Exposure of urban infrastructure because of climate change-induced flood: lesson from municipal level planning in Bangladesh

Md. Mostafizur Rahman
Department of Urban and Regional Planning, Rajshahi University of Engineering and Technology, Rajshahi, Bangladesh, and
Ishrat Islam
Department of Urban and Regional Planning, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh

Received 1 May 2020
Revised 8 June 2020
Accepted 10 June 2020

Abstract

Purpose – Bangladesh is one of the most flood-prone countries in the world. A number of research works have identified that the flood scenario will be aggravated with climate change context in Bangladesh. In 2014, Bangladesh had prepared municipal level master plan for 222 municipalities with a view to planned urban development. But climate change-induced flood has not been considered in master plan, which poses a question toward the sustainability of the plan. Ullapara Municipality of Sirajganj district has been selected to conduct the research. This study aims to evaluate how infrastructure in proposed master plan will be exposed to climate change-induced flood.

Design/methodology/approach – The methodology of this study follows geographic information system (GIS)-based flood exposure analysis of selected infrastructure. These infrastructures include transport infrastructure, educational infrastructure, health infrastructure and other urban facilities. Climate change-induced flood for the year 2040 has been used for flood exposure analysis.

Findings – It is evident from the flood exposure analysis that about 33.99% roads will be exposed to 1.5 m–2 m inundation level; seven primary school, six secondary school and four colleges would be highly exposed to 2.0 m–2.50 m inundation level; four health facilities would be exposed to 1.0 m–2.0 m inundation level because of future climate change. This inundation scenario for long duration will lead to dysfunction of concerned infrastructure and, in turn, undermine the stability of a socioeconomic system of Ullapara Municipality.

Originality/value – As the master plan is not fully implemented till now, there is scope for intervention for considering climate change-induced flood to make the plan sustainable.

Keywords Bangladesh, Infrastructure, GIS, Climate change, Master plan, Flood exposure analysis

Paper type Research paper

The authors would like to express their gratitude to Institute of Water Modelling and LGED for providing valuable data support in this research.

Ecofeminism and Climate Change
Vol. 1 No. 3, 2020
pp. 107-125
Emerald Publishing Limited
e-ISSN: 2633-4070
p-ISSN: 2633-4062
DOI 10.1108/EFCC-05-2020-0011

1. Introduction

Bangladesh is a low-lying deltaic country formed at the confluence of the Ganges, the Brahmaputra and the Meghna (GBM) basin. The geographical setting of Bangladesh with low-lying floodplain topography makes the country more vulnerable to flood (Hoque *et al.*, 2011; Islam *et al.*, 2010). Bangladesh is located at the lower part of GBM basin and receives water from 57 transboundary rivers (Ali *et al.*, 2019). Flooding in Bangladesh is an annual phenomenon during monsoon period, which experiences about 80% of annual rainfall. Monsoon flood in Bangladesh is predominantly caused from the intensity, duration and magnitude of the rainfall in the GBM basin. Annual rainfall in Bangladesh ranges from 1,500 mm in the west to over 5,000 mm in the north-east having an average annual rainfall of about 2,300 mm (Milliman *et al.*, 1989). The country experiences annual flood in its one-fifth to one-third area during pre-monsoon (April to May) and monsoon (June to September) periods. The area is generally flooded because of overflow of river in the country. The flooding of the land results in physical damages to agricultural crops, physical infrastructure and social disruptions. The flood also negatively affects livelihoods, educational institutions and economic activities (Baky *et al.*, 2012; Bhuiyan and Dutta, 2012; Mirza, 2011). For example, the 2014 flood caused inundation in Sirajganj district affecting 69,438 families (partially and fully) and 250,624 people (DMIC, 2014). It is evident from the recent past flood hazards that the flood frequency and severity is becoming acute because of high density population and anthropogenic interventions (Bhuiyan and Baky, 2014; Paul and Routray, 2010). A number of research works have identified that the monsoon flood scenario will be aggravated with future climate change context in Bangladesh, which will directly affect infrastructure, livelihood, agriculture environment and people (Hossain *et al.*, 2018; Whitehead *et al.*, 2018).

Intergovernmental Panel on Climate Change (IPCC) has predicted a scenario of possible increase in earth surface temperature for 21st century. According to IPCC, global earth surface temperature may exceed 2.0°C by the end of 21st century for many climate change scenarios compared to the 1850–1900 period. Table 1 shows the prediction of global mean surface temperature change and global mean sea level rise for the mid- and late 21st century relative to the reference period of 1986–2005 by IPCC (2013).

This increase in temperature will result in ice melting and sea level rise (SLR) in the Himalayan region. At the same time, the intensity of rainfall, 98% of which depends upon South Asian monsoon in case of Bangladesh, will also be increased leading to intense

		2046–2065		2081–2100	
	Scenario	Mean	Likely range[c]	Mean	Likely range[c]
Global mean surface temperature change (°C)[a]	RCP206	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
Global mean SLR (m)[b]	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

Notes: [a]Based on the CMIP5 ensemble; anomalies calculated with respect to 1986-2005 using HadCRUT4 and its uncertainty estimate (5-95% confidence interval); [b]based on 21 CMIP5 models; anomalies calculated with respect to 1986-2005; [c]calculated from projections as 5-95% model ranges. These ranges are then assessed to be likely ranges after accounting for additional uncertainties or different levels of confidence in models
Source: IPCC (2013)

Table 1.
Projected change in global mean surface air temperature and global mean SLR for the mid- and late 21st century relative to the reference period of 1986-2005

flooding. And although Bangladesh constitutes only 7% of the GBM basin, the country is supposed to drain out about 92% of the total flow toward Bay of Bengal. As, two-thirds of Bangladesh belong to less than 5 m above sea level, the upstream flow will directly contribute to severe flooding in Bangladesh (Dastagir, 2015).

Being one of the most flood-prone countries in the world, Bangladesh has been ranked seventh in the Global Climate Risk Index 2020 considering the impacts caused by weather-related loss events (storms, floods and heat waves) occurred from 1999 to 2018. During this period, Bangladesh has experienced about 191 climate-induced extreme weather events resulting 9th in fatalities among all countries, 37th in fatalities per 100,000 inhabitants, 17th in losses and 40th in losses per unit GDP (Eckstein *et al.*, 2019). Many research studies claimed that it is very likely for Bangladesh to be one of the most vulnerable countries of the world in the face of climate change. The increase in the SLR, resulting from global warming because of greenhouse gas in the earth's atmosphere, is expected to add fuel to the fire. This will severely affect every socioeconomic sectors in Bangladesh. The geographical settings, geology and large delta plain along with about 230 rivers put the country at particular risk. In addition, the river water from the melting Himalayan glaciers in the north and existence of Bay of Bengal in the south makes the country prone to flooding to dangerous levels. The situation is becoming more worse by the occurrence of heavy storms triggered by climatic stress. For example, the 2007 Sidr that struck southern Bangladesh killed about 1,500 people and washed out the whole paddy field (Dastagir, 2015). The cyclone and storm surge risk spans over the entire coast of Bangladesh. Climate change is likely to increase the severity of cyclones and surges leading to an additional 15% inundation of coastal area by 2050. Climate change is also expected to increase depth and extent of monsoon flooding in Bangladesh. This may cause 4% additional inundation and 15 cm increase in inundation depth over 0.4% area of the country by 2050. The combined effects of climate change may cause decline in the rice production by 3.9% and agricultural GDP by 3.1% each year up to 2050 (World Bank, 2010).

