Flood hazard zonation of upper kolodyne using GIS and multi criteria decision analysis in Mizoram, India

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Abstract

Kolodyne is the largest river in Mizoram. The river originates in Myanmar where it flows in a southerly direction and enters Mizoram where it is called Chhimtuipui river and it becomes the international border between India and Myanmar. The Kolodyne river meets several rivers in Mizoram before it enters Chin State in Myanmar again. The upper Kolodyne river has caused destructive floods recently, however, attempts to delineate the flood hazard zones have not been carried out.

This river is a source of livelihood for many families in the region and it had wrecked havoc in the past monsoon seasons with the loss of lives and property. The potential flood hazard zonation of the upper Kolodyne watershed using geographic information systems and multi-criteria decision analysis has revealed that about 40% of the total watershed fall in the high and very high potential zones and flood control measures are needed to be updated.

Keywords: Flood, GIS, hazard, zonation, Kolodyne.

Introduction

The State of Mizoram shares international boundaries with Myanmar in the east and Bangladesh in the west. The Kolodyne river which originated from Myanmar enters Mizoram before re-entering Myanmar again in Chin State in Myanmar. The river upon entering Mizoram is locally known as *Chhimtuipui* as it flows through several districts within the State. This perennial river is a source of livelihood for many families who dwell along its course in the Kolodyne watershed and it provides occupations like fishing, building sand, recreational activities, agriculture and also it is a source of potable water for the locals. The upper Kolodyne watershed is situated in the southern part of Mizoram in northeast India as in fig. 1. The basin comprises of an area of 242.97 sq. km extending from roughly between 92^{0}53′00″ E, 22^{0}28′00″N to 93^{0}03′30″E, 22^{0}28′00″N.

Landscape and Geology: The landscape of Kolodyne watershed in southern Mizoram is geologically a young terrain with low and undulating hills running from N-S directions. The rocks are normally of sandstone, shale, siltstones, mudstone and combinations of these rocks. These rocks are highly weathered and eroded in some places and they encompass the whole study area. In the northeastern region of India, southern Mizoram around Kolodyne river boasts some of the most varied hilly topography. The hills are steep and split by rivers that produce deep gorges between the mountain ranges.

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Flooding is influenced by a variety of elements including the catchment's physical, hydrological, climatic and geomorphologic characteristics. Each of these flood-related factors has an impact on the risk of flooding. Different factors play a role in the incidence of watershed floods, so that these elements might be prioritised based on their impact on the occurrence of floods.

Review of Literature

Floods occur when water overflows and submerges the land, they are a type of natural hazards that cause fatalities resulting in huge loss of life and property with widespread devastations. Often in many areas whether in plains and mountains, floods are frequently caused by heavy rainfall, snowmelt, from tropical cyclone or tsunami. Flood hazard zonation maps are very important and are useful tools for communicating flood danger to the society. They provide compiled data to public bodies such as the water management authorities, municipalities, civil protection agencies as well as to the general public.

They are useful for disaster mitigation and for disaster management plans. Assessment of potential flood hazard zonation using geographic information systems (GIS) and multi-criteria decision analysis has been successfully used across different terrains in many countries like Iran, Iraq, Ivory Coast and Tunisia[2,6,8,12,13].

Also in Asian countries, this method has been successfully used to delineate flood hazard zones spanning from Nepal, China, Vietnam and Bangladesh[3,15,17,20,21,29]. In a vast country like India having different topographies, floods occur in the plains, mountains and coastal areas and have wreaked havoc every year. Also, urban flooding in metropolitans have added flood woos causing disruption and damage to life and property. Engineering techniques using GIS and multi-criteria decision analysis have also been useful in delineating the potential flood hazard zones in many parts of Inida from the Nilgiris in south India, Kerala and up to the northern border with Nepal[1,4,5,7,9].

