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Elevation based Flood-Susceptibility Mapping of the Pirojpur District using Remote Sensing and GIS

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Keywords

Flood susceptibility,
Flood management,
SRTM,
GIS.

Abstract

Mapping the flood-susceptibility is crucial in organizing and effectively planning for flood prevention. This study focused on mapping possible flood-susceptibility areas in Pirojpur, Bangladesh using SRTM elevation data and GIS by combining four flood-influencing factors: elevation, slope, topographic wetness index (TWI) and drainage density. The results showed that the district is mostly under medium-risk (27%) of flooding, however, all of the sub-districts have areas that fall under the high (26% total of the district) to very high-risk (24% total of the district). To reduce the impact on society, it is essential to be prepared for natural hazards. The approach taken in this study will be helpful to the local authorities and the policymakers in assisting in making effective flood mitigation strategies and reducing the threats associated with floods.

Introduction

The combination of a flood event probability and the adverse consequences that follow with it is defined as flood risk (UNISDR 2009). By definition, a flood is a sudden water overflow that inundates dry land and can lead to the loss of life and widespread damage to crops, infrastructure and property. Though a flood on its own does not constitute a hazard, a flood hazard develops due to the fact that flood-prone areas such as lands alongside rivers and on alluvial fans tend to attract people because water can be easily available, the land tends to be fertile, flat, and farming becomes much easier. With time, the occupancy density could increase and result in urbanization eventually becoming a large-scale placement of residents, infrastructure, and agriculture in the path of floods (Burkham, 1988).

As a small component of a larger hydrodynamic system consisting of several countries in the region, common flood types in Bangladesh include flash floods which occur due to the overflow of the hilly rivers, rain floods because of poor drainage, monsoon floods in the flood plains of major rivers and coastal floods resulting after a storm surge occurring over a coastline 800 km along the southern part (Dewan, 2015). The anticipated adverse effects of climate change such as sea level rise, higher temperatures, more precipitation during monsoon and an increase in cyclone intensity are all capable of aggravating the existing stresses that already impede the development in Bangladesh. It was also estimated that in a normal year, river spills and drainage congestion can cause the inundation of 20–25% of the country's area however; the floods in 1987, 1988 and 1998 were capable of inundating more than 60% of the country's area (IPCC, 2012). As the continental shelves in this part of the Bay of Bengal tend to be shallow and as the coastline in the eastern part is conical and funnel-like in shape, storm surges that happen during any cyclonic storm tend to be relatively higher in comparison to the same kind of storm in other parts of the world (MDMR, 2014). Furthermore, the coastal areas are also susceptible to tidal flooding from June to September because of the southwest monsoon wind that goes over the Bay of Bengal.

Approximately more than 33% of the world's property (82% of which consists of the world's total inhabitants) suffer from some kind of flooding event (Samela et al. 2015).Scientific studies show that the risks of flooding will significantly rise in the main river basins of Bangladesh where a rapid change in flooding extent and depth can occur with a global mean temperature rise of 2.6°C above pre-industrial levels (Dewan, 2015). Thus, in perspective of the changing climate, preparedness to avoid loss from hydro-meteorological disasters is thought to be a massive challenge for humanity. To assess floods, the estimation of the associated flood hazard and risk in terms of intensity, magnitude, and spatial/temporal distribution tend to be crucial. During the last few decades, various methods have been developed and applied to investigate flood hazards nonetheless, flood threat remains frequent despite the increased awareness regarding the vulnerability. In spite of that, remote sensing and GIS offer a way that is suitable to analyze relevant information to limit hazard zones (Pourghasemi et al. 2014). As the pattern of flooding in Bangladesh suggests a rise in frequency with time, this study aims to combine flood-influencing factors based on digital elevation to identify flood-susceptible zones in the Pirojpur district to be used as a basis for better-producing strategies to reduce flooding.

