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RESEARCH ARTICLE

APPLICATION OF GIS FOR CYCLONE VULNERABILITY ANALYSIS OF BANGLADESH

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ABSTRACT

Cyclones are one of the most common and foremost natural hazards in the world that causes extensive causalities. Bangladesh is highly vulnerable to cyclone hazard for its geographical location and socio-economic conditions. This study has aimed to analyze the historical cyclonic hazards and creating vulnerability maps and risk maps for Bangladesh. The apposite variables were selected by reviewing pertinent literatures and necessary data were retrieved for 1900 to 2015. GIS tool has been used for visualization of weighed scores for hazard, vulnerability and risk based on historical cyclones' intensities, magnitudes, causalities and existing coping capacities. Moreover, hotspot analysis that implies Getis-Ord Gi* spatial statistics was also used in this study to identify the patterns of spatial significance and relationship of areas among their neighbors. This analysis produced Z scores from weighed variables those were proportional to the degree of vulnerability and risk. The low negative to high positive Z scores are correlative of low to high cyclone vulnerability and risk. Consequently, the weighed scores have elicited the coastal areas are in front line in terms of vulnerability and risk to cyclone. Besides, Gi* revealed that some areas are significantly risk prone for being spatially influenced by their neighbors.

KEYWORDS

Bangladesh, cyclone, risk, mapping, hotspot analysis, spatial analysis, natural hazards, coping capacity.

1. INTRODUCTION

A hazard is an extreme situation that can cause or has potential negative impacts on biophysical, socio-economic and environmental aspects. The susceptibility for being disrupt, damage and or loss of these systems and or a community or an individual to that hazard is known as the vulnerability i.e., a function of susceptibility, adaptive capacity and exposure [1-6]. It is trans-disciplinary, dynamic, change with temporal and spatial scales and depend on multi-dimensional factor and central focus point of disaster research [7,8]. Meanwhile, a disaster is the severe consequences combined with hazard and vulnerability on any or all aspects causes serious disruption and damage where capabilities are insufficient to minimize the potential risk by using their available resources [9-11]. Cyclone vulnerability comprises the factors of susceptibility and lack of coping and adaptive capacity [12,13]. Hence, it is portrayed as the susceptibility to be harmed or waning people's capability to adapt to cyclone hazard. Besides, disaster risk refers to the interaction between hazard and vulnerabilities [14]. In this vein, cyclone risk can be analyzed from the historical vulnerability and the existing coping and adaptive capacities [15,16].

Bangladesh is an extremely disaster-prone country and highly vulnerable to devastation of natural disasters. Atmospheric (e.g., hurricanes, tropical storms, tornadoes) and hydrologic (e.g., flooding, drought, storm surges, salinization, sedimentation and erosion) disasters are common annual phenomenon in this country. For geographical location, its 97.1% of total landmass is hazard prone and 97.7% of the population is at multiple hazards risk [17]. Consequently, it has been ranked as the sixth most vulnerable country in the world [18]. Cyclones and induced tidal surges are the most common and foremost natural hazard in the world [19]. Bay of Bengal is bearing all physical and meteorological characteristics for cyclonogenesis and has been acting as an ideal ground for 6-10% of global cyclone formation [20]. Bangladesh comprises a 711 km of its total coastline with Bay of Bengal and stricken by a severe cyclone on average every three years [21,22]. Consequently, it suffers invariably from direct cyclonic causalities including death, crop damage, infrastructure loss etc and indirectly affected by salinity intrusion, reduction of agricultural production, destruction and contamination of fresh water sources, biodiversity and ecosystems[23]. During the 19th century, there are about 178 cyclones were formed in Bay of Bengal with landfall on Bangladesh associated with more than 87 km.h^{-1} wind velocity and storm surge, caused extensive loss of human lives, property, livelihood and natural ecosystems. In addition, with geographical setting, it is a low income and densely populated country. The effects of natural calamities are more severe to poorer nations [8]. Hence Bangladesh is considered as highly vulnerable and at risk to cyclonic hazard in terms of physical, social, economic and environmental aspects [24,25].

Human vulnerability and risk to cyclone is still an emerging field along with the challenges of accuracy and paucity of data; standardize definition and inconsistencies in analysis procedures [26]. However, vulnerability and risk are hazard specific, characteristics of location and can be determined by the internal characteristics i.e., sensitivity, exposure and adaptive capacity. Nowadays, researchers are more interested to analyze these characteristics for a confined area rather than broader context due to the dynamic, temporal and spatial variations. In this case, they are using historical evidences; spatial characteristics and human capacities to cyclones. These factors are contingent upon areas, physical, socio-economic, cultural conditions and coping capacities and able to change the level of vulnerability and risk. The most common factors for analyzing human vulnerability used under these dimensions are physical condition, education, income, proportion of death, age, gender, intrinsic knowledge, weather forecasting and warning, land and livestock ownership, livelihood diversity, house quality, food security, poverty, infrastructure, information and awareness, preparedness and evacuation, profession, availability of job, availability of resource and access etc. [27]. The most relevant studies on human vulnerability and risk analysis to cyclone are summarized in Appendix 1 including the factors under different dimensions.

Cyclone is contingent upon location, hence different tools and methods have been using for analyzing and assessing its vulnerability. Geographical Information System (GIS) is such an important tool, has been using for scientific study of disaster analysis, impacts assessment, reduction and management by developing planning and cartography [28,29]. Moreover, it is a modern technology that can be used for estimating, measuring, monitoring, modeling the geo-environmental and natural information to identify disaster prone areas and create maps by incorporating statistical tools. Similarly, it also can be used to manifest geo-environmentally referenced information for cartographic visualization for cyclones to generate easily understandable, accessible and visible for all groups of peoples [30]. By using GIS, there are some significant studies on human vulnerability to cyclone have been conducted for analyzing and assessing cyclone's pre and post impacts. This study is aimed to analyze and mapping of cyclone vulnerable and risk zones in Bangladesh.

2. METHODOLOGY

This study was done by means of both descriptive and GIS based statistical analysis to create cyclone vulnerable and risk maps of Bangladesh. The CRED-EM DAT was used as the base of this analysis [31]. Besides, some other important database was also used for avoiding the missing data as well as enhancing the quality of study. The historical cyclonic data were tabulated with scrutinizing the resemblance with different database. This tabulated data was added into an administrative shape file of Bangladesh in ArcGIS 10.1 software according to types of the hazard, vulnerability and coping capacity variables. These variables were categorized in relation to respective dimension and ranked according to their inferential importance. The values of these variables were normalized in order to acquire the unambiguous dataset between 0 to 1. These normalized values were multiplied by given values according to their ranks to acquire the weighed values for each variable. The high weighed value of an area in comparison with others was representing comparatively more vulnerable and risk prone. Afterwards, hotspot analysis was done to identify the spatial relationship of areas among their surrounding neighbors. It is an advanced mapping technique that generally illustrates the patterns of spatial significance and interaction among different neighboring zones. It implies Getis-Ord Gi* statistics that generates Z scores and P values. The low negative Z scores and small P values are indicating the cold zones i.e., less significant where increasing the positive scores and values represent the hots or high significant zones (ESRI, 2015). In this study, Gi* statistics was done based on the weighed variables. The increasing values of Z scores from low to high were illustrating the low to high vulnerability and risk to cyclones. In particular, the entire study comprises three parts. Firstly, analysis the frequency and magnitude of historical cyclone hazards, secondly, analysis the human vulnerability to historical cyclones and finally analysis the potential risk zones to cyclone hazards in Bangladesh. The details of variables and their sources, analysis and mapping methods are given in below:

2.1 Variables and sources of data

2.1.1 Historical cyclones

The historical data since 1900-2015 of landfall cyclones' causalities on Bangladesh were used for analysis of historical cyclone events. The historical cyclonic information were collected fromEM-DAT, Khan, BMD, DMIC and IFRC [32-35]. Afterwards, all cyclonic hazards were classified based on their intensities according to the Bangladesh tropical cyclone classification system [36]. A district-wise descriptive statistical analysis based previous physical characteristics such as cyclone frequencies, magnitudes; intensities as well as human causalities have been done. The number of total struck hurricane, total severe storms, total storms, wind velocity and surge height were taken to understand the cyclone threats and vulnerability to each individual district of Bangladesh.

