Flood risk assessment of Panchganga River (Kolhapur district, Maharashtra) using GIS-based multicriteria decision technique

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Flood hazard causes great loss to lives and properties leading to disturbance in human society. Flood is the single most hydrometeorological hazard causing substantial losses. To gain better understanding of the flood phenomena especially for planning and mitigation purposes, flood risk analysis is often required. For the present study, the middle part of Panchganga river of Kolhapur district, Maharashtra was selected. The main objective of the present study was to evaluate the potential flood risk areas of Panchganga river using GIS-based multicriteria decision analysis. The flood scenario across the Panchganga river was analysed using RADARSAT SAR data of 5 August 2005. To remove the speckle of SAR image, a median filtered technique was used. Thresholding technique was applied on RADARSAT SAR data to segregate flooded areas from non-flooded areas. Factors considered for evaluation of the flood risk analysis were flood layer, elevation, infrastructure and land use/ land cover analysis. The spatial multicriteria analysis with ranking, rating and analytical hierarchy process (AHP) method was used to compute the priority weights of each criterion. Accuracy assessment reveals that AHP is the most accurate technique to assess flood risk of Panchganga river.

Keywords: Flood risk, multicriteria decision, photogrammetry, Radarsat SAR data.

IN many parts of the world, flood is a common phenomenon and it invades river plains to become a serious natural hazard. The Indian sub-continent, due to its unique geo-climatic conditions, is quite vulnerable to natural hazards like flood. During 1994–2004, Asia accounted for one third of 1,562 flood hazard worldwide killing nearly 60,000 people[1]. After Bangladesh, India ranks second with respect to flood events and it accounts for one-fifth of global death count due to floods. According to the National Flood Commission, around 4 lakh sq. km of land in India is highly vulnerable to floods, and an average of 1.86 lakh sq. km of land is affected annually. The annual average affected crop area is approximately 3.7 lakh sq. km.

Every year in India, one third of the area is inundated due to overflowing of rivers. As per the working group of Planning Commission on Flood Control Programme, the total flood prone area of our country is about 4.56 lakh sq. km (ref. 2).

Flood inundation in rural India is mainly associated with large scale loss in agriculture production, loss of livestock and sometimes loss of human lives[3]. Human activities in the upstream section of the river system are mainly responsible for enhanced size and frequency of flood[4]. Flood risk is defined as the 'combination of probability of a flood event and of the potential adverse consequences for human health, the environment, culture heritage and economic activity associated with a flood event'[5].

Remote sensing and GIS are extremely useful and powerful tools in hazard management. Satellite data can provide hazardous footprints with greater accuracy, which are useful for assessing or monitoring the impact of hazard and mitigate flood activities. Remotely sensed data (optical and microwave) can be used effectively for quickly assessing severity and impact of damage due to flooding. In the past two decades, various studies have been carried out using remote sensing data to assess and detect flood inundation areas and to assess the dynamics behaviours of floods.

Two distinctive areas of research, GIS and multicriteria decision making (MCDM) can benefit from each other. GIS techniques and procedure have an important role to play in analysis of MCDM problems through automating, managing and analysing spatial data for decision making. MCDM approach offers various techniques and methods to analyse end-users preference and to integrate them into GIS-based decision making.

Otsubo *et al.*[6] have used RADARSAT-SAR images for mapping of inundated areas around the Lower Mekong basin. Time-series flood maps have been developed to assess flood damage. The analysis reveals that time-series inundation images can be used to create maximum inundation flood maps through overlaying method. Wilson and Rashid[7] have delineated flood boundaries of the 1997 Red River Valley flood with RADARSAT images. They compared hydrologic characteristics with RADARSAT images and observed some inconsistencies between the

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hydrologic regimes of the flood and areal extent of flooding images. Sharma *et al.*[8] have prepared village-wise flood risk index map for the Naogaon district of Assam state by using multi-temporal satellite data. Flood hazard was integrated with land use/land cover, infrastructure, and population data by specifying weightage for individual class and by considering village as a reference unit. The analysis reveals that GIS environment is quite capable of generating flood risk maps. Sinha *et al.*[9] have used multi-parametric approach of analytical hierarchy process (AHP) to assess flood risk of Kosi river basin. The hydrological analysis of the basin was integrated with a GIS-based flood risk mapping. Parameters like land cover, topographic, social (population density) and geomorphological were integrated with analytical hierarchy process to generate a flood risk index (FRI). Finally, the flood risk map was validated with long-term inundation maps.

Flood devastation is increasing in this region due to rapid increase in population and human activities. In 2005, 107 villages were heavily affected by flood and 27 villages completely marooned by flood water. During that period, 40,000 people were shifted to relief camps and 26 human casualties were reported. Agricultural area (520 sq. km^2) of Kolhapur district was also inundated as per state government report.

