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RESEARCH ARTICLE

FLOOD HAZARD ZONATION BASED ON MULTI CRITERIA ASSESSMENT USING REMOTE SENSING AND GIS TECHNIQUES: A CASE STUDY OF TUNGABHADRA AND HAGARI RIVER SUBCATCHMENTS IN NORTH-EAST KARNATAKA, INDIA

[1]Lingadevaru, D. C., *,[1]Govindaraju, [1]Jayakumar, P. D. and [2]Govindaiah, S.

[1]Department of Applied Geology, Kuvempu University, Shankaraghatta-577 451, India
[2]Department of Earth Science, University of Mysore, Mansagangotri-570 006, India

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ABSTRACT

Flood is a relatively high flow of water that overtops the natural and artificial banks in any of the reaches of a stream. When banks are overtopped, water spreads over flood plain and generally causes problem for inhabitants, crops and vegetation. The present study aims to estimate Flood hazard zonation for Thungabhadra and Hagari river sub catchments based on multi criteria assessment using remote sensing data (Fused data of Cartosat-1 PAN and Resourcesat-2 LISS-IV Mx images) in a GIS environment. The factors which are limited for the study are land use, slope, soil, Lith-Geom (Lithology-Geomorphology), drainage density, size of sub watershed and rainfall distribution. The weighted overlay analysis method is adopted to generate the Flood hazard zonation map. The resultant flood hazard zonation map of the study area depicts the total area is subjected to five categories such as very high hazard (17%), high hazard (32%), moderate hazard (30%), low hazard (14%) and very low hazard zones (7%). The results of this study can initiate appropriate measures to mitigate the probable flood hazard in the study area.

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INTRODUCTION

Floods are the major disaster affecting many countries in the world year after year and the study reported, it has been ranked "first" out of sixteen natural disaster type in the world (Ogah *et al*., 2013). Most floods are caused by convective or frontal storms in which a lot of precipitation falls in a short period of time, Intensity and duration of the rain are the most influencing factors for flood hazards (Ahmed M. Youssef *et al*., 2011). The major flood in more than 100 years has hit parts of Karnataka and Andhra Pradesh States during 28th September to 5th October of 2009 in south-east parts of India due to depression (low atmospheric pressure) in Bay of Bengal (Situation Report, 2009). Due to this, a large area remained under water for long period of time which resulted in heavy loss of agricultural crops, damages to the properties and also to the human beings. There are several factors contributing to the flooding problem ranging from topography, soil, geomorphology, lithology, drainage, engineering structures, and climate.

***Corresponding author: Govindaraju,**
Department of Applied Geology, Kuvempu University, Shankaraghatta-577 451, India.

In addition to heavy rains all the reservoirs built across the Krishna and Tungabhadra Rivers have been receives maximum inflow and discharge of water in downstream resulted flooding (IFRDRCS, 2009). These events have a long-term negative effect on the agricultural productivity and rural livelihood security in the region (Natarajan *et al*., 2010).

In this paper, the authors evaluate the Flood hazard risk zone map based on multi criteria assessment using remote sensing and GIS tools. The factors contributing for flood hazard are annual rainfall, size of watershed, slope of watershed, gradient of river and stream, drainage density, type of soil, land use and lithology-geomorphology which were considered for rating the degree of hazard by means of weight age in assessing the flood hazard zonation (Surjit *et al*., 2012). These maps facilitate the administrators and planners to identify areas of risk and prioritize their mitigation efforts.

Study area and Objective

The Study area belongs to north eastern part of Karnataka, falls under semi-arid zone with dry climate (Report, 2010), the aerial extent lies between 15° 00' 11.23" N to 16° 14' 34.60" N Latitude and 76° 18' 33.89" E to 77° 24' 5.85" E Longitude and covers an area of 12298.36 Km^2 with large rural population and settlements (Fig.1). Flooding in this area is not frequent but severe in the monsoon season, usually begins in June and wanes by September.