2.1.2 Cyclone vulnerability

By definition, cyclones vulnerability of a community or an individual refers to its sensitivity character to be exposed or degree of loss due to lack of capabilities (coping and adaptive). Therefore, it is the weakness or gap of a community or an individual against the negative consequences of cyclones hazards. As it is dependent on geographical along with demographical characteristics, the variables for this study have been selected in consistency with relevant studies. The considered variables for human vulnerability to cyclones are the total number of deaths, total number of storms, distance from the coastline, elevation from mean sea level and population density within the specific district.

2.1.3 Coping Capacity

Coping capacity is the instant or short time response to the impacts of a hazard within the existing resources or limited skills by a community or an individual where adaption is the long-term adjustments for a permanent change in the climate, system, society or community [8]. This study considered only the coping capacities to cyclone hazards. The variables are suggested by different researchers and consistent with geo-demographical characteristics to act as coping capacities against vulnerabilities. This study is used per capita income, human holding capacity by cyclone shelters, people living upper poverty line, road density and illiteracy rate.

2.2 Calculation of Risk Scores

By definition, cyclone risk analysis refers to the ability to cope or adapt to hazard's vulnerability. In this vein, this study has divided the risk analysis into two steps. Firstly, selection of variables as used for manageable capacity and generating their normalized scores for each variable and district were done similar to the technique used for vulnerability analysis. Accordingly, following equation were used to get individual risk scores for each district.

$$Cyclone\ Risk\ =\frac{Cyclone\ Hazard\times Vulnerability}{Coping\ Capacity}$$

2.3 Analysis and Mapping

The actual values of each variable in consistent with the district names were tabulated in a excel sheet one by one. Afterwards, the excel sheet for each variable were joined consecutively in the administrative shape file that already been added and opened in ArcGIS running project file. Subsequently, a new field was added into the attribute data to normalize the data from different scales according to the standard normalization formula:

$$Normalization_v=\frac{X_v-X_{min}}{X_{max}-X_{min}}$$

Where, $X_v$is the actual value of a given variable for district X;$X_{max}$is the maximum value of that given variable among all districts and $X_{min}$is the minimum value that variable among all districts. As a result, the scores for individual variable differ within '0-1' scale.

Subsequently, the normalized values were prioritized based on their importance among the all other variables. The highest to lowest prioritized variables were multiplied by 0.35, 0.25, 0.20, 0.15 and 0.05 respectively and summed up for the total weighted value of each district. The relative high score represents the comparative degree of high intensity of a variable's value among different district. Number of total hurricanes, number of severe storms, and number of total storms, maximum wind velocity (km^{-1}) and surge height (m) for was given priority for hazard analysis. Besides, total deaths, total number of storms, distance from coast line (km), elevation from mean sea level (m) and population density (km^{-1}) for vulnerability as well as per capital GDP ($), cyclone shelter's capacity (%), road density (km^{-1}), literacy rate (%) and people living the upper poverty line (%) were given highest to lowest inferential priority ranking for calculating 'weighed' scores.

Lastly, there are four maps were created in ArcGIS based on cyclone intensities, vulnerability, coping capacity and risk scores. The advanced hotspot mapping technique (Gi* static) was used to identify the spatial patterns in relationship to neighbor of vulnerability and risk zones. This spatial analysis was based on the total weighed scores of different variables in consideration with a '1 km' fixed distance band. The '1 km fixed distance band' is the critical distance that decides to what neighbors and their commonalities will be included for an area. Here it is fixed for 1km i.e., the scale of analysis and commonalities will be remained consistent within this distance. It is an important factor for more reliable spatial analysis. The Gi* analysis based on weighed values generates the Z scores and P values. Z scores are based on null hypothesis and represent the standard deviation. Besides, P-values are the probabilities of being statistically significant of the spatially distributed values at different confidence levels within the given distance band (ESRI, 2015). These Z scores were used for classifying the zones from very low to extremely high vulnerable and risk zones. The low negative Z score and small P values are indicating the low vulnerability and risk zone while increasing the positive score and values represent the degree of high vulnerability and risk to cyclones.

3. RESULTS AND DISCUSSIONS

The results comprise four different but interconnected sections. Firstly, analyzed historical cyclone hazards along with their causalities to scrutinize the actual threats and vulnerability to Bangladesh; secondly, generated maps based on selected variables on historical loss of lives and other causalities along with a coping capacities map based on tools and or skills to minimize the adverse impacts of cyclone; and finally, created composite future cyclone risk map for Bangladesh based on previous hazard events, causalities and available coping capacities. There are two maps for each aspect were created based on their weighed score and Gi* score. The classification of scores in context to identify zones is given in the following Table 1.

Table 1: Classification of zones based on different scores

Category	Stand. Dev	Hazard Scores		Vulnerable Scores		Coping capacity Scores		Risk Scores	
		Z-Score	Weighed Score	Z-Score	Weighed Score	Z-score	Weighed Score	Z-score	Weighed Score
Very Low	<-2.58	-2.52 - -1.86	0.000 - 0.015	<-2.77	0.112 - 0.184	-2.33- -2.00	0.102-0.170	0.00 - 0.03	0.000 - 0.033
Moderately Low	-2.58- -1.96	-1.86 - -1.42	0.015 - 0.045	-2.77 - -1.52	0.184-0.238	-2.00- -0.99	0.170-0.211	0.03 - 0.10	0.033 - 0.107
Low	-1.96- -1.65	-1.42 - -0.64	0.045 - 0.090	-1.52 - -0.38	0.238-0.282	-0.99 - -0.42	0.211-0.243	0.10 - 0.23	0.107 - 0.232
Medium	-1.65-1.65	-0.64 - 0.35	0.090-0.137	-0.38 - 0.82	0.282-0.339	-0.42 - 0.52	0.243-0.294	0.23 - 0.54	0.232 - 0.543
High	1.65-1.96	0.35 - 1.66	0.137 - 0.267	0.82 - 1.91	0.339-0.443	0.52-1.68	0.294-0.335	0.54 - 1.44	0.543 - 1.442
Moderately High	1.96-2.58	1.66 - 2.81	0.267-0.443	1.91-2.74	0.443-0.568	1.68-3.06	0.335-0.396	1.44 - 4.64	1.442 - 4.640
Extremely High	> 2.58	2.81 - 4.14	0.443-0.892	>2.74	0.568-0.973	3.06 - 4.38	0.396-0.559	4.64 - 14.56	4.640 - 14.560

3.1 Historical cyclone hazards analysis

The study has developed a complied database to historical analysis by scrutinizing the resemblance among different but most widely use databases for avoiding missing data along with enriching statistical interpretation. It was based on struck cyclonic events since 1900 to 2015 on Bangladesh and classified into two individual time periods for interpretation. Firstly, the whole time series for analyzing the total causalities (i.e., total deaths, affected districts, damage etc) and since 1960 to 2015 for identifying and interpreting cyclones characteristics (i.e., wind velocity, storm surge etc). The cyclonic characteristics have been recorder since 1960; hence this categorization was done for avoiding missing data.

