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Climate extremes and challenges to infrastructure development in coastal cities in Bangladesh

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ABSTRACT

Most of the coastal cities in Bangladesh are situated on the riverbanks of low-lying tidal zones at an average elevation of 1.0–1.5 m from the sea level. Construction and management of buildings, roads, power and telecommunication transmission lines, drainage and sewerage and waste management are very difficult and vulnerable to climate change disasters. Cyclonic storms associated with tidal floods impact seriously the infrastructures and thus the livelihoods. Although coastal cities are the ultimate shelters of the coastal people during the extremes events, the coastal cities are not safe and cannot support them due to poor infrastructure. This study analyses the challenges coastal urbanization faces under different situations like cyclones, floods and water-logging, salinity, land-sliding and erosion etc. during the disasters and their effects on city lives for water supply and sanitation, power and electricity and waste management etc., and puts forward recommendations towards sustainable planning of coastal cities.

1. Introduction

Nearly a quarter of mankind lives in low-lying coastal areas, and urbanization is drawing still more people into them. Commercial activities mostly related to port, shipping, industry, agriculture etc. have delineated to commercial hubs. These hubs are catered by a huge forward and backward linkage activities and establishments like banks and insurance companies, clearing and forwarding agents, warehouses and hotels (NBC News, 2009). Most of the world's biggest cities have grown up around natural harbors. While people have been living in coastal areas for thousands of years, the huge cities and megacities that have grown over the past 100 years have quickly destroyed the natural marine and coastal habitats. Migration for shelter to the cities during the recent extreme climate events, and the sufferings of city-lives exacerbated. The rising sea level endangers several smaller island nations, such as Tuvalu, Maldives, etc., which are barely 2 m above the sea level (Brown, 2001). Millions of people in low-lying regions of many countries including Bangladesh, China (Strohecker, 2008) and Vietnam (Tanh and Furukawa, 2007) face the danger of being displaced.

The construction of general infrastructure such as roads, houses, shops, factories, airports, and ports completely replaces natural habitats. Estuaries, deltas, and their rivers are often dredged and deepened to cope with increased shipping. In addition to this, impacts such as increased erosion due to coastal development, increased pollution, boat traffic etc., which lead to further habitat loss and put increased pressure on marine species.

Many dams and dykes are constructed to protect coastal towns, cities and farmland from storm surges and high tides but these carry negative effects particularly for reclaimed land and drainage. These constructions have destroyed the natural coastal dynamics and functions, as well as, rare habitats like salt marshes (WWF, 2013; Stanley et al., 2011). Along with the coastal morphology; coastal slope is the major factor in estimating the impact of sea-level rise (SLR). On a steep coast, the impact of SLR is insignificant on contrary to a gently sloping coast where any rise in sea level would inundate large areas of land (Nageswara Rao et al., 2008). With a few exceptions, most of the coastal towns and cities are situated on the riverbanks of low-lying tidal zones of Bangladesh, at an average elevation of 1.0–1.5 m from the sea level and are prone to multiple threats such as cyclones, storm surges and floods, as well as earthquakes, tsunamis, and above all, climate change. SLR is a great threat to the 75 million people of Bangladesh, who are projected to be environmental refugees (Nitish Priodarshi, 2011). Analysis of available data on population displacement shows that 39 million people in Bangladesh were

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displaced by major natural events from 1970 to 2009 (Tahera Akter, 2009).

The National Plan for Disaster Management 2010–2015 was prepared aiming at reducing vulnerability according to the Hyogo Framework for Action 2005–2015 and adopting the SAARC Framework. It emphasizes to work together with all stakeholders to build strategic, scientific and implementation partnerships with all relevant government departments and agencies, other key non-government players including NGOs, academic and technical institutions, the private sector and donors. The role of Government is mainly to ensure that risk reduction and comprehensive disaster management is a focus of national policy and programmes (DMB, 2010).

In 2005, Bangladesh developed the National Adaptation Program of Action (NAPA). In 2008, Bangladesh prepared Bangladesh Climate Change Strategy and Action Plan (BCCSAP) to strengthen its six pillars: Food security, Social protection and health; Comprehensive disaster management; Infrastructure; Research and knowledge management; Mitigation and Low carbon development and capacity building and institutional strengthening (MoEF, 2009). Bangladesh has also formulated a Coastal Zone Policy (CZPo) in 2005 but that paid very little attention about SLR (CZPo, Coastal Zone Policy, 2005) as well as the challenges of the coastal cities and their infrastructure. CZPo has identified the zone as an "agro-ecologically disadvantaged region" (Government of Bangladesh (GoB), 2005). Scarcity of drinking water, land erosion, the high groundwater arsenic content, water-logging, water and soil salinity and various forms of pollution have also slowed down social and economic developments (Islam, 2007; Islam and Ahmed, 2004)

Although human death has significantly been reduced but overall economic loss increased a lot (Table 1). There are some drawbacks in the policies and in the implementation level and lack of coordination among the agencies is one of the failures. On the other hand, poor coordination among the government departments hampers quick response in times of emergency. As the role of the agencies is not clearly defined, confusion about jurisdiction of work destroys the congenial atmosphere. There is a huge lack of grant monitoring system. The foreign grants are not monitored to ensure proper allocation of funds (TIB Report, 2013).

2. Vulnerability of the coastal area

Bangladesh is situated at the interface of the two contrasting settings with the Bay of Bengal to the south and the Himalayas to the north. Land characteristics with low and almost flat topography, multiplicity of rivers and the monsoon climate render Bangladesh highly vulnerable to natural hazards. The coastal morphology influences the impact of natural hazards in the area, increases the vulnerability of the coastal dwellers and slows down the process of social and economic development. The waterways are the main transportation mode in eastern and central coastal zone (Sarwar, 2013). The huge river networks are the greatest influential factor for poor transportation infrastructure. Most of the rivers and rivulets are flowing from the north and a few from the east and discharging water to the Bay. The unplanned road transportation networks of the coastal zone are being connected to different cities including Dhaka and Chittagong but in many cases across the water flow *i.e.* east to west, thus interfering the natural water dynamics. In addition, erosion of the river banks and fragile land mass have worsened the situation. The rivers discharge water which is heavily laden with sediments funneling to the coastal area. Many islands between the channels, shallow northern Bay of Bengal and strong tidal, wind action etc. are the significant features of the coastal zone of Bangladesh (National Plan for Disaster Management, 2010).

The vulnerable low-elevated coastal zone with 54 thousand km^2, about 40% of the country, is facing the consequences of growing pressure on the environment resulting in rising demand for water, inadequate maintenance of existing embankments and other environment protection measures, and rapid unplanned urbanization and industrialization. Climate change-induced frequent and severe floods, cyclones, storms, tidal surges, SLR, salt water intrusion, river and coastal erosions etc. force many rural people to migrate to the coastal cities thus creating new environmental problems in the country's fast urban slums (McGranahan et al., 2007; IOM, 2010).

The coastal urban areas include three city corporations: Chittagong, Barisal and Khulna, 74 municipalities and many towns including Upazila Headquarters (Fig. 1).

The oldest municipalities were set up in Jessore and Chittagong in 1864 followed by Cox's Bazar and Satkhira in 1869 and the recent municipality is Shariatpur, established in 1983. After independence of Bangladesh, all municipalities were renamed as Pourashava. Tungipara has the least area, 132 ha and Banaripara has only 1300 households (LGED, Local Government Engineering Department, 2002; BBS, 2003). The urban expansion has occurred only in terms of population size, devoid of urban facilities. Since 1901, data indicate that Dhaka, Chittagong and Barisal have never changed their rank throughout the century. This is indicative of regional primacy (Ahmed, 2004). Khulna, once a small town under Jessore district, rose to prominence since the 1960s and now Khulna is the third largest city of Bangladesh having a population of about 1.3 million on about 47 km^2 area. There is no sewerage system in Khulna City and most of the areas have neither piped water supply nor any permanent drain (ERMP, 2001; Hasan et al., 2004).

