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Flood Hazard Zonation Mapping using Geoinformatics Technology; Bennihalla Basin, Gadag and Dharwad District, Karnataka, India

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Abstract **– Flood is an unpredictable and unexpected phenomenon occurring from time to time in river basins and natural drainage systems, which not only damages the lives, natural resources and environment, but also causes loss of economy and health. Using modern technique it is essential for proper understanding, utilization and management of this precious natural resource. With the advent of powerful and high-speed personal computers, efficient techniques for flood hazard have evolved, of which Geoinformatics technology includes RS (Remote Sensing), GIS (Geographic Information System) and GPS (Global Positioning System) are of great significance. In the present study, an attempt has been made to delineate flood hazard prone areas in the Bennihalla basin, Gadag and Dharwad district of Karnataka, using Geoinformatics technology. The thematic layers considered in this study are lithology, landform, drainage density, recharge, soil, land slope and surface water body, which were prepared using the satellite data, toposheets, google Earth imagery and conventional data. All these themes and their individual features were then assigned weights according to their relative importance in flood occurrence and the corresponding normalized weights were obtained based on number of causative factors including annual rainfall, size of basin, side slopes of basin, gradient of river and stream, drainage density, type of soil, land use & land cover, communication line and infrastructures. The population densities were considered for rating the degree of hazard and risk. The thematic layers were finally integrated using Auto Desk MAP and MapInfo GIS software to flood hazard zonation map of the study area. Thus, different flood hazard zonations were identified, namely 'high', 'moderate' and 'low'. Finally, it is concluded that the Geoinformatics technology is very resourceful and useful tool for the flood hazard zonation mapping.**

Keywords - Flood; Geoinformatics; Drainage; Basin; Rainfall

I. INTRODUCTION

Floods are considered as recurrent phenomenon in many parts of the India, causing loss of lives, public property and bringing inexpressible sadness to the people, especially those in the rural areas. There is also a larger economic impact, as they derail economic activities, thus affecting growth of the country. The government has allocated at outlay of XII five year (2012-2017) plan, ` 57,575.00 crores for the country and for Karnataka ` 15,000.00 crores for relief measures and other disaster action [1].

Basavaraj Hutti and Nijagunappa R; Venkata B. G. and Rajiv Sinha has tried to identify areas of risk and prioritize their mitigation or response efforts in the natural disaster hazard areas in the Ghatapraba river basin, north Karnataka, India [4] and Kosi river basin, north Bihar, India [11] in a GIS environment. The primary data used for this study were obtained from the digital remote sensing satellite imagery IRS-1D, LISS III for 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. They have prepared flood hazard index. This study formulates an efficient methodology to accurately delineate the flood hazard areas in the lower Kosi river basin, north Bihar, India [11]. 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.

Geoinformatics techniques in flood hazard management in north Indian. As data management and map representations tools of GIS helps in exploring new potions its integration with remote sensing images, enhance the ability for preparing flood hazard map and forecasting. The restraints like Geoinformatics technological knowledge requirements, hardware and software requirements, thus GIS can be very useful to minimize flood hazard [2] [8] [9].

Natural resources and hazard mapping which has vital component for appropriate land use planning in disaster 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 or response efforts. An efficient methodology is used to accurately delineate the decision making areas in the Ghatapraba basin [3].

However it is essentially a natural phenomenon, overexploitation of natural resources by man increases disaster rate year by year [5]. Realizing that its actual and potential consequences are serious and will increase every year, the government, instead of focusing on relief action as before, set up a plan for preventing and /or mitigating this disaster. This paper presents the study of flood hazard zonation mapping procedures for Bennihalla basin, Gagad and Dharwad districts of Karnataka, India [6] [7].

