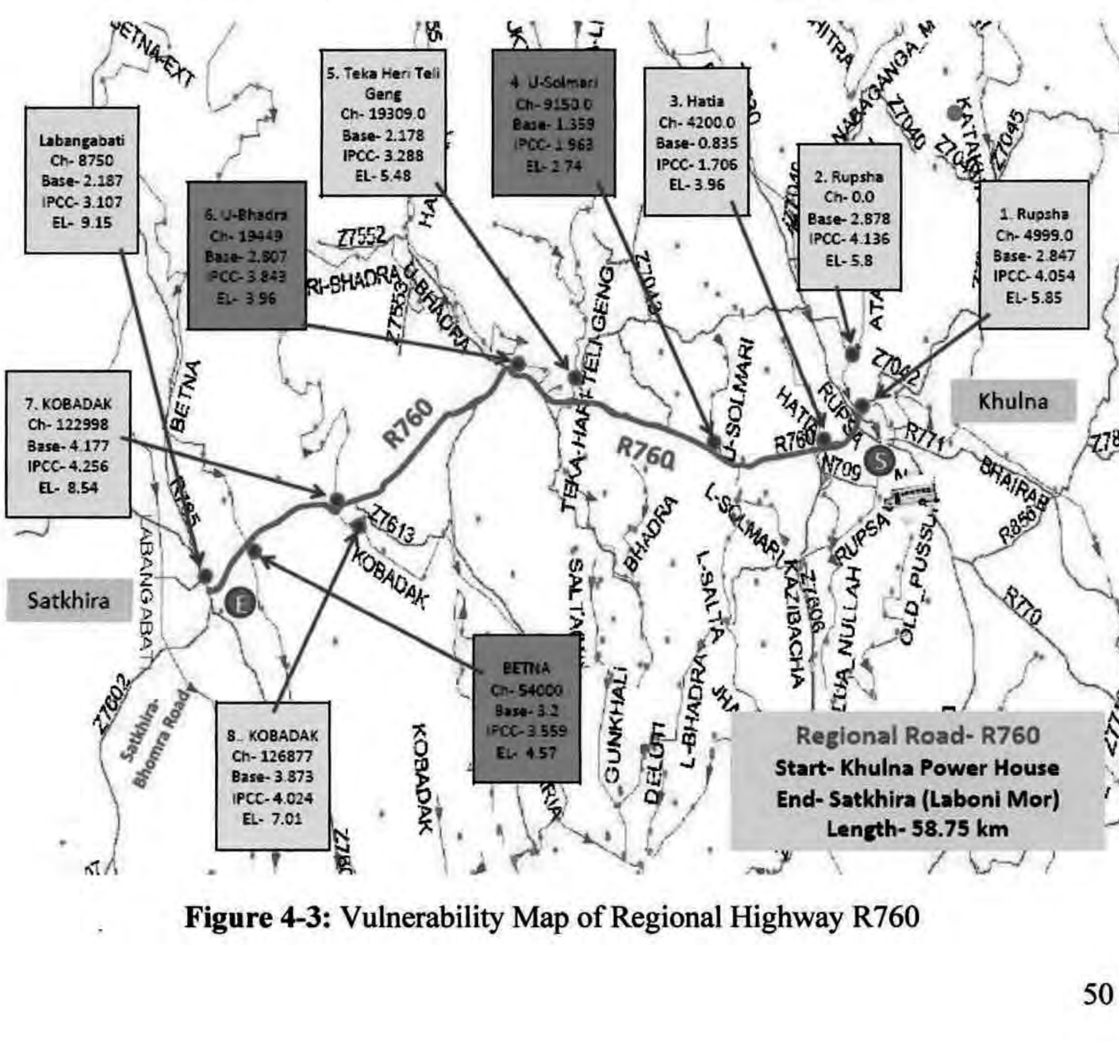


Figure 4-3: Vulnerability Map of Regional Highway R760

Figure 4.3 shows the vulnerability map of R760. It shows that parts of the road in Satkhira district are at significantly lower elevation compared to water level in base year (1998) and that predicted for 2080. Among the ten locations analyzed (Fig. 4.3), at 7 locations the difference in elevation has been found to be more than 1.5 m for both cases (i.e., IPCC 2080 and Base Year Scenario); these means that the roadway at these locations are comparatively safe. However, a total of 14.50 km road near Dumuria Bazar (Fig. 4.4), Chuknagar Bazar (Fig. 4.5), and Satkira town (Fig. 4.6) have been found to be at significant lower elevation. At these locations, the difference between the road formation level and base year water level is over 1 m; however the difference between the formation level and IPCC predicted water level varies from +0.117m to +1.011m, indicating significant risk of inundation.

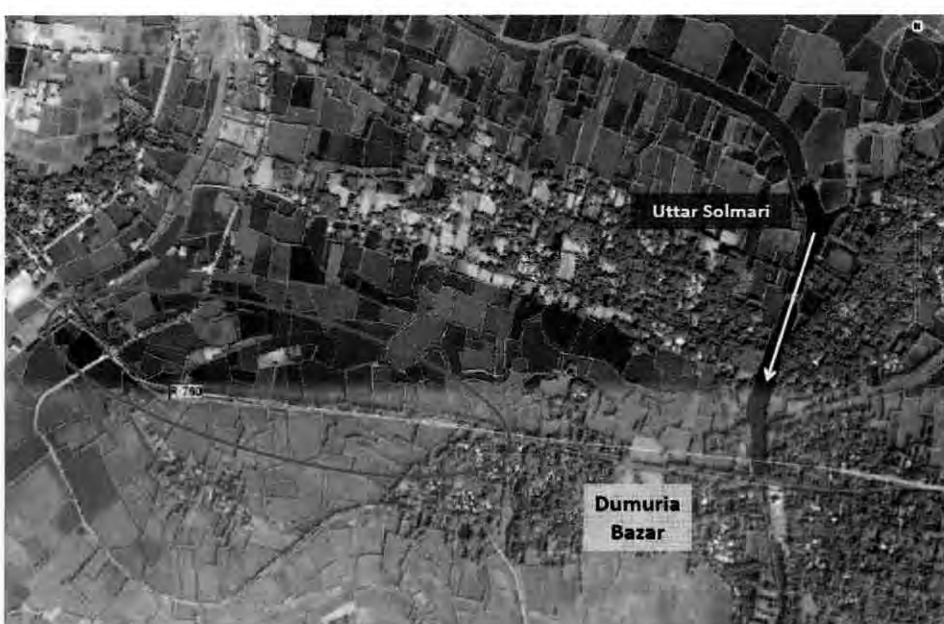


Figure 4-4: Vulnerable areas along R760 near Dumuria Bazar Area

Figure 4-5: Vulnerable areas along R760 at Chuknagar near Bhadra River

Figure 4-6: Vulnerable areas along R760 near Satkhira Town (Betna river bisects the alignment)

Zilla Road- Z7602

RHD Zilla Road Z7602 (Satkhira to Kaliganj road) is an important road that connects the district town with Shyamnagar and Sundarban. This is the entry road to get into Sundarban and economic activities of Sundarban with Satkhira district largely depend on this road. Table 4.5 shows the basic characteristics of Z7602, and Table 4.6 shows the vulnerability of Z7602 to inundation at three selected points.

Table 4-5: Basic Data and Characteristics of Zilla Road Z7602

Road No.	Z7602				
Road Name	Satkhira-Shakhipur-Kaliganj Road				
Road Classification	Zilla Road				
Length (km)	35.68	Start	Satkhira (Laboni More)	End	Kaliganj
Traffic (AADT)	13218	Bridges	10	Ferry	-
Average Width (m)	5.5	LRP	71	Probable Length of Damage (km)	6.30
Value of Ongoing Maintenance	315.91 Lac BDT				

Table 4-6: Assessment of vulnerability of Z7602

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3
Z7602	35.68	Satkhira (Laboni More)	Kaliganj	1. Labangabati Ch- 0.0 Base- 2.18 IPCC- 3.115 EL- 3.05	2. Khal_P3 Ch- 0.0 Base- 1.546 IPCC- 2.125 EL- 8.54	3. Kankshiali Ch- 10000.0 Base- 3.304 IPCC- 3.394 EL- 6.707
			BASE	2.18	1.546	3.304
			IPCC	3.115	2.125	3.394
			EL	3.05	8.54	6.707
			EL-BASE= X	0.87	6.994	3.403
			EL-IPCC = Y	-0.065	6.415	3.313

Figure 4.7 and Table 4.6 show three points where road elevations have been compared with the SWRM water level data. Near Bhomra port station, the area is slightly low-lying and the road embankment has been found to be low and vulnerable to inundation (6.30 km stretch). The difference in elevation (Y) between road level and IPCC 2080 scenario is -0.065, which means that in 2080 water level will overtop the roadway embankment. The vulnerable road section is near to the Labangabati river, which comes into Bangladesh from India. Figure 4.8 shows vulnerable area along the road on a Google image.

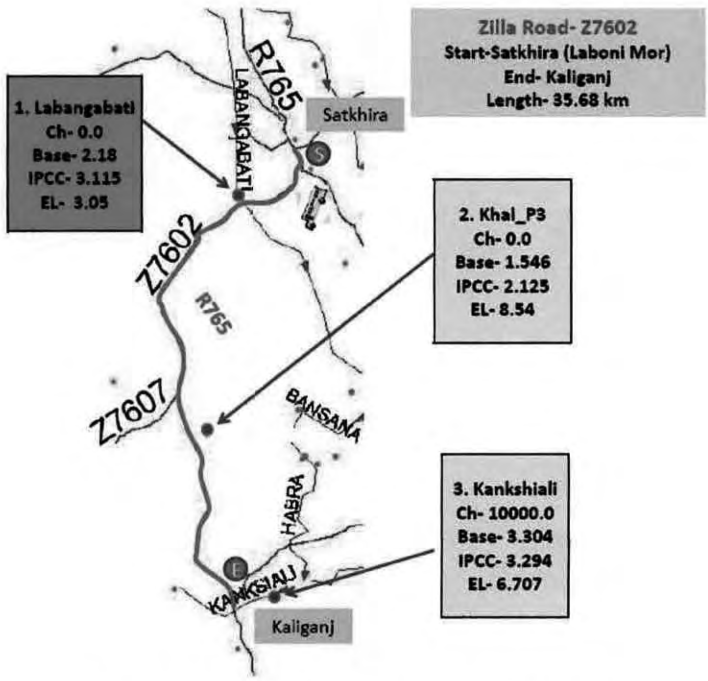


Figure 4-7: Vulnerability Map of Z7602

Figure 4-8: Vulnerable areas along Z7602 at Satkhira near Bhomra Port

Zilla Road- Z7617

Zilla Road 7617connects Kaliganj to Vatkhali Bus stand, which is the main road to enter to the southern region of Sundarbans. The length of the road is 27.69 km; it crosses over the marooned area/land used for shrimp culture. Table 4.7 shows the basic characteristics of Z7617, and Table 4.8 shows the vulnerability of Z7617 to inundation at two selected points.

Table 4-7: Basic Data and Characteristics of Zilla Road 7617

Road No.	Z7617				
Road Name	Kaliganj-Shyamnagar-Vetkhali Road				
Road Classification	Zilla Road				
Length (km)	27.69	Start	Kaliganj	End	Vetkhali (Bus Stand)
Traffic (AADT)	9423	Bridges	2	Ferry	-
Average Width (m)	5.5	LRP	48	Probable Length of Damage (km)	8.40
Value of Ongoing Maintenance	27.73 Lac BDT				

Table 4-8: Assessment of vulnerability of Z7617

Road	Length (km)	Start	End	Point ID1	Point ID2
Z7617	27.69	Kaliganj	Vatkhali (Bus Stand)	1. Khal_P5 Ch- 0.0 Base- 1.869 IPCC- 2.0 EL- 4.57	2. Jamuna SW Ch-259.83 Base- 2.84 IPCC- 2.94 EL- 3.05
			BASE	1.869	2.84
			IPCC	2	2.94
			EL	4.57	3.05
			EL-BASE= X	↑ 2.701	↘ 0.21
			EL-IPCC = Y	↑ 2.57	↘ 0.11

Figure 4.9 vulnerability map of the road. From the figure it is evident that near Banshipur, a large portion of the road is very much vulnerable not only under the base year situation but also under IPCC 2080 scenario. Almost 40% of the road is likely to be inundated during a flood similar to the 1998 flood. The roadway embankment should be reconstructed soon. Adaptation measure can only save the embankment from probable damage. The existing road maintenance programs of RHD do not encompass raising the embankment.

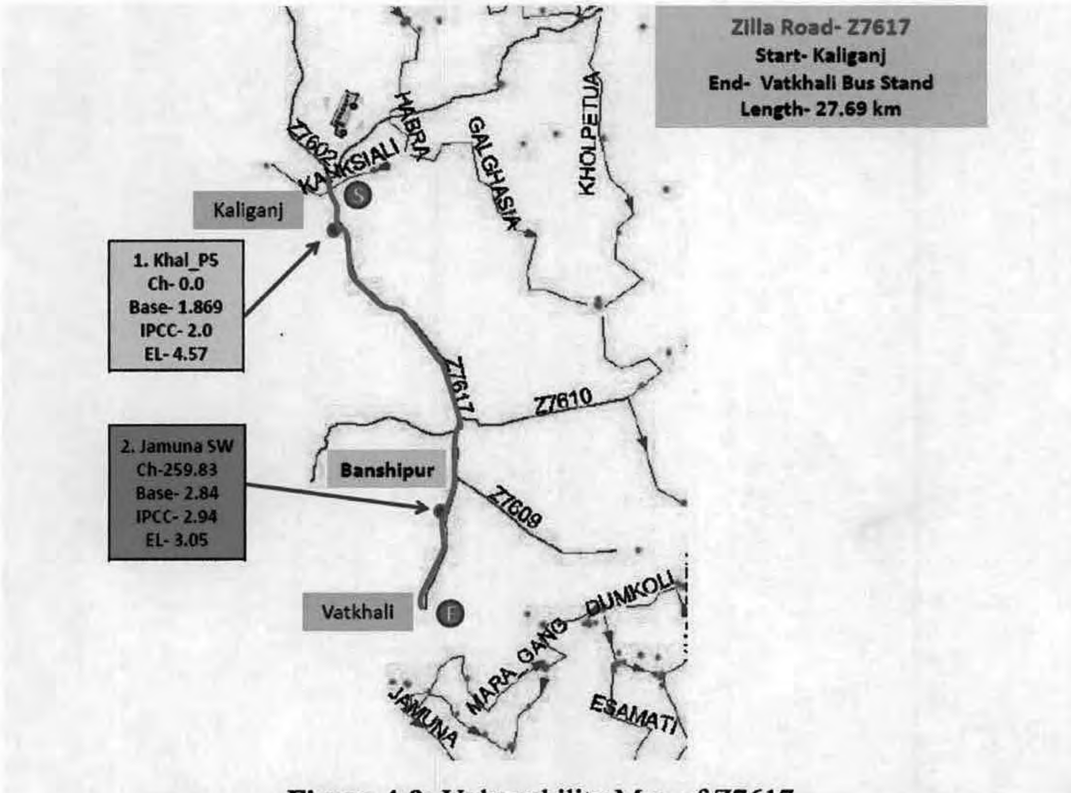


Figure 4-9: Vulnerability Map of Z7617

Figure 4-10: Vulnerable areas along Z7617 near Ramjanagar

Figure 4-11: Low terrain along Z7617 near Vetkhali

Zilla Road- Z7609

Munshiganj is the entry point of Sundarban from the Satkhira district. This Zilla Road RHD Z7609 serves as a feeder road from the Banshipur to Munshiganj. This portion of the road is very much vulnerable to climatic hazard and historic climatic events are present to support the fact. Table 4.9 shows the basic characteristics of Z7609, and Table 4.10 shows the vulnerability of Z7609 to inundation at two selected points.

Table 4-9: Basic Data and Characteristics of Zilla Road Z7609

Road No.	Z7609					
Road Name	Banshipur-Munshiganj road					
Road Classification	Zilla Road					
Length (km)	10.5	Start	Banshipur (Y Junction)		End	Munshiganj
Traffic (AADT)	3451	Bridges	22		Ferry	-
Average Width (m)	4.38	LRP	32	Probable Length of Damage (km)		10.50
Value of Ongoing Maintenance	133.88 Lac BDT					

Table 4-10: Assessment of vulnerability of Z7609

Road	Length (km)	Start	End	Point ID1	Point ID2
Z7609	10.5	Banshipur (Y Junction)	Munshiganj	1. Kholpetua Ch- 38000.0 Base- 2.714 IPCC- 3.866 EL- 2.70	2. Dumkoli Ch- 12855.0 Base- 2.529 IPCC- 3.552 EL- 2.70
			BASE	2.714	2.529
			IPCC	3.866	3.552
			EL	2.7	2.7
			EL-BASE= X	-0.014	0.171
			EL-IPCC = Y	-1.166	-0.852

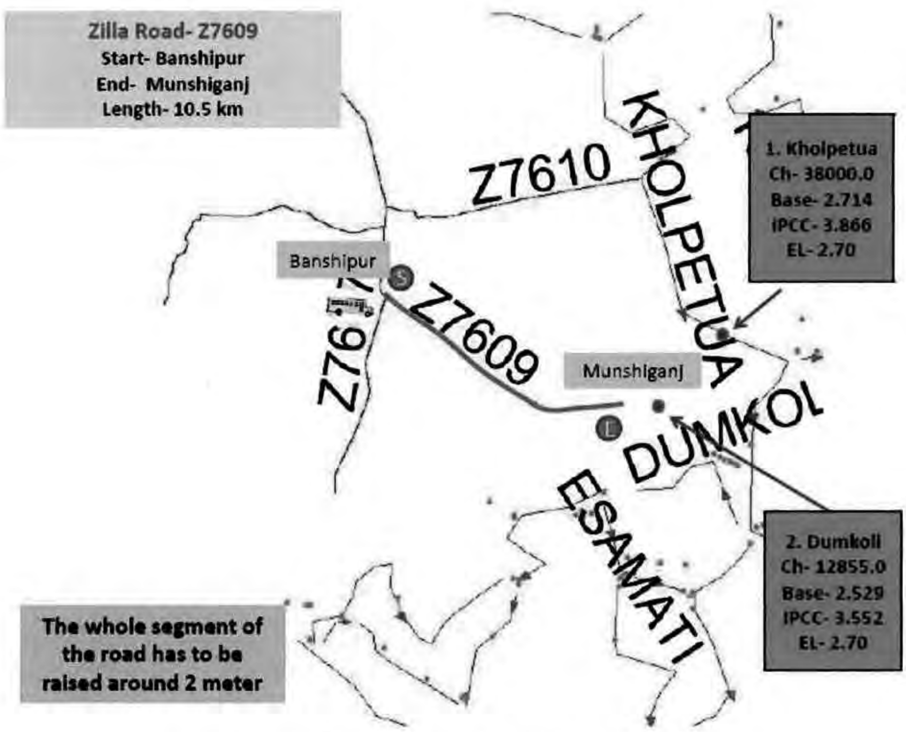


Figure 4-12: Vulnerability Map of Z7609

Figure 4.12 shows the vulnerability map of Z7609. Figure 4.12 and Table 4.10 show that the roadway elevation is very low and it is very vulnerable to inundation, even under th 1998 base year scenario. At Kholpetua, the current road level is 0.014 m and 1.166 m below the base year water level and IPCC 2080 water level (predicted), respectively. The roadway embankment needs very urgent reconstruction, including raising the embankment. Kholpetua River crossed the transversely; the whole segment of the roadway embankment has been found to be weak and vulnerable. During Sidr 2007 and

Aila 2080, major parts of the road were destructed by the deadly surges of water and a PSB (Portable Steel Bridge) along the road was blown away by the gusty wind.