According to the Asian Development Bank, in 19 coastal districts towns including Khulna, Chittagong and Barisal infrastructure is still inadequate in many areas as they are either damaged by natural disasters or otherwise no longer functioning effectively. World Bank economist Stephane Hallegatte reported that "*Coastal cities face a high risk from increasingly costly flooding. Their current defenses will not be enough as the water level rises.*" "Coastal defenses reduce the risk of floods today, but they also attract population and assets in protected areas and thus put them at risk in case the defense fails, or if an event overwhelms it." According to his report, Khulna is at number 8 out of 10 most vulnerable cities when measured as

Table 1
Coastal zones affected by tropical cyclones.
Sources: (Rahman, 2010; Miyan 2012; Rahman 2013).

Cyclones	Affected regions	Wind Speed (km/h)	Deaths	Damages (million US$)
Bhola Cyclone-1970	Bangladesh, India	205	500,000	86.4
Bangladesh Cylone-1991	Bangladesh	260	138,000	1500
Sidr-2007	Bangladesh	260	4036	1700
Nargis-2008	Myanmar Bangladesh India, Srilanka	215	138,366 (126 in Bangladesh)	10,000
Aila-2009	Bangladesh India	120	325 (26 in Bangladesh)	552.6
Mahasen- 2013	Bangladesh, Myanmar, India	95	107 (17 in Bangladesh)	5.14

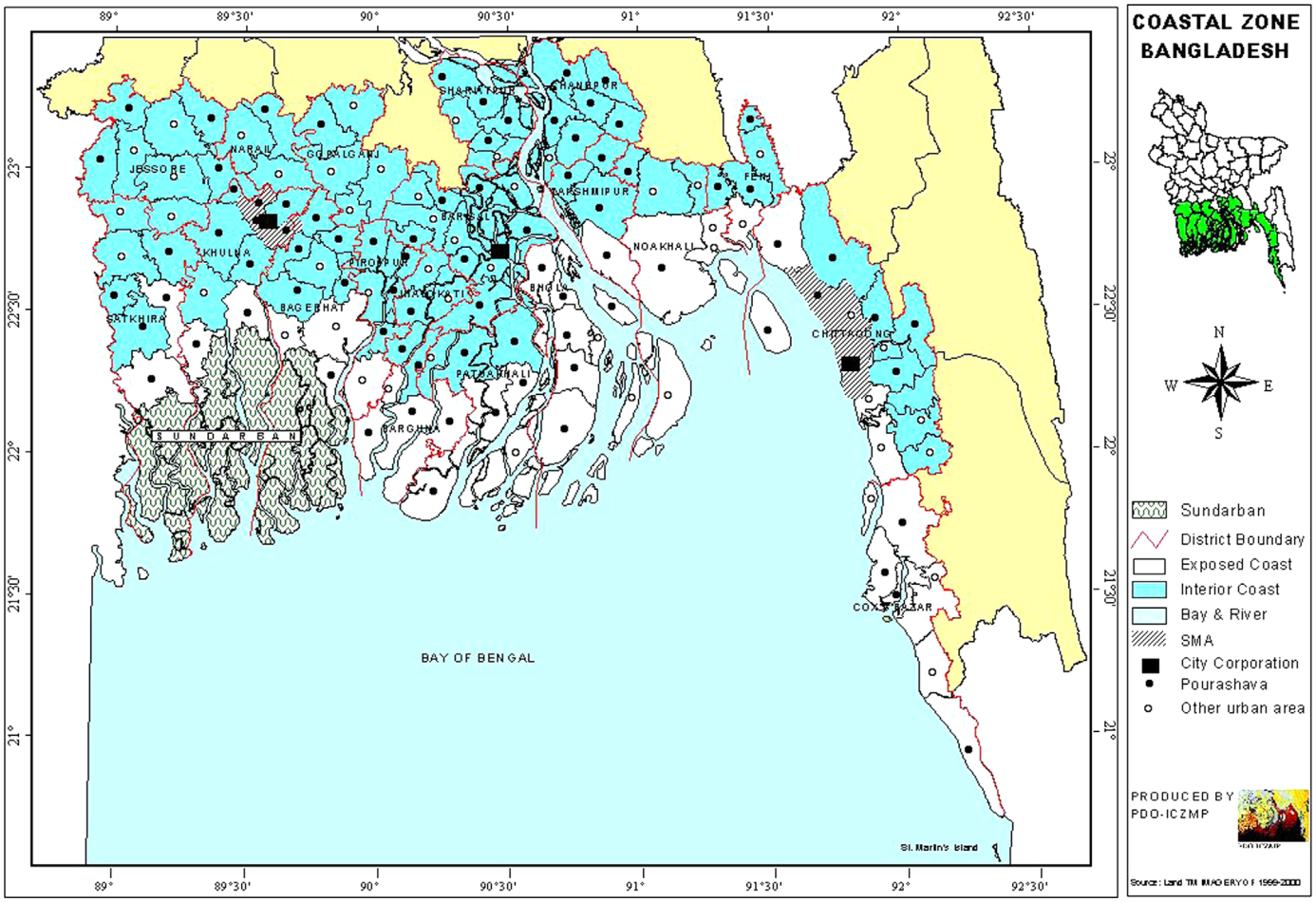

Fig. 1. Urban centers in the coastal zone of Bangladesh.
Source: Integrated Coastal Zone Management Project, 2004.

Table 2
The Long-Term Climate Risk Index (CRI): results (annual average) in specific indicators in the 10 countries most affected from 1992 to 2011.

CRI 1992–2011 (1991–2010)	**Country**	**CRI score**	Death toll	Deaths per 100,000 inhabitants	Total losses in million US$ PPP	Losses per unit GDP in %	Number of events (total 1992–2011)
1 (3)	Honduras	10.83	329.25	4.96	679	2.84	60
2 (2)	Myanmar	11.00	7137.25	13.79	640	1.41	37
3 (4)	Nicaragua	18.50	160.0	2.82	223	1.89	44
4 (1)	Bangladesh	20.83	824.4	0.58	1721	1.18	247
5 (5)	Haiti	21.17	301.1	3.43	148	1.08	54
6 (6)	Vietnam	23.67	433.15	0.55	1741	1.06	214
7 (9)	Korea, DPR	26.00	76.65	0.33	3188	7.64	37
8 (8)	Pakistan	30.50	545.9	0.38	2183	0.73	141
9 (55)	Thailand	31.17	160.4	0.26	5413	1.38	182
10 (7)	Dominican Republic	31.33	211.6	2.47	185	0.35	49

Source: (German Watch, 2013).

percentage of gross domestic product (GDP). The poor are most at risk as rapid urbanization has pushed them into the most vulnerable neighborhoods (World Bank, 2013).

The German Watch in its report "Global Climate Risk Index (CRI) 2013: Who Suffers Most from Extreme Weather Events?" mentioned that Bangladesh is number 4 among the countries most affected in the period of 1992–2011 (Table 2).

3. Rationale of the study

The coastal cities and towns are the ultimate shelters of the coastal people during the disasters (Rahman, 2011; McGranahan et al., 2007). But most of the coastal towns are expanded from little Bazar or Gonjes (market and trade centers) and are eventually converted into administrative centers (Pourashavas), and some are large industrial port-cities and tourist centers e.g. Chittagong, Cox's Bazar, Khulna, Patuakhali, Barisal etc. However, most of the towns and cities are unplanned and due to lack of sufficient infrastructure, the people are suffering badly. Limited study is available on the challenges of infrastructure development of the coastal towns and cities. Therefore, the International Geosphere Biosphere Program (IGBP) has started to accumulate the relevant information about coastal zone management in Bangladesh under the funding of Asia Pacific Networks (APN) to formulate a policy for the most vulnerable sector. In this project, coastal cities and towns are given prime

importance for highlighting the challenges for the wellbeing of more than 30% population of the coastal region.

