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Flood loss assessment and risk management plan for aquaculture and agriculture in South West Bangladesh

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CGIAR RESEARCH PROGRAM ON Fish

WorldFish

Flood loss assessment and risk management plan for aquaculture and agriculture in South West Bangladesh

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Citation

The publication should be cited as: Morshed MM, Khan N, Chakraborty T, Azad uz zaman Q, Zzaman MRU and Dickson M. 2018. Flood loss assessment and risk management plan for aquaculture and agriculture in South West Bangladesh. Khulna, Bangladesh: WorldFish. Special Study Report.

Acknowledgments

This work was undertaken as part of the CGIAR Research Program on Fish. This publication was made possible by the support of the British people through the Improving Food Security and Livelihoods Project of the United Kingdom Agency for International Development (UKAid).

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List of abbreviations

2D	Two Dimensional
3D	Three Dimensional
BBS	Bangladesh Bureau of Statistics
BARC	Bangladesh Agriculture Research Council (BARC)
DEM	Digital Elevation Model
EC	Electrical Conductivity
GDP	Gross Domestic Product
GIS	Geographic Information System (GIS)
GoB	Government of Bangladesh
ICZM	Integrated Coastal Zone Management (ICZM)
IDW	Inverse Distance Weight
IFSL	Improving Food Security & Livelihoods Project
KUET	Khulna University of Engineering & Technology
SPA	Service Provider Association
NGOs	Non-Government Organization
RS	Remote Sensing (RS)
LSP	Local Service Provider
SWMM	Storm Water Management Model (SWMM)
USGS	United States Geological Survey (USGS)

Executive summary

Since 2015, United Purpose (Former Concern Universal) has been implementing the Improving Food Security and Livelihoods project in Bangladesh in partnership with WorldFish and Helvetas, promoting better informal services and networking among rural farmers. The project, funded by UKAid, was designed to improve food security and livelihoods for some of the poorest and most vulnerable people in south western Bangladesh.

A special study was implemented by WorldFish to assess flood losses and develop a risk management plan for aquaculture and agriculture in south-west Bangladesh. The study focused on six upazilas – Bagerhat, Fakirhat, Mollahat, Batiaghata, Chitalmari and Rupsha in Khulna and Bagerhat districts.

The study aimed to develop an interactive GIS based map identifying potential risks to farming practices, to document aquaculture and integrated aquaculture-agriculture practices and their adaptation to changing environmental and market conditions, to identify vulnerability zones and propose land use zones to mitigate salinity intrusion and to recommend risk-reduction strategies.

Geographic Information System (GIS) and Remote Sensing Techniques (RS), complemented by field surveys and focus group discussions were used to calculate land use changes, salinity levels, water logged areas, flood frequencies and flood heights. Field survey and focus group discussions data were collected through 12 focus group discussions with advanced farmers and local service providers (LSPs) in 6 upazilas. Thereafter, using Digital Elevation Modeling (DEM), flood risks were assessed for the study area. Flood protection requirements were assessed and a particularly intense rainfall event was explored to provide further detail. A HEC- RAS hydrologic model was used to develop GIS based flooding scenarios and estimate water depths for particular areas.

From the flood mapping and GIS based analysis, about 229.4 sq. km of the study requires protection by 1.83 to 3.5 meter embankments. This flood protection is recommended for a flood level of maximum of 4 meters. The study area has experienced rapid land use change from predominantly rice paddy to rice-fish poly-culture systems made possible due to low salinities. However, clogging of natural drainage, illegal acquisition of natural water bodies by local elites, and unplanned infrastructure and industrial development are increasing the risk of damaging floods.

Nevertheless, there is significant potential for further development of coastal Bangladesh. One of the major land use opportunities would be to consider poly-culture of rice/shrimp/prawn/fish to maximize the use of natural land and water resources as well as minimize flood risks. Other recommendations are to restore the capacity of water channels, and to enforce control over construction of industrial and road developments.

Introduction

While floods have been a constant threat for humanity, population growth and changes in land-use patterns have increased vulnerability resulting in loss of life and displacement of vulnerable populations as well as widespread damage to crops, infrastructure and property (Ferreira, 2011; Doocy et al., 2013; IPCC, 2007). Flooding in Bangladesh is a normal and recurrent phenomenon particularly during the annual monsoon season (Mirza, 2010). Bangladesh is ranked as the sixth vulnerable country in the Climate Risk Index for the period 1994-2013 (Kreft et al., 2014) while rapid population growth places extra pressure on land creating the potential for more flooding problems.

Bangladesh experiences four types of flooding; overflow from rivers in hilly areas, flooding due to poor drainage, rain-fed monsoon floods and coastal floods following storm surges. In the coastal region, the greatest threats are from rain-fed floods and cyclonic storm surges.

Rain-fed floods are exacerbated by disruptions to natural drainage systems due to reduced inflows from the distributaries of the Ganges and through human interference such as the construction of rural roads and embankments. When intense rainfall takes place, the natural drainage system cannot carry the run-off generated by the rain resulting in temporary flooding. In 2016, this occurred in 16 districts in Rajshahi, Rangpur, Dhaka, Mymensingh, Khulna, and Sylhet divisions (Davies, 2016). Flash floods have a devastating effect on livelihoods and can inundate vast tracts of cropland, limiting agricultural potential and creating food insecurity and shortages (Toufique and Islam, 2014).

Storm surges occur in coastal areas of Bangladesh due to cyclonic storms including super-cyclones where surges can be up to 15 m, causing flooding along the entire coastal belt (Hossain, 2003). The worst flooding incidents were on 10 November 1970 and 30 April 1991 resulting in the loss of 300,000 and 130,000 lives respectively. Apart from the effect of cyclones, coastal areas are also subject to tidal flooding from June to September due to surges caused by the south-westerly monsoon wind.

The entire coastline of Bangladesh is exposed to numerous natural hazards: cyclones, floods, tidal and storm surges, sea-level rise and increased salinity (Shameem et al., 2014; Toufique and Islam 2014). Coastal areas are also affected by erosion or deposition of silt (Ruane et al., 2013). A longitudinal study of changes in coastal areas from 1972 to 2010 found that while the Sundarbans mangrove forest in southern Khulna was in a phase of erosion, the Meghna Estuary, in Noakhali District in southeastern Bangladesh, was in a deposition phase, indicating regional variations that complicate land protection measures (Islam et al., 2011).

Meanwhile the majority of coastline residents are very vulnerable as they are mostly low-income agricultural workers who live in structurally weak houses or are landless and relatively asset-poor (Akter and Mallick 2013; Pulla and Das 2015). A recent study indicated that 52 percent were in absolute poverty, and 25 percent in extreme poverty (Fakruddin, 2006). Agriculture comprises 18.6% of the country's gross domestic product (GDP) and employs 45% of the total labour force (Weisman et al., 2011). In twelve of the coastal districts, comprising 51 sub districts (covering 50 percent of the land area of the coastal zone) conditions are likely to worsen due to the effects of climate change. The government has identified the zone as an "agro-ecologically disadvantaged region" (GoB, 2006). Scarcity of drinking water, land erosion, high arsenic levels in groundwater, waterlogging, flooding, increased soil salinity and various forms of pollution have slowed down social and economic development. Therefore, the coastal zone of Bangladesh is perceived as a zone of multiple vulnerabilities.

However, in addition to the disadvantages, the coastal zone offers distinctive development opportunities that could be instrumental in reducing vulnerability. Export promotion sites, harbours, airports, ports, tourism, and other industries are also located in the coastal area. Coastal communities are developing resilience and fighting poverty by investing in new opportunities many of which have significant potential for expansion.

South western Bangladesh has experienced rapid land use changes during the last three decades, one of the main changes being the replacement of traditional agriculture with prawn and shrimp aquaculture (Haque, 2004; Islam, 2006). Shrimp is the second largest export item and shrimp farming is one of the key economic activities in Cox's Bazar, Khulna, Bagerhat and Satkhira and is expanding in other districts. The sector contributes around US$ 300 million annually towards GDP. There are several reasons for the rapid change including rising global demand for shrimp and trade liberalization coupled with government incentives for prawn and shrimp exports which have driven farmers towards the sector (Adnan, 2013). Also, prawn, shrimp and carp farming have replaced traditional paddy farming due to the suitability of land and the environment as well as profitability (Ibrahim, 2004; Shang et al., 1998).

Traditional agriculture such as paddy has adjusted to the local environment and ecology over time. On the other hand, cultivation of prawn and shrimp may create adverse environmental and ecological impacts such as reduction of land fertility and depletion of potable ground water (Ali, 2006; Flaherty et al., 1999). Other negative impacts might include effects on human health, destruction of coastal mangroves, land-use conflicts, marginalization of rural households, unemployment and migration as a consequence of shrimp farming (Johnson et al., 2016; Primavera, 1997; Ali, 2006; Azad et al., 2009). Sustainable use of local land and water resources has thus become a challenge.

The Improving Food Security & Livelihoods project (IFSL), is a collaboration between United Purpose and WorldFish. It was implemented with the aim of supporting small holder farmers in Bangladesh through improved access to appropriate technical advice, affordable inputs, business and market support. The project played a key role in these efforts, particularly in the promotion of sustainable aquaculture systems.

This study focused on six upazilas (Bagerhat Sadar, Fakirhat, Chitalmari, Mollahat, Batiaghata and Rupsha) in Bagerhat and Khulna districts in south west Bangladesh. Although water levels in most of these upazilas are affected by tides, low salinities mean that many different crops can be produced in mixed culture systems growing prawn, shrimp, carp and seasonal rice farming. The operation of these systems depends on the availability and quality of water which is impacted by rainfall patterns, tidal flows, salinity levels, and micro-locational factors such as access to water channels. One indicator of high economic output from the study area is high land rent, which is ~50% more than the high saline areas, where extensive shrimp culture along with naturally occurring brackish water fish is the common farming practice. Polyculture has higher economic return than shrimp based extensive farming or only rice production. Our field survey indicates that farmers opt to multiple crops, e.g., fish, shrimp, prawn, as well as paddy during monsoon. Such polyculture ensures high productivity, crop rotation and economic return; and at the same time minimizes risk of investment.

However, heavy and unseasonal rainfall, has been the main risk to production resulting in sudden flooding and waterlogging while gradual salinity intrusion has also been a major concern. High soil and water salinity has a major impact on the natural environment, ecosystem, and economy resulting in land use changes in the study area.

Along with climatic conditions, manmade causes also severely affect the local micro-locational factors. For example, infrastructure such as poorly located roads and culverts, clogging of natural water channels, and illegal acquisition of natural water flows by local elites for commercial purposes are affecting local water management. However, such encroachment of the natural resources and its outcome is mostly a socio-political phenomenon, which is beyond the scope of this study.

In this study, we focus on the natural causes of flooding such as, heavy and intense rainfall events, and their impacts on loss of fish due to water over-flow and inundation. The study investigates various solutions for flood management and improved water discharges. Thereafter, the study proposes recommended practices for construction of embankments and flood management measures to prevent loss of crops.

Study objectives

The aims of the study are to assess flood losses, to develop risk management plans for aquaculture and agriculture, and to identify improved carp and prawn management practices that can withstand the impacts of the changing environmental cycles of south west Bangladesh. Therefore, the ultimate goal of the study is to reduce risk by developing improved land use practices for the coastal zones.
Specific aims are:

- To develop an interactive GIS based map for better understanding of flood risks and land use changes in the study area
- To gather information on the different aquaculture and integrated aquaculture-agriculture practices and adaptations to the changing environmental and market factors in the IFSL working area
- To assess the current loss of crops/fish in recent flooding incidents linked with the various environmental and water management systems
- To identify the potential disaster risks for different farming practices through GIS and flood mapping

Major potential outcomes of the study are:

- To identify zones that are particularly vulnerable to floods
- To propose management practices in specific zones to contain or reverse salinity intrusion
- To recommend appropriate land use and risk-reduction strategies to withstand floods

The study uses GIS and RS techniques to show land use changes in the study area, particularly from traditional agriculture (rice paddy) to cash crops (prawn/shrimp). This provides an understanding of changes in economic activity, which in turn can give an indication of changing climatic conditions and peoples' adaptation techniques in coastal regions. Similarly, the study provides a broad understanding regarding land use conflicts as well as the consequences of land use changes from the perspective of sustainable natural resource management.

One of the major limitations of this study is the lack of primary data due to the limited time-frame and budget. In-depth interviews with the local stakeholders are the key to address appropriate localized issues concerning disaster risk reduction. GIS and RS is used to compensate the lack of primary field data. Satellite images used are of small scale, 30m×30m, which are rarely efficient to provide accurate information on local geography. However, the GIS and RS based Storm Water Management Model (SWMM) for flood modelling provides acceptable level of accuracy for flood disaster modelling.

After this introduction, the second chapter explains the materials and methods, describing the study areas and methodology of the study including the GIS and remote sensing techniques. The third chapter provides details of the results and explains flood risk management through a series of maps. The final chapter provides proposals, conclusions and suggestions for improved flood risk management.