In 2014, Local Government Engineering Department (LGED) of Bangladesh prepared master plan (2011–2031) for municipal level in Bangladesh. Municipality is the lowest unit of urban local governance in Bangladesh. There are about 320 municipalities in Bangladesh, out of which 222 municipalities were taken under the project. The core objective of the project is to prepare urban infrastructure plan, land use plan, drainage master plan and traffic management plan to ensure planned urban development and to meet the increasing demands of the citizen for basic services (LGED, 2014). It is evident from the master plan report that it did not consider future climate-induced flood scenario, which poses a question toward the sustainability of the proposed urban infrastructure plan in a flood-prone country such as Bangladesh. This research aims to evaluate how different infrastructures in the proposed master will be exposed because of future climate change-induced flood and the consequences thereof.

To date many research works have been conducted on climate change and flood in Bangladesh (Ali *et al.*, 2019; Bhuiyan and Baky, 2014; Hossain *et al.*, 2018; Mirza, 2011; World Bank, 2010). However, those studies mainly focused on modeling flood under different climate change scenarios. The prime interest of those research works was improving methods of flood detection, simulation, forecasting and modeling and rarely touched upon flood exposure of infrastructure. For example, Ali *et al.* (2019) focused on identifying characteristics of flood in most vulnerable area in Bangladesh and developed the depth-damage curve. Bhuiyan and Baky (2014) developed flood hazard maps of Sirajganj Sdara Upazila for different flood magnitudes using the digital elevation model (DEM) data of Shuttle Radar Topographic Mission. Hossain *et al.* (2018) conducted analysis of perceived impacts in the face of changing climate and human activities in the coastal area of Bangladesh. They also studied the adaptive responses from the aquatic system livelihoods.

Islam *et al.* (2010) developed spatiotemporal extent of flood inundation of whole Bangladesh using MODIS data. They primarily focused on the use of satellite image in flood detection. Hoque *et al.* (2011) did similar works as Islam *et al.* (2010), where they tried to assess the capability of RADARSAT remote sensing, geographic information system (GIS) and ground data in flood monitoring and mapping. Paul and Routray (2010) explored indigenous survival strategies and their spatial variation among flood affected people. They did their study from only socioeconomic perspective. So, it is evident that the past studies mainly concentrated on flood detection and adaptation from socioeconomic point of view. There is lack of flood exposure analysis in relation to infrastructure and urban planning. But flood exposure analysis is one of the important elements of flood risk assessment and has direct implication in urban policy and planning. Although a study was conducted by World Bank in 2010 to address this issue, but this study was a national level study (World Bank, 2010), which may not be useful in local-level planning. To our knowledge, there is less attention given to exploring and understanding the local-level flood exposure in Bangladesh. So, this study aims to fill this gap by introducing flood exposure analysis in relation to infrastructure and local-level urban planning in Bangladesh.

2. Description of the study area

Sirajganj district is located on the banks of the Jamuna River. This river observes high monsoon discharge regularly, causing overflows on the banks and creating flood in most parts of the district. Ullapara municipality is one of the most flood-prone area. This municipality has been selected as a case study for this research. The municipality is located in eastern side of Ullapara Upazila of Sirajganj District and is bounded by 24°16'47.83"N and 24°20'02.11"N latitude and 89° 32'57.01"E and 89°36'01.61"E longitude. Total area of the municipality is about 13.91 km^2 (LGED, 2014). The location map of Ullapara Municipality has been shown in the Figure 1. It is home for around 47,639 people [Bangladesh Bureau of Statistics (BBS), 2011]. In this area, the flood inundation scenario will be amplified with future climate change because of upstream Himalayan glaciers melting, SLR, increased runoff and precipitation because of its geo-physical settings beside the Jamuna River (DoE, 2008). The mean elevation of Ullapara is about 10.78 m [Institute of Water Modelling (IWM), 2009]. This low elevation, urban character, important land use activities and enriched infrastructures of Ullapara Municipality make it most vulnerable to flood and the infrastructure within this Municipality will be at risk in climate-induced flood because of high level of exposure (DoE, 2008). Ullapara Municipality has been selected as case study because it represents other flood-prone municipalities across the country, because of its geo-physical settings.

Ullapara Municipality, under Sirajganj district experiences recurrent floods almost every year. The record shows that this area was severely flooded in 1949, 1956, 1961, 1962, 1966, 1968, 1974, 1979, 1987, 1988, 1996, 1998, 2002, 2004, 2007, 2008, 2014 and 2016 (Ali *et al.*, 2019). Jamuna river-borne trans boundary inflow from upstream catchment is the major contributing factor for flooding in this area. The flow of some other rivers, such as Bangali, Jamuneswari, Karatoa and Hurasagar in and around the area, also combined increase the flooding (Bhuiyan and Baky, 2014). In 1998 flood, the area was severely affected and caused enormous losses to people and resources. In 2007 flood, the whole area was inundated very quickly. As of September 10, 2007, at 6 a.m., the highest flood water level was recorded 77 cm above the Danger level, which is 13.75 m, according to Bangladesh Water Development Board, at Sirajganj point in the Jamuna river. The area was also inundated for about 15 days in 2014 flood. Some localities in this district are critically vulnerable because of low-lying area made up of deposited silt. Generally, poor people live in this area who always struggle to lead their lives throughout the year, while occurrence of flood makes it more difficult for them to survive during flood (Ali *et al.*, 2019).

