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Development of flood hazard maps using 1988 event and examine the results by other events: case study of Bangladesh

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1. Introduction

Flood is a common environmental disaster in the three river basins of the Ganges, Brahmaputra and Meghna in Bangladesh and Indian peninsular[1),2),3),4)]. Every year nation faces flood, while sever one causes the lose of lives, damages of infrastructures, which make the hardship for the economical developments, normal one increases the fertility of agricultural land, which lead to increases the crops production. The flood of 1988 which set a hundred-year new record was the most devastating flood from the every aspect. Therefore, this event was selected for the development of flood hazard map. Four types of floods are normally occurred in Bangladesh those were also recognized in the year of 1988[1),6)]. Three NOAA AVHRR images those were taken on September 18, September 24, and October 8, 1988, within one event of 1988, were used in this study. Flood hazard maps were developed for the event of 1988 by using satellite remote sensing (RS) data with geographical information system (GIS). Floodwater depth, flood frequency and flood extent were estimated from NOAA AVHRR images by supervised land cover classification. Floodwater depth and flood frequency were considered as the hydraulic factors for the evaluation of flood hazard assessment. Three flood hazard maps were developed: by considering the floodwater depth and floodwater frequency independently, and another one was developed by considering the interact effect of floodwater depth and flood frequency simultaneously, for the event of 1988.

Finally, developed flood hazards maps were examined by using the NOAA AVHRR data of August 31, 1995, and September 18, 1998, those were taken from the medium and another severe flood of 1995 and 1998, respectively.

2. Considered thematic data as GIS

In this study, GIS technology was used for the development of flood hazard maps. GIS technology is very important and has been widely used for surface water modeling[5),6),7),8),9),10),11)]. Physiographic divisions, geological divisions, land cover classification, administrative districts, elevation height and drainage network data were used as GIS data. Thematic data were converted to digital form of thematic maps with common coordinate system with RS data. Physiographic divisions, geologic divisions and administrative districts were divided into 31 divisions, 28 divisions and 64 districts, respectively. Land cover was classified into 9 categories and elevation height was divided into 9 interval of heights.

3. Considered Hydraulic factors for flood hazard assessment

Flood damage depends on the hydraulic factors which include characteristics of the flood as the depth of flooding, rate of rise in water level, propagation of flood wave, duration of flood, frequency of flood, sediment load and timing of flood. In this study we considered flood frequency and floodwater depth for the development of flood hazard maps where the floodwater depth and flood frequency of the flooding were assumed to be the major determinant in estimating the total damages function. Floodwater depth and flood frequency were estimated from NOAA AVHRR data.

3.1 Estimation of floodwater depth

Floodwater depths were classified as shallow, medium and deep by using maximum likelihood method of supervised land cover classification. Training areas for shallow, medium and deep flood depth were assigned on NOAA AVHRR images according to the differences of colors and gray scales for different depths, these differences were understood after superimposing the NOAA AVHRR images onto digital elevation image of

Bangladesh. Flood depths were classified using NOAA AVHRR images of September 18, September 24 and October 8, 1988, for 1988 flood and August 31, 1995, and September 18, 1998, for 1995 and 1998 flood, respectively. The priority was given for the highest degree of depth among the three classes' floodwater depths for three images of 1998 flood. If deep flood depth appeared in a single image then it was considered as deep depth, and if medium depth appeared in a single image for the area that were represented as shallow depth by other two images then it was considered as medium depth. The rankings for floodwater depths were considered as class 1, class 2, class 3 and class 4 for no flooding, shallow, medium and deep depth, respectively. Furthermore, flood depths for 1995 and 1998 floods were estimated by using only one image of August 31, 1995, and September 18, 1988, respectively, and rankings for flood depths were classified as above mentioned four classes. The estimated area percentages for non-flooded, shallow, medium and deep depth for 1988 flood are shown in **Table 1** with categorized classes.