Figure 4-13: Vulnerable areas along Z7609 near Munshiganj

Figure 4-14: Vulnerable areas along Z7609 near Kholpetua River

Zilla Road- Z7610

Zilla Road Z7610 connects Nawabeki at Koyra, Khulna with Nakipur of Shyamnagar, Satkhira. This road traverses from west to east crossing many rivers. Kholpetua is the river crosses across the road posing threats to the embankment. Table 4.11 shows the basic characteristics of Z7610, and Table 4.12 shows the vulnerability of Z7610 to inundation at three selected points.

Table 4-11: Basic Data and Characteristics of Zilla Road 7610

Road No.	Z7610				
Road Name	Koyra-Noabaki-Shamnagar Road				
Road Classification	Zilla Road				
Length (km)	10.37	Start	Shyamnagar (Nakipur)	End	Koyra (Nawabeki)
Traffic (AADT)	7221	Bridges	7	Ferry	-
Average Width (m)	3.21	LRP	59	Probable Length of Damage (km)	8.00
Value of Ongoing Maintenance	525.79 Lac BDT				

Table 4-12: Assessment of vulnerability of Z7610

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3
Z7610	10.37	Shyamnagar (Nakipur)	Koyra (Nawabeki)	1. Kholpetua Ch- 21010.0 Base- 2.926 IPCC- 4.003 EL- 2.44	2. Kholpetua Ch- 29505.0 Base- 2.846 IPCC- 3.933 EL- 2.44	3. Galghasia Ch- 10750.0 Base- 2.425 IPCC- 2.919 EL- 1.83
			BASE	2.926	2.846	2.425
			IPCC	4.003	3.9330	2.919
			EL	2.44	2.44	1.83
			EL-BASE= X	↓ -0.486	↓ -0.406	↓ -0.595
			EL-IPCC = Y	↓ -1.563	↓ -1.493	↓ -1.089

Figure 4.15 shows vulnerability map of Z7610. Shyampur to Nawabeki portion of the road is one of the vulnerable portions of road, where almost 96% of the road would remain under water for the IPCC 2080 flood scenario. After Aila 2009, the top bituminous surface of the road was dismantled by the tide and large volume of water overtopped the embankment. Alarmingly, all the existing road crest levels data along the road have been found to be below than the inundation data of Flood 1998 (Table 4.12). The vulnerable areas along the road are shown in Figs. 4.16 to 4.18.

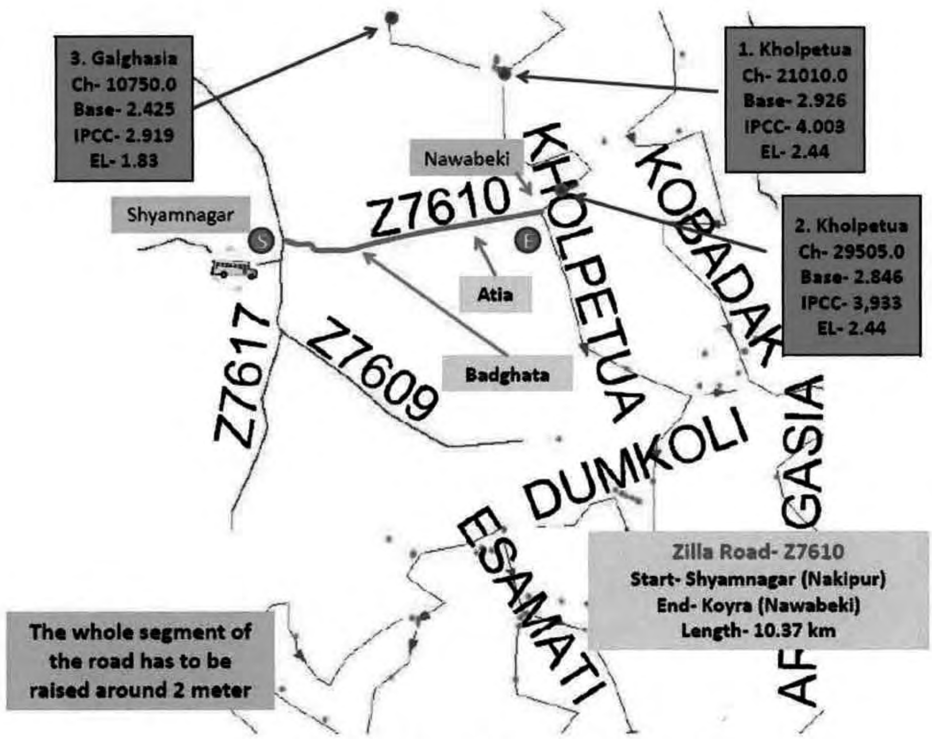


Figure 4-15: Vulnerability Map of Z7610

Figure 4-16: Vulnerable areas along Z7610 near Atia region

Figure 4-17: Vulnerable areas along Z7610 at Badghata

Figure 4-18: Extremely vulnerable areas along Z7610 at Nawabeki

Zilla Road- Z7607

This is a small road of Roads & Highways Department (only 5.423 km), but has comparatively more traffic (9098 AADT). This highway connects Satkhira district to Debhata upazila, one of the low-lying upazilas in Bangladesh. Table 4.13 shows the basic characteristics of Z7607, and Table 4.14 shows the vulnerability of Z7607 to inundation at two selected points.

Table 4-13: Basic Data and Characteristics of Z7607

Road No.	Z7607				
Road Name	Satkhira (Shakhipur)-Debhata Road				
Road Classification	Zilla Road				
Length (km)	5.423	Start	Shakhipur	End	Debhata
Traffic (AADT)	9098	Bridges	-	Ferry	-
Average Width (m)	5.02	LRP	9	Probable Length of Damage (km)	0
Value of Ongoing Maintenance	134.63 Lac BDT				

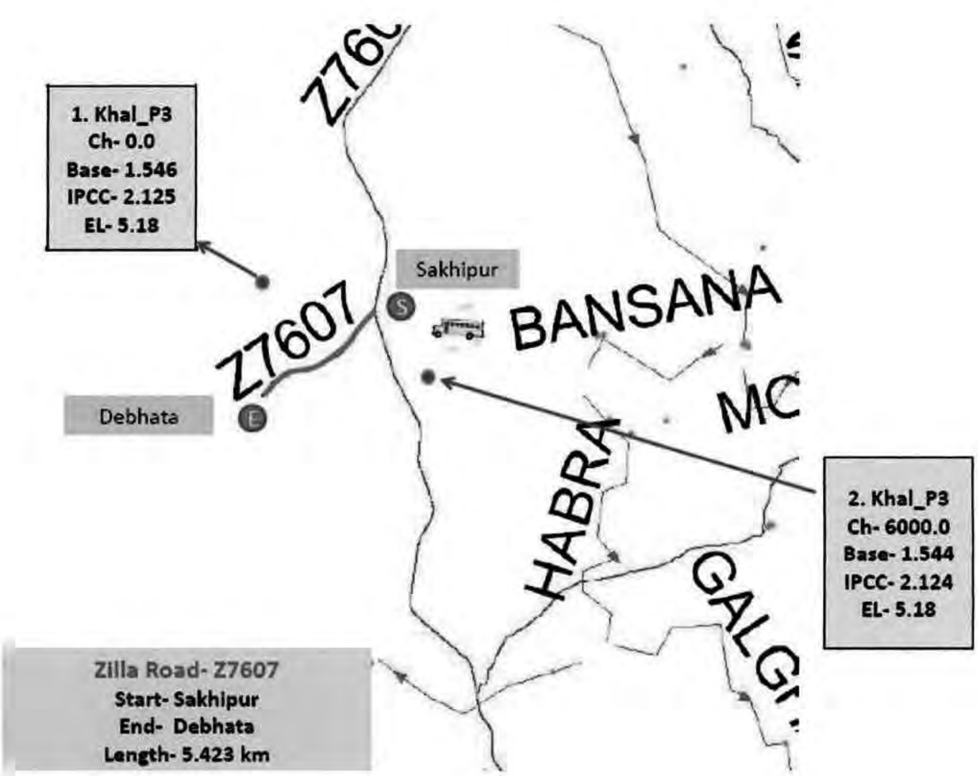


Figure 4-19: Vulnerability Map of Z7607

Table 4-14: Assessment of vulnerability of Z7607

Road	Length (km)	Start	End	Point ID1	Point ID2
Z7607	5.423	Shakhipur	Debhata	1. Khal_P3 Ch- 0.0 Base- 1.546 IPCC- 2.125 EL- 5.18	2. Khal_P3 Ch- 6000.0 Base- 1.544 IPCC- 2.124 EL- 5.18
			BASE	1.546	1.544
			IPCC	2.125	2.124
			EL	5.18	5.18
			EL-BASE= X	↑ 3.634	↑ 3.636
			EL-IPCC = Y	↑ 3.055	↑ 3.056

Figure 4.19 shows vulnerability map of Z7607. The Satkhira to Debhata road is a link road which connects the areas adjacent to India-Bangladesh border, especially Debhata bazaar road. This road was constructed long ago to facilitate historical Debhata bazaar, and the road embankment has been found to be high, and not susceptible to inundation (see Table 4.14).

Zilla Road- Z7603

Satkhira-Asasuni-Goaldanga-Paikgachha Road, Z7603, road is a long road connecting three Upazila/Thana of Satkhira District. Comparative traffic movement and growth is also high. The southernmost point of the road i.e. Paikgacha is low-lying area. Table 4.15 shows the basic characteristics of Z7603, and Table 4.16 shows the vulnerability of Z7603 to inundation at five selected points.

Table 4-15: Basic Data and Characteristics of Zilla Road Z7603

Road No.	Z7603				
Road Name	Satkhira-Asasuni-Goaldanga-Paikgachha Road				
Road Classification	Zilla Road				
Length (km)	25.57	Start	Satkhira	End	Ashashuni
Traffic (AADT)	9761	Bridges	4	Ferry	-
Average Width (m)	4.05	LRP	114	Probable Length of Damage (km)	4.20
Value of Ongoing Maintenance	899.60 Lac BDT				

Table 4-16: Assessment of vulnerability of Z7603

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4	Point ID5
Z7603	25.57	Satkhira	Ashashuni	1. Labangabati Ch- 8750 Base- 2.187 IPCC- 3.107 EL- 9.15	2. BETNA Ch- 62000 Base- 2.622 IPCC- 3.484 EL- 6.7	3. BETNA Ch- 70000 Base- 2.464 IPCC- 3.428 EL- 5.8	4. BETNA Ch- 84000 Base- 2.561 IPCC- 3.675 EL- 3.96	5. Morichap Ch- 7000 Base- 2.756 IPCC- 3.821 EL- 1.45
			BASE	2.187	2.622	2.464	2.561	2.756
			IPCC	3.107	3.484	3.428	3.675	3.821
			EL	9.15	6.7	5.8	3.96	1.45
			EL-BASE= X	6.963	4.078	3.336	1.399	-1.306
			EL-IPCC = Y	6.043	3.216	2.372	0.285	-2.371

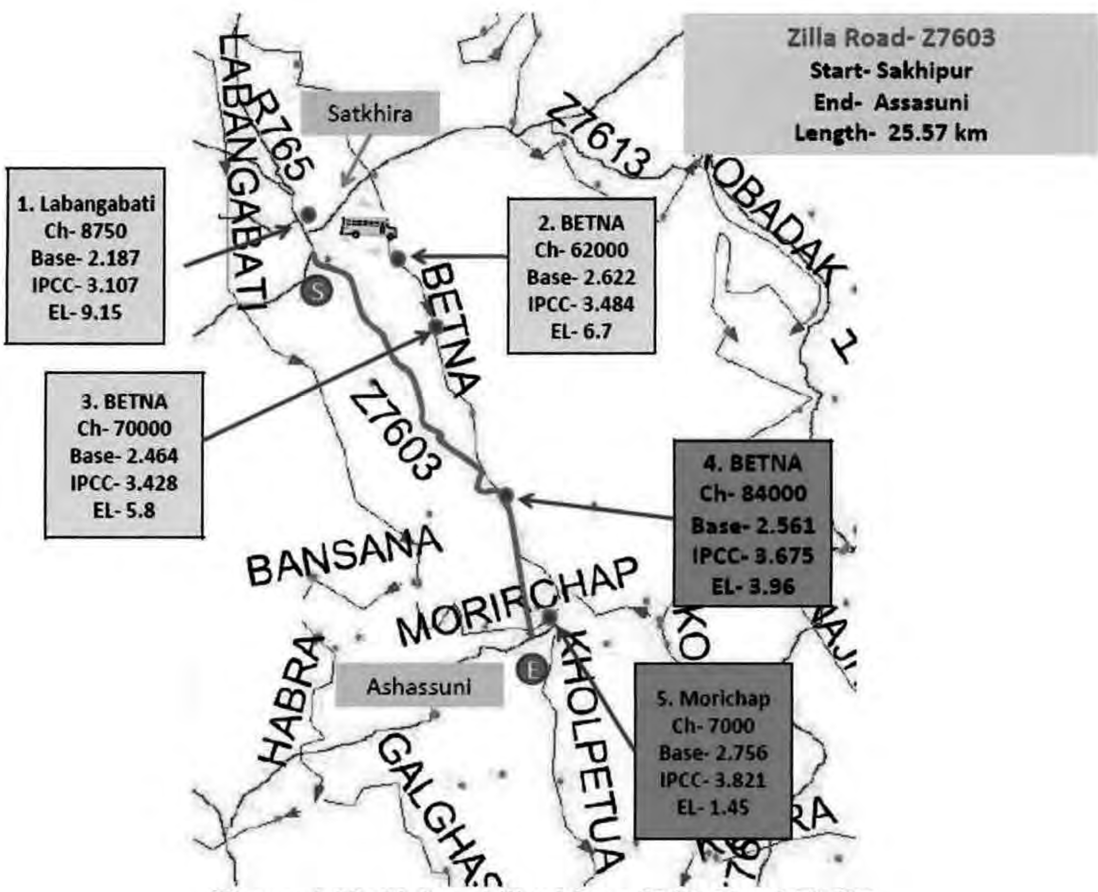


Figure 4-20: Vulnerability Map of Zilla Road Z7603

Figure 4.20 shows vulnerability map of Z7603. Assashuni is one of the low lying upazilas in Bangladesh surrounded by Kholpetua and Morchap Rivers. Nearby Assashuni upazila road has been found vulnerable to inundation. Two locations along the road are particularly vulnerable to inundation (see Table 4.16), these are Betna and Morichap (Figs. 4.21 - 4.23).

Figure 4-21: Vulnerable areas along Z7603 near Assasuni beside Betna River

Figure 4-22: Vulnerable Road (Z7603) on the Bank of Betna River

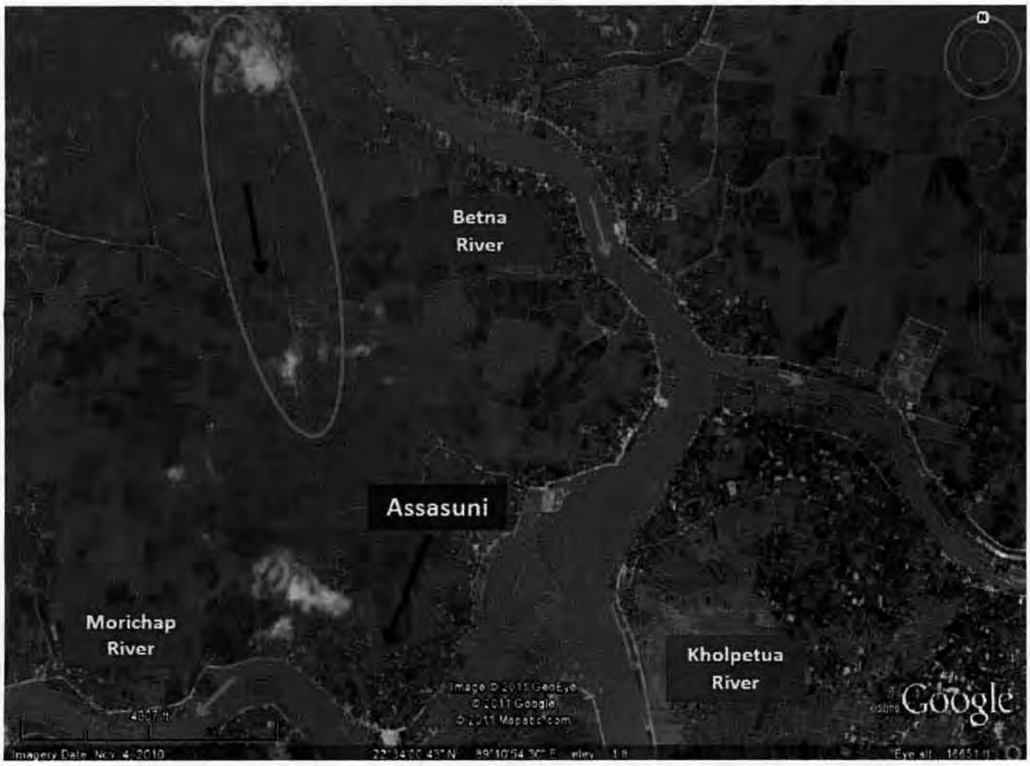


Figure 4-23: Vulnerable areas along Z7603 near the confluence of three rivers

Zilla Road- Z7618

The Zilla Road Z7618 is a long road (35 km), connecting Assasuni to the largest upazila of the country Shyamnagar. Table 4.17 shows the basic characteristics of Z7618, and Table 4.18 shows the vulnerability of Z7618 to inundation at five selected points.