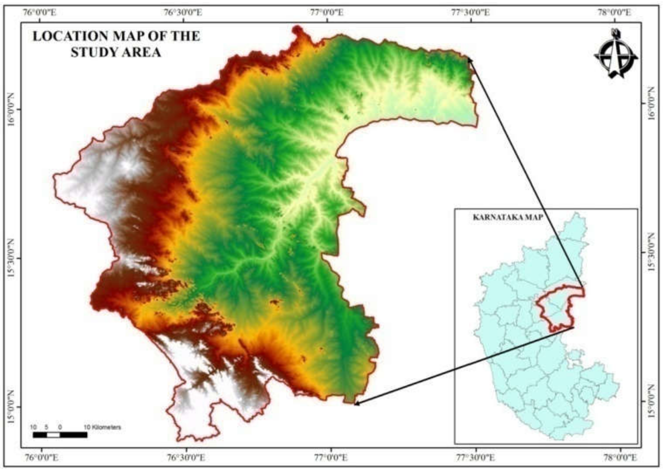


Fig. 1. Location map of the study area

Objective

The main objective of the study is to prepare the flood hazard zonation map based on the weighted overlay method.

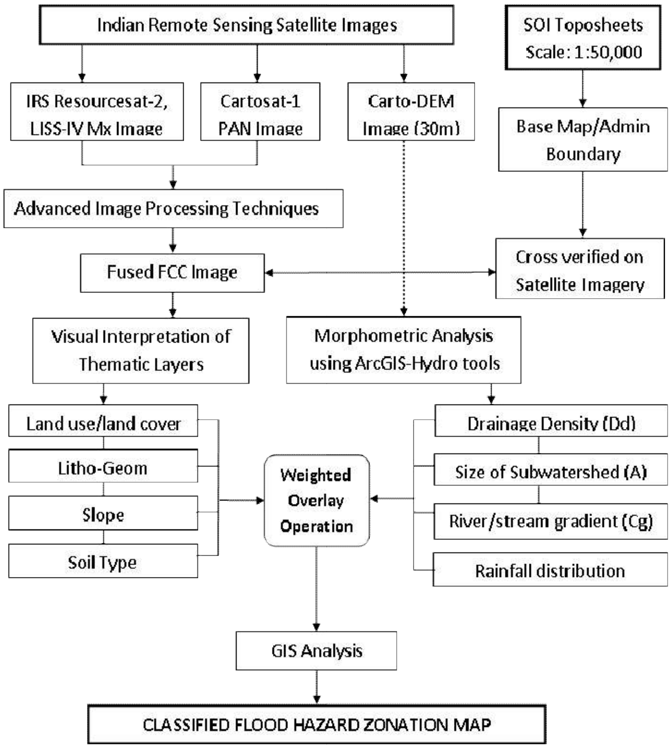
MATERIALS AND METHODS

The data used for the study are, Survey of India toposheets (57 A, B, E and 56 D, H series) of 1:50,000 scale, IRS Resourcesat-2 and Cartosat-1 of year 2011, CartoDEM (30m spatial resolution) and rainfall data. The fused product of false color composite (FCC) image was generated using LISS-IV image with 5.6m resolution and Cartosat-1 PAN image with 2.5m resolution using advanced image processing techniques in ERDAS environment. The base layers such as surface water bodies, transport networks and settlements were generated using toposheets and updated using satellite imagery. There are 220 sub watersheds are delineated in the study area according to the technical guidelines of All India Soil and Land Use Survey (AIS&LUS). The different features of each theme were assigned weights according to their relative influence on flood. The thematic layers have been integrated in GIS environment by Weighted Overlay Analysis using Raster calculator. The flow chart (Fig-2) showing the brief methodology of the study.

RESULTS AND DISCUSSION

Land Use Land Cover (LU/LC)

The land use / land cover map has been prepared up to level-3 classification (NRC-LU/LC-50K Project Manual, 2006) includes built-up, forest, agriculture, waste land and water bodies and the classes were grouped into five different categories based on their influence to flooding. The weights are assigned to each class as shown in Table-1. The weights assigned land use / land cover map with respect to flooding is shown in Fig. 2.



Flow chart shows the brief methodology of the study

Slope

The slope influences the direction and amount of surface runoff or subsurface drainage reaching a site (Dai, *et al*., 2002). Slope has a dominant effect on the contribution of rainfall to stream flow. It controls the duration of overland flow, infiltration and subsurface flow.