4. Objectives

Due to natural and climate change effects, the coastal zones of Bangladesh are facing frequent serious disasters. The disasters have been devastating for the people of the coastal cities which are the ultimate shelters for the coastal people during the disasters (Rahman, 2011). The objective of this research paper is to highlight the vulnerability of the coastal cities and their inhabitants in the context of climate change in Bangladesh. Through this explorative analysis on the disasters and the challenges for the coastal cities, this study puts forward recommendations that have the potential towards sustainable planning of the vulnerable coastal cities.

5. Methodology

The present work was conducted using the information from different scientific and gray literature published in different forms either in peer reviewed journals or periodicals, news media, folklore and local records. Information was also gathered by organizing workshops, seminars and also by attending different regional workshops and conferences and visiting research institutions and public administrative centers. More importantly, some information is collected directly from the stakeholders, rural and urban administrative bodies, civil societies, NGOs, women and youth communities. Electronic media is also an important source for information. The impacts and vulnerabilities of coastal cities and the challenges for infrastructure development are studied and documented for a cross-scale synthesis towards policy recommendation.

6. Challenges of coastal urbanization

Weak local governance and municipal management coupled with high poverty incidence, and remote locations, create persistent development challenges to these areas. Poor coordination between City Development Authority and the Ministry of Housing and Public Works, and high dependency on the central government are the important causes of hindrance in infrastructure development of the coastal cities. Climate change, climate variability, and natural disasters further aggravate development in coastal towns, with a disproportionate impacts on women and the poor.

The increased incidences of drought and salinity intrusion into groundwater, coupled with high non-revenue water are posing serious risks to drinking water supplies, requiring the potential for developing new, but costlier, water supply sources located at far distances. Due to the Ganges barrage, the sweet water flow has decreased alarmingly and caused severe salinity intrusion especially in the southwest region. Salinity increases steadily from December and reaches a maximum in the early March and April when many people suffer from contagious diseases (EGIS, Environmental and Social Impact Assessment of Gorai River restoration Project, 2001; PDO-ICZMP, 2004; Khanom and Salehin, 2012).

The coastal zone is a zone of multiple vulnerabilities. The coastal towns and cities are badly impacted by the natural and climate change effects and of huge population influx especially during and after the cyclones: Chittagong cyclone, Sidr (2007), Nargis (2008), Aila (2009) , Mahasen (2013) etc. The major challenges, and the risks and hazards of coastal towns and cities are summarized below:

6.1. Spatial expansion

For topography and the communications route the coastal cities are spatially expanded and the built environment of most of the old towns with high density did not follow the setback rules and are situated just at the edge of the road thus limiting any further widening and expansion of the road. These problems are being intensified by mismanagement, lack of maintenance, growing importance and activities in the area, inadequate infrastructure, and lack of awareness of the concerned authority (Aziz, 2010).

6.2. Earthquake

The coastal districts are less vulnerable to earthquakes than the rest of the country. Recently, however, earthquake incidents occurred in the Chittagong area several times. The Chittagong earthquake of 27 July 2003 occurred with a magnitude of 5.6 in Richter scale. Moheshkhali Island of tectonic origin has hills of tertiary age and has also experienced earthquakes in recent times (Alam et al., 2006). Other major earthquakes are those which occurred in 1997 and 1996 with magnitudes 6.1 and 5.2 resulting in the sinking of two underground floors of a five storied building and 32 and seven people died respectively. Widespread damage and loss of property, mainly thousands of buildings, were reported (Islam, 2005).

6.3. Salinity

Water and soil salinity is a common hazard in many parts of the coastal zone. In the southwest region, surface water salinity has been accentuated by the reduction in the dry season upland flows entering the Gorai distributaries. Salinity now reaches as far as Khulna city affecting the supply of clean water for domestic and industrial use. A number of industries in Khulna are facing shortage of fresh water during the dry season. Consequently, no new heavy industry was set up in the recent years in the Khulna region despite increasing infrastructure facilities (road, sea-port, etc.). Groundwater salinity is also high in Noakhali (WARPO, 2005). Under climate change induced increasing salinity along the coastal rivers; the above processes will be aggravated. This in turn will further complicate the current state of water logging. It is inferred that water logging will be spread over a larger area, involving many smaller river basins within the Ganges Dependent Area. Salinity has put severe forms of constraints in terms availability of safe drinking water. Both surface and ground water salinity exceeded 20 dS/m in 2009 in 17 coastal towns in the dry season (March–May). This rate is a strong threat for human health and risk for normal agricultural production. Almost 50 coastal towns out of 102 are severely affected by high salinity intrusion due to shrimp cultivation, upstream fresh water shortage and climate change impacts. Urban drinking water supply is a challenging issue for the 3 metropolitan cities located in the coastal region such as Chittagong, Barisal and Khulna. The most portion of the land area of these 17 towns is affected by salinity intrusion (Table 3).

Accordingly 75% land area of Sathkhira, 66% of Bagerhat, 32% Khulna and 72% of Barguna districts are affected by salinity intrusion which is a threat for drinking water supply to the urban citizens (Islam, 2007, 2010). Salinity intrusion in the coast varies seasonally. In the rainy season (June–October) intrusion of saline water is low due to extreme flow of fresh water, but in the dry season, especially in winter, saline water goes upward gradually. In the rainy season where saline water ingresses to 10% of country's area, in the dry season saline water reaches to country's 40% area even.

Due to the changing climate, the ingression of salinity is being increased through: increased sea level causing water ingression in the rivers, decreasing trend of fresh water flow from the upstream causing intrusion of saline water, upward pressure of the saline and fresh water interface in the level of underground aquifer, downward seepage of saline water from surface and salinity of underground water. The pace of evaporation in winter will increase soil salinity and frequency and intensity of tidal surges will increase ingression of saline water (Shamsuddoha and Chowdhury, 2007).

6.4. Water logging

In the recent years, most of the coastal cities got flooded even with a little rainfall of about 20–30 mm and the roads became waterways and collapsed the normal road transportation systems of conventional rickshaws, vans, taxis, cars etc. Sometimes people used to use boats on the city roads (Rahman, 2011). Water-logging is especially experienced in the southwest (Khulna–Jessore) and south-central (Noakhali–Lakshmipur) areas. Noakhali town remains waterlogged for most part of the monsoon season. Water-logging appears to be highly pronounced along the coastal rivers in the southwestern region, where the adjoining lands are mostly empoldered. Often it is found that the drainage infrastructure such as sluice gates also gets choked due to heavy sedimentation and eventually becomes inoperable. Ill-planning of the Bangladesh Water Development Board (BWDB), especially towards wrong placement of such sluices, has also contributed to the choking up of the infrastructure. Once spillage takes place over an existing embankment, water does not find ways to recede, and inundates both agricultural lands and homesteads. Non-functioning of sluices often aggravates the situation and water logging within an embankment system becomes a perennial problem. The infamous water logging in Polder No. 24 of the BWDB had become a major concern in the 1990s (Rahman, 1995). Currently, vast areas in Manirampur, Keshabpur, and Abhaynagar Upazilas of Jessore District, Dumuria of Khulna District, and Tala of Satkhira District are permanently water-logged. In case of Manirampur and Keshabpur Upazilas, over 85% land has been remained water-logged for more than 7 years. During the flood of 2007, Kobadak river had been flowing above the danger level in Jhikargachcha for over 80 continuous days (FFWC, 2007). However, in the other flooded river basins towards the northern reaches, continuous inundation lasted up to 20 days in each of the two flood spells (Ahmed, 2008; Ahmed et al., 2007).

Irresponsible shrimp cultivation is also responsible for floods. The following examples with satellite images show how shrimp cultivation caused floods.

