Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454

Vol. 21 | No. 1 | pp. 101-109 | 2022

Original Research Paper

https://doi.org/10.46488/NEPT.2022.v21i01.011

Open Access Journal

Assessment of Flood Hazard Zonation Using Geographic Information System and Analytical Hierarchy Process: A Case Study of Tlawng River Watershed in Sairang, Mizoram, India

Malsawmtluanga*† and Ch. Vabeihmo**
Department of Geology, Lunglei Govt College, Mizoram-796 701, India
Department of Geology, NEHU, Shillong-793022, Meghalaya, India
†Corresponding author: Malsawmtluanga; mstmzu.gps@gmail.com

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 04-06-2021
Revised: 26-06-2021
Accepted: 13-07-2021

Key Words:
Flood hazard
GIS
AHP
Tlawng river watershed

ABSTRACT

Flood occurs when the water inundates normally dry ground, which could happen in a variety of ways like excessive rainfall, overflowing of embankments, dams, rivers, snowmelt, and other factors. Floods are one form of a natural hazard which are difficult to contain and control. A flood susceptibility mapping using Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) techniques were carried out at Sairang village in Aizawl, Mizoram in Northeast India. The study area Sairang is situated on the banks of the Tlawng river, the longest river in Mizoram. Floods have wreaked havoc in Sairang frequently resulting in huge losses and damage to property with numerous loss of life over the years. The total study area is 131.27 sq km and the resulting flood hazard potential zonation map shows that 1/3 of the watershed area falls in Vey High and High Potential Flood Hazard Zonation areas.

INTRODUCTION

Sairang in Mizoram is a thriving village in the Northwestern part of Aizawl, the capital of Mizoram. The NH306, Mizoram's lifeline which connects to the rest of the country runs through the village which is 20 km from Aizawl. The Tlawng river basin enhances Sairang's local economy as well as supplies a majority of the sand for construction activities in and around Aizawl city. Apart from small-scale and marginal farming, fishing, recreational activities, and other sources of income are practiced along the river, as are a variety of other economic activities. However, in the Tlawng river basin in Sairang, floods have caused disasters frequently in the past decade (Lalhmingliana et al. 2019). The watershed lies between 92° 35′0″ E, 23°50′0″N to 92°45′0″E 23°50′0″N and is covered under Toposheet sheet no.84 A/9 by the Survey of India Fig.1.

Flood Hazard maps provide useful and critical information to help people and authorities to understand the risks of natural disasters, to aid in disaster mitigation and its management. And because of these reasons, many workers have been using GIS-AHP methods to successfully delineate flood hazard zonations across the world (Ouma & Tateishi 2014, Gigovic et al. 2017, Khaleghi & Mahmoodi 2017, Das 2018, Hammami et al. 2019, Ghezelsofloo & Hajibigloo 2020). Also, preparations of flood Ajin hazard maps using GIS-AHP have been successfully implemented in many areas in mainland India (Sinha et al. 2008, Ajin et al. 2013,

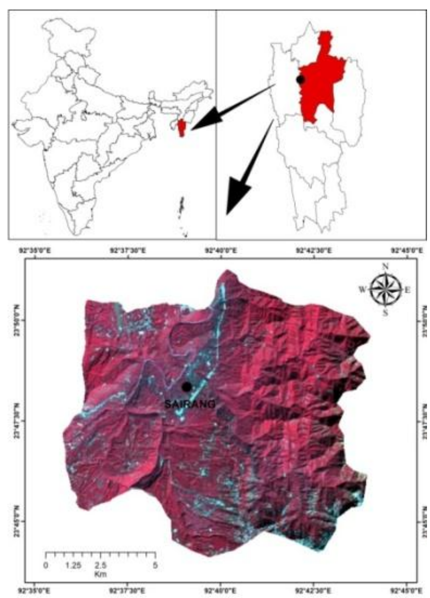

Fig.1: Location map of the study area Sairang, Mizoram in northeast India.

Das et al. 2017, Dash & Sar 2020, Vignesh et al. 2020). In the mountainous regions of Northeast India, flood hazard maps were prepared to tackle flooding in the river basins (Ganguly & De 2015, Hazarika et al. 2016, Laikangbam et al. 2019). Flood hazard mapping along the Tlawng river basin in Sairang in Aizawl will make it possible to quantify what is at risk of flooding, such as the number of households, economic activities, and businesses, etc that are under threat from floods.

