

Application of GIS in flood hazard mapping: a case study of Gangetic West Bengal, India.

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1. INTRODUCTION:

The deltaic part of West Bengal state is traditionally identified as a flood prone area of India. Most of the flood management strategies in this region have been geared towards 'preventing' flood by an attempt to contain the river. Very little attention is paid on formulating rational land use planning to reduce flood induced disaster. Preparation of a comprehensive flood hazard map for this state would be the one of most crucial steps for implementing non-structural remedial measures. This paper attempts to synthesize the relevant database in a spatial framework to evolve a flood hazard map for Gangetic West Bengal. Geographical Information System (GIS) is extensively used to assemble information from different maps and digital elevation models. Census data and other relevant statistical abstract about the available infrastructure facilities have also been used to make the hazard map more oriented to need of the local inhabitants.

2. STUDY AREA:

Three major river basins of the southern West Bengal, namely Bhagirathi-Hoogly, Jalangi and Churni have been selected for the current study. These three rivers are the distributaries of Ganga River (Refer Figure 1). Eastern part of the district Bardhaman, Murshidabad, Hoogly, Howrah, Western part of North 24-Pargana and most of the Nadia and Kolkata constitute the administrative entity of these three river basins. Due to unavailability of information in and around Kolkata urban mass district Kolkata, Howrah and North 24 Pargana have been excluded from the current study. In the rest of our discussion we shall collectively designate these three river basins as Gangetic West Bengal. The current study area is typically identified as moribund delta. In this section of the delta the rivers are decaying and the land building process has entirely ceased. The interfluves of the numerous distributaries are ill drained (Spate, 1965). This situation ultimately led to stagnation of water and development of palaeo channels locally known as *bills*. The overall geomorphology of the study area depicts a degenerating fluvial system.

3. FLOOD HAZARD MAPPING FROM DIFFERENT SCALE PERSPECTIVE:

Mapping flood hazard is not a new endeavour in the developed countries of the world. Federal Emergency Management Agency (FEMA) is one of the most active and well known in this sphere. However, a closer look reveals that these hazard maps are very data intensive in nature and primarily depends upon very high resolution terrain data. In the current state of technology and resources possessed by India preparation of this kind of hazard maps is not feasible. Islam *et al* (2000a) formulated methodology to prepare flood hazard map for data poor Bangladesh. Later, efforts have been made to integrate population density in the flood hazard maps in order to create land development priority maps (Islam, 2002).

In the current study the issue of flood hazard mapping has been addressed from the perspective of different mapping scale in a GIS environment. The present study has been done in regional and sub-regional scale. In both occasion administrative units have been selected as the unit of investigation. A flood hazard map based on administrative units is particularly handy for the planners and administrators for formulating remedial strategy. It also makes the process of resource allocation simple resulting in a smooth and effective implementation of the adopted flood management strategy. The aim of regional study is to broadly identify the high hazard area in the three river basins. A regional study eventually leads to identification of the higher hazard zone. A more detailed and high resolution study of this zone optimizes resource allocation and saves time.

3.1 The regional study

3.1.1 Choice of variable:

For the regional study a total of 69 development blocks been analyzed. Mean area of the blocks is 205.42Sq. Km.

Therefore, the hazard map is not expected to depict any finer detail. In the regional scale 4 factors have been taken into consideration for developing the composite flood hazard index. Each of the factors has been assigned different weightage to quantify the severity of hazard. Frequency of flood occurrence in last 10 years has been considered as the measure of flood proneness of a particular block. The variable is named as 'flood-prone'. This variable suites with the current frame work of investigation as the flood record is collected in development block basis by the Irrigation and Waterways Department. To quantify the economic assets under potential flood threat population density of the development blocks has been chosen as another important variable.

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Population density figures have been collected from Census of India, 2001. Later in this study this variable will be identified as 'pop-den'.

One of the main components of flood mitigation strategy is fast evacuation of the affected community. Good network of all-weather roads is an essential prerequisite of safe and effective evacuation during severe floods. Availability of surfaced road per Sq. Km. in each of the development blocks is considered to quantify the ease of movement. Source of this data was the District Statistical Handbook of West Bengal, 1998. This variable was assigned the name as 'evacuation'. As mentioned earlier, any Access to safe drinking water has been considered as the key factor to prevent this post flood hazard like out break of a water borne disease. To quantify this aspect of intangible hazard we devised another variable named 'epidemic'. This variable measures percentage of villages having no access to safe drinking water to the total number of villages in each of the development blocks.

