

GIS in Flood Hazard Mapping: a case study of Kosi River Basin, India



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Flood Hazard Mapping is a vital component for appropriate land use planning in flood-prone areas. It creates easily-read, rapidly-accessible charts and maps which facilitates the administrators and planners to identify areas of risk and prioritize their mitigation/ response efforts. This article presents an efficient methodology to accurately delineate the flood-hazard areas in the Kosi River Basin, North Bihar, India in a GIS environment. We have used one of the multi-criteria decision-making techniques, Analytical Hierarchical Process (AHP) which provides a systematic approach for assessing and integrating the impact of various factors, involving several levels of dependent and independent, qualitative and quantitative information. We present a novel methodology for computing a composite index of flood hazard derived from topographical, land cover, geomorphic and population related data. All data are finally integrated in a GIS environment to prepare a final Flood Hazard map. This flood hazard index computed from AHP method not only considers susceptibility of each area to be inundated but also takes into account the factors that are inherently related to flood emergency management.

Floods are probably the most recurring, widespread, disastrous and frequent natural hazards of the world. India is one of the worst flood-affected countries, being second in the world after Bangladesh and accounts for one fifth of global death count due to floods. About 40 million hectares or nearly 1/8th of India's geographical area is flood-prone. The plains of north Bihar are some of the most susceptible areas in India, prone to flooding. A review by Kale (1997) indicated that the plains of north Bihar have recorded the highest number of floods during the last 30 years. The total area affected by floods has also increased during these years. Drained by two major rivers, the Kosi and Gandak, and several smaller systems such as Burhi Gandak, Baghmata and Kamla-Balan, the plains of north Bihar have experienced extensive and frequent loss of life and property over the last several decades (Sinha and Jain, 1998). The Kosi River (The Sorrow of Bihar) is well-known in India for rapid and frequent avulsions of its course and the extensive flood damages it causes almost every year. The Kosi is one of the major tributaries of the Ganga River, and rises in the Nepal Himalayas. After traversing through the Nepal Himalayas, it enters India near Bhimnagar. Thereafter, it flows through the plains of north Bihar and joins the Ganga River near Kursela, after traversing for 320 km from Chatra. The river has been causing a lot of destruction by lateral movement and extensive flooding. As its waters carry heavy silt load and the river has a steep

gradient, the river has a tendency to move sideways. Thus, in about 200 years the river has moved laterally by about 150 km (Gole and Chitale, 1966; Wells and Dorr, 1987). To check the lateral movement as well as for flood control, embankments on both sides of the river were constructed, five to sixteen km apart. Although this has confined the lateral shift of the river within the embankments, but the problem of flooding is still a challenge in this area. The problem of river flooding is getting more and more acute due to human intervention in the flood plain at an ever increasing scale. There must be a realization that minimizing the risk and damage from floods may be more rational way of flood management rather than formulating structural measures along the dynamic rivers such as the Kosi.

In this scenario, the regulation of flood hazard areas coupled with enactment and enforcement of flood hazard zoning could prevent damage of life and property from flooding in short term as well as in long term. Flood management and control are necessary not only because floods impose a curse on the society, but the optimal exploitation of the land and proper management and control of water resources are of vital importance for bringing prosperity in the predominantly agricultural based economy of this diversely populated country. This cannot become technically feasible without effective flood hazard maps. Flood hazard mapping and flood inundation modeling are the vital components in flood mitigation measures and land use planning, and are prerequisites for the flood insurance schemes. This article presents a multi-parametric analysis to compute a composite index of flood hazard and to produce a Flood Hazard map. The primary data used for this study were obtained from three sources. The first set of data includes topographic maps, district level maps, and census data of 1991 for the regional divisions of Bihar are obtained from the Survey of India, National Atlas & Thematic Mapping Organization (NATMO), and District Statistical Office, Saharsa respectively. The second set of data includes the digital elevation data (GTOPO30), a global digital elevation model (DEM) from U.S. Geological Survey's EROS Data Center in Sioux Falls, South Dakota and the DEM derived from the toposheets of the study area. The third set of data is the digital remote sensing images for the study area (IRS-1D, LISS III) obtained from the National Remote Sensing Agency, Hyderabad.

