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Abstract:

Spatial information for efficient flood emergency management is very limited in the developing countries. This paper combines cartographic and remotely sensed data to identify the rural settlements that are vulnerable to flood in Ajay River Basin of West Bengal, India. An ERS-1 Synthetic Aperture Radar (SAR) flood scene has been acquired over Ajay River Basin. Several digital image processing techniques including thresholding have been applied to identify the flood affected settlements in the scene. The principles of optimum location have been extensively applied through geographic information system (GIS) to come up with a map showing the ideal location for elevated concrete structures that can serve as flood shelter for the vulnerable communities.

Key Words: Geographic Information System (GIS), Remote Sensing, Synthetic Aperture Radar, Location Analysis, Flood Shelter

Introduction

Mitigation, preparedness-response and recovery are three major components of natural hazard management. Constraint of resource allocation for natural hazard management is a typical phenomenon of developing countries. Therefore, cost effective planning for remedial measures is the key to successful implementation of any hazard management strategy. This paper places special emphasis on existing funding situation in developing countries and tried to propose a preparedness plan to combat river flooding. GIS and remote sensing technology have been extensively used in this study to formulate a preparedness-response strategy in micro scale. Primary objective of this study is twofold. It seeks to identify the settlements that are vulnerable to monsoon floods in Ajay River Basin of India. Remotely sensed data and large-scale topographic maps have been used to achieve this goal. Consequently effort has been made to determine optimum location for establishing flood shelters for those flood prone settlements in a cost effective manner. Proximity analysis tools in vector GIS and relational database management system (RDBMS) have been extensively utilized to formulate this strategy.

Overall focus of this investigation is centred upon assessment of flood risk and formulation of a non-structural response plan based on geo-information technology. It is essentially a micro level study and the problem has been addressed to its maximum possible details. The study has been structured in such a way that the identified vulnerable settlements have been used as the input for the site selection for flood shelter.

Materials and methods

Study area

Ajay River Basin has been chosen for this large scale study because most detailed topographic maps and SAR data, capturing peak of a major flood, are available for this tact of West Bengal state. Ajay is one of the major western tributary of River Bhagirathi. It originates in the Chotanagpur Plateau flows from West to East from Indian state of Jharkhand to West Bengal. Location of the study area is shown in Figure1. This area marks the boundary of Ganga Delta with the Deccan Plateau of India. The current study area is designated as Older Deltaic Plain or Rampurhat Plain (Bhatacharya and Banerjee, 1979). A Digital Elevation Model (DEM) of 30 m grid size has been created in Arc Info by incorporating available spot heights with vectorized contours. 1:25,000 topographic maps, prepared by Survey of India, have been used as the source data. The region is gradually undulating from West to East with some pocket of low lying and elevated area at the Eastern portion.

This area has been affected my major flood at least 5 times in last 15 years (Irrigation and Waterways Deptt.W.B., 1995). Major events took place in Year 1991, 1995, 1999 and 2000. Embankments protect the entire northern bank and a considerable portion of the southern bank of Ajay River. Major floods occur when the river overtop these embankments or even breaches some vulnerable portions. Agricultural land is the dominant land use. Arable land is dotted with small rural settlements.