Materials and methods

Study area

The coastal area of Bangladesh covers 19 districts facing or close to the Bay of Bengal, including 148 sub districts (upazilas) and the Exclusive Economic Zone (Figure 1). It accounts for 32 percent of the land area and 25.7 percent (37 million) of the population of Bangladesh (BBS, 2011).

The 19 coastal districts are Jessore, Narail, Gopalganj, Shariatpur, Chandpur, Satkhira, Khulna, Bagerhat, Pirozpur, Jhalakati, Barguna, Barisal, Patuakhali, Bhola, Lakshmipur, Noakhali, Feni, Chittagong and Cox's Bazar. The combined out-falls of the Ganges, the Brahmaputra and the Meghna rivers, discharge into the Bay of Bengal. A major part of the coastal zone is covered by the deltas of the Ganges and the Meghna where the coastline is oriented along an east-west axis. These regions are crisscrossed by a network of interconnected distributaries and estuaries. The other portion includes the Chittagong coastal plain bordered by hills, where the coastline is oriented along a North-South axis. The coastal zone includes diverse natural resources include critical ecosystems such as the Sundarban mangrove forests, fisheries, shrimp farms, agriculture and deposits of minerals and salts (GoB, 2006).

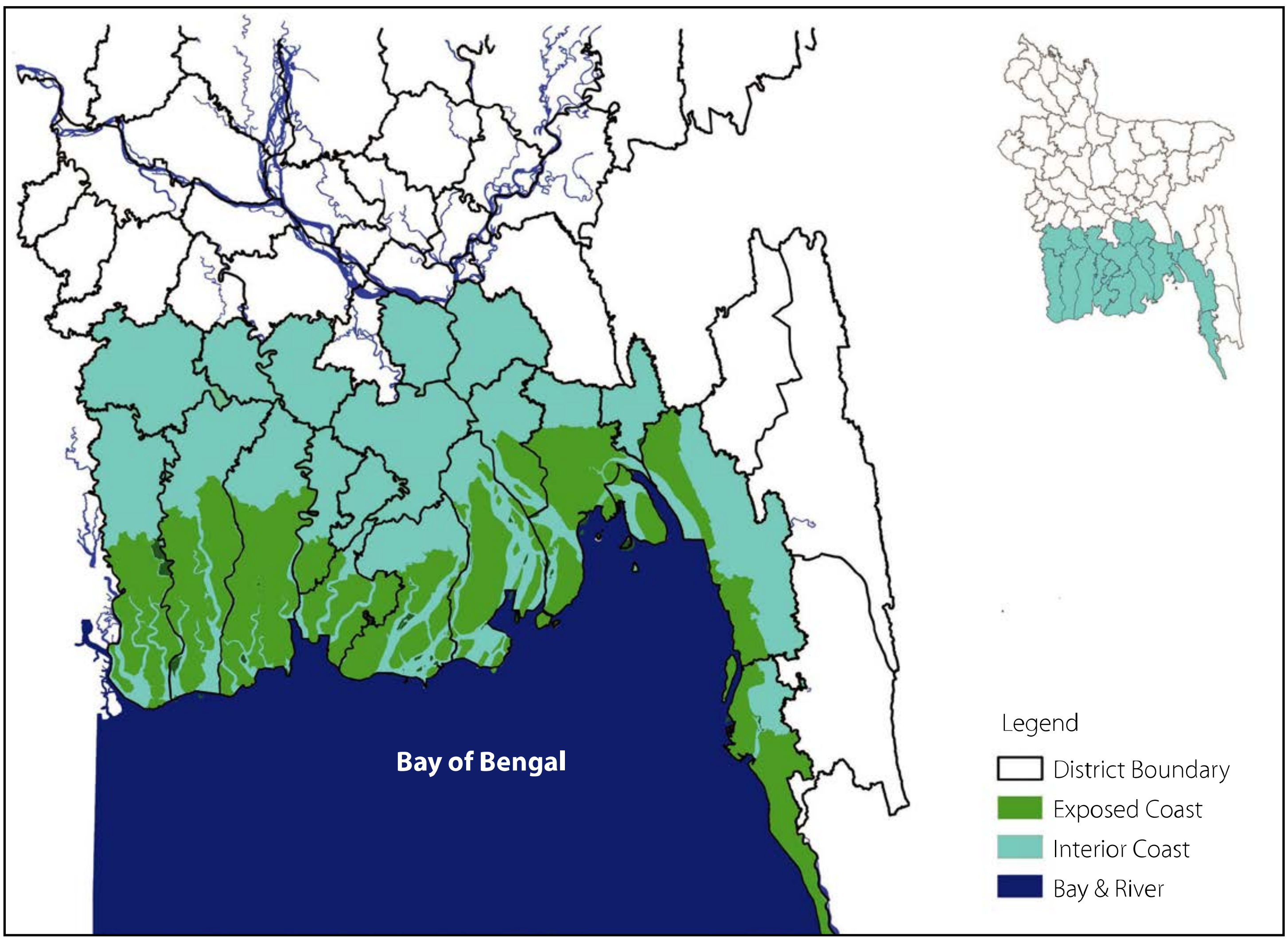


Figure 1. Map of coastal zone of Bangladesh.

The study focused on six upazilas within two districts[1] in south west Bangladesh. These were Bagerhat Sadar, Fakirhat, Chitalmari and Mollahat in Bagerhat district and Batiaghata and Rupsha in Khulna district (Figure 2).

Analysis method

The approaches used to assess flood loss and to manage risk were field surveys and secondary data analysis such as Geographic Information System (GIS) and Remote Sensing (RS). United States Geological Survey (USGS) satellite images were used along with the Storm Water Management Model (SWMM) for flood modelling. However, GIS and RS techniques used freely available data from a range of different sources therefore data accuracy was limited; Morshed et al., 2016 used USGS's freely available satellite images for salinity detection with 73% accuracy.

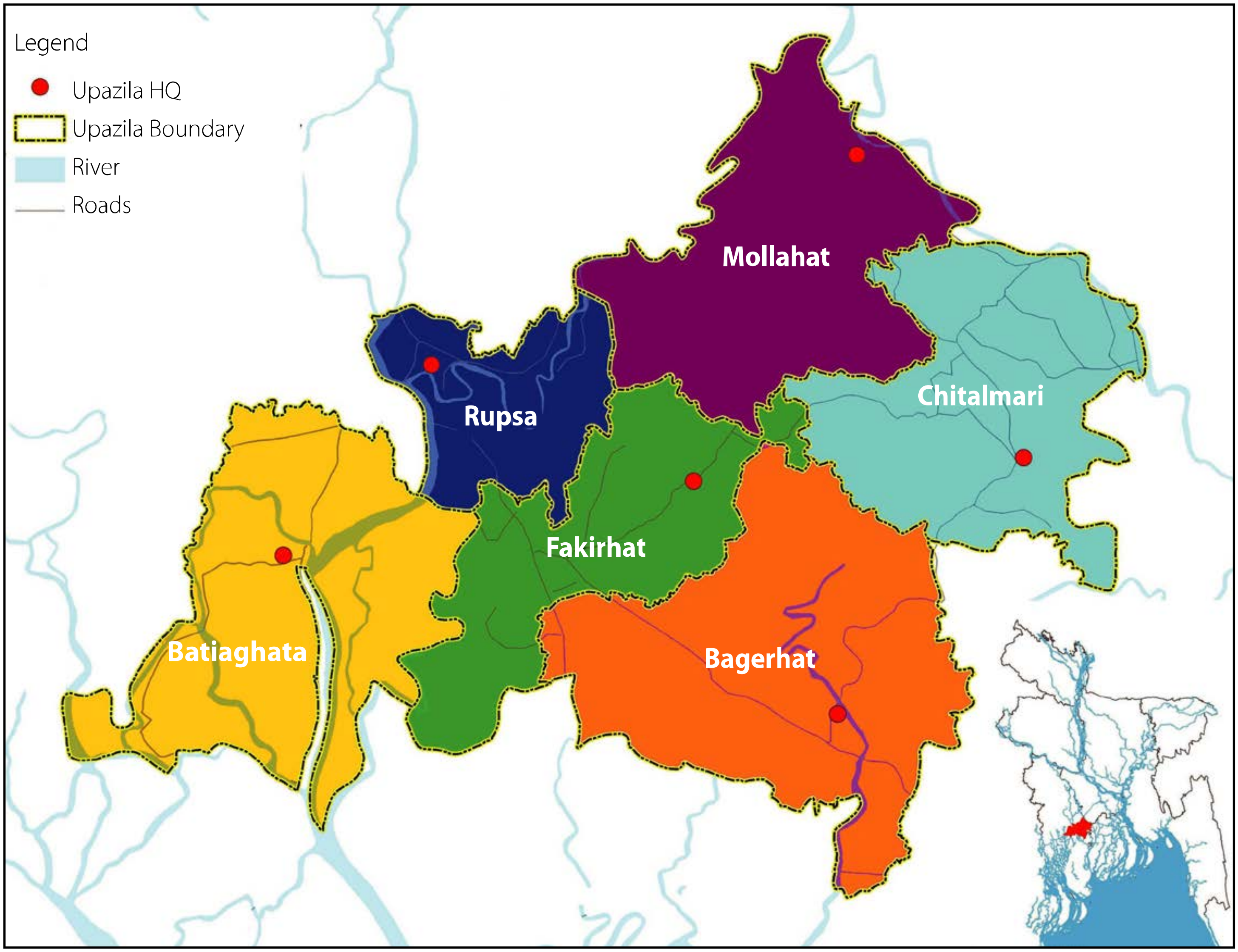


Figure 2. Study area.

However, this should not limit broader understanding about land use changes, salinity intrusion and disaster risks.

These secondary sources were complemented by primary key informant interviews from six sites. The study was based on a step-wise analysis of the study areas, firstly by identifying major land uses and salinity changes in the study area, thus developing maps identifying the problems related to aquaculture flood management. Secondly, waterlogging and surface water flows were identified using GIS and RS techniques. Finally, the study identified and proposed locations for flood embankments to protect aquaculture systems in the study area.

Figure 3 illustrates the overall analysis method. The method is comprised of two sections, primary, or GIS and Remote sensing techniques, and secondary data. Primary data from GIS and Remote sensing techniques were used to identify changes in land use between 1990 and 2017. Changes in salinity between 1990 and 2017 and elevation of the total area were estimated from satellite images. Surface runoff was estimated using data from a particularly intense flash flood on 21 August, 2016 using the SWMM by analyzing satellite images. Secondary data was collected from drainage, flood, and constraint (waterlogging) maps compiled by the Bangladesh Agriculture Research Council (BARC). Information from these three maps was used to construct a flood level map for the study area.

Information from both data sets was combined to develop a deduction matrix which was used to calculate the difference between flood levels and embankment elevations to estimate the required level of protection from future floods. A smoothing technique was used to retrieve the homogeneous zones of required protection.

Changes in land use within the study area over time (1990 and 2017), were estimated using images collected from four different time periods. These images were then analyzed using Iso cluster unsupervised classification methodology. Field observations and Google Earth were used as reference data to delineate various classes. Finally, a zonal statistical method was used in GIS to detect changes over this time period. The overall process for detection of land use changes is shown in Figure 4.

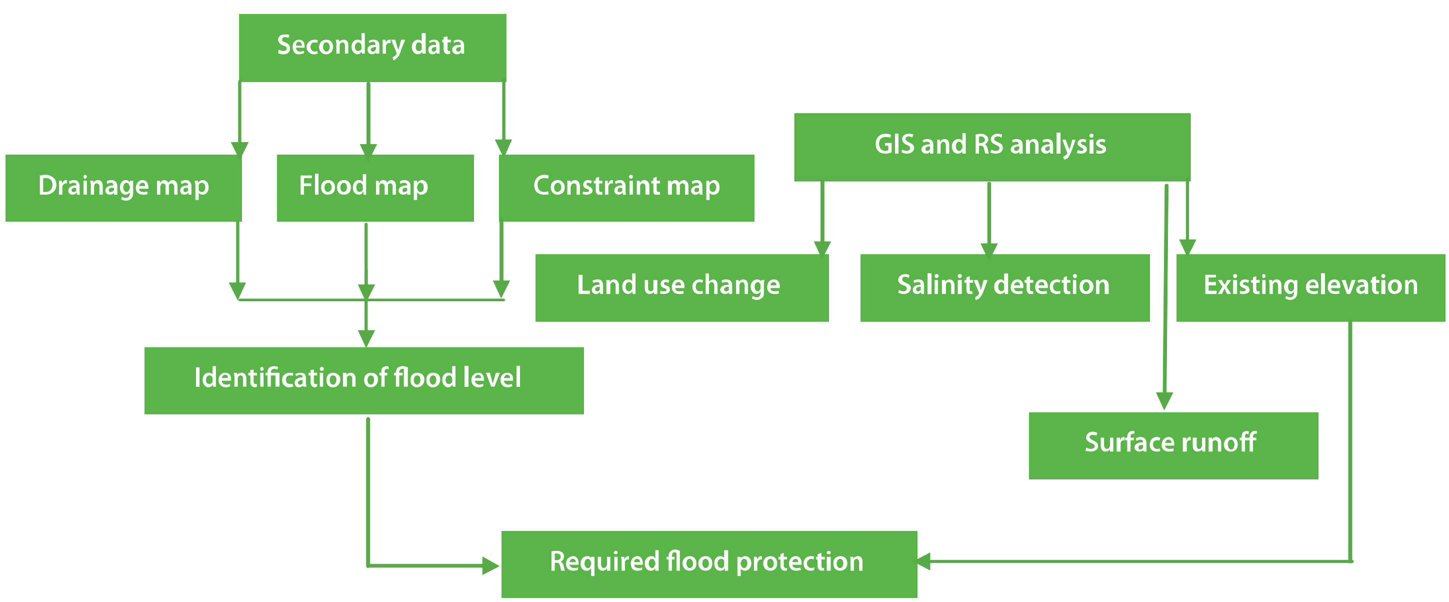


Figure 3. Flow diagram of the methodology.

