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Development of multi hazards map for Bangladesh using GIS technique

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ABSTRACT: *Bangladesh is one of the most disaster-prone areas in the world. Many different natural disasters – flood, cyclonic storms, tidal surges, droughts, tornadoes, riverbank erosion, earthquake, water contamination due to arsenic, etc. – occur in Bangladesh. Identifying the risk areas with reference to natural hazards causing damage to people of the country, the housing stock and the related infrastructure are most important for infrastructures development. In this study, using six of the most common natural hazards, namely earthquake, cyclones, tornadoes, drought, ground water arsenic and floods, we developed a hazard map using the country's 64 districts as geographic units. The hazard level is based on a combination of observed local hazard intensity, frequency of occurrences and vulnerability.*

This study assesses the relative threat, by district, of disasters in Bangladesh, and also the damages, history, severity of these areas, intensities of those natural disasters and housing vulnerability. GIS based disaster database is very crucial and an important aspect for environmental management strategy for planning and disaster mitigation, preparedness and preventive actions. This study prepared GIS based data sets which were used in the development of multi hazard zoning map. This multi-hazard zoning map will guide officials at the national and regional levels in the formulation of development strategies in multi-hazard active zones, land use management, revision and enforcement of appropriate codes and formulation of plans for mitigating measures against hazard risks affecting areas.

KEYWORDS: *Arsenic, drought, earthquake, flood, tornado, cyclone, multi hazard map, natural hazards*

Introduction

Bangladesh is one of the most disaster-prone areas in the world. Many different natural disasters – flood, cyclonic storms, tidal surges, droughts, tornadoes, riverbank erosion, earthquake, water contamination due to arsenic, etc. – occur frequently in Bangladesh. The 1988 flood killed 2389 people and nearly half of the population was affected (Islam & Sado 2002). The 1970 cyclone killed almost 500,000 people (Karim 1996). About 1300 people were killed by tornado at Saturia of Manikganj district in Bangladesh in 1989 (EIA 2004). The 1897 Great Indian Earthquake, with magnitude 8.7, was one of the most severe in the world; it killed 1542 peoples and affected almost the whole of the country (Oldham 1899). Crop and livestock losses were extremely high. Arsenic contamination of ground water in Bangladesh has emerged as perhaps the biggest natural calamity in the world. Arsenic concentrations in water samples taken from about half of the country's area are above the maximum permissible level of 0.05mg/l in Bangladesh. At least some people in 59 out of 64 districts are suffering due to the arsenic contamination in drinking water (Saifuddin and Karim, 2001). Among the major factors to explain the severity of disasters are flat topography, rapid run-off and drainage congestion of rain, low relief of the floods plains, low river gradients, heavy monsoon rainfall, and enormous discharges of sediments. The funnel shape and shallow depth of the Bay of Bengal increases the severity of cyclones. Cyclones and floods are the most damaging disasters in Bangladesh. But other disasters are also creating severe damage. Drought is recurrent in northern Bangladesh. It is causing permanent loss of agricultural production and desertification processes in some parts of North Bengal (Shahid and Behrawan, 2008). River erosion destroys thousands of hectares of land every year in a country where land is its scarcest resource. A future severe earthquake may cause billions of Taka worth of damage.

Earthquakes, cyclones, tornadoes, drought, arsenic contamination and floods arise from natural phenomena connected with the earth's interior and atmosphere, and they intersect the human environment. Geographic concentration of regular and frequent disasters impedes the overall socio-economic development efforts of the country (Haque 1997), as well as causing devastating loss of life, property, infrastructure and communities (Barua et al. 2016).

Some areas normally subjected to drought are in certain years subject to floods. Hazards like earthquakes, landslides, tornados, etc. occur suddenly, but their impact lasts over time. The extent of the impact of an earthquake depends on its magnitude; the impact of a tornado depends on wind speed, and the impact of a cyclone depends on wind speed as well as tidal height. The impact of arsenic depends on the ground water contamination level. Natural calamities may be broadly grouped into major and minor types depending upon their potential to cause damage to human life and property. Earthquakes, droughts, floods, tornadoes and cyclones can be regarded as major hazards. Landslides, riverbank erosion, groundwater contamination, fires, and tsunamis, whose impacts are localized and whose damage intensity is much less can be categorized as minor hazards. So far as damage to housing and infrastructure is concerned, floods, cyclones, tornadoes and earthquakes are the four major disasters confronting the country.