Study Area:

Established in 1984, the Pirojpur district consists of 7 upazilas, 51 unions, 648 villages and 27 wards (BBS, 2013). The sub-districts include Bhandaria, Kawkhali, Modbaria, Nazirpur, Pirojpur Sadar, Shorupkati and Zia Nagar (Figure 1). The main rivers flowing through the district include the Kacha, Baleswar, Shorupkati, Kaliganga and Madhumati. These rivers consist of several tributary channels and creeks and eventually fall into the Bay of Bengal. The total area covered by the rivers is about 106 km^2 and consists of 8.1% of the total area of the Pirojpur district (BBS, 2013). In the Barisal division, Pirojpur has the Ganges river floodplain which occupies an extensive area of the tidal floodplain land within the southwest part of Bangladesh.

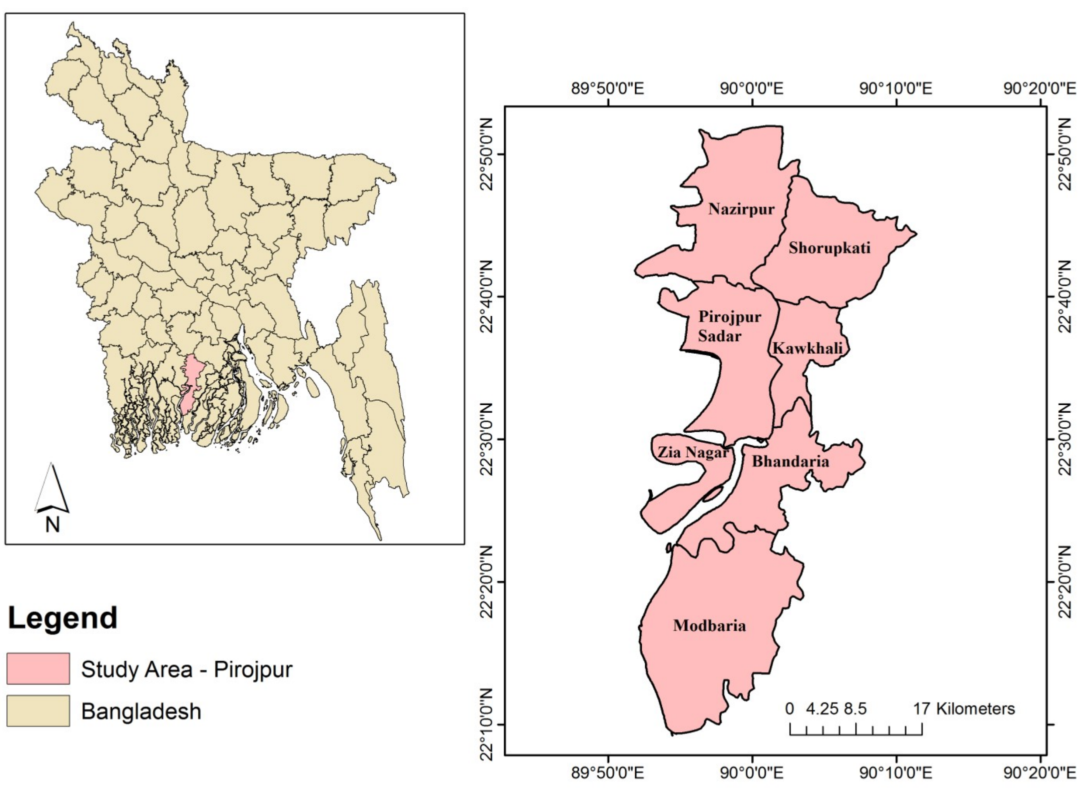

Figure 1: Map of the study area seen highlighted within Bangladesh.

The Pirojpur district has a tropical climatic nature because of its geographical location falling within the tropical zone. The district remarkably has uniform temperature, high humidity and heavy rainfall from June to August making the climate moist and equable. The summer months also have a maximum temperature of up to 35°C (BBS, 2013). The humidity rises to around 88% from August to February and then decreases to 77% from December to February.