Satellite image in Fig. 2 shows an area under the risk of severe flood at Bedkashi in Khulna district on 27 November, 2008.

Table 3
Coastal Towns affected by Salinity.
Source: (Islam and Gnauck 2010).

Name of the City	City area (km²)	Area affected by salinity (%)	Name of the city	City area (km²)	Area affected by salinity (%)
Barguna	15.57	46	Botiaghata	8.30	69
Mathbaria	15.92	65	Dumuria	6.39	68
Pathorghata	18.31	68	Rupsha	2.30	45
Galachipa	9.60	72	Mongla	17.79	78
Kalapara	19.49	74	Paikgacha	2.12	81
Munchiganj	2.10	88	Bagherhat	7.53	56
Kaliganj	7.96	77	Morelganj	15.36	65
Ashasuni	6.81	85	Koira	10.06	81
Sathkhira	27.84	45			

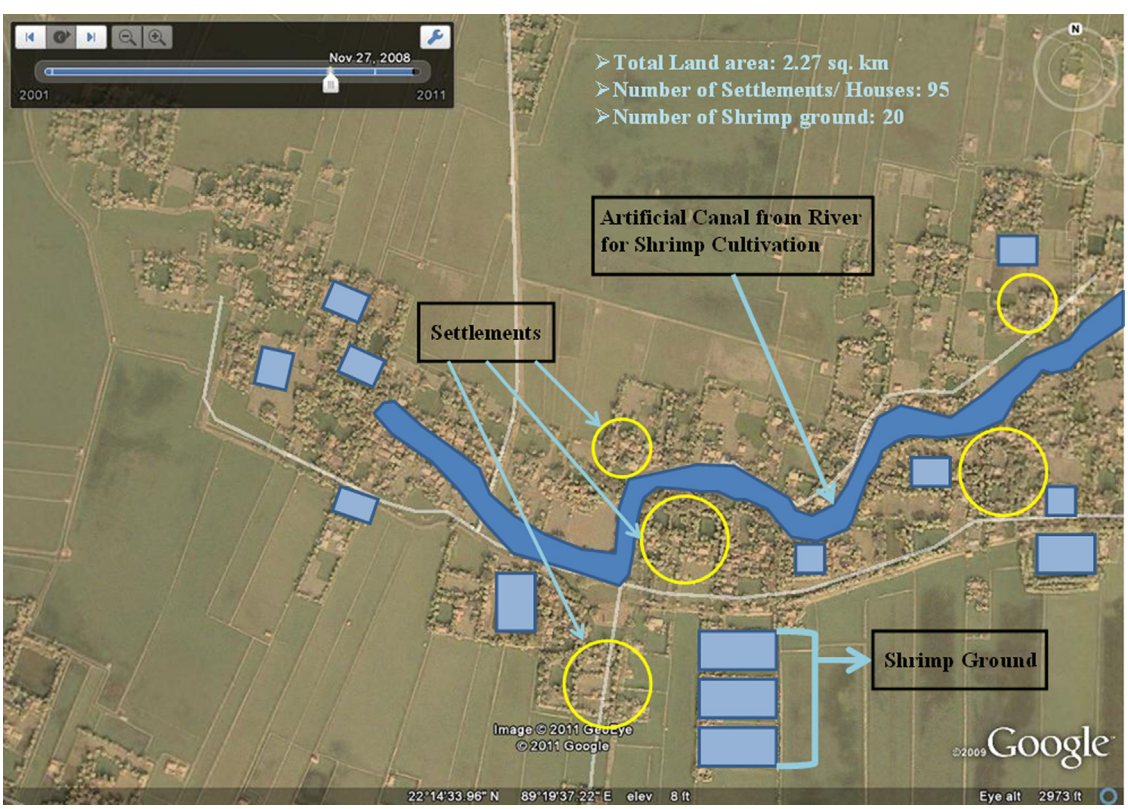

Fig. 2. Satellite image of Bedkashi.
Source: Hassan, 2012

From the image, it is visible that the area was free from flooding in November 2008. It is possible to detect number of settlements, agricultural land, shrimp grounds and ponds from the satellite image. The total land area was 2.27 km^2. Numbers of settlement were 95. Number of shrimp grounds were 20. Damage estimation of the visible portion of this image is shown in the form of disaster mapping. Flooding of this area in different seasons has been presented in Fig. 3.

The satellite image in Fig. 3 shows the same location in different seasons. This image was taken on 1 March, 2010. From the image it is visible that the area is severely affected by flood. Floods usually occur during mid of March to last week of September. Water logging caused by flooding stayed for a long time. A vast track of crop land, shrimp grounds and houses has gone under water, while people became displaced and many others take shelter at different embankments, high lands, road sides and flood shelters. Many people decided to migrate to other areas. Flood water stayed for a long time. This duration may be 3–7 days or more than a month. Due to severe flooding, people lost their houses and work.

Satellite image in Fig. 4 shows the reason of severe flooding of this area. From the image it is visible that there was a flood protection embankment in the south side of the village, but the embankment failed to protect the area from flood. Villagers used to cultivate shrimps in their shrimp grounds and it is important to supply continuous water flow from the adjacent river. So, they cut artificial canal from embankment to their shrimp grounds, which made the embankment weak and gave little enforcement against the heavy force of flood water. Consequently, 398 m flood protection embankment was destroyed by strong force of flood water and 95 settlements containing approximately 380 people were displaced (Hassan, 2012).

6.4.1. Coastal embankment

Degradation of the coastal ecosystem started with the implementation of Coastal Embankment Project (CEP) during 1960–1980 through which flood embankments were raised with an intention to save agricultural lands as well as to intensify rice production all through the coastal region. A total of 5017 km of embankments were raised throughout the coastal region against the will of nature.

6.4.2. Polderization

The adverse effects of the donor funded polders constructed since 1960s intervening the estuarine river systems have caused serious river drainage congestion and water-logging problems in the coastal areas of Bangladesh as the polders de-linked the floodplain wetlands from the rivers creating disastrous consequences for the local communities with inundation of massive areas under stagnant water that seriously jeopardized livelihoods and environment and created a massive migration to the coastal cities (Islam and Kibria, 2006; Adnan, 2005; Sarker, 2004; Islam et al., 2004).

Polder systems are meant as the first line of defense for coastal communities against tidal surges. A damaged polder following Cyclone Sidr 2007 has been shown in Fig. 5. Changing weather patterns, poor maintenance and lack of investment are taking their toll on Bangladesh's extensive polder system. Many of the polders are in various states of disrepair. Despite an extensive infrastructure to protect coastal residents from cyclones, currently 44 out of 123 coastal polders run the risk of overtopping if a severe cyclone hits, while by 2050, another 59 coastal polders could be overtopped as inadequate mangrove forests mean higher-velocity storm surges (Reliefweb, 2013).