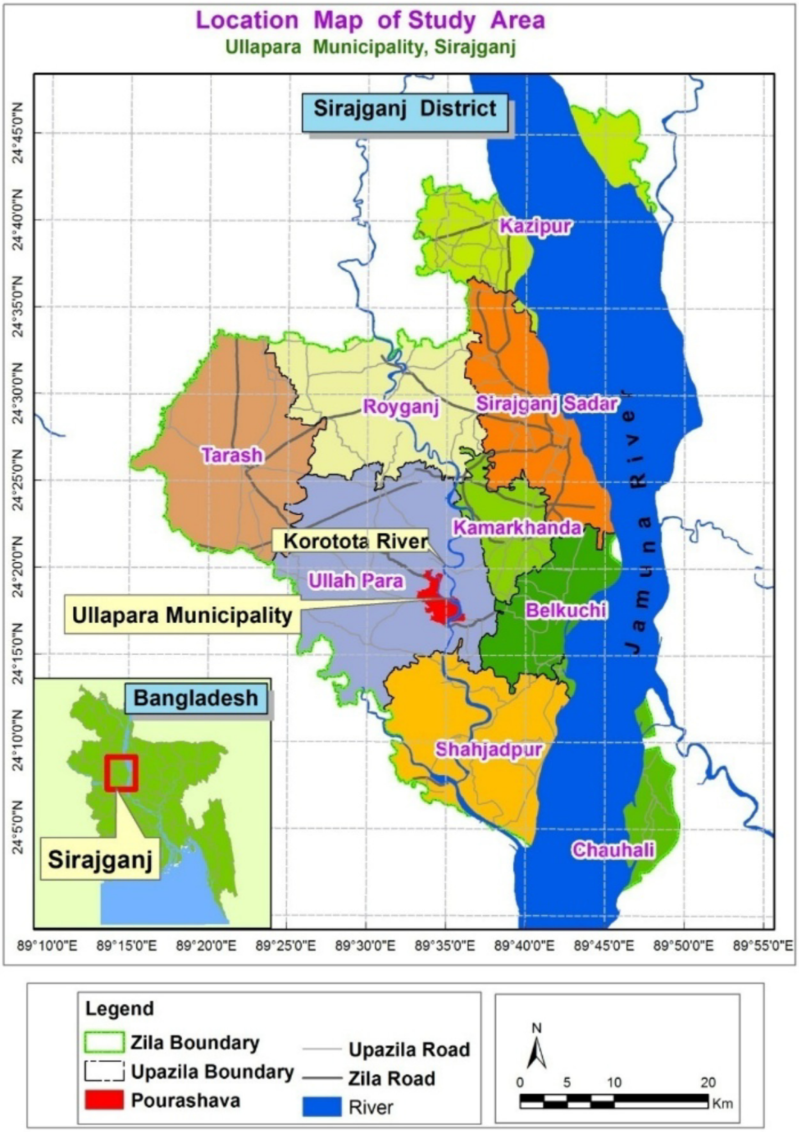


Figure 1.
Location map of the study area

According to the field-level discussion with the local people, it was found that during past severe floods, the whole area of Ullapara Municipality was inundated by floodwater. Homestead and dwellings were also submerged making people homeless and damaging agricultural crops, roads and infrastructure. Communication system was disrupted because of the inundation and damage of road. Because of the inundation of road, students could not attend schools. Public health was also threatened by waterborne diseases, as most of the wells were submerged. Similarly, the disruption of communication system affected many patients to access the health facilities. Economic system was also hampered, resulting in income loss of farmers, daily earners and small businessmen. Thus, flood negatively affects aspects of life of the people in this area.

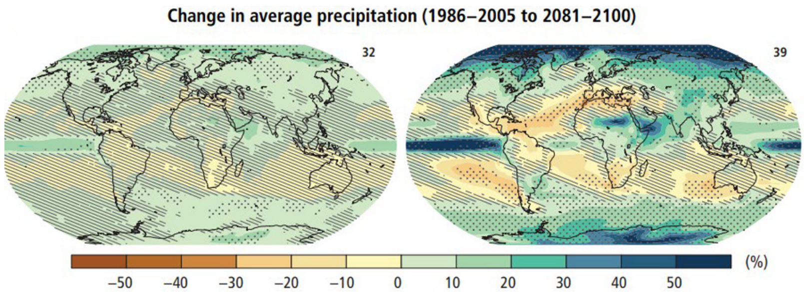
3. Data and methodology

GIS-based flood exposure analysis has been conducted to evaluate how existing and proposed infrastructure will be exposed to climate change-induced flood in the study area. ArcGIS 10.2 software has been used for flood exposure analysis. Data and methodology have been described in the subsequent sections.

3.1 Data used

This study has been carried out mainly based on secondary data, which include climate change-induced flood level data for the year 2040, DEM, selected infrastructure and land use data. The flood level data for the year 2040 and DEM have been collected from Institute of Water Modeling (IWM), Bangladesh. Generally, flood modeling is conducted based on different factors. One of important factors is precipitation. Precipitation is estimated considering different climate change scenario, e.g. low, medium and high. Figure 2 shows the change in average precipitation based on multi-model mean projections for 2081–2100 relative to 1986–2005 under the RCP2.6 (left) and RCP8.5 (right) scenarios (IPCC, 2013).

The precipitation pattern of Bangladesh cannot be obtained directly from the IPCC report. But precipitation condition of South Asia for different scenarios can be calculated from the 4th Assessment report, which is presented in Table 2 (IPCC, 2007). From this information, precipitation condition of Bangladesh can be estimated.



Source: IPCC (2013)

Figure 2. Change in average precipitation based on multi-model mean projections for 2081–2100 relative to 1986–2005 under the RCP2.6 (left) and RCP8.5 (right) scenarios

Table 2. Predicted precipitation change (%) for the next 100 years

Sub- regions	Season Scenario	2010–2039 A1Fl	2010–2039 B1	2040–2069 A1Fl	2040–2069 B1	2070–2099 A1Fl	2070–2099 B1
South Asia	DJF	–3	4	0	0	–16	–6
	MAM	7	8	26	24	31	20
	JJA	5	7	13	11	26	15
	SON	1	3	8	6	26	10

Note: DJF: December January February; MAM: March April May; JJA: June July August; SON: September October November
Source: IPCC (2007)

Climate change scenario projections show that mean monthly rainfall may significantly change over normal (i.e. current variability). It can be mentioned that climate change-induced flood data for the year 2040 has been collected from IWM. They used 13% increased precipitation because of climate change for the year 2040 for flood modeling.

This is ten-year return period flood. This flood level map has been developed under the project "Impact Assessment of Climate Change and Sea Level Rise on Monsoon Flooding" commissioned by Department of Environment, Bangladesh (DoE, 2008). In that study, the year 2040 has been considered to incorporate climate change whose usual period is about 30 years (please note that the aforementioned study by DoE was conducted in 2008). In this research, infrastructure includes transport infrastructure, educational infrastructure, health infrastructure and other urban facilities. These data have been collected from LGED that has been prepared under Upazila Towns Infrastructure Development Project . Detailed list of the data has been presented in Table 3.

3.2 Flood exposure analysis

GIS-based flood exposure analysis has been conducted in the study. Steps of flood exposure analysis have been discussed further.

3.2.1 Generation of flood inundation map. Flood inundation map has been generated from water level depth map and DEM through raster calculation in ArcGIS 10.1 software. DEM (Figure 3) has been deducted from flood map (Figure 4) to generate flood inundation depth map. Cell size of both flood level data and DEM has been taken as 20 m (Figure 5).

3.2.2 Classification of flood hazard map. Flood hazard is the probability of occurrence of a potentially damaging flood event of a certain magnitude within a given time and area (Brooks, 2003). The flood inundation depth is not same across the municipality. So the inundation of infrastructure and land will not be same everywhere. In some places, inundation will be higher and in some places inundation will be lower and even there may be flood free area. Thus, it requires classifying the flood hazard map to understand level of exposure and vulnerability of specific infrastructure in particular location. To conduct flood exposure analysis, it is necessary to classify flood hazard map. The interval of classification was different in many studies. Following the World Bank (2010) classification, six categories of flood hazard zones have been identified based on extent of flood inundation depth. These hazard zones are Zone-A, Zone-B, Zone-C, Zone-D, Zone-E and Zone-F and these zones are characterized with 0 m–0.5 m, 0.5 m–1 m, 1 m–1.5 m, 1.5 m–2 m, 2 m–2.5 m and 2.5–3 m

Sl no.	Data	Data type	Format	Source
1	Flood water level	Raster	GRID	IWM
2	Land elevation	Raster	GRID	IWM
3	Road network	Vector	Shapefile	LGED
4	Terminal facilities	Vector	Shapefile	LGED
5	Educational infrastructure	Vector	Shapefile	LGED
6	Health facilities	Vector	Shapefile	LGED
7	Community center	Vector	Shapefile	LGED
8	Fire station	Vector	Shapefile	LGED
9	Police station	Vector	Shapefile	LGED
10	Solid waste disposal site	Vector	Shapefile	LGED
11	Land use	Vector	Shapefile	LGED
12	Municipality ward boundary	Vector	Shapefile	LGED