Table 1. Table showing the land use weight details

Sl No	LU/LC Class	Rank/Weight
1	Reservoire/Tank, River/Stream, Canal, Lake/Pond, Waterloged Area, Salt Affected land, Sandy Area-Riverine, Aquaculture/Pisciculture and Double Crop	V
2	Kharif Crop, Zaid Crop, Mixed Crop land, Built Up - Mining/Industrial and Scrub land-Grazing land	IV
3	Built Up – Urban, Built Up – Rural, Rabi Crop, Current Fallow, Forest-Open and Scrub land-Open/Dense	III
4	Agri-Plantation, Forest-Dense, Forest-Scrub and Tree Clad Area	II
5	Forest-Plantation, Grass land and Barren Rocky/Stony Waste	I

Table 2. Table showing the slope weight details

Sl No.	Slope Type	Rank/Weight
1	Nearly Level (0-1%) & Very Gentle Slope (1-3%)	V
2	Gentle Slope (3-5%)	IV
3	Moderate Slope (5-10%) & Strong Slope (10-15%)	III
4	Moderately Steep Slope (15-35%)	II
5	Very steep slope (35 - 50%)	I

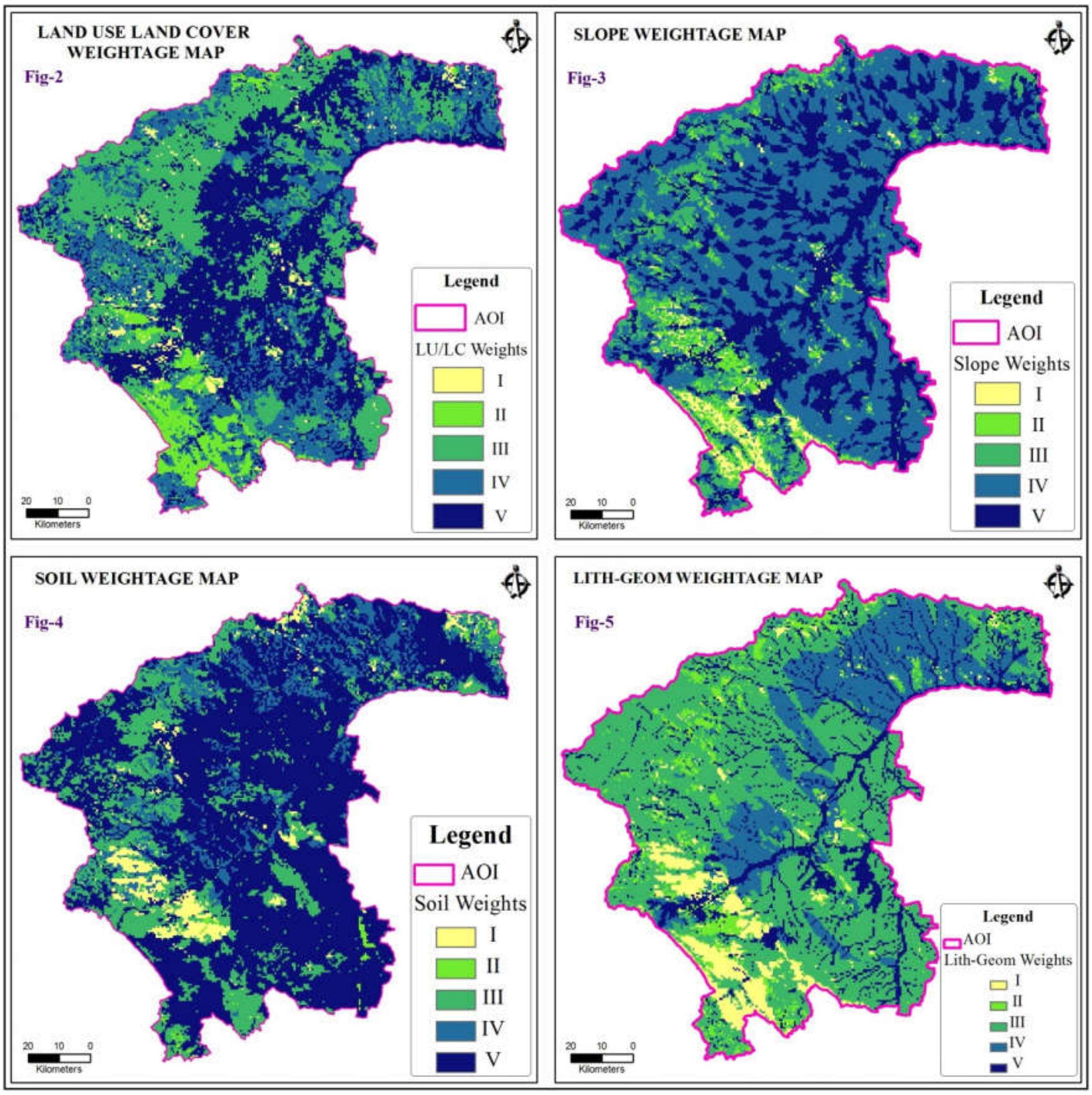


Fig. 2. Land use weightage map; Fig. 3. Slope weightage map; Fig. 4. Soil weightage map; Fig. 5. Lith-Geom weightage map

Combination of the slope angles basically defines the form of the slope and its relationship with the lithology, structure, type of soil and the drainage. A smooth/flat surface that allows the water to flow quickly is not desirable and causes flooding, whereas a higher surface roughness can slow down the flood response and is desirable (Krumbien, 1965). Steeper slopes are more susceptible to surface runoff, while flat terrains are susceptible to water logging. Slope angle of watershed ranges from 0 to >50, weights are assigned for slope categories are shown in Table-2. Class having less value was assigned higher rank due to almost flat terrain while the class having maximum value was categorized as lower rank due to relatively high run-off. The weights assigned slope map with respect to flooding is as shown in Fig.3.

Soil type

The soil types in an area is important as they control the amount of water that can infiltrate into the soil, and hence the amount of water which becomes flow (Nicholls & Wong, 1990). The chance of Flood hazard increases with decrease in soil infiltration capacity, which causes increase in surface runoff.