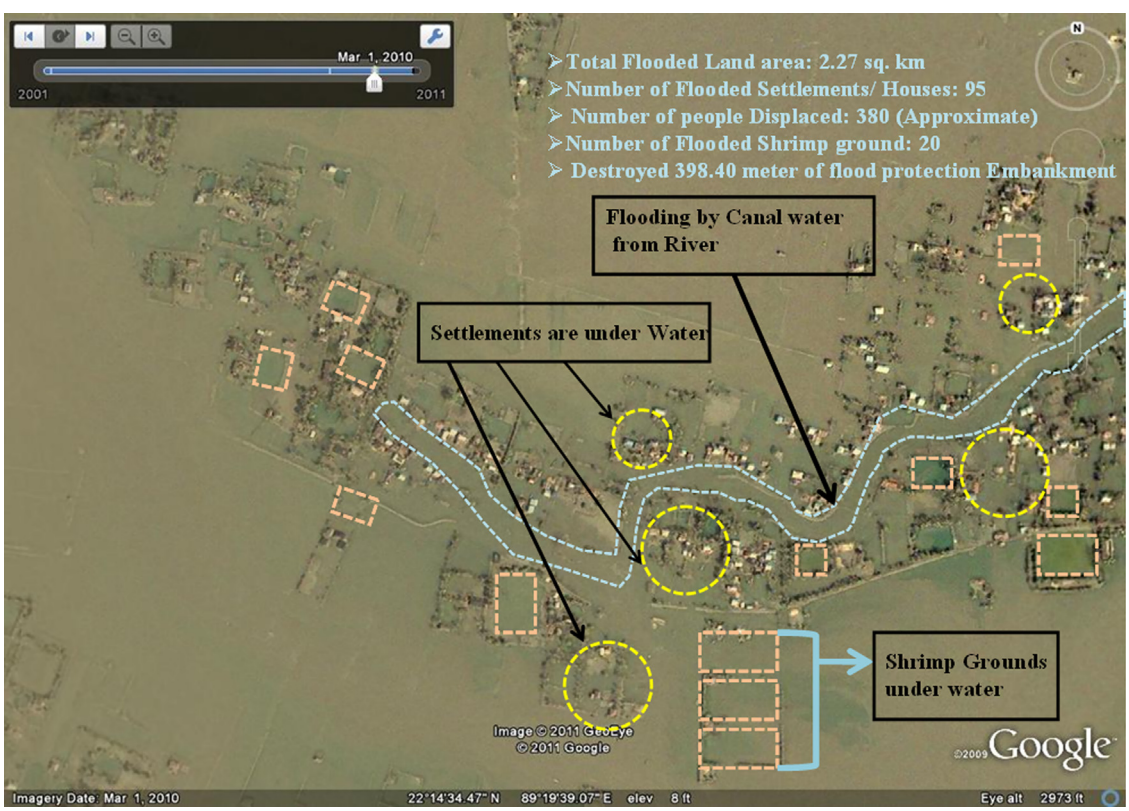

Fig. 3. Satellite image of Bedkashi, Khulna.
Source: Hassan, 2012

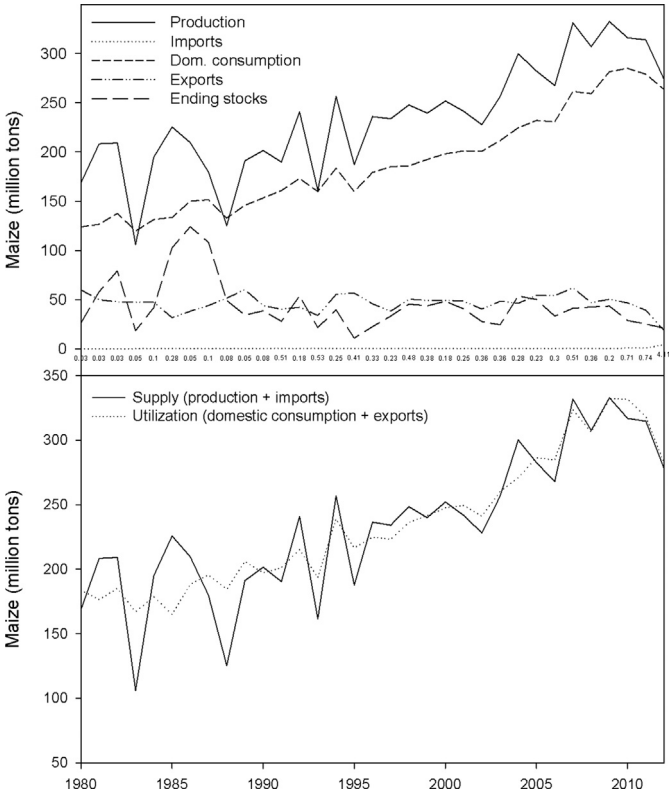

Fig. 4. Satellite image of Bedkashi, Khulna.
Source: Hassan, 2012

Fig. 5. Polders under threat.
Source: Reliefweb, 2013

6.5. Arsenic

Arsenic contamination is common in many parts of the coastal zone, but mainly in Barisal, Khulna, Gopalganj, Chandpur, Noakhali, Satkhira and Laxmipur. Some towns such as Satkhira, Khulna and Bagerhat are affected by arsenic contamination in ground water. A limited number of southern coastal towns are contaminated by arsenic in ground water and 82% of the drinking water is collected from ground water (Islam, 2010).

Fig. 6 shows that the coastal zone of Bangladesh is mostly affected by arsenic. Satkhira, Gopalganj, Laxmipur, Daodkandhi and Shibchar are arsenic affected areas containing more than

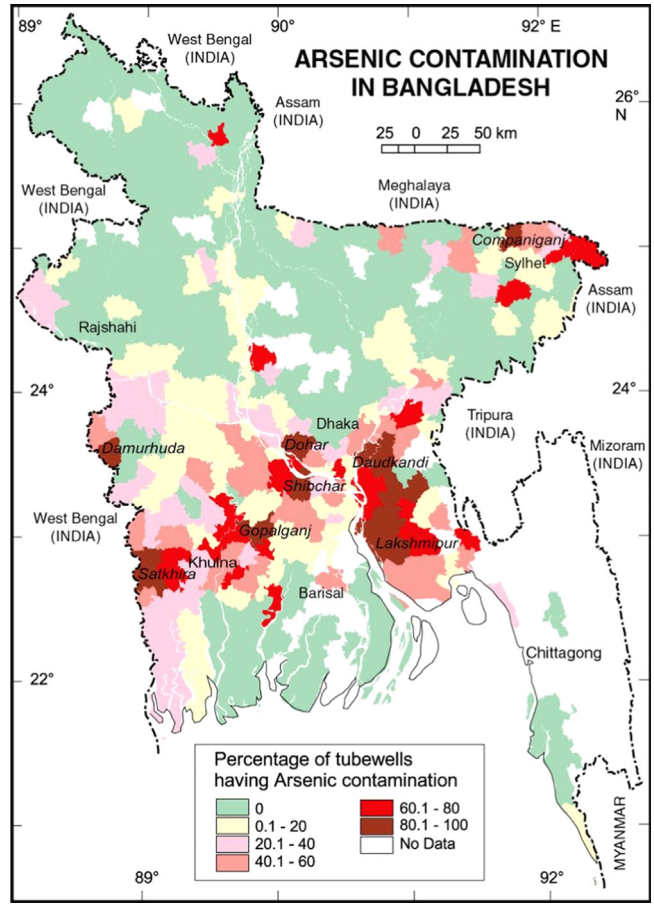

Fig. 6. Arsenic contamination in Bangladesh.
Source: http://www.banglapedia.org/HT/A_0308.HTM

80–100 μg arsenic per liter against Government's standard for drinking water of 50 μg per liter.

6.6. Land erosion

Land erosion is a common phenomenon. Embankment systems are posing a continuous problem in the coastal areas. This exposes interior lands to the threats of cyclone surges and salt-water intrusion. River erosion has taken a serious turn in several urban centers including Chandpur and Bhola (Ahmad, 2005). Comprehensive erosion control or protection plan does not exist there. River bank erosion of Padma and Jamuna was studied by the Center for Environmental and Geographic Information Services (CEGIS) and Disaster Management Bureau (DMB) (CEGIS, 2005; DMB, 2010). The ancient Noakhali (Bulua), also called Sudharam, got extinct by the erosion of the Meghna River and the district administration has been shifted 8 km to the north at Maijdi (Sinha and Noakhali, 2008).

Erosion has been becoming a regular natural phenomenon along the belts of out reach coastal islands like Bhola, Sandwip, Hatia and Kutubdia, which turned massive in the recent years (Rahman, 2010; Miyan, 2012). The major causes of erosion are because the Ganges Brahamputra Meghna (GBM) river system carries immense volume of water with silt. During the monsoon, GBM system carries about 1.7 billion tons of silt per year causing severe turbulence the rivers. This results in gradual undercutting of riverbanks leading to erosion. During high tide, 30,868 m^3 of sea water flows upward through the cannels of Kutubdia, Sandwip and Hatia. Again, these channels carry down the upstream fresh waters from 38,896 km^2 coastal and midland areas of Bangladesh.