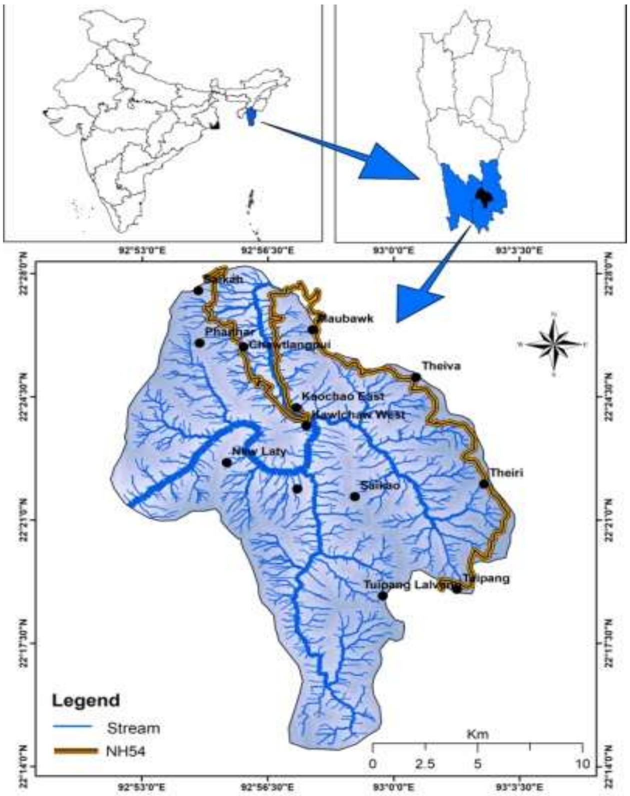

Fig. 1: Location map of the study area

Also, in Madhya Pradesh to eastern India covering UP, Bihar and even up to Tripura, GIS and multi-criteria decision making processes have been used to assess flood hazard zonation around rivers and river basins[11,18,22-24,27,28].

In the northeast of India, workers have been successfully using GIS and multi-criteria decision analysis to produce the flood hazard maps in several states like Assam, Tripura and Manipur[10,14,16].

Material and Methods

The flood hazard zones of upper Kolodyne watershed were identified by interpreting a dataset comprising satellite data, Google Earth data and conventional maps including the Survey of India (SOI) topographic sheets in GIS environment. The SOI toposheets (84B/15, 84B/16 and 84F/3) covering the study area at a scale of 1:50,000 scales were downloaded from Survey of India and were rectified and geometrically corrected. These images were then mosaicked to form a single image and transferred into ArcGIS 10.2 software to prepare the thematic layers. The ALOS PALSAR (DEM) downloaded from website https://vertex.daac.asf.alaska.edu was used for the preparation of thematic maps of drainage networks and other thematic layers such as the elevation map, slope map, curvature map, drainage density map, flow accumulation etc. using hydrology tools in ArcMap 10.2.

The land use classification map was prepared from Landsat 8 satellite image downloaded from United States Geological Survey (USGS) official website and processed in Erdas Imagine 2014 and ArcMap 10.2 software.

Further, the mean rainfall for 10 years was then spatially interpolated using the Inverse Distance Weighted (IDW) method to obtain the rainfall distribution map. The soil layer was prepared by digitizing the soil map published by ICAR[19]. After preparation of the thematic layers, all the layers were converted to raster format and used for the overlay analysis. After preparation of the thematic layers, all the layers have been converted to raster format and were used for the overlay analysis.

During weighted overlay analysis, a rank was given for each individual parameter of each thematic layer map and weights were assigned according to the output of the multi-criteria decision analysis (AHP techniques) and the output map shows the flood hazard potential zone of the of the study area. The methodology adopted in the present study is given in flow chart in fig. 2.

Analytical Hierarchy Process

The analytical hierarchy process (AHP) was calculated according to Saaty[25] and the multi-criteria decision analysis was calculated according to Siddayao et al[26]. Pair-wise comparison matrix is created by assigning weights by experts[25]. These weights computed automatically in Expert Choice software called Multi-Criteria Decision Analysis (MCDA) tool[26]. The pairwise comparisons of all the criteria were used as inputs in the AHP approach while the relative weights of the criterion were used as outputs.