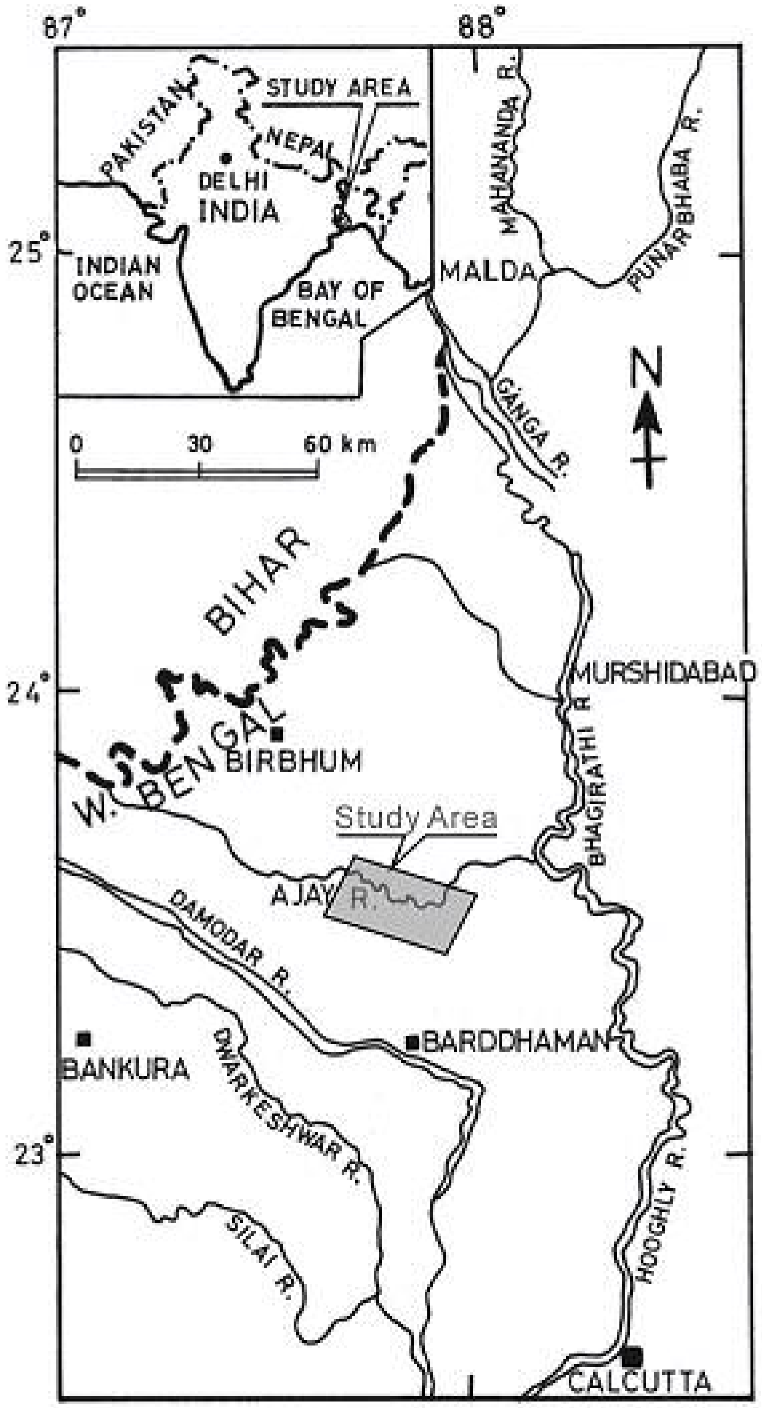


Figure 1: Location of the study area. Inset showing location of Ajay River Basin in West Bengal,India.

Identification of flood prone settlements

A high magnitude flood has been used as an index of flood threat in Ajay River Basin. A high magnitude flood in which individuals and society suffers substantial damage can be designated as a damaging flood. The relationship between hydrologic and damaging flood is guided by numerous intervening factors such as, river channel modification, land use, structural mitigation etc (Pielke Jr, 2000). The concept of damaging flood brings hydrologists and policy makers in a common platform. It results in a better floodplain management and mitigation effort.

The September, 1995 flooding along the Ajay River Basin meets all criteria of being considered as a damaging flood. Due to continuous heavy precipitation over the upper and lower reach of its catchment River Ajay overtopped its embankments causing havoc to the life and property along its two banks. At least an area of 85 km^2 was inundated (Irrigation and Waterways Deptt.W.B., 1995).

Remote sensing technology can immensely help us to capture extent of particular flood and make it possible to visualize spatial pattern of the hazard. Dominance of cloud cover during flooding season is the most severe constraint for using space borne sensors that operate in the visible and near infrared portion of the electromagnetic spectrum. Radar images with its cloud penetrating capability prove extremely useful to overcome this problem. For last two decades synthetic aperture radar (SAR) has been extensively used in the field of flood detection (Immhoff *et al*, 1987; Zhou *et al*, 2000). Application of

SAR data for flood detection ranges from simple change detection technique using scenes of dry and flood season for same area (Lee and Lee, 2003) to creating colour composite by assigning grey scale image of each date to basic colour (RGB) channels (Long and Trong, 2001). This range of literature has been found very useful in devising the methodology for delineating the flooded area in the current study.

A European Remote Sensing Satellite (ERS-2) SAR Precision Image (PRI) data has been used in this study to analyze spatial dimension of a damaging flood. It was acquired on 28th September, 1995, during the peak of the flood in Ajay River Basin. The imagery provided an uninterrupted coverage of flood situation. ERS-1 is a side looking radar system. ERS-1 SAR mode has a wavelength of 55 m (C-Band) and an incidence angle of 23°. PRI scenes are projected to ground range and resampled to a 15 m × 15 m pixel size. The PRI scene has been georeferenced to 3 topographic sheets of 1:25,000 scale using 19 GCPs. A RMSE of 0.93 pixels has been achieved.

There are number of constraints associated with the use of SAR data for flood delineation. One of the most important of them is speckle. A sensor can receive microwave signal returning from same place on earth surface in a phase in or out of phase manner. This produces a random pattern of brighter and darker pixels in the SAR image giving it a distinct grainy look (Lillesand *et al*, 2004). It has been reported that in rural areas where large homogeneous textural areas exist a median filter provides very effective means to reduce speckle (Badji and Dautrebande, 1997). Median filter of varying dimensions have been applied over our data and an optimum solution has been achieved by applying it twice in a 5 × 5 moving window. After reducing the speckle the PRI scene has been enhanced to improve its visual interpretability.