Table 4-17: Basic Data and Characteristics of Zilla Road Z7618

Road No.	Z7618				
Road Name	Ashasuni-Shyamnagar Road				
Road Classification	Zilla Road				
Length (km)	35	Start	Ashassuni	End	Shyamnagar
Traffic (AADT)	6715	Bridges	-	Ferry	-
Average Width (m)	3.60	LRP	2	Probable Length of Damage (km)	14.0
Value of Ongoing Maintenance	817.95 Lac BDT				

Table 4-18: Assessment of vulnerability of Z7618

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4	Point ID5
Z7618	35	Ashassuni	Shyamnagar	1. Morirchap Ch- 7000 Base- 2.756 IPCC- 3.821 EL- 3.04	2. Kankshiali Ch- 0.0 Base- 2.763 IPCC- 2.82 EL- 2.50	3. Kholpetua Ch- 8500.0 Base- 2.918 IPCC- 3.942 EL- 2.134	4. Kholpetua Ch- 21000.0 Base- 2.926 IPCC- 4.002 EL- 3.96	5. Kholpetua Ch- 29505.0 Base- 2.846 IPCC- 3.933 EL- 3.96
			BASE	2.756	2.763	2.918	2.926	2.846
			IPCC	3.821	2.82	3.942	4.002	3.933
			EL	3.04	2.5	2.134	3.96	3.96
			EL-BASE= X	0.284	-0.263	-0.784	1.034	1.114
			EL-IPCC = Y	-0.781	-0.32	-1.808	-0.042	0.027

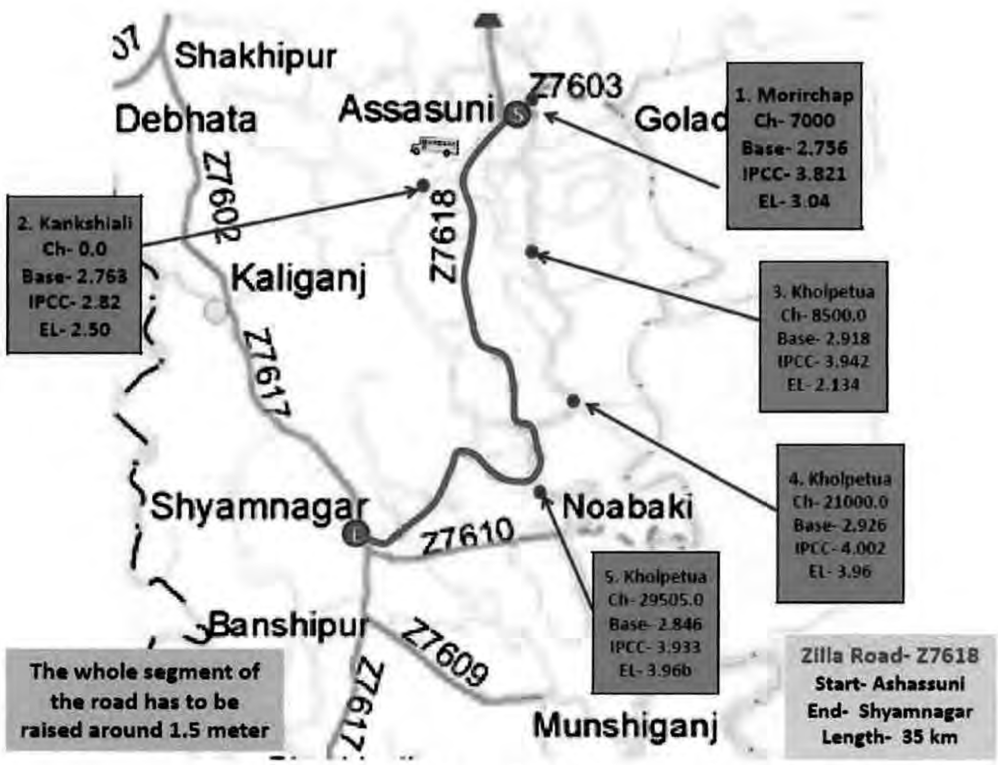


Figure 4-24: Vulnerability Map of Z7618

Figure 4.24 shows vulnerability map of Z7618. Shyamnagar to Assashuni road is one of the major important links between the eastern and western parts of the district. But the road passes through low-lying areas of the upazila. Moreover, the embankment height of this road is relatively low. Similarly, the road is very much narrow. Table 4.18 shows that the existing road crest level is below the 1998 water level at two out of five points considered. At four out of the five selected points, the existing crest levels are below the IPCC 2080 predicted water level. Therefore, this road appears to be very risky with respect to inundation. Figures 4.25-4.27 show vulnerable locations along the road.

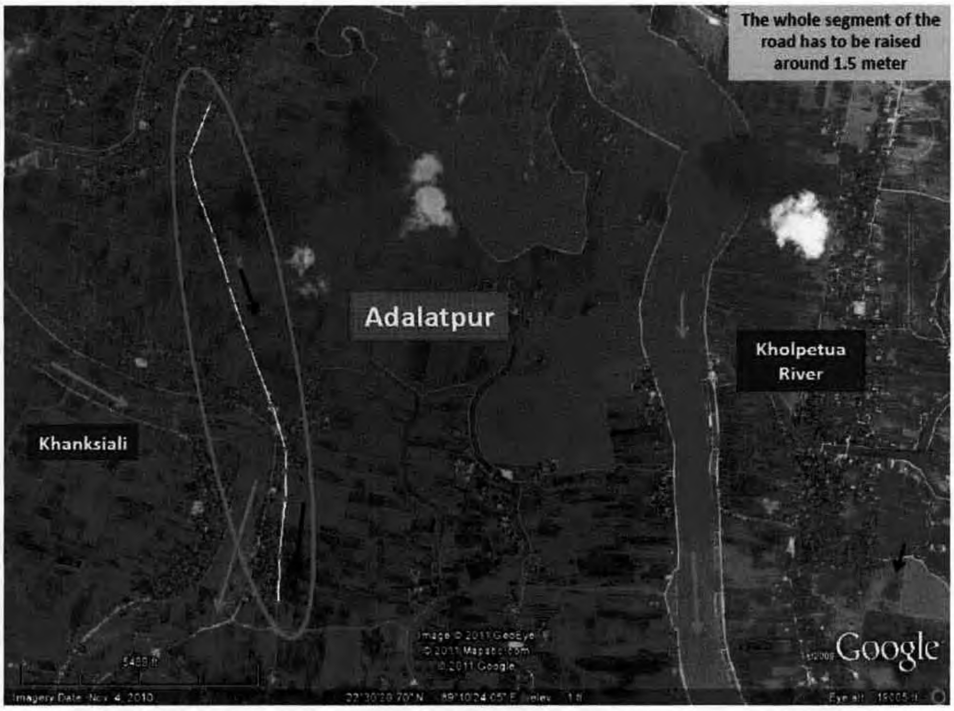


Figure 4-25: Vulnerable areas along Z7618 near Adalatpur

Figure 4-26: Vulnerable areas along Z7618 at Adalatpur

Figure 4-27: Vulnerable areas along Z7618 clsoe to Adalatpur

Zilla Road- Z7613

The Zilla Road Z7613 connects Satkhira district to Tala upazila, where traffic movement is very less due to low economic activities. But during Sidr, the road suffered significant damage, and had to undergo vast repair. Table 4.19 shows the basic characteristics of Z7613, and Table 4.20 shows the vulnerability of Z7613 to inundation at three selected points.

Table 4-19: Basic Data and Characteristics of Zilla Road Z7613

Road No.	Z7613				
Road Name	Tala-Islamkati-Sujanshaha-Satkhira (Patkelghata) Road				
Road Classification	Zilla Road				
Length (km)	9.9	Start	Patkelghata	End	Tala
Traffic (AADT)	1405	Bridges	2	Ferry	-
Average Width (m)	4.0	LRP	27	Probable Length of Damage (km)	0
Value of Ongoing Maintenance	1128.56 Lac BDT				

Table 4-20: Assessment of vulnerability of Z7613

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3
Z7613	9.9	Patkelghata	Tala	1. Kobadak Ch- 118658 Base- 4.461 IPCC- 4.497 EL- 6.7	2. Kobadak Ch- 126877 Base- 3.873 IPCC- 4.024 EL- 8.23	3. Kobadak Ch- 137518 Base- 3.242 IPCC- 3.782 EL- 7.93
			BASE	4.461	3.873	3.242
			IPCC	4.497	4.024	3.782
			EL	6.7	8.23	7.93
			EL-BASE= X	2.239	4.357	4.688
			EL-IPCC = Y	2.203	4.206	4.148

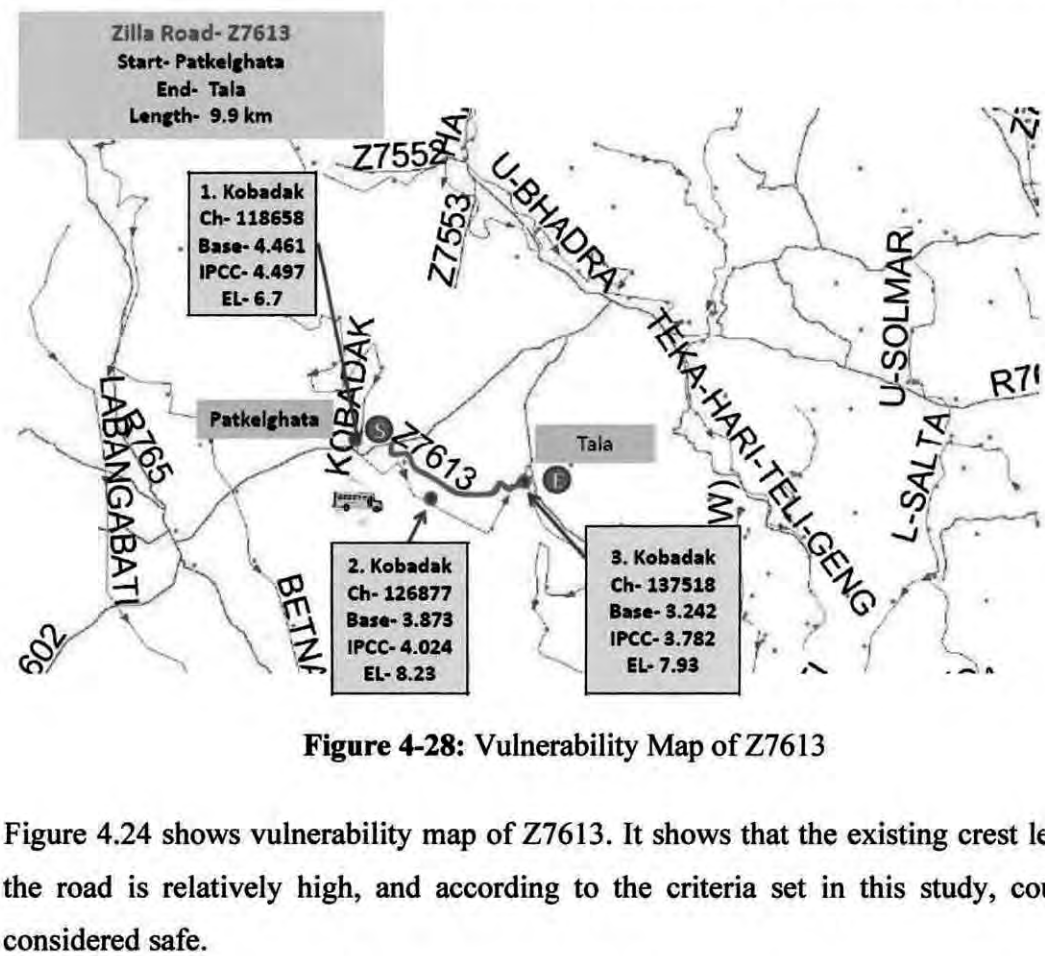


Figure 4-28: Vulnerability Map of Z7613

Figure 4.24 shows vulnerability map of Z7613. It shows that the existing crest level of the road is relatively high, and according to the criteria set in this study, could be considered safe.

__Zilla Road- Z7604__

Zilla Road Z7604 connects Betgram-Tala-Paikgacha-Koyra of Khulna. Strategically the road is important as it connects Satkhira district to the Sundarban entry point from Khulna. The southern portion of the road is very low in height and narrow in width. Table 4.21 shows the basic characteristics of Z7604, and Table 4.22 shows the vulnerability of Z7604 to inundation at eight selected points.

Table 4-21: Basic Data and Characteristics of Zilla Road Z7604

Road No.	Z7604				
Road Name	Betgram-Tala-Paikgachha-Koyra Road				
Road Classification	Zilla Road				
Length (km)	65.276	Start	Betgram (18 mile bazar)	End	Koyra (kharnia)
Traffic (AADT)	3327	Bridges	-	Ferry	-
Average Width (m)	3.92	LRP	128	Probable Length of Damage (km)	12.6
Value of Ongoing Maintenance	3346.4 Lac BDT				

Table 4-22: Assessment of vulnerability of Z7604

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4	Point ID5	Point ID6	Point ID7	Point ID8
Z7604	65.276	Betgram (18 mile bazar)	Koyra (kharnia)	1. U-Bhadra Ch- 10762 Base- 2.581 IPCC- 3.409 EL- 6.4	2. Kobadak Ch- 137518 Base- 3.242 IPCC- 3.782 EL- 5.89	3. Kobadak Ch- 145870 Base- 2.868 IPCC- 3.907 EL- 7.62	4. Kobadak Ch- 160090 Base- 2.89 IPCC- 4.163 EL- 6.5	5. Haria Ch- 17000 Base- 2.76 IPCC- 4.012 EL- 3.05	6. Minajnadi Ch- 2500 Base- 2.74 IPCC- 3.981 EL- 3.96	7. Koyra Ch- 0.0 Base- 2.97 IPCC- 4.03 EL- 4.9	8. Shakbaria Ch- 10545 Base- 2.675 IPCC- 4.03 EL- 3.5
			BASE	2.581	3.242	2.868	2.89	2.76	2.74	2.97	2.675
			IPCC	3.409	3.782	3.907	4.163	4.012	3.981	4.03	4.03
			EL	6.4	5.89	7.62	6.5	3.05	3.96	4.9	3.5
			EL-BASE= X	3.819	2.648	4.752	3.61	0.29	1.22	1.93	0.825
			EL-IPCC = Y	2.991	2.108	3.713	2.337	-0.962	-0.021	0.87	-0.53

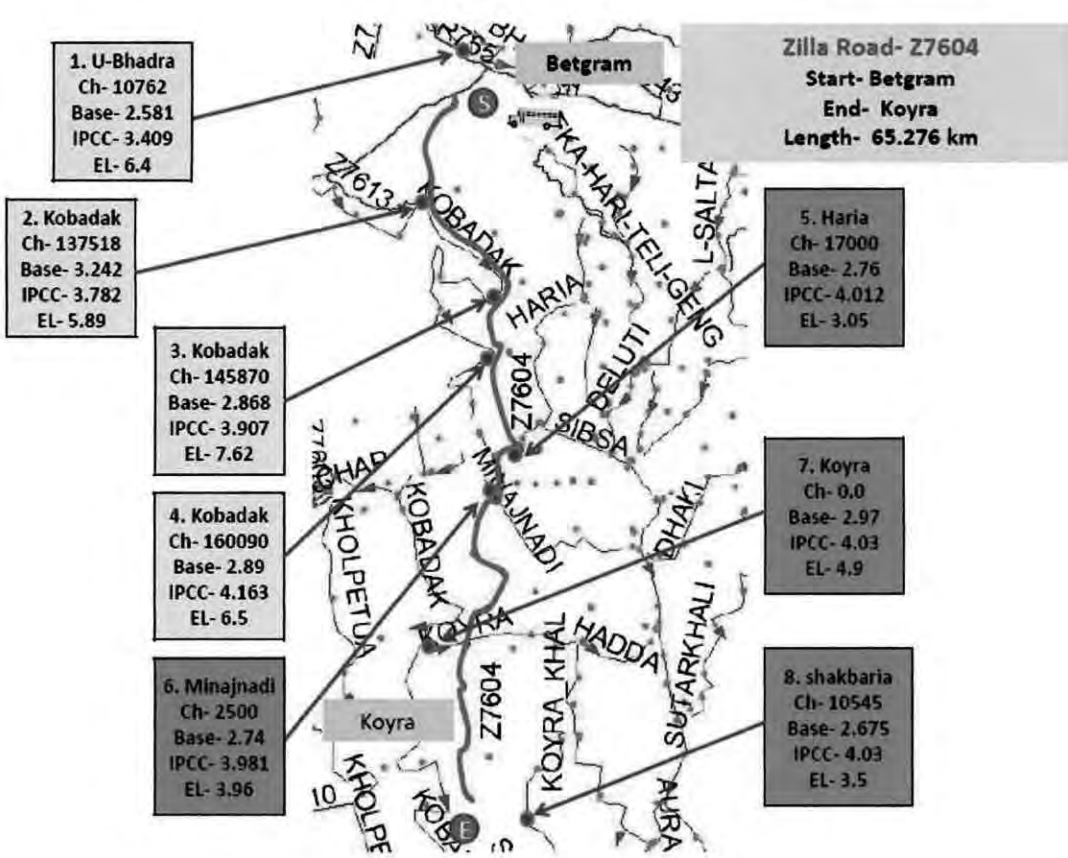


Figure 4-29: Vulnerability Map of Z7604

Figure 4.24 shows vulnerability map of Z7604. Betgram-Tala-Paikgacha-Koyra Road is an important road in terms of Upazilla connectivity. But a number of turbulent rivers crosses the Tala-Koyra-Paikgacha areas both longitudinally and transversely. Of them, Kholpetua, Haria,Katakhali, Kobadak, Koyra, Minajnadi and Shibsa are important channels. In the analysis, 25% of the roadway embankment has been found vulnerable and weak. The stretch of road from Betgram area up to Kabadak is at relatively high elevation, and not susceptible to inundation (see Fig. 4.29); on the other and remaining portion of the road up to Koyra passes through relatively low-lying area and susceptible to inundation. Figures 4-30 to 4-33 show vulnerable locations of the along Z7604.