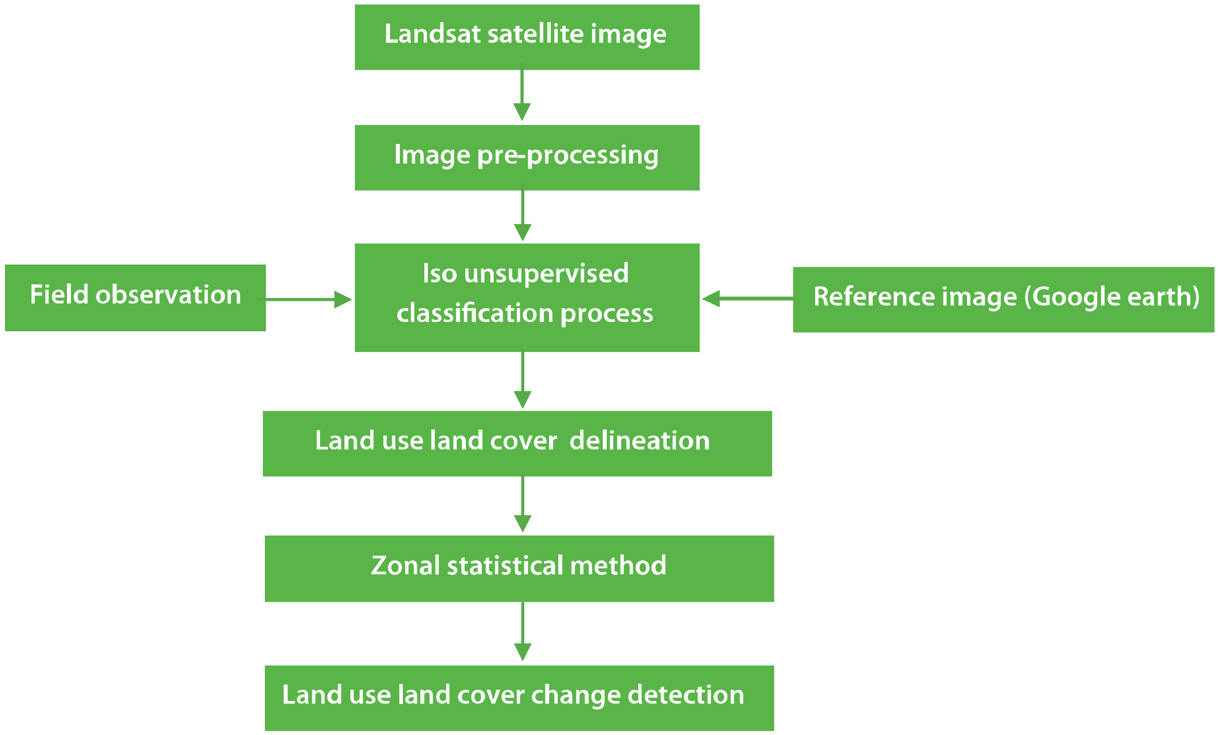


Figure 4. Stepwise process for detection of land use change.

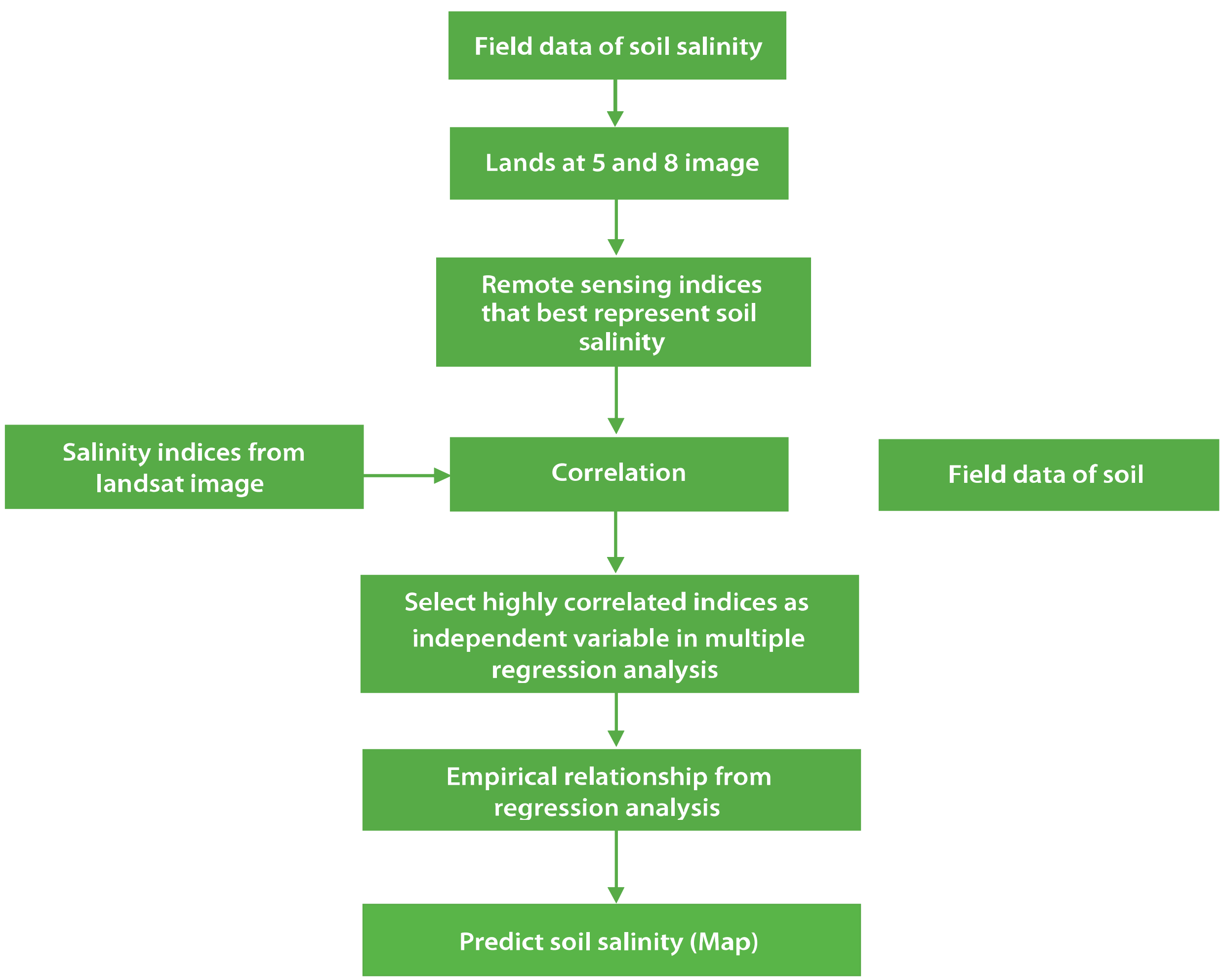


Figure 5. Land use change detection.

Salinity detection

This study used an integrated approach of salinity indices and field data developed by Morshed et al., 2016. The overall working procedure is given in figure 5.

Thirteen salinity indices were identified that best represent soil salinity (Garcia et al., 2005; Khan et al., 2001).

(i) Salinity Index[2] : SI-1, SI-2, SI-3, SI-11
(ii) Intensity index[3] : INT-1, INT-2, BI
(iii) Vegetation Index[4] : SAVI, NDVI, EVI, RVI
(iv) Blue Band
(v) NIR

These were calculated using ERDAS model maker from the corrected images. Highly correlated indices were selected from the correlation between the salinity indices and field soil salinity data. Infrared bands of the satellite image as well as Salinity index-2 (SI-2), ratio of Near Infrared and Red (NIR/R) and Soil Adjusted Vegetation Index (SAVI) showed high correlation with the field data.

Following Morshed et al., 2016, stepwise regression was used to identify the combination of bands that best relate to salinity. Ordinary least squares (OLS), spatial auto regressive (SAR), and Spatial Lag (SLAG) models were used to develop a multiple regression model to predict the salinity. The regression equation 1 explains the salinity from satellite image with 74% accuracy. Using the same equation, we predicted the salinity map for 1990.

Salinity detection equation= -ln (SAVI*NDVI*5) ….. (1)

Digital Elevation Model (DEM) refers to the surface terrain of a particular area. DEM data highlighting elevation data were estimated using GIS. The catchment is an area which is bounded by the same topographic height. Surface runoff is the extra water that passes over the surface, which depends upon various factors such as infiltration, evaporation, and soil type. A significant part of the study area is shrimp/prawn mixed water bodies. Because these water bodies do not absorb rain water, surface water runoff equates to rainfall in the study area. The Storm Water Management Model (SWMM) is a mathematical model capable of estimating run off due to rainfall. Figure 6 demonstrates the SWMM process used to calculate surface water runoff.

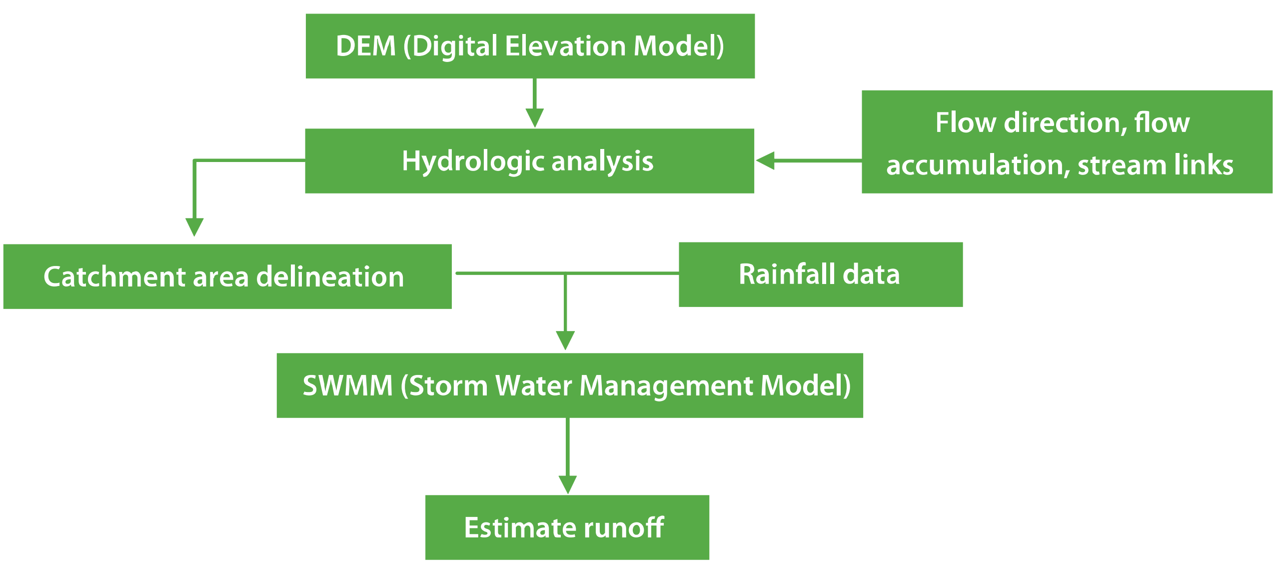


Figure 6. Stepwise process of flood, surface runoff and embankment calculation.

Sources of data

GIS maps of flood, flood intensity, constraint and drainage system were collected from the BARC website. Landsat 7 ETM+ images of 2017, 2007 and 2000 and a Landsat 5 TM image of 1990 were collected from the United States Geological Survey (USGS). A description of the images is given in Table 1. Field visits were made to the six upazilas to gather information through field survey on local dynamics as well as local solutions to the various problems. Local SPAs organized small meetings with stakeholders for the consultants. Thereafter, the LSPs showed researchers the areas that became inundated during the 21 August, 2016 flood, the type of protection farmers used, the associated costs for protection against flood, and information on depth of flood during normal rainy season and flash floods, and types and amount of losses occurred to the farmers. This information was vital for planning and suggesting flood protection measures in the study areas.

