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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.

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

Rank	Hazard Prone Zones			
	District Name	Weighed Score	District	GiZ Score
1	Chittagong	0.892196	Cox's Bazar	4.140374
2	Cox's Bazar	0.716121	Bandarbon	4.140374
3	Khulna	0.555584	Patuakhali	3.604535
4	Noakhali	0.528948	Chittagong	3.575456
5	Bhola	0.443938	Pirojpur	3.317068
6	Bagerhat	0.325411	Noakhali	3.185516
7	Patuakhali	0.311459	Borgona	2.810148
8	Shatkhira	0.309386	Jhalakati	2.776566
9	Feni	0.287933	Feni	2.717391
10	Borgona	0.267442	Barisal	2.663484

Rank	Vulnerable Zones			
	District Name	Weighed Score	District Name	GiZ Score
1	Chittagong	0.973171	Patuakhali	3.855314
2	Cox's Bazar	0.876837	Barisal	3.671704
3	Khulna	0.787097	Cox's Bazar	3.571353
4	Noakhali	0.726901	Bandarbon	3.571353
5	Barisal	0.568452	Jhalakati	3.418721
6	Borgona	0.558367	Noakhali	3.407465
7	Bagerhat	0.546869	Pirojpur	3.250437
8	Dhaka	0.520976	Chittagong	3.134034
9	Bhola	0.520121	Borgona	3.131765
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).

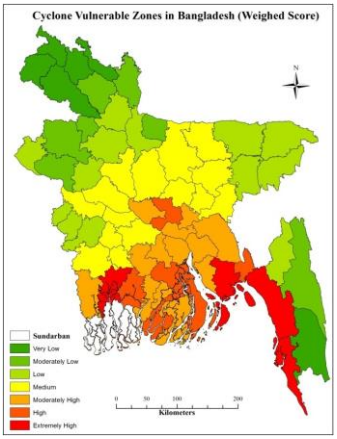

Figure 2(a): Cyclone vulnerable zones based on weighed scores

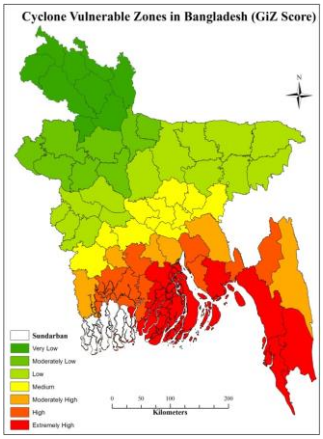

Figure 2(b): Cyclone vulnerable zones based on GiZ scores

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).

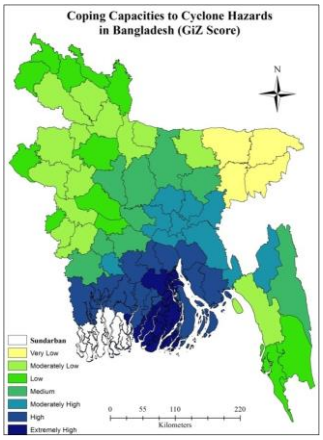

Figure 3(a): Coping capacities of different zones to cyclone vulnerability based on weighed scores

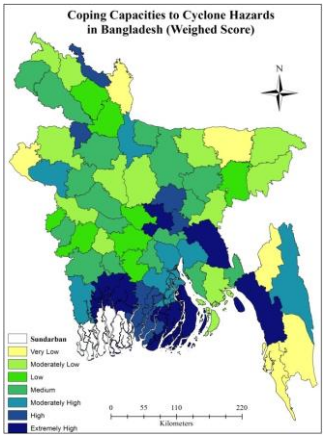

Figure 3(b): Coping capacities of different zones to cyclone vulnerability based on GiZ scores

