ISSN 1870-4069

Geoinformatics Based Mapping and Assessment of Flood Risk in Periyar River Basin, South India: A Pairwise Weighted Approach

Sreelakshmi A.R.[1], Sumith Satheendran S.[2], Latha P. [3]

[1] College of Engineering Trivandrum,
Department of Civil Engineering,
Environmental Engineering Division,
India

[2] Dr. R. Satheesh Centre for Remote Sensing and GIS,
School of Environmental Sciences,
India

Mahatma Gandhi University Kottayam, Kerala,
India

ar.sreelakshmi95@gmail.com

Abstract. Flood risk assessment is important to be carried out in areas susceptible to flood so that proper urban planning can be done accordingly. Periyar is the longest river in the state of Kerala which is known as the "Lifeline of Kerala". The Periyar river basin experienced an increasing number of flood events over years and highlighted the need for flood-related studies. GIS-based multi-criteria evaluation was performed to determine the flood risk assessment in the present study. The identification of flood risk zones was done by the Analytical Hierarchy Process and pairwise weighted approach. The major parameters used in this study were Flood vulnerability, Flow accumulation, Topographical Wetness Index and Rainfall. From this study, 20.78 % area of the Periyar River basin was identified with high flood risk, 71.35% with moderate flood risk and 7.86% with low flood risk. The flood risk assessment will be helpful to figure out the mitigation measures and reduce the chances of future flooding damages.

Keywords: Flood risk, topographic wetness index (TWI), pairwise weightage.

1 Introduction

Flood is a natural disaster caused due to climate change, rapid urbanization, and population growth. Floods happen in different places in varying magnitude and their influence on people and the environment differs. Kerala is highly vulnerable to natural disasters and floods are the most common natural hazard in the state. Nearly 14.5% of the state's land area is prone to floods. The mega-floods of 2018 have impacted the economy and society of Kerala in many different ways. Floods and subsequent landslides caused extensive damages to houses, roads, railways, bridges, power supplies, communication networks, infrastructures, agriculture, and also the lives and livelihoods of millions of people in the state were affected. In the Periyar river basin, the increasing number of flood events over the years highlighted the need for flood-related studies.

1.1 State of Art

Flood is the most common natural hazard in the world and has caused serious loss of life and property (Xiao, Y. et al., 2017). Assessment of flood-prone areas is of great importance for watershed management and reduction of potential loss of life and property. Multi-Criteria Analysis (MCA) incorporating Geographic Information System (GIS), Fuzzy Analytic Hierarchy Process (AHP) and spatial Ordered Weighted Averaging (OWA) method are popular for flood hazard assessment. In risk assessment, the factors associated with geographical, hydrological and flood-resistant characteristics of the basin are selected as evaluation criteria.

For natural phenomena such as floods, G.I.S proves to be taking an effective role to make assessments. Multi-criteria decision-making can be adopted after considering different favoring factors that impact the flood. Analytical Hierarchy Process (AHP) has been performed in many research works.

The terms ‘‘flood risk’’ and ‘‘flood hazard’’ are often used synonymously (A. Shalikovskiy and K. Kurganovich, 2016). Recently two main approaches to risk assessment have been developed in the world. The first approach was based on an understanding that risk can be defined as the combination of hazard and vulnerability. Another approach relies on priority conception, according to which the qualitative methods of flood risk assessment are used.

For endangering natural hazards like floods, GIS can play a critical role with its visualization capacity to make results from assessments (Mohamad et al., 2019). For natural phenomena such as floods, G.I.S proves to be taking an effective role to make assessments. Multi-criteria decision-making can be adopted after considering different favoring factors that impact the flood. Analytical Hierarchy Process (AHP) has been performed in many research works. Assessment of flood risks, especially extreme floods, is required for any location that is faced with recurrent flooding events for proper implementation of proactive measures (Zulkhairi, MD et al., 2019).

Susceptibility factors such as elevation, slope, flow accumulation, topographic wetness index (TWI), drainage density, etc., are very useful while assessment and flood risk mapping through AHP (Kumar and Agrawal, 2020). Basan et al., (2019), consider the flood-affected LULC and its area extend determines the economic loss the flood caused. The flood risk map after the AHP process can be used to identify the high risk, medium risk, and low-risk areas.