The study has revealed that there are 151 cyclonic events struck on Bangladesh since 1900 to 2015. These events caused to death of '955128' people and extensive damage of properties. The coastal districts were found as the most affected zones in terms of cyclones number, damage and deaths. There are 99.53% of total death has been occurred in the coastal 16 districts. However, south-eastern 04 districts were found as high vulnerable due to loss of more than half of total lives (54.16%) and struck cyclone number (115 out of total 320 times). Chittagong ranked as the highest rank for being affected maximum times and causalities. Since 1960, there are 131 cyclonic events have been recorded in which 43 were above the depression level. Among them, only hurricanes struck 33 times while 11 events were with more than 200 kmh^{-1} wind velocity. 428363 people died during these events where Chittagong (142110), Khulna (101162), Noakhali (32830), Cox's Bazar (34542) and Feni (32609) were found as the five most affected districts respectively.

Besides, the total weighted scores of hazard characteristics have been calculated to create the map. Chittagong is ranked as the most cyclone hazard prone district in Bangladesh. Cox's Bazar, Khulna, Noakhali and Bhola are found as the top five of cyclone hazard districts. Among the 64 districts, most of the cyclone prone areas were found as located in the coastalzones and 2 districts were found extremely cyclone hazard prone (Fig. 1a). Due to use of 'conceptualization of spatial relationships' for this hotspot analysis, Bandorban has found as the extremely cyclone hazard prone district grippingly although there are no previous cyclone events and causalities had been reordered to this district (Fig.1b). Similarly, Rangamati and Khagrachari are also found as the high cyclone prone for the same reason. The comparative ranking of 10 foremost cyclones prone areas based on their historical cyclones weighed and GiZ scores is given in Table 2.

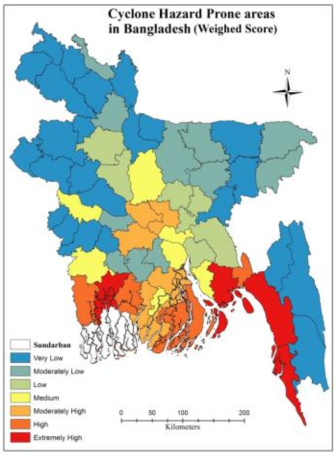

Figure 1(a): Cyclone hazard prone areas based on weighed scores

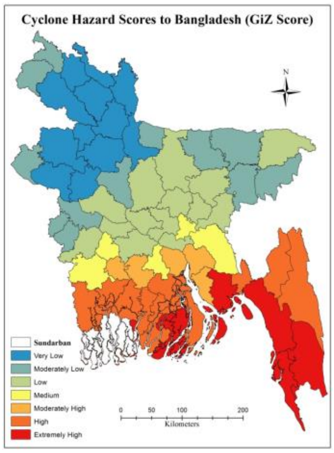

Figure 1(b): Cyclone hazard prone areas based on GiZ scores

3.2 Analysis of cyclone vulnerability

In similar to most cyclone hazard prone district, Chittagong has also been ranked as the top cyclone hazard vulnerable district in Bangladesh. Cox's bazaar, Khulna and Noakhali were consecutively extremely vulnerable due to more struck storms, high causalities, population and for being located near the Bay of Bengal. Dhaka has also come out with ranked 5 dues to possess average weighted values for all variables (Table 2). The population density, elevation and near distance were the main reasons to make it in high rank (Fig. 2a).

Table 2: Most cyclone hazard prone and vulnerable zones in Bangladesh

Rank	Hazard Prone Zones					Rank	Vulnerable Zones			
	District Name	Weighed Score	District	GiZ Score			District Name	Weighed Score	District Name	GiZ Score
1	Chittagong	0.892196	Cox's Bazar	4.140374		1	Chittagong	0.973171	Patuakhali	3.855314
2	Cox's Bazar	0.716121	Bandarbon	4.140374		2	Cox's Bazar	0.876837	Barisal	3.671704
3	Khulna	0.555584	Patuakhali	3.604535		3	Khulna	0.787097	Cox's Bazar	3.571353
4	Noakhali	0.528948	Chittagong	3.575456		4	Noakhali	0.726901	Bandarbon	3.571353
5	Bhola	0.443938	Pirojpur	3.317068		5	Barisal	0.568452	Jhalakati	3.418721
6	Bagerhat	0.325411	Noakhali	3.185516		6	Borgona	0.558367	Noakhali	3.407465
7	Patuakhali	0.311459	Borgona	2.810148		7	Bagerhat	0.546869	Pirojpur	3.250437
8	Shatkhira	0.309386	Jhalakati	2.776566		8	Dhaka	0.520976	Chittagong	3.134034
9	Feni	0.287933	Feni	2.717391		9	Bhola	0.520121	Borgona	3.131765
10	Borgona	0.267442	Barisal	2.663484		10	Feni	0.498634	Bhola	2.987671

However, the priority based multiplying analysis of variables generated significant changes between the total weighted values and Z scores. In this circumstance, Patuakhali has been ranked highest vulnerable position in terms of Z score and P-value. Barisal, Cox's bazaar, Bandorban and Jhalakati were the top five vulnerable districts based on Z scores respectively (Fig. 2b).

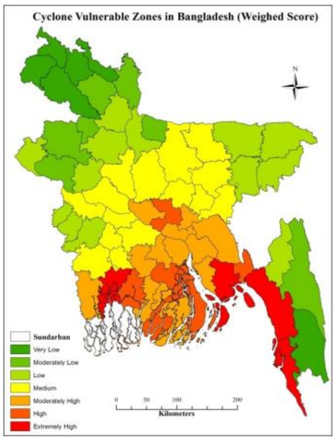

Figure 2(a): Cyclone vulnerable zones based on weighed scores

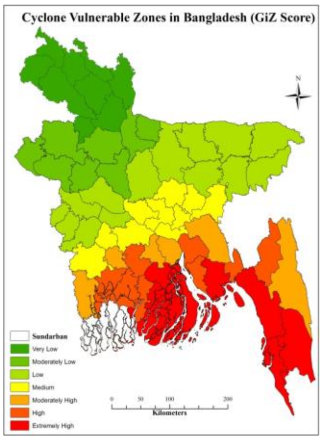

Figure 2(b): Cyclone vulnerable zones based on GiZ scores

3.3 Analysis of Coping capacities

Dhaka has the highest coping capacities to any types of disasters including cyclones due to its high per capita income, literacy rate and people living upper poverty line. Jhalokati, Bhola, Pirojpur and Comilla were possessing consecutive highest coping values similarly.

Although the analysis found heterogeneity in coping capabilities among different districts but Gi* analysis revealed the coastal districts as in foremost (Table 3). Since these districts were been considered as the most vulnerable, hence the physical facilities are higher than other districts. For example, coastal districts are possessing cyclone shelters those were adding an extra-value for them. The Z score of coping capacity was found highest for Barisal and Pirojpur and Borguna, Patuakhali and Jhalokati were in ranking of top five districts (Fig. 3a and Fig. 3b).