Table 3.
Data used in this study and sources

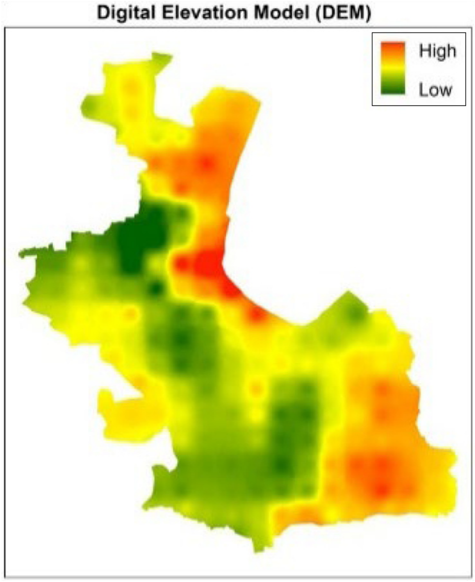


Figure 3.
DEM

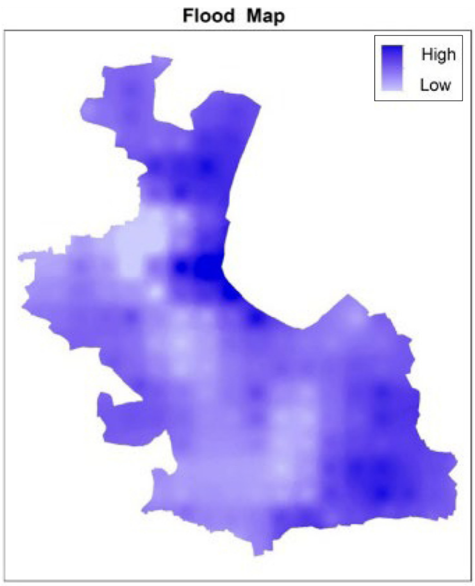


Figure 4.
Flood map (water level)

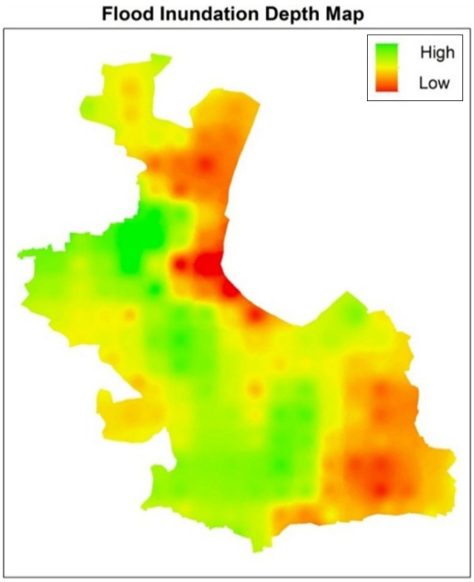


Figure 5.
Generated flood inundation depth map

inundation depth, respectively. The climate change-induced flood hazard zone has been presented in Figure 6.

3.2.3 Quantification of exposed infrastructure. The next step is to quantify the exposed elements. For this, the infrastructure maps are overlaid on flood hazard map to quantify the exposed elements in different inundation depth.

The exposed elements are quantified in terms of number (for point feature, e.g. educational infrastructure), length (for linear feature, e.g. road) and area (for area feature, e.g. land). Then the quantified infrastructures are presented in the form of tables, figures and maps. After the flood hazard map has been classified, the exposed infrastructure is determined by overlaying infrastructure map and flood hazard map. Thus, in this stage overlaying and intersection operation are done in ArcGIS 10.1 software to identify the exposed infrastructure at various inundation depths.

4. Result and discussion

In this section, results of flood exposure analysis of different infrastructures and their consequences will be discussed.

4.1 Transport infrastructure

Transport and communication infrastructure is a key element for the economic growth and development. In urban areas, roads generally comprise the most important part of the transport infrastructure system. Transport and communications infrastructure as a means of access to basic services, residence, workplace and other urban facilities is the key factor to accelerate economic growth and sustainable development (Matthias, 2003). So, provision and development of road infrastructure should be well planned with long-term vision, keeping in mind possible future threats that may be harmful to these infrastructures (UN-HABITAT, 2014).

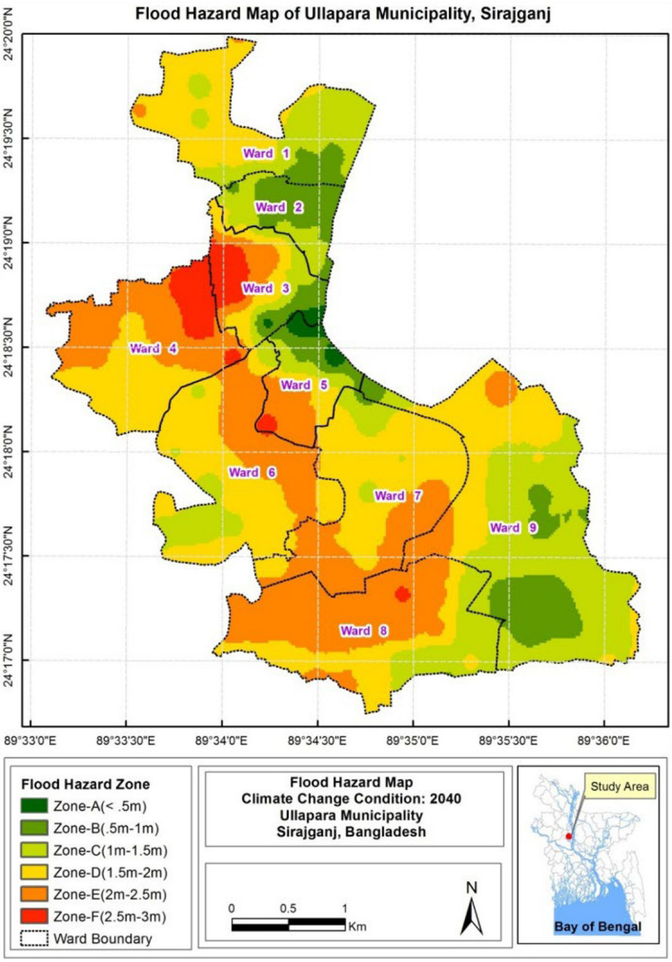


Figure 6.
Flood hazard map of the study area

At present, the total road length in Ullapara Municipality is about 84.51 km. In newly proposed master plan, only 16.39 km additional road has been proposed. Figure 7 illustrates how road infrastructure is supposed to be exposed because of climate change-induced flood in the Ullapara Municipality. From the flood exposure analysis, it has been assessed that about 20.41%, 33.99% and 26.35% pucca road will be exposed to 1 m–1.5 m, 1.5 m–2 m and 2 m–2.5 m inundation, respectively. About 28.69%, 28.72% and 29.99% katcha road will be exposed to 1 m–1.5 m, 1.5 m–2 m and 2 m–2.5 m flood inundation, respectively. In future, the inundation scenario will be increased and road infrastructure would be highly exposed because of climate change-induced flood. This exposure to flooding will shorten the life expectancy of roads in Ullapara Municipality. The stress of water may cause damage, requiring frequent maintenance, repairs and rebuilding. High level of exposure of and damage to road infrastructure in Ullapara Municipality will cause long-term impacts, such as disruptions to clean water (in case of piped water supply), electricity connection, gas