When water is supplied at a rate that exceeds the soil's infiltration capacity, it moves down slope as runoff on sloping land, and can lead to flooding (Lowery *et al*., 1996). Weights are assigned for soil categories based on infiltration capacity are shown in Table-3 and the weights assigned soil map with respect to flooding is as shown in Fig.4.

Table 3. Table showing the soil weight details

Sl No.	Soil Family Texture	Rank/Weight
1	Very Fine & Fine	V
2	Fine Loamy & Clayey	IV
3	Clayey Skeletal, Clayey over Sandy, Loamy & Loamy Skeletal	III
4	Coarse Loamy , Sandy & Sandy Skeletal	II
5	Rock Outcrops & Dyke Ridges	I

Lithology-Geomorphology

The study of lithology and geomorphology may play very important role for flood analysis.

The overlay operation is carried out for lithology and geomorphology layers to get integrated lithology-geomorphology (Lith-Geom) layer with simple-combined classifications. The classes were grouped into five different categories based on their influence to flooding process. The weights are assigned to each class as shown in Table-4. The prepared weights assigned- Lith-Geom map with respect to flooding is as shown in Fig.5.

Table 5. Table showing the drainage density weight details

S.No.	Drainage Density (Dd) Dd = Lu/A	Rank/Weights
1	1.20 - 1.33	V
2	1.12 - 1.20	IV
3	1.02 - 1.12	III
4	0.86 - 1.02	II
5	0.54 - 0.86	I

Table 4. Table shows the Lith-Geom weight details

Sl No.	Lithology	Geomorphology	Rank / Weight
1	Dolerite & Amphibolite Dykes	Valley, Valley filled, Valley eroded, Channel bar (Flood Plain), Pediplain Shallow weathered under canal command & Wterbodies	V
2	Amphibolitic Metapelitic Schist/Pelitic Schist & Granite	Pediplain Eroded & Shallow weathered/ shallow buried Pediplain	IV
3	Syenite, Granodiorite and Granite & Migmatites and Granodiorite - Tonalitic Gneiss	Moderately weathered/ moderately buried Pediplain, Pediplain gullied, Pediment/ Valley Floor, Intermountain valley/ Structural Valley (Large) & Settlement	III
4	Amphibolite Hornblende Schist, Chlorite Schist, Grey / Pink Granite, Greywacke / Argillite & Metabasalt Including Thin Iron Stone	Pediment - Inselberg Complex, Inselberg & Plateau highly dissected	II
5	Laterite, Metabasalt, Metavolcanics, Phyllite Quartz Chlorite Schist and Greywalke & Pink & Grey Granite	Linear Ridge, Ridge type Structural Hills (Small), Denudational Hills, Residual Hill & Structural Hills	I