MATERIALS AND METHODS

A toposheet map at a scale of 1:50,000 obtained from the Survey of India, as well as satellite photos Landsat-8 and Digital Elevation Model (DEM) of *ALOS PALSAR* (12.3 m resolution), were utilized to create thematic layers in a GIS environment to delineate the flood hazard potential zone of the Sairang watershed. Alaska Satellite Facility provided *ALOS PALSAR* (DEM) with a resolution of 12.3 m, which was processed in *ArcMap 10.2* software to outline the watershed and provide elevation, slope, and curvature maps. The resultant drainage network, drainage density, and flow accumulation were created using *ArcMap 10.2* software. The United States Geological Survey (USGS) Landsat-8 satellite photos of the study area were subsequently processed in *ERDAS IMAGINE 2014* and *ArcMap 10.2* software to create the land use classification and vegetation cover maps. Rainfall data for the last eight years was obtained (Economics and Statistics 2019). The mean rainfall for the eight years was processed in *Microsoft Excel* software, and the data were then spatially interpolated using the Inverse Distance Weighted (IDW) method to produce the rainfall distribution map. The soil map was derived from Maji et al. (2001) and was geo-referenced and digitized before being used to construct theme layer maps. Following the production of the theme layers, all of the layers were converted to raster format and used for the overlay analysis. During weighted overlay analysis, a rank was assigned to each individual parameter of each thematic layer map, and weights were assigned based on the output of the MCDM (AHP) approach, and the resulting output map depicts the flood hazard potential zones of the research area. The schematic graphic depicts the approach used in this investigation (Fig. 2.)

Analytical Hierarchy Process

The AHP assigns a weight to each evaluation criterion based on the decision-pair-wise maker's comparisons of the criteria, as shown in Table 1. The consistency ratio has been tested for accuracy. The following equation would be used to check the table's consistency ratio.

Strength of Significance Explanation

After completion of preparing the data layers, the variables were weighted according to the Analytical Hierarchical Process (AHP) method, which is a multi-criteria decision-making process based on a 9-point scale (Table 1) (Saaty 1980). Following the construction of a decision hierarchy, this method involved a pair-wise evaluation of the relative preferences of a small number of decision criteria for flood risk assessment. Experts assign weights to form the pair-wise comparison matrix (Saaty 2008). These weights were calculated automatically using *Expert Choice* software's Multi-Criteria Decision Analysis (MCDA) tool (Siddayao et al. 2015). The AHP approach used pair-wise comparisons of all the criteria as inputs and the relative weights of the crite-

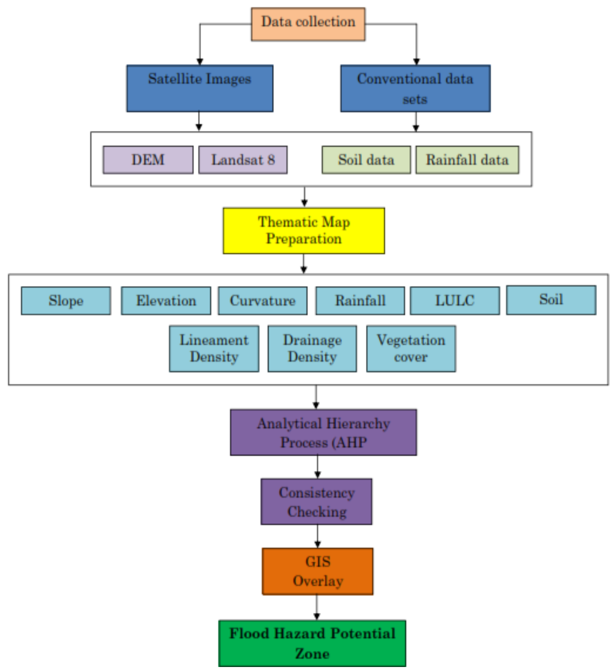

Fig.2: Flow chart of methodologies used in the study.

Table 1: The fundamental scale of absolute numbers (Saaty 1980).

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

rion as outputs. Furthermore, because the final weightings for the criteria are the normalized values of the Eigenvectors associated with the highest Eigenvalues of the AHP matrix, its consistency must be checked. The consistency of the comparisons was then examined using the consistency ratio (CR). The consistency ratio (CR) cannot be more than 0.1.

