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Flood Hazard Mapping in Dikrong Basin of Arunachal Pradesh (India)

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Abstract**—**Flood zoning studies have become more efficient in recent years because of the availability of advanced computational facilities and use of Geographic Information Systems (GIS). In the present study, flood inundated areas were mapped using GIS for the Dikrong river basin of Arunachal Pradesh, India, corresponding to different return periods (2, 5, 25, 50, and 100 years). Further, the developed inundation maps corresponding to 25, 50, and 100 year return period floods were compared to corresponding maps developed by conventional methods as reported in the Brahmaputra Board Master Plan for Dikrong basin. It was found that, the average deviation of modelled flood inundation areas from reported map inundation areas is below 5% (4.52%). Therefore, it can be said that the modelled flood inundation areas matched satisfactorily with reported map inundation areas. Hence, GIS techniques were proved to be successful in extracting the flood inundation extent in a time and cost effective manner for the remotely located hilly basin of Dikrong, where conducting conventional surveys is very difficult.

Keywords**—**Flood hazard mapping, GIS, inundation area, return period.

I. INTRODUCTION

INDIA is a flood prone country and is the worst affected by flood in the world after Bangladesh. The occurrence of floods in India is an annual feature. Floods are mainly caused by heavy rain associated with deep depressions (low pressure) and cyclones in areas having inadequate drainage. The tangible and intangible losses due to floods in India are increasing due to speedy growth of population and increased encroachments of the flood plains for habitation, cultivation and other developmental activities.

The chronic flood-prone river basins in India are the Ganga and the Brahmaputra. These Himalayan rivers flowing down the hills cause flood problems in Uttar Pradesh, Bihar, West Bengal, and Assam due to high discharges concentrated during monsoon months (June to September). India accounts for nearly one-fifth of global death count due to floods. About 4 lac km^2 or nearly 1/8th of India's geographical area is flood prone. In a country like India where one part or the other is affected by flood every year, it is very important to plan flood management measures in frequently flood prone areas.

Floodplains and regions near rivers, where social and economic activities take place due to their special conditions, are always in danger of flooding. Determining the amount of flood advance and its height with respect to ground surface elevations, and finding flood characteristics with different return periods (known as "flood zoning") have tremendous importance. Flood zoning is considered a prerequisite for sustainable development within the limits of flood prone rivers, because it determines the type of development, construction criteria, basis for the ecological and environmental effects, and the amount of investment risk. Hence, flood zoning provides a valuable tool to managers and planners.

One definition of a flood is a flow rate greater than common discharge rates in rivers. It has a limited duration and the water overflows the natural river's bed, occupies the lowlands and lands near the rivers and has financial and human damages [1]. The most important factors affecting the intensity and flood return period in each region are: volume and time of upstream surface runoff and river or flood conditions, physical characteristics of watershed (area, morphology), hydrological characteristics of the watershed (rainfall, storage, evapotranspiration), and human activities causing and intensifying the flood flows. Investigations have shown that the cause of flood damages is neither the short-term flood return period or high flood intensity, but over use of flood plain around rivers.

The management methods to decrease flood hazards are divided into structural and non-structural categories. Various types of structural as well as non-structural measures have been taken up to reduce the damages in the flood plains. The structural measures, such as the construction of embankments, levees, spurs, etc. have not proved to be effective in the long run. On the other hand, whereas, the non-structural measures such as flood forecasting and warning, flood plain mapping, flood hazard mapping, and flood plain zoning may prove to be quite effective in reducing losses from floods. Flood zoning using Geographic Information System (GIS) as a non-structural method, is an efficient tool for flood damage mitigation management. GIS technology is a well-established tool used in hydrologic modeling, which facilitates processing, management, and interpretation of all available data. In addition, the concerned authorities can use the method as a legal tool to control and apply management and zoning of lands, plan development, decrease flood hazards and protect the environment.