The stream flow data and rainfall analysis of Panchganga river for the last fifteen years (2000–2015) show that the rate of discharge on 9 September 2011 with 68,109 cusec was the highest at Rajaram river gauging station and on 26 July 2005, this region received the highest amount of rainfall within 24 h which was about 210 mm at Wadange station. The main impacts of floods are damage to property, infrastructure, and disruption to social and economic activities.

At present, 133 villages are prone to flood. The problems related to flooding have greatly increased in Panchganga basin, and there is a need for effective modelling to understand the problem and to mitigate its disastrous effects. The main limitation of flood risk analysis is the generation of accurate terrain information and identification of inundated areas during the event. Cartosat stereo data with 2.5 m resolution can only provide vertical accuracy up to 6 m.

The main objective of the present study is to identify potential flood risk areas of Panchganga river using GIS and Multicriteria decision techniques.

Study area

The study area (Figure 1) lies between 16°25′–16°55′N and 74°5′–74°30′E. This catchment area covers part of Karveer, Hatkanangle and Shirol tahsils of Kolhapur district. The total area of the study region was 615 sq. km. The area has diversified physiography with a complex geological structure. Geologically, the region belongs to Deccan Trap Formation which overlies Kaladgi beds. Underlying Kaladgi and Dharwar group of rocks may have been exposed because of large scale erosion of the lava-beds along river valleys[10].

Database and methodology

For the present study, a number of different data sets were used to carry out flood risk assessment. For base map preparation, the Survey of India toposheets on 1 : 50000 scale were used. These toposheets and digital satellite data were geometrically rectified and georeferenced with the help of ERDAS imagine software by assigning WGS 1984/UTM Zone 43 N projection system. Village boundaries were demarcated using toposheet. Roads were digitized with the help of PAN merge LISS-IV data.

SAR data makes interpretation and classification more difficult. To remove the speckle of SAR image, a median filtered technique was used. It was geometrically corrected with toposheet by defining the projection system. The value of backscatter of water pixel ranges between –17 and –35 db. Thresholding, the most accurate techniques, was used to segregate flooded areas from non-flooded areas. This flood layer was used with village and road network for overlay analysis to identify the area under inundation.

LISS-IV data of IRS P6 dated 15 December 2014 was used with Cartosat PAN (1–23 March 2007) image to improve spatial resolution. The image was classified with visual classification techniques to prepare land use/land cover map of the study area.

Digital elevation model is the finest tool for visual and mathematical analysis of topography, landscapes, land forms and modelling of surface processes. Cartosat-1

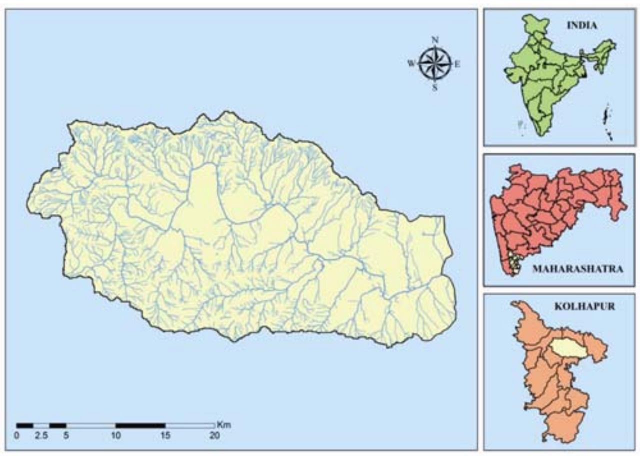

Figure 1. Location map of study area.