As a result, CR is a numerical index used to assess the consistency of the pairwise comparison matrix, and it is defined as

$$CR=CI/RI$$

Where CI stands for Consistency Index and RI stands for Random Index.

$$CI = \lambda\ max-n/n-1$$

Where ‘λ max’ is the main Eigenvalue and ‘n’ is the number of comparisons.

RESULTS AND DISCUSSION

Results

The different elevation values of the areas in Sairang are represented in the Elevation map Fig. 3 and the elevation values are given in Table 2.

The areas near the Tlawng river in Sairang are represented by variable slope angles which are represented in degrees. They range from the lowest slope angle category (Very gentle slope) to the highest slope angle (Escarpment/cliff) category (Fig.4) and the areas covered in sq km are given in Table 3.

Table 2: Elevation details of the study area.

Height [in m]	Area [Sq km]	Percentage [%]
59 – 266.435	26.77	20.39
266.436 – 439.298	35.26	26.85
439.299 – 594.874	33.45	25.48
549.875 – 776.380	23.04	17.55
776.381 – 1156.678	12.77	9.72

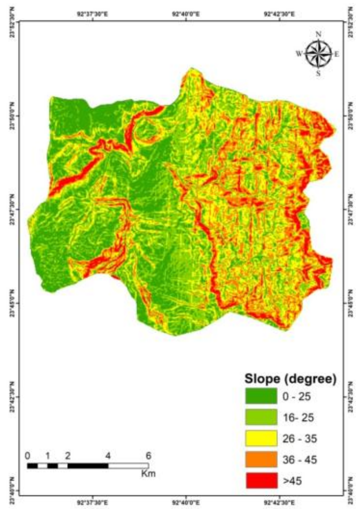

Fig. 4: Variable slope angles of the study area.

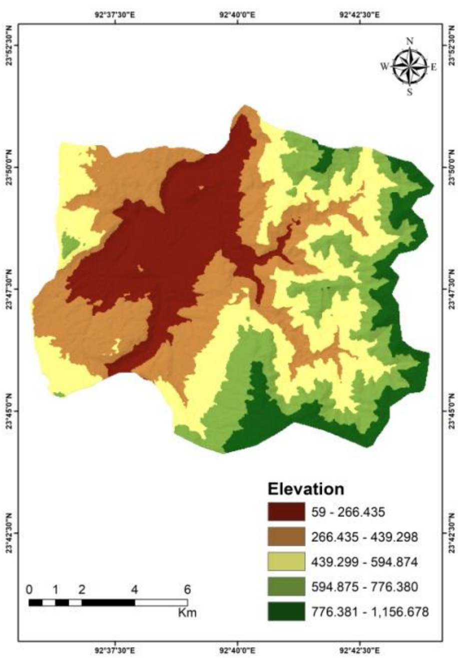

Fig. 3: Elevation map of the study area.

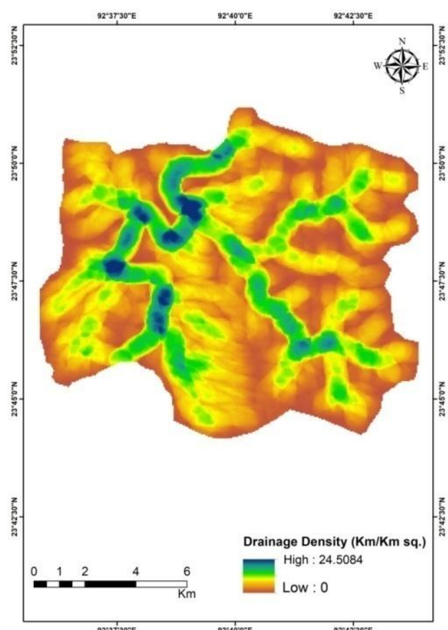

Fig. 5: Drainage density of the different areas in the watershed.

Drainage and drainage density factors are critical for calculating and assessing flood-prone locations along the Tlawng River. The drainage density calculations are given in Table 4 and the drainage density and drainage areas in and around Sairang village are given in Fig. 5 and Fig. 6 respectively.

A relevant part of waterlogging can be described by the flow accumulation which is the water flow below the downslope of the Tlawng river and it represents the ability to drain the excess water in the watershed area. This is represented by the flow accumulation values given in Table 5 and is also represented in Fig. 7.