The major disasters require disaster mitigation plans. Traditionally, many countries have been reactive to disasters. Adoption of the Hyogo Framework for Action, 2005–2015, by 168 countries has led to a paradigm shift, from emergency response to a comprehensive approach which, includes preparedness and preventive strategies to reduce risk. Early Warning Systems are well recognized as a critical life-saving tool for floods, droughts, storms and tidal storms, bushfires, and other hazards (WMO 2017). The World Meteorological Organization has suggested developing multi-hazard risk assessment techniques for early warning systems that reduce loss of life and property.

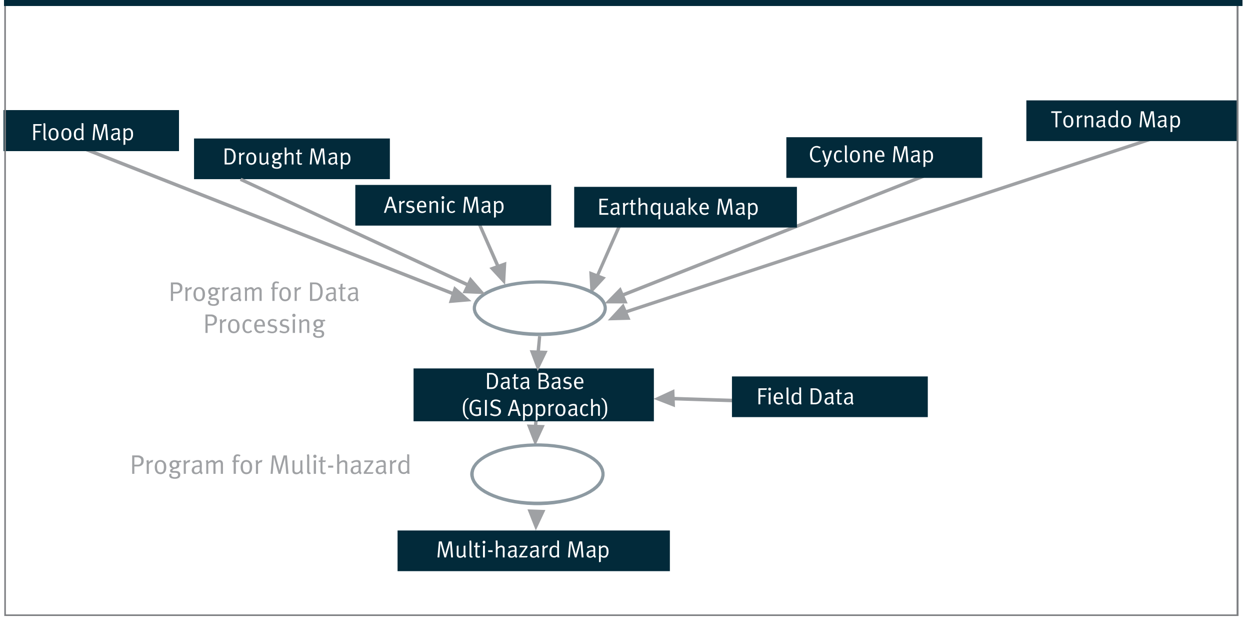
Multi-hazard maps are a practical tool in disaster mitigation planning and design of structures because they provide guidance when it is not feasible to do an assessment at particular sites. These maps give a good indication on the geographic distribution of expected high risk areas. This study identifies disaster-prone areas of Bangladesh and also history, damage severity and intensity of natural disasters. The GIS disaster database is an important source for developing an environmental management strategy. The information will assist engineers, architects, agriculture and fisheries specialists, and policy makers in mitigation planning for Bangladesh. This study will guide officials in land use management, revision and enforcement of appropriate building codes, and formulation of plans for mitigating measures.