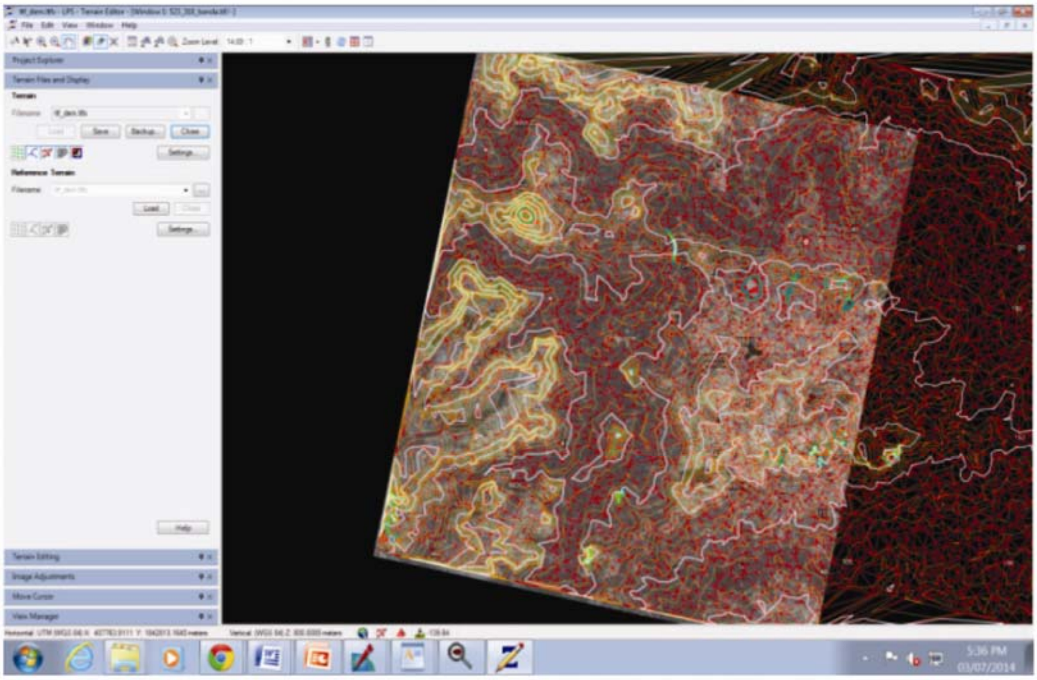

Figure 2. DEM extraction and editing.

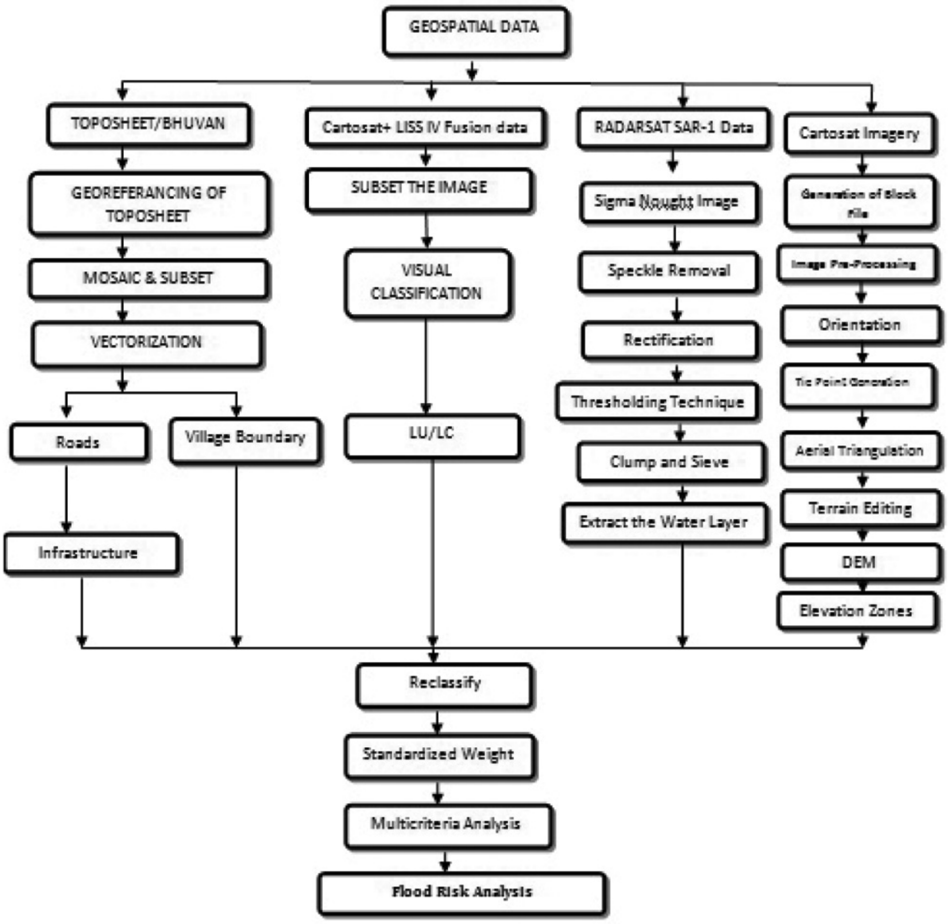

Figure 3. Methodology.