Satellite	Date	Path/Row
Landsat 5	09/12/1990	138/044
	21/01/2000	
	24/12/2007	
Landsat 8	01/12/2017	

Table 1. Satellite image description.

A fishing net, Khulna, Bangladesh.

Results - problem mapping

Land use change

As shown in Figure 7 and Table 2, southwestern coastal areas of Bangladesh experienced rapid land use changes between 1990 and 2017. About 20 percent of the study area was converted to prawn/shrimp polyculture over this time. Land use change is associated with rising salinity in the coastal areas. Salinization primarily occurs through natural processes

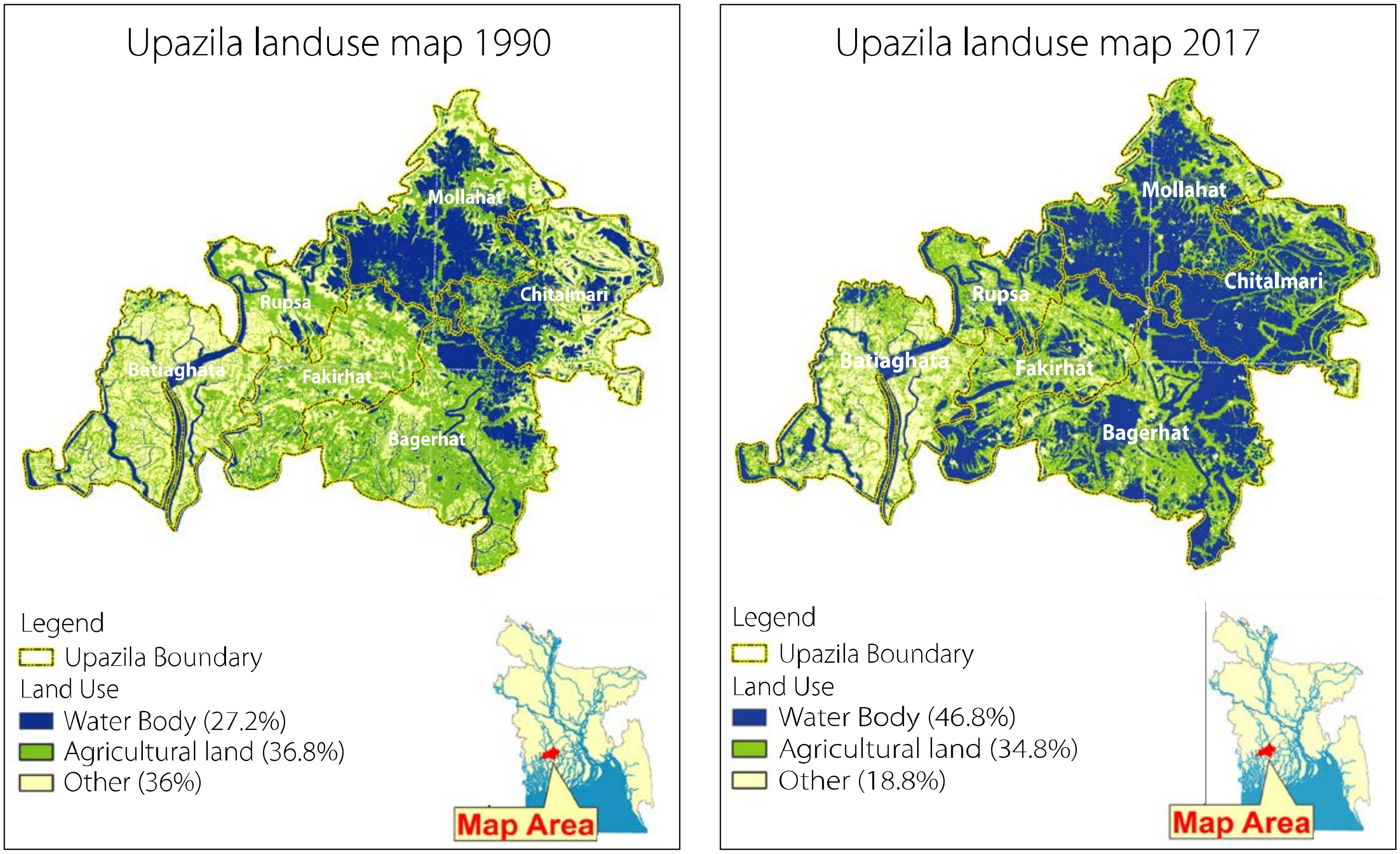


Figure 7. Land use change, 1990-2017.

Year	1990		2000		2007		2017	
Land use	%	Area	%	Area	%	Area	%	Area
Water body	27.20	333.47	34.30	420.51	44.70	548.01	46.80	573.76
Agriculture	36.80	451.16	35.80	438.90	32.50	398.44	34.80	426.64
Other	36.00	441.35	29.90	366.57	22.80	279.52	18.40	225.58
Total	100.00	225.98	100.00	225.98	100.00	225.98	100.00	225.98

Source: Adapted from Morshed et al., 2016

Table 2. Land use change between 1990 and 2017.

such as flood and storm surges, while secondary salinization occurs through human activities such as poor management practices (Mashimbye, 2013; Wu et al., 2008). Climate change has added impetus to the salinization process through more frequent flood and storm surges in the coastal regions.

Land suitability for main agricultural crops

Similar to with other parts of Bangladesh, coastal livelihoods are largely dependent on agricultural crops, mainly rice. Important factors affecting land use for agriculture are flooding, physiography, soil salinity, and drainage congestion and irrigation facilities.

Crop	Upazila name	Very suitable (Km^2)	Suitable (Km^2)	Moderately suitable (Km^2)	Marginally suitable (Km^2)	Not suitable (Km^2)	Total area (Km^2)
Aman rice	Bagerhat	8645.9	5321	2236.6	529.1	685.4	17418
	Batiaghata	11500.3	1992	4183.9	51.8	162.9	17891
	Fakirhat	2965.5	4117.2	2531.5	116.8	345	10076
	Chitalmari	2813.9	3386.4	5288.2	0	2823.6	14312
	Rupsha	2122.5	923.9	1342.1	6.2	1036.3	5431
	Mollahat	4131.6	604.3	5916.3	0	5276.9	15929
Boro rice	Chitalmari	8267	4017.1	2027.9	0	0	14312
	Mollahat	8621.5	6239.5	505.9	512.9	49.2	15929
	Rupsha	1885.2	2453.3	405.8	199.8	486.9	5431
	Bagerhat	0	1004 0.8	4449.2	511.1	2417	17418
	Batiaghata	540.6	11122.6	2169.7	3998.8	59.2	17891
	Fakirhat	11.1	4172.8	817.9	3427.3	1646.9	10076
Potato	Bagerhat	0	1924	9649.9	3523.3	2320.8	17418
	Fakirhat	0	1480	5157.6	1352	2086.4	10076
	Batiaghata	0	518.4	11004.1	2458.5	3910	17891
	Chitalmari	1678.6	543.4	5618.1	349.3	6122.6	14312
	Mollahat	2880.9	1897.1	203.8	7	10940.2	15929
	Rupsha	680.4	1467	1304.7	330.9	1648	5431
Jute	Bagerhat	0	6794	6806.1	3132.5	685.4	17418
	Fakirhat	0	2503.7	4584.6	2531.5	456.2	10076
	Batiaghata	518.4	10819	2095.7	3991.4	466.5	17891
	Chitalmari	1998.8	5637.5	2377.2	1474.9	2823.6	14312
	Mollahat	2353.9	2494.4	5494.7	1735.5	3850.5	15929
	Rupsha	992.6	1005	1747.9	705.4	980.1	5431
Total area (Km^2)		62608.7	91474.4	87919.4	30946	51279.6	32422 8
Total area (%)		19.31	28.21	27.12	9.54	15.82	100.00

Source: Bangladesh Agricultural Research Council, 2014

Table 3. Suitability of land for cultivation of the major crops in the upazilas.

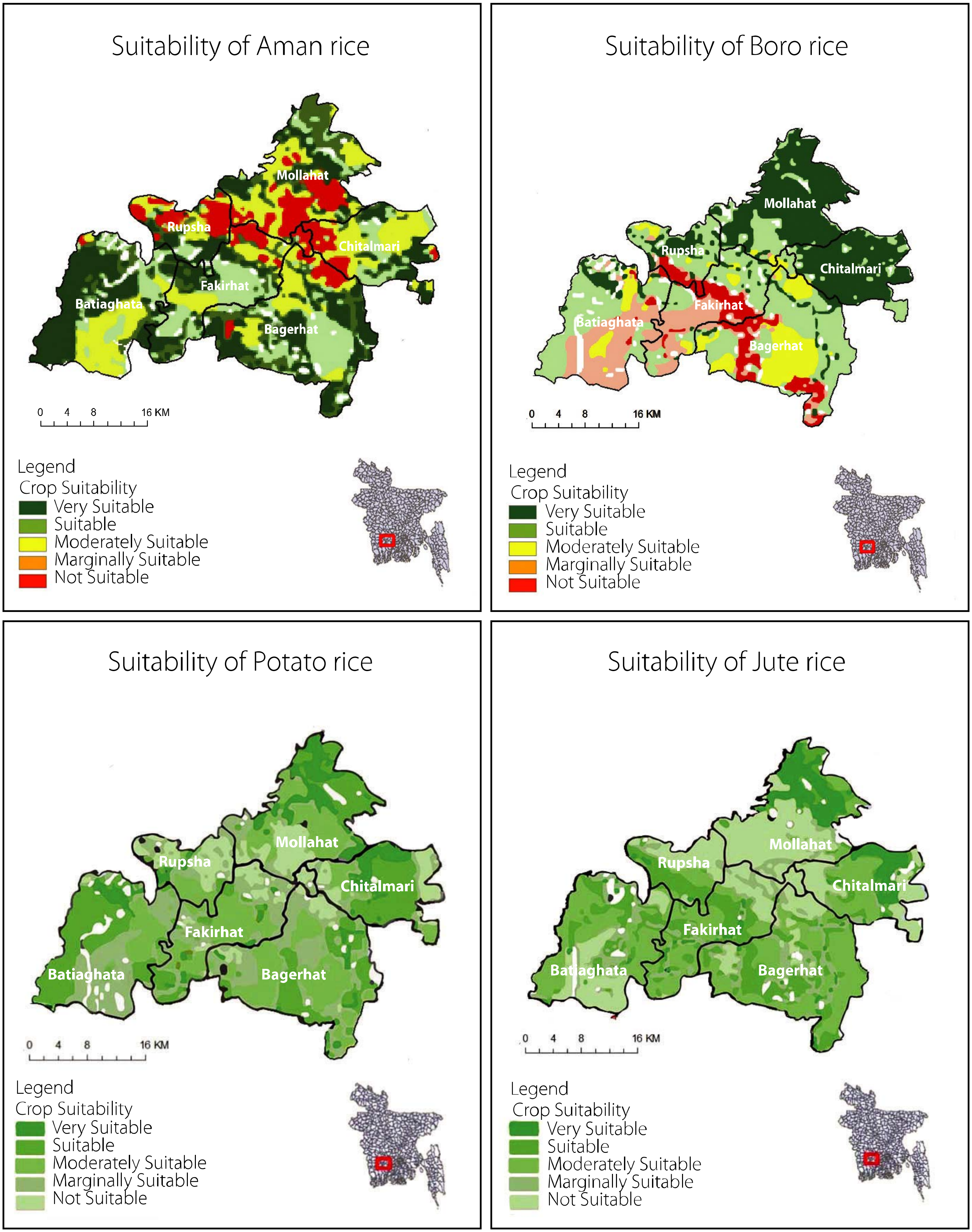


Figure 8. Land suitability of the study area.

Agricultural land in the coastal area is limited to wet season cropping because soil salinity is high in the dry season. Medium-high land dominates the coastal area, followed by high land, medium-low land and low land. Table 3 shows a summary of land suitability and crop diversity.

Table 3 shows, 74.6 % of land is classed as suitable (very suitable, suitable and moderately suitable) for the cultivation of major crops compared to 25.4% which is classed as unsuitable (marginally suitable and not suitable). Bagerhat, Batiaghata and Fakirhat are the most suitable upazilas for Aman Rice but are less suitable for Boro Rice, Potato and Jute. Chitalmari is suitable for most crops. This indicates that there is high potential for agricultural growth through improved irrigation, high-yielding crop varieties, more efficient markets and mechanization. Policy reforms and investments in agriculture research, human capital and roads can enhance agricultural growth in the study area.

More rapid diversification of agriculture with continued attention to rice is necessary. This needs to include balanced incentives to promote high value agriculture that includes horticulture, livestock, poultry, and fisheries. For non-farm growth to flourish, it is essential to make it easy for enterprises to do business. Access to finance, power, roads, technology, and information along while removing discriminatory taxes and stifling regulations are essential. Figure 8 gives an overview of the agricultural suitability of the study area.