The immense pressure of the downward flows, strong tidal circulation etc. results in unprecedented erosion of coastal habitats. Due to erosion, Hatiya has reduced from 1000 km^2 to only 21 km^2 over 350 years and Swandip lost 180 km^2 in the last 100 years. Such erosion adversely affects the ecosystem, navigation, planned-agriculture development and drainage system. It has also affected the inland navigational route due to shifting and migration of channels. The factors accelerating riverbank and land erosion include: destruction of coastal mangroves for shrimp farming, unplanned dams, cross road construction etc. (Shamsuddoha and Chowdhury, 2007; ERMP, 2001).

6.6.1. Land-sliding

Unplanned urbanization, deforestation and hill cutting have created serious land-sliding in Chittagong and Cox's Bazar resulting in the death of hundreds of people. Heavy monsoon rainfall, intensified by strong storms from the Bay of Bengal, caused an abnormal precipitation in the area causing landslides. The combined effect of rainfall and hill cutting induced slope instability and triggered landslides in Chittagong. The combined effect of hill cutting and climatic change have induced erratic behavior of the nature causing tragic deaths in 2000, 2007, 2008, 2012 and 2013 (Sarwar, 2008; Rahman, 2012; Dhaka Tribune, 2013).

6.7. Water supply and sanitation

For healthy living, it is crucial to have hygienic latrine facilities, proper management of solid waste and proper disposal of household wastewater and storm water (Local Government Division, 2005). Most of the coastal towns/cities lack sewerage system and are dependent on the septic tank systems where the effluent is released untreated into the nearby drains and low-lying areas. The untreated industrial effluent is also being released in the river and its distributaries. The coastal topography makes it all the more important to have proper drainage, sewerage and storm water system at places to avoid accumulation of water and associated hazards. The subsoil water-table is very high in many areas in the city, leading to non-functional soak pit (Ahsan, 2011). Proportion of urban households possessing sanitary latrines is slightly higher (70%) in the coastal zone than in the country (67%). Extent of sanitation is, however, much higher among urban households compared to rural households in the coastal zone (urban and rural together 46%). Sanitation coverage is the highest in Pirojpur (86%), followed by Jhalokati (84%) and Barisal (82%) and the lowest in Bagerhat (32%), followed by Cox's Bazar (53%). About 11% of the urban households have no latrine at all in the coastal zone compared to 7% urban households in the country as a whole. Poor access to sanitation in coastal towns is also posing serious public and environmental health risks. Drainage systems are underdeveloped and poorly maintained, and would be made further obsolete under more intense and frequent storm events. Given this scenario, future investments in urban infrastructure need to be climate resilient to manage the long term costs of investments and to ensure that such investment deliver their intended benefits (ADB, 2013; Health Bulletin, 2012).

Reportedly, Sanitation coverage has attained the Millennium Development Goal, Target 7.C: "Halve by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation". In some areas, it reached 100%. But the report of the Ministry of Health and Family Welfare shows that the number of diarrhea patient is still high, whereas the corresponding area attained 100% sanitation (Table 4).

A test of Hypothesis has been conducted to find the corresponding relation between sanitation coverage and diarrhea.

Table 4
District-wise sanitation and number of diarrhea patients in Bangladesh.
Source: (Health Bulletin, 2012).

District name	Sanitation coverage (s)	Total population (p)	Attacked by diarrhea and hospitalized (h)	Percentage of population attacked by diarrhea (h∗100)/p
Barguna	68.76	1,010,833	1296	0.128
Barisal	87.68	2,636,227	4513	0.17
Bhola	77.50	1,976,652	7769	0.39
Jhalokathi	94.46	659,484	3112	0.72
Patuakhali	80.74	1,634,403	4207	0.257
Pirojpur	89.71	1,103,903	1466	0.133
Chittagong	76.13	5,266,683	47,074	0.89
Chandpur	88.51	2,426,274	9595	0.396
Comilla	99.76	5,634,654	9829	0.174
Cox's Bazar	69.87	2,444,598	2501	1.024
Laxmipur	78.32	1,797,974	3500	0.19
Feni	79.84	1,519,786	10,355	0.68
Noakhali	74	3,243,015	5312	0.167
Brahmanbaria	84	3,029,156	11,326	0.374
Rangamati	80.56	641,994	2206	0.344
Bandarban	47.40	383,000	800	0.21
Khagrachari	66.93	623,404	563	0.09
Khulna	99.54	3,237,190	7630	0.236
Chuadanga	99.99	1,141,879	4687	0.41
Jhenaidah	100	1,857,149	5663	0.305
Kushtia	84.36	1,972,326	6965	0.353
Jessore	99.23	2,795,522	4588	0.164
Bagerhat	100	1,591,359	1950	0.123
Narail	67.46	696,123	3014	0.433
Magura	100	960,572	3685	0.389
Sathkhira	100	2,087,493	4696	0.225

Null Hypothesis (H_0):. There is no correlation between Sanitation Coverage and Percentage of Diarrhea Patients.

Alternative Hypothesis (H_1):. There is correlation between Sanitation Coverage and Percentage of Diarrhea Patients.

By Bivariate Correlation Test (Pearson correlation), using the Sig. (2-tailed) value, we can determine whether the correlation is a significant one. Here the significance value is 0.408 (shown in Table 4). As the significance is more than 0.05, we accept the Null Hypothesis and reject the Alternative Hypothesis that there is sufficient evidence of no correlation between Sanitation Coverage and Percentage of Diarrhea Patients.

The Government is working forward to achieve the MDG goal to halve the proportion of population below water supply and sanitation facilities. Donor agencies and NGOs are assisting the government to achieve this goal. Although pans are provided in the villages and slums by development agencies, donor agencies and NGOs; management of pits and cleaning is a challenging task in absence of flush system. Often the goose-neck of the pan cannot pass the water. So, the pan remains flooded. Goose-neck is then cut to pass the water. But it further causes problem. Foul odor and insects enter the pan and cause unhygienic sanitation environment. This unhygienic and unhealthy condition is a common nature in the coastal regions especially in the slums and squatters. It helps to spread communicable diseases. Vent pipe has been set up in some toilets to pass out the odor, but it does not solve all the problems. Flushing system is still needed to help to cause liquidity in the excreta and maintain the flow.

6.8. Power and electricity

Household electricity connection in urban areas is relatively high in Chittagong, Feni, Jessore, Khulna and Barisal (> 70%) and very low in Shariatpur, Bhola, Narail and Cox's Bazar (< 40%).