The research work has been initiated to understand the general topography, nature of soil and type of vegetation in the study area. Demarcate the area of vulnerability and appreciate the effect of resultant flood, to prepare a flood hazard zonation map through Geoinformatics technology. To demarcate the river overflow and breaches that lead to free flow of water into the rural as well as urban areas and damages caused to men and materials using GPS and integrate with RS-GIS softwares. To design a flood zonation map using the Geoinformatics and spatial technology and suggest a flood control and disaster reduction model taking all the detrimental indicators for flood situation, which can reduce the flood disaster in the study area.

II. STUDY AREA

The Bennihalla basin is one of the important tributary of Malaprabha river which is main tributary of Krishna river. The investigated area lies in between north latitudes 15°04'27" and 15°50'23" and east longitudes between 74°58'43" to 75°38'44". The study area is surrounded by Rona, Gadag and Shirhatti taluks in the east, Dharwad and Hubli taluks in the west. Shiggaon taluka in the south west and Nargund and Parasgad taluk in the north. Navalgund taluk in the Center. The study area falls in the semi-arid region. The physiographical of the study area is characterized by gently undulating terrain with alternating ridges and slope elevation ranges from 600 m above MSL. The climate of the study area is generally pleasant in the entire basin area. April and May are hottest months with average daily maximum temperature of about 38°C and average daily minimum temperature of about 20°C. The southwest monsoon sets in by June and ends by the middle of October. During this period the basin receives above 50% of the annual rainfall and the climate will be generally humid. Geologically, the study area is underlain by Dharwar schistose rocks and granitic gneiss. The northeastern part of the study area is occupied by granitic gneiss, which are mainly covered by thick black cotton soil, shales, phyllites and altered grey wackes of schistose rock are covered the rest of the area. The schistose formations strike in NNW-SSE direction and are dip varying from 35° to nearly vertical. Granitic gneiss strike in NNW- SSE direction and is highly weathered. The index map of the sub-basin is shown in "*Fig. 1*".

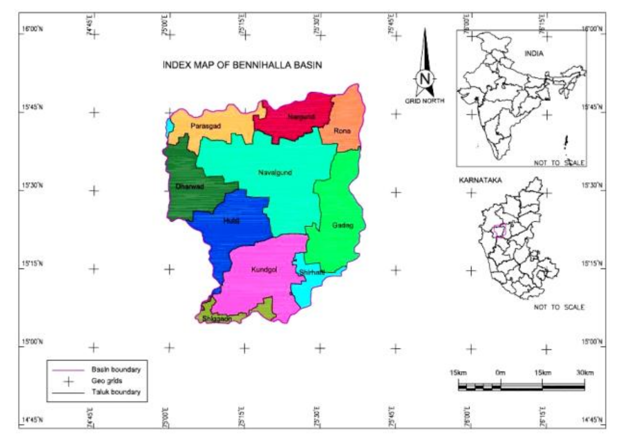

Figure 2: Index map of Bennihalla basin

III. MATERIAL AND METHODOLOGY

The following materials are used in study area:

- Satellite images (IRS-1D, LISS-III)
- Google Earth images
- Topographic (map scale)
- Thematic maps (soil, LU/LC, geology, drainage network, slop, DEM, contours, etc.)
- Hydrogeological data and maps
- Garmin GPS - eTREX
- Geoinformatics softwares (MapInfo, AutoCAD, Google Earth, ERDAS)

The detailed methodology flow chart to be adopted for the study is given below at "*Fig. 2"*.