Table 7. Table showing the Rainfall distribution details in millimeters (10 years annual average)

Sl No	Station Code	Location Name	Annual Rainfall (mm)	Sl No	Station Code	Location Name	Annual Rainfall (mm)
1	10403	Ilkal	595	24	200206	Munirabad	629
2	10405	Kandgal	410	25	200302	Hanamsagar	632
3	50101	Bellary	515	26	200303	Kushtagi	595
4	50102	Bellary Rly	479	27	200304	Kalarhatti	579
5	50103	Hagari	497	28	200305	Tawargeri	566
6	50104	Kurugodu	511	29	200401	Bevur	587
7	50401	Hospet	669	30	200403	Yelbarga	594
8	50402	Hospet Rly	590	31	230101	Arakeri	684
9	50403	Kampli	363	32	230103	Gabbur	495
10	50404	T B Dam	633	33	230104	Galaga	658
11	50505	Kudligi	620	34	230201	Hatti	670
12	50602	Kurekuppa	471	35	230202	Lingsugur	582
13	50603	Sandur	813	36	230203	Maski Camp	730
14	50604	Yeshvantnagar Rly	756	37	230304	Manvi	650
15	50701	Siruguppa	649	38	230305	Rajalabanda	850
16	50702	Siruguppa Ars	681	39	230306	Sirvar	694
17	100603	Rampura	452	40	230401	Chandrabanda	682
18	140401	Ganjendragarh	798	41	230407	Raichur	923
19	200101	Gangawati Ib	654	42	230408	Raichur Rly	671
20	200103	Kanakgeri	618	43	230410	Yergara	847
21	200104	Oddarahalli Camp	612	44	230502	Dhadesugur	712
22	200202	Guddanahalli	591	45	230503	Sindhnur	708
23	200204	Koopal	618				

Drainage density (Dd)

Drainage density indicates the closeness of spacing of streams and a key detrimental factor for water to travel from source to sink (Horton, 1945). Drainage density is an inverse function of infiltration, lesser the infiltration of rainfall, which conversely tends to be concentrated in surface run-off (Shiva Shankar *et al*., 2014).

Drainage density is classified into 5 categories, high drainage density values are favorable for runoff, and hence indicate low flood chance. Higher weights are assigned to poor drainage density area and lower weights were assigned to areas with adequate drainage as shown in table-5. The weights assigned drainage density map with respect to flooding is as shown in Fig.6.

Size of Subwatershed (A)

Table 6. Table showing the sub watershed (size) weight details

Sl No	Subwatershed Area (A)	Rank/Weights
1	70.86 - 117.75	V
2	58.09 - 70.86	IV
3	47.15 - 58.09	III
4	35.35 - 47.15	II
5	9.70 - 35.36	I

The sub watersheds with larger drainage areas require runoff of longer duration for a significant increase in water level to become a flood. Therefore the sub-watersheds with smaller area are greatly affected by floods. These were mapped and size of each sub watershed was computed, and the sub watersheds were classified based on their size. The Size of sub watershed ranges from 9.7 to 117.75 Km^2.

The weights assigned are shown in Table-6 and weights assigned sub watershed-size map with respect to flooding is shown in Fig.7.

Rainfall Distribution

The amount of runoff is related to the amount of rain a region experiences.