Wondim, Y. K. (2016), conducted a study on Awash River, Ethiopia considered the application of GIS and Remote Sensing techniques on flood hazard/risk management process. Flood causative factors such as slope, elevation, drainage density, soil type and land cover were developed in the GIS environment.

Assessing risk from flood using composite hazard and vulnerability index has been a widely recognized tool that acts as an important element for the formulation of policies aiming at flood risk reduction (Ghosh and Kumar, 2019). To assess risk due to flooding using Analytical Hierarchical Processes, incorporating flood hazard elements and vulnerability indicators in the geographical information system environment. Flood hazard map has been prepared using selected morphological and hydro-meteorological elements whereas the vulnerability map has been produced using demographic, socio-economic and infrastructural elements.

Salam, A. and Rubeena, T.A, (2020), examines the temporal correlation of flood damages that occurred in Kerala and analyzed the peripheral land-use change of Periyar River for a stretch of 25 km flowing through Aluva and Paravur Taluks of Ernakulam District, Kerala. There is a huge expansion of the built-up area within 10 years around the river, which is highly prone to flood.

Flood risk assessment is important to be carried out in areas susceptible to flood so that proper urban planning can be done accordingly. This can also be used in forecasting and warning of floods. Due to the development of GIS technology, this can be used in spatial policy and space management systems, including the determination of ways to develop and use flood risk land in a planned way.

The present study aimed at flood risk assessment using Analytical Hierarchy Process (AHP), a pairwise weighted approach.

1.2 Study Area

Periyar (Big river) is the longest river in the state of Kerala with the largest discharge potential. Periyar is known as the "Lifeline of Kerala". Periyar River originates from the forest land of Sivagiri hills, 80 km South of Devikulam (2438 MSL) (CWC, 2018). Periyar River is about 244 km in length with a catchment area of 5398 km2. Periyar river mouth is Vembanad Lake and the Arabian Sea. The study area extends between 9º 0'0" - 10º 30'0" North latitudes, 76º 0'0" - 77º 30'0" East longitudes as shown in Fig 1.

1.3 Data Collection

The study area was delineated from Survey of India toposheets numbered 58B3, 58B7, 58B11, 58B15, 58F3, 58F7, 58B4, 58B8, 58B12, 58B16, 58F4, 58F8, 58C1, 58C5, 58C13, 58G11, 58G5, 58C14, 58G2, 58G6, 58C14, 58G2, 58G2, 58G6, 58G3 and 58G7. The remotely sensed satellite imageries of Sentinel-2 (10m spatial resolution) on February 7 and 12, 2021, were used to interpret the present land use/land cover of the study area. ALOS DEM, a 12.5 m elevation data from the Japanese Exploration Agency, was used to develop elevation, slope, aspect, curvature and stream density layer. Road networks were developed after vectorization from Google Earth. Soil data for the study area was developed from the Benchmark soils of Kerala (Soils of Kerala), Demographic data was taken from the Census of India 2011 report. Rainfall data for the study was sourced from the Global Precipitation Measurement Mission of NASA.

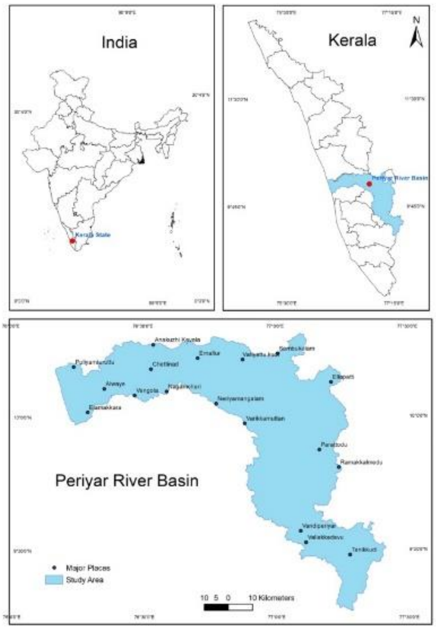

Fig. 1. Index map of the study area: Periyar river basin.