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			
	District Name	Weighed Score	District Name	GiZ Score
1	Bhola	0.559072	Barisal	4.382222
2	Dhaka	0.536705	Pirojpur	4.259345
3	Comilla	0.480694	Borgona	3.984132
4	Bagerhat	0.461563	Patuakhali	3.681106
5	Chittagong	0.445168	Pirojpur	3.061565
6	Patuakhali	0.441455	Jhalakati	2.966801
7	Khulna	0.438376	Bhola	2.732507
8	Borgona	0.396665	Lakshmipur	2.645014
9	Narangonj	0.393894	Bagerhat	2.592344
10	Gazipur	0.385292	Noakhali	2.406532

Rank	Risk Zones			
	District Name	Weighed Score	District Name	GiZ Score
1	Cox's Bazar	14.5608	Cox's Bazar	4.984753
2	Chittagong	8.09511	Bandarbon	4.984753
3	Noakhali	7.70165	Chittagong	4.362992
4	Khulna	4.64008	Patuakhali	2.342017
5	Bhola	2.58038	Khagrachari	2.196358
6	Shatkhira	2.36168	Noakhali	2.166228
7	Feni	2.33549	Feni	2.07109
8	Borgona	2.21681	Bhola	1.662393
9	Bagerhat	2.10288	Jhalakati	1.565162
10	Barisal	2.0386	Rangamati	1.364124

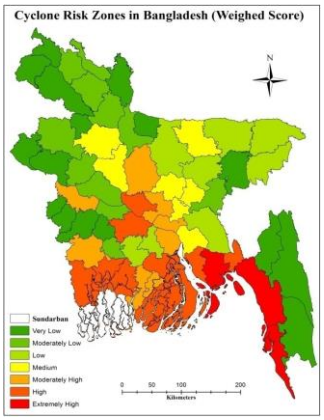

Figure 4(a): Composite cyclone risk map based on weighed scores

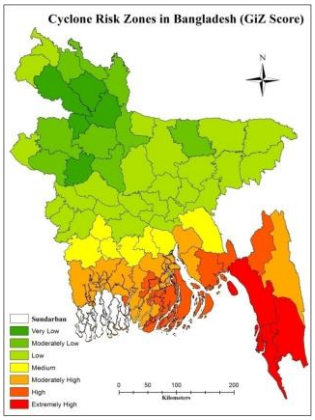

Figure 4(b): Composite cyclone risk map based on GiZ scores

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)
Bagerhat	0.435897	0.272486	0.035171	0.998374	0.937463
Bandarbon	0	0	0	0	0.924168
Barisal	0.358974	0.368626	0.091817	0.97242	0.950268
Bhola	0.512821	0.111636	0.053511	0.97242	0.994768
Bogra	0.051282	0.000058	0.132559	0.913663	0.43028
Borgona	0.435897	0.274205	0.049217	0.998374	0.981412
Brahmanbaria	0.051282	0.000266	0.170517	0.954484	0.729717
Chandpur	0.25641	0.030767	0.163668	0.980493	0.919942
Chittagong	1	1	0.166338	0.995123	0.99476
Chouadanga	0.025641	0.000005	0.107255	0.938456	0.564001
Comilla	0.153846	0.000637	0.203947	0.943104	0.858507
Cox's Bazar	1	0.752014	0.102263	0.988621	1
Dhaka	0.307692	0.002023	1	0.933351	0.766713
Dinajpur	0.025641	0.000019	0.096227	0.815055	0.175456
Faridpur	0.102564	0.001472	0.102728	0.957735	0.773751
Feni	0.153846	0.27014	0.179919	0.965863	0.968782
Gaibanda	0.102564	0.000034	0.123389	0.889958	0.33386
Gazipur	0	0	0.222287	0.937118	0.699841
Gopalgonj	0.128205	0.000101	0.086013	0.984241	0.834423
Hobiganj	0	0	0.086593	0.930385	0.610318
Jaipurhat	0	0	0.105746	0.892265	0.332379
Jamalpur	0.051282	0.001294	0.128033	0.906764	0.44387
Jessore	0.076923	0.002052	0.121764	0.969127	0.72014
Jhalakati	0.102564	0.001192	0.101335	0.957735	0.898348
Jhenaidah	0	0.000005	0.100406	0.952997	0.620245
Khagrachari	0	0	0.017295	0.492496	0.868529
Khulna	0.641026	0.846734	0.054092	0.965863	0.887453
Kishoreganj	0.076923	0.000039	0.122461	0.965847	0.630376
Kurigram	0.025641	0.000014	0.100058	0.865165	0.227234
Kustia	0.102564	0.018814	0.138712	0.934976	0.548863
Lakshmipur	0.128205	0.012074	0.135229	0.949607	0.992999
Lalmonirhat	0.102564	0.000154	0.113639	0.778511	0.122797