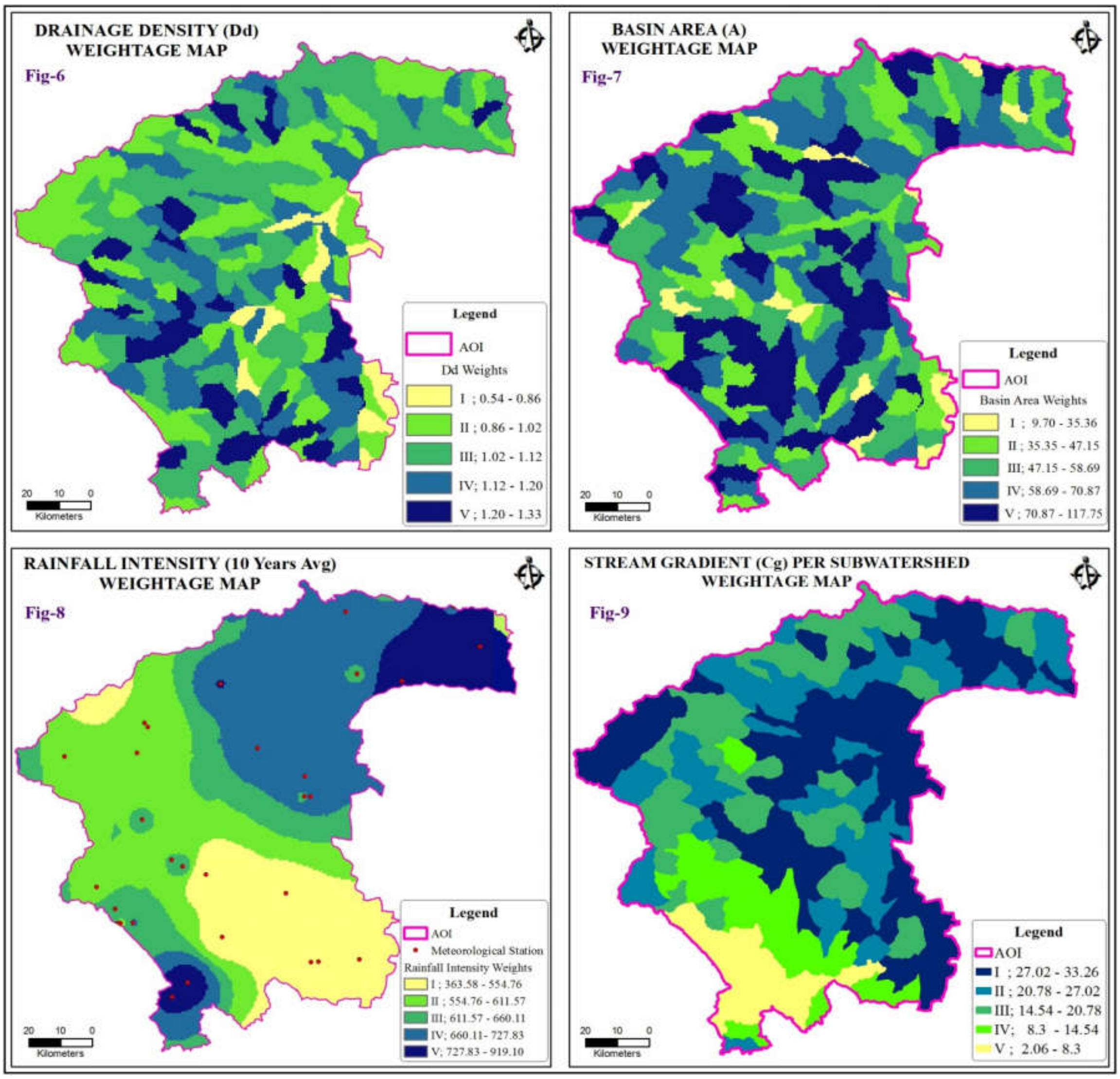


Fig. 6. Drainage density (Dd) weightage map; Fig. 7. Basin area (A) weightage map; Fig. 8. Rainfall intensity weightage map; Fig. 9. Stream gradient per sub watershed (Cg) weightage map