2 Methodology

In the present study, flood risk assessment through the Analytical Hierarchy Process, of the Periyar river basin was performed. The flood vulnerability assessment was done firstly by weighted overlay analysis and then this result was incorporated in the determination of flood risk. Different layers were selected depending on the topography of the area, referring to pieces of literature and also considering expert opinion.

2.1 Flood Vulnerability Assessment Using Weighted Overlay Analysis

Influencing thematic layers in raster form for determining the flood vulnerability includes: Elevation, Slope, Aspect, Curvature, Population density, Land use Land cover, Soil type, Stream density, Distance from road networks, and Distance from water body as shown in Fig 2.

In the flood vulnerability assessment, ten different influencing thematic layers were considered mainly Elevation, Slope, Aspect, Curvature, Population density, Land use Land cover, Soil type, Stream density, Distance from road networks, and Distance from the water body.

Elevation. The elevation is an important factor that affects flooding; low-level areas are more prone to flooding and were given more weightage. Elevation was categorized into different classes and weights were assigned. In the study area, the elevation ranged from 0 to 2705 m above the mean sea level.

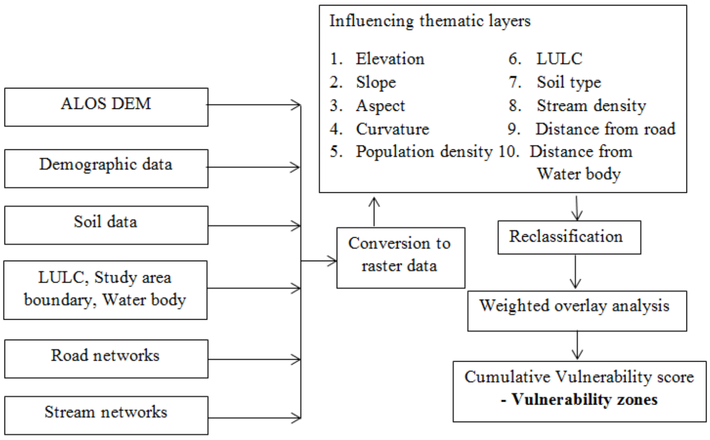

Fig. 2. Flow chart for flood vulnerability assessment.

Slope. Low slope areas are more prone to flooding. The slope is directly related to the runoff velocity, vertical percolation, and stream power in the downstream portion. The value ranged from 0 to 76.7872. The slope was derived from DEM using the slope function in the Arc toolbox.

Aspect. Aspect is the direction of the slope. The aspect was derived from DEM using the Aspect function in the Arc toolbox. Periyar River originates from the Sivagiri hills of Western Ghats and is located along the North-East border of the Idukki district in Kerala state. The mouth of the Periyar River is the Arabian Sea and Vembanad Lake. So the river flows from the North East to the West direction. Thus, priority was assigned in such a way that along the entire Periyar River basin, the West direction was given more preference. In the North West direction, there is flat land that is very vulnerable to flooding and thus highest priority was given accordingly.

Curvature. The curvature of Earth considers the topological characteristics of the study area. The curvature layer was developed from DEM and the values range between 1.40093 e^11 to 1.27303e^11. As the values changes from negative, zero to positive, curvature changes from concave, flat, and convex.

Population density. Taluk-wise population data of Ernakulam and Idukki district from Census 2011, after population forecasting using geometric method were used to develop population density layer. There were nearly 50 locations of major Census towns taken throughout the study area. Total population, male, female and children population in the age of 0 to 6 years were attributed. The population density layer was developed from the density tool of the Arc toolbox. The population growth rate was calculated using the formula:

$$Population\ growth\ rate\ = \left(Increase\ in \frac{population}{Original} population\right) \times 100. \tag{1}$$