Figure 4-30: Vulnerable areas along Z7604 near Koyra Ferry Ghat

Figure 4-31: Vulnerable areas along Z7604 at Minajnadi, beside Minajnadi River

Figure 4-32: Vulnerable areas along Z7604 where it is surrounded by tidal rivers

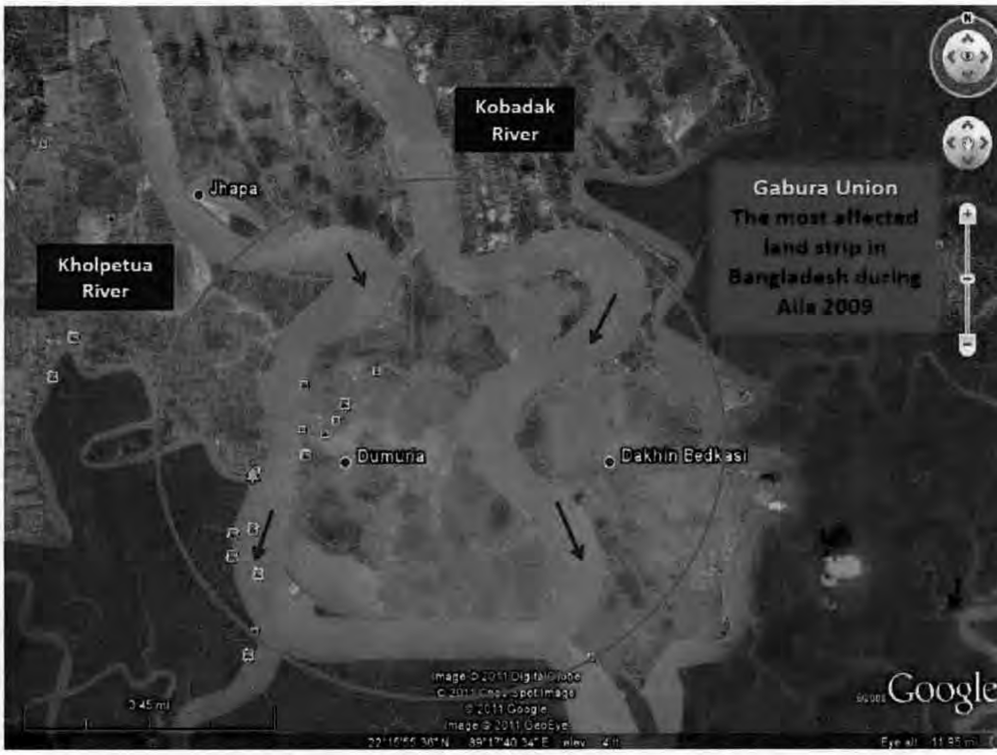


Figure 4-33: Vulnerable areas along Z7604 near Gabura Union

4.2.2 STUDY AREA-2: KHULNA

Zilla Road- Z7606

RHD Zilla Road Z7606 is one of the main route to enter Dacope and then to Nalian Forest in Sundarbans. The length of the road is 53.05 km and traffic is 3770 AADT. In the southern part of the highway the elevation is very low compared to the northern region. It crosses Rupsa, Pussur, Chunkuri, Kazibacha and Suterkhali River. Table 4.23 shows the basic characteristics of Z7606, and Table 4.24 shows the vulnerability of Z7606 to inundation at eight selected points.

Table 4-23: Basic Data and Characteristics of Zilla Road Z7606

Road No.	Z7606				
Road Name	Gollamari-Batiaghata-Dacope-Nalian Forest Road				
Road Classification	Zilla Road				
Length (km)	53.05	Start	Gollamari	End	Kala Bogi
Traffic (AADT)	3770	Bridges	2	Ferry	-
Average Width (m)	3.7	LRP	75	Probable Length of Damage (km)	20.5
Value of Ongoing Maintenance	1088.25 Lac BDT				

Table 4-24: Assessment of vulnerability of Z7606

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4
Z7606	53.05	Gollamari	Kala Bogi	1. Hatia Ch- 4200.0 Base- 0.835 IPCC- 1.706 EL- 4.57	2. Hatia Ch- 9250.0 Base- 0.835 IPCC- 1.706 EL- 5.18	3. Rupsa Ch- 17400.0 Base- 2.187 IPCC- 3.949 EL- 4.40	4. Kazibacha Ch- 3500.0 Base- 2.781 IPCC- 3.889 EL- 3.96
			BASE	0.835	0.835	2.187	2.781
			IPCC	1.706	1.706	3.949	3.889
			EL	4.57	5.18	4.4	3.96
			EL-BASE= X	3.735	4.345	2.213	1.179
			EL-IPCC = Y	2.864	3.474	0.451	0.071

Road	Length (km)	Start	End	Point ID5	Point ID6	Point ID7	Point ID8
Z7606	53.05	Gollamari	Kala Bogi	5. Old Possur Ch- 27500.0 Base- 2.705 IPCC- 3.858 EL- 4.58	6. Kazibacha Ch- 1300.0 Base- 2.697 IPCC- 3.838 EL- 3.96	7. Possur Ch- 0.0 Base- 2.68 IPCC- 3.824 EL- 3.78	8. Sutarkhali Ch- 0.0 Base- 2.651 IPCC- 3.796 EL- 3.05
			BASE	2.705	2.697	2.68	2.651
			IPCC	3.858	3.838	3.824	3.796
			EL	4.58	3.96	3.78	3.05
			EL-BASE= X	1.875	1.263	1.1	0.399
			EL-IPCC = Y	0.722	0.122	-0.044	-0.746

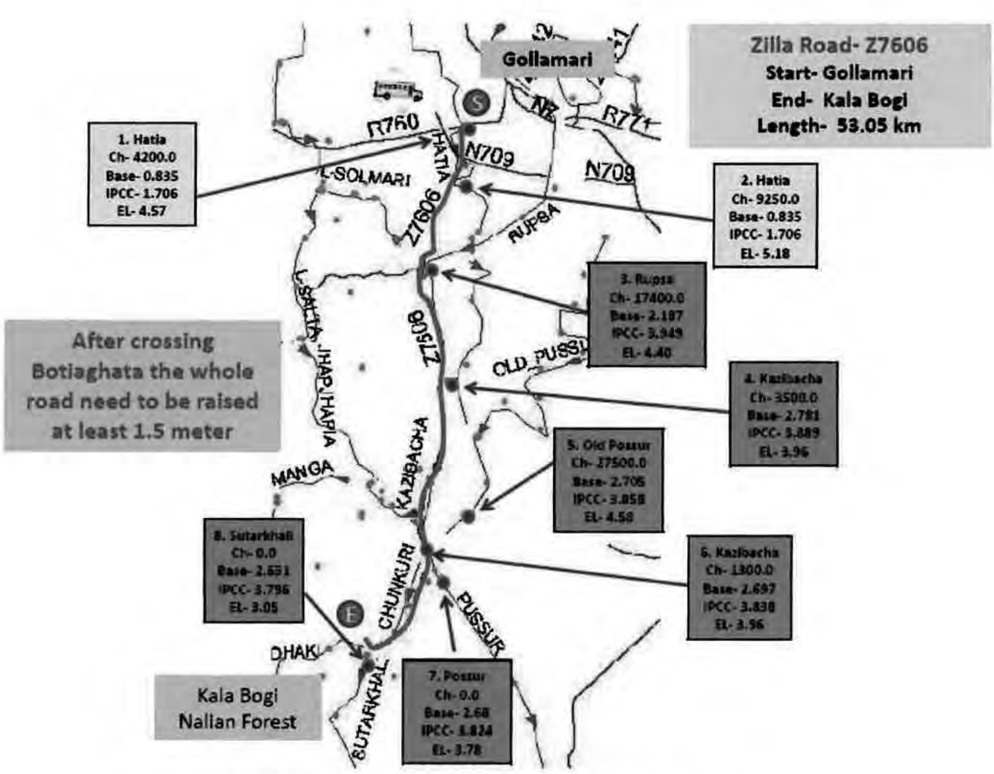


Figure 4-34: Vulnerability Map of Z7606

Figure 4.34 shows the vulnerability of the road and its embankment on the southern part of Z7606. After crossing Rupsha khal and Batiaghata Bazar, the whole portion of the road is basically vulnerable for two reasons- low embankment height and close proximity to rivers. Dacope (Chalna Bazar) is a low-lying area. Maximum portion of the road is earthen /HBB and act as polder/dykes to protect from flood. Nalian forest is a remote place where road access is limited due to the inundation of the area for 5-6 moths of a year. At the Nalian forest point the difference in the water level and road level has been found very low, +0.399 for base scenario and -0.746 for IPCC scenario. Figures 4.35 to 4.40 show vulnerable areas along Z7606.

Figure 4-35: Very risky road (Z7606) embankment at Dacope ferry ghat

Figure 4-36: Z7606 at Dacope Bazar- vulnerable to inundation

Figure 4-37: Vulnerable Z7606 roadway embankment acting as Berm

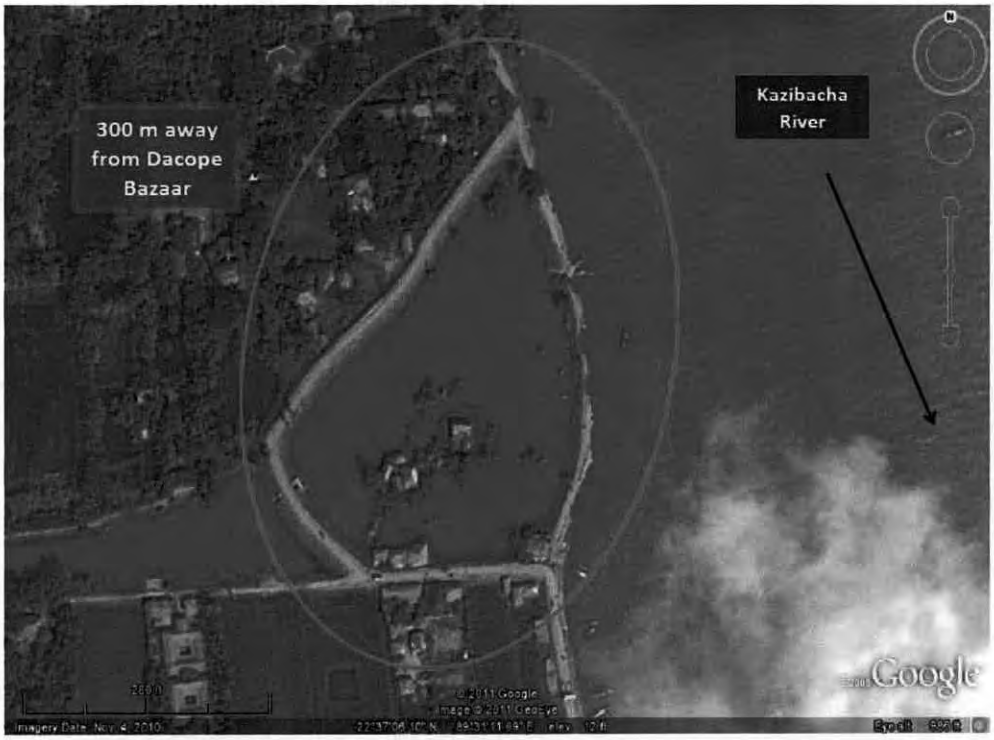


Figure 4-38: Vulnerable location along Z7606 near Dacope Bazar

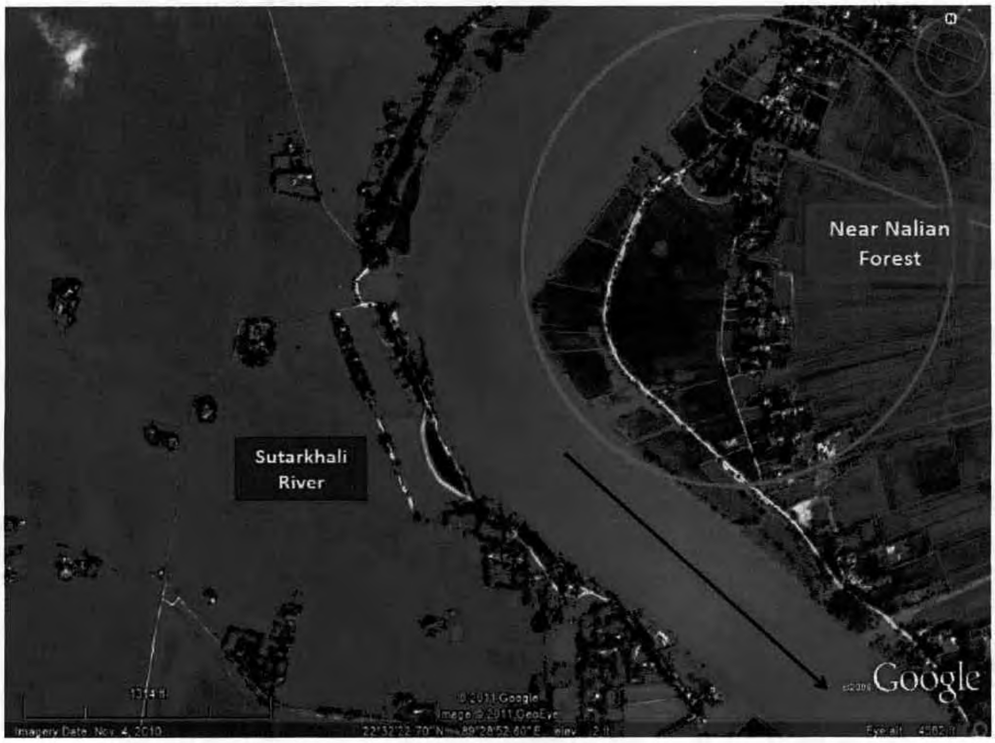


Figure 4-39: Vulnerable area of Z7606 near Nalian Forest

Figure 4-40: Water Board embankment acts as Zilla Road Z7606 near Nalian Forest

Zilla Road- Z7043

Zilla Road Z7043 is an important road connecting two Upazilas of Khulna i.e. Fultala and Dumuria. There are a lot of open spaces near the road, and the average height of the roadway embankment is very high (6.8 m MSL). Average traffic flow on the road is also high- 9741 AADT. Table 4.25 shows the basic characteristics of Z7043, and Table 4.26 shows the vulnerability of Z7043 to inundation at three selected points.

Table 4-25: Basic Data and Characteristics of Zilla Road Z7043

Road No.	Z7043				
Road Name	Fultala-Shahapur-Miximil-Dumuria Road				
Road Classification	Zilla Road				
Length (km)	28.8	Start	Dumuria	End	Phultala
Traffic (AADT)	9741	Bridges	1	Ferry	-
Average Width (m)	3.74	LRP	92	Probable Length of Damage (km)	0
Value of Ongoing Maintenance	2067.05 Lac BDT				

Table 4-26: Assessment of vulnerability of Z7043

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3
Z7043	28.8	Dumuria	Phultala	1. Bhairab Ch- 11314.0 Base- 2.95 IPCC- 4.206 EL- 7.54	2. Teka Heri Teli Geng Ch- 8000.0 Base- 2.07 IPCC- 2.995 EL- 6.7	3. Khal_P27 Ch- 3000.0 Base- 1.311 IPCC- 1.392 EL- 7.2
			BASE	2.95	2.07	1.311
			IPCC	4.206	2.995	1.392
			EL	7.54	6.7	7.2
			EL-BASE= X	↑ 4.59	↑ 4.63	↑ 5.889
			EL-IPCC = Y	↑ 3.334	↑ 3.705	↑ 5.808

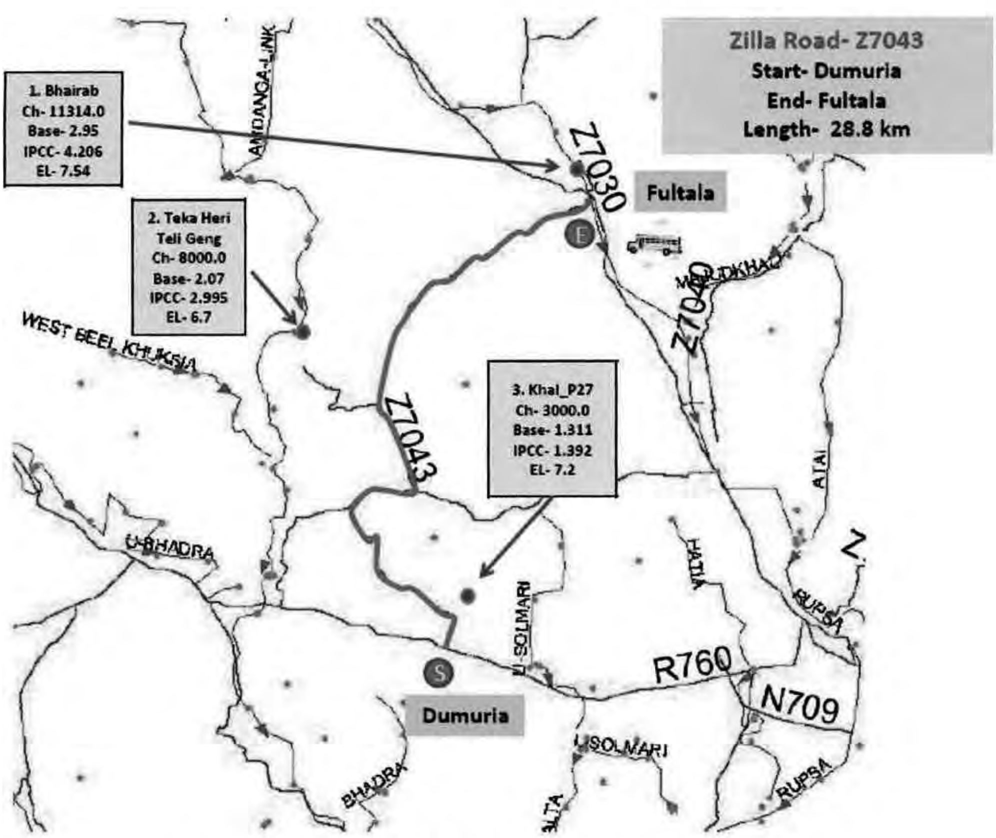


Figure 4-41: Vulnerability Map of Z7043

Figure 4.41 shows vulnerability map of Z7043. It shows that the average height of the roadway embankment is very high, and the road is safe with respect to inundation.

National Highway- N709

The National Highway N709 of the Roads and Highways Department generally known as Khulna City Bypass road is one of the important routes in the Khulna City area. It runs from Fultala to Rupsha (Kudir Battala). It has the important Khan Jahan Ali (R) Bridge along its alignment. Average height of the embankment of this road is comparatively high. Table 4.27 shows the basic characteristics of N709, and Table 4.28 shows the vulnerability of N709 to inundation at three selected points.