Methodology

Preparation of the Data for the Study

We have explored historical disaster events, their duration, and information on the damages arising. We have also relied on GIS, a powerful planning tool to identify disaster-prone areas. Disaster data were collected from different organizations and sources. The maps for cyclone, earthquake, drought, arsenic, flood and tornado have been prepared by different organizations, such as Bangladesh Meteorological Department (BMD), Bangladesh Space Research and Remote Sensing Organization (SPARRSO), Disaster Management Bureau (DMB) and concerned non-government organizations (NGOs), Cyclone Preparedness Programme (CPP), and the Geological Survey of Bangladesh (GSB). Moreover, information from local and environmental organizations, and international journals was gathered for this study. Further, the disaster data were analyzed and compared with zoning maps. The zoning maps for individual disasters were digitized and converted to geo-referenced maps separately. Then the data were converted into GIS and finally superimposed onto the base map. The location, type, year and damages were digitized to put the database into the GIS system. The available historical data gathered from different sources for the disaster-prone areas of Bangladesh have been identified through GIS-based analysis and finally a multi-hazard map has been prepared. The schematic concept of the model we developed is shown in Fig. 1.

Figure 1: Schematic concept of a model for multi-hazard assessment



Estimation of risk score for natural hazard

The "hazard factor" for a particular hazard in a particular district was defined by comparing the district-wide historical disaster database with the corresponding intensity scales and damage risk levels (Barua et al., 2016). Hazard factors were considered on a scale from 1 to 3 for arsenic, 1 to 7 for drought, 1 to 8 for earthquake, 1 to 7 for flood and 1 to 8 for cyclone and 1 to 5 for tornado. "Weighting factors" for particular hazards in a particular district were defined based on the frequency of particular disasters in different districts. This employed a relative priority scoring system (higher scores for higher hazard-prone areas), where the base point is considered 1.0 for locations with no occurrence of a particular disaster; increases in frequency of disasters add 0.1 point (NOAA, 2007).Weighting factors for earthquake, flood, tornado used the suggested values assigned by Barua, et al. (2016). Weighting factors for arsenic and drought were also suggested in this paper. Weighting factors for earthquake and cyclone were revised on the basis of the new earthquake map suggested in the Bangladesh National Building Code (BNBC, 2015) and the frequency of occurrences of earthquakes and cyclones. Table 1 shows the hazard factor and weighting factor for each category of the hazards assessed (arsenic, drought, earthquake, flood, cyclone and tornado). The estimated hazard intensity, hazard factor and weighting factor for each type of hazard for each district are shown in Table 2. Hazard factors were considered on the scale from lowest to the highest value, where lowest value was assigned for zones with no hazards and the highest value for highly hazardous zones. Thus, the total hazard score from an individual hazard event (such as a cyclone) could affect the multi-hazard total score for any district of the county. For each district of Bangladesh the hazard scores for arsenic, drought, earthquake, flood, tornado and cyclone are calculated (see Table 2). Adding those scores, after multiplying by weighting factor, yields the total risk score for each of the 64 districts, as expressed in equation 1.

$$HS = \sum_{k=1}^{n} (\mathrm{HFxWF}) \qquad (1)$$

Where, HS: total hazard score, WF: weighting factor, k=1 for arsenic, k=2 for drought, k=3 for earthquake, k=4 for flood, k=5 for cyclone, k=6 for tornado, and k=n (n: totalnumber of disasters) disaster. In these equations, two of the hazards have locations with a risk score of 0 (Cyclone and Tornado).

Table 1: Hazard factor and weighting factor for the calculation of multi hazard score

(a) For Arsenic, drought and earthquake

Arsenic			Drought			Earthquake		
	HF	WF		HF	WF		HF	WF
Arsenic not found	1	1	No drought	1		Low	1	
Arsenic found	2	1.25	Low	2		Moderate	2	
Arsenic and patient found	3	1.5	Moderate	3	1.25 to 1.80	Severe	5	1.1 to 1.7
			Severe	5		Very severe	8	
			Very severe	7				

(b) For flood, cyclone and tornado

Flood			Cyclone			Tornado		
	HF	WF		HF	WF		HF	WF
No flood	1		No cyclone	1		No Tornado		
Low	2		Moderate	2		Moderate	2	
Moderate	4	1 to 1.7	Severe	5	1.0 to 1.8	Severe	3	1.1 to 1.8
Severe	5		Very severe	8		Very severe	5	
Very severe	7							

Table 2 Total hazard score for individual districts of Bangladesh for multi-hazard events (WF: Weighting Factor, HF: Hazard Factor and HR: Hazard Rank)