While the above Table 3 and Figure 8 highlight the land use potential of the study area, this omit the present land use trend – that is, shrimp or rice-shrimp rotational poly-culture. Apart from the suitable geographical location and land suitability, rising salinity in the south western areas of Bangladesh is a contentious issue. Primary salinization occurs through natural processes, such as, flood and storm surges. About two-thirds of the total saline affected land area is due to human activity. Currently, rising salinity trends in the study area have become a cause and consequence of land use change as farmers try to adapt to the changing salinity, for example, from rice/crop to shrimp/poly-culture. Excessive accumulation of salts in plant root zones affects soil properties by decreasing productivity and limiting the growth of crops (Li et al., 2011).

Salinity intrusion

Land use change is associated with rising salinity in the coastal areas. Salinization primarily occurs through natural processes such as flood and storm surges, while secondary salinization occurs through human activities such as poor management practices (Mashimbye, 2013; Wu et al., 2008). Climate change has added impetus to the salinization process through more frequent flood and storm surges in the coastal regions.

Salinity intrusion results from both natural and manmade factors and was estimated from Satellite Images using GIS and RS techniques. Figure 9 and Table 4 show comparisons between 1990 and 2017. The salinity (electrical conductivity (EC) expressed in deci-siemens/meter (dS/m)) map was classified into three categories: low saline (EC<1), medium saline (EC 1-3), high saline (EC ≥3). In 1990, about 84% of the total area had low salinity (EC<1), 13.1% medium (EC=1-3) and 2.7% had high levels of salinity (EC>3). However, by 2017, the area of low salinity had decreased to 60.6%, while areas with medium and high salinity had increased to 35.4% and 4% respectively (Table 4) indicating an overall increase in salinity within in the study area.

The most common causes of salinity intrusion are; upstream water diversion, high salinity in river water during the dry season, frequent flooding and tidal surges (Seal and Baten, 2012). However, because rivers along with their tributaries (canals) are the major source of salinity intrusion and the study area is not

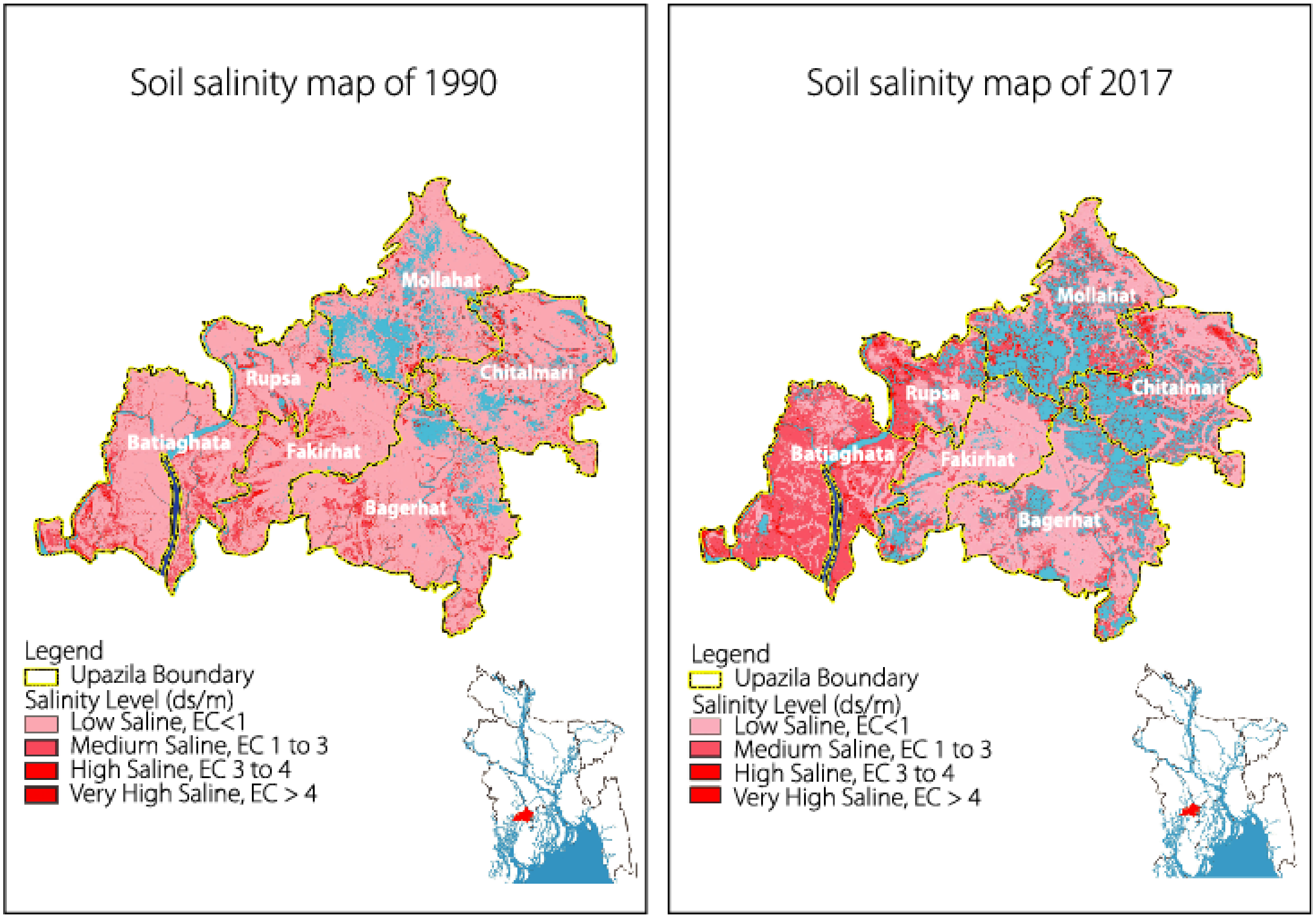


Figure 9. Salinity change between 1990 and 2017.

Salinity level	Area (km^2)		Percentage (%)	
	1990	2017	1990	2017
Low saline, (EC<1)	856.1	616.1	84.2	60.6
Medium saline (EC, 1 -3)	133.2	360.1	13.1	35.4
High saline, (EC> 3)	27.2	41.3	2.7	4.0

Table 4. Salinity changes between 1990 and 2017.

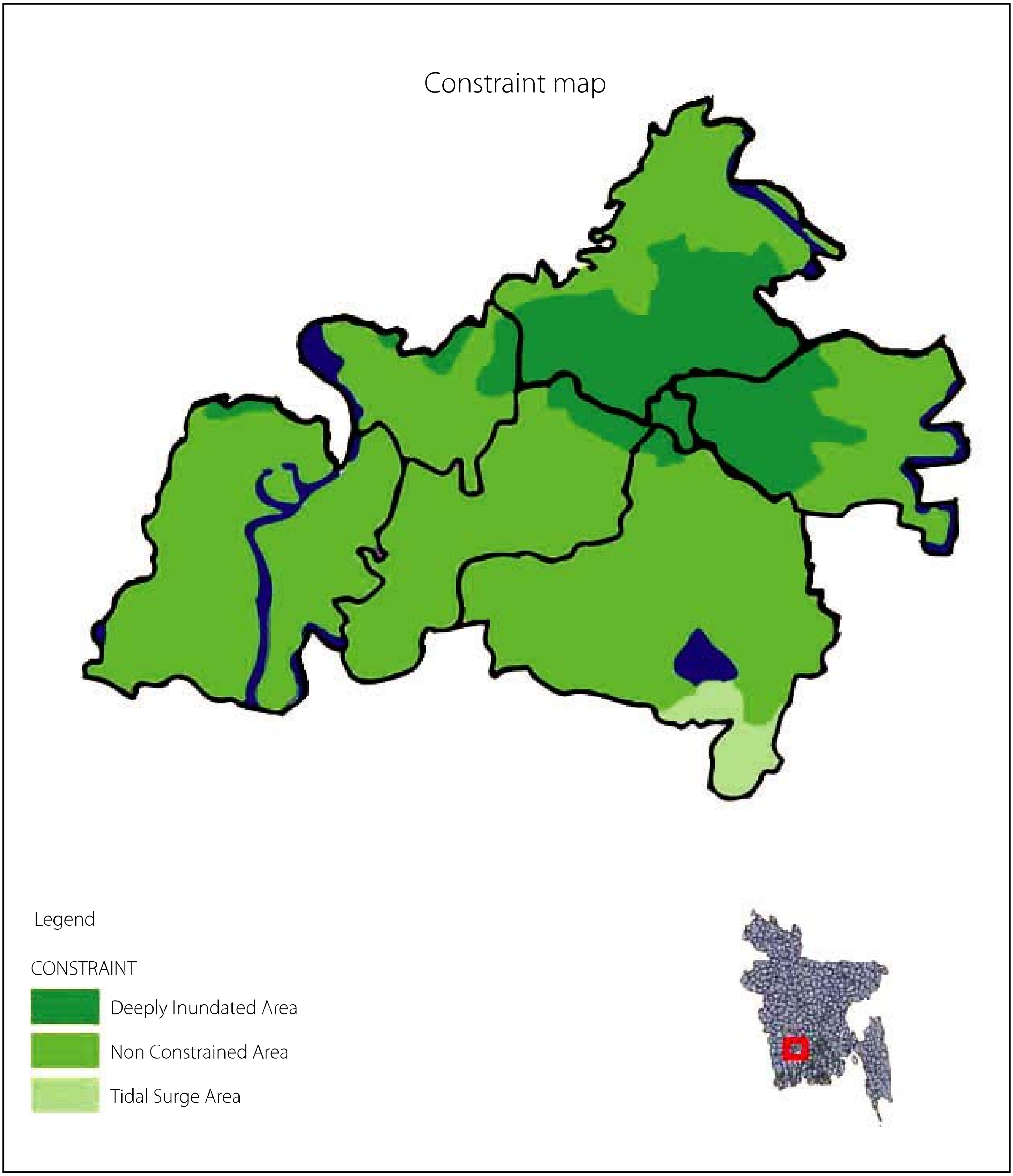


Figure 10. Constraint area map.

crisscrossed by any rivers, flooding in the area is mainly due to rainfall and subsequent surface water runoff. This has kept the salinity level quite low in comparison with some adjacent coastal areas allowing farmers to invest in poly-culture systems, thereby increasing economic returns.

Constrained areas

A constraint area map (Figure 10 and Table 5) was produced to provide insights into the characterization of areas with different levels of both biophysical and socioeconomic limitations so that due consideration is given in local development interventions. The methodology involves characterizing and delineating areas with a unique combination of factors constraining agricultural development. This is important to determine areas of harmful restrictions along existing routes and potential locations for new interventions to minimize impacts, particularly in the context of flood hazards. A gap analysis was carried out using ArcGIS. Selected layers of the GIS database were overlaid to map particular areas of concern. The map was modified to show where multiple areas lay, indicating the degree of sensitivity.

Sl. no.	Constraint	Area sq. km
1	Deeply inundated area	395.940597
2	Tidal surge area	26.59457344
3	Non -constrained area	790.4382979
4	Urban	13.00653167
Total		1225.98

Source: Adapted from BARC, 2014

Table 5. Water constrained area.