Table 1 Area occupied by each category of floodwater depth for combined images of September 18, September 24 and October 8, 1988 and the assigned classes of categories

Category	Occupied area (%)	Class
Non-flooded area	45.30	1
Shallow depth	4.55	2
Medium depth	26.55	3
Deep depth	23.60	4
Total	**100.00**	

3.2 Estimation of flood frequency

Flood affected frequencies were estimated by using the images of September 18, September 24 and October 8, 1988. The three hypotheses can be surmised for flooded and newly flooded areas on September 18, September 24 and October 8, 1988. The hypotheses concerning the presence of water in the image taken on September 24, but its absence on September 18, are that either it rained again between September 18 and 24, or that water came from the previously flooded areas and spread out over the new areas, or that both phenomena occurred simultaneously. The above hypotheses can be adopted for water presence in the image of October 8 but absence on September 24 or September 18. The hypotheses regarding the presence of common water in the three images are that either flooded water did not drain or flooded again after recovering between the two intervals of the three images. Inundated water not appeared in any above mentioned three images was considered to be a non hazard area, the inundated area that appeared in a single image was considered to be a low hazard area, the common inundated area that appeared in two images was considered to be a medium hazard area and the common inundated area that appeared in all three images was considered to be a high hazard area. The damage rankings were decided as class 1, class 2, class 3 and class 4 for non hazard, low, medium and high hazard areas, respectively. The classification of frequency and occupied area percentages by different classes of frequency are shown in **Table 2.**

Table 2 Classification of flood affected frequency and occupied area percentage of each frequency (W: water, NW: non-water)

Sep. 18, 1988	Sep. 24, 1988	Oct. 8, 1988	Area (%)	Class
W	W	W	20.42	4
W	W	NW	8.37	3
NW	W	W	2.17	3
W	NW	W	3.25	3
W	NW	NW	6.29	2
NW	W	NW	4.40	2
NW	NW	W	4.48	2
NW	NW	NW	50.62	1
Total			100.00	

4. Development of flood hazard map

4.1 Estimation of weighted score and hazard rank

Hazard ranks were chosen based on a weighted score for the physiographic, geological, land cover classification and elevation height data for each pixel of the land area of Bangladesh. A weighted score was estimated by

$$Weighted\ score = 0.0 \times class1 + 1.0 \times class2 + 3.0 \times class3 + 5.0 \times class4 \quad (1)$$

The acquired area percentage of each class number for the physiographic divisions (31 divisions), geological divisions (28 divisions), land cover classification (9 categories) and elevation (9 intervals) were estimated on the basis of flood frequency and flood depth which were considered as hydraulic factors. Only estimated scores, points and hazard ranks using water depth for physiographic divisions are shown in Table 3. Points for each ID category were estimated on the basis of linear interpolation among 0 to 100. The points 0 and 100 corresponded to the lowest (0) and highest score (483.27). In order to quantify the flood hazard, the three rankings were obtained from the points those were prepared by considering the interact effects of the physiography, geology, land cover classification and elevation on the flood hazard assessment. Hazard ranks were fixed by the corresponding value of the point, 0 to 33 correspond to hazard rank 1, 33 to 66 for 2 and 66 to 100 for 3, so that hazard ranks were categorized from 1 to 3. Flood hazard map which was created on the basis of flood frequency using land cover classification and elevation height data was shown in Hydrological Process[6]. All possible combinations of thematic maps were prepared for both flood frequency and flood depth, and combination by physiography, geology and land cover classification data shows the best combination for each of the flood hazard map performed for floodwater depth and flood frequency independently, those have congruence for 66% areas to each other[7]. The ideas of ranking matrix for three dimensional multiplication modes are shown in **Fig. 1**.

Table 3 Hazard rank for physiographic divisions by floodwater depth (ID: physiographic divisions identification number, HR: hazard rank)