Basic principle of detecting water over a SAR image is that surface of flood water in the absence of strong wind produces specular reflection (Oberstadler *et al*, 1997). Specular reflection, in terms of back scattering, results in low intensity signal. Pixels characterised by this process appear in dark grey while due to high back scattering coefficient dry surface appears bright. The boundary between inundation and dry surface appears exceptionally dark, making it easy to visually detect the extent of flooding.

Rural settlements in the study area have been vectorized from topographic map and the layer has been superimposed over the processed SAR flood scene. It is noted in Figure 2 that the flooded area stands out in distinct dark shade along both banks of Ajay River. Flooding was widespread over the right bank (Northern portion) and South-central portion of the study area. Settlements that fall within the maximum extent of inundation have been identified as the vulnerable settlements. Only those settlements have been considered for being served by flood shelters.

Unavailability of multi-date SAR scenes for the same area and high resolution terrain data have limited our capability to employ more sophisticated digital image processing techniques and spatial models. However, central focus of this study is not improving upon digital image processing techniques for delineating flood. This study sought to identify the settlements that are exposed to the risk of monsoon flooding in Ajay River Basin. Visual interpretation of the processed SAR flood scene, supported by documented account of that particular flood (Irrigation and Waterways Deptt., 1995) can effectively perform this task. It is widely noted that ripples in water due to prevalence of strong wind

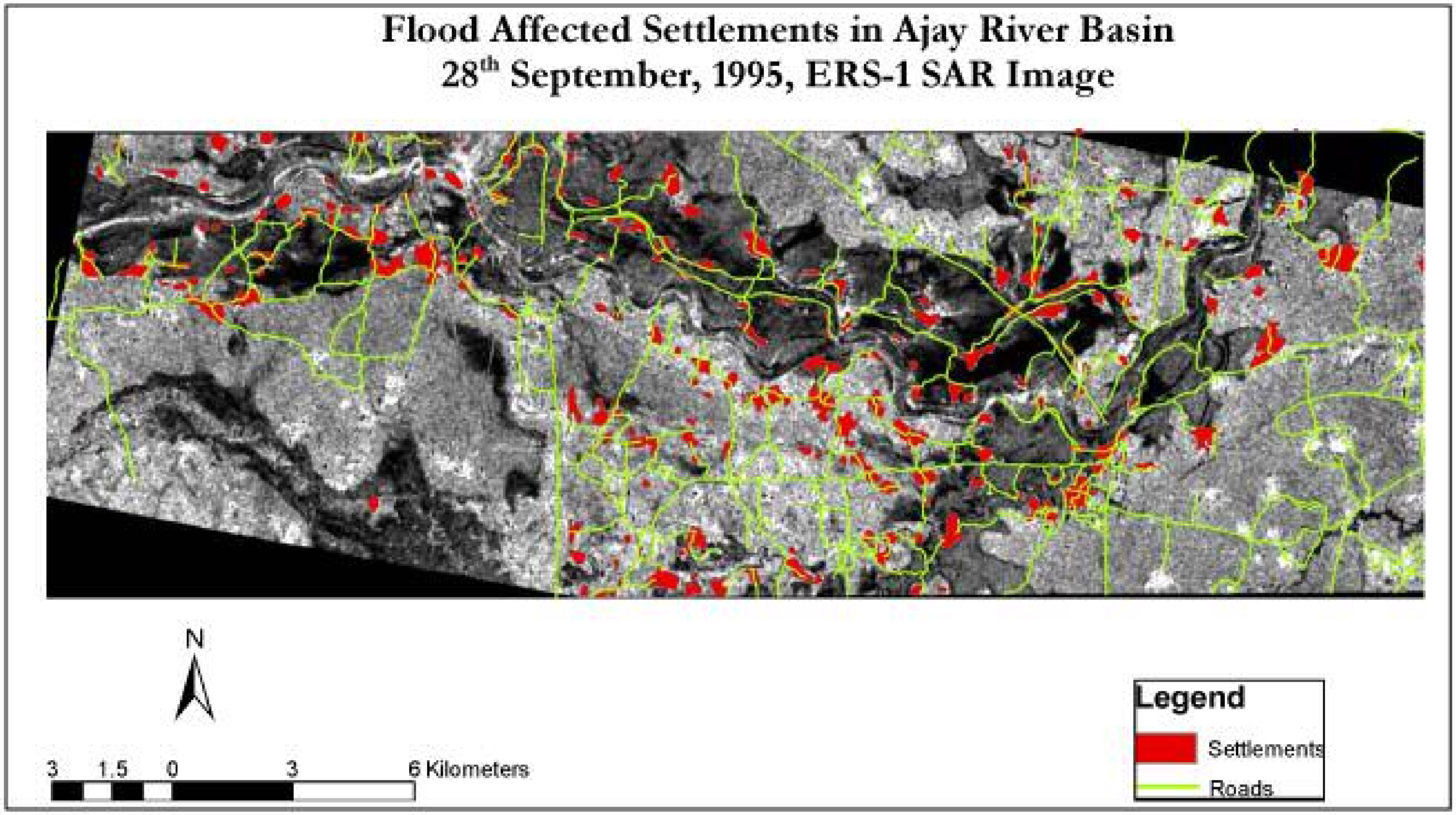


Figure 2: ERS-1 SAR scene showing flood situation in entire study area during the peak of a major flood on 28th September, 1995. Affected rural settlements have been superimposed over the SAR scene and shown in red.