Remote sensing has emerged as a powerful tool for cost effective data acquisition in a short time at periodic intervals (temporal), at different wave length bands (spectral) and

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covering large area (spatial). GIS allows the combination of remotely sensed data with spatial data forms such as topography, soil maps, and hydrologic variables such as rainfall distribution and soil moisture. The availability of GIS tools and more powerful computing facilities makes it possible to overcome many difficulties and limitations and to develop distributed continuous time models, based on available regional information. Flood zoning studies have become more efficient and less tedious because of the use of GIS technologies, and more accurate because of the availability of remote sensing techniques to validate the results with satellite imageries [2]–[8]. Tate et al. (2002) linked Geographic Information System (GIS) with the hydraulic numerical models to provide the functionality capable of assessing and analyzing parameters and visualization of the results [9]. The study presented a systematic approach for the analysis of the Babai river channels in Nepal and floodplains, and assessment of the flood risk using 1D numerical model HEC-RAS and ARC/INFO and ArcView GIS. Griva et al. (2003) created flood plain maps by linking the available GIS software and the hydraulic modeling (HEC-RAS) [10]. Patro et al. (2009) coupled 1D-2D hydrodynamic model, MIKE FLOOD to simulate the flood inundation extent and flooding depth in the delta region of Mahanadi River basin in India [11].

Keep in mind the above facts, present study was taken up to determine the flood hazard maps for Dikrong basin in Arunachal Pradesh using Remote Sensing and GIS techniques. In this study attempts were made to delineate flood inundation areas for Dikrong river with reference to different return periods and validate modelled flood inundation areas by matching with flood plains reported in the Brahmaputra Board Master Plan for Dikrong basin.

II. STUDY AREA AND DATA ACQUISITION

The Dikrong river basin is situated in the western part of the Arunachal Pradesh. The total area of the catchment is 1,556 km^2, out of which 1,278 km^2 falls in Arunachal Pradesh and rest falls in Assam. It is located between 27°00’ and 27°25’ N latitudes, and 93°00’ and 94°15’ E longitudes (Fig. 1). The total length of the Dikrong river is 145 km, out of which 113 km length is within Arunachal Pradesh and 32 km length is lying in Assam. In every monsoon, the river Dikrong carries tremendous amount of silt, gravel, small boulder and causes flood in some parts of the catchment. For the entire Dikrong river basin, altitude ranges from 73 to 2,846 m above mean sea level.

The hydrologically corrected digital elevation model of the Dikrong basin (Fig. 2) was downloaded from the website of global land cover facility (http://glcf.umiacs.umd.edu/ data/). The inundated maps corresponding to 25, 50, and 100 years return period floods (Figs. 3, 4, and 5), were also collected from Brahmaputra Board Master Plan for Dikrong basin. The yearly highest flood data in terms of gauge at Sisapathar site and their corresponding return periods are reported in Table I.