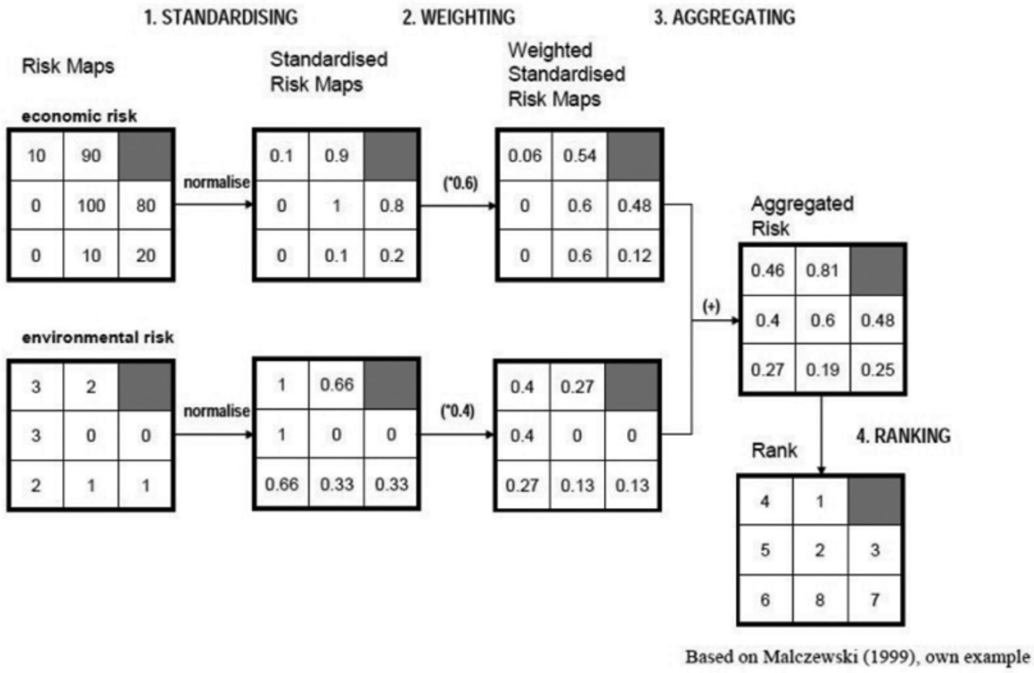

Figure 4. MCDA-approach for flood risk analysis.

stereo images were used in the present study to generate DEM up to 7 m vertical accuracy. Three Cartosat-1 scenes were acquired from NRSC, Hyderabad of 1–23 March 2007 time period. To collect GCPs, south DGPS instrument was used with static surveying techniques and corrections obtained in post-processing mode. These collected GCP datasets were used to refine the orientation of the images and to improve the vertical and horizontal accuracy of DEM. Interior and exterior orientation of stereo pairs was performed. Image matching was completed to check correspondence between two images in the stereo model. Ground coordinates were established for all generated tie points.

However, RMSE error was more than one pixel. Those points with higher error were adjusted or removed and the triangulation process was then performed. Epipolar images were generated after the process of triangulation. These images were kept as background in 3D environment for DEM editing process (Figure 2). The LPS Terrain Editor facilitates verification, visualization and editing of DEM. Breaklines were used to show changes in topography in terms of smoothness and continuity. Hard and soft breaklines were added to improve the quality of DEM. Hard breaklines were used to demarcate ridges, streams and valleys and soft breaklines were used to mark roadway. Finally, DEM was generated in LPS environment to define elevation zones.

The generated different datasets are considered as an input for multi-criteria analysis. All inputs were preprocessed and standardized in accordance with criteria set to develop flood risk analysis. Weights were generated for each layer by using ranking, rating and AHP method. Final risk maps were prepared by aggregating all these layers as per the above given MCDA approach (Figures 3 and 4).

Finally accuracy assessment of generated flood risk map was carried out with the help of ERDAS Imagine software and GPS based field techniques.

Results and discussion

Flood risk is basically determined as a result of probability and consequences[11]. Accurate information on flood inundation and flood zonation is essential for sound planning and management of urban and rural land. It also provides the base line data required for proper understanding of flood phenomena. This study will hopefully yield valuable information for analysis of flood hazard. It would be of great use to planners and administrators to resolve the conflict between human and functioning of river system.

Optical sensors are unable to penetrate through clouds. Therefore, it is necessary to see an alternative way to tackle such problems. Synthetic Aperture Radar (SAR) is the most effective sensor as it can penetrate through clouds and detect the flood inundation area. In SAR, the calm water shows least backscattering values among the natural objects in microwave region. Calm water and completely submerged land covers under water have the same backscattering range[12,13]. RADARSAT image

(Figure 5) of 5 August 2005 was used to generate flood inundation map. RADARSAT image was geometrically and radiometrically corrected. Then, DB values for land and water were observed for the image. Threshold values for water pixel ranges between –17 and –35 db which are being used to extract the water pixel. The erdas modeller (Figure 6) was used to extract the water pixel to generate flood map.

Figure 5. RADARSAT-SAR Image.