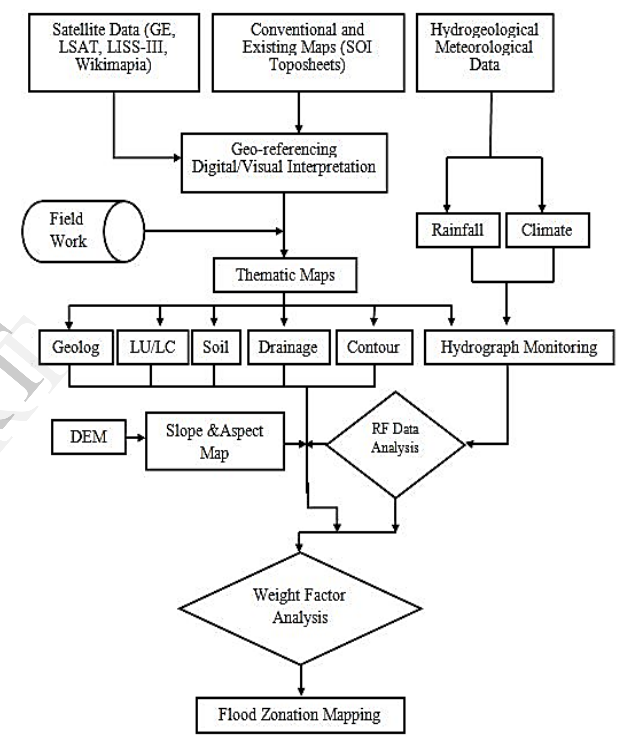

Figure 1: Research methodology flow chart

IV. Data Analysis and Compilation

A. Generation of thematic layers

The flooding hazard zones were identified by interpreting in the study area, a multipara metric dataset comprising satellite data, google Earth data and conventional maps including survey of India (SOI) topographic sheets was used. IRS-1D LISS-III data collected from the national remote sensing center (NRSC), Hyderabad, India has been used for the preparation of thematic maps of drainage density and surface water body etc. All the 11 SOI toposheets (D43D1, D43D2, D43D3, D43D4, D43D5, D43D6, D43D8, D43D9, D43D10, D43D11, 48M5 and 48M7) covering the study area at 1:50,000 scales were scanned separately and all the scanned images were rectified and geometrically corrected. These images were then mosaicked to form a single image and transferred into MapInfo software to prepare thematic layers, namely study area boundary and slope. Further the thematic layers of geology and geomorphology were prepared from existing maps obtained from the natural resources data management system (NRDMS) center. The soil layer was prepared by digitizing the soil map obtained from the Karnataka state remote sensing application center (KSRSAC). Considering the data availability in the study area in the process the Bennihalla basin of each stream networks and river was firstly identified from the topographic map and delineated. After that flood plain lower terrace plain in each sub-basin were identified and delineated by considering both soil map and LU/LC map. Finally each flooding hazard zone was transferred and digitized coverages were spatially organized in the Geoinformatics environment with the same resolution and coordinate system. The checking of these spatial maps was done with respect to other database layers by the overlaying technique and refined mutually as part of standardization of the database. The errors due to digitization and miss mapping were removed in this process. In the present study, the cloud free digital image of IRS-1D LISS-III (linear imaging self-scanner) sensor having 23.5m spatial resolution was classified using ERDAS IMAGINE v8.6 digital image processing software. Initially the satellite image was registered with the base map after matching some of the identifiable features such as crossing of roads, railways, canals, bridges, etc., on both the base map as well as on the satellite image and topographic map of the same scale and stored in the Geoinformatics data base of the computer system.

B. Assessment of the flood hazard zone

Assessment of flooding in each hazard zone in Bennihalla basin was done by considering certain relevant factors. Their significance was indicated by weighting. The causative factors taken into account for this study include:

- Size of the Bennihalla basin
- Annual rainfall sum
- Slopes and aspect ratio of the basin
- Gradient of stream networks in the Bennihalla basin
- Drainage density of the basin
- Soil type in the basin
- Land use and land cover of the basin,
- Infrastructure and communication lines impacts of the basin.

Theoretically, there are still more causative factors, for example daily rainfall, the hydrograph of the main stream networks of the basin, etc.