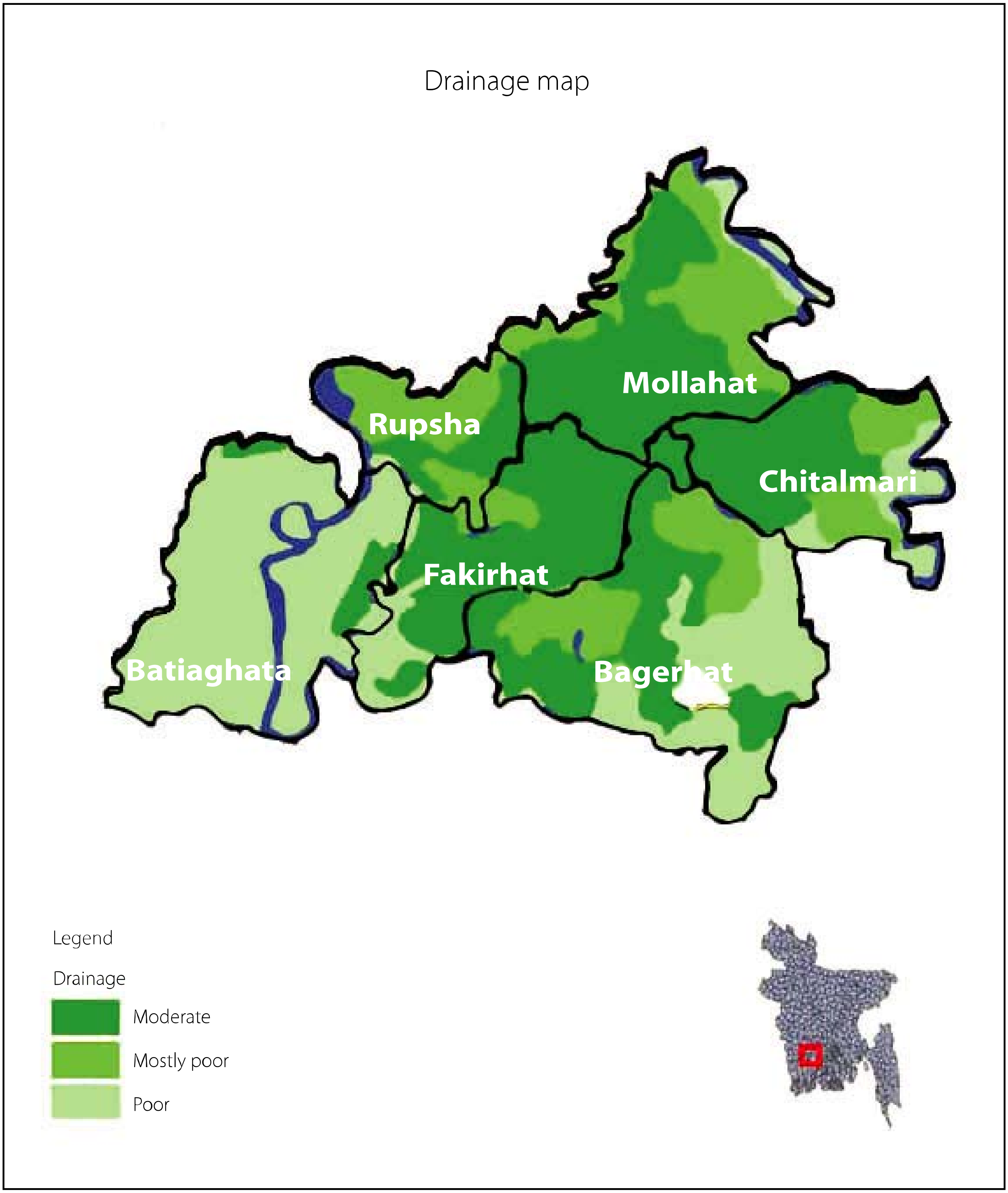
Drainage map

Drainage is the natural or artificial removal of surface and sub-surface water from an area. The internal drainage of most agricultural soils is good enough to prevent severe waterlogging, but some areas need artificial drainage to improve production or to manage water supplies (Table 6 and Figure 11). The drainage condition of the study area is poor. This is mainly a consequence of poor engineering and location of embankments and also blockage of inlets/outlets within the farming areas rather than natural soil conditions.

Sl. no.	Drainage	Area sq. km
1	Moderate	456.77
2	Mostly poor	217.28
3	Poor	551.91
Total		1225.98

Source: Adapted from BARC, 2014

Table 6. Drainage characteristics.



Source: Adapted from BARC, 2014

Figure 11. Drainage map.

The study area is generally very flat and low lying which together with high annual and high intensity rainfall during the seasonal monsoon, proximity to the ocean, tidal and cyclonic influences, makes much of it prone to flooding. The area is also exposed to storm surges that contribute to overall flood levels. A storm surge is a rise above the normal water level along a shore that is the result of strong onshore winds and/or reduced atmospheric pressure often accompanying a tropical cyclone.

Field observations and local dynamics

During the field survey, and through focus group discussions, several local factors affecting the management of local land and water resources were identified. Because of secondary data limitations, which provided only a broad idea about the flood system, primary consultations with stakeholders were very important. Examples of local land and water management are illustrated mainly by photographs.

Poly-culture practices

Low salinity conditions in the study area have created abundant opportunities for poly-culture. Land and water salinity changes follow a seasonal cycle with highest salinities during the dry season and lowest during the monsoon season (July-October). Farmers stock shrimp/prawn/finfish together during the dry season when the water salinity is high and rice during the monsoon season. Embankments have become the major source of vegetable produce. Therefore, such poly-culture (Figure 12) practices and multiple use the same land are low risk production techniques in contrast to high risk intensive mono-culture

Figure 12. Poly-culture practices in the study area.

Illegal acquisition

Most water channels (canals/khals and rivers) have lost their natural flow due to illegal land acquisition by socio-politically powerful groups (Figure 13). Loss of natural water flow ultimately results in water logging during the monsoon season and high tides. Excavation and maintenance of water channels are key to improving water flow in the study area.

Haphazard road/ infrastructure development

Road infrastructure development in many parts of the study area has closed cross-flow of water (Figure 14). This becomes a problem during the monsoon period and disrupts water flow resulting in negative impacts on fish breeding and local ecosystems.

Industry and land acquisition

Rupsha and Mollahat upazilas are close to built-up urban centres and have become attractive areas for the establishment of industry (Figure 15). While there are regulations regarding industrial development, as well as agricultural and aquaculture land use, these are frequently violated. Poorly managed industrial developments also contaminate local ecosystems and block natural drainage.

Shrinking river channels

Rivers and natural water channels like canals are shrinking due to poor management practices, both locally and nationally. Upstream water diversion has reduced natural water flows. Shrinking water channels are then used for other purposes including rice cultivation (Figure 16). During the monsoon, tidal water flow augmented by intense rainfall results in severe flooding.

Land use change in the south western regions of Bangladesh is taking place at a rapid pace, for example, crop/paddy to shrimp and rapid

Figure 13. Illegal land acquisition.

industrialization have been mostly in an unplanned and unregulated way. Existing land use regulations have been ineffective due to the sheer speed at which land use change is taking place, inconsistency among the policies and lack of coordination among the authorized bodies. There are 16 policies, acts and ordinances on protection of fish, land and water use in Bangladesh. Most of the regulations are incomplete and contradictory to sectoral objectives, belong to multiple agencies' jurisdiction and at the same time, land use regulations are violated with impunity. For example the Shrimp Mohal Management Policy, 1992 suggests that all suitable land should be used for shrimp cultivation, which ultimately contradicts with the National Environment Policy of 1992 restricting land use that promotes salination in the vicinity (Afroz and Alam, 2013, 279). Recently, however, the introduction of Integrated Coastal Zone Management (ICZM) has been trying to ensure sustainable use of coastal natural resources and regulate land uses. One major objective of ICZM is to minimize land use conflicts and maximize economic return through sustainable land use management.

From the above field observations, natural endowment in the form of land and water availability is key to sustainable livelihoods and economic returns in the study area. FGDs in the study area, along with field observations, suggest that blocking of natural water channels is the biggest problem affecting water discharges. Siltation of natural water channels, illegal acquisition for private use and unplanned infrastructure developments have been major barriers to swift discharges of floods and rainwater. Intense rainfall therefore is a major cause of water over-flow and inundation of fish ponds. One of the major demands of all the surveyed LSPs is to clear the natural water channels to allow rapid drainage of rainwater, as almost all LSPs agreed that poor drainage is the main reason for water logging and flooding in the study area. While farmers use safety nets against flooding, many are not prepared for such events.

Figure 14. Road blocking cross-flow of water.

Figure 15. Industry in rural areas.

Figure 16. Shrinking natural water channels.

Carrying bamboo fishing craft, Khulna, Bangladesh.

Results - flood risk assessments

Hazard frequency assessment

One of the primary ways to communicate more complete flood risk information and to spread knowledge on actions that can be taken to reduce flood risk is to deliver detailed information on depth of flooding, probability of flooding and other flooding characteristics in the form of maps, clearly illustrating flood depths. Similar to the pixels of a photo or graphic, a grid is a digital raster dataset that defines geographic space as an array of equally sized square cells arranged in rows and columns. The value in each cell represents the magnitude in that location of the flooding characteristic represented by that particular grid.

The key to informed decision making on risk management and risk transfer (insurance) is an accurate assessment of risk. In the context of this report, flood risk refers to the magnitude of economic flood loss and the probability that losses of that magnitude will occur. Flood risk assessments focus on many components but the major one is flood hazard i.e. the probability and magnitude (e.g., depth, velocity, discharge) of flooding.

Hazard frequency assessment estimates the probability of different magnitudes of damaging flood conditions, such as the depth of inundation, duration of inundation, velocity of moving water, quality of water, debris content of water, or the wave height in addition to still water level. For example, in many urban riverine settings, the most important flood condition is the annual maximum depth of inundation at the location of an insured structure. The depth of inundation is computed as the difference between the annual maximum water surface elevation and a reference elevation at the structure (commonly the lowest floor elevation of the structure, because this is the elevation above which water ponding will cause damage). The hazard in that location can be represented as a water surface elevation–exceedance probability function. This function represents the probability that the annual maximum water surface elevation at a specified location will equal or exceed a specified magnitude. Greater water surface elevations have lesser probability of exceedance. The magnitudes for the various hazard probabilities depend on meteorological, hydrological, hydraulic, and topographic properties of the watershed, channels, and floodplains at and upstream of the location of interest (National Flood Insurance Program 2018).

For the identification of hazard prone areas, particularly floods, a hazard frequency map (Figure 17) has been created from the data obtained from the Bangladesh Agricultural Research Council (BARC). Categories have been divided into 15 parts to enhance the modular range in the analysis of hazard frequency, mostly floods. Once again, the map indicates that the central region of the study area is at greatest risk from flooding.

Flood category

Based on the hazard frequency map, a flood category map was created allowing information about floods to be categorized. Five categories of flood have been identified and the areas affected by each type of flood are outlined in Table 7.

This suppirts previous information regarding the frequency of hazards with significant correlation between the two outputs to suggest the area that needs most protection. Although this will be further evaluated with the help of DEM in both 3D and 2D formats, it is worth noticing that most of these areas are where water bodies are located.

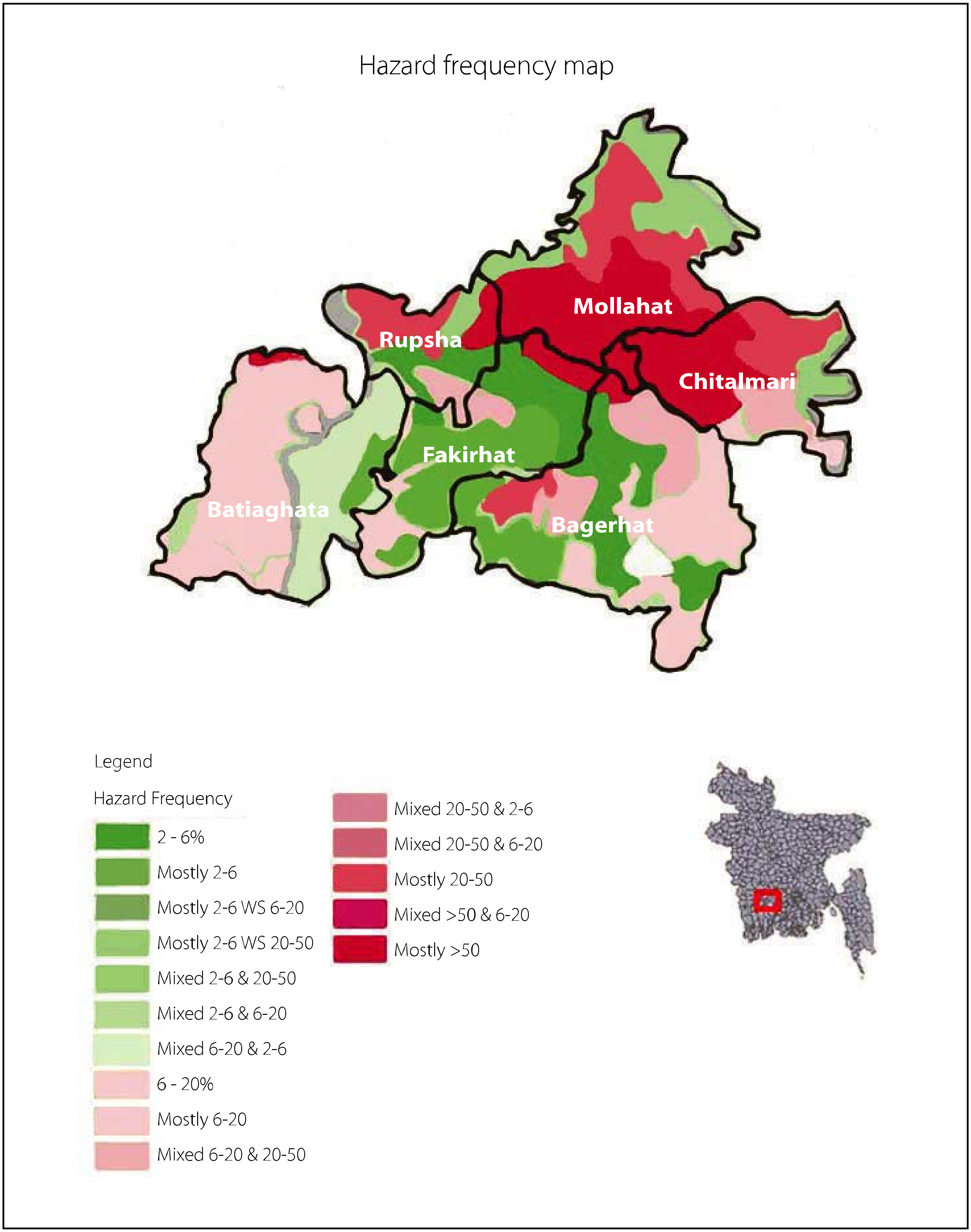


Figure 17. Hazard frequency map of the study area.