Forecasted population of 2021:

$$[P2021 = P2011(1+r/100)]^{n}, \tag{2}$$

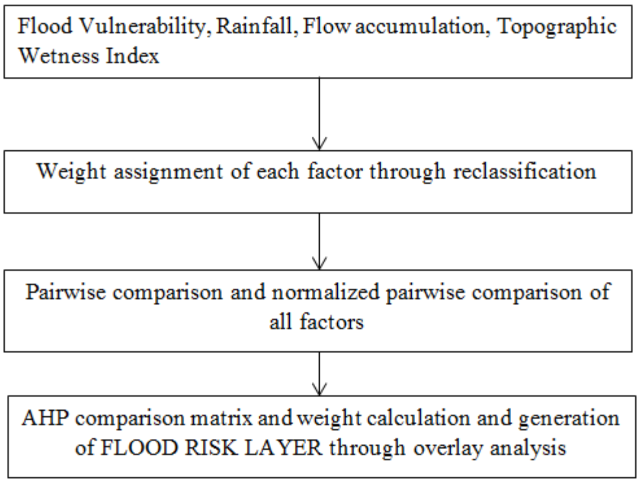

Fig. 3. Flow chart for flood risk assessment.

where, P2021 is forecasted population of 2021,
P2011 is population as per 2011 Census,
n is number of decades, here n = 1.

The population density was considered per km2 basis using density function in Arc toolbox. The values range between 0 to 16807.3.

Land use land cover (LULC). Land use/land cover affects the infiltration rate. Urban areas have low infiltration compared to forests. Land use pattern thus affects the flooding. An urbanized area generates more runoff and is thus more flood-prone. Iso-cluster unsupervised classification was performed to identify the different land use/land cover classes. For unsupervised classification, satellite image scenes of Sentinel 2 dated 07/2/2021 (2 scenes), 12/2/2021 (2 scenes) of the US Geological Survey were used. After unsupervised classification, different classes obtained were water body, paddy field, barren land and built-ups, vegetation, mixed crop, rocky land, and agricultural land.

Soil type. The nature of the soil in the particular area is very important while considering the infiltration characteristics. If infiltration is more there is less probability the water gets inundated and thus less flooding occurs. So, the soil type was taken district-wise into account in the present study and then finally considered as the entire Periyar river basin after topology correction. Soil data was sourced from Benchmark soils of Kerala (Soils of Kerala). The predominant soil types found were Alluvium, Black cotton soil, Acid saline soil, Red soil, Forest soil, Laterite soil, and Hill soil.

Stream density. The density of the stream is an important characteristic to be considered. As the stream density increases, there is more chance of easy drainage as thus less probability of flooding.

Distance from the road. As the distance from the road increases, there are fewer chances the area gets affected by the flood. In urban areas, the sewer systems are laid along the roads. Improper management of the drainages across the urban areas causes congestions and trouble for natural drainages and causes urban flooding.

Distance from the water body. As the distance from the water body decreases, the chance of flooding increases. After LULC classification, the water body was extracted separately and then converted to vector format using Raster to Polygon function in Arc GIS. The distance from the river was then calculated by using the Euclidean distance tool in the Arc toolbox. The distance varied from 0 to 17.516 km from the river to different points in the study area.

For generating a flood vulnerability map, layers were prepared for all the parameters, and reclassification was performed to provide weights. Table 1 shows the weights for different parameters in a hierarchical manner.

The reclassified influencing layers were assigned relative weights depending upon the influence in flooding. The order of priority is fixed after referring to the literatures:

$$\text{Cumulative vulnerability} = F1 * W1 + F2 * W2 + \ldots\ldots + Fn * Wn, \tag{3}$$

where, F is contributing factor reclassed with flood vulnerability score,

W is the relative weight applied to each contributing factor:

$$\text{Cumulative vulnerability} = 15*\text{Elevation} + 10*\text{Slope} + 10*\text{Aspect} + 10*\text{Curvature} + 5*\text{Population density} + 10*\text{Stream density} + 10*\text{LULC} + 10*\text{Soil type} + 5*\text{Distance from road} + 15*\text{Distance from water body}. \tag{4}$$

The cumulative flood vulnerability value ranged from 2 to 6. The cumulative vulnerability output thus generated, equally sized and then reclassified into four zones viz., Low, Moderate, High and Very highly vulnerable as shown in Table 2.