3.1.2. Preparation of data:

Boundary of the river basins namely; Bhagirathi-Hoogly, Jalangi and Churni has been delineated from a 1:500,000 map prepared by Geological Circle, State Water Investigation Directorate, Water Investigation and Development Department of Government of West Bengal. The map has been transformed into soft copy. It has been georeferenced using GPS control points collected during a field survey in the area. Since GPS satellites use WGS 84 as their reference ellipsoid the rectified map has been defined in that particular reference system using ArcCatalog component of ArcInfo. Using onscreen digitization method all development blocks have been digitized in a single polygon shape file from this rectified image. Each polygon has been assigned a unique ID in the attribute table so that composite hazard index can be joined to the GIS data base using the common unique ID.

For preparing a composite index an additive model has been adopted. It is recognized that the principle of assigning weightage to the variables is very crucial in this entire process of hazard mapping. To make the variables suitable for a composite index they have been made unit free by dividing each series by their corresponding means. This process has an edge over the standard process of $(x - \bar{x}) / \sigma_x$ as the standard deviation of the standardized series is not transformed into 1; mean of the standardized series becomes 1.

Thus, it helps in retaining the inherent heterogeneity of the data.

In this paper the process of assigning weightages to the flood hazard indicators is primarily knowledge based. The variable 'flood-prone' has been attached high importance because where the risk of inundation is very low other variables do not contribute anything to the element of flood hazard. Indicators representing a high level of dispersion across the development blocks have been given more weightages and vice versa. The weightage scheme has been implemented in three steps. First, all the 4 variables have been standardized and named as st_epdm, st_evcn, st_popden and st fldprn. Then an intermediate hazard index has been computed by the following formula:

$$\text{Intermediate Index} = [\text{st_epdm} \times 1 + \text{st_evcn} \times (-1.2) + \text{st_popden} \times 1.4]$$

A negative weightage is assigned to 'st_evcn' as it has an inverse relationship with flood hazard.

Association of Figure 2 with Figure 1 reveals that in Bhagirathi and Jalangi Basin the high hazard zone roughly corresponds with the low lying area. In the extreme south two blocks of Hoogly District fall in high hazard category by virtue of their proximity to Kolkata urban mass and consequent high population density. The overall picture shows that majority of the development blocks in Murshidabad district and the adjoining blocks in Nadia district need greater attention as far as flood management measures are concerned.

3.2. A closer look of the high hazard zone: A sub-regional study

The development block level regional hazard map is not capable of revealing the hazard scenario in adequate detail. This paper argues that a detailed large scale hazard mapping is suitable and cost-effective when it deals with maximum risk zone. The regional study leads the way to identify the high risk zone. For detailed sub-regional analysis very highly hazardous blocks in Jalangi River Basin has been considered. The study area constitutes of entire Domkal, Hariharpara, Noada and Tehatta-I, Tehatta-II blocks and part of Raninagar-I, Berhampur, Beldanga-I, Beldanga-II and Kaligunj blocks. Although Tehatta-II block was not classified in very high hazard category in Fig 2 it has been considered within the study area to maintain geographic contiguity between Kaligunj and Tehatta-I blocks. Revenue village is the smallest administrative unit of West Bengal. It is also the highest spatial resolution of census data collection in India. Therefore, revenue villages of the above mentioned development blocks have been chosen as the unit of inquiry for the sub-regional study.

3.2.1. Indicators of flood hazard at sub-regional scale:

Flood hazard index for this village level study has been devised on the same line as the regional study but the sources of data vary to some extent. Three indicators of flood hazard have been chosen. Number of flood occurrence in each village for last 10 years has been considered as the measure of flood proneness. Irrigation and Waterways Department of West Bengal Government prepares maps annually to show the flood affected areas each year. These maps are not uniform in scale. The maps used for this study vary in scale from 1:250,000 to 1:2,000,000. Heterogeneity in the source map scale is one of the limitations of this study but considering the maximum spatial resolution of this investigation small scale maps have also been used. We named the indicator as 'flood-fqr'.

Population density per hectare has been taken into consideration as the indicator showing intensity of land use. This indicator is named as 'pop'.

The third indicator takes into account the aspect of flood emergency management. During the time of inundation affected population are required to be evacuated to a safe place for temporary shelter. Relatively higher ground, not likely to be submerged by flood water, can serve as the temporary flood shelter. Availability of such 'higher' land in each revenue village has been calculated from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) digital elevation model (DEM). If the maximum elevation of a village is below a critical threshold the population is assumed to have no access to a flood shelter during contingency. These villages have been considered as under potential threat of flood and associated hazard. This indicator is given the name 'shelter'.