(Yang et al, 1999), orientation of the radar antenna to the water surface and forest cover (Kundus *et al.*, 2001) can pose severe constraint to distinguish flood water in SAR scene. Mountainous topography produce shadow in the SAR scene and dry surface appears as water due to suppressed backscattering coefficient. Luckily, terrain of Ajay River Basin is absolutely flat and forest cover is almost insignificant. Prevalence of strong wind might have affected the pattern of backscattering. A careful association of the inundated surface with other features such as, levee dry crop land etc. helps us to partially overcome this problem and enhances our capability to visually identify the actual extent of flooding.

Flood shelter planning for preparedness and response

Flood mitigation strategies are broadly classified under two categories; structural and non-structural. While structural strategy mainly concentrates on building dams and embankments to contain the river, non-structural measures focus on implementing floodplain zoning and corrective floodplain landuse pattern in highly flood prone areas. With increasing experience in flood management it has been realized that structural measures are not quite effective in reducing frequency of flood occurrence over most of floodplains of the world. The Federal Interagency Task Force in USA analysed the flood damage related data for that country for a seventy-year period (1916-85) and concluded that property losses due to flood have remained constant in USA in relation to her overall economy (FIFMTF, 1992). As a result, in recent years more and more emphasis has been placed on formulating efficient non-structural strategy that will keep the fluvial system unaltered while reducing the impact of this natural hazard.

One of the important realizations from experience of implementing floodplain zoning is that given a choice, existing population of a flood prone area always favours the structural measures (Smith, 2000) over the non-structural ones. In a developing country like India, where existing high population density has already made agricultural land a scarce resource, implementation of a proper floodplain zoning is an uphill task. Practical feasibility of relocating the existing communities from the flood prone area is only marginal. In this socioeconomic scenario, ensuring safety of the life and property of the vulnerable communities without dislodge them from their land would be the most appropriate flood management strategy and it can be achieved by developing an effective preparedness and recovery system.

A practical way to mitigate flood hazard in densely populated developing countries is to build flood shelter in the highly flood prone area. Flood shelters can be perceived as high concrete structure where flood affected communities can take refuge during extreme hydrological events. Developing countries, such as India, often faces sharp trade-offs between allocating precious fund to cover different aspects of flood management. Therefore, the issue of locating the flood shelters assumes great importance. This factor places the current research well in the ambit of GIS based optimum location analysis. GIS has been used for location analysis and site selection in a variety of way over last 20 years. Application of GIS in site selection started in 1970s with Keifer and Robbins (1973). Dobson (1979) carried out a study to explore the best possible site of a power plant in the state of Maryland in USA. In recent years GIS has been widely used to find out optimum and cost-effective location for healthcare facilities (Birkin, 1996, Deshpande, 2004). GIS has been used for expanding banking business by assisting the management to find optimum location for opening new branches (Reidenbach & Pitts, 1986). GIS has also been assisting in the simulation of physical access route in the remote areas of Bolivia (Perry and Gesler, 2000) and Costa Rica (Rosero-Bixby, 1993).

Location analysis of flood shelters

Chowdhury *et al* (1998) identified three reasonable criteria of locating a flood shelter; I) providing necessary protection to largest area or maximum number of planning units, II) providing same level of protection to all planning units and III) minimize overall risk of the vulnerable community. He addressed the problem from the point of view of macro level planning for entire Bangladesh. Our study, on the other hand, is a micro level planning effort. Hence, it is apt to improvise the suitable criteria for selecting optimum sites of flood shelters in Ajay River Basin. Bangladesh administration has built some flood shelters to protect the population from storm surges (Plate 1)

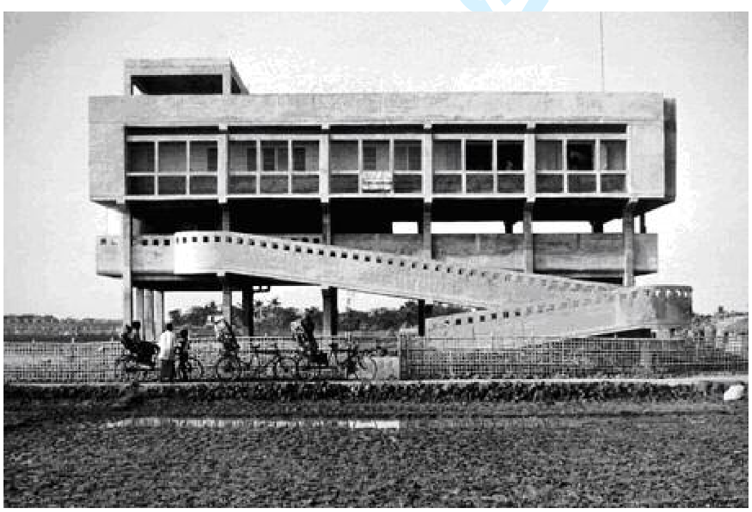


Plate 1: Photograph of a flood shelter in CoxBazar, Bangladesh. The second floor built on high pillars is designed to provide shelter to flood affected people during emergency. (Source of Photograph: http://archnet.org/library/images/)