Although, households are connected with the electricity grid, supply of power is often interrupted in many urban centers because of load management. The large and small industries especially related with fish preservation are being hampered seriously in the coastal towns like Barisal, Patuakhali, Chandpur, Bhola etc. Huge quantities of fishes, especially the Hilsa are destroyed every year due to paucity of ice for preservation. Moreover, the fishermen cannot go for fishing without ice for preserving their catches. Even in the fish industries some synthetic chemical preservatives are reported to be used and polluting the environment and water bodies (Rahman, 2013; Kleih et al., 2003). All the 25 ice plants at Mohipur, a fish landing station in Kalapara, remained closed and fishes worth about $130 thousand got rotten due to lack of electricity during Cyclone Mahasen in 2013 (SAARC DMC, 2013). In 2007, the Rural Electrification Board reported that about 20,000 km of power supply lines were damaged (CONCERN Worldwide Bangladesh, 2007). Sidr (2007) induced a damage of $8.2 million with an estimated potential additional loss is $150.0 million in the power sector of coastal Bangladesh (Dasgupta et al., 2010). Damage and loss to the power sector totaled US$ 13.4 million. Cyclone Bijli in April 2009 caused high waves and a tidal surge of up to 3 m above the normal tide. The cyclone battered 14 southeastern coastal districts of Bangladesh with heavy rain and winds of up to 100 km/h. Hundreds of electricity poles were uprooted or damaged, leaving parts of the southeastern districts without power for a long time. Cyclone Aila in May 2009 uprooted numerous electric poles, downed power lines and caused widespread power outages in the southwest coastal area of Bangladesh. Increased frequency and severity of storms due to climate change may severely affect the power distribution system in Bangladesh in the near future (Shahid, 2012). Many areas including Kuakata tourist spot, Dashmina and Kalapara Upazila towns under Patuakhali district and Amtali, Taltali and Pathorghata Upazila towns under Barguna district passed without electricity. About 150 km electricity lines out of 3200 km got damaged in Patuakhali and Barguna districts during cyclone Mahasen 2013; electricity towers collapsed, three river crossing lines got disconnected, 80 electric polls broke, 300 others got damaged and over 500 electric meters were broken.

6.9. Climate change

Climate change is expected to increase the intensity of cyclones, resulting in the penetration of storm surges further inland, causing higher damages. According to the Center for Global Development Working Paper 182 (Dasgupta et al., 2009), intensified storm surges due to SLR and ice melting will create more damaging flood conditions and inundations of the coastal cities. Cox's Bazar, Khulna, Barisal and Chandpur are identified at Ranks 1, 2, 3 and 8.5 respectively among the regional Top-10 cities of the world; and Chittagong and Khulna are estimated as highly affected population among the 25 cities with the largest population exposures (60% and 51% respectively). Their results indicate large effects in the coastal cities and the exposure of coastal urban population in the 21st century.

Coastal polders offer the first line of defense against SLR. But maintenance of sea dykes of polders will involve higher cost. Moreover, increased frequencies of cyclonic storms and tidal surges and floods are affecting the city-lives especially of the slums inhabited by urban poor. The important urban sectors that suffered severely by the previous floods in Bangladesh include urban infrastructure, industry, trade, commerce, utility services etc. As a consequence, it hampered usual productivity during and after major floods and hence increased the vulnerability of the urban poor by many-folds (Anne-Katrien Denissen, 2012).

Districts with higher extent of urbanization are also more industrialized (in terms of sectoral share of GDP) and more well off (in terms of GDP). For example, Chittagong has the highest number of urban population in the coastal zone and also has the highest amount of GDP. Khulna ranks second in these respects and Jessore ranks third. The relative share of industry in GDP is highest in Chittagong (36%), followed by Jessore (24%), Khulna (21%), Feni (20%), Cox's Bazar (19%) and Barisal (18%). Manufacturing industries are mainly located in urban or peri-urban areas. The coastal zone is poorly endowed with manufacturing establishments having percent of medium and large manufacturing units in the country. However, in terms of gross value added, these establishments are at par with the country (Ahmad, 2005).

According to the Census of Manufacturing Industries (CMI) 1999–2000, there were 3,56 medium and large establishments in the coastal zone of which 62% are located in Chittagong district alone, followed by 16% in Khulna and 8% in Chandpur. Most poorly endowed districts are Bhola, Patuakhali, Pirojpur, Barguna, Bagerhat, Lakshmipur and Noakhali.

6.10. Waste management

Solid waste management is the responsibility of the coastal Pourashavas and municipalities but the cities are unable to manage such volume of waste and to make the city clean and healthy, there is a strong need for having an integrated solid waste management system citywide. During the floods the garbage floats throughout the city area and pollutes the environment and thus different diseases outbreak in the cities and disrupt lives (Rahman, 2012).

6.11. Migration

Disaster induced migration is responsible for growing slums in the cities and in the floodplains. The rate of out migration of the coastal areas is high as the cities are relatively safer (Fig. 7). As the price of land and rent of the houses are higher than the village, these people reside in the slums or in the floodplains. It causes environmental pollution and degradation. Net Out-Migrations per day of Khulna and Barisal districts are around 31 people per day (Hassan, 2012).

There are pushing and pulling factors for this migration. The pushing factors are those which lead populations to leave their origins and pulling factors are those which attract to catch this population. This pushing factor of the residents of Khulna and pulling factors in the capital are shown in Fig. 8.

The natural disaster induced migration rates in Bangladesh are shown in Fig. 9.

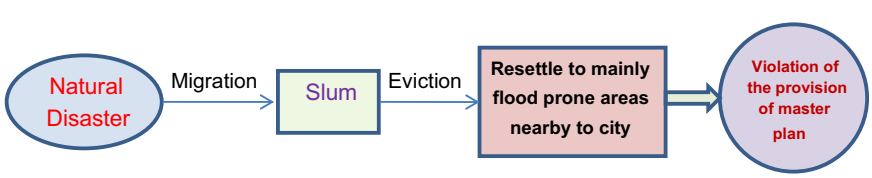

Fig. 7. How natural disaster is responsible for violation of provision of city master plan..
Source: Hassan, 2012.

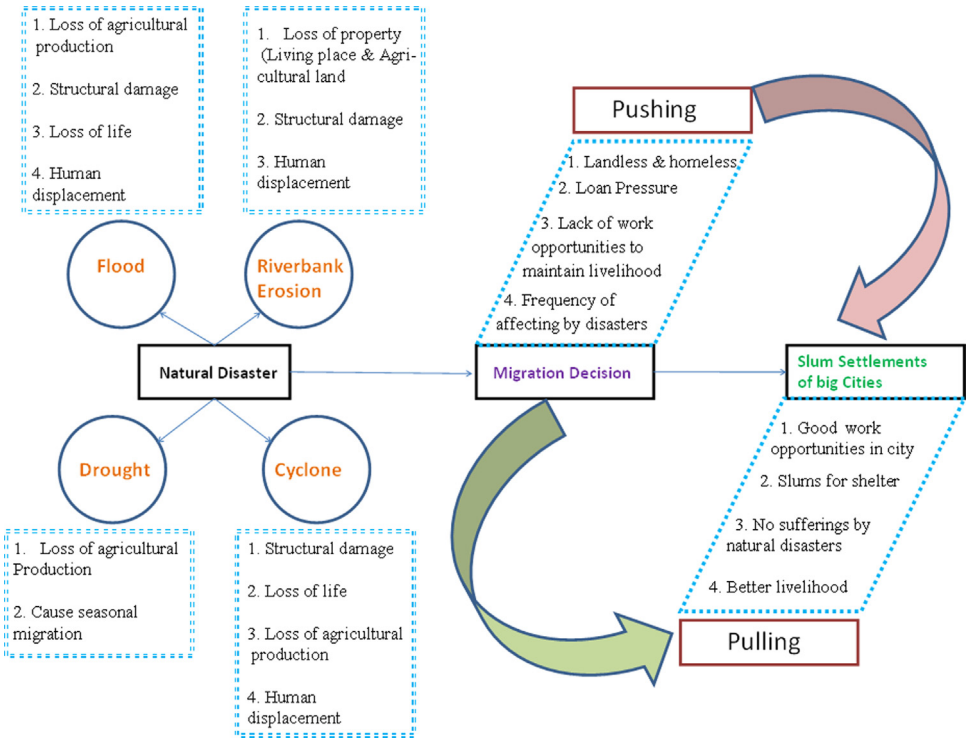

Fig. 8. Disaster induced human migration.
Source: Hassan, 2012

The capital Dhaka has already become unlivable. If the pressure continues in this trend, it will no longer remain livable. So, it is important to develop the infrastructure of the coastal cities although developing the city resilience is a major challenge.

7. Coping up behavior

People prefer using of waterways with traditional boats, canoes, bamboo and banana rafts. However, for long routes they use launch, steamer and motorized boats and trawlers in addition to road transportation.