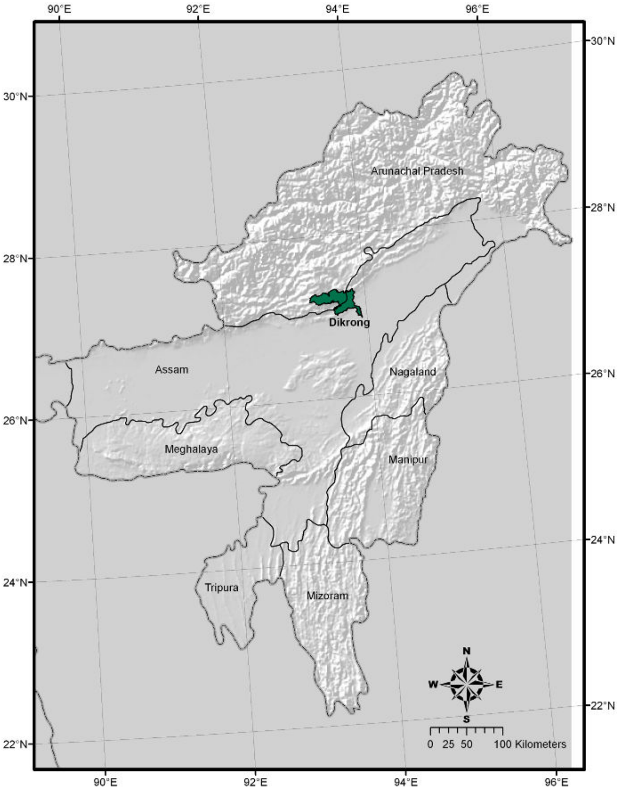

Fig. 1 Location map of the entire Dikrong basin

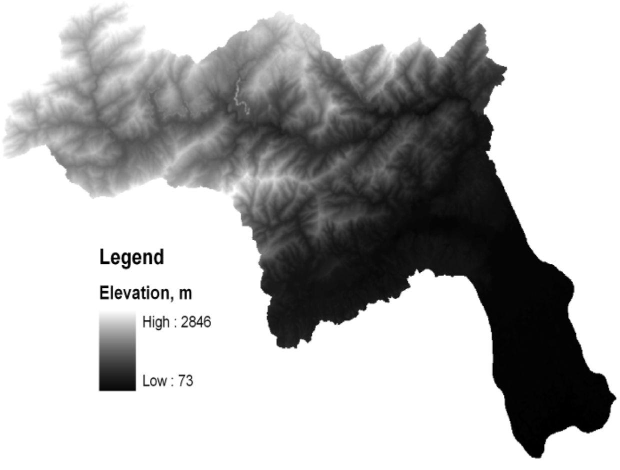

Fig. 2 DEM of entire Dikrong basin

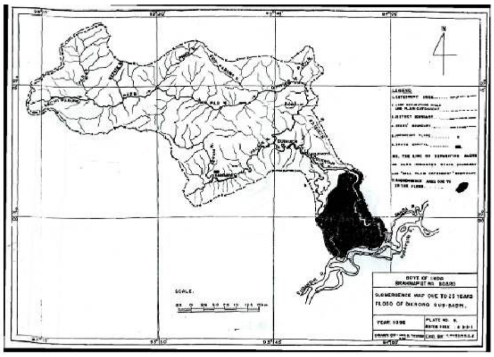

Fig. 3 Flood inundation map (25 years)

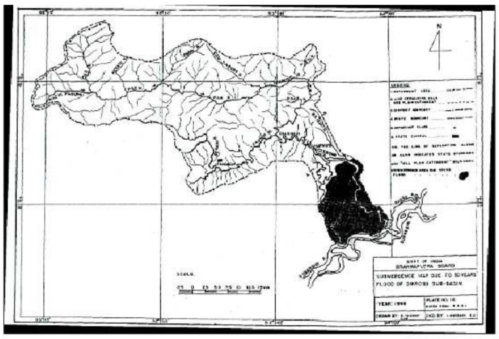

Fig. 4 Flood inundation map (50 years)

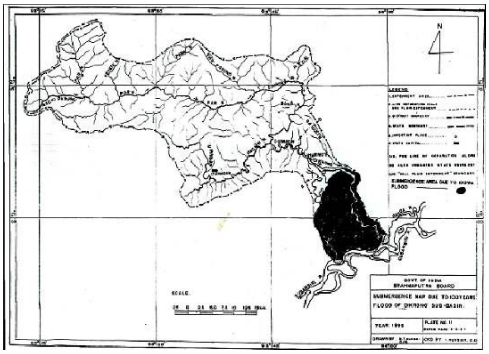

Fig. 5 Flood inundation map (100 years)

TABLE 1
FLOOD AT SISAPATHAR FOR VARIOUS FREQUENCIES

Return period, year	Gauge, m
2	87.42
5	88.86
10	89.81
25	91.02
50	91.91
100	92.80

III. METHODOLOGY

A. Computation of Inundation Area

Analysis for computing the inundation area for different water levels (gauge heights) in the Dikrong river corresponding to different return periods (Table 1) was carried out in ESRI ArcGIS 9.3 (ArcInfo License) using Spatial Analyst Extension. First the digital elevation model (DEM) of the entire Dikrong basin and the water source grid were loaded into ArcGIS 9.3. Every cell of DEM, has some elevation value (Fig. 6). Then a cost grid map (Fig. 7) was created for a particular return period. In this map, if the elevation value of a particular cell is greater than the gauge height corresponding to the return period (Table 1), a new value (one) is assigned for that cell. Other cells having lower elevation than the gauge height get new values as zero. Then it can be said that if:

- cell elevation value > elevation of water level corresponding to return period (T) – not flooded (new cell value = 1)
- cell elevation value <= elevation of water level corresponding to return period (T) – flooded (new cell value = 0)

But, in actual condition, it cannot be always true that if elevation value of a particular cell of DEM is lower than gauge height of a particular return period, that cell should be flooded. As to reach that particular cell, water may have to cross another cell which is having greater elevation value than gauge height. In that case water may not reach that cell which is having lower elevation. So, cost distance analysis was done using ArcGIS Spatial Analyst to identify the cells which will be flooded for gauge height corresponding to a particular return period.