Integrated analysis of GIS & Analytical Hierarchical Process (AHP)

In this study, ArcView GIS 3.2a was used for working with grids and shape files. The sequence of operations followed is schematically shown in Figure 1. Firstly, the DEM of the study area was generated using the spot height data collected from the topomaps in ILWIS 3.2 Image Processing software. Then, it was converted into a point map and exported into ArcView GIS; where this vector elevation map is converted into raster grid format for overlay analysis. Secondly, the satellite imagery was georeferenced and registered to the geographic space. On this georeferenced image, image classification algorithms like GMLC, NDVI were applied to extract the land cover and vegetation information. Also, onscreen digitization process was carried out to delineate the geomorphic features from the image. All these classified and processed images were then exported into ArcView GIS for conducting overlay analysis. Thirdly, demographic data like population density (delineated from Census data in ArcView GIS) was also included in the overlay analysis. Some extra GIS operations like buffering were applied on some of the above obtained data to derive some new important data which in turn used in overlay analysis. Finally, all data was integrated in a GIS environment using AHP method discussed next. The study is carried out using ENVI 4.0, ERDAS IMAGINE 8.5, ILWIS 3.2, Arcview GIS 3.2a, Arcview GIS – Spatial Analyst Extension with Model Builder, Arcview GIS – 3D Analyst Extension

Analytical Hierarchical Process (AHP) is a multi-criteria decision making technique, which provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of dependent or independent, qualitative as well as quantitative information. It is a methodology to systematically evaluate, often conflicting, qualitative criteria (Saaty, 1980). Like other multi-attribute decision models, AHP also attempts to resolve conflicts and analyze judgments through a process of determining the relative importance of a set of activities or criteria by pairwise comparison of these criteria on a 9-point scale. In order to do this, a complex problem is first divided into a number of simpler problems in the form of a decision hierarchy (Erkut and Moran, 1991). AHP is often used to compare the relative preferences of a small number of alternatives concerning an overall goal. AHP is becoming popular in decision-making studies where conflicting objectives are involved. Recently,

Siddiqui et al., (1996) introduced a new method known as Spatial – AHP to identify and rank areas that are suitable for a landfill, using knowledge based user preferences and data contained in GIS maps.

The goal or the objective of this research is the mapping of flood hazard zones in the Lower Kosi river basin. The decision factors to relate attribute to suitability concerning a particular goal are the factors controlling flood hazard in the study area. The primary decision factors considered in this study are geomorphic features, elevation, vegetation, land cover, distance to active channels, and population density (Fig. 2). Once the decision factors are identified and selected, sub-factors and even sub-sub-factors are identified to describe these criteria better. For example, the geomorphologic factor was sub-divided into nine sub-factors as shown in Figure 2. Similarly, the other decision factors like vegetation, land cover, elevation, distance, and population density are sub-divided into sub-factors.

The RIWs are the normalized eigen vectors corresponding to the maximum eigen values of the pair-wise comparison matrices constructed at each level of the decision hierarchy. The RIW assigned to each hierarchy element was determined by normalizing the eigen vector of the decision matrix. Eigen vectors were then estimated by multiplying all the elements in a row and taking the n th root of the product, where n is the number of row elements (Saaty, 1980). Normalization of the eigen vectors was accomplished by dividing each eigen vector elements to the decision factor.

For the hierarchy represented in the Figure 2, the relative importance weightage of level 2 decision factors like population density, distance, elevation, vegetation, land cover, geomorphic features was determined by comparing the decision factors pairwise. This was followed by pairwise comparison within each level 3-decision factor. An attempt has been made to resolve conflicts and analyze judgement by a process of determining the relative importance of decision factors related to this study by pairwise comparison of these factors on a nine point scale.

Flood Hazard Index (FHI)

The FHI for each pixel was determined by aggregating RIWs at each level of the hierarchy. FHI for all raster cells in all the thematic layers were determined simultaneously using overlay analysis conducted in Model Builder of ArcView GIS3.2a. Higher the FHI value, higher is the flood hazard for that pixel.

FHI was calculated by multiplying the RIWs of level 3-decision factor by the associated RIWs of the level 2 factors at each level and summing the values of all grouped elements. Since our problem is defined in three level hierarchies, the simplified equation for 3 level hierarchies is:

$$FHI = \sum_{i=1}^{N_2} [(RIW_i^2) * (RIW_{ij}^3)]$$

Where, FHI = Flood Hazard Index,

N_2 = the number of level 2 decision factor,

RIW_i^2 = relative importance weight of level 2 decision factor i .

RIW_{ij}^3 = relative importance weight of level 3 sub-factor j of level 2 decision factor i .

If the decision hierarchy has more or fewer levels, the formula must be modified appropriately.