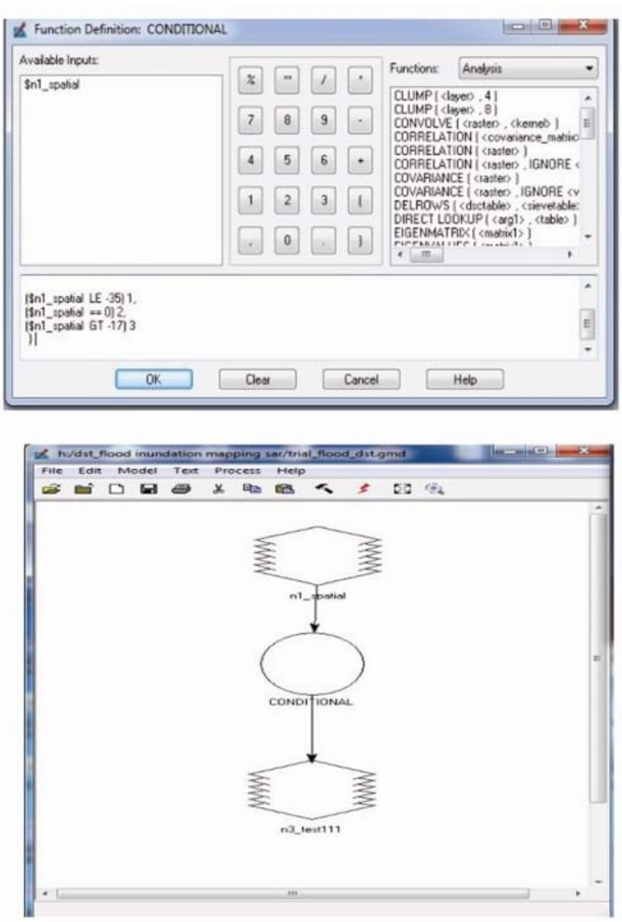

Figure 6. Model used in Erdas Modeller to extract the water pixel from the RADARSAT-1 imagery.

Elevation data generation

DEM analysis reveals that the minimum and maximum elevation of the region is 550 and 957 m respectively. Vertical and horizontal accuracy of generated DEM is about 6 and 3 m respectively. North western and southern part (Figure 7) of the catchment area is of high gradient and it is dominated by hills with rugged topography and the plain surface is towards the eastern part.

Land use/land cover analysis

LU/LC analysis is quite crucial for various natural resource management, planning and monitoring programmes. According to the LU/LC analysis (Figure 8), the area of settlement is 84.95 sq. km while the area of agriculture is 383 sq. km. The remaining area is barren and grass land in which barren land covers 136 sq. km and grass land covers about 3 sq. km. Water bodies have an area about 7.57 sq. km. Infrastructure like major and other roads plays an important role in mitigation during flood period. This infrastructure data (Figure 9) was generated from LISS-IV images.

Multicriteria decision technique

Four indices were generated and then reclassified and standardized by assigning weightage for each indicator. The weight given to a criterion indicates its relative importance compared to other criteria or, more precisely,

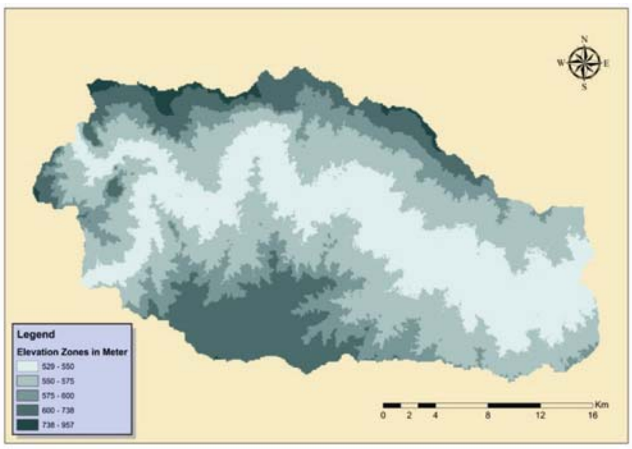

Figure 7. Elevation map of Panchganga basin.

the relative importance of a change of a criterion from lowest to highest possible score compared to a similar change of the other criteria[14]. The degree of influence of that criterion in the overall evolution is determined by the assigned criterion weightage. Aggregation procedure was accomplished through criterion weights. Thus, the assignment of weightage was the most sensitive part of the whole MCA method with concern to its output. Hence, it is also described as the most time consuming and controversial part of MCA, especially when several decision makers are involved[15]. For the present study, ranking, rating and AHP methods were used.

Ranking method

In this method, the importance of weight can be simply assessed by arranging them in rank order. Thereby, every indicator is ranked as per decision-maker's preference. Either straight ranking (the most important is = 1, next comes = 2, etc.) or inverse ranking (least important = 1, next least important = 2, etc.) can be used. Once ranking is established for a set of criteria, several producers for generating numerical weights from rank order information are available. Rank sum weights are calculated according to the formula

$$W_i = \frac{n - r_j + 1}{\sum(n - rk + 1)},$$

where W_i is the normalized weight for j criterion, n the number of criteria under consideration ($k = 1, 2, \ldots, n$), and r_j is the rank position of the criterion.