Methodology

Most commonly, flooding is related to several flood-influencing factors which are difficult to choose unanimously to use in flood susceptibility mapping (Tehrany et al. 2014). The data used in this study was the Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global elevation data which was acquired from the United States Geological Survey (USGS) in the year 2014 with a 30 m resolution. The point elevation changes in the study area were evaluated from the SRTM in meters. Likewise, the amount of slope relative to the surface level was obtained from the SRTM in degrees. Another criterion, the topographic wetness index (TWI), is also considered an alternative method for outlining flood-susceptible areas and is widely used to describe the state of the wetness (Grabs et al. 2009). The TWI was calculated by evaluating the flow direction, flow accumulation, slope, and various geometric functions. To calculate the TWI, eq (1) was utilized:

$$\text{TWI} = \text{In}(\alpha/\tan \beta) \quad (1)$$

Where α is the upslope contributing area and β is the topographic gradient. The smaller values indicate less potential for the development of ponding whereas, the larger values happen where greater upslope areas are drained (Wolock, 1995). Moreover, the drainage density which aids in describing the degree of drainage network development and tends to increase with an increasing chance of heavy rainstorms (Pallard et al., 2009) was calculated using eq (2):

$$D_{density} = \frac{\text{The length of all the streams within the area}}{\text{Total area}} \quad (2)$$

The drainage density map was generated from the drainage network map of the study area. Lastly, the flood susceptibility map was made by evenly distributing the weights of the four different factors using weighted sum. All the factors were pre-processed in the raster dataset format and reclassified on a scale of 1 (very low risk) to 5 (very high risk).

Results and Discussion

Because coastal lands tend to be low-lying, elevation has been widely utilized to conduct assessments of the effects of rising sea levels making elevation data crucial for assessing vulnerability and risk to flooding and other effects of rising water levels (Neumann et al., 2015). Researchers have put forward that elevation acts as the fundamental factor in controlling the overflow direction, movement, and depth of the flood (Botzen et al., 2013). Moreover, it was also found that flooding was less concerning at higher elevations (Wondim 2016). In this study, the elevation varied from 1 m to 26 m in Pirojpur. The elevation map was thus developed after reclassifying the layer into 5 classes: 1-4 m (very high risk - 5), 4-7 m (high risk - 4), 7-10 m (medium risk - 3), 10-13 m (low risk - 2) and 13-26 m (very low risk - 1). As seen from Figure 2a, the majority of the study area falls under classes 3 to 5 indicating that the majority of the land ranges from an elevation of 1-7 m indicating that the study area has relatively low elevation. On the other hand, the slope ranged from 0° to 30.64° and was similarly reclassified such that 0-2.28° (very high risk – 5), 2.28–3.96° (high risk - 4), 3.96–6.00° (medium risk - 3), 6–8.65° (low risk - 2) and 8.65–30.6° (very low risk - 1) based on the fact that the lower the slope gradient, the more likely it is to be flooded. The slope plays a key role in indicating flood-prone zones since the water flow across areas with a high steepness tends to concentrate the flow, forming channels moving through the landscape, however, flatter areas have a substantial decrease in the water movement and show an increase in the probability of ponding.