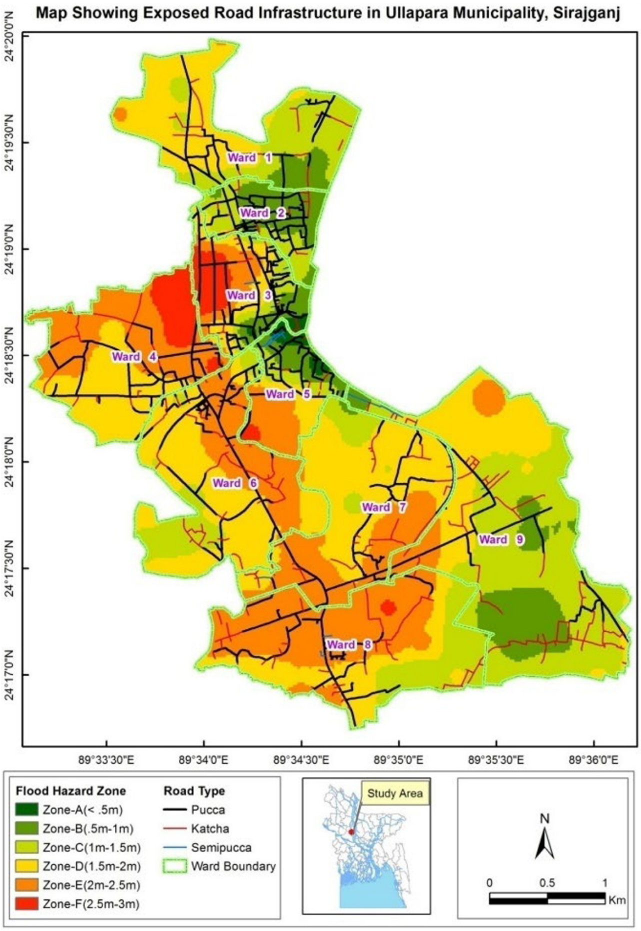


Figure 7.
Road infrastructure to be exposed to climate change-induced flood

connection, access to education and health care and other basic urban services. In this area, because of inundation and damage of road infrastructure, communication will be disrupted and economic activities will come to a standstill, resulting in dislocation and the dysfunction of normal life for a period much beyond the duration of the flooding.

Student will not be able to attend the educational institution for long duration, which may lead to dropout from the school; patient may find it difficult to access health-care facilities, which may cause increased intensity of diseases or deaths. Business people will find it difficult to access their workplace leading to lessening their income.

In the proposed master plan, there is no consideration of future climate change-induced flood. Different studies show that future climate change will negatively affect the road infrastructure through increased precipitation, increased temperature and other weather events. The intensity of such impact will be higher in developing countries (Paul and Routray, 2010; AUSTROADS, 2004). So, it is clear from the discussion that existing and proposed road systems in Ullapara Municipality will not suffice to maintain smooth communication during climate change-induced flood in this area rather the severity will be increased in 2040.

4.2 Educational infrastructure

Educational infrastructure is considered as one of the critical facilities that is supposed to be heavily affected by climate change-induced flood in developing countries. In Bangladesh, there are already evidences of negative impact of flood on educational infrastructure (Das, 2010). The severity of this negative impact would be increased in more flood-prone areas. In Ullapara Municipality, there are different types of educational institutions out of which primary schools, secondary schools and colleges have been considered for flood exposure analysis. According to the Ullapara Municipality Master Plan, there will be about 18 primary schools, 11 secondary schools and 8 colleges in the year 2031. Figure 8 illustrates the different types of educational infrastructures that are supposed to be exposed to climate change-induced flood in the study area. From the Figure 8, it is seen that most of the educational infrastructure in thein the study area will be exposed to future flood. The figure 8 depicts that in Ullapara Municipality about 68.75%primary schools and 72.72% secondary school will be exposed to more than 2 m inundation; 87.50% colleges will be exposed to 1 m–2 m inundation. Overall, 91.43% educational institutions will be exposed to more than 1 m inundation because of climate change-induced flood.

Access to education has long been considered as an important vehicle for poverty alleviation. Educational facility is thought as one of the important facilities and it plays a vital role to increase the literacy rate in any area (Habibullah and Williams, 2006). Education is recognized as a basic human right and it is closely linked to virtually all dimensions of development – economic, social and human [United Nations Educational, Scientific and Cultural Organization (UNESCO), 1997]. It is also a key factor in improving the quality of governance that has a significant impact on national income (Habibullah and Williams, 2006).

In Bangladesh, flood normally occurs during the monsoon season from June to September and stays normally from three to five weeks. Because of climate change, the inundation scenario will be increased during this period. As a result, educational institution will remain closed during floods because of high level of inundation. This will create a gap in the delivery of educational services, students will not be able to attend and perform well in subsequent exams and they will lose interest in study and will be reluctant to attend schools leading to higher dropout rate. The flood inundation of educational infrastructure for longer period along with high floodwater flow may also lead to destruction or damage of the infrastructure, which may require replacement or reconstruction. This discussion makes it clear that with changing climate, the proposed plan for educational facilities in Ullapara Municipality will not work properly rather it will create difficulties to access the educational facilities. These difficulties will affect education level of the locality.

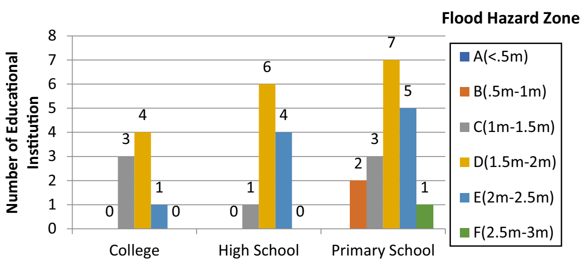


Figure 8.
Flood inundation level of educational institution in Ullapara Municipality

4.3 Health infrastructure

In climate change-induced flood, it will be a great challenge to maintain the health services during flood because health infrastructures are supposed to be exposed in climate change-induced flood. So, it is necessary to study how health infrastructure will be exposed to climate change-induced flood. According to Ullapara Municipality Master plan (2011–2031), there will be total 13 community clinics including one Upazila health complex. The proposed distribution of community clinic with respect to future flood inundation scenario has been presented in Figure 9, which illustrates how community clinic will be inundated in future climate change scenarios in the study area. From exposure analysis, it has been found that about 15.38% health Infrastructure will be exposed to Zone-B (0.5 m–1.0 m inundation), Zone-C (1.0 m–1.5 m) inundation and Zone-F (2.5–3.0 m inundation). About 30.77% and 28.08% will be exposed to Zone-D (1.5 m–2.0 m inundation) and Zone-E (2.0 m–2.5 m inundation), respectively, because of climate change-induced flood in Ullapara Municipality.