Each criterion is weighted ($n - r_j + 1$) and then normalized by the sum of all weights, that is, $\sum(n - rj + 1)$. Therefore, the ranking method estimated weight should be considered as an approximation. Nevertheless, such ranking approaches produce better results than equal weighting at the cost of little extra elicitation effort[16].

Flood risk is basically defined by probability and consequences. From probability point of view, flood layer and elevation zones are considered and with respect to consequences, land use/land cover and infrastructure have been considered. First priority was given to flood layer followed by the remaining layers as per Table 1. Flood layer has 0.4 weightage followed by elevation with 0.3 weightage. Flood risk analysis (Figure 11) was carried out to demarcate the area into high, moderate and low zone. Analysis reveals that as per ranking method 7.47%

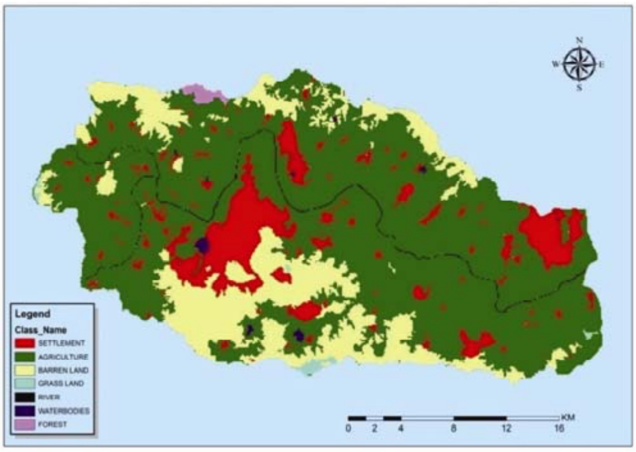

Figure 8. LU/LC map of Panchganga basin.

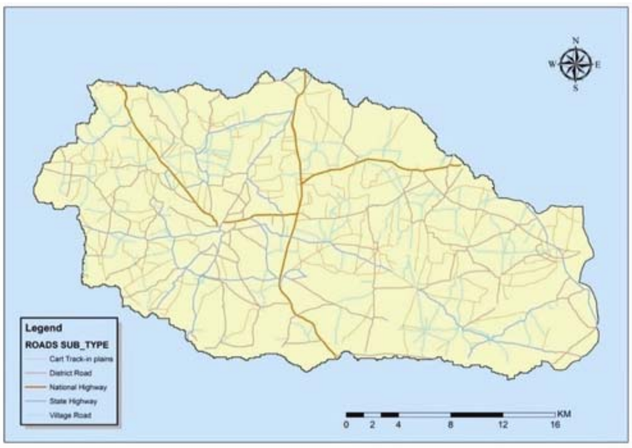

Figure 9. Infrastructure map of Panchganga basin.

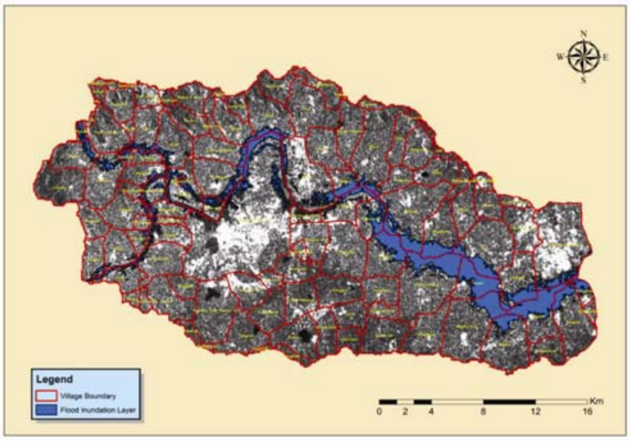

Figure 10. RADARSAT-SAR image of flood inundation mapping.

Table 1. Weightages assigned by ranking method

Ranking name	Rank	Weight	Normalized weight
LU/LC	3	4 – 3 + 1 = 2	2/10 = 0.2
Infrastructure	4	4 – 4 + 1 = 1	1/10 = 0.1
Elevation	2	4 – 2 + 1 = 3	3/10 = 0.3
Flood layer	1	4 – 1 + 1 = 4	4/10 = 0.4
Total		10	

area of the study region falls in high risk zone and 21% area in moderate risk zone.