The FHI values as obtained from the above equation for the study area in the lower Kosi River basin were classified into low, medium, high and very high hazard based on histogram distribution and the final Flood Hazard Map is shown in figure 3. Higher values of FHI signify more susceptibility to floods and are the places of potential flood threat. The flood hazard map obtained by overlaying various thematic layers in a GIS environment is showing very satisfactory results when compared to the inundation map derived from the MODIS flood inundation map of July 25, 2004 for the Kosi basin. The source of this MODIS flood inundation map is the Dartmouth Flood Observatory, Dartmouth College, Hanover NH 03755, USA. This inundation map is showing the flooded areas from the period 1988 to 2004 which

served as the latest information source for the validation of the current research work. Not only that the inundation areas coincide in the final flood hazard map but the severity of the hazard areas is also reflected. A comparison of the flood hazard map with July 25th, MODIS flood inundation image reflects the following:

- ? The western part of the study area is under high and very high flood hazard zone. The population density is also high (701-1000, > 1001 persons per sq.km) in this region. This area is frequently inundated as is evident from the MODIS inundation map.
- ? Distance to active channels (which are the main sources of flood discharge) is playing an important role in the control of flood hazard in the study area.
- ? Geomorphic features like active channels, inactive channels, channel bars, water-logged areas, oxbow-lakes, moist sand are undergoing rapid modifications due to channel avulsion, meandering cut-offs in the study area. Such kind of dynamic behaviour also contributes to frequent and extensive flooding in the area.
- ? The entire region is a plain having a gentle slope from north-west to south-east. The elevation in the study window gradually reduces from 49m in the north to 32m in the south and as a result a number of marshes and swamps have developed in this region. Moreover, a number of tributaries join the Kosi in this region. As a result, this area has very high flood hazard index.
- ? The inundation limit or extent of MODIS inundation map of 2004 and previous years closely match with the hazard areas in the map validating (or confirming) the logic followed in the analysis and the model developed; reflecting flood effects for operational years.
- ? Hazard areas mapped are as per the integrated effect of different parameters and not just on the basis of a few years of inundation data. Thus, the potential of flood hazard of the areas is based on an integrated analysis and not merely on a hydrological phenomenon.
- ? There are some areas which have not been inundated during the last 1-2 years but they still fall under high and very hazard areas e.g. parts of Kiratpur, Gouraboram, Biraul, Mahisi, Kusheswarasthan west, Alauli development blocks. This suggests that the future potential of flooding is high in these regions and adequate measures should be taken to protect these areas.
- ? The development blocks viz. Singheshwar, Madhepura, Sour-Bazar, Eastern-parts of Kahara, Simri Bakthiarpur, Supaul which fall under low hazard areas and have also been inundated for the last 10 years indicate much lower probability of flooding in future. This is perhaps a manifestation of gradual migration of the Kosi river towards west during the last 200 years.

Final remarks

The research presented in this article formulates an efficient methodology to accurately delineate the flood hazard areas in the lower Kosi River basin, North Bihar, India. This study represents some exploratory steps towards developing a new methodology for inexpensive, easily-read, rapidly-accessible charts and maps of flood hazard based on morphological, topographical, demographical related data. The study has also focused on the identification of factors controlling flood hazard in the study area. It accomplishes this goal by combining Spatial AHP technique with GIS-based overlay analysis.

Such efforts should be a part of non-structural measures of flood management to reduce short term and long-term damages and to bring awareness among the scientific community on the potential need of this research. The basic merit of this methodology lies in its simplicity and low cost. This is one of the initial projects attempted; the lessons learned from this pilot effort can be applied to a larger area encompassing the entire Kosi River basin and other river basins of the country.

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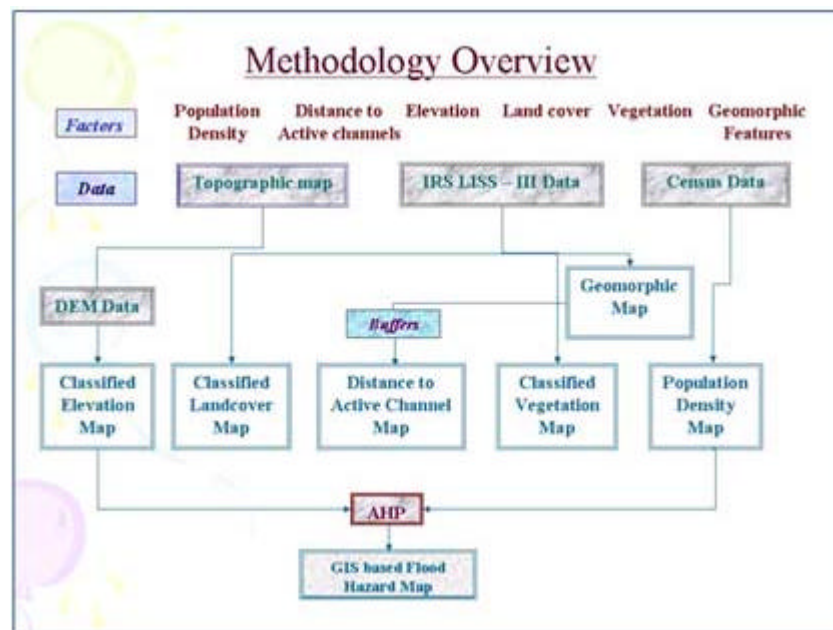