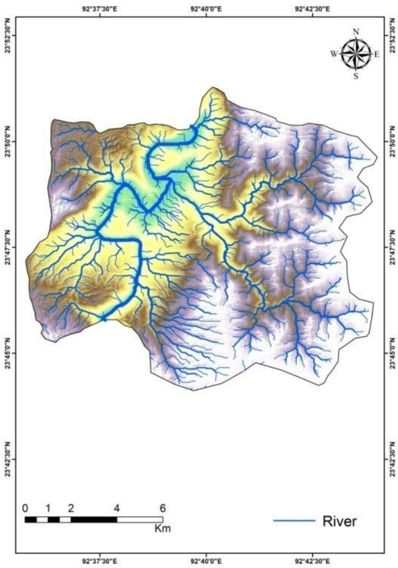

Fig. 6: Drainage of Tlawng river in Sairang.

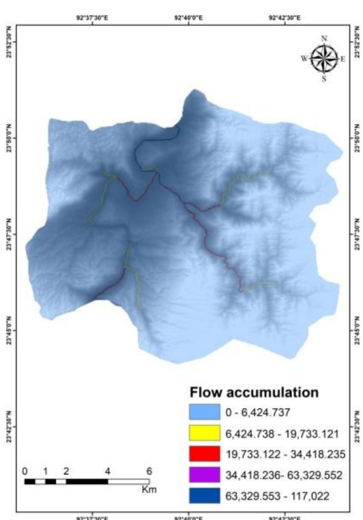

Fig. 7: Flow accumulation of different areas of the watershed.

The occurrence of floods is determined by the slope curvatures. The curvature values are given in Table 6 and are represented in Fig. 8. The areas having curvature values of -0.31-0.49 have the strongest correlation for the occurrence of floods. This covers 40.81% of the watershed area.

The thematic map for Land Use/ Land Cover for Sairang village is represented in Fig. 9 and the LULC values are given in Table 7. The built-up and cropland plantations have higher flood hazard values as compared to the other Land Use/ Land Covers.

The vegetation areas near the Tlawng river with different values are given in Table 8 and the different vegetation

Table 3: Slope angles of the study area.

Slope Angle	Category	Area [Sq km]	Percentage [%]
$<15^{o}$	Very gentle slope	30.95	23.57
16^{o}-25^{o}	Gentle slope	37.10	28.26
26^{o}-35^{o}	Moderately slope	31.36	23.89
36^{o}-45^{o}	Steep slope	22.82	17.39
$>45^{o}$	Escarpment/cliff	9.03	6.88

Table 4: Drainage Density of the study areas.

Category	Area [Sq km]	Percentage [%]
0 – 3.13	41.36	31.39
3.14 – 6.04	36.79	27.92
6.05 – 9.28	31.08	23.59
9.29 – 13.33	16.30	12.37
13.34 – 24.51	6.21	4.71

Table 5: Flow accumulation.

Category	Area [Sq km]	Percentage [%]
0 – 6,424.737	130.43	99.35
6,424.738 – 19,733.121	0.35	0.27
19,733.122 – 34,418.235	0.32	0.24
34,418.236 – 63,329.552	0.05	0.04
63,329.553 – 117,022	0.13	0.10

Table 6: Different areas with different curvature categories.

Category	Area [Sq km]	Percentage [%]
-9.68 – -1.49	5.67	4.32
-1.50 – -0.30	39.82	30.33
-0.31 – 0.49	53.58	40.81
0.50 – 1.57	26.75	20.38
1.58 – 15.39	5.46	4.16

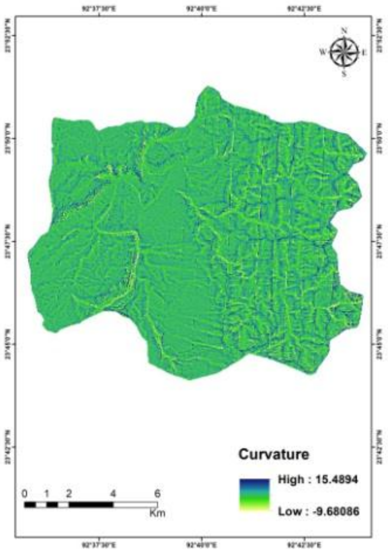

Fig. 8: Areas representing the Low and High Curvatures.