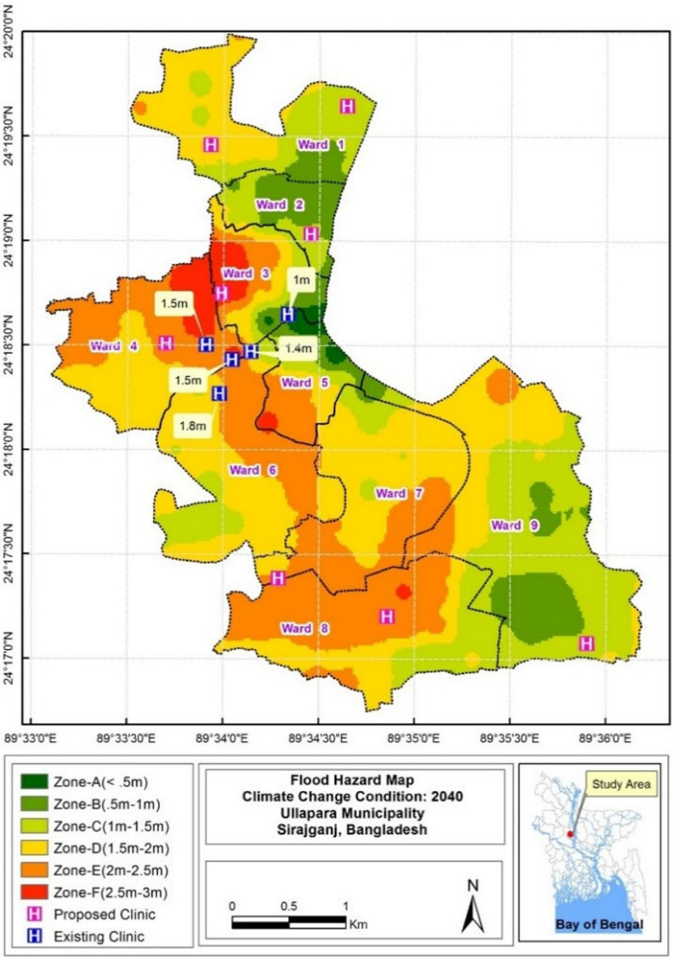


Figure 9.
Location of health facilities in respect of climate change-induced flood

This inundation scenario indicates that it will be a great challenge to meet the increasing health-care facilities that would be required because of increase of both vector-borne and waterborne diseases to be caused by global warming under climate change scenario.

Bangladesh is already vulnerable to outbreaks of infectious, waterborne and other types of diseases (WHO, 2002). Records show that the incidences of malaria increased from 1,556 cases in 1971 to 15,375 in 1981 and from 30,282 cases in 1991 to 42,012 in 2004 (WHO, 2010). Other diseases such as diarrhea and dysentery are also on the rise, especially during the summer months. It has been predicted that because of climate change, the combination of higher temperatures and potential increase in summer precipitation and increase in flood may cause the spread of many infectious and waterborne diseases (BCAS and NIPSOM, 2007). A study conducted by DoE indicates that waterborne diseases remained a major public health problem in Bangladesh because of climate change-induced flood. And the scenario of such waterborne diseases will be severe in more flood-prone areas of Bangladesh (DoE, 2008). Climate change will also bring about additional stresses such as dehydration, malnutrition and heat-related morbidity, especially among children and the elderly. Several studies recommended specific activities, programs, measures to be taken to address health impacts because of climate change (DoE, 2008; WHO, 2003; IPCC, 2001, IPCC, 2007; Githeko and Woodward, 2003). Among others, protection of health infrastructure from climate change-induced flood has been identified as a key element of policies and programmes (Campbell-Lendrum and Corvalán, 2007). Many researchers argued that if health infrastructures are damaged or functionally disrupted by flood events, it will affect the access to and quality of health care and any breakdown of health services will be a situation of double jeopardy (Menne, 1999; Milsten, 2000; Orellana, 2002).

4.4 Urban facilities

The urban facilities that are now being built in small urban areas of Bangladesh are particularly vulnerable to flood damage. The vulnerability of urban facilities is expected to increase because of climate change-induced flood. Figure 10 illustrates how urban facilities will be exposed to future climate change-induced flood in Ullapara Municipality. Four important urban facilities have been considered for flood exposure analysis. These are community center, fire service, police station and solid waste disposal site. Levels of flood exposure of these facilities and the consequence are discussed further.

4.4.1 Community centers. Community centers are public locations where members of a community tend to gather for group activities, social support, public information and other purposes. It performs many functions in its community and is an important part of social life. At present, there is no community center in Ullapara Municipality. However, based on the projected population and planning standard, one community center has been proposed in Ullapara Municipality Master Plan. From the flood exposure analysis, it is seen that if proposed community center is built without any height enhancement, then it would be highly exposed to climate change-induced flood for about 2.0 m–2.50 m inundation depth. This inundation for long time during flood and even in post-flood period will hamper the services. If this facility is inundated for long period, it will not be able to serve the purpose. Even it will not be functional after immediate flood while cleanup and repairs will be undertaken after flood.

4.4.2 Fire station. A fire station, by its nature and function, is a critical facility and needs to function continuously. Fire service is essential for the delivery of vital services and for the protection of the community. The adverse effects of impaired fire station can extend far beyond direct physical damage. This facility may be isolated by the flood, requiring

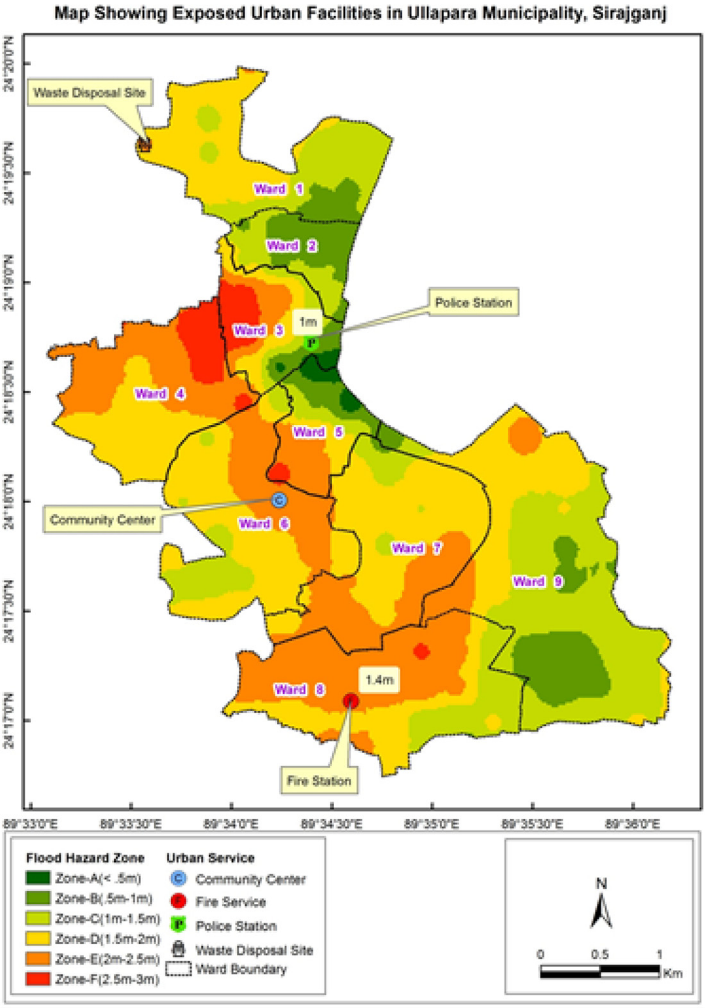


Figure 10.
Location of urban facilities in respect of climate change-induced flood

additional resources to maintain its operations and thus should be located in flood-free areas.