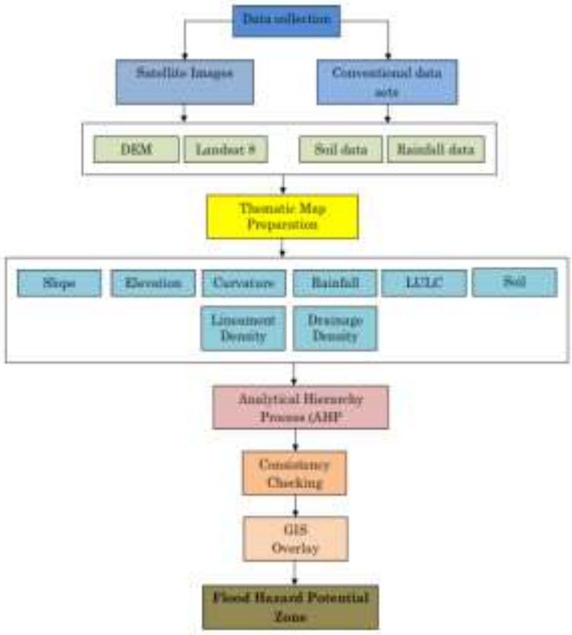

Fig. 2: Methodologies used for the study

Furthermore, because the final weightings for the criteria are the normalised values of the Eigen vectors that are associated with the AHP matrix's maximal Eigen values, its consistency must be assessed. The consistency of the comparisons was examined using the consistency ratio (CR). The consistency ratio (CR) must be less than or equal to 0.1. Therefore, CR is a numerical index to examine the consistency of the pair wise comparison matrix and is defined as:

$CR=CI/RI$

where consistency index is given by CI. Also, The random index is denoted by RI and $CI = \lambda_{max}$-n/n-1 and the principle Eigen value is λ_{max} where 'n' is the no. of comparisons.

Now, the consistency ratio is:
$CR=CI/RI$

where $CI = \lambda max$-n/n-1, $\lambda max = 8.49$, CI= 0.07, RI=1.41 and CR = 0.05 which is <0.1.

Hence the consistency ratio is < 0.1 which is significant and the assigned weightage value is acceptable.[8,15,18]

Estimation of the flood hazard potential index (FHPI): All of the criteria mentioned above were created as thematic layers. They are also weighted and rated based on the nature of its influence. The AHP technique was used to assign weight. It is ranked according to its priorities. The weighted and ranked layers were integrated into the Arc GIS 10.2 software's GIS environment. The table shows the weighting and ranking for flood hazard. The following formula can be used to compute the potential index:[8,15,18]

FHPI= (Ws*Rs) + (We*Re) + (Wcv*Rcv) + (Wdd*Rdd) + (Wt*Rt) + (Wlu*Rlu) + (Wr*Rr) + (Wfa*Rfa).

where W – Weightage, R- Rank, s – Slope, e – Elevation, cv – Curvature, dd- Drainage Density, r- Rainfall, t- Soil Texture, lu- Landuse and fa- Flow accumulation.

Results and Discussion

Out of the 242.97 sq km of the watershed, the different areas from the lowest point 24 m to the highest point 1652 m are shown in table 1. The elevation ranging from 24 m-336 m consists of 44.77 sq km of the watershed which is 18.43% and these are areas close to the river. Areas ranging from 336 m to 572 m constitute about 61.85 sq. km. of the total area which is 25.46% of the area. Most of the human settlements and economic activities are located here. Areas 572 m-810 m occupy the largest area which is 26.06% of the total watershed. Elevated areas ranging from 810 m-1081 m and 1081 m-1652 m constitute 19.63% and 10.40% and are farthest areas from the river. Different elevated areas are given in the elevation map in fig. 3.