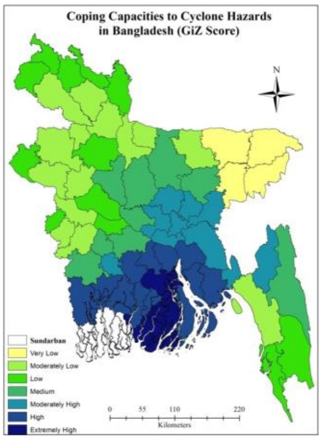

Figure 3(a): Coping capacities of different zones to cyclone vulnerability based on weighed scores

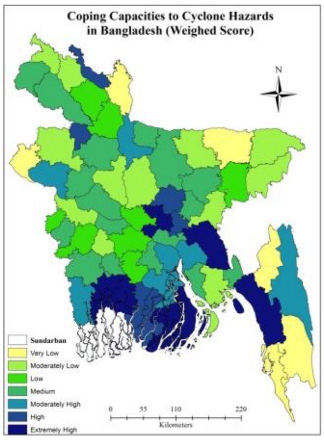

Figure 3(b): Coping capacities of different zones to cyclone vulnerability based on GiZ scores

3.4 Analysis of cyclone risk mapping

Cox's bazaar has revealed as the most disaster risk to cyclone hazard in Bangladesh. The foremost districts are coastal areas i.e., Chittagong, Noakhali, Khulna, Bhola, Satkhira according to the risk rank (Fig. 4a). All of the coastal districts possessed their risk rank within 15 out of 64 districts (Table 3). On the other hand, Gi* analysis has ranked Bandorban as the most risk prone district all over the country. Cox's Bazaar and Chittagong were also most extremely cyclone disaster risk prone districts. The spatial hotspot analysis also has brought Khagrachari within the top risk prone district. However, most of the districts from coastal areas were found as at high risk to cyclone disasters (Fig. 4a and Fig. 4b).

Table 3: Highest coping capacities and risk scores to cyclone hazards in Bangladesh

Rank	Coping Capacity					Rank	Risk Zones			
	District Name	Weighed Score	District Name	GiZ Score			District Name	Weighed Score	District Name	GiZ Score
1	Bhola	0.559072	Barisal	4.382222		1	Cox's Bazar	14.5608	Cox's Bazar	4.984753
2	Dhaka	0.536705	Pirojpur	4.259345		2	Chittagong	8.09511	Bandarbon	4.984753
3	Comilla	0.480694	Borgona	3.984132		3	Noakhali	7.70165	Chittagong	4.362992
4	Bagerhat	0.461563	Patuakhali	3.681106		4	Khulna	4.64008	Patuakhali	2.342017
5	Chittagong	0.445168	Pirojpur	3.061565		5	Bhola	2.58038	Khagrachari	2.196358
6	Patuakhali	0.441455	Jhalakati	2.966801		6	Shatkhira	2.36168	Noakhali	2.166228
7	Khulna	0.438376	Bhola	2.732507		7	Feni	2.33549	Feni	2.07109
8	Borgona	0.396665	Lakshmipur	2.645014		8	Borgona	2.21681	Bhola	1.662393
9	Narangonj	0.393894	Bagerhat	2.592344		9	Bagerhat	2.10288	Jhalakati	1.565162
10	Gazipur	0.385292	Noakhali	2.406532		10	Barisal	2.0386	Rangamati	1.364124

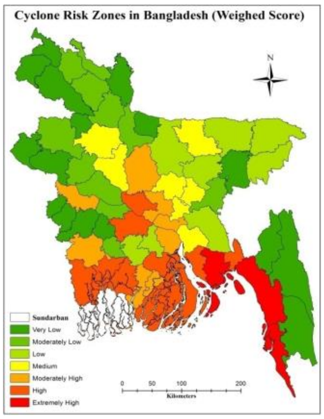

Figure 4(a): Composite cyclone risk map based on weighed scores

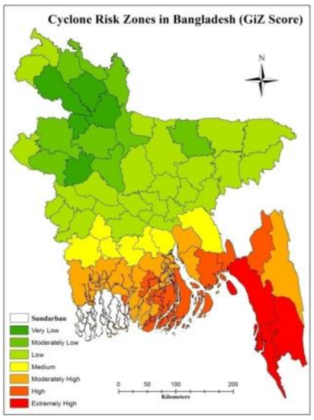

Figure 4(b): Composite cyclone risk map based on GiZ scores

4. CONCLUSIONS

Bangladesh has been suffering from causalities to tropical cyclones hazards due to its geographical location as well as low coping capacities. Cyclonic causalities are common phenomenon to this country including human death, missing, crop damage and property loss. Its influence on different socioeconomic and environmental dimensions has been identified. Consequently, it has been considered as an important factor that exacerbates human socioeconomic problems and might be a significant challenge to achieve Sustainable Development Goals (SDGs).

This cyclones hazard analysis and mapping have brought significant vulnerability and risk information to Bangladesh. The most significant findings of this study are the total and district wise deaths and the times of being affected by cyclones for last 115 years. It has found that there are 151 cyclonic storms struck Bangladesh since 1900 and caused to death of '955128' people along with extensive damage and losses of properties. Coastal districts were found for suffering maximum of struck and causalities. Consequently, these districts were found more hazard prone, vulnerable and risk zones according to the weighted values of respective variables. Meanwhile, GIS based hotspot analysis has also revealed some important outcomes regarding spatial relationships for this cyclone vulnerability and risk mapping study. Notably, there are some districts e.g., Bandorban, Khagrachari and Rangamati were found also highly vulnerable and cyclone risk districts. Although these districts were not struck by any historical cyclonic events or caused any deaths but the spatial relationship brought them up at foremost due to be neighbor of two high vulnerable and risk districts e.g., Chittagong and Cox's bazaar. This historical statistical and spatial mapping also found a low vulnerability and risk scores for districts near Sundarban. The reason is assumed that high cyclonic wind velocity is reduced by the Sundarban forest and led to minimum human causalities.

However, this study comprises some limitations, delimitations and challenges. Lack of data or missing, selection of variables, not considering Sundarban, death, wind velocity and storm surge identification for each district were most noteworthy. Besides, compilation of data from different databases, heterogeneity and missing of data, undefined specific affected location rather than mentioning whole country were main challenges for interpreting the data. When the struck zones were undefined or not specific by the databases, in that cases this study was given equal and inferential number deaths for each district based on previous causalities. Therefore, the figure for total deaths and in each district may not entirely valid. Further, this study did not consider the coastal forest or environmental losses (i.e., damage of Sundarbans). Moreover, these maps with spatial relationships may bring a skeptic visualization when some regions were found more vulnerable though did not affected even for a single time.

In spite of that this variable based weighed and hotspot analysis in relation to spatial relationship of a district to its neighbor is important for decision makers for taking into account for incorporating in policy formulation. For example, hilly i.e., Rangamati, Bandorban and Khagrachari are not considered as the cyclone prone districts. But for being neighbor of most vulnerable and risk districts along with their low coping capacities, these are at high risk to cyclone hazard. Moreover, these maps also might be considered as an important tool for building awareness, capacity building as well as policy making for a more cyclone resilience country.

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Appendix 1

Table 1: Variables and indicators used under socioeconomic dimensions for assessing human vulnerability to cyclone

Exposure Dimensions	Variables	Susceptibility	Coping and Adaptive Capacities
Environmental Dimensions	Physical Conditions, Geography, Location, Place, Settlement Patterns, Elevation, cyclone shelter (O. D. Cardona et al., 2012; Nazir Hossain, 2015; Saha, 2014)	- Share of houses made by mud with straw roof, thatch roof, CI sheet or brick building - Distance of houses from river, open sea or Sundarban - Rurality or remoteness of the area and road density - Elevation of houses from the ground and mean sea level - Distance of nearest cyclone shelter from house - Share income dependency or profession based on environmental systems e.g., rice farming, fishing, aquaculture - Area under threat to salinity intrusion - Destruction of natural resources in which local people depend on	- Disaster resilient infrastructure, building houses according to national guild lines - A forestation around the houses to reduce wind speed - Increase the number of cyclone shelter - Appropriate land management - Increase the quality of transport or communication systems
Social Dimensions	Demography, Migration, Displacement, Social groups, Household, Poverty, Death, Education, Culture, Institutions, Governance(O. D. Cardona et al., 2012; Nazir Hossain, 2015; S. K. Paul & Routray, 2010)	- Percentage of children, women, very young, very old and physically and mentally challenged people - Total population and density - Percentage of ethnic, minority, immigrant group and share of race, caste, class among different groups - Percentage of women headed household - Percentage of landless household - Percentage of people living under the lower poverty line - Educational level - Social connectivity and information sharing - Response behavior, ethics, customs, norms, beliefs, institutions and intellectuality - Institutional and governing structures in society and national level for disaster management - Social instability, insecurity, violence and waning social cohesion - Percentage of people death, injured and affected - Destroy or scare the overall public services and evacuation processes	- Interactive and interlinked institutional and governance framework - Transparency and reduce corruption - Encourage and ensure women participation in disaster management training - Responding to early warning, sharing information - Increase all types literacy rate - Increase the capacity of cyclone shelter - Diminish loopholes of cyclone preparedness and management