Ideally each vulnerable settlement should have one flood shelter but due to lack of available resources this requirement is not economically viable. After considering the available dataset at our disposal and interacting with local people and administration

We have set 3 guidelines for selecting optimum site of flood shelters in the study area. These guidelines are discussed below.

A shelter should be located within an existing settlement. Building concrete structure on highly productive arable land would invite conflict between the administration and local people. A shelter located within a settlement (residential area) can take advantage of its existing infrastructure such as, drinking water source, link to transport and telecommunication etc. During dry season it can act as a school, warehouse, or a place for community activity providing more rationale for the government to invest.

Accessibility is always at the centre of the location problem and distance is very often taken as the measure of accessibility (Current *et al*, 1991). Therefore a shelter must be within walking distance of its neighbouring settlements. Here walking distance signifies a distance that people of all age can cover in short time on foot. After interviewing the local people it has been decided that 1 km is the maximum distance that people can walk during emergency to reach a flood shelter. A straight-line distance has been taken into consideration because majority of the rural roads in that area are unusable during flooding season. As the local topography is very flat it is not particularly inconvenient for the local people to walk in any direction from their dwellings.

A shelter has to be located at a place from where it can serve maximum number of its vulnerable neighbours. This is the key criterion of our spatial model that would dictate the final solution. To put simply, it has been decided that a particular settlement to be considered as a shelter, must be within 1 km of at least 2 of its neighbours. Our goal is to identify those settlements as flood shelter that is located within 1 km of maximum number of its neighbours.

Architecture of the GIS

Central focus of this study is to identify those settlements that satisfy all the above mentioned criteria and hence, suitable for establishing a multipurpose flood shelter. As the current study considers the straight line distance among the settlements as the prime criterion for site selection there is a need to transform dimension of the settlements from polygon to point. Vector GIS platforms, such as Arc Info, has readily available functionality that can compute distance between given points.

In a bid to facilitate proximity analysis, centroids of the settlement polygons have been computed in Arc Info. Apart from making use of the available proximity analysis tools there is another important justification for representing the settlement polygons with points. When measuring distance between two polygons for evaluating accessibility, a planner would do justice with all the people of both settlements only if the distance is measured between their centroids. Otherwise, some people of each settlement would be in disadvantageous situation during evacuation. Moreover, no concrete guiding principle can be adopted for developing the desired location model without considering the settlements as points.

Flood affected settlements have been conceptually classified into two groups; shelter settlements and the settlements that would be served by the shelter settlements during monsoon floods. Our effort is to determine which particular settlements qualify for being considered as a 'shelter' and which are the neighbouring settlements that are served by them.

Point-Distance tool in Arc Info has been used to compute the distance of each settlement centroid from all of its surrounding settlement centroids. It has been recognized that straight-line distance cannot act as a measure of accessibility where conspicuous physical boundaries such as a mountain or a river exists between two settlements. Although Ajay River Basin in West Bengal is very flat with no prominent obstruction the river itself acts as a formidable barrier for the local inhabitants to travel across it, especially during monsoon season. Keeping this in mind, calculations of distance between the settlements have been done separately for the northern and southern bank of Ajay River. As mentioned before, based on local people's experience, a search radius of 1000 m or 1 km has been specified for measuring distance. Anything beyond this distance has been considered unrealistic for people to travel on foot during a major flood.

Output of Point-distance Tool is an INFO table that represents distance of each point from all the points within the specified search radius. It is evident that such a table can be quite huge when a good number of points are included in the computation with a longer search radius. Our original table is also quite big and not suitable for presenting in this paper. Table 1 shows a sample of our output Info table with all typical characteristics associated with it.