Rating method

In this method, the decision-maker has to estimate weights on the basis of a predetermined scale. The criteria should not to be weighed without knowing their specific unit and range in the risk within this approach[14]. Otherwise, the weights would be meaningless. For this method, flood layer was given the highest rank and

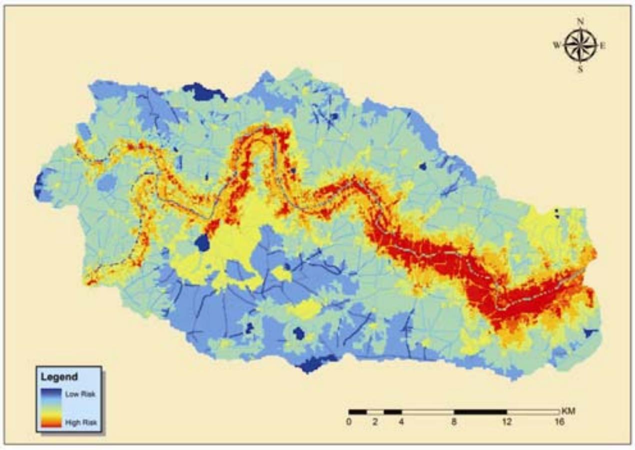

Figure 11. Flood risk map based on ranking method.

elevation data came next, least rank was given to infrastructure (Table 2) and the final map (Figure 12) was prepared.

AHP

AHP calculates the required weights associated with the relevant criterion map layers with the help of a preference matrix in which the identified relevant criteria are compared with each other on the basis of preference factors[17]. AHP is widely used in MCDA to obtain the required weights for different criteria[18–20]. It has been successfully employed in GIS-based MCDA since the early 1990s[21–25].

Preference structure of decision makers can be easily defined through pairwise comparison approach. This is the biggest advantage of this method. The present approach is helpful to identify and evaluate potential flood risk areas of Panchganga river. The weightage was obtained (Table 3) by pairwise comparisons and the consistency was evaluated among their relationship.

As seen in Figure 13 the entire study area was broadly categorized as high, moderate and low flood risk areas. About 63 sq. km area of study area come under high flood risk area. This area includes about 17 villages such as Kolhapur, Rukadi, Pattan kodoli, Rangoli, Rendalm, etc.

In the case of agricultural land, about 42 sq. km is flood vulnerable area. In addition, there were two

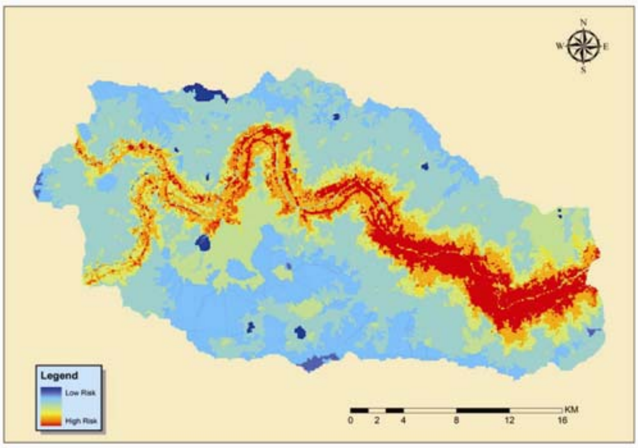

Figure. 12. Flood risk map based on rating method.

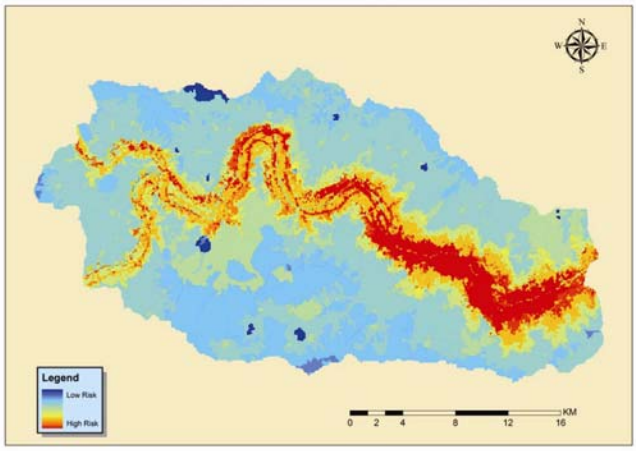

Figure 13. Flood risk map based on AHP method.

Table 2. Weightages assigned to flood hazard by rating method

Rating name	Rank	Weight	Normalized weight
LU/LC	50	50/4 = 12.5	12.5/62.5 = 0.2
Infrastructure	20	20/4 = 5	5/62.5 = 0.08
Elevation	80	80/4 = 20	20/62.5 = 0.32
Flood layer	100	100/4 = 25	25/62.5 = 0.4
Total		62.5	

Table 3. Weightages assigned to flood hazard by AHP method

	Flood layer	Elevation	Infrastructure	LU/LC	Weight
Flood layer	1	2	4	3	1.909341
Elevation	0.5	1	2	2	1.026099
Infrastructure	0.25	0.5	1	1	0.513049
LU/LC	0.33	0.5	1	1	0.551511