3.2.2. Preparation of data:

Boundary of the revenue villages have been derived from individual Development Block maps. Scale of the map was 1:63360. Each block map has been registered to geographical coordinate system using a digitizing tablet. Then the village boundaries of each block have been digitized as polygon shape file. These shape files have been projected into UTM Projection, zone 45N, using Project Wizard of ArcToolbox and then integrated into a single shape file using the merge function in Geoprocessing Wizard of ArcMap. A total of 384 villages have been considered. Like the previous exercise a unique ID has been assigned to each of the polygon that represents a revenue village.

All the Irrigation and Waterways Department's maps have been registered to geographical coordinate using ArcInfo software. Flooded areas for year 1991, 1993, 1995, 1996, 1998, 1999 and 2000 have been vectorized in individual shape files as polygon using ArcMap and ArcCatalog. Later these layers have been projected into UTM Projection (Zone 45N) to conform the village level map of the sub-regional study area. Selection function of ArcMap was used to select polygons from the village layer that intersect with the above mentioned flooded

area polygons. This process calculates the number of flood occurrence for each village and the result is tabulated under the indicator 'flood-fqr'.

Population density figure for each village has been derived from dividing the total population by the area. Source of the data was Village Directory of Census India, 1991. Same unique ID, as assigned to the polygons in the village shape file, have been given to the population data to make it compatible with the GIS layer.

ASTER Relative DEM has been used to extract the highest point for each village. ASTER Relative DEM has a spatial resolution of 30m. This digital data is suitable to meet 1:50,000 to 1:250,000 map accuracy standard (United States Geological Survey, 2003). The village boundary layer has been overlaid to the DEM and highest elevation for each polygon has been extracted using Zonal Statistics function of ArcInfo Spatial Analyst.

Unlike the regional analysis a multiplicative model has been adopted for creating a composite flood hazard map in sub-regional scale. Villages have been assigned rank for each of the 3 hazard indicators. Nature of the indicators, especially 'shelter', does not allow application of any statistical treatment to the original data set for creating composite flood hazard index. Hazard ranks are commonly integrated into a multiplicative model to create a composite hazard index (Islam *et al* 2000b). The ranking scheme for first two flood hazard indicators is presented in Table 2, 3 and 4.

Knowledge based hazard ranking of the selected hazard indicators for the sub-regional study

| PopulationDensity (persons/hectare) (Pop) | HazardRank (R_pop) |
|---|--------------------|
| 0 | .25 |
| .001-5.40 | 1 |
| 5.41-7.84 | 1.5 |
| 7.85-11.62 | 2.5 |
| 11.63-80.29 | 4 |
| 3091 | 6 |

| Highest elevation (m) (shelter) | Hazard rank (R_shelter) |
|---------------------------------|-------------------------|
| 20 and above | 1 |
| 19-20 | 1.5 |
| 18-19 | 2.5 |
| 17-18 | 3 |
| 16-17 | 3.5 |
| 15-16 | 4 |
| 14.75-15 | 5 |
| Less than 14.75 | 6 |

Table: 2

Table: 3

Table: 4

Villages that never experienced inundation in last 10 years have been assigned a hazard rank of 0 in Table. 2. This method has been adopted to ensure that these villages get a composite hazard index of 0 in the multiplicative model. In Table 3 the revenue villages exhibiting a population density of 0 are mostly marshy land and abandoned river channels. These villages have been assigned a hazard rank of .25 so that they acquire a smaller composite hazard index value. Kamalpur village, showing a population density of 3091 person per hectare, has been given a hazard rank of 6. Excluding the value 0 and 3091 rest of the series has been subdivided into 4 quartiles and given hazard rank from 1 to 5.

Assigning hazard rank to indicator 'shelter' requires a detailed knowledge of the local topography. Our main objective is to roughly identify the critical elevation above which flood water is not likely to submerge the ground. Villages having their highest point below this critical elevation threshold are subject to high hazard rank. To determine the break of slope or the critical elevation value a number of transverse profiles have been drawn across Jalangi River using the ASTER digital elevation mode. One such transect profile is shown in Figure 3 whose location is marked in Figure 4.