District Name	Arsenic		Drought		Earth Quake		Flood		Cyclone		Tornado		Multi Hazard	Hazard Rank
	WF	HF	WF	HF	WF	HF	WF	HF	WF	HF	WF	HF	Total Score	HR
Panchagar	1	1	1.49	7	1.1	2	1.2	1	1	1	1.1	2	18.03	2
Thakurgaon	1	1	1.49	7	1.1	2	1	1	1	1	1	2	17.63	2
Nilphamari	1	1	1.49	5	1.1	1	1.5	5	1	1	1.2	2	20.45	2
Lalmonirhat	1.2	1	1.49	5	1.3	5	1.4	5	1	1	1.2	2	25.55	3
Kurigram	1.2	1	1.49	5	1.6	8	1.7	7	1	1	1.1	2	36.55	4
Rangpur	1.2	1	1.49	5	1.3	5	1.6	5	1	1	1.4	3	28.35	3
Dinajpur	1	1	1.49	5	1.1	2	1.3	4	1	1	1	1	17.85	2
Gaibandha	1	1	1.49	3	1.5	5	1.6	5	1	1	1.4	3	26.17	3
Joypurhat	1.2	1	1.49	3	1.3	2	1.3	2	1	1	1	1	12.87	1
Naogaon	1	1	1.49	5	1.2	2	1.6	4	1	1	1	1	19.25	2
Bogra	1.2	5	1.49	2	1.4	5	1.6	5	1	1	1.1	2	27.18	3
Nawabgonj	1.6	5	1.49	7	1.1	1	1.5	4	1	1	1	1	27.53	3
Rajshahi	1.4	5	1.49	5	1.2	1	1.5	4	1	1	1.1	2	24.85	3
Natore	1.4	3	1.49	2	1.2	2	1.6	5	1	1	1	1	19.58	2
Serajgonj	1.3	3	1.64	2	1.3	5	1.6	5	1	1	1.4	3	26.88	3
Pabna	1.6	5	1.64	2	1.3	2	1.6	5	1	1	1.2	2	25.28	3
Kushtia	1.6	5	1.64	2	1.2	2	1.2	2	1	1	1.2	2	19.48	2
Meherpur	1.5	5	1.64	5	1.2	1	1.1	1	1	1	1.1	2	21.2	2
Chuadanga	1.5	5	1.64	2	1.1	1	1.1	2	1	1	1	1	16.08	1
Jhenaidah	1.5	1	1.64	2	1.1	1	1	1	1	1	1	1	8.88	1
Magura	1.5	5	1.64	2	1.2	1	1.5	4	1	1	1.2	2	21.38	2
Jessore	1.5	5	1.64	2	1.1	1	1.1	1	1	2	1.2	2	17.38	2
Narail	1.4	3	1.64	2	1.2	1	1.6	4	1	2	1.4	3	21.28	2
Satkhira	1.5	5	1.64	2	1.1	1	1.1	1	1.2	5	1	1	19.98	2
Khulna	1.4	5	1.64	2	1.1	1	1.2	1	1.3	8	1.3	3	26.88	3
Bagerhat	1.6	5	1.64	2	1.1	1	1.3	1	1.2	5	1.2	2	22.08	2
Rajbari	1.4	5	1.64	2	1.3	2	1.6	5	1	5	1.1	2	28.08	3
Faridpur	1.6	5	1.64	3	1.2	2	1.6	5	1	2	1.5	5	32.82	4
Shariatpur	1.5	1	1.64	2	1.2	2	1.6	5	1	2	1.3	3	21.08	2
Madaripur	1.5	5	1.64	3	1.2	2	1.6	5	1	2	1	2	26.82	3
Gopalgonj	1.4	5	1.64	3	1.2	1	1.6	4	1	2	1.3	3	25.42	3