At present, there is one fire station in Ullapara Municipality, which serves the whole Upazila. The flood exposure analysis shows that the existing fire station is supposed to be exposed to about 2.0 m–2.50 m inundation in future climate change-induced flood. From the consultation with fire station office, it is found that at present there are 3 firefighting trucks, 3 firefighting water tenders, 2 towing vehicles, 4 portable pumps, 1 rescue vehicle, 2 foam tenders, 2 chemical tenders, two cold cuts (cobra), 20 fire extinguishers and other valuable apparatus in the Ullapara Fire Brigade. If the station is inundated, then the total system of fire station will collapse; it will be difficult to move its heavy and bulky apparatus and even they may be damaged or destroyed. The inundation of apparatus may lead to dysfunction. The building may be damaged because of inundation for longer time. In Ullapara

Municipality Master Plan, there is no consideration of climate change-induced flood. That is why, this inconsiderateness will cause flood inundation of fire station, making it unoperational and which will further lead to severe losses of lives and properties.

4.4.3 Police station. Police department is the law enforcement division of any city. The department is responsible for the enforcement of state law, as well as local ordinances. This is a symbol of safety and security to the people of a locality and responsible for the maintenance of public order, prevention and detection of crimes in the state. So, it should be ensured that police station is not disrupted by any means. At present, in Ullapara Municipality there is one police station, which serves the whole Upazila. Flood exposure analysis shows that the police station is supposed to be exposed to 0.5 m–1.0 m inundation in future climate change-induced flood. If the police station is inundated for long time during flood, what would be the situation at that time? They themselves will be at risk because of inundation in flood and will be busy to save themselves. When they will be at risk, how will they be able to serve the people? When this critical facility is located in flood-prone space, valuable records may be lost. Ultimately, the law and order situation will be deteriorated and they will not be able to take part in search and rescue operation and relief work, if needed.

4.4.4 Solid waste disposal site. Municipal solid waste consists of various organic and inorganic matters. Some of these may be hazardous and thus harmful to environment and health. So, solid waste management is an important health issue. It needs to be addressed because of several reasons ranging from its impact on health and the environment. Improper management of solid waste has negative impact on environment; pollutes the local environment (such as contamination of groundwater and/or aquifers by leakage or sinkholes and residual soil contamination during landfill usage, as well as after landfill closure); causes off-gassing of methane generated by decaying organic wastes (methane is a greenhouse gas many times more potent than carbon dioxide and can itself be a danger to inhabitants of an area); and harbors disease vectors such as rats and flies. The negative impact of solid waste may be triggered if it is inundated by floodwater.

From the flood exposure analysis, it is seen that the proposed solid waste disposal site in Ullapara Municipality would be inundated up to 2.0 m–2.5 m inundation because of climate change-induced flood. The floodwaters could collect and transport chemical pollutants and waste to Ullapara Municipality and its adjoining area. Inundation of waste disposal site will lead to increased leaching of pollutants into the groundwater and methane generation to the atmosphere. This could cause serious damage to the locality, both physically and socially. In Ullapara Municipality master plan, there is no consideration of future climate change-induced flood. Even there is no proposal for protective or adaptive measures regarding waste disposal site in response to flood. But from the analysis it is found that the proposed waste disposal site is located in Zone-E, which is characterized with 2.0 m–2.50 m flood inundation and, in turn, this will cause environmental risk to Ullapara Municipality.

5. Conclusion

Bangladesh is already vulnerable to many climate change-related extreme events and natural disasters. It is expected that climate change will bring changes in characteristics of natural hazards. Studies and assessments of impacts, vulnerabilities and adaptation to climate change and SLR for Bangladesh clearly demonstrates that Bangladesh is one of the most climate vulnerable countries in the world. Many sectors will be affected by climate change in Bangladesh. Infrastructure is one of the most vulnerable sectors to climate. This present case study is based on proposed master plan prepared by LGED and is an attempt to examine how infrastructure will be affected by climate change-induced flood in Ullapara Municipality. This study finds that most of the infrastructure, both existing and proposed, will be exposed to climate change-induced flood. The inundation of infrastructure will severely affect the socioeconomic life including education, health, business and income. In future, the inundation scenario will be aggravated because of climate change. This exposure will lead to dysfunction of concerned infrastructure and, in turn, undermine the stability of the socioeconomic system of Ullapara Municipality. This study also indicates that infrastructure of other urban areas is susceptible to flood exposure. As the infrastructure plan is not implemented till now, there is a scope for further intervention in the plan to incorporate climate change-induced flood for sustainable urban development.

This study is an attempt to understand how climate change-induced flood may affect urban infrastructure and their consequences. Many researchers suggest that proper climate-adaptive and climate-resilient urban planning can tackle the negative impacts with climate change in many cases. For this, individual to collective and local to global actions are required. Achieving adaptive and resilient planning encompasses many facets. Recent studies on climate change adaptation strategies underscore the need for attention to multilevel governance, i.e. governance across all levels of government and active engagement with stakeholders within a particular level for successful adaptation with climate extremes (Corfee-Morlot *et al.*, 2009). Sphere of multilevel governance encompasses local, regional, national and international governance. Governance at all these levels is somehow interconnected. However, local governance is directly linked with cities and urban planning and they can play an important role in the preparation and implementation of climate-resilient urban planning. There is consensus that climate change must be integrated and mainstreamed in local-level plan, policies and programmes to adapt with climate change. Many cities are developing number of tools and principles in support of addressing climate change in urban planning. This requires coordinated approach, city-scale climate action planning and measures through urban planning in response to evaluation and understanding of vulnerability and probable risk. One element to achieving this is analyzing flood exposure of infrastructure. The aim of this research was to address this component of the whole process of mainstreaming climate change in urban planning. This approach of exposure analysis may be helpful for policymakers in anticipating the situation and bringing their attention to incorporate climate change in infrastructure planning. The next step of research may be identifying the sustainable ways in which we can integrate climate change-induced flood into urban planning.

References

Ali, M.H., Bhattacharya, B., Islam, A.K.M.S., Islam, G.M.T., Hossain, M.S. and Khan, A.S. (2019), "Challenges for flood risk management in flood-prone Sirajganj region of Bangladesh", *Journal of Flood Risk Management*, Vol. 12 No. 1, doi: 10.1111/jfr3.12450.

AUSTROADS (2004), Impact of Climate Change on Road Infrastructure, Sydney, available at: www.austroads.com.au

Baky, A.A., Zaman, A. and Khan, A.U. (2012), "Managing flood flows for crop production risk management with hydraulic and GIS modeling: case study of agricultural areas in Shariatpur", *APCBEE Procedia*, Vol. 1, doi: 10.1016/j.apcbee.2012.03.052.

Bangladesh Bureau of Statistics (BBS) (2011), Population census 2011, Dhaka.

BCAS and NIPSOM (2007), *Climate Change and Health Impacts*, Report prepared for Climate Change Cell, Ministry of Environment and Forests, Department of Environment, Dhaka.