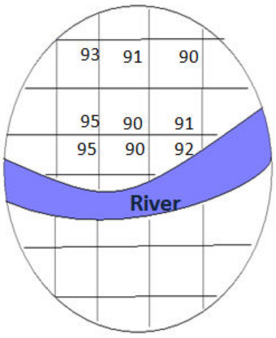

Fig. 6 DEM (e.g., return period = 25 yr.; gauge height = 91 m)

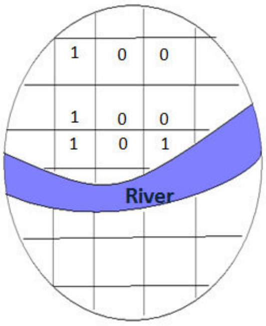

Fig. 7 Cost grid (e.g., return period = 25 yr.; gauge height = 91 m)

From the cell perspective, the objective of the cost tools is to determine the least costly path to reach a cell from source for each cell location in the Analysis window. The least accumulative cost path to a cell from source and the least-cost path itself must be determined for each cell. The cost distance tools are similar to Euclidean tools, but instead of calculating the actual distance from one location to another, the cost distance tools determine the shortest weighted distance (or accumulated travel cost) to each cell from the nearest source location. These tools apply distance in cost units, not in geographic units. All cost distance tools require both a source dataset and a cost raster as input.

The CostDistance function computes the cost of traveling the cells, beginning from the water source grid. The CostDistance request is, fundamentally, a flooding request, but it accumulates a penalty for flooding across cells whose elevation exceeds the flood level. Thus, by picking the cells of zero cost, we can find all cells reachable without crossing any elevation above the flood level. Cost grid (Fig. 7) shows the cost of travel across the each cell. Now, to reach a particular cell from water source, cost values of individual cells (obtained from cost grid map) need to be summed up. Then it can be said that:

- If total cost to reach a particular cell = 0, then that cell is flooded.
- If total cost to reach a particular cell > 0, then that cell is not flooded.

Fig. 8 shows the total cost required to reach a particular cell from source (assuming vertical flow only). Then the flooding of that particular cell would be decided as:

- Total cost to reach cell a = 1+1+1 = 3 *(Not Flooded)*
- Total cost to reach cell b = 0+0+0 = 0 *(Flooded)*
- Total cost to reach cell c = 1+0+0 = 1 *(Not flooded)*

Based on total cost grid map (Fig. 8), flood hazard map can be created. If total required cost for reaching a particular cell is zero, cell gets ‘0’ value. Otherwise, if total cost required for reaching a cell is greater than zero, no data value is assigned to that cell. Therefore, the total travel cost will equal to zero exactly within the region flooded by the water source.

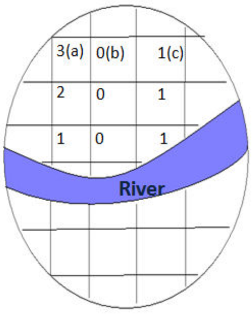

Fig. 8 Total cost grid (e.g., return period = 25 yr.; gauge height = 91 m)

B. Digitization of Inundation Area

The flood hazard maps corresponding to 2, 5, 25, 50, and 100 year return period floods were digitized to determine the inundation area. Using ArcCatalog, a file geodatabase was created. Inside the file geodatabase, different polygon feature classes were created for different return periods. Then in ArcMap, flood inundation area corresponding to 2, 5, 25, 50, and 100 year return period floods were digitized using the sketch tool and then the digitized maps were saved in the corresponding polygon feature classes. From the polygon feature classes, inundated areas were calculated.

Further, inundated maps corresponding to 25, 50, and 100 year return period floods as collected from Brahmaputra Board (1996) [12], were also scanned and geo-rectified. Then, using ArcCatalog, a file geodatabase was created. Inside the file geodatabase, different polygon feature classes were created to represent flooded areas corresponding to 25, 50, and 100 year return periods. Then in ArcMap, flood inundation areas corresponding to 25, 50, and 100 year return period floods were digitized using the sketch tool and were saved in the corresponding polygon feature classes. From these polygon feature classes, inundated areas were determined and compared with the previous ones.