According to Pramojanee et al. [10], the weight of each factor was given on the basis of its estimated significance in causing flooding. The weight of each factor is as shown in table - I:

TABLE I. ASSIGNED WEIGHT FACTOR CLASSES

Sl. No.	Weight of factor	Assigned weight
1	Annual rainfall	10
2	Size of basin	9
3	Slopes and aspect ratio of the basin	8
4	Gradient of stream networks in the basin	7
5	Drainage density	6
6	Land use and land cover	3
7	Soil type	2
8	Infrastructure and communication lines	1

Further each factor was divided into a number of classes and each class, weighted according to the estimated significance for causing flooding. The maximum weight for each class of every factor is 10 whilst the minimum is 2 and the total weight used for considering the rate of probability of flooding is:

$$T_w = W_f * W_c \qquad (1)$$

Where, T_w is total weight of each factor, W_f is factor weight and W_c is weight of factor class.

C. Rainfall and climate

The Bennihalla basin falls under semi-arid region of the state and it is categorized as draught prone and flood hazard area. The normal rainfall is 613 mm. The north-east monsoon contributes nearly 24.8% and prevails from October to early December, and about 54.7% precipitation takes place during south – west monsoon period from June to September. Remaining 20.5% takes place during rest of the year. In the Bennihalla basin from December to February month is winter season, during April to May temperature reaches up to 42°C and December and January temperature will go down up to 16°C. The standard deviation of rainfall in the Bennihalla basin varies from 1.3 to 263.5mm from west to east. The average standard deviation for the Bennihalla basin is about 146 mm. South west monsoons is dominant followed by north east monsoon. The classes distinguished for annual rainfall factor as shown in table II.

TABLE II. RAINFALL OF BASIN

Class	Rainfall (mm)	Weight
1	> 600	10
2	500 – 600	8
3	300 – 500	6
4	< 300	2

D. Size of basin

The Bennihalla administrative convenience, the basin is divided in to 10 taluks (Rona, Nargund, Navalgund, Gadag, Shirahatti, Kundgol, Shiggaon, Hubli, Dharwad and Parasgad) with total of 389 villages. The Bennihalla sub basin is a part of Malaprabha basin, The total area of Bennihalla basin 4,417 km^2 covers and the total perimeter is 320.1 km. A Bennihalla river flowing parellel to the Malaprabha river and joins the Malapraba river at Ron taluk which is located north eastern part of the Bennihalla basin. A map showing administrative details of the Bennihalla basin is presented as shown in *"Fig. 3"*. The size of basin factor is classified as shown in table III.

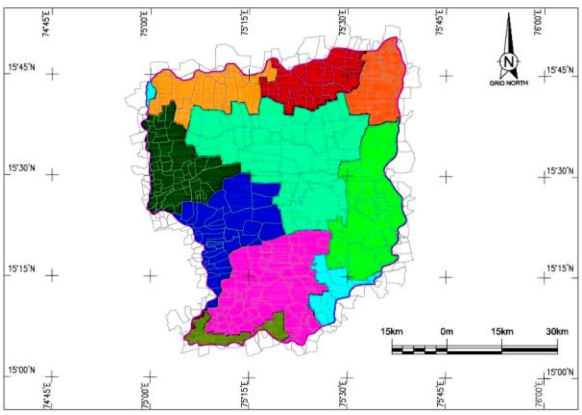

Figure 3: Size of Bennihalla basin

TABLE III. SIZE OF BASIN

Class	Size (km^2)	Weight
1	> 4000	10
2	2500 – 4000	8
3	1000 – 2500	6
4	500 – 1000	4
5	< 500	2