Areas of the upper Kolodyne watershed having slope angles are classified into five categories and are shown in table 2 and the slope map is given in fig. 4. Very gentle slope <15º areas constitute 31.69 sq. km. and make up 13.05% of the total area of the watershed. Slope angles ranging from 16º-25º are defined as the gentle slope areas which encompass areas of 67.76 sq. km. of the watershed and occupy 27.89% of the total area. The moderately slope angles 26º-35º constitute 29.86% of the watershed which are 72.54 sq. km. of the watershed area which is the largest category amongst the slope area classification. Steep slope angles 36º-45º constitute 21.56% and the escarpments and cliffs which are having >45º slope angles occupy the least areas which are 18.50 sq km and this category contributes 7.61% of the upper Kolodyne watershed in southern Mizoram.

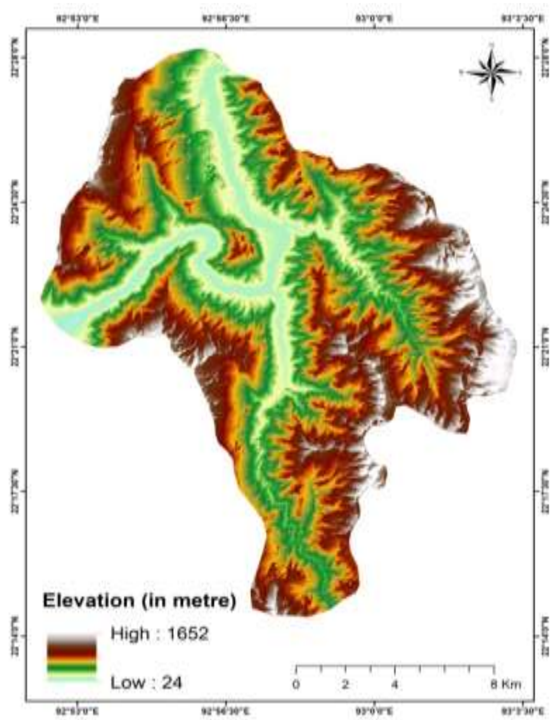

Fig. 3: Elevation map of the study area

Table 1
Difference in elevation of the watershed

Height (m)	Area (Sq. Km)	Percentage
24-336	44.77	18.43
336-572	61.85	25.46
572-810	63.31	26.06
810-1081	47.68	19.63
1081-1652	25.27	10.40

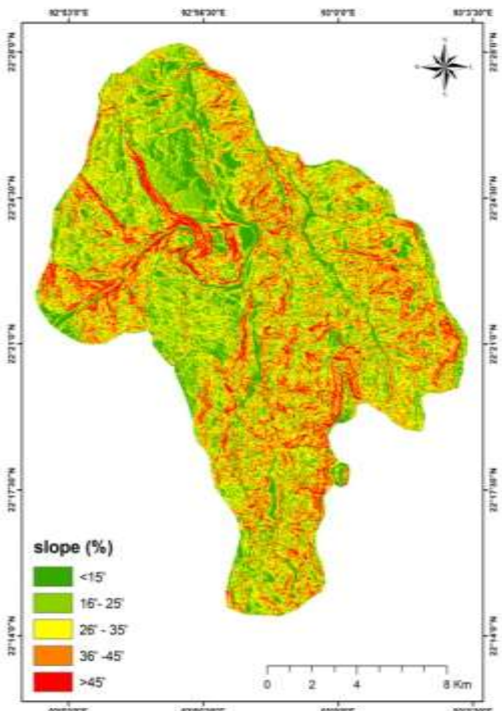

Fig. 4: Slope map of upper Kolodyne watershed

Table 2
Slope angles of the study area

Slope Angles	Category	Area (Sq. km)	Percentage
<15º	Very gentle slope	31.69	13.05
16º-25º	Gentle slope	67.76	27.89
26º-35º	Moderately slope	72.54	29.86
36º-45º	Steep slope	52.38	21.56
>45º	Escarpment/cliff	18.50	7.61