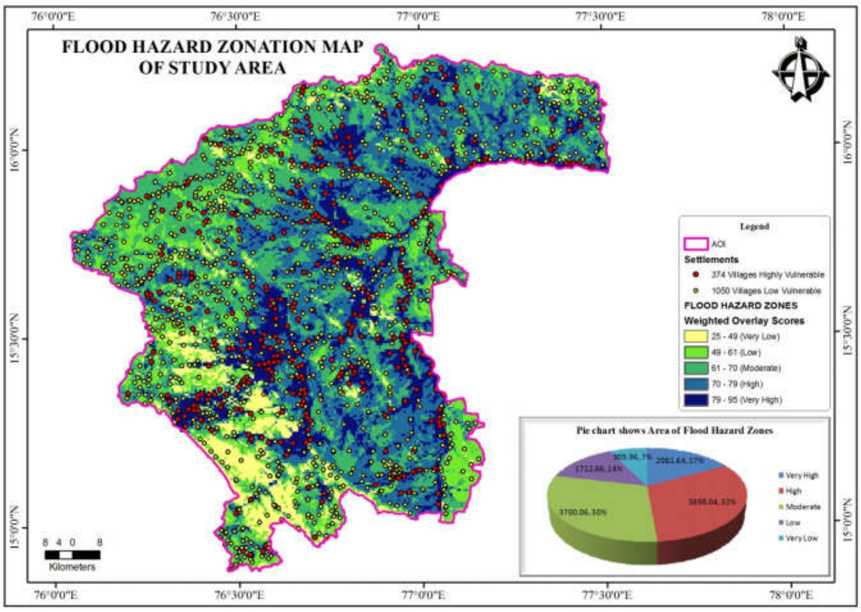


Fig. 10. Flood hazard zonation map of Tungabhadra and Hagari river sub catchments

There are 45 rain gauge stations in the study area (Table 7), record shows the annual average rainfall is varies from 363mm to 923mm. Using inverse distance weighted (IWD) method, 10 years annual average rainfall has been studied.

The computed rainfall distribution map is classified into 5 categories based on their values, higher weights are assigned to high rainfall trends and lower weights to low rainfall trends is as shown in Table 7 and the weights assigned rainfall distribution map with respect to flooding is shown in Fig.8.

Table 8. Table showing the Intensity of Rainfall distribution-weight details

S.No	Intensity of Rainfall distribution (mm)	Rank/Weights
1	727.83 - 919.10	V
2	660.11 - 727.83	IV
3	611.57 - 660.11	III
4	554.76 - 611.57	II
5	363.58 - 554.76	I

Stream Gradient

The relief aspects of the watershed are appreciably associated with the study of three dimensional features involving area, volume and altitude. It is observed that the mean channel slope decreases with increasing order number.

The Stream gradient value is varies from 2.06 to 33.26 in the study area, Higher Cg values are favorable for runoff, and hence indicate low flood chance and vice versa. Higher weights are assigned to lower values of stream gradient and lower weights were assigned to high values of stream gradient shown in Table 9. The weights assigned Stream gradient map with respect to flooding is shown in Fig.9.

Table 9. Table showing the stream gradient weight details

Sl No	Channel Gradient (Cg) $Cg = H / \{(\pi/2) \times Clp\}$	Rank/Weights
1	2.06 - 8.3	V
2	8.3 - 14.54	IV
3	14.54 - 20.78	III
4	20.78 - 27.02	II
5	27.02 - 33.26	I

Flood Hazard Risk Zone

The processes such as the compilation of contributing factors, overlay operation and the calculation of hazard area were obtained using raster calculator in GIS environment. The factors which contribute to the floods are given in the Table 10.

The resultant flood hazard zonation map (Fig.10) depicts the total area is subjected to five categories such as very high hazard (17%), high hazard (32%), moderate hazard (30%), low hazard (14%) and very low hazard zones (7%) are shown in the Table 11 and there are 374 settlements are very high vulnerable to floods out of 1424 settlements in Tungabhadra and Hagari river sub catchment.

Table 10. Showing the contributing factors to flood

Sl. No.	Contributing Factor	Rank
1	Rainfall distribution	9
2	Slope	8
3	Size of subwatershed	7
4	Drainage density (Dd)	6
5	Land use type	5
6	Lith-Geom	4
7	Channel/Stream gradient (Cg)	3
8	Soil type	2

Table 11. Showing the area details of Flood Hazard zonation map

Sl No	Weights Score	Pixel No.	Flood Hazard	Area in Km^2	Area %
1	79 - 95	5478	Very High	2081.64	16.93
2	70 - 79	10258	High	3898.04	31.70
3	61 - 70	9737	Moderate	3700.06	30.09
4	49 - 61	4507	Low	1712.66	13.93
5	25 - 49	2384	Very Low	905.96	7.37
		32364		12298.36	100.00

Conclusions

The present study shows a simple and cost effective way of using remote sensing and geographical information system for creating flood hazard map from the available data base. In this study, an attempt has been made to prepare flood hazard map using ArcGIS and ERDAS Imagine software tools.

The flood hazard zonation map of the study area shows there are 374 settlements are in very high vulnerable zone. Using the flood hazard map, flood prone areas can be identified, which will assist in appropriate planning of development works.

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