ID	Class 1	Class 2	Class 3	Class 4	Score	Point	HR
1	72.48	12.54	12.36	2.62	62.74	12.98	1
2	39.88	7.62	43.62	8.88	182.88	37.84	2
3	64.40	8.54	25.86	1.19	92.09	19.06	1
4	20.86	0.95	54.10	24.08	283.67	58.70	2
5	75.60	5.77	13.94	4.68	71.02	14.70	1
6	46.71	0.40	35.79	17.10	193.25	39.99	2
7	0.27	0.00	26.65	73.08	445.33	92.15	3
8	71.57	4.24	19.09	5.11	87.02	18.01	1
9	2.30	0.21	62.39	35.10	362.87	75.09	3
10	12.19	0.16	50.93	36.72	336.56	69.64	3
11	22.10	0.05	54.86	23.00	279.62	57.86	2
12	47.15	0.62	32.42	19.81	196.93	40.75	2
13	0.00	0.00	65.08	34.92	369.85	76.53	3
14	1.15	0.00	5.49	93.36	483.27	100.00	3
15	27.68	0.90	30.22	41.20	297.55	61.57	2
16	50.66	3.51	15.33	30.50	202.03	41.81	2
17	43.73	1.67	25.28	29.32	224.12	46.37	2
18	2.10	0.21	55.88	41.81	376.89	77.99	3
19	5.17	0.00	26.98	67.85	420.19	86.95	3
20	52.18	14.50	25.79	7.53	129.53	26.80	1
21	68.88	4.61	22.24	4.27	92.68	19.18	1
22	16.04	0.45	51.41	32.10	315.17	65.22	2
23	26.67	1.12	38.13	34.07	285.87	59.15	2
24	50.91	18.50	16.28	14.31	138.87	28.74	1
25	62.34	9.45	12.34	15.86	125.80	26.03	1
26	64.60	3.37	13.53	18.49	136.43	28.23	1
27	63.11	29.96	5.83	1.09	52.91	10.95	1
28	89.34	1.64	2.42	6.61	41.92	8.67	1
29	97.62	1.09	0.61	0.68	6.32	1.31	1
30	89.20	4.24	0.22	6.34	36.61	7.57	1
31	8.06	4.46	3.71	71.29	416.82	86.25	3

4.2 Considering the interact effect of flood depth and frequency for flood hazard map

Two hazard maps were developed for floodwater depth and flood frequency respectively, by considering hazard rank from 1 to 27, which were estimated by the ranking matrix of three dimensional multiplication modes for the combination of physiographic division, geological division and land cover classification data. In these two hazard maps, 66% pixels show the same hazard ranks and 34% is different, because depth and frequency were considered independently. Therefore, for the good agreement of the results, a new hazard map was constructed from above mentioned two hazard maps by considering the interact effect of floodwater depth and flood frequency simultaneously. Priority was given to the higher risk rank of a pixel for new hazard map. If one hazard map between the two hazard maps which was either constructed by considering floodwater depth or flood frequency shows the higher rank for a pixel than the other, then the higher rank was assigned for that pixel. Physiographic and geological maps show different water courses' areas, therefor the drainage network was superimposed onto the new developed hazard map. The final hazard map is shown in **Fig. 2**. This new hazard map will give more safety for the flood countermeasure compared with our previous developed hazard maps[7], because the pixels belonging to higher degrees were increased due to the consideration of higher degrees of ranks.

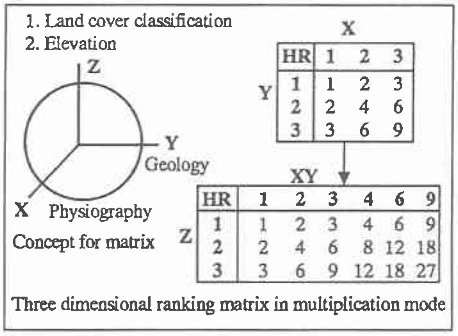

Fig. 1 Ranking matrix in three dimensional multiplication modes

5. Examine the results of developed flood hazard maps

In the year of 1995 and 1998 there were floods in Bangladesh, but these floods did not exceed the flood record of 1988. Flood hazard map constructed for the event of 1988 was examined for the events of 1995 and 1998. Flood hazard maps were developed for the event of 1995 and 1998 by using flood depth only for the combination of three thematic maps: physiographic division, geological division and land cover classification. The comparison results for the final hazard map with 1998 event are shown in **Table 3**. The elements of the column of the Table represent the number of pixels for the hazard ranks of 1998 flood while the rows of the Table represent the number of pixels for the hazard ranks of 1988 flood. If the elements of the flood hazard map of 1998 remain in and under the diagonal elements of the Table then the hazard map developed by using the flood event of 1988 is to be considered as a perfect one for the event 1998. Summation of upper diagonal elements is 10.06%, summation of under diagonal elements is 45.35%, and the summation of diagonal elements is 44.59%. Therefore, the hazard ranks for 1998 flood remained within the ranges of hazard ranks of the final hazard map of 1988 are 89.94% (summation of diagonal elements plus summation of under diagonal elements), and 10.06% are exceeded the hazard ranks of the final hazard map. Same