Economic Dimensions	Profession, Livelihood(Saha, 2014; WB, 2015)	- Percentage of different professional attributes - Major income source and dependency - Declining monthly average household income - Amount of monthly savings - Amount of monthly loan payment - Damage of property and infrastructure - Food scarcity and malnourishment	- Insurance - Savings - Encourage for alternative and supplementary income sources - Reduce tax and financial assistance to reform - Food security

Table 2: Most relevant literatures used GIS tool to assess human vulnerability to cyclone

Author(s)	Main purpose(s) for using GIS
Fuhrmann, MacEachren, and Cai (2008)	Assessing disaster impacts for planning, cartography and management
Sims, Warrendorf, Matheson, and Madsen (2008)	For post impacts assessment, rehabilitation and reconstruction work
S. M. T. Islam and Chik (2011)	Using GIS and other relevant information technologies for hazard mapping
O.-D. Cardona et al. (2014)	To assess the coarse grain probabilistic risk assessment
Nazir Hossain (2015)	Used to assess the human vulnerability to cyclone and storm surge
Hossain (2001)	To calculate and assess the vulnerable population to cyclone
Chavoshi et al. (2008)	For zoning hazard prone areas in response to spatial exposure
Taramelli et al. (2008)	To analyze and visualize hurricane hazards
T. Islam (2006)	To generate cyclone vulnerable and risk zones

Appendix 2: Reasons of selecting variables

Poverty: Poverty is an indicator that represents the inability to recover the losses from a cyclonic disaster. Human vulnerability is extremely codependent on it and hence considered as the biggest barrier to societal resilience (Brooks et al., 2005; IPCC, 2012). Moreover, poor people are socioeconomic, politically and culturally vulnerable in a cyclone prone area (Bobby, 2012). Accordingly, data of people living above the upper-poverty line has been collected from (BBS, 2011; WB, 2015).

Number of cyclones, wind speed and Surge Height: The damage of property and loss of human lives are inextricably interlinked with the number of cyclones including their intensities and magnitudes. Besides, surge height is considered as a phenomenon associated with wind speed of storm in coastal regions. A cyclones associated with high wind velocity and surge height portrayed severe strengths and caused a significant devastation to loss of lives, property and water sources (Alam & Collins, 2010; O.-D. Cardona et al., 2014; S. K. Paul & Routray, 2010; Rana et al., 2011). Thus, numbers of cyclones along with wind speed and surge height were considered for this study. To careful examine and avoid missing data, there are some others important databases as well as literatures were considered along with EM-DAT database. The total number of cyclones has been denoted in this study for a district as times of being affected by cyclonic hazards i.e., given equal hazard number for all affected districts caused by a single cyclone hazard.

Deaths: Loss of human lives represents the severe consequences or extreme vulnerable condition of a community due to cyclone hazard. The data of human causalities to specific cyclone has been collected and tabulated individually for each affected district. Finally, the total number of deaths for each district was found by summing up all historical loss of lives.

Population Density

Population distribution and density are important factors in hazard prone areas in terms of evacuation, easily access, planning as well force to live in the highly susceptible areas (T. Islam & Peterson, 2008; Khomarudin, 2010). High population density refers to be more affected by cyclone hazard. The district level population data were collected from BBS (2011).

Elevation: The elevation and surface roughness are important factors of vulnerability to cyclone. Low lands and low elevation houses from mean sea level are being affected by the storm surge. The low lands are also easily being affected by inundation and cause to damage of agricultural production and unpaved houses. Thus, low elevation of a surface land alongside with a sea or river means more vulnerable for being damaged or causalities (Das, 2012; Nazir Hossain, 2015). The spatial elevation data was extracted as raster file from (BARC, 2015).

Distance from Coast: The susceptibility to cyclone hazard is largely dependent on the physical location of a community from the landfall location (Nazir Hossain, 2015). Bangladesh is generally affected by the cyclones formed in the Bay of Bengal. Hence, decreasing distance between coastline and a land area represent the more susceptible to cyclone. In this vein, there is a coastal line and a central point of each district were drawn and created by GIS. Afterwards, the distance from coastal line to central point has been recorded as the distance of districts from open sea level.

Per capita income: Income is a strong factor that significantly influences the overall coping capabilities of a person or community (Haque, 2001). High income represents the ability to cope themselves in terms of procuring food & water, migrate to temporary shelter, reduce the risks and bounce back to damages (S. K. Paul & Routray, 2010). The district wise per capita income was collected from Lagging Districts Development 7th five year plan report (Khondker & Mahzab, 2015). Afterwards, average income of a district has been divided by its population for per capita income.

Capacity cyclone shelter: Cyclone shelter plays an essential role for saving lives during the cyclonic hazard. Though it is an indispensable physical humanitarian facility but the degree of coping capacities are determined by some other relevant factors regarding the cyclone shelters e.g., distance from the house, access, suitability, transport and road network to reach, total number, dependent people and its capacity (Nazir Hossain, 2015; B. K. Paul, 2009). The total number of cyclone shelters were collected and tabulated from CEGIS and DMIC online database (DMIC, 2015). The shelters for per thousand people have been used as one of coping factor where relative high value conveys positive coping capacities to that district.

Road density: Communication system notably influences the evacuation, rescue and timely arrival at shelters of peoples. It depends on different but important characteristics e.g., total length, paved, unpaved (earthen), narrow etc. (Alam & Collins, 2010). The total road density was calculated from total district area and road networks for each district collected from LGRD (2015) Bangladesh.

Literacy Rate: Level of education is an important determinant that helps to aware, response, precaution, saving and copes with cyclone hazard vulnerability (Akter & Mallick, 2013; B. K. Paul, 2009). Conversely, some earlier research findings are inconsistent with this statement. In consistent with some other relevant studies and inferential analysis, literacy rate collected from BBS has been used in this study as one of coping determinants (BBS, 2011).

Table 3: Classification of wind velocity to analyze the historical cyclone characteristics(Khan, 1995)

Classification	Wind Speed (kmph^{-1})	Wind Speed (knots)	Wind Speed (mph)
Depression	<62	<33	<38
Cyclonic Storm	63-87	34-<47	39-54
Severe Cyclonic Storm	88-117	48-63	55-73
Severe Cyclonic Storm of Hurricane Intensity	>118	64>	>74

Appendix 3

Table 4: Analysis of historical cyclones and their causalities (1900-2015)