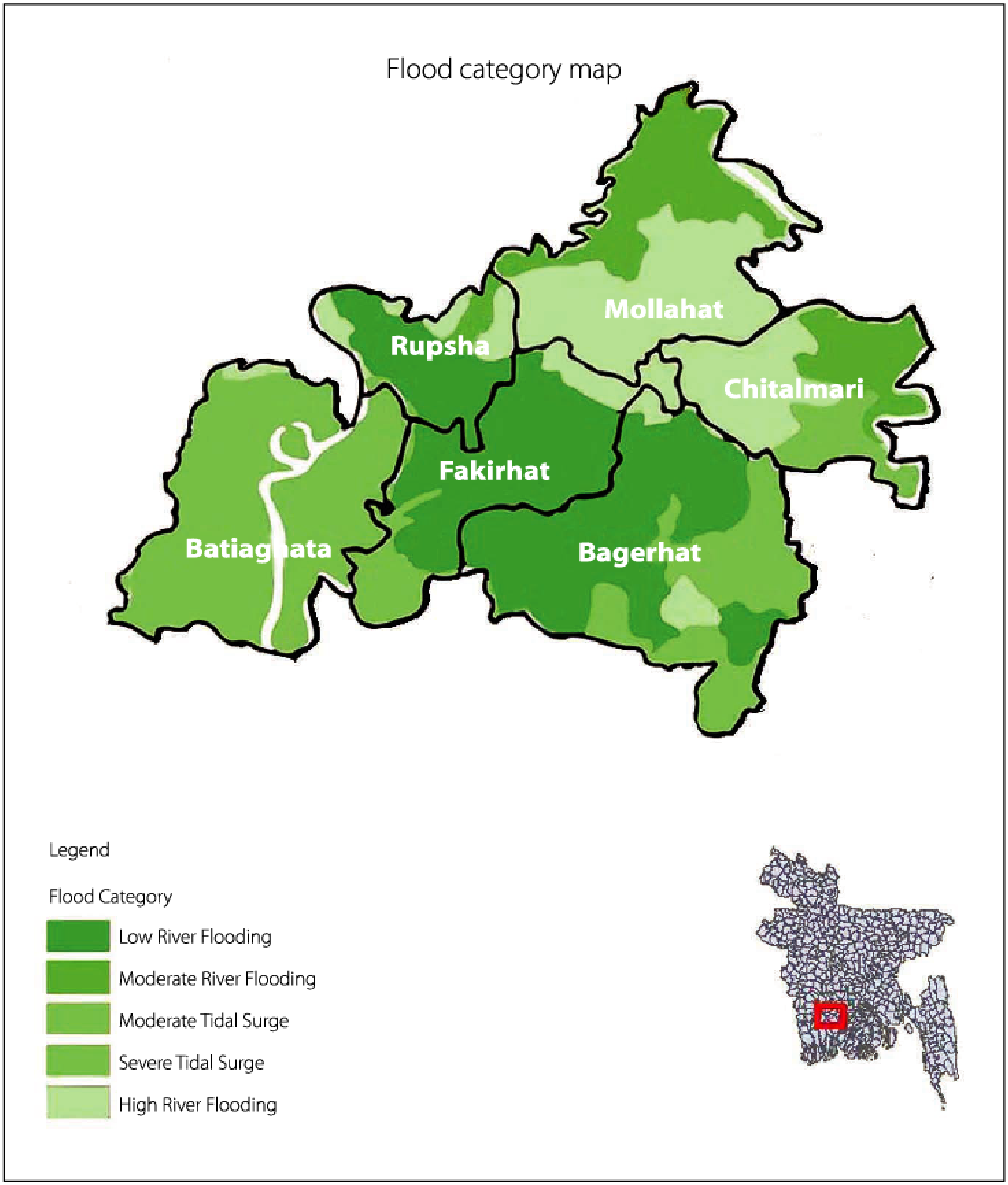


Figure 18. Categorization of flood risks in the study area.

Flood depth

In the absence of a consistent national topographic and water level data set, flood outlines and depths are usually generated using a rapid parametric inundation routine. Potential economic and social impacts of flooding are assessed using national databases of floodplain properties and demography. Although this has not been done here due to the lack of transparent national databases of floodplain properties and demography, the flood depth was calculated with the help of Geospatial technologies.

A Digital Elevation Model (DEM) of the study was created with the help of satellite images (Figure 19). A DEM is the representation of continuous elevation values over a topographic surface by a regular array of z-values, referenced to a common vertical datum. The 2D and 3D view of the raster is provided for a better understanding of the elevation properties in the study area. With the help of the 3D DEM the low elevation profile of the central region in the study area can be clearly seen so it is no wonder that it has a very high hazard frequency.

The DEM, which shows the lowest and highest topographical elevation of the study area, is crucial in understanding the flood status and relief measures that have been provided in this research. Fakirhat has higher elevations than the rest of the Upazilas considered in this study resulting in fewer problems. However, because of lower elevations found across Mollahat and Chitalmari (Figure 20) these areas are more prone to serious flood conditions. This needs to be addressed by implementation of effective flood prevention strategies.

The process of flood map generation consists of the following steps:

(1) Identify the flood elevation at a generalized value;

(2) Generate the surface of flood elevation based on the identified flood elevation values. Here, the method of inverse distance weight (IDW) was used for spatial interpolation;

(3) Generate a flood map using the raster subtraction geo-processing tool: Flood extent can be obtained by subtracting the surface elevation raster dataset (DEM) from the flood elevation raster dataset. Any raster cell for which the water surface elevation was greater than the surface elevation was considered as part of the flood extent.

Computation of the inundation level was carried out using modelling software. The depth, was calculated using water discharge, precipitation data and DEM. The total area was divided into various sub catchment areas and according to this, the rainfall was estimated. This rainfall has direct contribution in the creation of inundation over the area. As a secondary parameter, tidal water and discharge values were used to identify constraints. As this area is a polder area, precipitation data contributed to create the inundation map (Figure 21).

Sl. no.	Flood Category	Area Sq. km
1	High river flooding	222.30
2	Moderate river flooding	137.30
3	Low river flooding	314.31
4	Severe tidal surge	26.67
5	Moderate tidal surge	525.40
Total		1225.98

Table 7. Areas under different flood categories.

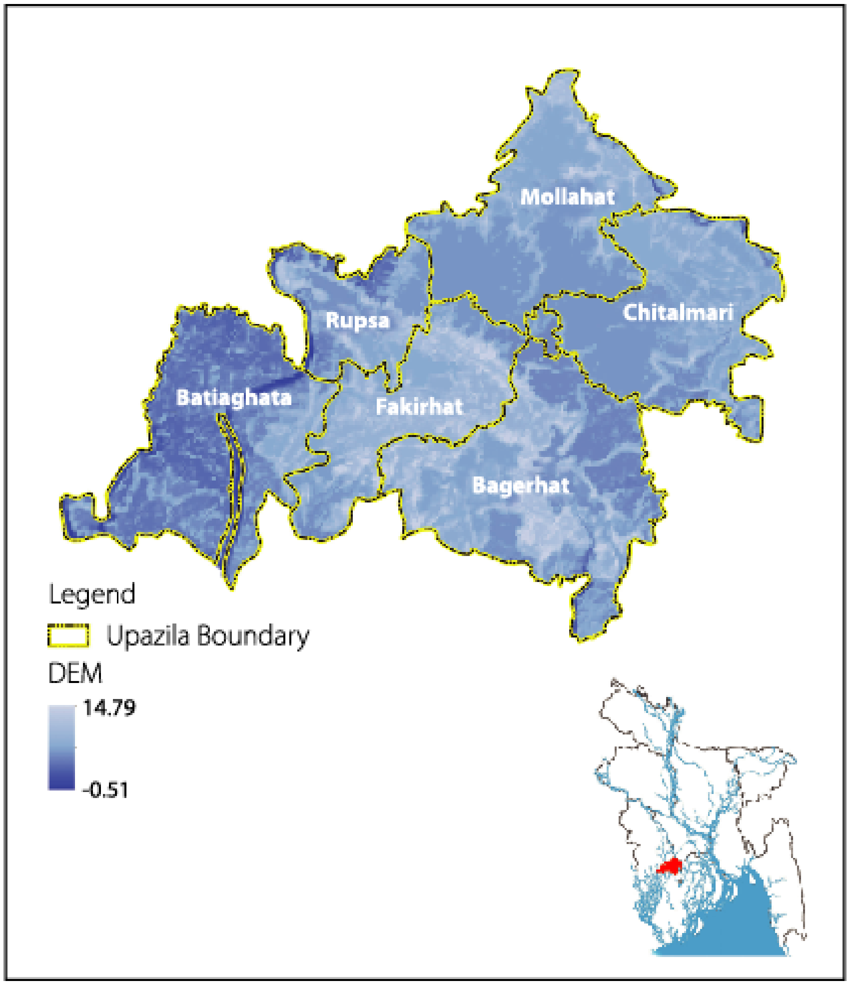


Figure 19. Digital Elevation Model (2D) of study area.

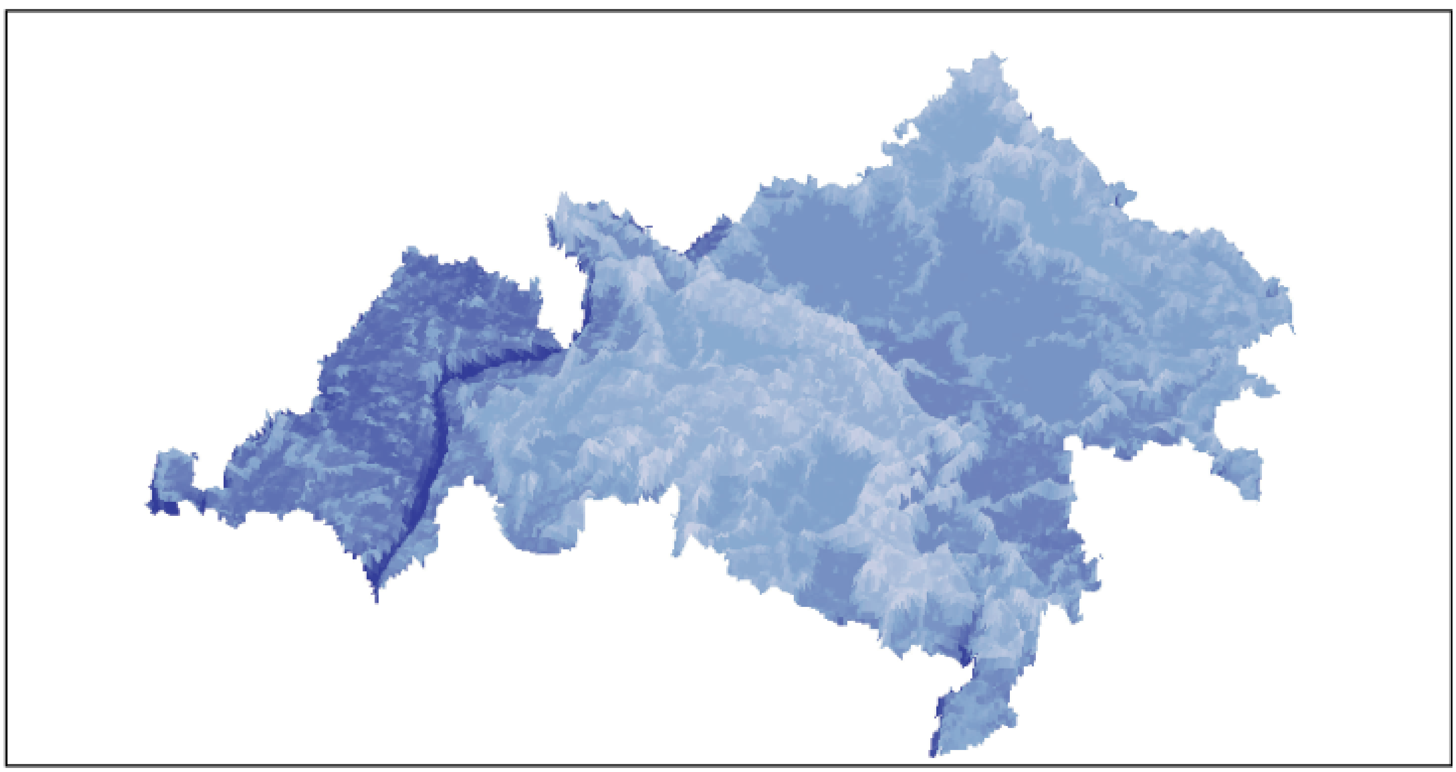


Figure 20. Digital Elevation Model (3D) of study area.