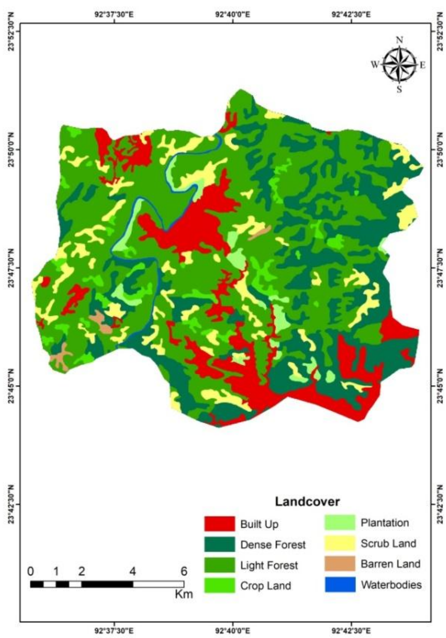

Fig. 9: Land Use classes in and around Sairang village.

covers are represented in Fig. 10. The vegetative areas in the Sairang watershed have low flood hazards as there is a negative relationship between floods and vegetative cover density. The volume and pace of stormwater runoff are significantly reduced by vegetation and this prevents soil erosion and lowers flooding. The rainfall map and the soil map are given in Fig. 11 and Fig. 12 respectively.

Table 7: Different Land Use/ Land Cover classes.

Description	Area [Sq km]	Percentage [%]
Built Up	17.86	13.58
Dense Forest	32.19	24.48
Light Forest	61.53	46.80
Crop Land	4.15	3.15
Plantation	3.31	2.52
Scrub Land	10.72	8.16
Barren Land	0.75	0.57
Water bodies	0.95	0.73

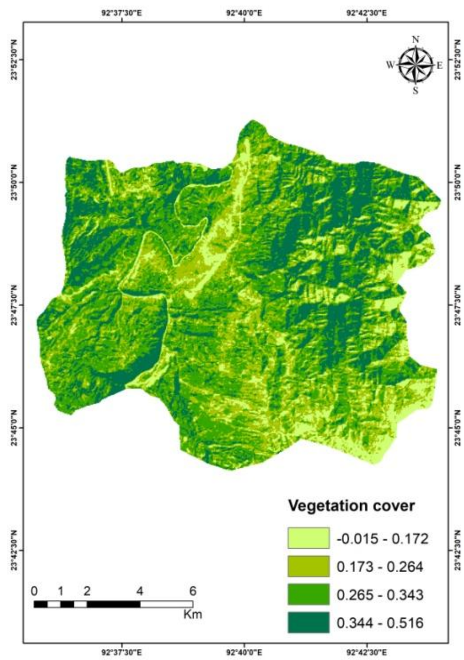

Fig. 10: Different vegetative covers in and around Sairang village.

Table 8: Vegetation cover in Sairang.

Category	Area [sq km]	Percentage [%]
-0.015 – 0.172	14.55	11.05
0.173 – 0.264	35.39	26.89
0.265 – 0.343	50.60	38.45
0.344 – 0.516	31.08	23.61

Consistency Ratio

$$CR = CI/RI$$

$$CI = \lambda\ max-n/n-1$$

$$\lambda\ max=9.73$$

CI = 0.09

RI = 1.45

CR = 0.06 which is <0.1

Hence the consistency ratio is<0.1 and which is significant and the assigned weightage value is acceptable. To obtain the Consistency ratio 'CR', the Ratio Index 'RI' is given in Table 9 and the pair-wise comparison matrix and normalized weight in Table 10. To obtain the weight

Table 9: Ratio index (RI) table for various n scores.

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

Table 10: Pair wise comparison matrix and normalized weight.

Thematic map	Elevation	Slope	Drainage Density	Rainfall	Flow Accumulation	Landuse	Soil	Vegetation Cover	Curvature	Normalized Weight
Elevation	1.000	2.000	2.000	3.000	4.000	5.000	6.000	6.000	6.000	0.27
Slope	0.500	1.000	1.000	2.000	3.000	5.000	5.000	6.000	6.000	0.18
Drainage Density	0.500	1.000	1.000	2.000	3.000	5.000	6.000	6.000	6.000	0.19
Rainfall	0.333	0.500	0.500	1.000	2.000	3.000	4.000	6.000	6.000	0.12
Flow accumulation	0.250	0.333	0.333	0.500	1.000	2.000	3.000	5.000	6.000	0.09
Landuse	0.200	0.200	0.200	0.333	0.500	1.000	2.000	4.000	6.000	0.06
Soil	0.167	0.200	0.167	0.250	0.333	0.500	1.000	3.000	4.000	0.04
Vegetation cover	0.167	0.167	0.167	0.167	0.200	0.250	0.333	1.000	3.000	0.03
Topographic Curvature	0.167	0.167	0.167	0.167	0.167	0.167	0.250	1.000	1.000	0.02
SUM	3.283	5.567	5.533	9.417	14.200	21.917	27.583	38.000	44.000	**1.00**