District Name	No Strom (1900-2015)	Max Surge Height (m) (1960-2015)	Depression (1960-2015)	Cyclonic Storm (1960-2015)	Severe Cyclone (1960-2015)	Hurricane (1960-2015)	Total Deaths (1900-2015)
Bagerhat	17	4.5	*	0	1	5	56442
Bandarbon	0	0	*	0	0	0	0
Barisal	14	4.5	*	0	0	4	76356
Bhola	20	5.8	*	0	1	9	23124
Bogra	2	0	*	0	0	0	12
Borgona	17	5.8	*	0	0	5	56798
Brahmanbaria	2	0	*	0	0	0	55
Chandpur	10	0	*	0	0	2	6373
Chittagong	39	7.1	*	0	3	18	207137
Comilla	6	0	*	0	0	1	132
Cox's Bazar	39	5.8	*	0	2	13	155770
ChouaDanga	1	0	*	0	0	0	1
Dhaka	12	0	*	0	0	1	419
Dinajpur	1	0	*	0	0	0	4
Faridpur	4	3.5	*	0	1	0	305
Feni	6	5.8	*	0	1	5	55956
Gaibanda	4	0	*	0	0	0	7
Gazipur	0	0	*	0	0	0	0
Gopalgonj	5	0	*	0	0	1	21
Hobiganj	0	0	*	0	0	0	0
Jaipurhat	0	0	*	0	0	0	0
Jamalpur	2	0	*	0	0	0	268
Jessore	3	4.5	*	0	0	2	425
Jhalakati	4	4.5	*	0	0	1	247
Jhenaidah	0	0	*	0	0	0	1
Khagrachari	0	0	*	0	0	0	0
Khulna	25	5.5	*	1	3	5	175390
Kishoreganj	3	0	*	0	0	1	8
Kustia	4	1	*	0	1	0	3897
Kurigram	1	0	*	0	0	0	3
Lalmonirhat	4	0	*	0	0	0	32
Lakshmipur	5	5.8	*	0	0	1	2501

District Name	No of Storm (1900-2015)	Max Surge Height (m) (1960-2015)	Depression (1960-2015)	Cyclonic Storm (1960-2015)	Severe Cyclone (1960-2015)	Hurricane (1960-2015)	Total Deaths (1900-2015)
Madaripur	3	0	*	0	0	1	59
Magura	0	0	*	0	0	0	0
Manikgonj	8	1	*	0	1	1	3982
Meherpur	1	0	*	0	0	0	1
Moulvibazar	3	0	*	0	0	1	1
Munshigonj	4	1	*	0	1	1	3915
Mymensingh	5	0	*	0	0	0	737
Narail	1	0	*	0	0	1	1
Narayangonj	2	0	*	0	0	1	1
Naogaon	3	0	*	0	0	0	14
Narshingdi	2	0	*	0	0	1	40
Natore	2	0	*	0	0	0	1
Nawabganj	0	0	*	0	0	0	0
Netrakona	7	0	*	0	0	0	34
Nilphamari	2	0	*	0	0	0	6
Noakhali	31	7.1	*	0	1	10	97912
Pabna	3	0	*	0	0	0	53
Panchagarh	1	0	*	0	0	0	0
Rangamati	0	0	*	0	0	0	0
Patuakhali	18	5.8	*	0	0	7	1188
Pirojpur	10	4.5	*	0	0	3	735
Rajbari	1	0	*	0	0	1	1
Rongpur	3	0	*	0	0	0	13
Rajshahi	1	0	*	0	0	0	10
Shariatpur	4	1	*	0	1	1	4693
Shatkhira	9	4.5	*	0	2	2	18647
Sherpur	0	0	*	0	0	0	0
Sirajgonj	4	0	*	0	0	0	53
Sunamgonj	2	0	*	0	0	0	6
Sylhet	4	0	*	0	0	0	59
Tangail	6	0	*	0	0	0	547
Thakurgaon	0	0	*	0	0	0	0

'*' represents the events characteristics are not available in case of struck before 1960, but bearing 'depression' characteristics for the events after 1960

Table 5: Weighed values based on intensities and magnitudes of historical cyclones

District	No of Storms	Wind Velocity (kmh-1)	Surge Height (m)	No of sever cyclones	No of hurricane
Bagerhat	0.435897	0.173242	0.633803	0.333333	0.277778
Bandarbon	0	0	0	0	0
Barisal	0.358974	0.255575	0.633803	0	0.222222
Bhola	0.512821	0.281304	0.816901	0.333333	0.5
Bogra	0.051282	0.310463	0	0	0
Borgona	0.435897	0.281304	0.816901	0	0.277778
Brahmanbaria	0.051282	0	0	0	0
Chandpur	0.25641	0	0	0	0.111111
Chittagong	1	0.281304	1	1	1
Chouadanga	0.025641	0	0	0	0
Comilla	0.153846	0	0	0	0.055556
Cox's Bazar	1	0.372213	0.816901	0.666667	0.722222
Dhaka	0.307692	1	0	0	0.055556
Dinajpur	0.025641	0	0	0	0
Faridpur	0.102564	0.447684	0.492958	0.333333	0
Feni	0.153846	0.238422	0.816901	0.333333	0.277778
Gaibanda	0.102564	0	0	0	0
Gazipur	0	0.406518	0	0	0
Gopalgonj	0.128205	0	0	0	0.055556
Hobiganj	0	0	0	0	0
Jaipurhat	0	0	0	0	0
Jamalpur	0.051282	0	0	0	0
Jessore	0.076923	0.173242	0.633803	0	0.111111
Jhalakati	0.102564	0.281304	0.633803	0	0.055556
Jhenaidah	0	0	0	0	0
Khagrachari	0	0	0	0	0
Khulna	0.641026	0.276158	0.774648	1	0.277778
Kishoreganj	0.076923	0	0	0	0.055556
Kurigram	0.025641	0	0	0	0
Kustia	0.102564	0.049743	0.140845	0.333333	0
Lakshmipur	0.128205	0.238422	0.816901	0	0.055556
Lalmonirhat	0.102564	0	0	0	0

District	No of Storms	Wind Velocity (kmh-1)	Surge Height (m)	No of sever cyclones	No of hurricane
Madaripur	0.076923	0	0	0	0.055556
Magura	0	0	0	0	0
Manikgonj	0.205128	0.572899	0.140845	0.333333	0.055556
Meherpur	0.025641	0	0	0	0
Moulvibazar	0.076923	0	0	0	0.055556
Munshigonj	0.102564	0.049743	0.140845	0.333333	0.055556
Mymensingh	0.128205	0	0	0	0
Naogaon	0.076923	0	0	0	0
Narail	0.025641	0	0	0	0.055556
Narayangonj	0.051282	0.310463	0	0	0.055556
Narshingdi	0.051282	0.324185	0	0	0.055556
Natore	0.051282	0	0	0	0
Nawabganj	0	0	0	0	0
Netrakona	0.179487	0	0	0	0
Nilphamari	0.051282	0	0	0	0
Noakhali	0.794872	0.281304	1	0.333333	0.555556
Pabna	0.076923	0	0	0	0
Panchagarh	0.025641	0	0	0	0
Patuakhali	0.461538	0.281304	0.816901	0	0.388889
Pirojpur	0.25641	0.255575	0.633803	0	0.166667
Pirojpur	0.25641	0.255575	0.633803	0	0.166667
Rajbari	0.025641	0	0	0	0.055556
Rajshahi	0.025641	0	0	0	0
Rangamati	0	0	0	0	0
Rongpur	0.076923	0	0	0	0
Shariatpur	0.102564	0.049743	0.140845	0.333333	0.055556
Shatkhira	0.230769	0.173242	0.633803	0.666667	0.111111
Sherpur	0	0	0	0	0
Sirajgonj	0.102564	0.226415	0	0	0
Sunamgonj	0.051282	0	0	0	0
Sylhet	0.102564	0	0	0	0
Tangail	0.153846	0.512864	0	0	0