Figure 1. Methodology followed for flood hazard mapping

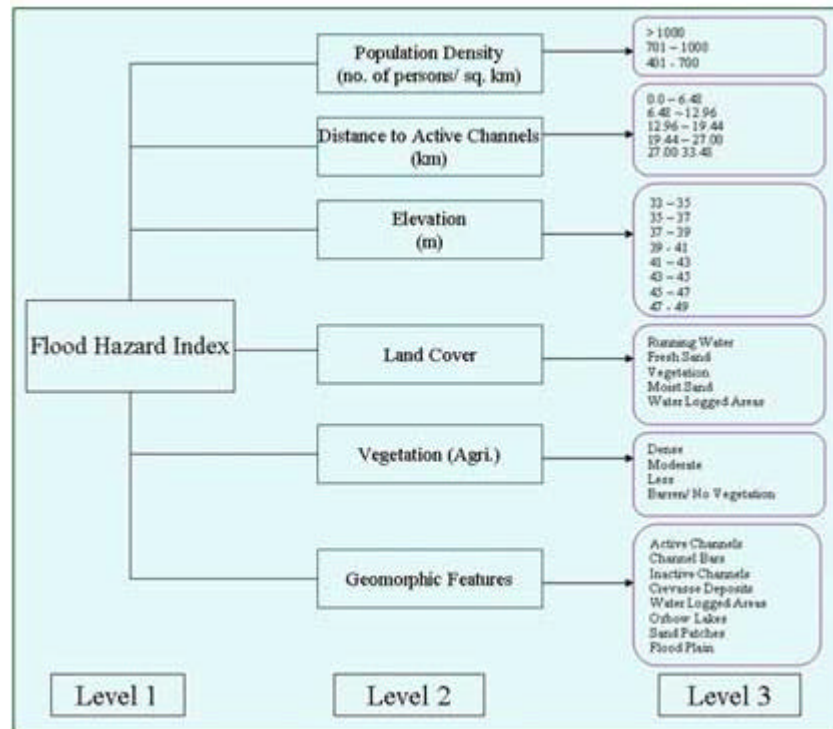


Figure 2. Decision Hierarchies for Flood Hazard Index Ranking

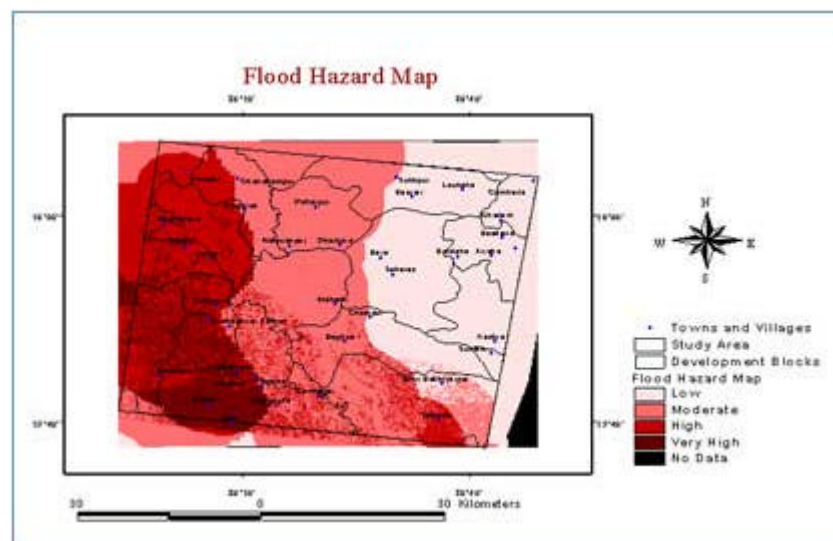


Figure 3. Flood Hazard Map for the study area