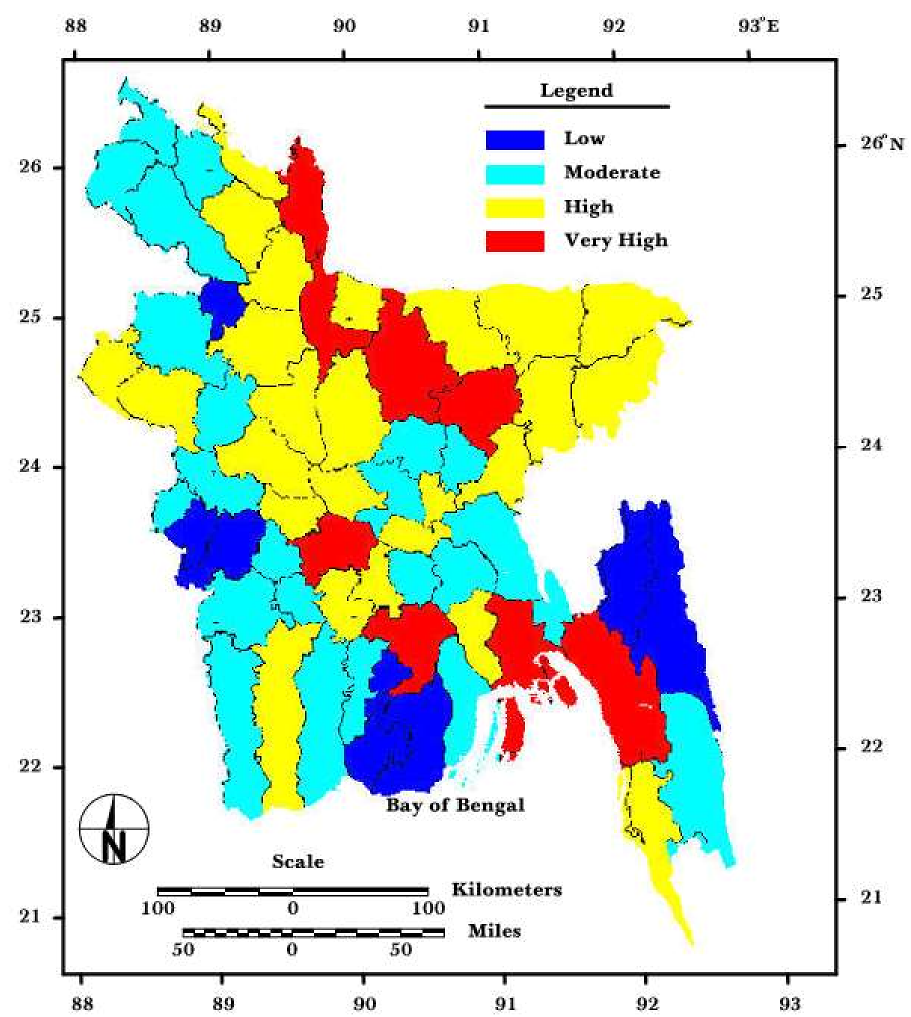
Barisal	1.5	5	1.64	5	1.2	1	1.6	4	1.6	8	1.3	3	40	4
Perojpur	1.4	1	1.64	5	1.2	1	1.2	2	1	2	1	2	17.2	2
Jhalakhati	1.4	1	1.64	5	1.2	1	1.1	1	1	2	1	1	14.9	1
Patuakhali	1	1	1.64	3	1.2	1	1	1	1.3	5	1	1	15.62	1
Barguna	1.2	1	1.64	3	1.2	1	1.2	1	1	5	1	1	14.52	1
Bhola	1.2	1	1.64	3	1.2	1	1.4	4	1.2	5	1.2	2	21.32	2
Sherpur	1.3	3	1.80	2	1.7	8	1.6	4	1	1	1.1	2	30.7	3
Jamalpur	1.3	5	1.80	3	1.7	8	1.7	4	1	1	1.4	3	37.5	4
Mymenshing	1.3	3	1.80	2	1.4	8	1.7	4	1	1	1.8	5	35.5	4
Netrokona	1.4	3	1.80	2	1.7	8	1.6	4	1	1	1.1	2	31	3
Kishoregonj	1.4	3	1.25	2	1.4	8	1.7	5	1	2	1.5	5	35.9	4
Sunamgonj	1.4	3	1.25	1	1.6	8	1.7	7	1	1	1	1	32.15	3
Sylhet	1.4	1	1.25	1	1.6	8	1.7	7	1	1	1	1	29.35	3
Moulvibazar	1.3	1	1.25	1	1.6	8	1.7	7	1	2	1.1	2	31.45	3
Habigonj	1.4	1	1.80	1	1.4	8	1.7	7	1	1	1	1	28.3	3
Tangail	1.3	3	1.80	5	1.3	5	1.7	5	1	1	1.2	2	31.3	3
Manikgonj	1.3	5	1.80	2	1.2	2	1.6	4	1	2	1.4	3	25.1	3
Gazipur	1.2	1	1.80	2	1.3	2	1.6	4	1	1	1.4	3	19	2
Norshingdi	1.3	1	1.80	2	1.2	5	1.6	5	1	2	1	1	21.9	2
Dhaka	1.2	1	1.80	1	1.2	2	1.6	5	1	2	1.8	5	24.4	2
Narayangonj	1.6	5	1.80	2	1.1	2	1.6	5	1	2	1.1	2	26	3
Munshigonj	1.4	5	1.80	2	1.2	2	1.5	5	1	2	1.2	2	24.9	3
Bramanbaria	1.6	3	1.80	1	1.2	5	1.6	7	1	1	1	3	27.8	3
Comilla	1.3	5	1.25	1	1.2	2	1.5	4	1.1	2	1.4	2	21.15	2
Chandpur	1.5	5	1.25	1	1.2	2	1.7	5	1.1	2	1.1	2	24.05	2
Lakshmipur	1.6	5	1.25	2	1.1	2	1.5	4	1	5	1.1	2	25.9	3
Noakhali	1.6	5	1.80	2	1.1	2	1.4	4	1.5	8	1.6	5	39.4	4
Feni	1.6	3	1.25	2	1.1	2	1.4	4	1.1	5	1.1	2	22.8	2
Khagrachari	1	1	1.25	1	1.2	5	1	1	1	2	1	1	12.25	1
Rangamati	1	1	1.25	1	1.2	5	1.1	1	1	2	1	1	12.35	1
Chittagong	1	3	1.25	2	1.2	5	1.5	7	1.8	8	1.1	2	38.6	4
Bandarban	1	1	1.25	1	1.3	5	1.2	4	1	2	1	1	16.55	2
Cox`s Bazar	1	1	1.80	1	1.2	5	1.3	4	1.7	8	1.1	1	28.7	3