Table 4-27: Basic Data and Characteristics of National Highway N709

Road No.	N709				
Road Name	Khulna City By-Pass Road				
Road Classification	National Highway				
Length (km)	18	Start	Phultala	End	Rupsha (Kudir Battala)
Traffic (AADT)	7880	Bridges	2	Ferry	-
Average Width (m)	7.17	LRP	2	Probable Length of Damage (km)	0
Value of Ongoing Maintenance	21.98 Lac BDT				

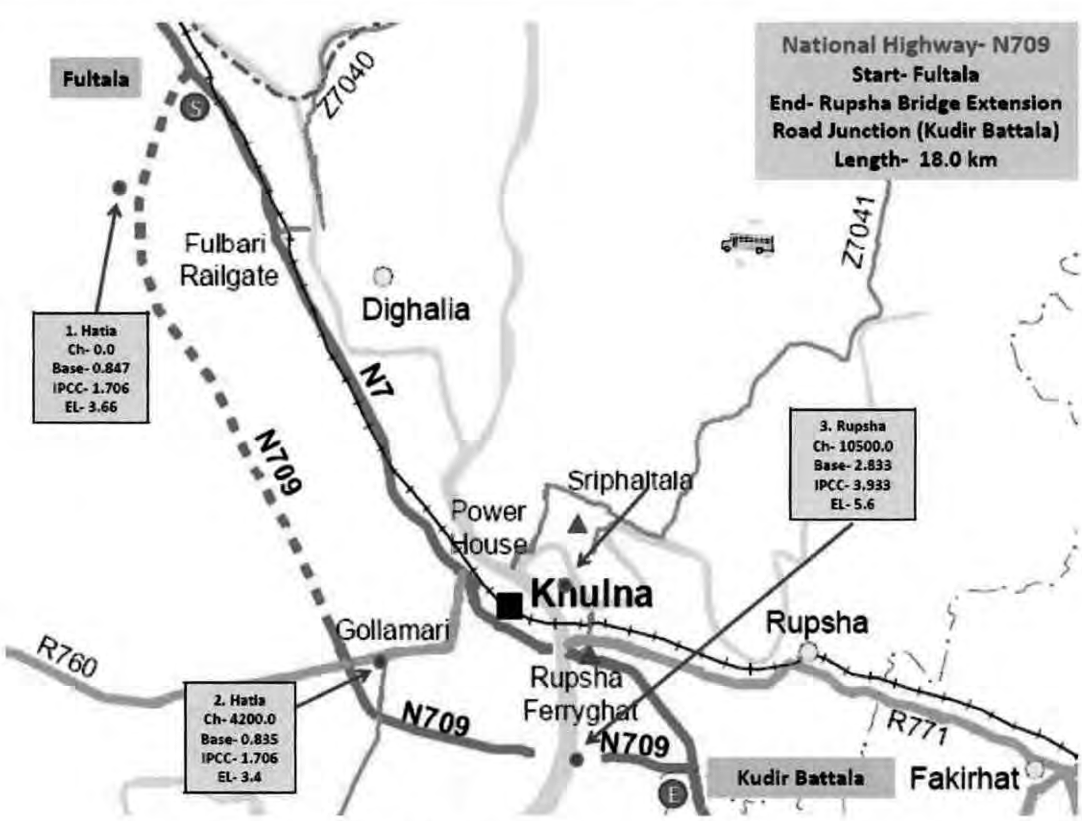


Figure 4-42: Vulnerability Map of N709

Table 4-28: Assessment of vulnerability of N709

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3
N709	18	Phultala	Rupsha (Kudir Battala)	1. Hatia Ch- 0.0 Base- 0.847 IPCC- 1.706 EL- 3.66	2. Hatia Ch- 4200.0 Base- 0.835 IPCC- 1.706 EL- 3.4	3. Rupsha Ch- 10500.0 Base- 2.833 IPCC- 3.933 EL- 5.6
			BASE	0.847	0.835	2.833
			IPCC	1.706	1.706	3.933
			EL	3.66	3.4	5.6
			EL-BASE= X	↑ 2.813	↑ 2.565	↑ 2.767
			EL-IPCC = Y	↑ 1.954	↑ 1.694	↑ 1.667

Figure 4.42 shows vulnerability map of N709. Due to its high elevation, this national highway is not susceptible to inundation according to the criteria set in this study.

Zilla Road- Z7040

The Zilla Road Z7040 connects the traffic from Khulna city to the Terokhada Upazila, having a length of 29.153 km; it runs from Fulbari Railgate to Terokhada Upazila. Middle portion of the road crosses through lowlands; the roadway at these locations also has low embankment height, thereby making them vulnerable to inundation. Table 4.29 shows the basic characteristics of Z7040, and Table 4.30 shows the vulnerability of Z7040 to inundation at eight selected points. Figure 4.43 shows the vulnerability map of Z7040. It shows that the roadway sections near Majd Khal and Nabaganga River are vulnerable to inundation. Figures 4.44 and 4.45 show vulnerable locations along Z7040.

Table 4-29: Basic Data and Characteristics of Zilla Road Z7040

Road No.	Z7040				
Road Name	Fulbari Railgate-Dighalia (Ngarghata)-Arua-Gazirhat-Terokhada Road				
Road Classification	Zilla Road				
Length (km)	29.153	Start	Fulbari Railgate (Kadarnath Rd)	End	Terokhada
Traffic (AADT)	2637	Bridges	10	Ferry	2
Average Width (m)	3.84	LRP	67	Probable Length of Damage (km)	5.5
Value of Ongoing Maintenance	1957.38 Lac BDT				

Table 4-30: Assessment of vulnerability of Z7040

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4
Z7040	29.153	Fulbari Railgate (Kadarnath Rd)	Terokhada	1. Bhairab Ch- 124000.0 Base- 2.941 IPCC- 4.201 EL- 6.7	2. Bhairab Ch- 123325.0 Base- 2.946 IPCC- 4.207 EL- 6.15	3. Majudkhal Ch- 6500.0 Base- 3.071 IPCC- 4.273 EL- 5.48	4. Majudkhal Ch- 3250.0 Base- 3.00 IPCC- 4.276 EL- 5.18
			BASE	2.941	2.946	3.071	3
			IPCC	4.201	4.207	4.273	4.276
			EL	6.7	6.15	5.48	5.18
			EL-BASE= X	3.759	3.204	2.409	2.18
			EL-IPCC = Y	2.499	1.943	1.207	0.904

Road	Length (km)	Start	End	Point ID5	Point ID6	Point ID7	Point ID8
Z7040	29.153	Fulbari Railgate (Kadarnath Rd)	Terokhada	5. Atai Ch- 3000.0 Base- 3.071 IPCC- 4.273 EL- 4.88	6. Nabaganga Ch- 26000.0 Base- 3.101 IPCC- 4.291 EL- 6.15	7. Polder-KNG3 Ch- 11288.0 Base- 1.175 IPCC- 1.718 EL- 6.09	8. Katakhali Ch- 18000.0 Base- 3.385 IPCC- 4.574 EL- 7.012
			BASE	3.071	3.101	1.175	3.385
			IPCC	4.273	4.291	1.718	4.574
			EL	4.88	6.15	6.09	7.012
			EL-BASE= X	1.809	3.049	4.915	3.627
			EL-IPCC = Y	0.607	1.859	4.372	2.438

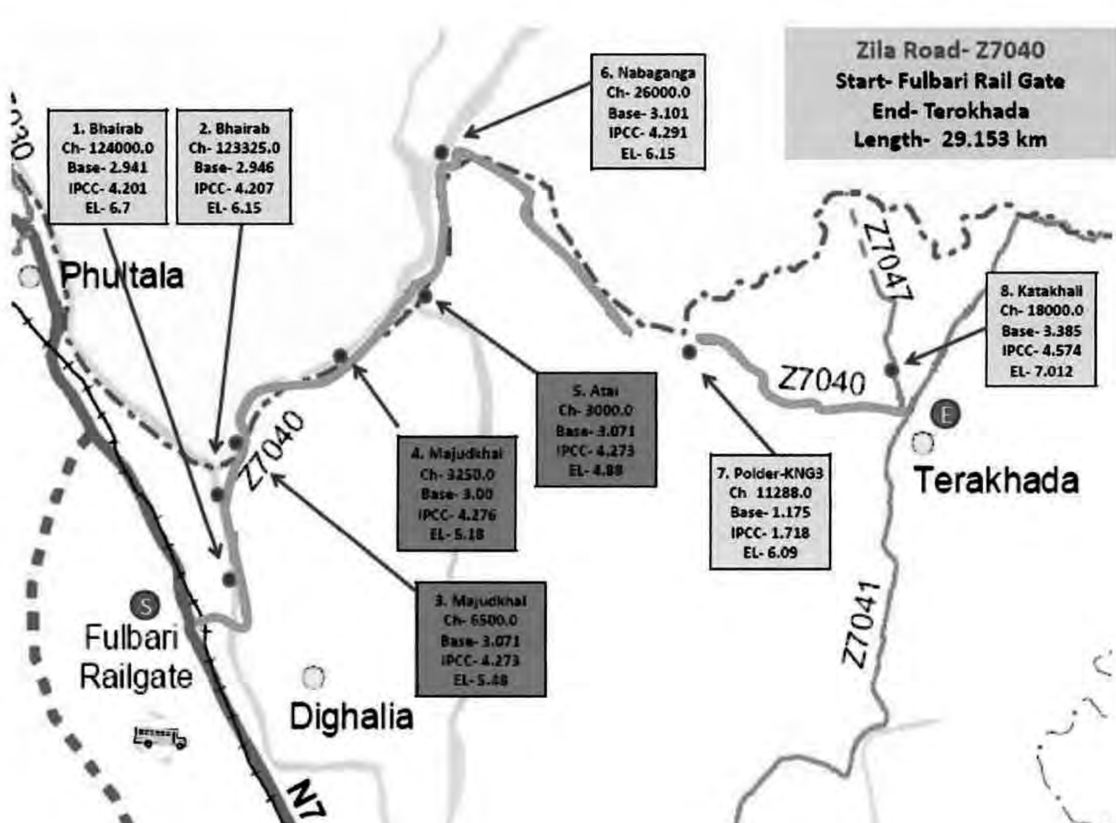


Figure 4-43: Vulnerability Map of Z7040

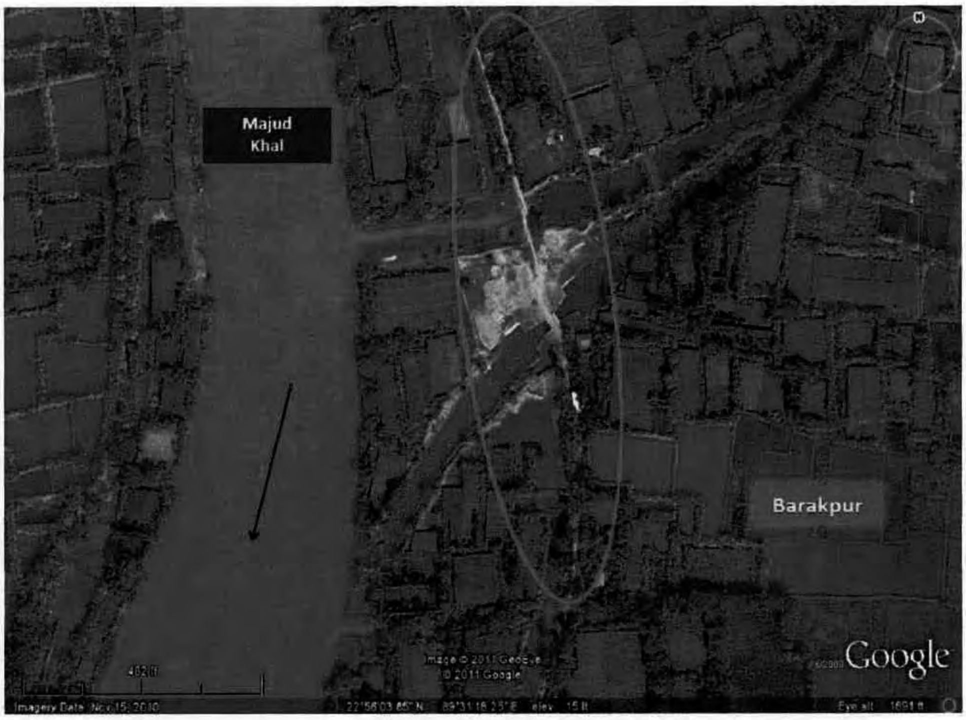


Figure 4-44: Vulnerable area of Z7040 near at Barakpur

Figure 4-45: Vulnerable area of Z7040 near Chandrapur

Zilla Road- Z7041

Zilla Road Z7041 (22.832 km) connects Khulna main city to the Terokhada via Srifaltala; road is located on the northern side of the city. River Atharobanki and Katakhali have direct impact on the roadway embankment during flood. Table 4.31 shows the basic characteristics of Z7041, and Table 4.33 shows the vulnerability of Z7041 to inundation at eight selected points.

Table 4-31: Basic Data and Characteristics of Zilla Road Z7041

Road No.	Z7041				
Road Name	Khulna (Rupsha)-Srifaltala-Terokhada Road				
Road Classification	Zilla Road				
Length (km)	22.832	Start	Khulna (Rupsha)	End	Terokhada
Traffic (AADT)	5052	Bridges	7	Ferry	-
Average Width (m)	5.10	LRP	55	Probable Length of Damage (km)	4.8
Value of Ongoing Maintenance	971.52 Lac BDT				

Table 4-32: Assessment of vulnerability of Z7041

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4
Z7041	22.832	Khulna (Rupsha)	Terokhada	1. Rupsa Ch- 4999.0 Base- 2.8477 IPCC- 4.054 EL- 6.7	2. Atharobanki Ch- 51350.0 Base- 2.87 IPCC- 4.065 EL- 6.4	3. Atharobanki Ch- 48000.0 Base- 2.874 IPCC- 4.069 EL- 6.09	4. Polder-KNG3 Ch- 21226.0 Base- 1.174 IPCC- 1.719 EL- 6.09
			BASE	2.8477	2.87	2.874	1.174
			IPCC	4.054	4.065	4.069	1.719
			EL	6.7	6.4	6.09	6.09
			EL-BASE= X	3.8523	3.53	3.216	4.916
			EL-IPCC = Y	2.646	2.335	2.021	4.371

Road	Length (km)	Start	End	Point ID5	Point ID6	Point ID7	Point ID8
Z7041	22.832	Khulna (Rupsha)	Terokhada	5. Atharobanki Ch- 36550.0 Base- 2.98 IPCC- 4.181 EL- 5.48	6. Atharobanki Ch- 33000.0 Base- 3.261 IPCC- 4.391 EL- 4.68	7. Katakhali Ch- 22500.0 Base- 3.326 IPCC- 4.492 EL- 4.57	8. Katakhali Ch- 18000.0 Base- 3.385 IPCC- 4.574 EL- 4.67
			BASE	2.98	3.261	3.326	3.385
			IPCC	4.181	4.391	4.492	4.574
			EL	5.48	4.68	4.57	4.67
			EL-BASE= X	2.5	1.419	1.244	1.285
			EL-IPCC = Y	1.299	0.289	0.078	0.096

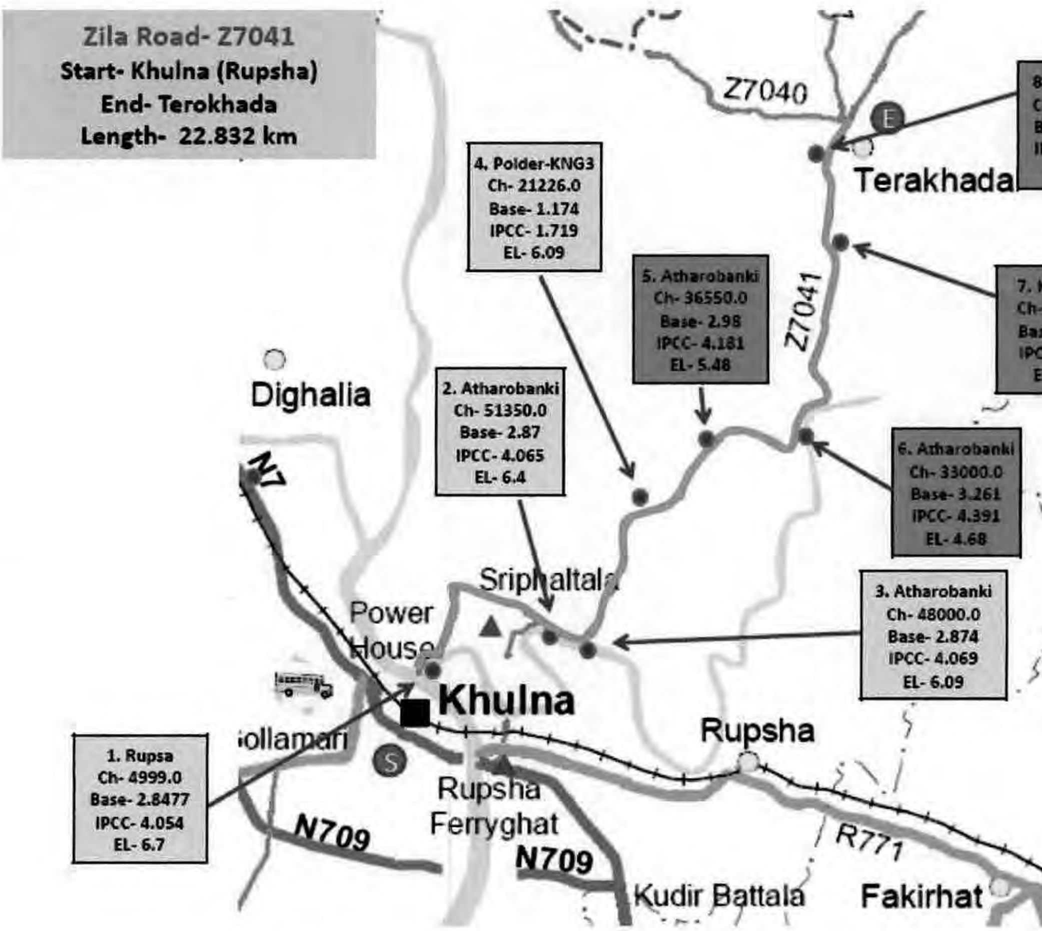


Figure 4-46: Vulnerability Map of Z7041

Figure 4.46 shows vulnerability map of Z7041. This figure and Table 4.32 shows that the roadway from Atharobanki (Ch. 36550.0) to Terakhada is more vulnerable to inundation due to existing lower elevation. From Khulna city up to Polder-KNG3 (Ch. 5135.), the road level is relatively high, and not susceptible to inundation. On the bank of River Atharobanki and Katakhali, large proportions of the road have been found to be vulnerable due to low height of the embankment. Figures 4.47 to 4.49 show vulnerable locations along Z7041.

Figure 4-47: Vulnerable area of Z7041 at Rupsha, Khulna

Figure 4-48: Vulnerable area of Z7041 at Ajaipur

Figure 4-49: Vulnerable area of Z7041 (due to low height embankment) at Sialli

4.2.3 STUDY AREA-3: BAGHERHAT

National Highway- N7 (Partial)

National Highway N7 (partial) connects Khulna with Mongla Road; it is 42.09 km long running from northern part of Khulna to the southern part port city Mongla, the entry point of Sundarban from Khulna. Traffic flow and growth of this road is very high. Table 4.33 shows the basic characteristics of N7 (partial), and Table 4.34 shows the vulnerability of N7 (partial) to inundation at four selected points.