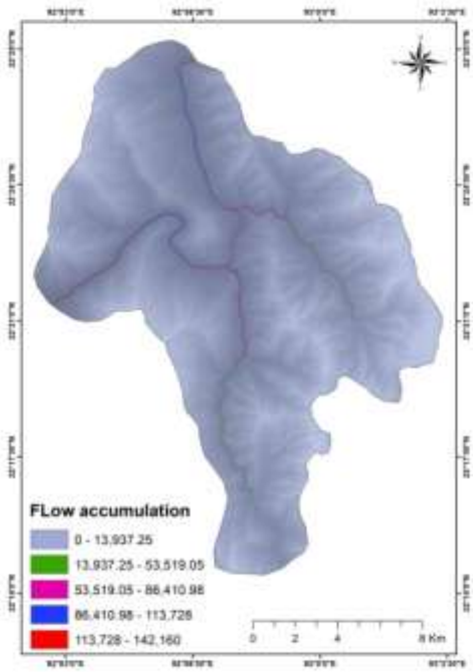

Fig. 5: Flow accumulation of upper Kolodyne river

Table 3
Flow accumulation

Category	Area (Sq. km)	Percentage
0-13,937.25	241.71	99.51
13,937.25-53,519.05	0.41	0.17
53,519.05-86,410.98	0.34	0.14
86,410.98-113,728	0.25	0.10
113,728.98-142,160	0.17	0.07

The flow accumulation threshold is a significant component in hydrology that determined the structure and morphology of stream networks. For the upper Kolodyne watershed, the flow map of the river is given in Fig. 5 and and the values are shown in table 3. Drainage density is a measurement for describing the physical characteristics of a drainage basin and it is determined by the climate and physical characteristics. The drainage density values are shown in table 4 and the drainange density map is given in Fig. 6.

Drainage density is low in drainage basins with porous rock and soil types. Drainage density of areas having values 0-2.94 encompass 65.69 sq. km. of the watershed which is 27.20% of the area which is the highest category amongst the drainage densities in upper Kolodyne watershed. The low nature of the drainage densities is supported by the presence of sedimentary rocks such as sandstone, shales and sometimes siltstones.

The areas having curvature values 4.13-44.94 have the highest correlation for the occurrence of floods which is a total of 4.73 sq. km. in area. About 20.28% which covers an area of 49.28 sq. km. also has high probability according to the curvature values. The other curvature values are shown in table 5 and the curvature map is shown in fig. 7.

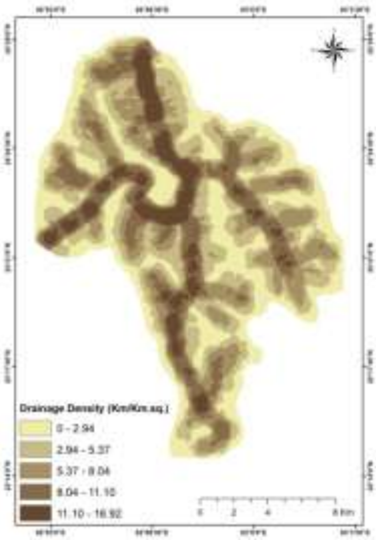

Fig. 6: Different drainage densisities of the study area

Table 4
Drainage density of Upper Kolodyne watershed

Category	Area (Sq. Km)	Percentage
0-2.94	65.69	27.20
2.94-5.37	64.86	26.86
5.37-8.04	51.96	21.51
8.04-11.10	37.80	15.65
11.10-16.92	21.17	8.76

Table 5
Curvature values

Category	Area (Sq. Km)	Percentage
-24.15 – -2.66	12.78	5.26
-2.66 – -0.76	61.48	25.31
-0.76 – 0.87	114.62	47.18
0.87 – 4.13	49.28	20.28
4.13 – 44.94	4.73	1.94