Bhuiyan, S.R. and Baky, A.A. (2014), "Digital elevation based flood hazard and vulnerability study at various return periods in Sirajganj Sadar Upazila", *International Journal of Disaster Risk Reduction*, Vol. 10, doi: 10.1016/j.ijdrr.2014.06.001.

Bhuiyan, M.J.A.N. and Dutta, D. (2012), "Analysis of flood vulnerability and assessment of the impacts in coastal zones of Bangladesh due to potential sea-level rise", *Natural Hazards*, Vol. 61 No. 2.

Brooks, N. (2003), "Vulnerability, risk and adaptation: a conceptual framework", *Tyndall Centre for Climate Change Research*, East Anglia, p. 38, available at: https://gsdrc.org/document-library/vulnerability-risk-and-adaptation-a-conceptual-framework/

Campbell-Lendrum, D. and Corvalán, C. (2007), "Climate change and developing-country cities: implications for environmental health and equity", *Journal of Urban Health*, doi: 10.1007/s11524-007-9170-x.

Corfee-Morlot, J. Kamal-Chaoui, L. Donovan, M.G. Cochran, I. Robert, A. and Teasdale, P.J. (2009), "Cities, climate change and multilevel governance (no. 14)", available at: www.oecd.org/env/cc/44242293.pdf

Das, P.K. (2010), Climate Change and Education: Bangladesh, Educational Philosophy and Theory, available at: www.preventionweb.net/files/16355_climatechangeedbangladesh.pdf

Dastagir, M.R. (2015), "Modeling recent climate change induced extreme events in Bangladesh: a review", *Weather and Climate Extremes*, Vol. 7, pp. 49-60, doi: 10.1016/j.wace.2014.10.003.

DMIC (2014), Stuation Report, available at: https://reliefweb.int/sites/reliefweb.int/files/resources/SitRep-140910.pdf

DoE (2008), *Impact Assessment of Climate Change and Sea Level Rise on Monsoon Flooding*, Department of Environment, Dhaka.

Eckstein, D. Künzel, V. Schäfer, L. and Winges, M. (2019), "Global climate risk index 2020 who suffers most from extreme weather events?", available at: https://germanwatch.org/sites/germanwatch.org/files/20-2-01eGlobalClimateRiskIndex2020_14.pdf

Githeko, A.K. and Woodward, A. (2003), "International consensus on the science of climate and health: the IPCC Third Assessment Report", in McMichael, A.J., Campbell-Lendrum, D.H., Corvalán, C.F., Ebi, K.L., Githeko, A.K., Scheraga, J.D. and Woodward, A. (Eds), *Climate Change and Human Health-Risks and Responses*, World Health Organization, pp. 43-60.

Habibullah, K. and Williams, J.B. (2016) "Poverty alleviation through access to education: can e-learning deliver?", U21Global Working Paper No. 002/2006, 1 July, available at: https://ssrn.com/abstract=1606102 or doi: 10.2139/ssrn.1606102.

Hoque, R., Nakayama, D., Matsuyama, H. and Matsumoto, J. (2011), "Flood monitoring, mapping and assessing capabilities using RADARSAT remote sensing", *Natural Hazards*, Vol. 57 No. 2, doi: 10.1007/s11069-010-9638-y.

Hossain, M.A.R., Ahmed, M., Ojea, E. and Fernandes, J.A. (2018), "Impacts and responses to environmental change in coastal livelihoods of south-west Bangladesh", *Science of the Total Environment*, Vol. 637-638, doi: 10.1016/j.scitotenv.2018.04.328.

Institute of Water Modelling (IWM) (2009), National Digital Elevation Model (DEM) of Bangladesh, Updated from Survey of Bangladesh (SOB) DEM, 1960.

IPCC (2001), Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, in Houghton, J.T., Ding, D.J., Griggs, M., Noguer, P.J., van der Linden, X., Dai, K., Maskell and Johnson, C.A. (Eds), Cambridge University Press, Cambridge, United Kingdom and New York, NY, p. 881.

IPCC (2007), "Regional climate projections", in Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M. and Averyt, K.B. (Eds), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, available at: www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter11-1.pdf

IPCC (2013), "Climate change 2013: the physical science basis summary for policymakers", In Stocker, V. B., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A. and Xia, Y. (Eds), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, available at: https://archive.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf

Islam, A.S., Bala, S.K. and Haque, M.A. (2010), "Flood inundation map of Bangladesh using MODIS time-series images", *Journal of Flood Risk Management*, Vol. 3 No. 3, doi: 10.1111/j.1753-318X.2010.01074.x.

LGED (2014), *Ullapara Pourashava Master Plan: 2011-2031*, Bangladesh, Dhaka.

Matthias, R. (2003), "Modeling infrastructure vulnerabilities and adaptation to climate change in urban systems: methodology and application to metropolitan Boston", Paper presented at 43rd Congress of the European Regional Science Association, available at: www.jyu.fi/ersa2003/cdrom/papers/400.pdf

Menne, B. (1999), "Floods and public health consequences, prevention and control measures – 1st draft", *UN-ECE Task Force Meeting on Flood Prevention and Protection*, 15-17 April, WHO – European Center for Environment and Health, Berlin.

Milliman, J.D., Broadus, J.M., Gable, F., Milliman, J.D., Broadus, J.M. and Gable, F. (1989), "Environmental and economic implications of rising sea level and subsiding deltas: the Nile and Bengal examples", *Ambio*, Vol. 18 No. 6, pp. 340-345.available at: www.jstor.org/stable/4313605

Milsten, A. (2000), "Hospital responses to acute-onset disasters: a review", *Prehospital and Disaster Medicine*, doi: 10.1017/S1049023X00024900.

Mirza, M.M.Q. (2011), "Climate change, flooding in South Asia and implications", *Regional Environmental Change*, Vol. 11<SE-START> NO. </SE-START>S1, doi: 10.1007/s10113-010-0184-7.

Orellana, C. (2002), "Germany counts cost of flood damage to health-care services", *Lancet*, doi: 10.1016/S0140-6736(02)09888-4.

Paul, S.K. and Routray, J.K. (2010), "Flood proneness and coping strategies: the experiences of two villages in Bangladesh", *Disasters*, Vol. 34 No. 2, doi: 10.1111/j.1467-7717.2009.01139.x.

United Nations Educational, Scientific and Cultural Organization (UNESCO) (1997), Adult Education in a Polarizing World, UNESCO, Paris, available at http://unesdoc.unesco.org/images/0011/001137/113758eo.pdf

UN-HABITAT (2014), "Planning for climate change: a strategic, values-based approach for Urban planners, available at: www.zaragoza.es/contenidos/medioambiente/onu/1319-eng-res1_Planning_for_Climate_Change_Guide.pdf

Whitehead, P.G., Jin, L., Macadam, I., Janes, T., Sarkar, S., Rodda, H.J.E., … Nicholls, R.J. (2018), "Modelling impacts of climate change and socio-economic change on the Ganga, Brahmaputra, Meghna, Hooghly and Mahanadi river systems in India and Bangladesh", *Science of the Total Environment*, Vol. 636, doi: 10.1016/j.scitotenv.2018.04.362.

World Bank (2010), "Economics of adaption to climate change: Bangladesh country study", available at: https://openknowledge.worldbank.org/handle/10986/12837

Corresponding author
Md. Mostafizur Rahman can be contacted at: mostafizur@urp.ruet.ac.bd