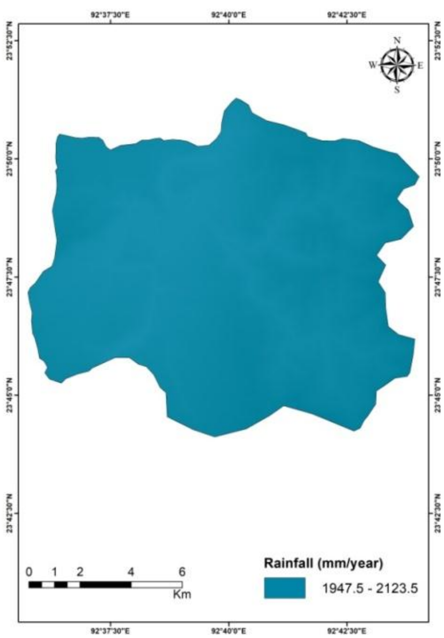

Fig.11: Rainfall map of Sairang watershed area.

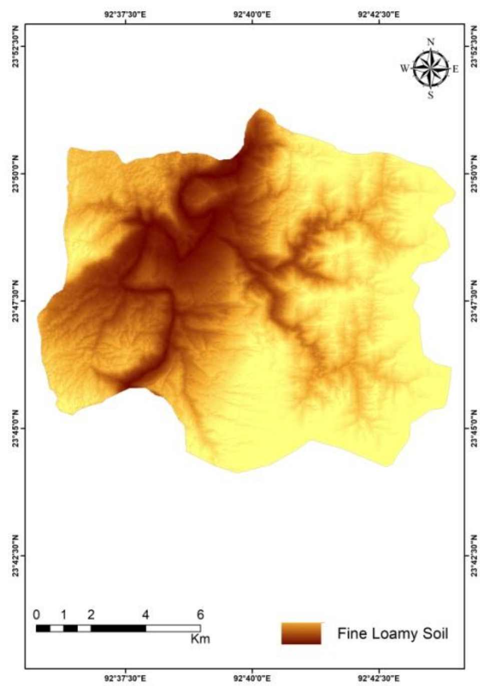

Fig. 12: Soil map of Sairang watershed area.

and ranks for each class, the aggregated weights for each parameter were given in Table 11 and the Assigned, Normalized weight and Ranks for the individual classes in Table 12.

Estimation of the Flood Hazard Potential Index (FHPI)

All of the aforementioned criteria were created as themed layers. It is also weighted and rated based on the nature of

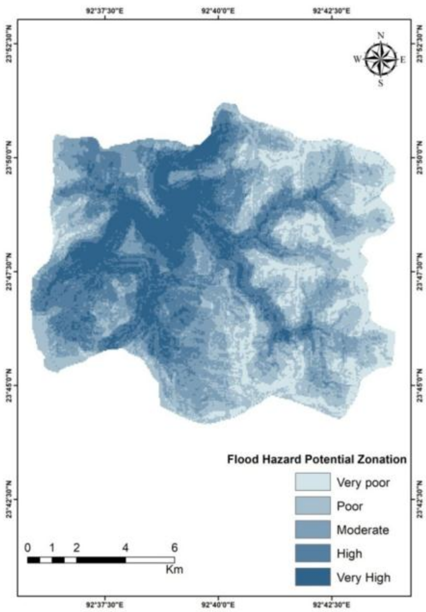

Fig. 13: Flood hazard potential zone map.

its effects. The AHP technique was used to assign weightage. It is ranked based on its priorities. The weighted and ranked

Table 11: Aggregated weight for each parameters.

Elevation	0.27
Slope	0.18
Drainage Density	0.19
Rainfall	0.12
Flow accumulation	0.09
Landuse	0.06
Soil	0.04
Vegetation cover	0.03
Topographic Curvature	0.02

layers were integrated into the *ArcGIS 10.2* software's GIS environment. The table showed the weightage and rank. Flood hazard potential index can be calculated accordingly:

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

Where, W – Weightage, R- Rank, s – Slope, e – Elevation, cv – Curvature, vg – Vegetation Cover, dd- Drainage Density, r- Rainfall, t- Soil Texture, lu- Landuse, fa- Flow accumulation

Table 12: The Assigned, Normalized weight and Ranks for the individual classes.