Table 6: Weighed values based on selective variables for vulnerability analysis

District	No of Storms	Total Death	Pop density (km-1)	Elevation (m)	Distance from coast (km)	District	No of Storms	Total Death	Pop density (km-1)	Elevation (m)	Distance from coast (km)
Bagerhat	0.435897	0.272486	0.035171	0.998374	0.937463	Madaripur	0.076923	0.000285	0.114452	0.977242	0.877672
Bandarbon	0	0	0	0	0.924168	Magura	0	0	0.096924	0.964649	0.69757
Barisal	0.358974	0.368626	0.091817	0.97242	0.950268	Manikgonj	0.205128	0.019224	0.113407	0.957735	0.722456
Bhola	0.512821	0.111636	0.053511	0.97242	0.994768	Meherpur	0.025641	0.000005	0.101799	0.923632	0.504962
Bogra	0.051282	0.000058	0.132559	0.913663	0.43028	Moulvibazar	0.076923	0.000005	0.073593	0.852252	0.566122
Borgona	0.435897	0.274205	0.049217	0.998374	0.981412	Munshigonj	0.102564	0.018901	0.175276	0.975616	0.846671
Brahmanbaria	0.051282	0.000266	0.170517	0.954484	0.729717	Mymensingh	0.128205	0.003558	0.133256	0.933445	0.547117
Chandpur	0.25641	0.030767	0.163668	0.980493	0.919942	Naogaon	0.076923	0.000068	0.082298	0.897182	0.326625
Chittagong	1	1	0.166338	0.995123	0.99476	Narail	0.025641	0.000005	0.078932	0.978499	0.757675
Chouadanga	0.025641	0.000005	0.107255	0.938456	0.564001	Narayangonj	0.051282	0.000005	0.508416	0.947981	0.799958
Comilla	0.153846	0.000637	0.203947	0.943104	0.858507	Narshingdi	0.051282	0.000193	0.229135	0.957358	0.731114
Cox's Bazar	1	0.752014	0.102263	0.988621	1	Natore	0.051282	0.000005	0.099942	0.933902	0.481372
Dhaka	0.307692	0.002023	1	0.933351	0.766713	Nawabganj	0	0	0.508416	0.87037	0.279117
Dinajpur	0.025641	0.000019	0.096227	0.815055	0.175456	Netrakona	0.179487	0.000164	0.086825	0.955533	0.503885
Faridpur	0.102564	0.001472	0.102728	0.957735	0.773751	Nilphamari	0.051282	0.000029	0.131979	0.746186	0.101473
Feni	0.153846	0.27014	0.179919	0.965863	0.968782	Noakhali	0.794872	0.472692	0.095415	1	0.992141
Gaibanda	0.102564	0.000034	0.123389	0.889958	0.33386	Pabna	0.076923	0.000256	0.120139	0.933351	0.593212
Gazipur	0	0	0.222287	0.937118	0.699841	Panchagarh	0.025641	0	0.075682	0.6339	0
Gopalgonj	0.128205	0.000101	0.086013	0.984241	0.834423	Patuakhali	0.461538	0.005735	0.04794	0.841643	0.963948
Hobiganj	0	0	0.086593	0.930385	0.610318	Pirojpur	0.25641	0.003548	0.093906	0.98537	0.946175
Jaipurhat	0	0	0.105746	0.892265	0.332379	Rajbari	0.025641	0.000005	0.104585	0.947981	0.681698
Jamalpur	0.051282	0.001294	0.128033	0.906764	0.44387	Rajshahi	0.025641	0.000048	0.12188	0.902719	0.390798
Jessore	0.076923	0.002052	0.121764	0.969127	0.72014	Rangamati	0	0	0.001277	0.283254	0.858185
Jhalakati	0.102564	0.001192	0.101335	0.957735	0.898348	Rongpur	0.076923	0.000063	0.138944	0.841643	0.223878
Jhenaidah	0	0.000005	0.100406	0.952997	0.620245	Shariatpur	0.102564	0.022657	0.093442	0.980493	0.912002
Khagrachari	0	0	0.017295	0.492496	0.868529	Shatkhira	0.230769	0.090023	0.052583	0.951087	0.88071
Khulna	0.641026	0.846734	0.054092	0.965863	0.887453	Sherpur	0	0	0.056181	0.892181	0.431035
Kishoreganj	0.076923	0.000039	0.122461	0.965847	0.630376	Sirajgonj	0.102564	0.000256	0.311434	0.94014	0.553356
Kurigram	0.025641	0.000014	0.100058	0.865165	0.227234	Sunamgonj	0.051282	0.000029	0.071968	0.962654	0.463885
Kustia	0.102564	0.018814	0.138712	0.934976	0.548863	Sylhet	0.102564	0.000285	0.110157	0.922109	0.448709
Lakshmipur	0.128205	0.012074	0.135229	0.949607	0.992999	Tangail	0.153846	0.002641	0.119095	0.928379	0.608017
Lalmonirhat	0.102564	0.000154	0.113639	0.778511	0.122797	Thakurgaon	0	0	0.083691	0.735592	0.03813

Table 7: Weighed values based on selective variables for coping capacity

District	Literacy rate (%)	Per capita GDP ($)	Road Density (km)	Cyclone shelter Cap (1000-1)	Upper line Poverty (%)	Literacy rate (%)	Per capita GDP ($)	Road Density (km)	Cyclone shelter Cap (1000-1)	Upper line Poverty (%)	Literacy rate (%)
Bagerhat	0.676056	0.574871	0.186869	0.272304	0.652246	Madaripur	0.366197	0.2224	0.511839	0	0.520799
Bandarbon	0.025352	0.111069	0	0	0.607321	Magura	0.439437	0.252786	0.344931	0	0.24792
Barisal	0.738028	0.373143	0.544065	0.06658	0.25624	Manikgonj	0.4	0.256978	0.552544	0	0.193012
Bhola	0.230986	0.318585	0.104237	1	0.851913	Meherpur	0.31831	0.282387	0.235097	0	0.36772
Bogra	0.405634	0.29689	0.288686	0	0.492512	Moulvibazar	0.453521	0.100995	0.399126	0	0.417637
Borgona	0.63662	0.23433	0.483214	0.668301	0.216306	Munshigonj	0.594366	0.122809	0.41003	0	0.780366
Brahmanbaria	0.290141	0.089589	0.337556	0	0.439268	Mymensingh	0.239437	0.192251	0.43623	0	0.695507
Chandpur	0.614084	0.177224	0.564302	0	0.788686	Naogaon	0.371831	0.277839	0.220655	0	0.221298
Chittagong	0.673239	0.731687	0.363105	0.298643	0.131448	Narail	0.740845	0.318037	0.383333	0	0.272879
ChouaDanga	0.307042	0.254072	0.529799	0	0.400998	NarayAngonj	0.622535	0.551319	0.632871	0	0.374376
Comilla	0.515493	0.223828	0.246053	0.902116	0.570715	Narshingdi	0.411268	0.296842	0.533852	0	0.334443
Cox's Bazar	0.121127	0.003548	0.335443	0	0.484193	Natore	0.411268	0.318727	0.367338	0	0.524126
Dhaka	1	1	0.642925	0	0.201331	Nawabganj	0.222535	0.092541	0.275768	0	0.361065
Dinajpur	0.490141	0.244213	0.34642	0	0.570715	Netrakona	0.123944	0.092541	0.284038	0	0.527454
Faridpur	0.394366	0.139288	0.323797	0	0.544093	Nilphamari	0.264789	0.07892	0.324508	0	0.519135
Feni	0.692958	0.039746	0.72797	0.14682	0.371048	Noakhali	0.459155	0.119285	0.325717	0.287699	0.099834
Gaibanda	0.219718	0.107973	0.314378	0	0.738769	Pabna	0.329577	0.342494	0.373981	0	0.464226
Gazipur	0.777465	0.498309	0.279293	0	0.650582	Panchagarh	0.473239	0.141003	0.399483	0	0.384359
Gopalgonj	0.650704	0.176891	0.514416	0	0.262895	Patuakhali	0.538028	0.334016	0.511913	0.587937	0.369384
Hobiganj	0.15493	0.079991	0.303444	0	0.790349	Pirojpur	0.842254	0.211874	0.575624	0.157003	0.673877
Jaipurhat	0.633803	0.359783	0.525741	0	0.589018	Rajbari	0.487324	0.191918	0.512348	0	0.628952
Jamalpur	0.095775	0.199228	0.83261	0.048854	0.613977	Rajshahi	0.507042	0.367975	0.444639	0	0.462562
Jessore	0.605634	0.349733	0.233127	0	0.361065	Rangamati	0.414084	0.29477	0.409368	0	0.708819
Jhalakati	0.892958	0.139336	1	0	0.58569	Rongpur	0.380282	0.182797	0.046629	0	0.708819
Jhenaidah	0.377465	0.22802	0.159008	0.145068	0.384359	Shariatpur	0.346479	0.13624	0.402071	0.170998	0.815308
Khagrachari	0.312676	0	0.26667	0	0.351082	Shatkhira	0.48169	0.298319	0.204778	0	0.710483
Khulna	0.707042	0.804677	0.216898	0	0.44426	Sherpur	0.08169	0.23333	0.278775	0	0.745424
Kishoreganj	0.166197	0.113569	0.276187	0	1	Sirajgonj	0.2	0.107925	0.263516	0	0.584027
Kurigram	0.211268	0.251262	0.477736	0	0	Sun Amgonj	0	0.031339	0.115633	0	0.372712
Kustia	0.31831	0.249571	0.091952	0	0.459235	Sylhet	0.456338	0.176462	0.298045	0	0.341098
Lakshmipur	0.405634	0.189846	0.455317	0	0.514143	Tangail	0.332394	0.152434	0.330766	0	0.434276
Lalmonirhat	0.312676	0.150171	0.643219	0.364452	0.514143	Thakurgaon	0.385915	0.283483	0.447488	0	0.389351