Table 4-33: Basic Data and Characteristics of National Highway N7 (Partial)

Road No.	N7 (Partial)				
Road Name	Khulna-Mangla Road				
Road Classification	National Highway				
Length (km)	42.09	Start	Khulna	End	Mangla
Traffic (AADT)	9744	Bridges	-	Ferry	-
Average Width (m)	7.05	LRP	-	Probable Length of Damage (km)	1.5
Value of Ongoing Maintenance	9481.34 Lac BDT				

Table 4-34: Assessment of vulnerability of N7 (Partial)

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4
N7 (partial)	42.09	Khulna	Mangla	1. Rupsha Ch- 6500.0 Base- 2.844 IPCC- 4.034 EL- 6.09	2. Old Pussur Ch- 0.0 Base- 2.888 IPCC- 4.017 EL- 5.9	3. Daudkhali Ch- 8500.0 Base- 0.705 IPCC- 1.798 EL- 3.96	4. Mongla-Nulla Ch- 6625.0 Base- 2.543 IPCC- 3.676 EL- 4.87
			BASE	2.844	2.888	0.705	2.543
			IPCC	4.034	4.017	1.798	3.676
			EL	6.09	5.9	3.96	4.87
			EL-BASE= X	3.246	3.012	3.255	2.327
			EL-IPCC = Y	2.056	1.883	2.162	1.194

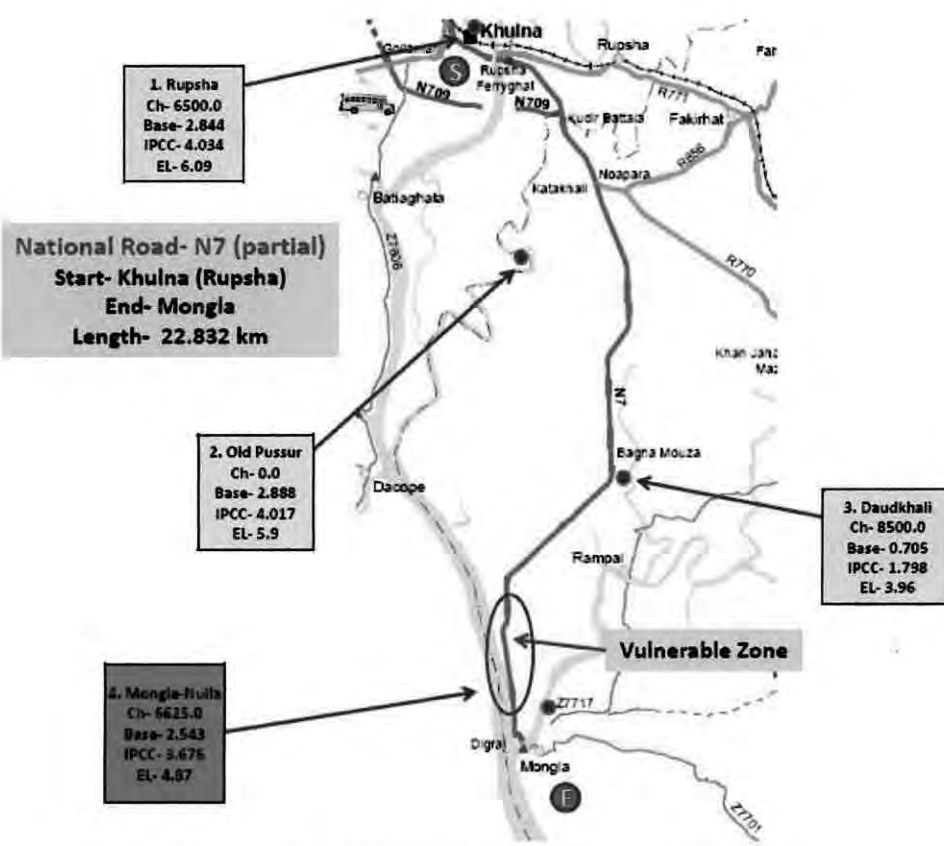


Figure 4-50: Vulnerability Map of N7 (Partial)

Figure 4.50 shows vulnerability map of N7 (partial). Except for a small portion near Mongla (about 1.5 km, see Fig. 4.50), the elevation of this highway is relatively high and is not susceptible to inundation. Figure 4.50 shows the vulnerable portion of the highway near Posssur river and the Mongla-Nulla river.

Figure 4-51: Vulnerable portion of N7 (partial) near Mongla port

Regional Highway R771

Regional Highway R771 connects Rupsha, Khulna with Khan Jahan Ali (R) Mazar, Bagerhat. Except Bahirab, the highway does not cross any major river. The highway has a relatively high elevation (6.2 m MSL). Table 4.35 shows the basic characteristics of R771, and Table 4.36 shows the vulnerability of R771 to inundation at four selected points.

Table 4-35: Basic Data and Characteristics of Regional Highway R771

Road No.	R771				
Road Name	Rupsha-Fakirhat-Bagerhat Road				
Road Classification	Regional Highway				
Length (km)	31.18	Start	Rupsha, Khulna	End	Khan Jahan Ali Majar
Traffic (AADT)	7013	Bridges	4	Ferry	-
Average Width (m)	3.44	LRP	70	Probable Length of Damage (km)	0
Value of Ongoing Maintenance	10.0 Lac BDT				

Table 4-36: Assessment of vulnerability of R771

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4
R771	31.18	Rupsha, Khulna	Khan Jahan Ali Majar	1. Atharobanki Ch- 54700.0 Base- 2.853 IPCC- 4.052 EL- 6.70	2. Atharobanki Ch- 44250.0 Base- 2.89 IPCC- 4.094 EL- 6.10	3. Bhairab Ch- 4250.0 Base- 2.743 IPCC- 3.912 EL- 6.40	4. Poylahara Ch- 10000.0 Base- 2.523 IPCC- 3.676 EL- 5.48
			BASE	2.853	2.89	2.743	2.523
			IPCC	4.052	4.094	3.912	3.676
			EL	6.7	6.1	6.4	5.48
			EL-BASE= X	↑ 3.847	↑ 3.21	↑ 3.657	↑ 2.957
			EL-IPCC = Y	↑ 2.648	↑ 2.006	↑ 2.488	↑ 1.804

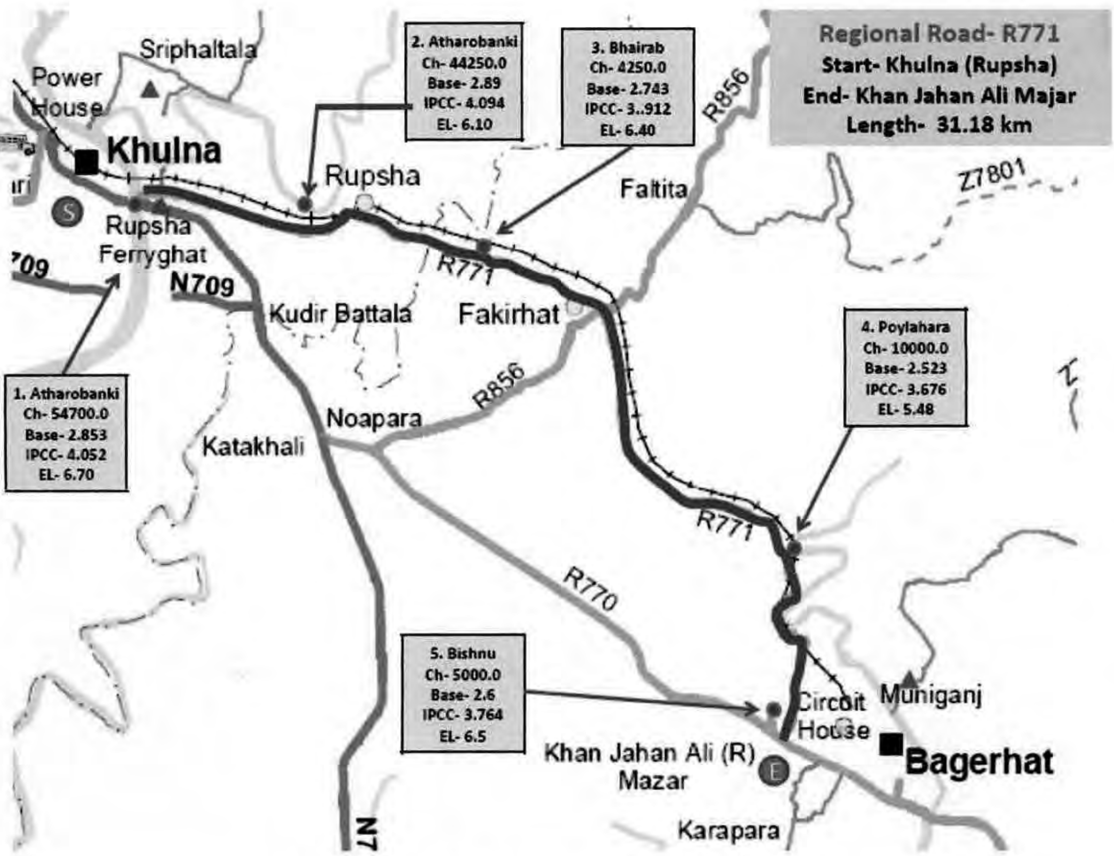


Figure 4-52: Vulnerability Map of R771

Figure 4.52 shows vulnerability map of R771. It shows that high elevation of the highway (6.2 m MSL) makes is safe against inundation or over-topping.

Regional Highway R856

Regional Highway R856 connects Noapara/Katakhali with Mollarhat; it has a length of 30.55 km, and average annual daily traffic at 7153. Basically, this regional highway connects two growth centres- Noapara and Mollarhat. Table 4.37 shows the basic characteristics of R856, and Table 4.38 shows the vulnerability of R856 to inundation at four selected points.

Table 4-37: Basic Data and Characteristics of Regional Highway R856

Road No.	R856				
Road Name	Noapara (Katakhali)-Fakirhat-Mollarhat Road				
Road Classification	Regional Highway				
Length (km)	30.55	Start	Katakhali	End	Mollarhat
Traffic (AADT)	7153	Bridges	36	Ferry	-
Average Width (m)	7.23	LRP	98	Probable Length of Damage (km)	3.8
Value of Ongoing Maintenance	96.36 Lac BDT				

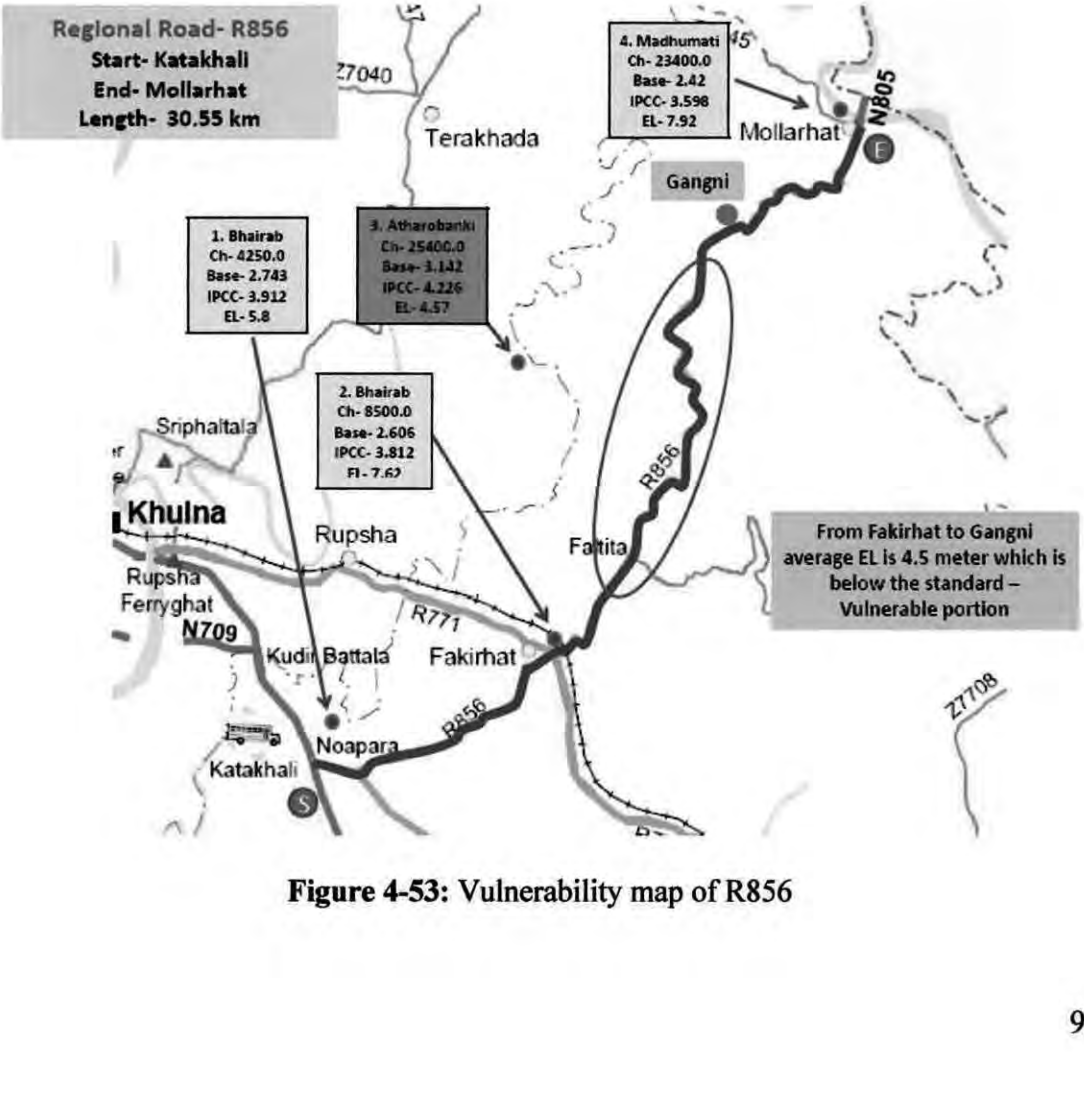


Figure 4-53: Vulnerability map of R856

Table 4-38: Assessment of vulnerability of R856

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4
R856	30.55	Katakhali	Mollarhat	1. Bhairab Ch- 4250.0 Base- 2.743 IPCC- 3.912 EL- 5.8	2. Bhairab Ch- 8500.0 Base- 2.606 IPCC- 3.812 EL- 7.62	3. Atharobanki Ch- 25400.0 Base- 3.142 IPCC- 4.226 EL- 4.57	4. Madhumati Ch- 23400.0 Base- 2.42 IPCC- 3.598 EL- 7.92
			BASE	2.743	2.606	3.142	2.42
			IPCC	3.912	3.812	4.226	3.598
			EL	5.8	7.62	4.57	7.92
			EL-BASE= X	3.057	5.014	1.428	5.5
			EL-IPCC = Y	1.888	3.808	0.344	4.322

Figure 4.53 shows vulnerable map of R856. It shows that the elevation of the middle portion of the road from Fakirhat to Gangni is relatively low (only 4.5 m MSL), and therefore susceptible to inundation (Table 4.38). Figure 4.54 shows vulnerable portion of the road on a Google image.

Figure 4-54: Vulnerable portion of R856 near Fakirhat

Zilla Road Z7701

The Z7701 road from Mongla to Morelganj is an important arterial road in terms of traffic and vehicle demand. The length of the road is about 26 km and has 12 bridges along its length. Table 4.39 shows the basic characteristics of Z7701, and Table 4.40

shows the vulnerability of Z7701 to inundation at four selected points. Figure 4.55 shows the vulnerability map of Z7701. Due to relatively high elevation of the existing road, it is not susceptible to inundation.

Table 4-39: Basic Data and Characteristics of Zilla Road Z7701

Road No.	Z7701				
Road Name	Morelganj (CARE Bazar) -Mongla Road				
Road Classification	Zilla Road				
Length (km)	26	Start	Mongla	End	Morelganj (Care Bazar)
Traffic (AADT)	2447	Bridges	12	Ferry	-
Average Width (m)	4.28	LRP	51	Probable Length of Damage (km)	0
Value of Ongoing Maintenance	340.00 Lac BDT				

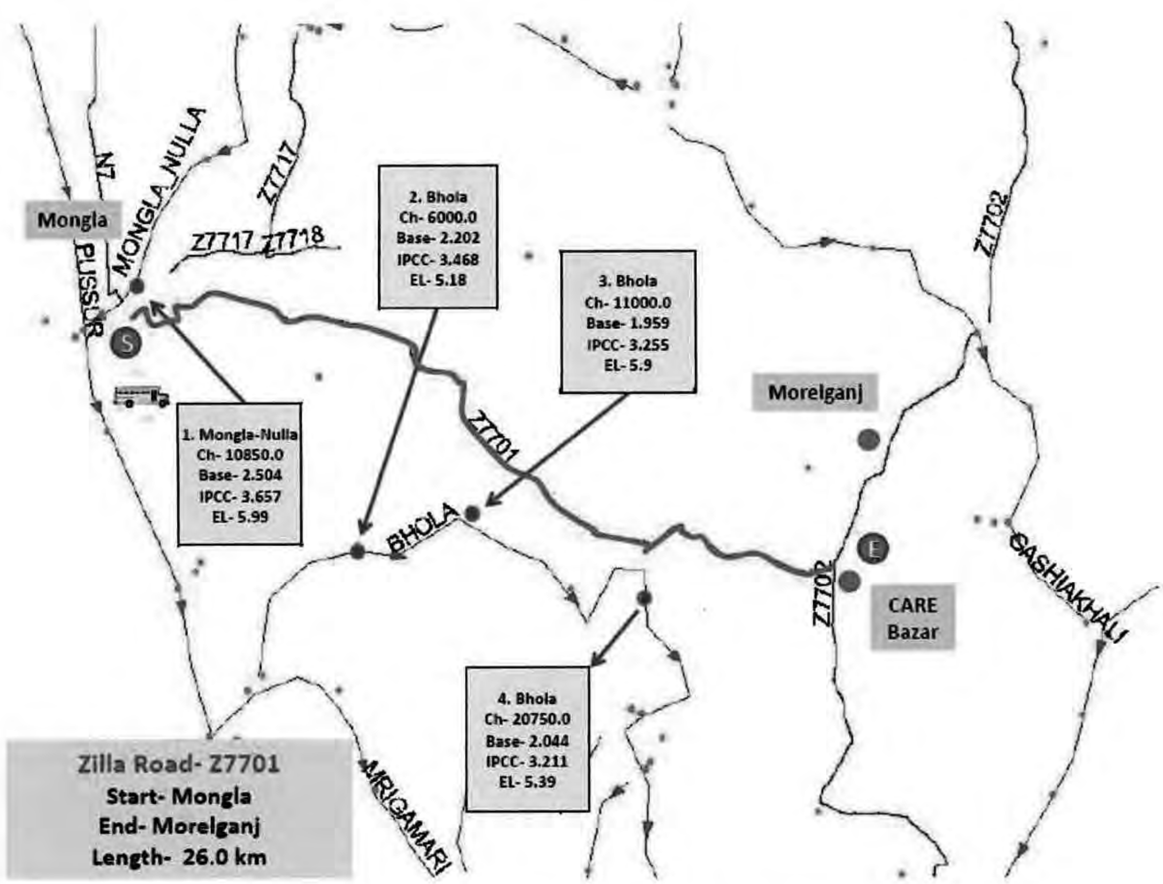


Figure 4-55: Vulnerability map of Z7701

Table 4-40: Assessment of vulnerability of Z7701

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4
Z7701	26.0	Mongla	Morelganj (Care Bazar)	1. Mongla-Nulla Ch- 10850.0 Base- 2.504 IPCC- 3.657 EL- 5.99	2. Bhola Ch- 6000.0 Base- 2.202 IPCC- 3.468 EL- 5.18	3. Bhola Ch- 11000.0 Base- 1.959 IPCC- 3.255 EL- 5.9	4. Bhola Ch- 20750.0 Base- 2.044 IPCC- 3.211 EL- 5.39
			BASE	2.504	2.202	1.959	2.044
			IPCC	3.657	3.468	3.255	3.211
			EL	5.99	5.18	5.9	5.39
			EL-BASE= X	↑ 3.486	↑ 2.978	↑ 3.941	↑ 3.346
			EL-IPCC = Y	↑ 2.333	↑ 1.712	↑ 2.645	↑ 2.179

Zilla Road- Z7702

Zilla Road Z7702 is one of the longest RHD roads in the Bagherhat district, but traffic flow through this road is much less compared to that in others (AADT is 2074). It connects Signboard to the Upazila Morelganj, remote place Sharankhola and Rainda-Bogi, close to Sundarbans. The Sidr storm imparted a lot of damage to the villages of Sharankhola. Table 4.41 shows the basic characteristics of Z7702, and Table 4.42 shows the vulnerability of Z7702 to inundation at eight selected points.