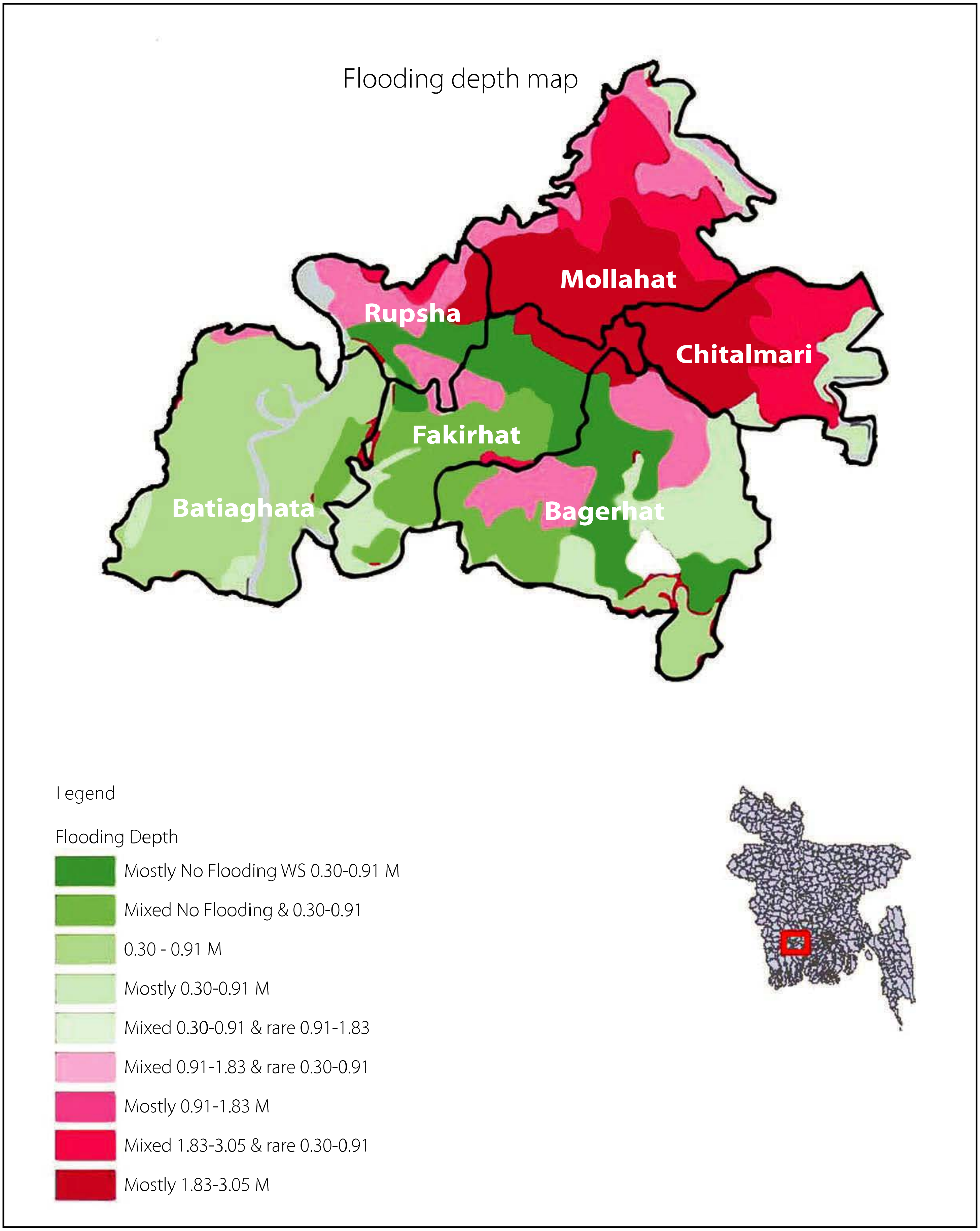


Figure 21. Depth of floods in the study area.

GIS software was utilized to calculate flood depth from this inundation raster. Flood depth was revealed by subtracting DEM from the inundated area (Figure 21 and Table 8). The depth is not uniform across the area due to variations in elevation and due to differences in land use. Because the flood depth is high in the shrimp pond area which has comparatively low lying areas, an embankment 1.83 to 3 m high is proposed, to protect this area from flood.

Sl. no.	Flood depth	Area Sq. km
1	0.30 - 0.91 M	213.8457
2	Moderate 0.30 - 0.91 & 0.91- 1.83	123.7341
3	Moderate 0.91 - 1.83 & 0.30 - 0.91	37.71782
4	Moderate 1.83 - 3.05 & 0.30 - 0.91	26.40822
5	Moderate no flooding & 0.30 - 0.91	107.6652
6	Mostly 0.30 - 0.91 M	135.7294
7	Mostly 0.91 - 1.83 M	90.42807
8	Mostly 0.91 - 1.83 WS 1.83 - 3.05 M	173.2562
9	Mostly no flooding WS 0.30 - 0.91 M	317.1953
	Total	1225.98

Table 8. Depth of flood.

Conclusions and recommendations

GIS based solution

After the production of the spatial database in terms of flood Category, Flooding Depth, Digital Elevation Model, Hazard Frequency, Drainage, Constraint Area, Salinity Intrusion and Land use, an overall picture of the upazilas can be estimated. With the help of geospatial techniques, prior estimation can be done on the area where protection is required. The embankment systems of the concerned areas are shown in Figure 22 with the corresponding height of the embankment.

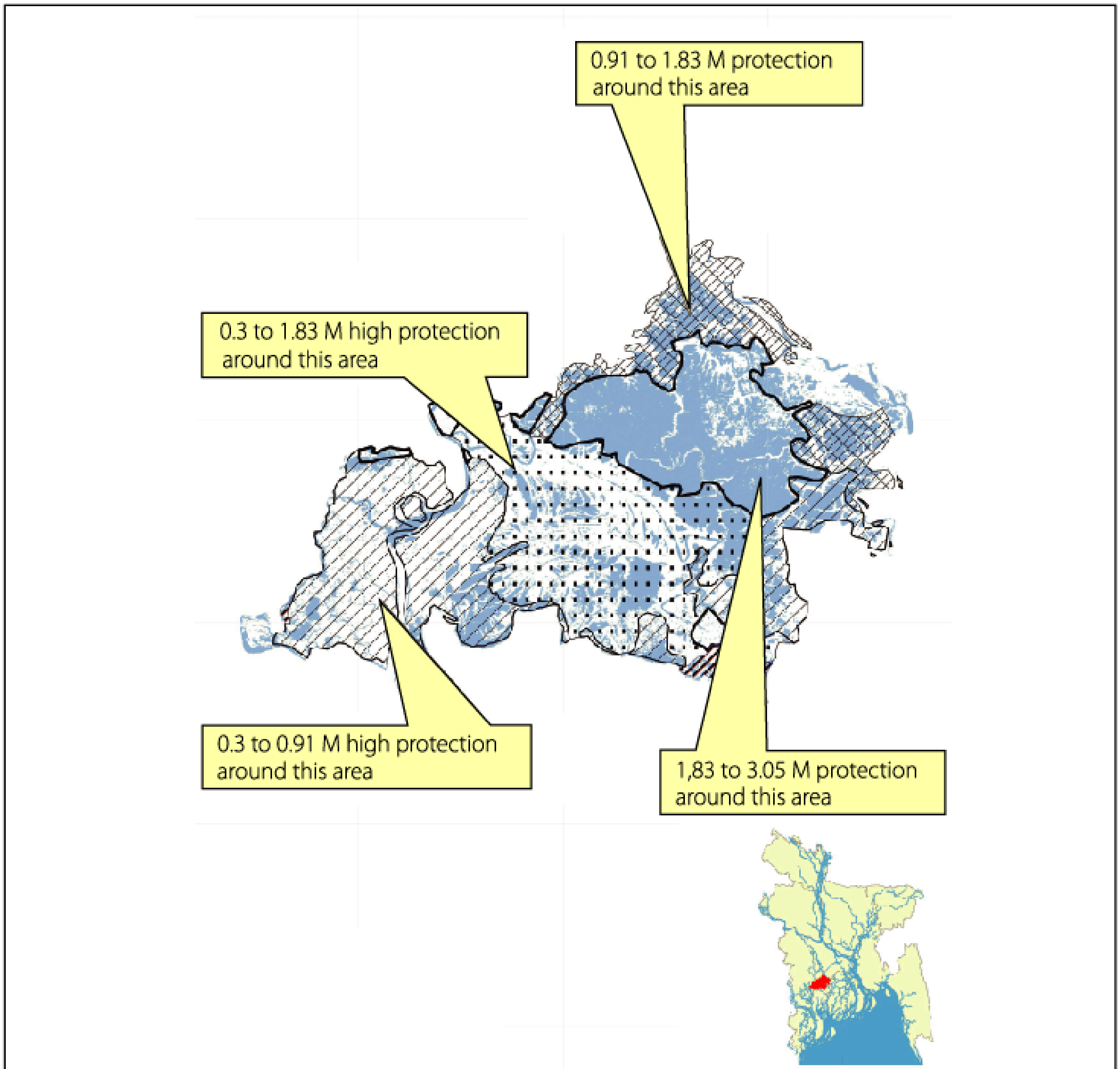


Figure 22. GIS based solution towards flooding.

Figure 22 indicates the high priority areas for embankments. Perimeter length and areas affected have also been calculated as shown in Table 9. An embankment with a height of 3.5 m might be too expensive but the surrounding areas could also be elevated to produce similar results.

Other recommendations

From previous flood mapping and GIS based analyses, a maximum of about 229.4 sqkm of the study area requires protection by an embankment of 1.83 to 3.5 metres. This flood protection is recommended for a maximum flood level of 4 metres.

A summary of recommendations based on field observations are as follows:

- Natural water channels need to be restored to full capacity. Dredging and clearing of illegally acquired natural water bodies are key to reducing flood risks in the study area.

- Unplanned infrastructure developments, such as roads, are a major problem as they restrict the discharge of rain and tidal water flows. The Local Government Engineering Division (LGED) should set clear guidelines and implement effective planning for road construction.

- Industrial development in the urban fringes results in extensive land acquisition and blockage of natural water channels. Enforcement of regulations for location of industrial developments needs to be strengthened.

- Because of favourable low salinity conditions, poly-culture is the most economic and low-risk production strategy in the study area. Such poly-culture practices are key to sustainable management of natural resources and maximising economic returns.

Successful implementation of such macro-scale land use policy recommendation must be complemented by micro-level community initiatives as well as incorporation of local knowledge with technical expertise. Grassroots involvements in the planning, implementation and monitoring of land use and infrastructure decision making should be the priority, and local stakeholders' participation in the land use decision making is key to sustainable natural resource management. Fernandez-Gimenez et al. (2008) proposed community-based monitoring to directly involve the local community in public and private decision making. Finally, removal of anomalies among the sectoral policies, e.g., the National Fisheries Policy and the draft shrimp strategy must be the policy priority, and co-operation among the public, private and community based organizations will be key to the successful implementation of ICZM.

Event	Area (sq. km)	Perimeter (km)
Flood prone (1.83 to 3.5 m)	229.44	141.06
Moderate river flooding (0.9 to 1.83 m)	141.70	149.88
Low river flooding (0.3 to 1.83 m)	324.44	139.73
Severe tidal surge (0.3 to .91 m)	27.52	39.13
Moderate tidal surge (0.3 to .91 m)	349.82	276.65
Total Area	1073	746.45

Table 9. Area and perimeter of the different flood depths in the study area.

Photo credit: < M. Yousuf Tushar> < WorldFish>

A woman adding flood protection netting to her fish pond, Khulna, Bangladesh.

Notes

1 The geographical area of Bangladesh is divided into 64 districts. Upazila is the lowest administrative unit of Bangladesh.

2 Salinity index : Intensity value of the image or soil is calculated through SI_1, SI_2, SI_3, and SI_11. High index value indicates high reflectance and high soil salinity.

3 Intensity index (INT_1) : Intensity within the visible spectral range; INT_2: Intensity within the VIS-NIR spectral range; BI: Soil brightness is detected by this and often associated with soil salinity.

4 Soil Adjusted Vegitation Index (SAVI) : It is a modification of the Normalized Difference Vegetation Index (NDVI). When vegetative cover is low, it is used to correct for the influence of soil brightness. The SAVI is structured similarly to the NDVI but the only difference is the addition of a soil brightness correction factor. Plant greenness or photosynthetic activity is associated with the normalized difference vegetation index (NDVI). A high NDVI value indicates that a high proportion of radiation is absorbed by vegetation. NDVI value ranges from minus one (-1) to plus one (+1). Some distortions in the reflected light caused by the particles in the air are corrected by the enhanced vegetation index (EVI) as well as the ground cover below the vegetation.

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The publication should be cited as: Morshed MM, Khan N, Chakraborty T, Azad uz zaman Q, Zzaman MRU and Dickson M. 2018. Flood loss assessment and risk management plan for aquaculture and agriculture in South West Bangladesh. Khulna, Bangladesh: WorldFish. Special Study Report.

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