District	No of Storms	Total Death	Pop density (km^{-1})	Elevation (m)	Distance from coast (km)
Madaripur	0.076923	0.000285	0.114452	0.977242	0.877672
Magura	0	0	0.096924	0.964649	0.69757
Manikgonj	0.205128	0.019224	0.113407	0.957735	0.722456
Meherpur	0.025641	0.000005	0.101799	0.923632	0.504962
Moulvibazar	0.076923	0.000005	0.073593	0.852252	0.566122
Munshigonj	0.102564	0.018901	0.175276	0.975616	0.846671
Mymensingh	0.128205	0.003558	0.133256	0.933445	0.547117
Naogaon	0.076923	0.000068	0.082298	0.897182	0.326625
Narail	0.025641	0.000005	0.078932	0.978499	0.757675
Narayangonj	0.051282	0.000005	0.508416	0.947981	0.799958
Narshingdi	0.051282	0.000193	0.229135	0.957358	0.731114
Natore	0.051282	0.000005	0.099942	0.933902	0.481372
Nawabganj	0	0	0.508416	0.87037	0.279117
Netrakona	0.179487	0.000164	0.086825	0.955533	0.503885
Nilphamari	0.051282	0.000029	0.131979	0.746186	0.101473
Noakhali	0.794872	0.472692	0.095415	1	0.992141
Pabna	0.076923	0.000256	0.120139	0.933351	0.593212
Panchagarh	0.025641	0	0.075682	0.6339	0
Patuakhali	0.461538	0.005735	0.04794	0.841643	0.963948
Pirojpur	0.25641	0.003548	0.093906	0.98537	0.946175
Rajbari	0.025641	0.000005	0.104585	0.947981	0.681698
Rajshahi	0.025641	0.000048	0.12188	0.902719	0.390798
Rangamati	0	0	0.001277	0.283254	0.858185
Rongpur	0.076923	0.000063	0.138944	0.841643	0.223878
Shariatpur	0.102564	0.022657	0.093442	0.980493	0.912002
Shatkhira	0.230769	0.090023	0.052583	0.951087	0.88071
Sherpur	0	0	0.056181	0.892181	0.431035
Sirajgonj	0.102564	0.000256	0.311434	0.94014	0.553356
Sunamgonj	0.051282	0.000029	0.071968	0.962654	0.463885
Sylhet	0.102564	0.000285	0.110157	0.922109	0.448709
Tangail	0.153846	0.002641	0.119095	0.928379	0.608017
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 (%)
Bagerhat	0.676056	0.574871	0.186869	0.272304	0.652246
Bandarbon	0.025352	0.111069	0	0	0.607321
Barisal	0.738028	0.373143	0.544065	0.06658	0.25624
Bhola	0.230986	0.318585	0.104237	1	0.851913
Bogra	0.405634	0.29689	0.288686	0	0.492512
Borgona	0.63662	0.23433	0.483214	0.668301	0.216306
Brahmanbaria	0.290141	0.089589	0.337556	0	0.439268
Chandpur	0.614084	0.177224	0.564302	0	0.788686
Chittagong	0.673239	0.731687	0.363105	0.298643	0.131448
ChouaDanga	0.307042	0.254072	0.529799	0	0.400998
Comilla	0.515493	0.223828	0.246053	0.902116	0.570715
Cox's Bazar	0.121127	0.003548	0.335443	0	0.484193
Dhaka	1	1	0.642925	0	0.201331
Dinajpur	0.490141	0.244213	0.34642	0	0.570715
Faridpur	0.394366	0.139288	0.323797	0	0.544093
Feni	0.692958	0.039746	0.72797	0.14682	0.371048
Gaibanda	0.219718	0.107973	0.314378	0	0.738769
Gazipur	0.777465	0.498309	0.279293	0	0.650582
Gopalgonj	0.650704	0.176891	0.514416	0	0.262895
Hobiganj	0.15493	0.079991	0.303444	0	0.790349
Jaipurhat	0.633803	0.359783	0.525741	0	0.589018
Jamalpur	0.095775	0.199228	0.83261	0.048854	0.613977
Jessore	0.605634	0.349733	0.233127	0	0.361065
Jhalakati	0.892958	0.139336	1	0	0.58569
Jhenaidah	0.377465	0.22802	0.159008	0.145068	0.384359
Khagrachari	0.312676	0	0.26667	0	0.351082
Khulna	0.707042	0.804677	0.216898	0	0.44426
Kishoreganj	0.166197	0.113569	0.276187	0	1
Kurigram	0.211268	0.251262	0.477736	0	0
Kustia	0.31831	0.249571	0.091952	0	0.459235
Lakshmipur	0.405634	0.189846	0.455317	0	0.514143
Lalmonirhat	0.312676	0.150171	0.643219	0.364452	0.514143