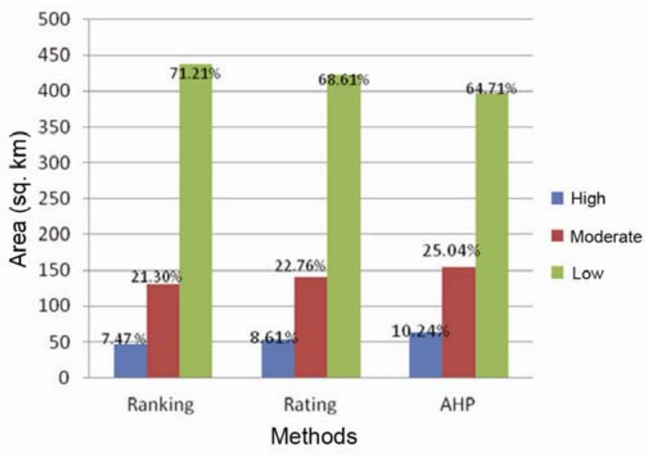

Figure 14. Comparative analysis of result in different methods.

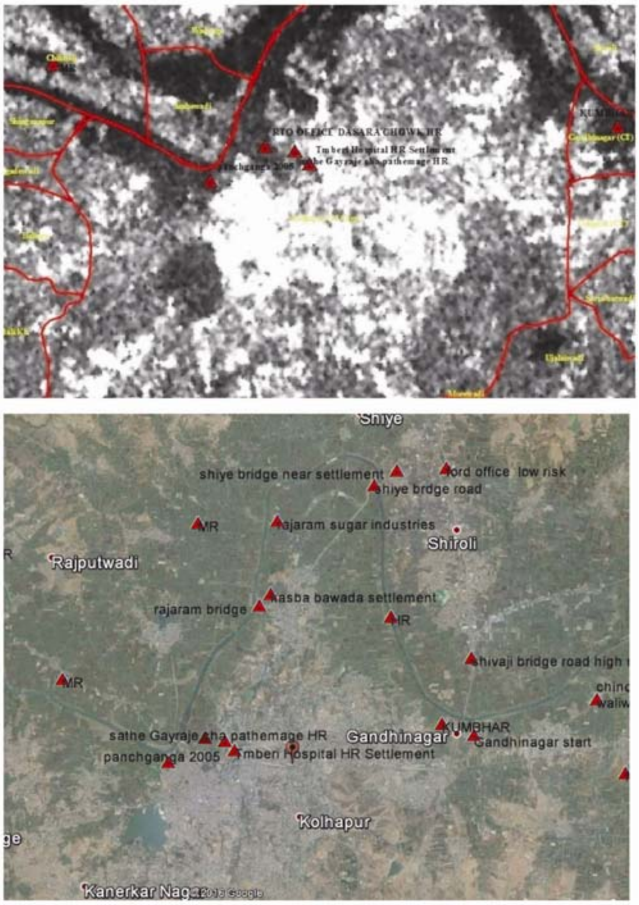

Figure 15. GPS dataset for accuracy assessment.

Table 4. Result of accuracy assessment

Method	Accuracy assessment (%)
Ranking	72.86
Rating	74.53
AHP	79.36

national highways (Mumbai–Bangalore and Ratanagiri) and three state highways. Sixteen district roads and some village roads were included in high flood risk zone.

However, according to the result obtained from AHP, 154 sq. km area has moderate flood risk area. Moderate flood risk area includes nearly 127 sq. km agricultural land of 31 villages. Major national highways, state highways, district roads and some village roads were also included in moderate flood risk zone.

All the above mentioned infrastructure, agriculture and settlement areas are located in high flood risk zone, which immediately requires proper zonation and planning to avoid the various kinds of losses during a flood.

In this study, ranking, rating and AHP method were compared (Figure 14) with each other. These form a promising and powerful tool, but an equally important ingredient of decision making process is the ability of the decision maker to select and combine in the most appropriate way the several criteria, depending on the nature of the objective[26]. The three methods have been assessed through GPS based field techniques and ancillary data of previous events. A total of thirty four points (Figure 15) were collected from the study region by applying stratified random technique and each point categorized as high, moderate and low flood risk point as per geo-spatial conditions. Finally, accuracy assessment was performed in Erdas imagine software. The result (Table 4) shows that the overall accuracy of AHP method is quite higher with 79.36% as compared to other methods like rating and ranking. Therefore, analysis reveals that AHP method is much more accurate and reliable for flood risk analysis for the present study.

Conclusion

It is clear that with the help of GIS and multicriterion techniques, useful information for flood risk analysis can be acquired. Comparative analysis shows that the area under high and moderate risk increases in AHP as compared to other methods.

According to AHP analysis, high flood risk area includes nearly 17 villages. In the case of agricultural land, about 42 sq. km is flood vulnerable area. Also, some major roads in the study area come under the high flood risk zone. All the above mentioned infrastructure, agriculture and settlement areas are located in high flood risk zone and it immediately requires proper attention to avoid socio-economic losses. The theoretical base of ranking leads to inaccurate weights but rating method required little effort. For more precise results, pairwise comparison method is the ideal option.

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