Table 4-41: Basic Data and Characteristics of Zilla Road Z7702

Road No.	Z7702					
Road Name	Signboard-Morelganj-Sharankhola-Rainda-Bogi Road					
Road Classification	Zilla Road					
Length (km)	56.62	Start	Sign Board		End	Bogi
Traffic (AADT)	2074	Bridges	29		Ferry	-
Average Width (m)	3.6	LRP	120	Probable Length of Damage (km)		5
Value of Ongoing Maintenance	1920.65 Lac BDT					

Figure 4.56 shows vulnerability map of Z7702. A number of turbulent rivers like Baleswar, Ghasiakhali and Bhairab are present in the area and pose a threat to the roadway embankment. After Sarankhola Bazar, a portion of road is very vulnerable up to Bogi. Basically this is a strip of land surrounded by Baleswar and Bhola River. A 5 km of portion (Sharankhola Bazar to Bogi) of road has to be raised almost 1.5 m from the existing crest level. Figures 4.57 and 4.58 show vulnerable locations along Z7702.

Table 4-42: Assessment of vulnerability of Z7702

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4
Z7702	56.62	Sign Board	Bogi	1. Bhairab Ch- 5250.0 Base- 2.406 IPCC- 3.707 EL- 6.44	2. Baleswar Ch- 59336.0 Base- 2.142 IPCC- 3.992 EL- 6.09	3. Khal_P37 Ch- 12000.0 Base- 1.324 IPCC- 1.786 EL- 5.18	4. Gashiakhali Ch- 13500.0 Base- 2.325 IPCC- 3.482 EL- 4.57
			BASE	2.406	2.142	1.324	2.325
			IPCC	3.707	3.992	1.786	3.482
			EL	6.44	6.09	5.18	4.57
			EL-BASE= X	4.034	3.948	3.856	2.245
			EL-IPCC = Y	2.733	2.098	3.394	1.088

Road	Length (km)	Start	End	Point ID5	Point ID6	Point ID7	Point ID8
Z7702	56.62	Sign Board	Bogi	5. Khal_P35_2R Ch- 8000.0 Base- 1.542 IPCC- 1.926 EL- 3.96	6. Khal_P35_1 Ch- 5000.0 Base- 1.607 IPCC- 1.933 EL- 6.4	7. Baleswar Ch- 108000.0 Base- 2.164 IPCC- 3.367 EL- 5.79	8. Baleswar Ch- 114380.0 Base- 2.151 IPCC- 3.406 EL- 4.87
			BASE	1.542	1.607	2.164	2.151
			IPCC	1.926	1.933	3.367	3.406
			EL	3.96	6.4	5.79	4.87
			EL-BASE= X	2.418	4.793	3.626	2.719
			EL-IPCC = Y	2.034	4.467	2.423	1.464

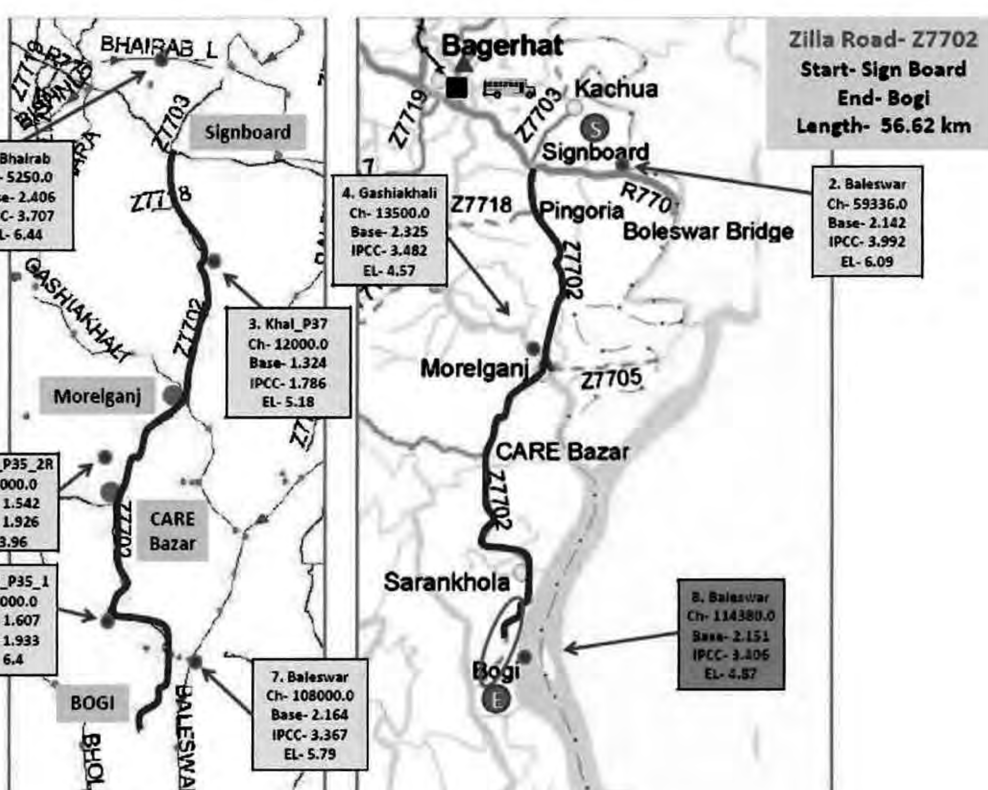


Figure 4-56: Vulnerability Map of Z7702

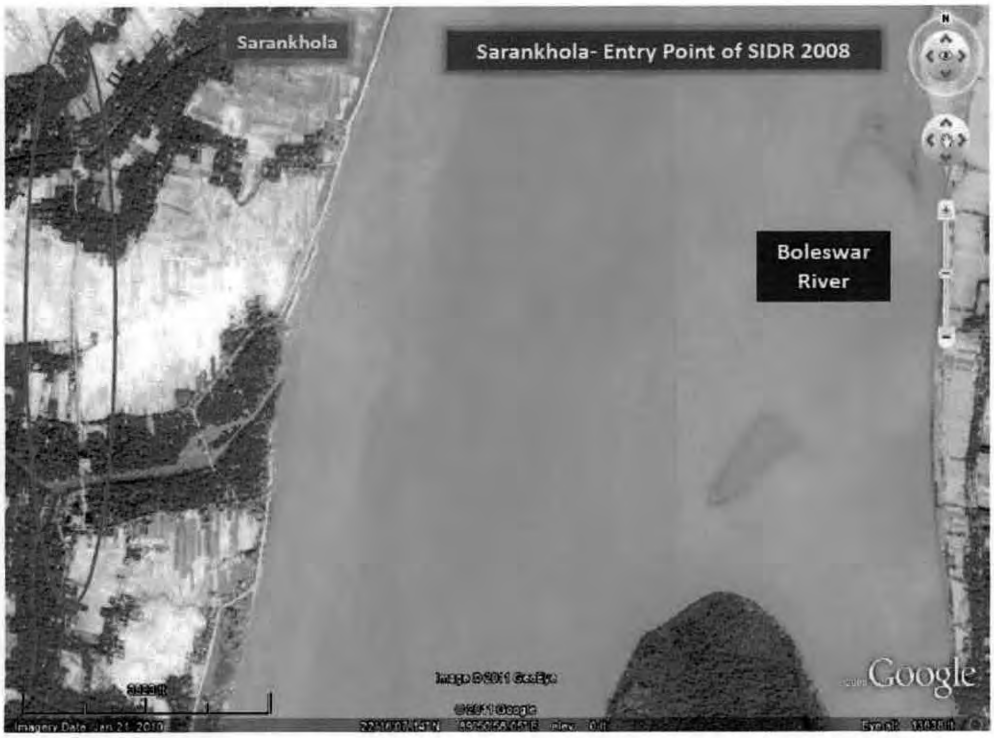


Figure 4-57: Vulnerable location of Z7702 near Sharankhola Bazar beside Baleswar river

Figure 4-58: Vulnerable location of Z7702 near Sharankhola Bazar

Regional Road R770

Noapara-Bagherhat-Pirojpur (i.e., R770) road is an important road which bridges Pirojpur, Khulna and Bagherhat. It connects two important districts. It crosses over Balwesar river by Balwesar Bridge. Table 4.43 shows the basic characteristics of R770, and Table 4.44 shows the vulnerability of R770 to inundation at six selected points.

Table 4-43: Basic Data and Characteristics of Regional Highway R770

Road No.	R770				
Road Name	Noapara-Bagerhat-Pirojpur Road				
Road Classification	Regional Highway				
Length (km)	42.74	Start	Noapara	End	Pirojpur (CO Office Mor)
Traffic (AADT)	5727	Bridges	22	Ferry	-
Average Width (m)	5.73	LRP	119	Probable Length of Damage (km)	1.2
Value of Ongoing Maintenance	96.22 Lac BDT				

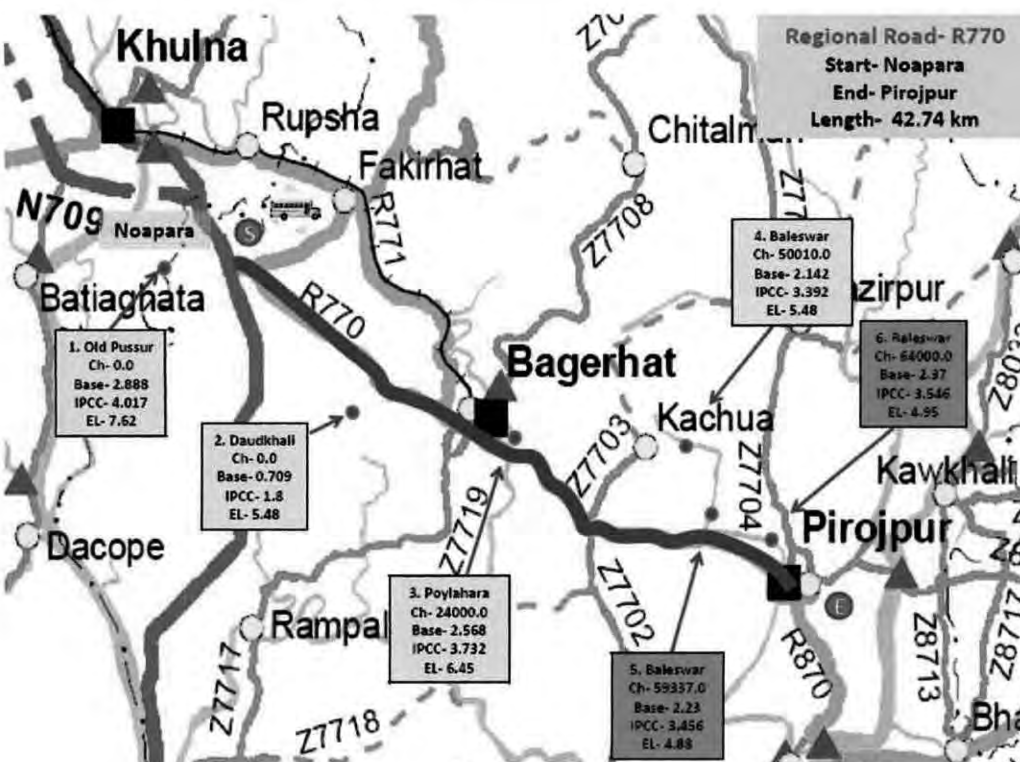


Figure 4-59: Vulnerability Map of R770

Table 4-44: Vulnerability map of R770

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4	Point ID5	Point ID6
R770	42.74	Noapara	Pirojpur (CO Office Mor)	1. Old Pussur Ch- 0.0 Base- 2.888 IPCC- 4.017 EL- 7.62	2. Daudkhali Ch- 0.0 Base- 0.709 IPCC- 1.8 EL- 5.48	3. Poylahara Ch- 24000.0 Base- 2.568 IPCC- 3.732 EL- 6.45	4. Baleswar Ch- 50010.0 Base- 2.142 IPCC- 3.392 EL- 5.48	5. Baleswar Ch- 59337.0 Base- 2.23 IPCC- 3.456 EL- 4.88	6. Baleswar Ch- 64000.0 Base- 2.37 IPCC- 3.546 EL- 4.95
			BASE	2.888	0.709	2.568	2.142	2.23	2.37
			IPCC	4.017	1.8	3.732	3.392	3.456	3.546
			EL	7.62	5.48	6.45	5.48	4.88	4.95
			EL-BASE= X	4.732	4.771	3.882	3.338	2.65	2.58
			EL-IPCC = Y	3.603	3.68	2.718	2.088	1.424	1.404

Figure 4.59 shows the vulnerability map of R770. Except of a small portion (about 1.2 km), the crest level of the existing road is at least 2m above both the base year (1998) and IPCC 2080 water level. A portion of the road before its entry to the Pirojpur city (crossing Baleswar bridge) has a relatively low elevation, and hence susceptible to inundation under IPCC 2080 scenario. Figure 4.60 shows vulnerable portion of R770.

Figure 4-60: Vulnerable portion of R770 near Baleswar Bridge

Zila Road Z7708

Zilla Road Z7708 starts from Muniganj ferry ghat and connects the Chitolmari Upazila; it is about 21 km long. This road has specific economic importance due to massive cultivation in the surrounding areas. Table 4.45 shows the basic characteristics of Z7708, and Table 4.46 shows the vulnerability of Z7708 to inundation at four selected points.

Table 4-45: Basic Data and Characteristics of Zilla Road Z7708

Road No.	Z7708					
Road Name	Bagerhat-Chitolmari Road					
Road Classification	Zilla Road					
Length (km)	21.531	Start	Muniganj		End	Chitalmari
Traffic (AADT)	7080	Bridges	21		Ferry	-
Average Width (m)	3.71	LRP	68	Probable Length of Damage (km)		1
Value of Ongoing Maintenance	519.12 Lac BDT					

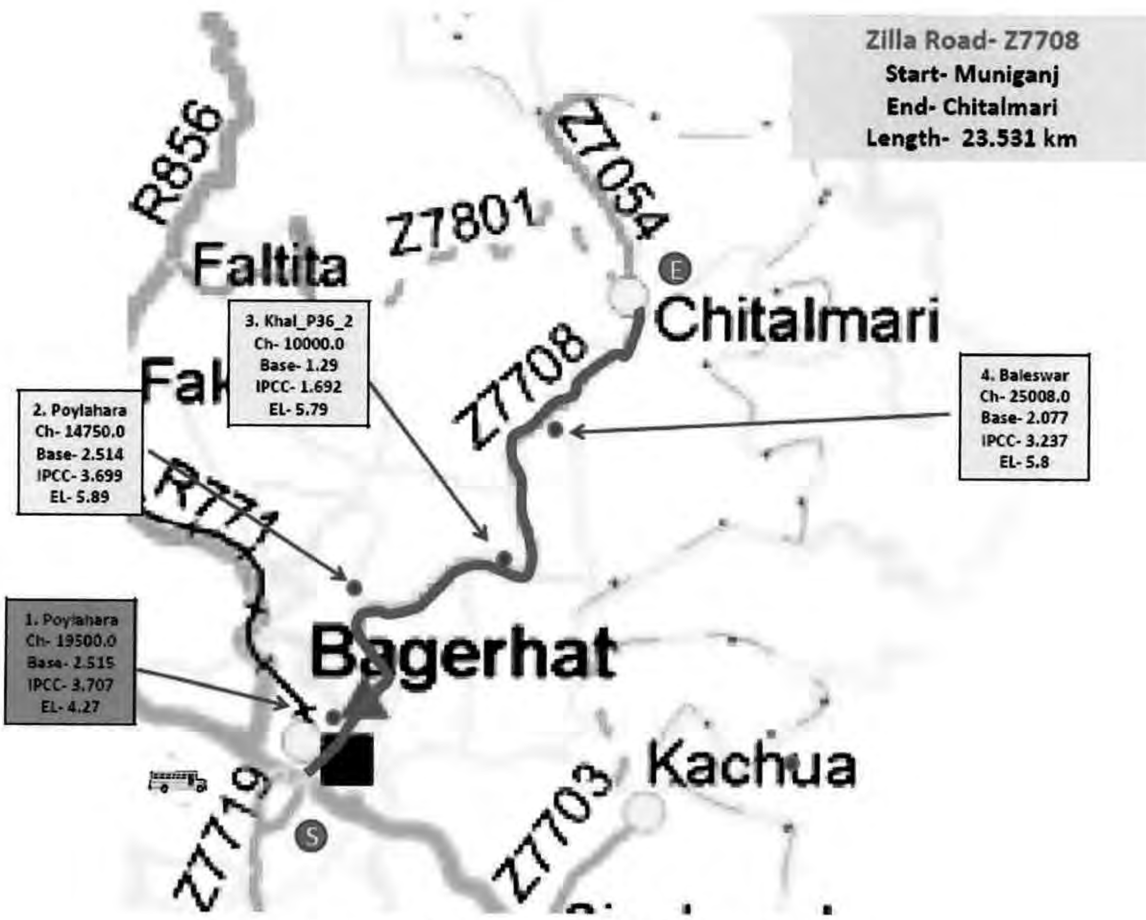


Figure 4-61: Vulnerability Map of Z7708

Table 4-46: Assessment of vulnerability of Z7708

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4
Z7708	21.531	Muniganj	Chitalmari	1. Poylahara Ch- 19500.0 Base- 2.515 IPCC- 3.707 EL- 4.27	2. Poylahara Ch- 14750.0 Base- 2.514 IPCC- 3.699 EL- 5.89	3. Khal_P36_2 Ch- 10000.0 Base- 1.29 IPCC- 1.692 EL- 5.79	4. Baleswar Ch- 25008.0 Base- 2.077 IPCC- 3.237 EL- 5.8
			BASE	2.515	2.514	1.29	2.077
			IPCC	3.707	3.699	1.692	3.237
			EL	4.27	5.89	5.79	5.8
			EL-BASE= X	1.755	3.376	4.5	3.723
			EL-IPCC = Y	0.563	2.191	4.098	2.563

As shown in Fig. 4.61 and Table 4.46, a small portion of the road after Muniganj ferry ghat has been found to be vulnerable to inundation considering IPCC 2080 scenario. Difference between road crest level and IPCC 2080 predicted water level has been found to be +0.563 m. Figure 4.62 shows vulnerable portion of Z7708

Figure 4-62: Vulnerable portion of Z7708 near Muniganj Ferry Ghat

__Zilla Road Z7717__

The Zilla Road Z7717 from Bagherhat to Mongla is an important road segment for direct communication between Dhaka and Mongla. Average road embankment height is 6.8 m MSL, which is moderately high to withstand flood surge and storms. Table 4.47 shows the basic characteristics of Z7717, and Table 4.48 shows the vulnerability of Z7717 to inundation at six selected points.