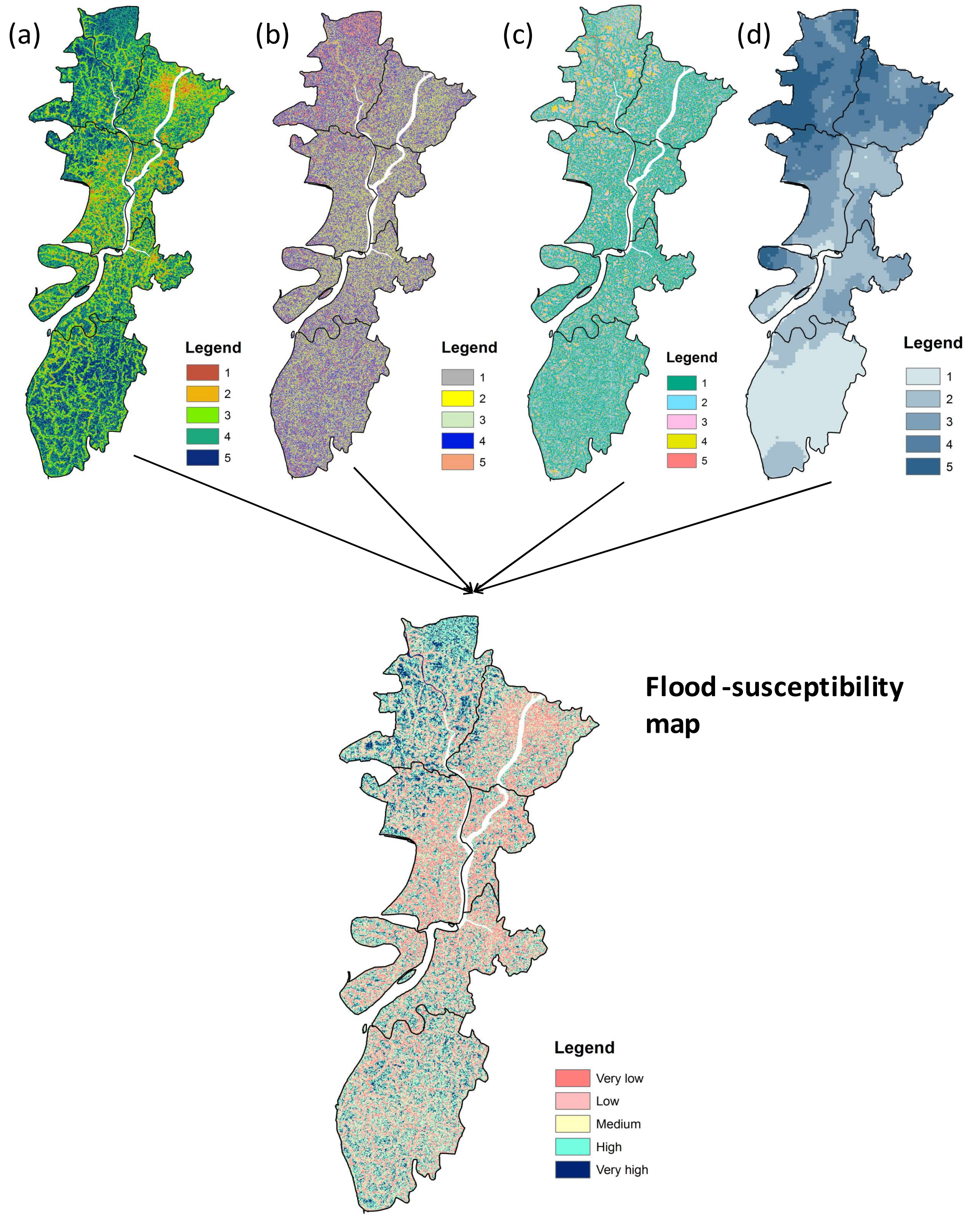

Figure 2: Flood-influencing factors: a) Elevation b) Slope c) TWI d) Drainage density maps and the flood-susceptibility map in 2014.

As seen in Figure 2b, the majority of the study area has scattered pixels of classes 4 and 5 suggesting that most of the slope ranges between 0–3.96°. Subsequently, the TWI index ranged from 3.99 to 20.3 and since the higher the TWI values, the higher the probability of flooding (Rahmati et al., 2016), the values were reclassified into: 3.99 - 6.75 (very low risk - 1), 6.75 - 8.09 (low risk – 2), 8.09 – 9.69 (medium risk – 3), 9.69 – 11.81 (high risk – 4) and 11.81 – 20.33 (very high risk – 5). From Figure 2c, it can be seen that the majority of Pirojpur falls under 3.99 - 6.75 with an exception of Nazirpur and Shorupkati showing few clusters of the high-risk category (yellow). As for the drainage density, it exerts significant control on flood peaks. Since the flow velocity is higher in the river network, the drainage density can significantly affect the concentration time and eventually the peak flow magnitude which suggests that an increasing drainage density results in increasing flood peaks (Pallard et al., 2009). Furthermore, the drainage density is one of the key influencing factors that strongly contribute to the occurrence of a flooding event (Gül, 2013). It has been found that there is an association between heavy and high flooding in an area with a high percentage of drainage density indicating a high percentage of surface run-off and vice-versa (Kumar et al., 2007).