Parameters	Class	Weight	Assigned Rank	Normalized Rank (NR)
Elevation	59 – 266.435	27	9	0.41
	266.436 – 439.298		7	0.32
	439.299 – 594.874		3	0.14
	549.875 – 776.380		2	0.09
	776.381 – 1156.678		1	0.04
Slope	$<15^{O}$	18	5	0.33
	16^{O}-25^{O}		4	0.27
	26^{O}-35^{O}		3	0.2
	36^{O}-45^{O}		2	0.13
	$>45^{O}$		1	0.07
Drainage Density	0 – 3.13	19	1	0.03
	3.14 – 6.04		5	0.17
	6.05 – 9.28		7	0.23
	9.29 – 13.33		8	0.27
	13.34 – 24.51		9	0.30
Rainfall	1947.5 – 2123.5	12	9	1

Table cont....

Parameters	Class	Weight	Assigned Rank	Normalized Rank (NR)
Flow accumulation	0 – 6,424.737	9	3	0.12
	6,424.738 – 19,733.121		4	0.16
	19,733.122 – 34,418.235		5	0.20
	34,418.236 – 63,329.552		6	0.24
	63,329.553 – 117,022		7	0.28
Land Use	Built Up	6	3	0.11
	Dense Forest		1	0.04
	Light Forest		2	0.07
	Crop Land		3	0.11
	Plantation		3	0.11
	Scrub Land		4	0.15
	Barren Land		4	0.15
	Water bodies		7	0.26
Soil	Fine Loamy Soil	4	3	1
Vegetation cover	-0.015 – 0.172	3	4	0.40
	0.173 – 0.264		3	0.30
	0.265 – 0.343		2	0.20
	0.344 – 0.516		1	0.10
Topographic Curvature	-9.68 – -1.49	2	1	0.07
	-1.50 – -0.30		2	0.13
	-0.31 – 0.49		3	0.20
	0.50 – 1.57		4	0.27
	1.58 – 15.39		5	0.33

Table 13: Flood Hazard potential zone of Sairang

Category	Area	Percentage
Very poor	17.05	13.11
Poor	33.85	36.01
Moderate	30.43	23.39
High	29.64	22.78
Very high	19.15	14.72

DISCUSSION

combining GIS and AHP for assessing flood susceptibility mapping in and around Tlawng river in the Sairang watershed area, a flood hazard zonation map was created based on different criteria such as slope, elevation, flow accumulation, drainage density, curvature, drainage (size of the watershed), soil, vegetation cover, LULC, and rainfall. Results for the study show that in this area, the flow accumulation, the elevation of the location of habitat areas, the distance from the Tlawng river drainage network, and the degree of the slope are crucial for the flood risk in and around the Sairang watershed area. The resultant flood hazard potential zone of Sairang in Aizawl is categorized into five classes: Very Poor, Poor, Moderate, High, and Very High zones Fig.13. The affirmation and verification of this flood hazard map for Sairang are validated by flood events that have occurred in the Very High and High flood hazard areas of Sairang. Areas of the catchment, sub-catchment and the Tlawng river flood plain all have the potential for flooding.

More than 1/3 of the total watershed areas are lying in the Very High and High Hazard zones. 22.78% of the watershed falls in the High hazard zones and 14.72% of the watershed falls in the Very High Hazard zones (Table 13). Farming, fishing, and other activities which are carried out in the catchment area are all prone to flooding. To reduce flood risks along the Tlawng river and for flood hazard mitigation, integrated catchment management along the river should be developed. The local authorities, government officials, and other stakeholders can use this flood hazard potential zonation map to reduce the impact of floods in this hilly catchment area.

ACKNOWLEDGMENT

Malsawmtluanga is thankful to the Ministry of Earth Sciences, Govt of India for the work which is carried out under the project sanction no MoES/PAMC/H&C/ 115/ 2018-PC-II dated 24.01.2020.

REFERENCES

Ajin, R.S., Krishnamurthy, R.R., Jayaprakash, M. and Vinod, P.G. 2013. Flood hazard assessment of Vamanapuram river basin, Kerala, India: An approach using remote sensing & GIS techniques. Adv. Appl. Sci. Res., 4(3): 263-274.