Table 4-47: Basic Data and Characteristics of Zilla Road Z7717

Road No.	Z7717				
Road Name	Bagerhat-Rampal -Mongla Road				
Road Classification	Zilla Road				
Length (km)	33.8	Start	Bagherhat	End	Mongla
Traffic (AADT)	7714	Bridges	17	Ferry	1
Average Width (m)	3.67	LRP	79	Probable Length of Damage (km)	1.5
Value of Ongoing Maintenance	947.17 Lac BDT				

Table 4-48: Assessment of vulnerability of Z7717

Road	Length (km)	Start	End	Point ID1	Point ID2	Point ID3	Point ID4	Point ID5	Point ID6
Z7717	33.8	Bagherhat	Mongla	1. Bishnu Ch- 0.0 Base- 2.568 IPCC- 3.732 EL- 8.14	2. Bishnu Ch- 5000.0 Base- 2.597 IPCC- 3.764 EL- 7.62	3. Khal_P35_3 Ch- 0.0 Base- 1.55 IPCC- 1.872 EL- 7.31	4. Daudkhali Ch- 18000.0 Base- 2.632 IPCC- 3.743 EL- 7.01	5. Mongla-Nulla Ch- 0.0 Base- 2.589 IPCC- 3.719 EL- 6.95	6. Mongla-Nulla Ch- 10850.0 Base- 2.504 IPCC- 3.716 EL- 4.87
			BASE	2.568	2.597	1.55	2.632	2.589	2.504
			IPCC	3.732	3.764	1.872	3.743	3.719	3.716
			EL	8.14	7.62	7.31	7.01	6.95	4.87
			EL-BASE= X	5.572	5.023	5.76	4.378	4.361	2.366
			EL-IPCC = Y	4.408	3.856	5.438	3.267	3.231	1.154

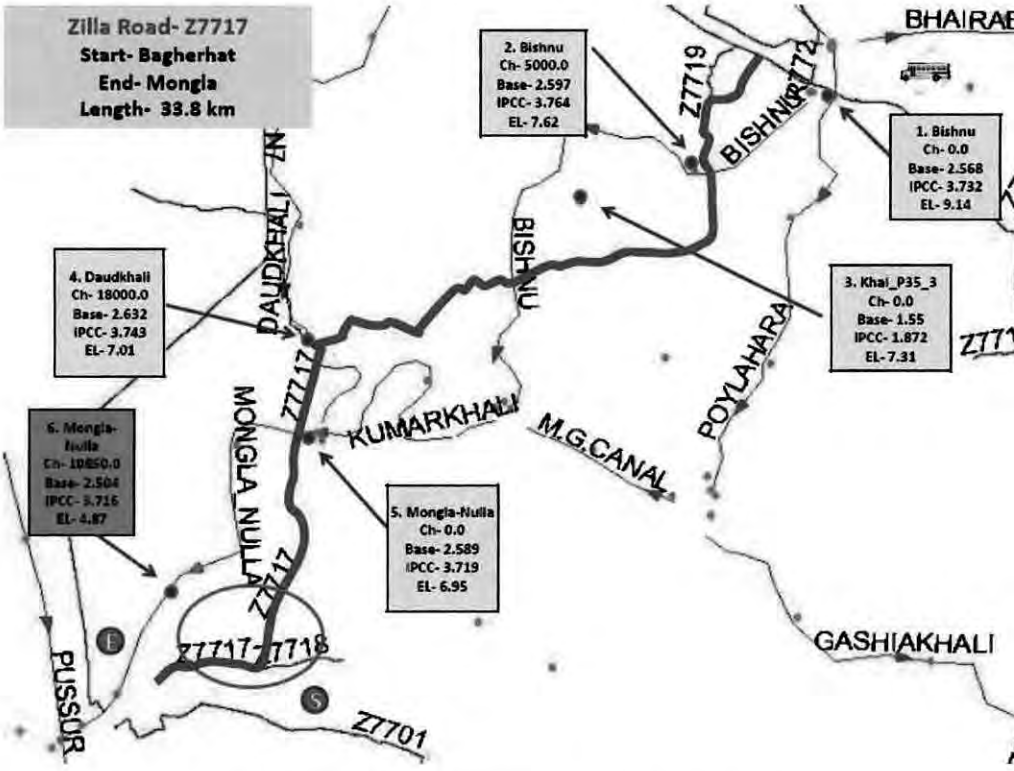


Figure 4-63: Vulnerability Map of Z7717

Figure 4.63 is the vulnerability map of Z7717, which shows a series of rivers and canals crossing the road, e.g., Possur, Nulla, Kumarkhali, Bishnu and Bhairab. Near Mongla, the road segment has been found to be vulnerable to inundation due to low embankment height (in comparison to IPCC 2080 scenario). Figure 4.64 shows vulnerable area of Z7717.

Figure 4-64: Vulnerable area of Z7717 near Mongla Port

4.3 SUMMARY OF VULNERABILITY ASSESSMENT

In this Chapter, vulnerability to inundation of selected roads in three coastal districts of Satkhira, Khulna and Bagherhat has been assessed. Table 4.49 shows a summary of the assessment. It shows length of roads "at risk" of inundation (in accordance with criteria described in Table 3.4), i.e., roads for which the difference between existing road crest level and the water level is between zero and 1 m. It should be noted that most of the roads for which existing road crest level (reported in this report) were below the 1998 flood water level (i.e., roads under "very risky" category), have been or are being rehabilitated by increasing embankment height.

Table 4-49: Summarized Results of Research Study

District	Length of Road Considered for Assessment (km)	Present Vulnerability (Considering 1998 Flood Water Level)		Future Vulnerability (Considering IPCC 2080 Predicted Water Level)	
		Km "At Risk"	Percentage	Km "At Risk"	Percentage
Satkhira	326.12	50.1	15.4	74.3	22.8
Khulna	151.84	16.3	10.7	30.8	20.3
Bagherhat	284.51	8.0	2.8	14.0	4.9
Total	**762.47**	**74.4**	**9.6**	**103.3**	**16.0**

"At Risk" indicates that the difference between present road crest level and water level is between 0 and 1m

Table 4.49 shows that among the roads considered, those in Satkhira are most vulnerable to inundation; on the other hand those in Bagerhat are least vulnerable. For example, over 15 percent roads at Satkhira are "at risk" of inundation considering 1998 (base year) flood water level, while about 23 percent are "at risk" considering 2080 predicted water level. The corresponding figures are about 3 percent and 5 percent, respectively, for Bagerhat. Overall, about 10 percent length of the roads considered in this study have been found to be "at risk" of inundation under baseline condition, while 16 percent are "at risk" under IPCC 2080 predicted water level.

CHAPTER 5
ADAPTATION MEASURES AND RHD MASTER PLAN AND NAPA

5.1 GENERAL

This Chapter examines recent research on climate change impacts and adaptation in the Bangladesh transportation sector, recognizing that this represents a relatively new field of study. An overview of potential impacts of climate change on transportation infrastructure and operations is followed by an examination of adaptation issues related to design and construction, information systems, and the need for a more resilient and sustainable transportation system. This Chapter also presents a brief discussion on the RHD Master Plan and NAPA.

5.2 ADAPTATION IN THE TRANSPORTATION SECTOR

The Bangladesh transportation sector has initiated limited adaptation measures to accommodate climate and weather variability. Many of these responses, intended to protect infrastructure, maintain mobility and ensure safety, involve significant expenditures but often do not bring about the desired benefits. Transportation systems, however, represent long-term investments that cannot be easily relocated, redesigned or reconstructed. Thus, there is a need to be forward looking and to consider not just our recent past, but also our near and longer term future. Under a changed climate, the nature and range of adaptive measures would likely change, with costs increasing in some areas and decreasing in others.

Current literature suggests that the risks associated with climate change and related impacts could be manageable, with appropriate forward planning. Nevertheless, at this time, there is little evidence that climate change is being factored into transportation decisions. The following discussion provides examples of current practices, innovations and potential adaptations that may reduce vulnerability related to climate change. The discussion focuses mainly on planned, rather than reactive, responses.

5.2.1 Design and Construction Standards and Practices

Weather sensitivities are reflected in design and construction standards and protocols. No matter what the form of infrastructure, new or existing, the transportation planning process should consider the probable effects of climate change, potentially building in more resilience to weather and climate. For coastal areas threatened by sea level rise and storm surges, adaptations may include relocation of facilities and redesigning and/or retrofitting structures with appropriate protection. In many of the cases, a one-meter rise in sea level has to be incorporated into the design of the bridges to reduce the potential effect of global warming over the estimated 100-year life of the bridge. For asphalt-surfaced facilities, such as roads and highways, temperature variations have to be considered in the selection of asphalt cements (and asphalt emulsions for surface-treated roads). The intent is to minimize both thermal cracking under cold temperatures and traffic-associated rutting under hot temperatures. To accommodate warmer summers in northern and southern Bangladesh, more expensive asphalt cements may be required, because materials used in roadways have a limited tolerance to heat, and the stress is exacerbated by the length of time temperatures are elevated. Although there may be associated costs, this could be accommodated at the time of construction or reconstruction. Both the full effects of climate change and the service life of many forms of transportation infrastructure will be realized over decades, rather than years. It is therefore important that applied scientific research be considered to help ensure that infrastructure that is replaced or retrofitted realizes its full service life.

5.2.2 Information Systems

Transportation managers hardly use advisory, control and treatment strategies to mitigate environmental impacts on roadways in Bangladesh. Each of these requires detailed site-specific information, often in real time. Information on atmospheric and other physical conditions may be integrated with Intelligent Transport Systems (ITS), such as automated traffic control and traveler-advisory systems, to address transportation challenges. Throughout the developed world, governments are investing hundreds of millions of dollars in ITS, with a view to improving mobility and safety and also reducing maintenance costs. One example of a weather-specific information system is ARWIS (Advanced Road Weather Information Systems), which is used primarily for winter-maintenance decisions in Canada. From a climate change perspective, there is a need to help steer the development and implementation of information technologies so that mobility and safety benefits will be maximized under future, as well as current, conditions.

5.2.3 Shifts to More Resilient and Sustainable Systems

There is increasing support for moving toward a more sustainable transportation system in Bangladesh, one that would add environment and equity to existing priorities of efficiency and safety. Fortunately, many initiatives that are consistent with sustainability principles not only facilitate the reduction of greenhouse gas emissions, but also increase resilience to potential climate change impacts. These may include the adoption of selected new technologies and best-management practices, as well as changes in travel patterns that reduce exposure to risk. For personal mobility, promising examples include encouraging information-sector employees to work from home (tele-work); changing land-use patterns to shorten commutes and increase accessibility to goods and services; and providing financial incentives to use transport modes that are inherently safer and more reliable, even in the face of a changing climate.

5.2.4 Knowledge Gaps and Research Needs

Despite considerable work examining climate change impacts and adaptation over the past two decades, relatively little attention has been given to built infrastructure and engineered systems, including transportation. This is reflected in the recent Third Assessment Report of the Intergovernmental Panel on Climate Change, where less than one page of the vulnerabilities, impacts and adaptations report is devoted to transportation. Rather, much of the work on transportation and climate change has been directed toward mitigation issues. This is not surprising, considering that transportation accounts for a significant share of global greenhouse gas emissions. Therefore, it is to be expected that many gaps exist in our understanding of potential climate change impacts and adaptation strategies in the transportation sector. Given the limited amount of work that has been completed, virtually all impact areas and adaptation strategies require further investigation. Specific priorities identified within papers cited in this chapter include:

- Greater attention to impacts and adaptation issues for road transportation in southern Bangladesh;

- Increased research on the vulnerability of Bangladesh's roads to changes in thermal conditions, including extreme temperatures;
- Studies that assess the significance of extreme weather events and weather variability in the design, cost, mobility and safety of Bangladesh's transportation systems;
- A more thorough evaluation of existing adaptive measures and their relative ability to defer infrastructure upgrades, reduce operational costs, and maintain or improve mobility and safety;
- An analysis of how changes in factors external to climate, such as technology, land-use patterns and economics, affect societal vulnerability to climate and climate change; and
- Studies that integrate mitigation (greenhouse gas emissions reduction) and climate change–related impacts and/or adaptation issues.

All of this research should be conducted in close working relationships with stakeholders, which in turn will provide the best opportunity for weather- and/or climate-sensitive issues to become acknowledged in legislation, standards and policies. Consideration of the institutional arrangements that would best foster appropriate adaptations in all parts of Bangladesh is also important.

5.3 ADEQUACY OF RHD MASTER PLAN AND NAPA

5.3.1 Initiatives of RHD and RHD Master Plan

DFID-sponsored program "Roads and Highways Policy Management, budgetary and TA Support" (RHD) considered flood as a direct disaster, and adaptation cost was enumerated considering the CLIMATE CHANGE PROOFING SYSTEMS of roads and highways by raising this infrastructure above the highest ever-recorded flood levels. Specifically, some 170 km of national and regional roads and some 518 km of district (feeder) roads in high-risk areas will have to be raised by 1m. Further, about 124 km of national and regional roads in low-risk areas will be raised by 0.5m. As the option comprises a long-term program and since the costs would be very high if incurred at one time, it proposes action when a particular road is due for major maintenance or re-surfacing, with priority given to high risk areas. Flood-proofing of roads and highways would involve raising road height to the highest recorded flood level and provision of adequate cross-drainage facilities. The Roads Master Plan (Government of Bangladesh, 2007) also recently reiterated the maintenance of 1 to 1.2 meter freeboard above a 50 year flood, although directives in this respect have been in existence since the time of the floods back in 1987 and 1988. Notwithstanding the above facts, so far, the efforts and resources of the RHD are meager compared to the enormous dimension of the problem. The proposed option in its entire scope will provide appropriate flood proofing to nearly 800 km of roads through roads-raising across the country. In recent time, experts have suggested that roads constructed along the east-west direction be given extra attention to ensure proper drainage of water, by providing extra spans for adequate passage at the peak flow stage. Experts also warned that the existing bituminous pavements are more susceptible to water-related damages than cement-concrete ones. Provision of asphalt concrete topping and hard shoulder can reduce the damage to roads caused by the flow of water over the road surface. Asphalt concrete produce more durable pavements than the usual road with mixed carpeting. It has also been suggested that in order to minimize the erosion of the road embankments and vulnerable road sections, slopes have to be protected with hard layers (C.C. blocks with geotextile); less vulnerable sections should be protected with flood resistant natural turfs and plants like vetiver (Kashful).

5.3.2 Formulation of NAPA

NAPAs (National Adaptation Programs of Action) provide a process for Least Developed Countries (LDCs) to identify priority activities that respond to their urgent and immediate needs with regard to adaptation to climate change. The rationale for NAPAs rests on the limited ability of LDCs to adapt to the adverse effects of climate change. In order to address the urgent adaptation needs of LDCs, a new approach was needed that would focus on enhancing adaptive capacity to climate variability, which itself would help address the adverse effects of climate change. The NAPA takes into account existing coping focusing on scenario-based modeling to assess future vulnerability priority activities. In the NAPA process, prominence is given to community level inputs as an important source of information, recognizing that grassroots communities are the main stakeholders.

Bangladesh has already formulated its NAPA in the year 2005 (MOEF, 2005). Fifteen adaptation measures have been formulated considering six sectors namely Water, Coastal area, Natural Disaster and Health, Agriculture, Fisheries and Livestock, Biodiversity, Forestry and Land-use; Industry and Infrastructure, Food security, Livelihood, Gender and Local governance, and Policies and Institutes. The total cost of adaptation stands at about US$ 75 million. Bangladesh is now seeking international assistance in implementation of its adaptation programs.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Global climate risks have now started to take concrete shapes and it is widely predicted that Bangladesh is one of the country's most vulnerable to climate change. Adaptation to climate change risk will put additional strain on development efforts of a country like Bangladesh. The scientific evidence available to date indicates that climate change may intensify monsoon rainfall and further exacerbate the inundation problem. At present, systematic studies of climate proofing of road infrastructure to potential additional inundation due to climate change is scarce in Bangladesh; this research is an attempt to narrow the gap.

The following conclusions may be drawn from this study:

1. In Bangladesh, only limited research has been carried out on road infrastructure vulnerability to climate change impacts.
2. Analysis of road damage costs of Sidr 2007 and Aila 2009 shows huge loss resulting from such natural disasters. For example, Aila 2009 caused damages worth about Taka 187 crores to road infrastructure in the three districts – Satkhira, Khulna and Bagherhat – considered in this study.
3. Significant stretches of different types of roads in the three coastal districts are vulnerable to inundation due to their existing low elevation. About 10 percent length of roads considered are "at risk" of inundation under baseline (1998 flood water level) condition, while 16 percent are "at risk" under IPCC 2080 predicted water level. Compared to base-year (1998) scenario, the vulnerability would increase significantly (by a factor of over 1.6) under climate change scenario in 2080.
4. Among the roads in the three districts, those in Satkhira appear to be most vulnerable with over 15 percent road-length "at risk" of inundation considering 1998 (base year) flood water level, while about 23 percent "at risk" considering

2080 (predicted) water level. The corresponding figures are about 3 percent and 5 percent, respectively, for roads in Bagherhat.

5. Adaptation should not attempt to resist the impact of climate change, but rather it should offer a path by which accommodation to its effects is less disruptive and does not fall disproportionately on the poor and the vulnerable.

6.2 RECOMMENDATIONS FOR FUTURE STUDY

Following recommendations can be made based on the study:

1. In this study road crest level data were taken from the Google Earth software, which may differ from the actual level of road. So, study should be carried out with provision for determination of road crest level by actual survey.
2. For time and funding constraint only 3 (three) coastal districts were considered in this study. Other districts (including non-coastal districts) should be included in future research.
3. Culverts and bridges are also important transport infrastructure, which could experience significant adverse impacts of climate change, including narrowing of navigation gap. These issues should be addressed in future studies.
4. Storms and cyclones are important climatic events with respect to climate change and impacts of these on road infrastructure should be considered in future studies.

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