2.2 Flood Risk Mapping through Analytical Hierarchy Process – A Pairwise Weighted Approach

Analytical Hierarchy Process (AHP) is a powerful method of decision making considering all the influencing factors, assigning weights depending upon the priority and influence of that particular parameter on the matter considered.

Many parameters that help to evaluate the flood situation were considered as different layers. Flood vulnerability, Flow accumulation, Topographical wetness index (TWI), and Rainfall are considered in this study. Each parameter is divided into different classes and weights were assigned after pairwise comparison as given in Table 4. Normalized pairwise classification, as shown in Table 5, ensured all the weights are between 0 and 1 so that the relative importance is scaled and easily understandable. A consistency check was also performed to ensure that the pairwise comparison aided the right result. Finally, the flood risk layer was prepared through the weighted overlay technique. The cumulative flood risk obtained was reclassified into three zones i.e., High, Moderate, Low.

Table 1. Influencing thematic layers and Weights.

Influencing Thematic Layer	Weights
Elevation	15
Slope	10
Aspect	10
Curvature	10
Population density	5
Stream density	10
LULC	10
Soil type	10
Distance from the road	5
Distance from the water body	15

Table 2. Cumulative Flood Vulnerability.

Cumulative Flood Vulnerability	
2	Very high
2 – 3	High
3 – 4	Moderate
4 - 6	Low

Four influencing thematic layers used for flood risk assessment include: Flood vulnerability, Flow accumulation, Topographic Wetness Index and Rainfall.

Flood vulnerability. The flood vulnerability ranged from 2 to 6 were reclassified into different zones namely, very high (2), High (2–3), Moderate (3–4), and Low (4–6) as shown in Fig. 4. This is an important layer used for flood risk assessment that considers all the topographical features, land use classes, soil characteristics, and distance from the water body into consideration.

Flow accumulation. This is a crucial parameter for flood mapping. The hydrology tool of Arc Toolbox was used to generate this layer. More amount of accumulated flow naturally leads to increased runoff in a low elevated area and thus contributing to more flooding (Kumar and Agarwal, 2020). This layer was also classified into four classes and assigned weights as shown in Fig. 4. The value ranges from 0 to 4346195, with the highest score value at the highest flow accumulation.

TWI (Topographical Wetness Index). TWI is defined as, $TWI = \ln(\alpha/\tan\beta)$, where α is flow accumulation and β is the slope in radian. There is a strong relationship between TWI and geomorphology as well as the hydrographic position of an area. This index evaluation is capable of predicting saturated land surfaces that reserves the potential of producing overland flow (Kumar and Agarwal, 2020). TWI layer is useful to demonstrate flood inundated regions due to produced overflow at the time of high precipitation intensity. TWI was calculated using the raster calculator of ArcGIS. The value range of TWI varies from 1.033213 - 24.718002 as shown in Fig. 4.

Rainfall. Average annual rainfall from 2015 to 2020 was considered for the study. Monthly data source was from the Global Precipitation Mission of NASA.

Annual rainfall was calculated from monthly data of each year using a raster calculator in Arc GIS 10.8. Finally, the average annual rainfall for all five years was computed using a raster calculator. Average annual rainfall for five years varied from

Table 3. Influencing thematic layers, their classes, score value.

Influencing Thematic Layer	Score Value
Flood Vulnerability	
2	1
2 - 3	2
3 - 4	3
4 – 6	4
Flow accumulation	
0 - 10000	7
10000 - 25000	6
25000 - 50000	5
50000 - 75000	4
75000 - 100000	3
100000 - 125000	2
125000 - 4346195	1
TWI	
1.033213 - 3	7
3 - 6	6
6 - 9	5
9 - 12	4
12 - 15	3
15 - 18	2
18 - 24.718002	1
Rainfall	
1308.21 - 2000	7
2000 - 2500	6
2500 - 3000	5
3000 - 3500	4
3500 - 4000	3
4000 - 4500	2
4500 - 4682.39	1

1308.21 mm to 4682.39 mm as shown in Fig. 4. Score value increases as the annual average rainfall increases.