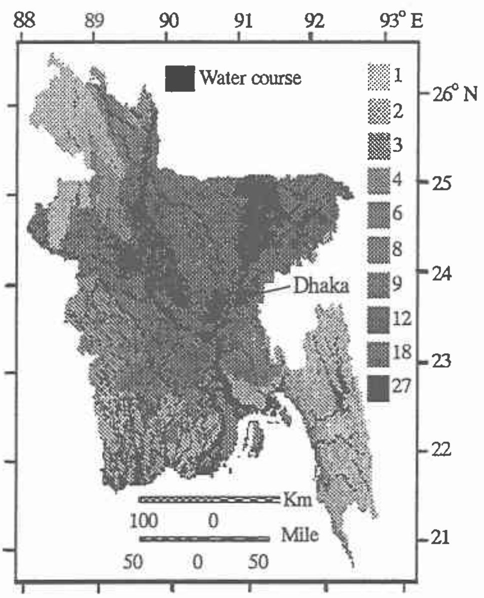

Fig. 2 Flood hazard map developed by considering the interact effect of flood frequency and flood depth with the combination of three thematic maps: physiographic division, geological division and land cover classification

comparison results for 1995 event show that the hazard ranks for 1995 flood remained within the ranges of hazard ranks of the final hazard map of 1988 are 92.15% (summation of diagonal elements plus summation of under diagonal elements), and 7.85% are exceeded the hazard ranks of the final hazard map.

The same comparisons were also performed for the developed hazard maps for 1988, which were developed by considering floodwater depth and flood frequency, respectively, by using the events of 1995 and 1998. The comparison results for the developed hazard maps are shown in **Table 4**. Study shows that the hazard map that was developed by considering the interact effect of floodwater depth and flood frequency (No. 3 in Table 4) shows the maximum congruencies for the events of 1995 and 1998. Although there are not one hundred percent of congruence of the results for 1995 and 1998 events, 89.94% and 92.15% were remained in the safe ranges of the developed hazard map for another event of 1995 and 1998, respectively. Therefore the results of the final developed hazard map is to be considered as satisfactory and it is best one among the three developed hazard maps.

Table 3 Hazard map results judging for another event of 1998 flood
(the column and row correspond to 1998 and 1988 flood, respectively)

HR	1	2	3	4	6	8	9	12	18	27
1	**5223**	0	0	20	0	0	0	0	0	0
2	8008	**7958**	0	153	5	66	0	0	0	0
3	911	0	**0**	589	4189	424	0	1873	0	0
4	5668	0	0	**7928**	41	40	0	120	0	0
6	0	0	0	1883	**8085**	11	497	655	461	0
8	5588	0	0	1265	0	**451**	0	25	0	0
9	0	0	1322	17	1732	0	**2381**	14	359	0
12	479	199	0	1905	5370	1521	2	**3985**	685	0
18	26	0	0	89	6330	0	5415	2816	**7298**	1714
27	0	0	0	0	0	0	0	554	2751	**9635**

$$\sum \textit{upper elements of diagonal} = 10.06\%$$

$$\sum \textit{diagonal elements} = 44.59\%$$

$$\sum \textit{under elements of diagonal} = 45.35\%$$

Table 4 Judgment of the hazard maps' results for the events of 1995 and 1988

No	Flood hazard map	Judgments results for other events	
		1995 event (%)	1998 event (%)
1	Developed by considering floodwater depth	91.07	88.98
2	Developed by considering flood frequency	86.26	82.30
3	Developed by considering interact effect of flood frequency and floodwater depth	92.15	89.94

6. Conclusions

The summarized conclusions are as follows:

(1) Three flood hazard maps were developed by considering floodwater depth and flood frequency independently, and by the consideration of the interact effect of floodwater depth and flood frequency simultaneously.

(2) Flood hazard maps which were developed by considering floodwater depth and flood frequency show the congruencies of 91.07% and 88.98%, and 86.26% and 82.30% for the events of 1995 and 1998, respectively. Furthermore, flood hazard map which was developed by considering the interact effect of floodwater depth and flood frequency shows the congruence of 92.15% and 89.94% for the event of 1995 and 1998, respectively.

(3) Comparing the results with other two events, it is concluded that the results of developed hazard maps are to be satisfactory.

(4) Study shows that the flood hazard map which was developed by considering the interact effect of floodwater depth and flood frequency is considered to be the best flood hazard map among the developed three flood hazard maps.

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