IV. RESULTS AND DISCUSSION

A. Development of flood hazard maps

The flood hazard maps in Dikrong river basin corresponding to 2, 5, 10, 25, 50, and 100 year return period floods were generated using ArcGIS Spatial Analyst (Figs. 9 through 14). Table 2 shows the different flood inundation areas corresponding to different return periods. As return period increases, flood inundation area gets increased (Fig. 15). Considering whole Dikrong basin (1,556 km^2), percentage inundation area for 2 year return period is 7.90%, which gradually increases to 11.69% for a 100 year flood. The reason for such small increase (less than 4%) in inundated area between 2 and 100 year return periods is that, the downstream part of the Dikrong basin (278 sq. km), which lies in Assam contains the entire floodplains. But the upstream part of the basin, in the Arunachal Pradesh (1,278 km^2), is hilly and part of the Siwalik hills with sudden increase in elevation.

Considering only the part of Dikrong basin in Assam (278 km^2), percentage inundation area for 2 year return period is 44.23%, which gets increased to 65.44% for 100 year flood. For this downstream part of the Dikrong basin, difference in flood inundation percentage is nearly 21% between 2 years and 100 years return period. So, it can be concluded that Arunachal Pradesh does not possess any serious threats from the flood of Dikrong river. However, land use in the part of the basin falling in Assam needs to be planned very carefully to avert serious losses.

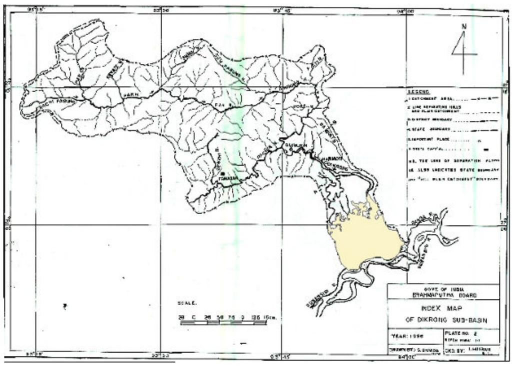

Fig. 9 Flood hazard map (2 years)

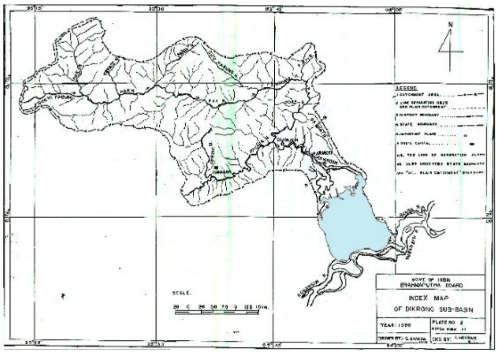

Fig. 10 Flood hazard map (5 years)

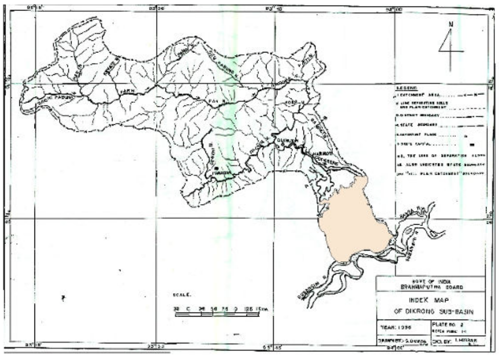

Fig. 11 Flood hazard map (10 years)

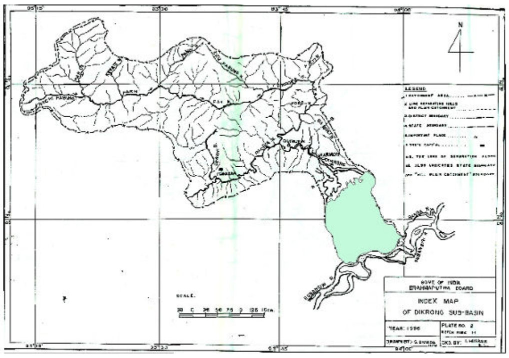

Fig. 12 Flood hazard map (25 years)

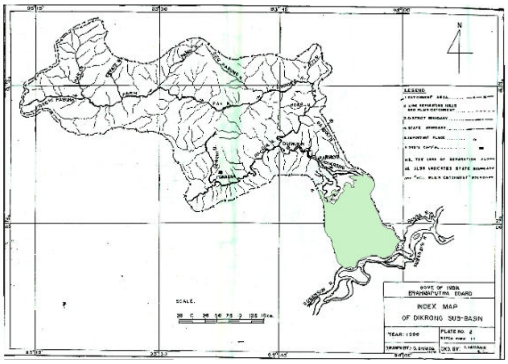

Fig. 13 Flood hazard map (50 years)