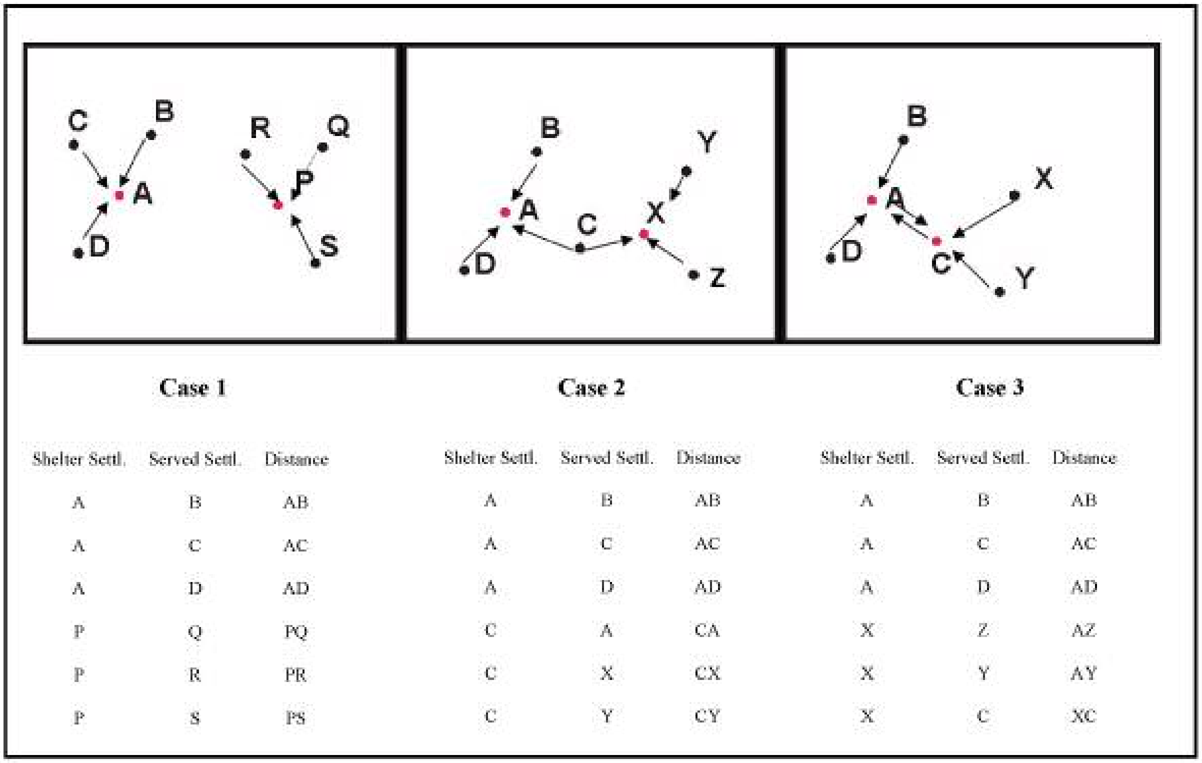
Row No	Settlement ID (distance from)	Settlement ID (distance to)	Distance (m)
1	A	A	0
2	B	C	432
3	C	B	432
4	D	F	870
5	E	G	0
6	F	D	870
7	A	C	624

Table 1: A sample output of the Point-Distance Tool in Arc INFO. Settlement IDs and distance figures are hypothetical.

Row 1 describes that each point computes its distance from its own and yields the result 0. Row 2 and 3 and row 4 and 6 illustrate that there is a repetition in the computation process. Row 5 depicts a situation where distance between settlement E and G is beyond the search radius (*i.e.* 1000 m), therefore yielding a 0 in the measured distance column. It is quite evident from the sample INFO table that the output of Point-Distance Tool in Arc Info is crude in nature and far from readymade to achieve our objective.

For treating the raw INFO table it has been imported in a Relational Data Base Management System (RDBMS). MS ACCESS has been chosen for performing the task. After this point major challenge of this project was to clean the raw data so that it can be joined with the feature dataset of the settlements. The major steps that have been taken to extract the relevant information from the raw INFO table are described below.

All the rows having a distance 0 have been omitted from further analysis as they are either redundant or not relevant under the specified criteria for optimum location of flood shelter. Frequency of the Settlement IDs has been calculated to determine how many times a particular settlement ID has appeared in the output INFO table. Any Settlement ID that appears for a good number of times in the same column in the INFO table is seemingly located within 1000 m of a number of settlements. Those settlements are of prime importance for setting up flood shelter as our objective is to serve as many settlements as possible from a single flood shelter. This apparently straightforward task becomes complicated due to overlapping of the territories of the shelter settlements. This situation calls for a systematic approach of managing the database to eliminate data redundancy. Different processing levels of the INFO table has been illustrated in Figure 3 with typical examples.



Case 1

Shelter Settl.	Served Settl.	Distance
A	B	AB
A	C	AC
A	D	AD
P	Q	PQ
P	R	PR
P	S	PS

Case 2

Shelter Settl.	Served Settl.	Distance
A	B	AB
A	C	AC
A	D	AD
C	A	CA
C	X	CX
C	Y	CY

Case 3

Shelter Settl.	Served Settl.	Distance
A	B	AB
A	C	AC
A	D	AD
X	Z	AZ
X	Y	AY
X	C	XC

Figure 3: Schematic diagrams depicting different processing level for the output INFO table for determining optimum flood shelter location.

Case 1 is the perfect situation where Settlement A and P appeared 3 times in the INFO table with no repetition. Settlement B, C and D are within 1km of Settlement A and same is the case for Settlement Q, R and S with Settlement P. In this situation Settlement A and P can be unambiguously attributed as the optimum location of flood shelter. They serve 3 of their neighbouring settlements.