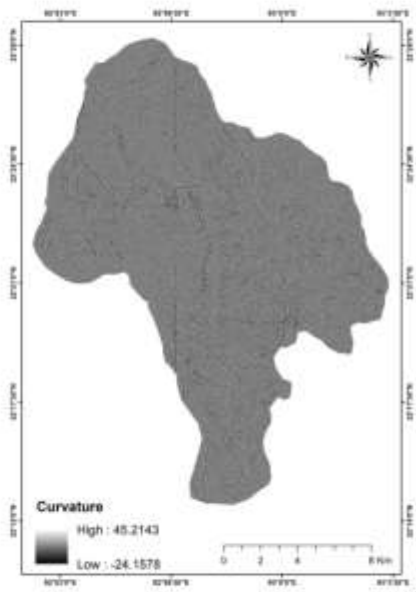

Fig. 7: Topographic curvature values of the study area

Different soils make up the upper Kolodyne watershed. Clayey skeletal soils are found in abundance and they constitute 29.84% of the study area. Coarse loamy soil forms the major type of soil of the study area which encompasses 102.67 sq km of the upper Kolodyne watershed, this type of soil consist of 42.25% of all the soils present. Fine loamy soil is also found in abundance which make up 33.61 sq km of the total stusy area and is 13.83% of the total watershed. Fine silty soils are almost negligible as they are sparse in this terrain, nevertheless they constitute 0.53 sq km of the study area and make up 0.22% of the watershed. Fine to coarse loamy soil is found to be 12.20% of the upper Kolodyne watershed and the loamy skeletal soil constitutes 3.95 sq km of the total watershed, this is roughly 1.62%. The values of the soil types are shown in table 6 and the soil map is given in fig. 8.

The different landuse class found in the upper Kolodyne river is shown in table 7 and the Landuse map is given in fig. 9. Light vegetation dominates the Landuse class which is 33.99% of the study area. The light vegetation encompasses an area of 82.54 sq km which is closely followed by thick vegetation which covers 81.50 sq km engulfing 33.56% of the study area. Fallow land (shifting abandoned) consists of 8.62% of the study area and this covers 20.95 sq km. It is remarkable to see how much fallow land is located in the study area, this depicts the magnitude of shifthing agriculture that is practised in the region. Forest scrub covers 19.97 sq km and constitutes 8.22% of the study area. Besides these, built up areas, plantation covers, grasslands and grazing pastures, waterbodies encompass few areas in the upper Kolodyne.

Moist tropical to moist sub-tropical is the climate of Mizoram and it receives heavy rainfall from the SW Monsoon. The mean 10 years annual rainfall of the study area is around 2200 mm and the rainfall map is given in fig. 10.

The fundamental scales of absolute numbers and the ratio index (RI) which are used for the different thematic maps are given in table 8 and table 9 respectively. After combining remote sensing and multi-criteria decision analysis, the flood hazard zonation of upper Kolodyne is given in fig. 11.

Table 6
Type of soils in Upper Kolodyne

Category	Area (Sq. Km)	Percentage
Clayey skeletal soil	72.51	29.84
Coarse Loamy soil	102.67	42.25
Fine Loamy soil	33.61	13.83
Fine silty soil	0.53	0.22
Fine to Coarse Loamy soil	29.66	12.20
Loamy skeletal soil	3.95	1.62

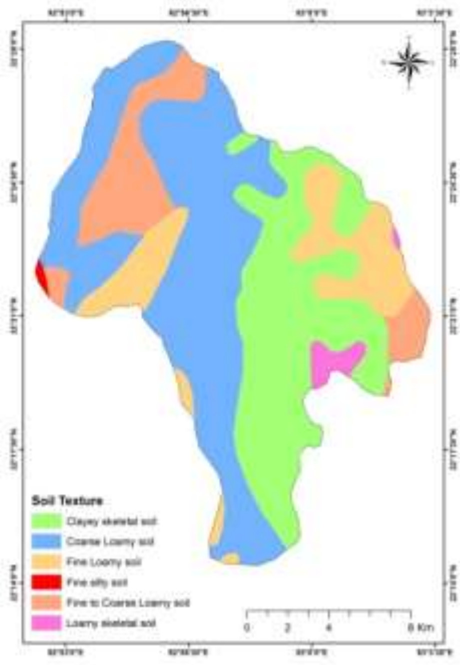

Fig. 8: Six types of soils found in the upper Kolodyne watershed

Table 7
Different landuse class in Upper Kolodyne

Description	Area (Sq km)	Percentage
Built Up	6.61	2.72
Thick Vegetation	81.509136	33.56
Light Vegetation	82.54	33.99
Forest-Scrub	19.97	8.22
Plantation	7.21	2.97
Agricultural Land	3.10	1.28
Natural Grassland & Grazing	0.05	0.02
Shifting Abandoned	20.95	8.62
Shifting Current	16.88	6.95
Waterbody	3.95	1.63