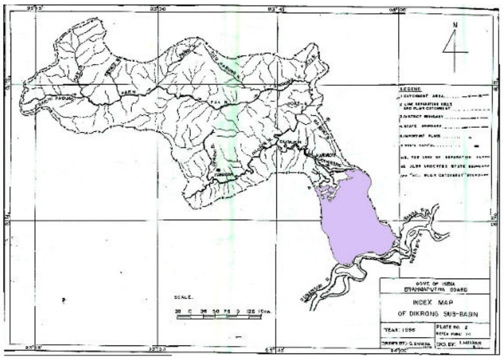

Fig. 14 Flood hazard map (100 years)

TABLE II
INUNDATED AREAS FOR DIFFERENT RETURN PERIODS

Return period (years)	Modelled inundated area (sq. km)	Percentage of whole Dikrong basin (1,556 sq. km) inundated (%)	Percentage of Dikrong basin (in Assam, 278 sq. km) inundated (%)
2	122.97	7.90	44.23
5	146.05	9.39	52.54
10	155.87	10.02	56.07
25	166.28	10.69	59.81
50	174.70	11.23	62.84
100	181.91	11.69	65.44

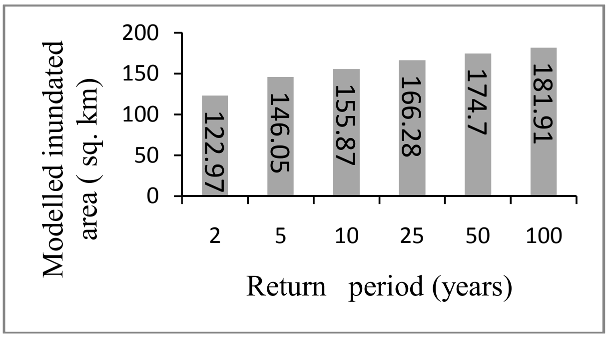

Fig.15 Modelled inundated area with respect to different return periods

B. Comparison of Flood Inundation Areas

Different inundation area were determined from flood inundation maps corresponding to 25, 50, and 100 years return period floods, as obtained from Brahmaputra Board Master Plan (Figs. 3 through 5). Above inundation areas as obtained from reported maps were compared with inundation areas (Figs. 12 through 14) obtained from DEM analysis for 25, 50, and 100 years return period floods using ArcGIS Spatial Analyst. Table 3 shows the comparison between the reported map and modelled flood inundation areas. Deviation of modelled flood inundation areas from reported map inundation areas are 3.16%, 6.11%, and 4.29% for 25, 50, and 100 years return period floods, respectively. It can be seen that, for all the three cases, the DEM modelled flood inundation areas were over-estimated than their reported counter-parts. However, as the average deviation (4.52 %) is below 5 %, it can be said that modelled flood inundation areas matched satisfactorily with reported map inundation areas and the error can be attributed to poor spatial referencing of the hand-drawn maps given in the Master Plan. Hence, GIS techniques were proved to be successful in extracting the flood inundation extent of Dikrong sub-basin.

TABLE III
COMPARISON OF INUNDATION AREA

Return period (years)	Reported map inundated area (sq. km)	Modelled inundated area (sq. km)	Deviation from reported value (%)
25	161.19	166.28	3.16
50	164.03	174.70	6.11
100	174.10	181.91	4.29
Average deviation (%)			4.52

V. CONCLUSIONS

A flood hazard map provides information about the return period associated with the areal extent of inundation for a reach of a river. The flood hazard maps are prepared by delineating areas subjected to inundation by floods of various magnitudes and frequencies. Flood zoning using Geographic Information System (GIS) as a non-structural method, is an efficient tool for flood damage mitigation management. GIS technology is a well-established tool used in hydrologic modeling, which facilitates processing, management, and interpretation of all available data. In addition, the concerned authorities can use the method as a legal tool to control and apply management and zoning of lands, plan development, decrease flood hazards, provide insurance, and protect the environment. Modelled flood inundation areas in Dikrong river basin corresponding to 25, 50, and 100 years return period floods matched satisfactorily with reported conventionally mapped inundation areas. Hence, GIS techniques were proved to be successful in extracting the flood inundation extent of Dikrong basin in a time and cost effective manner.

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