The most severe problem arises in Case 2. In this situation both Settlement A and C appeared 3 times in the INFO table and apparently they are acting as a potential flood shelter and serving 3 of their neighbouring settlements. A closure look at the INFO table reveals that the raw frequency of the settlements Ids can be quite misleading for evaluating hierarchy of the flood shelters. In Case 2 the territory of the potential flood shelters overlap and they compete with each other. In this situation Settlement A and C both appear as a potential flood shelter serving 3 of their neighbours while they consider each other as one of their served settlements. When both shelters are apparently serving equal number of adjacent settlements a guiding principle must be in place to select one of them. Incorporation of C in A's sphere of influence (or A in C's sphere of influence) automatically nullifies C's claim to be considered as a flood shelter. An objective guideline has been adopted in our spatial model to deal with this situation. Cumulative distance of A and C with its neighbours (*i.e.* $\overline{AB} + \overline{AC} + \overline{AD}$ and $\overline{CA} + \overline{CX} + \overline{CY}$) has been taken as the criterion for making a choice between A and C as the potential flood shelter. If ($\overline{AB} + \overline{AC} + \overline{AD}$) < ($\overline{CA} + \overline{CX} + \overline{CY}$) then Settlement C would be assigned to Settlement A and vies-versa. Assuming the above condition as true Settlement B, C and D would be assigned a code in the attribute table indicating that they are served by the shelter at Settlement A.

Case 3 is simpler than Case 2 and easy to settle. Here Settlement A and X appear as potential flood shelter serving 3 of their neighbours. It is evident from the sample INFO table that Settlement C falls within 1 km of both A and X. To avoid this kind of double counting in our spatial model it has been decided that if $\overline{AC}$ < $\overline{XC}$ then C would be assigned to A and vies-versa.

Once a vulnerable settlement is assigned to a potential flood shelter it is deleted in the parent database so that that settlement cannot compete with others as a flood shelter at a lower level of hierarchy. To give an example, a shelter may serve 8 of its neighbours and one or more of these neighbours can still be within 1 km of 7 settlements and appear as a shelter in the output INFO table. Therefore, once 8 settlements are assigned to a particular shelter they are deleted from the parent table to eliminate this kind of conflict in the database. This rule acts in accordance with our primary objective of finding shelter sites that can serve maximum number of neighbouring settlements.

Result and Discussion

Figure 4 depicts the hierarchy of the flood potential shelters and the group of settlements served by each of them. Different colours have been used to represent group of potential flood shelters that serve specific number of their neighbours. The settlements that would be served by a particular shelter have been assigned the same colour as the shelter to avoid confusion during interpretation. Permanent course of Ajay River is shown in blue colour. Road network of the area has also been depicted to give an idea of transport situation of the flood prone area. Information about population size of the vulnerable settlements would help the administration to determine the size of the flood shelter. Flood shelters built with this consideration would have the capacity to accommodate maximum number of flood affected population during in event of emergency.

The spatial model dealing with optimum site selection for flood shelters is simple and easy to implement but it takes into account only the straight line distance between the centroids of settlement as the guiding criterion of location optimization. Incorporation of other relevant factors like, population of the affected settlements, building materials for the houses, might make the model robust and more capable of dealing efficiently with the ground situation. The smallest unit of collecting population and other socioeconomic data in India is Revenue Village or *mauza*. Administrative boundary of *mauzas* in India is constant since the colonial period but the rural areas have experienced phenomenal increase in the number of rural settlements in the post-colonial period. As a result, *mauza* boundaries cut across individual rural settlements (Sanyal and Lu, 2005). Due to this fact Census of India database cannot be integrated in our spatial model. For critical situation it is recommended to take local population into account in the decision making process. This factor would particularly help to determine the size and capacity of flood shelters. Settlement to settlement survey of population can be justified for most flood prone settlements.