Transverse Profile

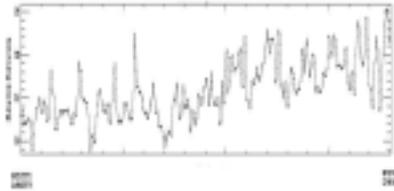


Figure: 3

A scheme of hazard ranking for indicator 'shelter' has been devised after analyzing a series of transverse profiles across Jalangi River. Details of the scheme are tabulated in table: 4. Final flood hazard index for sub-regional scale is created as follows:

$$\text{Flood Hazard} = (R_{\text{fld-fqr}} \times R_{\text{pop}} \times R_{\text{shelter}})$$

Since the data ranges are not very familiar it has been classified into 4 hazard categories by natural break (Jenks) scheme. In this process ArcMap identifies break points by identifying inherent clustering pattern of the data. Class boundaries are set where there are relatively big jump in the data values (Minami, 2000). Details of the classification scheme are shown in Table 5.

Classification of composite hazard ranks into qualitative hazard intensity classes

Table: 5

| Index Value Range | Number of Villages | Hazard Category |
|-------------------|--------------------|-----------------|
| 0.0000 – 3.00 | 160 | Low |
| 3.01 – 11.25 | 171 | Moderate |
| 11.26 – 24.50 | 41 | High |
| 24.51 – 63.60 | 10 | Very High |

| Number of flood occurrence (fld-fqr) | Hazard Rank (R _{fld-fqr}) |
|--------------------------------------|-------------------------------------|
| 0 | 0 |
| 1 | 1 |
| 2 | 1.2 |
| 3 | 1.75 |
| 4 | 3 |
| 5 | 4.5 |
| 6 | 4.5 |

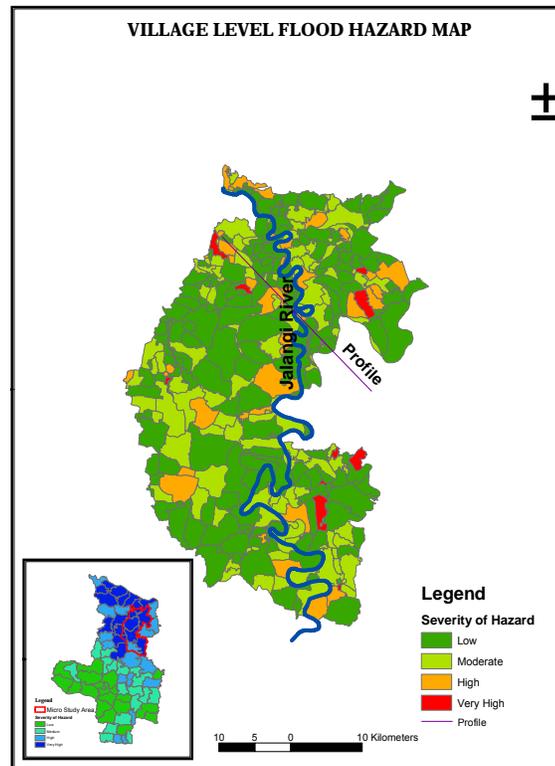


Figure: 4. Flood Hazard map prepared by village level sub-regional scale study. Inset showing location of the sub-regional study area within the entire study region

Figure 4 exhibits that there is no defined pattern in the disposition of flood hazard zones. Contrary to the overall topographic configuration moderate and high hazard zones are not necessarily located very near to Jalangi River. In the NE side of the area a cluster of villages depict high to very high hazard situation. More or less eastern side of Jalangi River is more hazard prone than the western part. Most probably the higher western bank of the river and natural levees prevent the flood water to spill its right bank very frequently. In the central portion of the area a few villages show moderate to high hazard potential by virtue of their higher population density and low road density. It should be noted that the reliability of this hazard map is more where the revenue village sizes are small. It is obvious that the larger villages mask out the finer details and reduce the spatial resolution of the map. The village boundaries have been derived from 1: 63360 maps but inclusion of the flood related data from small scale maps makes it unsuitable for large scale representation. The village level hazard map is recommended to be presented at 1: 250,000 scale.

4. CONCLUSION:

This study shows a simple and cost effective way to use geographical information system for creating flood hazard map from the available data base. It is acknowledged that accuracy of the key information, past records of flooding, depends upon the scale of the map that represents them. Due to lack of access to government resource we could not lay our hand on the large scale flood maps for the early 1990s. Incorporation of those resources would definitely enhance accuracy of the analysis. The weightage schemes are also open to suggestion and further improvement.

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Reference:

Map Asia 2003

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