Literacy rate (%)	Per capita GDP ($)	Road Density (km)	Cyclone shelter Cap (1000^{-1})	Upper line Poverty (%)	Literacy rate (%)
Madaripur	0.366197	0.2224	0.511839	0	0.520799
Magura	0.439437	0.252786	0.344931	0	0.24792
Manikgonj	0.4	0.256978	0.552544	0	0.193012
Meherpur	0.31831	0.282387	0.235097	0	0.36772
Moulvibazar	0.453521	0.100995	0.399126	0	0.417637
Munshigonj	0.594366	0.122809	0.41003	0	0.780366
Mymensingh	0.239437	0.192251	0.43623	0	0.695507
Naogaon	0.371831	0.277839	0.220655	0	0.221298
Narail	0.740845	0.318037	0.383333	0	0.272879
NarayAngonj	0.622535	0.551319	0.632871	0	0.374376
Narshingdi	0.411268	0.296842	0.533852	0	0.334443
Natore	0.411268	0.318727	0.367338	0	0.524126
Nawabganj	0.222535	0.092541	0.275768	0	0.361065
Netrakona	0.123944	0.092541	0.284038	0	0.527454
Nilphamari	0.264789	0.07892	0.324508	0	0.519135
Noakhali	0.459155	0.119285	0.325717	0.287699	0.099834
Pabna	0.329577	0.342494	0.373981	0	0.464226
Panchagarh	0.473239	0.141003	0.399483	0	0.384359
Patuakhali	0.538028	0.334016	0.511913	0.587937	0.369384
Pirojpur	0.842254	0.211874	0.575624	0.157003	0.673877
Rajbari	0.487324	0.191918	0.512348	0	0.628952
Rajshahi	0.507042	0.367975	0.444639	0	0.462562
Rangamati	0.414084	0.29477	0.409368	0	0.708819
Rongpur	0.380282	0.182797	0.046629	0	0.708819
Shariatpur	0.346479	0.13624	0.402071	0.170998	0.815308
Shatkhira	0.48169	0.298319	0.204778	0	0.710483
Sherpur	0.08169	0.23333	0.278775	0	0.745424
Sirajgonj	0.2	0.107925	0.263516	0	0.584027
Sun Amgonj	0	0.031339	0.115633	0	0.372712
Sylhet	0.456338	0.176462	0.298045	0	0.341098
Tangail	0.332394	0.152434	0.330766	0	0.434276
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