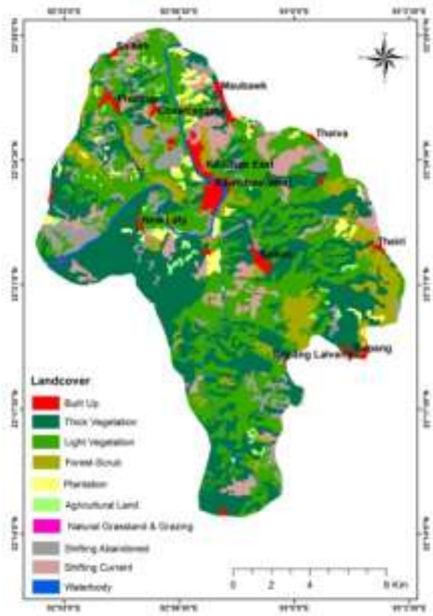

Fig. 9: Diffrerent landuse of the study area

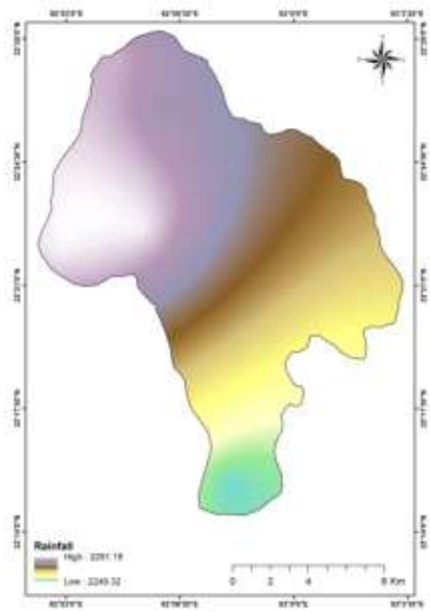

Fig. 10: The mean rainfall map for 10 years between 2011-2021

Table 8
Fundamental scale of absolute numbers

Strength of significance	Explanation
1	Equal significance
3	Medium significance
5	Strong
7	Very strong significance
9	Maximum significance
2,4,6 and 8	Interim number between two adjacent numbers

Table 9
Ratio Index (RI)

N	3	4	5	6	7	8	9	10
RI	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

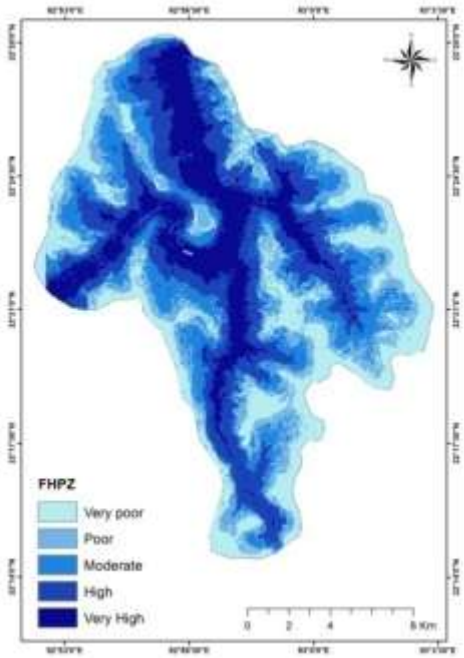

Fig. 11: Flood hazard zonation of upper Kolodyne

Also, the assigned and normalized weight and ranks for individual classes which depict the different parameters with their class, weight, assigned ranks and normalized ranks are shown in table 10.