E. Land slope and aspect ratio of the basin

A land slope map prepared from the satellite imagery, google Earth images and SOI toposheets of the study area. The area of the basin is plain to gently undulating terrain varies in altitude from 508 m – 740 m MSL. Bennihalla river sub basin is sloping towards north east direction. Master slope is 1.10 m per km where as Bennihalla river has 0.4 m per km slope. The Bennihalla river shows a seasonal regime varying from lean sluggish flow during summer to torrential muddy flow during the monsoon. The slope percentage in the area varies from 0 to 25%. On the basis of the slope the study area can be divided into five slope classes. The area with 0 to 1% slope falls in the 'very high' category due to the nearly flat terrain and relatively high infiltration rate. The eastern portion of the study area (65% of the total area) falls under this category. The area with 1–2% slope is considered as 'high' for floods due to slightly undulating topography with some run-off. Apart from a small portion in the extreme western portion of the basin, the entire central portion and the southern portion (35% of the total area) fall under this category. The area with a slope of 3–5% causes relatively high run-off and low infiltration, and hence is categorized as 'moderate'. The fourth (5–10%) and fifth (10–25%) category are considered as 'very low' due to higher slope and run-off is shown in *"Fig. 4"*. It's shown in table IV.

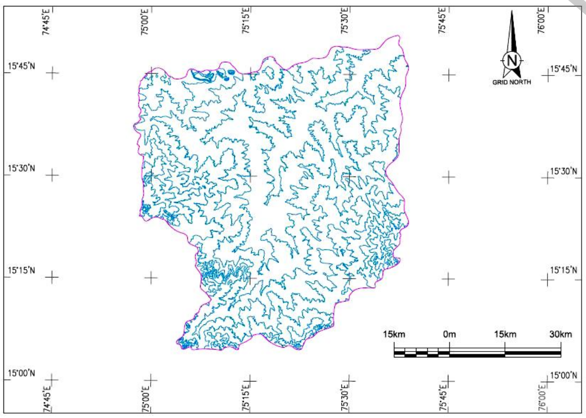

Figure 4: Land-aspect ratio map of Bennihalla basin

TABLE IV. LAND SLOPE

Class	Slope (%)	Weight
1	10-25	10
2	5-10	8
3	3-5	6
4	2-3	4
5	1-2	2

F. Gradient of stream networks in the basin

Calculating the gradient of the main stream of basin:

$$\textbf{River and stream gradient} = (H_2 - H_1) * 100\ D \qquad (2)$$

H_1 = altitude of the highest point of the slope at the upper river or stream channel (in meters), H_2 = the altitude of the outlet of the river or stream (in meters), D = Distance of H_1 to H_2 (in meters). The gradient stream network is shown in table V.

TABLE V. GRADIENT OF STREAM NETWORK

Class	Gradient (%)	Weight
1	> 5	10
2	4 – 5	8
3	3 – 4	6
4	2 – 3	5
5	1 – 2	4
6	< 1	2

G. Drainage density

In the present study, since the drainage density can indirectly indicate the overflow of an area due to its relation to surface run-off, it was considered as one of the indicators of flood occurrence. Drainage density measurements have been made for all the micro watersheds in the area and range from 1st to 5th orders. The drainage density map for the study area is shown in *"Fig. 5"*. Based on the drainage density of the micro basins, it can be grouped into four classes. Accordingly these classes have been assigned 'high', 'moderate' and 'low' categories, respectively. Most of the study area (70%) has a drainage density of 1st to 2nd orders. The drainage density of the basin is calculated as follows and shown in table VI.

$$D_d = L / A \qquad (3)$$

Figure 5: Drainage density map of Bennihalla basin

D_d = Drainage density of basin, L = Total length of drainage channel in basin (km.), A = Total area of basin (km^2)

TABLE VI. DRAINAGE DENSITY

Class	D_d	Weight
1	> 1	10
2	1 – 3	8
3	3 – 5	5
4	< 5	2

H. Land use and land cover

Considering the land use map complied from satellite imagery of the area the class and weight of each land use classes is shown in table VII. In the basin about 80% area is net irrigated, about 3% of the area is covered by forest and net sown area is about 87% of geographical area and the total LU/LC in the basin area is natural forest, cultivable waste, barren current, permanent pasture, net area sown, area sown.