Table 8: Composite weighed values for risk prone areas

District	Hazard Score	Vulnerability Score	Coping Score	Risk Score	GiZScore	GiPValue
Bagerhat	1.854053	2.679391	2.362346	2.10288	0.826484	0.408529
Bandarbon	0	0.924168	0.743742	0	4.984753	0.000001
Barisal	1.470574	2.742105	1.978056	2.0386	1.359662	0.173937
Bhola	2.444359	2.645156	2.505721	2.58038	1.662393	0.096434
Bogra	0.361745	1.527842	1.483722	0.372502	-1.55823	0.119178
Borgona	1.81188	2.739105	2.238771	2.21681	1.21751	0.22341
Brahmanbaria	0.051282	1.906266	1.156554	0.084525	-1.24923	0.211582
Chandpur	0.367521	2.35128	2.144296	0.402997	0.679676	0.49671
Chittagong	4.281304	4.156221	2.198122	8.09511	4.362992	0.000013
Chouadanga	0.025641	1.635358	1.491911	0.028106	-1.19264	0.233009
Comilla	0.209402	2.160041	2.458205	0.184003	0.213538	0.830907
Cox's Bazar	3.578003	3.842898	0.944311	14.5608	4.984753	0.000001
Dhaka	1.363248	3.009779	2.844256	1.44258	-1.21878	0.222928
Dinajpur	0.025641	1.112398	1.651489	0.017271	-1.60403	0.108707
Faridpur	1.376539	1.93825	1.401544	1.90367	-0.97024	0.331927
Feni	1.82028	2.53855	1.978542	2.33549	2.07109	0.03835
Gaibanda	0.102564	1.449805	1.380838	0.107687	-1.6217	0.104867
Gazipur	0.406518	1.859246	2.205649	0.342673	-1.02271	0.306447
Gopalgonj	0.183761	2.032983	1.604906	0.232776	0.155258	0.876618
Hobiganj	0	1.627296	1.328714	0	-1.18139	0.237449
Jaipurhat	0	1.33039	2.108345	0	-1.90228	0.057134
Jamalpur	0.051282	1.531243	1.790444	0.043858	-1.44883	0.147385
Jessore	0.995079	1.890006	1.549559	1.2137	-0.28529	0.775424
Jhalakati	1.073227	2.061174	2.617984	0.844966	1.565162	0.117545
Jhenaidah	0	1.673653	1.29392	0	-1.02124	0.30714
Khagrachari	0	1.37832	0.930428	0	2.196358	0.028066
Khulna	2.96961	3.395168	2.172877	4.64008	0.803934	0.421435
Kishoreganj	0.132479	1.795646	1.555953	0.152887	-1.25619	0.209048
Kurigram	0.025641	1.218112	0.940266	0.033218	-1.47016	0.141519
Kustia	0.626485	1.743929	1.119068	0.976299	-1.15808	0.246832
Lakshmipur	1.239084	2.218114	1.56494	1.75625	0.901386	0.367383
Lalmonirhat	0.102564	1.117665	1.984661	0.057759	-1.4749	0.140239
Madaripur	0.132479	2.046574	1.621235	0.167236	-0.51273	0.608139
Magura	0	1.759143	1.285074	0	-0.57179	0.567465
Manikgonj	1.307761	2.01795	1.402534	1.88159	-1.1686	0.242565
Meherpur	0.025641	1.556039	1.203514	0.033152	-1.25477	0.209562
Moulvibazar	0.132479	1.568895	1.371279	0.151571	-1.09178	0.27493
Munshigonj	0.682041	2.119028	1.907571	0.757646	-0.89698	0.369732
Mymensingh	0.128205	1.745581	1.563425	0.143142	-1.07573	0.282047
Naogaon	0.076923	1.383096	1.091623	0.097462	-1.43486	0.151327
Narail	0.081197	1.840752	1.715094	0.087146	-0.00202	0.998388
Narayangonj	0.417301	2.307642	2.181101	0.441512	-0.6485	0.516664
Narshingdi	0.431023	1.969082	1.576405	0.538389	-1.10607	0.268694
Natore	0.051282	1.566503	1.621459	0.049544	-1.66735	0.095445
Nawabganj	0	1.657903	0.951909	0	-1.06731	0.285831
Netrakona	0.179487	1.725894	1.027977	0.301345	-1.32963	0.183641
Nilphamari	0.051282	1.030949	1.187352	0.044527	-1.4749	0.140239
Noakhali	2.965065	3.35512	1.29169	7.70165	2.166228	0.030294
Pabna	0.076923	1.723881	1.510278	0.087802	-1.08168	0.279393
Panchagarh	0.025641	0.735223	1.398084	0.013484	-1.17783	0.238863
Patuakhali	1.948632	2.320804	2.341278	1.93159	2.342017	0.01918
Pirojpur	1.312455	2.285409	2.460632	1.21899	1.078367	0.28087
Rajbari	0.081197	1.75991	1.820542	0.078493	-1.19215	0.233202
Rajshahi	0.025641	1.441086	1.782218	0.020733	-1.40407	0.160297
Rangamati	0	1.142716	1.827041	0	1.364124	0.172529
Rongpur	0.076923	1.281451	1.318527	0.07476	-1.69534	0.090011
Shariatpur	0.682041	2.111158	1.871096	0.769547	0.172818	0.862794
Shatkhira	1.815592	2.205172	1.69527	2.36168	0.909341	0.36317
Sherpur	0	1.379397	1.339219	0	-1.25124	0.210848
Sirajgonj	0.328979	1.90775	1.155468	0.543165	-1.37765	0.168313
Sunamgonj	0.051282	1.549818	0.519684	0.152935	-1.14617	0.251726
Sylhet	0.102564	1.583824	1.271943	0.127713	-0.87989	0.378921
Tangail	0.66671	1.811978	1.24987	0.966552	-1.14982	0.250218
Thakurgaon	0	0.857413	1.506237	0	-1.17783	0.238863