Danumah, J. H., Odai, S. N., Saley, B. M., Szarzynski, J., Thiel, M., Kwaku, A., Kouame, F.K. and Akpa, L. Y. 2016. Flood risk assessment and mapping in Abidjan district using multi-criteria analysis (AHP) model and geoinformation techniques, (Cote D'Ivoire). Geoenvironmental Disasters., 3(1): 1-13.

Das, B., Pal, S.C. and Malik, S. 2017. Assessment of flood hazard in a riverine tract between Damodar and Dwarkeswar river, Hugli district, West Bengal, India. Spatial Infor. Res., 26(1): 91-101.

Das, S. 2018. Geographic information system and AHP-based flood hazard zonation of Vaitarna basin, Maharashtra, India. Arab. J. Geosci., 11(19): 1-13.

Dash, P. and Sar, J. 2020. Identification and validation of potential flood hazard areas using GIS-based multi-criteria analysis and satellite data-derived water index. J. Flood Risk Manag., 13(3): 1-14.

Economics and Statistics. 2019. Statistical Handbook of Mizoram. Govt of Mizoram, pp. 78.

Ganguly, K. and De, S.K. 2015. Spatio-temporal analysis of flood and identification of flood hazard zone of West Tripura district, India using Integrated Geospatial Technique. Hill Geograp., 31(1): 1-22.

Ghezelsofloo, A.A. and Hajibigloo, M. 2020. Application of flood hazard potential zoning by using AHP Algorithm. Civil Eng. Res. J., 9(5): 150- 159.

Gigovic, L., Pamučar, D., Bajić, Z. and Drobnjak, S. 2017. Application of GIS-interval rough AHP methodology for flood hazard mapping in urban areas. Water. 9(6): 360-366.

Hammami, S., Zouhri, L., Souissi, D., Souei, A., Zghibi, A., Marzougui, A. and Dlala, M. 2019. Application of the GIS-based multi-criteria decision analysis and analytical hierarchy process (AHP) in the flood susceptibility mapping (Tunisia). Arabian J. Geosciences., 12(21): 1-16.

Hazarika, N., Barman, D., Das, A.K., Sarma, A.K. and Borah, S.B. 2018. Assessing and mapping flood hazard, vulnerability, and risk in the upper Brahmaputra River valley using stakeholders' knowledge and multicriteria evaluation (MCE). J. Flood Risk Manag., 11: 700-716.

Khaleghi, S. and Mahmoodi, M. 2017. Assessment of flood hazard zonation in a mountainous area based on GIS and analytical hierarchy process. Carpathian J. Earth Environ. Sci., 12(1): 311-322.

Laikangbam, L., Loukrakpam, C. and Singh, T. S. 2019. Flood hazard zonation of Imphal river, Manipur, India, using AWS data. Int. J. Eng. Adv. Technol., 8(4): 1676-1680.

Lalhmingliana., R., Ch, U.B. and Saha, G. 2019. Computational water management strategy of Tlawng river basin using geoinformatics. Environ. Eng. Res., 25(5): 693-699.

Maji, A.K., Dubey, P.N., Sen, T.K., Verma, T.P., Marathe, R.A., Chamuah, G.S. and Gajbhiye, K.S. 2001. Soils of Mizoram: Their kinds, distribution, characterization, and interpretations for optimizing land use. NBSS Publ., 75: 28.

Ouma, O.Y. and Tateishi, R. 2014. Urban flood vulnerability and risk mapping using integrated multi-parametric AHP and GIS: Methodological overview and case study assessment. Water, 6(6): 1515-1545.

Saaty, T.L. 1980. The Analytic Hierarchy Process. Mcgraw Hill, New York, pp.70.

Saaty, T.L. 2008. Decision making with the analytic hierarchy process. Int. J. of Ser. Sci., 1(1): 83-98.

Siddayao, G.P., Valdez, S.E. and Fernandez, P.L. 2015. Modeling flood risk for an urban CBD using AHP and GIS. Int. J. Inform. Edu. Technol., 5(10): 748-753.

Sinha, R., Bapalu, G.V. Singh., L.K. and Rath, B. 2008. Flood risk analysis in the Kosi river basin, north Bihar using the multi-parametric approach of analytical hierarchy process (AHP). J. Indian Soc. Remote Sens., 36(4): 335-349.

Vignesh, K.S., Anandakumar, I., Ranjan, R. and Borah, D. 2021. Flood vulnerability assessment using an integrated approach of multi-criteria decision-making model and geospatial techniques. Model. Earth Sys. Environ., 7(2): 767-781.