TABLE VII. LAND USE AND LAND COVER

Class	LU/LC	Weight
1	< 10%	10
2	10 – 20%	8
3	20 – 40%	6
4	40 – 60%	4
5	> 60%	2

I. Soil type

It is apparent from *"Fig. 6"* that the majority of the study area is dominated by deep black soil to medium black soils and extends up to 1.80 MBGL (meters below ground level), average being 1.10 MBGL. The constant rate of infiltration in sandy to clayey residuum ranges between 0.5 to 4.5 cm/hr. Phyllitic soils are confined to hilly region, with other soil types covering relatively small areas. The soil description of the basin area is covers with shallow soil, sandy to clayey poorly

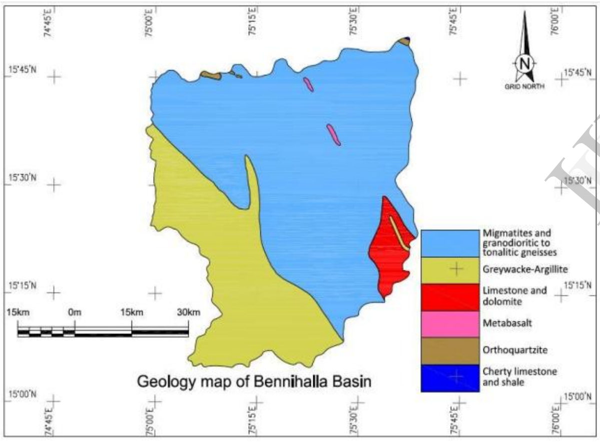

Figure 6: Soil and Geology of Bennihalla basin

drained soil and soil with high percentage of silt and very fine sand particle as shown in table VIII.

TABLE VIII. SOIL TYPE

Class	Soil type	Weight
1	> 60%	10
2	40 – 60%	8
3	20 – 40%	5
4	< 20%	2

J. Infrastructure and communication lines

National highways, state highways, metal roads, black top roads, check dams, bridges, railway tracks and other infrastructure that obstruct the flow of the river and stream promote flooding has infrastructure obstructing the flow direction of stream and river within the flood hazard zone. The classes and weight of each class of this factor are shown in table IX.

TABLE IX. INFRASTRUCTURE AND COMMUNICATION LINES

Class	Infrastructure	Weight
1	> 10 locations	10
2	6 – 10 locations	8
3	3 – 5 locations	5
4	< 3 locations	2

IV. RESULT AND DISCUSSION

The study area thematic maps are prepared based on assigned weight factors and classes in the above said, a map of every causative factor compiled and the weight identified. The data sources used include satellite imagery, topographic map, basin map, soil map, LU/LC map, and climatic data. In the procedure, the occurrence of flooding in each flood hazard zone is estimated from the total sum of the weight of each causative factor considered. To obtain this total sum weight, all of causative factor maps were overlaid.

The total weight for estimating flooding in a particular flood hazard zone = the sum of every causative factor. All of these processes, the compilation of causative factor maps, the overlaying of all maps and the calculation of total weight were obtained by applying MapInfo, AutoCAD, and ERDAS.

Based on the weight of every factor and its class, the maximum total weight of each factor is the result of the multiplication of such factor weight with the weight of its dividing first class. Thus, maximum total weight of the factors rainfall, size of basin, land slope, gradient, drainage density, land use, soil type, and infrastructure are 100, 90, 80, 70, 60, 30, 20, and 10 respectively. The sum of these total maximum weights is 460.

For the total minimum weight of each factor, the same, it is the result of the multiplication of the factor weight with the weight of its lowest class. These are 20, 18, 16, 14, 12, 6, 4, and 2 respectively and the summed minimum total weight is 92.

Considering this the total weight of the flood hazard zone with the highest to be flooded is 460 whilst the lowest is 92. Considering the statistic standard deviation values of the total weight data obtained for the research area, the weight of each class was given as table X:

TABLE X. WEIGHT OF EACH CLASS RANGE

Sl. No.	Class	Weight range
1	High	306 – 460
2	Moderate	155 – 305
3	Low	92 – 154

However, after fieldwork for checking the validity and reliability of the map these statistics were adjusted. When compiling the final flood hazard map the following statistics were considered for identifying the degree of flooding in the identifying flood hazard zone as shown in *"Fig. 7"* and table XI.