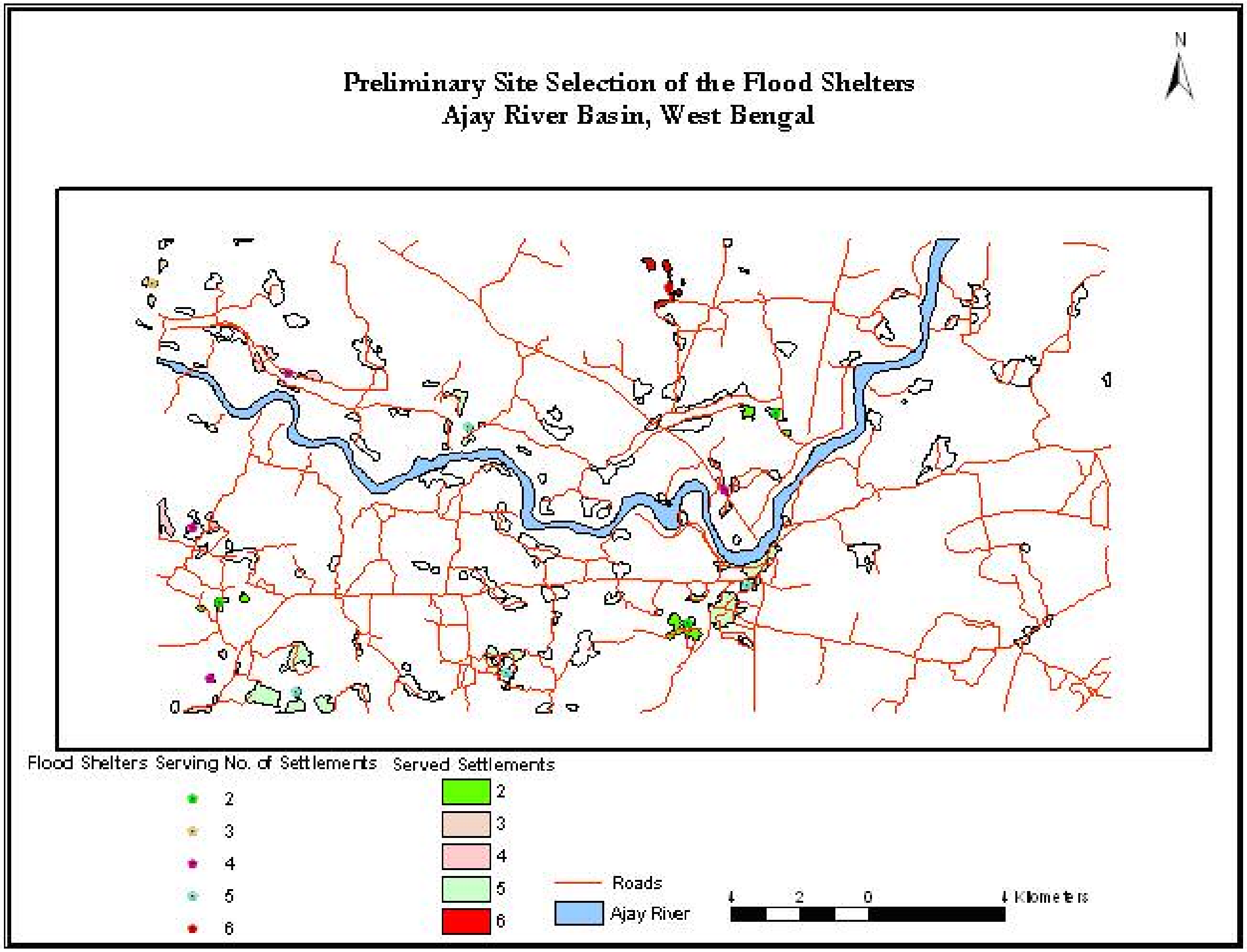


Figure 4: Potential sites for building flood shelters and the settlements served by them: Part of Ajay River Basin, West Bengal.

It is noted in Figure 4 that there are quite a few settlements in the flood-prone zone that have not been covered by any potential flood shelter. It is recognized that the spatial model developed in this study can only optimize the site selection procedure based on certain criteria. Here straight-line distance has been used as the determining factor. This methodology would enable a planner to view the location allocation problem in an objective manner. In the implementation stage rigorous interaction is required between the administration and local inhabitants of Ajay River Basin. Intense people's participation might help in modifying this model in meaningful direction. Other than distance, several criteria of the uncovered settlements, such as size or past history can be utilized to build flood shelters at or near them. But undoubtedly distance is the primary factor of accessibility in a flat floodplain like this and therefore should be given maximum importance in formulation any such location based solution.

Conclusion

The current study is an effort to provide an effective planning tool for the flood plain managers and administrators. Rather than using flood frequency analysis of river discharge we have adopted a methodology to identify the highly vulnerable zone directly from past flood experience. Use of remotely sensed data would enable a planner to visualize spatial extent of the problem. Such an approach would provide a synoptic view of the flood as well as the flood prone human settlements. Application of Geo-Information technology has facilitated a comprehensive spatial solution of the problem. This study utilized spatial data of highest possible resolution, available for civilian use, in India. This is a large scale study which accounts for each and every settlement of the study area and hence, suites perfectly for grass-root level flood management of rural communities. Such methodology can be of interest to a wide range of development agencies in the developing countries that optimum utilization of limited resources is the prime concern of the planners.

Availability of high resolution terrain data might have helped in applying a hydrological model. With such a model it might have been possible to classify the affected settlements at different level of vulnerability based on estimated accumulation of water from the channel. More intensive survey of the area and participation of the flood prone communities would make this model more efficient. Multipurpose flood shelter can be put to varieties of uses such as, warehouse, community gathering centre, to benefit the local masses. These uses are likely to minimize the conflict between government agencies and local people during acquisition of land for building the flood shelters.

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