Conclusion

Flood hazard maps are important tools for determining the vulnerability of flood-prone areas along rivers. This study focuses on assessment of potential flood hazard zones in the upper Kolodyne watershed which has experienced floods on a yearly basis with varying degrees of severity. The assessment of the upper Kolodyne watershed using GIS and multi-criteria decision analysis has categorized the watershed into five potential flood hazard zonation areas. These range from very poor, poor, moderate, high and very high flood hazard areas. Out of the 242.97 sq km of the basin area, 47.90 sq km of the area situated in the periphery of the watershed is categorized as very poor flood hazard zone. These areas are the safest places for dwelling in the watershed but they are located farthest from the Kolodyne river. They normally are the high elevated areas and are often the crest of hills and ridges. The very poor flood hazard zone constitutes 20.01 % of the total watershed area. The poor category for potential flood hazard zone encompasses an area of 45.34 of the upper Kolodyne watershed.

They are also located far away from the main rivercourse as compared to the other zones and they constitute 18.94 % of the total area. Using the multi-criteria decision analysis, 47.99 sq km of the watershed is located in the moderate zone for potential Flood hazard which constitutes 20.04% of the watershed. The areas covering the largest areas of the upper Kolodyne watershed falls in the high hazard zones for flood hazard zonation.

Table 10
Assigned and normalized weight and ranks for individual classes

Parameters	Class	Weight	Assigned Rank	Normalized rank (NR)
Slope	<15^0	18	5	0.33
	16^0- 25^0		4	0.27
	26^0- 35^0		3	0.20
	36^0- 45^0		2	0.14
	>45^0		1	0.06
Drainage Density	0-2.94	19	1	0.03
	2.94-5.37		5	0.17
	5.37-8.04		7	0.23
	8.04-11.10		8	0.27
	11.10-16.92		9	0.30
Elevation	24-336	30	9	0.41
	336-572		7	0.32
	572-810		3	0.14
	810-1081		2	0.09
	1081-1652		1	0.04
Rainfall	High	12	9	1
Topographic Curvature	-24.15 – -2.66	2	1	0.33
	-2.66 – -0.76		2	0.27
	-0.76 – 0.87		3	0.20
	0.87 – 4.13		4	0.14
	4-13 – 44.94		5	0.06
Landuse	Built Up	6	2	0.05
	Thick Vegetation		2	0.05
	Light Vegetation		3	0.08
	Forest-Scrub		4	0.11
	Plantation		3	0.08
	Agricultural Land		4	0.11
	Natural Grassland & Grazing		4	0.11
	Shifting Abandoned		3	0.08
	Shifting Current		3	0.08
	Waterbody		9	0.25
Soil	Clayey skeletal soil	4	5	0.19
	Coarse Loamy soil		5	0.19
	Fine Loamy soil		4	0.15
	Fine silty soil		5	0.19
	Fine to Coarse Loamy soil		4	0.15
	Loamy skeletal soil		3	0.13
Flow accumulation	0-13,937.25	9	3	0.12
	13,937.25-53,519.05		4	0.16
	53,519.05-86,410.98		5	0.20
	86,410.98-113,728		6	0.24
	113,728.98-142,160		7	0.28

Table 11
Summarized values for Kolodyne Flood Hazard map

Category	Area (Sq. Km)	Percentage
Very poor	47.90	20.01
Poor	45.34	18.94
Moderate	47.99	20.04
High	58.73	24.53
Very high	43.01	16.46

They encompass a total area of 58.73 sq km which is the widest area among the different categories zones and they constitute 24.53 % of the total watershed. The areas lying closest to the river are categorized as the very high flood hazard zone which constitutes a total area of 43.01 sq km of the watershed. Most of the dwelling and occupation livelihoods are located within this zone and constitute about 16.46 % of the area. The summarized value for the flood hazard zonation map is given in table 11.

Flood control measures along the Kolodyne must include planting vegetation and protecting them to retain surplus water, terrace slopes to limit slope flow and building man-made channels to divert water from flooding as well as the construction of irrigation channels, dykes, dams and reservoirs wherever applicable. Every effort must be worked out to establish the cause-effect relationship between human activities and the periodical floods caused by the Kolodyne to check the loss of human life and property.

Acknowledgement

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