TABLE XI. FLOOD HAZARD ZONATION

Sl. No.	Class	Weight range	Basin area in %	Basin area in km^2
1	High	306 – 460	46	2032
2	Moderate	155 – 305	20	883
3	Low	92 – 154	14	619
4	Very low	< 92	20	883

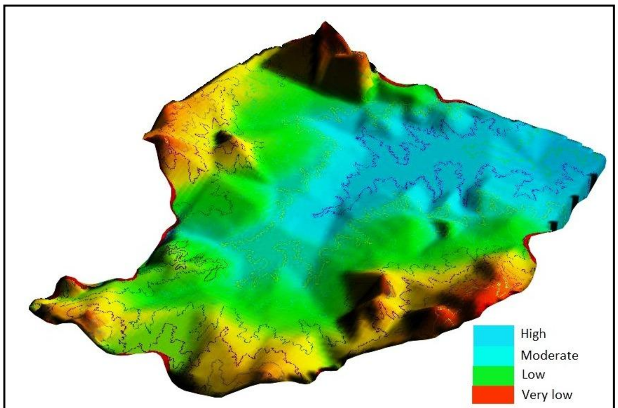

Figure 7: Flood hazard zonation map of Bennihalla basin

This study suggests that about 46 percent of the total area of the province is under a high flooding zone whereas 20, 14 and 20 percent are under moderate, low and very low hazard respectively. The high and moderate hazard areas are mostly in the relatively higher stream networks with high slope gradients and thin vegetation. However, due to the type of use (sheep farm) certain areas on the flat relief plain also at risk. Comparing the moderate and high risk areas identified in this study with the ground truth data obtained from the field work however, it is found that the risk area obtained from the study is about 30 – 40 percent higher than the actual one. This might be due to the reliability of the used data or the number of causative factors considered. It might also be connected with the scale of the map. Nevertheless, a 10 – 15 percent error is still acceptable. Recently, the flood hazard zonation map obtained from this study have been distributed to all provinces concerned to use as basic data for designing flood prevention and mitigation measures.

V. CONCLUSIONS

This study was carried out with the aim of creating a flood hazard zonation map along the Bennihalla river basin, where it passes through the Gadag and Dharwad districts of Karnataka. Geoinformatics technology method was robust, using coordinate and elevation data of the study area and remotely sensed satellite IRS-1D, LISS – III imagery and SOI toposheets, analysis was carried out within MapInfo, ERDAS and AutoCAD. Digital elevation model was generated, reclassified and integrated with imagery of the area to show areas of different flood hazard zonation. Natural barriers exist between the river and the surrounding area, however urban explosion within the past decade and relocation after the Bennihalla basin in 2005 have led to settlement within flood prone areas like Navalgund, Byahatti, Hebsur, Amargol, Arhatti, Kongawad and Nargund have residential buildings, farms and industrial compounds within flood hazard zones.

The primary purpose of producing these kinds of maps is for public dissemination of flood maps which will serve to increase public awareness. The study was to identify flood hazard zones and find out flood vulnerability to settlement, transportation network and risk to human life.

Overall the results of this study demonstrated that the Geoinformatics technology is a powerful tool for assessment of flood hazard zone, based on which suitable locations for floods withdrawals could be identified. Consideration of an adequate number of thematic layers and proper assignment of weights are keys to the success of Geoinformatics techniques in identifying flood zonation maps. Based on the results of this study, concerned decision makers can formulate an efficient flood zonation plan for the study area so as to ensure as this methodology adopted in this study is based on logical conditions and reasoning, it can also be applied in other regions of India or abroad.

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