Table 3 Hazard index and risk score

SN	HI	THS	Area (%)	Hazardous Districts
1.	Low	<17	12	Joypurhat, Chuadanga, Jhenaidah, Jhalakhati, Patuakhali, Barguna, Khagrachari, and Rangamati
2.	Moderate	17-24	34	Panchagar, Thakurgaon, Nilphamari, Dinajpur, Naogaon, Natore, Kushtia, Meherpur, Magura, Jessore, Narail, Satkhira, Bagerhat, Shariatpur, Perojpur, Bhola, Gazipur, Norshingdi, Dhaka, Comilla, Chandpur, Feni, and Bandarban
3.	High	25-32	38	Lalmonirhat, Rangpur, Gaibandha, Bogra, Nawabgonj, Rajshahi, Serajgonj, Pabna, Khulna, Rajbari, Madaripur, Gopalgonj, Sherpur, Netrokona, Sunamgonj, Sylhet, Moulvibazar, Habigonj, Tangail, Manikgonj, Narayangonj, Munshigonj, Bramanbaria, Lakshmipur, and Cox`s Bazar
4	Very High	>32	16	Kurigram, Faridpur, Barisal, Jamalpur, Mymenshing, Kishoregonj, Noakhali, and Chittagong

HI:Hazard index, TRS=Total hazard score

Figure 2: Mulit-hazzard Map



District wise multi-hazard map

We prepared a multi hazard map (see Figure 2) using the total hazard district-level scores estimated in Table 2. The hazard levels were categorized as follows: low total score <17, moderate 17-24, high 25-32, and very high >32. This map shows the hazard scenario of Bangladesh at a glance. Table 3 lists the districts corresponding to each multi-hazard zone. The total area of districts in very high hazard zone is 16%. Districts in the high hazard zone cover 38%; districts in moderate and low hazard zones cover 34% and 12%, respectively.

Conclusions

Bangladesh is undeniably a disaster-prone country. The prime objective of this study is to identify the particularly vulnerable areas due to natural hazards arising from arsenic, drought, earthquakes, floods, cyclones and tornadoes. In this study, a complete data base has been prepared and all required maps have been developed in digital form, which can be used as a GIS database in other fields. The district-wide multi-hazard scores were calculated from the risk and weighting factors. By using this multi-hazard score to rank districts, we prepared a zoning map. The results described in this study should provide helpful information about disaster management strategy for planning and disaster mitigation, preparedness and preventive actions, and should be useful in assigning priority for mitigating development in very high and high hazard zone.

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