Nazirpur, Shorupkati, Pirojpur Sadar and Zia Nagar are seen to have the highest drainage density while Modbaria shows the lowest (Figure 2d). The equal distribution of these four parameters yielded the flood susceptibility map which shows that majority of Pirojpur falls under the moderate/medium risk . category of flooding (Figure 2) however, Nazirpur is seen to have fallen under the high to very high-risk category along with a few parts of Shorupkati, Pirojpur Sadar, Zia Nagar with areas indicating very-high risk of flooding.

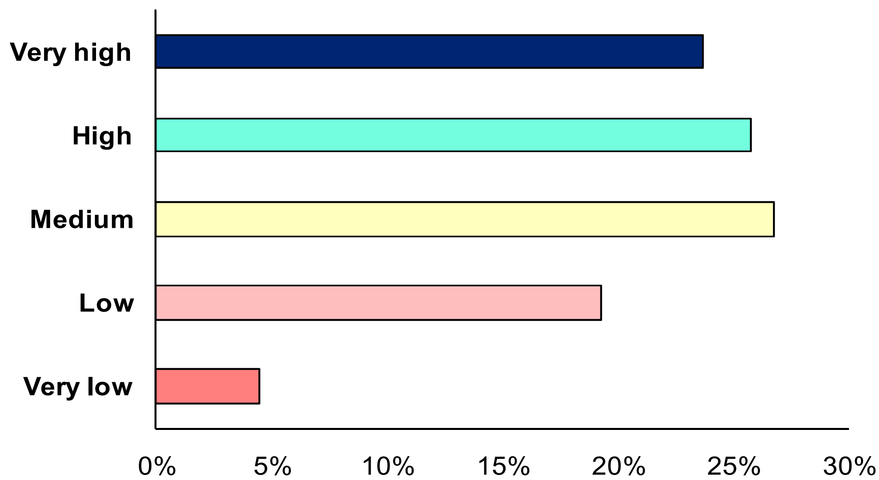

Figure 3: Flood-susceptibility on a percentile basis.

From Figure 3 it can be seen that the majority of the Pirojpur district falls under the medium flood risk category (27%) followed by high-risk (26%), very-high risk (24%), low-risk (19%) and very-low risk (4%) although it is possible to say that the district falls under the medium to high-risk category considering the one percent difference. A similar conclusion was also found in the BBS Census Survey 2011 which categorized the Pirojpur district within the medium vulnerability rank for the population. With this in mind, river and channel dredging and dispersion of the dredged sediments can help increase both the elevation and the river storage, better tilling practices and contour tilling could help reduce the damage to crops as ploughing makes the soil more prone to erosion from surface run-off and inter-basinal co-operation could all be considered for better flood management (Khalequzzaman, 1994).

Conclusion

With excessive infrastructural development, deforestation and global warming, there comes an increase in the impact of the flood. In this study, SRTM data was used to map out the flood-susceptibility zones of the Pirojpur district using a combined approach. It was found that the overall highest area falls under the medium risk category (27%) however, high (26%) and very-high risk (24%) is also considered significant. It is hoped that this study would be able to empower flood management agencies and the other associated agencies along with the decision-makers to accurately make decisions by applying management practices while progressing toward building resilient infrastructures. Further research considering the influence of the changing land cover could help to better map the flood-susceptibility conditions.

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