In every town and city, there are many freshwater ponds with raised banks for using water for domestic use. Rain water harvesting in the wet monsoon is still in practice in many coastal cities.

From the early ages children are trained for swimming in the rivers, ponds and canals and in floods people usually do not get drown.

Traditionally, houses are built on wooden platform above the flood level. However, with the increasing crisis of durable timber people are constructing building with corrugated iron-sheet or coconut and Golpata leaf-thatched-roofed mud-wall houses on earth piled raised floor. Brick building multistoried buildings are also being constructed in the large cities.

Due to unavailability of power and electricity, people complete their works by daytime. However, small petrol operated power generators are used now-a-days. Small scale solar energy and efficient cook-stoves are being introduced in the coastal towns. Dry cow-dung-jute sticks are still commonly used by the people especially the slum dwellers.

In most of the towns, latrines are pit-slab designed and sweepers used to collect wastes and recycled for cropping. However, in flooding situation wastes are drained out to the wet bodies which again are being utilized by the fishes and other aquatic animals.

To control erosion, people used to plant sedges like *Cyperus* along the river banks (Fig. 10). Piling with Sundri trees are common practice in the coastal towns.

8. Recommendations

The following points are strongly recommended for implementation in the coastal urban region in Bangladesh under sustainable planning and policy framework:

(a) Increase public awareness concerning environmental training and education, particularly related to the importance of the sustainable use of coastal urban drinking water and other natural resources.
(b) Ensure community involvement in maintaining and protecting coastal urban drinking water quality and other resource development and management.
(c) Extend the technology of sustainable use of urban drinking water resources and desalination measures to the local community along with the rain water harvesting and reuse of used water (gray water recycling).
(d) Formulate a landscape management policy for coastal cities, especially of the hilly and river-channeled ones, highly essential to prevent land-sliding, erosion and water logging.
(e) Develop and train up for capacity building of the local community groups, local government, stakeholders, NGOs and national policy makers and planners involved in coastal urban drinking water resource management activities.
(f) Maintain upstream fresh water supply and mitigate the affects of tidal inundation and high salinity intrusion in the urban areas which is degrading the drinking water quality. As these are in a very deplorable condition, so re-excavation of water bodies and sinking of deep tube-well for ground water use are essential.

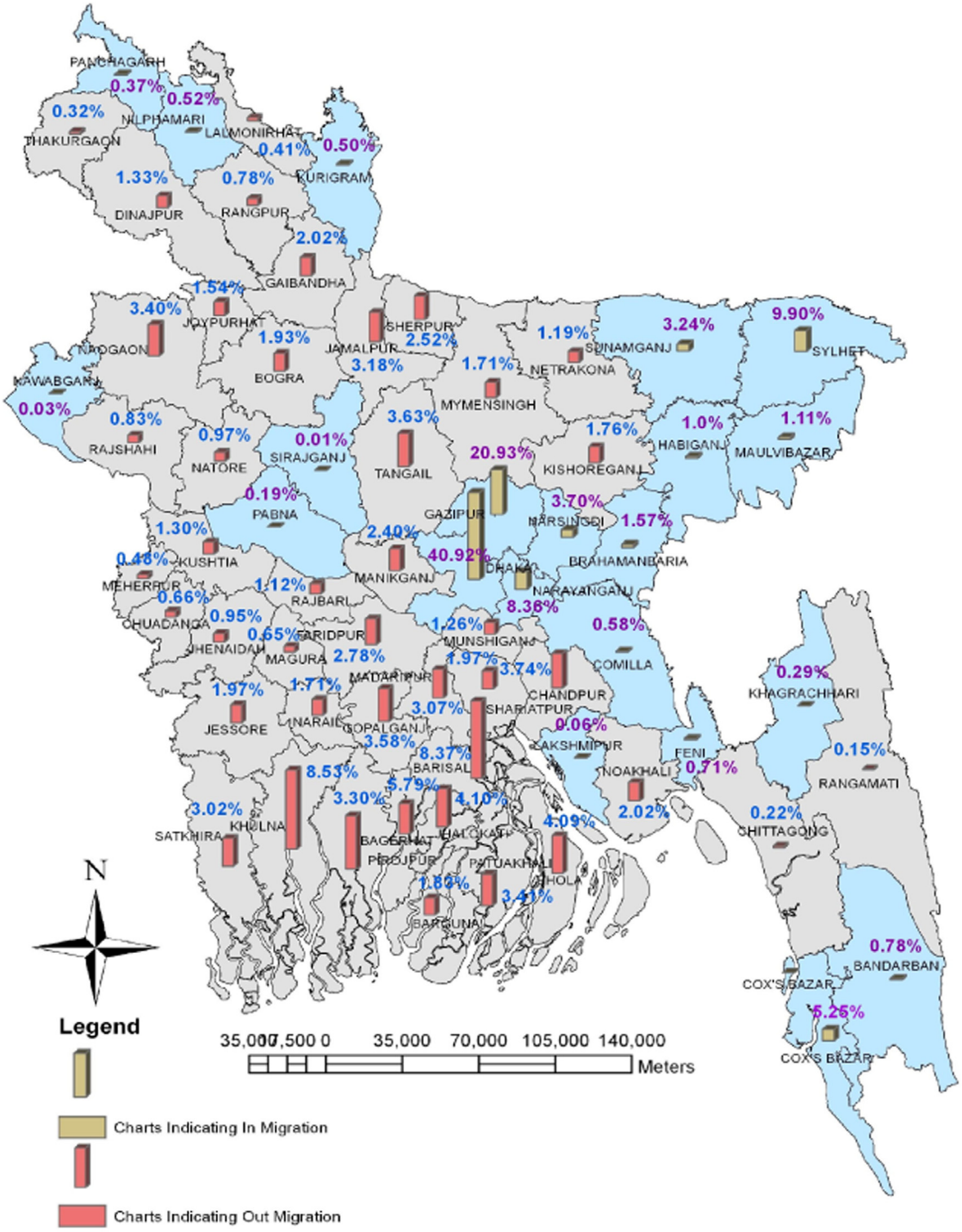

Fig. 9. Natural disaster induced migration in Bangladesh.
Source: Hassan, 2012.

(g) The national water policy should be implemented properly; in addition a policy guideline of coastal urban drinking water supply issue should be incorporated in national water policy in Bangladesh.
(h) Sanitation, sewage, power and electricity transmission system and river routes needs to be developed with proper and sustainable long-term policy frame.
(i) River and canals should be protected from encroachment and navigation system should be improved.
(j) Safe and setback distances should be strictly followed while constructing industries, buildings and other infrastructures.

9. Conclusions

Since coastal cities are ultimate shelter for the coastal people, it is very important to assess and evaluate the necessity for

Fig. 10. Bangladeshi women working together to plant sedges.

infrastructure development. This synthesis has tried to highlight some of the very important issues. Due to negligence of well-planned coastal development activities and the long term impacts, the climate change impacts like long-term water-logging, SLR, cyclones, tidal surges, floods, erosion, salinity intrusion, drainage congestion etc. have accentuated in the recent years. Most of the coastal urban conglomerates are unplanned and not facilitated by urban infrastructure facilities *viz.* appropriate transportation system, water supply and sewage, power and electricity. An integrated urban coastal water policy for rainwater harvesting and reuse of surface and gray water in the urban cities should immediately be planned and implemented. Since coastal zone is the most resourceful area of the country and the coastal cities are maintaining the linkage of production and supply-chain, the infrastructure development of the coastal cities should be undertaken on a priority basis. Bangladesh government has already taken a few steps towards infrastructure development. But it has been observed that the policies concerning coastal communities are not often rooted in ground realities and the policy formulation process is too remote and inaccessible for the communities concerned, although participation of the stakeholders in that process is all the more necessary for proper formulation and implementation (SAARC DMC, 2013).

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