In the AHP process, relative weights for each influencing factor were fixed after pairwise comparison as shown in Table 4. The consistency check assures the weights assigned are correct (Kumar and Agarwal, 2020). The factors which were of very high importance, equal importance and less importance were assigned weights according to Saaty's scale (Wondim, Y. K., 2016). All pairwise comparisons are considered to be correct when the Consistency Ratio (CR) is within the permissible limit of inconsistency i.e., <10%.

In AHP, pairwise comparisons are correct when the Consistency ratio is within permissible limit of inconsistency (<10%):

$$\textit{Consistency ratio} = (\textit{Consistency index} / \textit{Random index}), \quad (5)$$

$$\textit{Consistency index} = (\lambda max - n) / (n - 1). \quad (6)$$

where, λmax = average of priority vector:

n = 4, Random index = 0.9 as per Table 6.

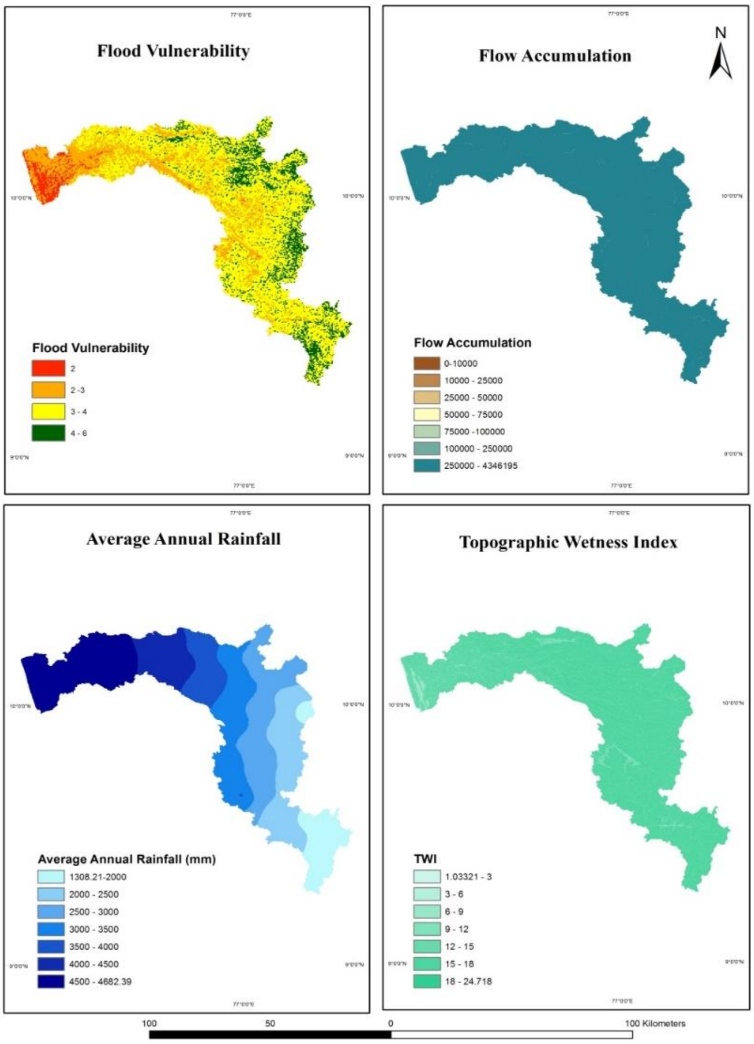

Fig. 4. Influencing thematic layers for flood risk assessment.

Table 4. Pairwise comparison matrix.

	Flood Vulnerability	**Flow Accumulation**	**Rainfall**	**TWI**
Flood Vulnerability	1.00	5.00	4.00	7.00
Flow Accumulation	0.20	1.00	0.50	3.00
Rainfall	0.25	2.00	1.00	3.00
TWI	0.14	0.33	0.33	1.00
SUM	1.59	8.33	5.83	14.00

Table 5. Normalized pairwise comparison matrix.

	Flood Vulnerability	**Flow Accumulation**	**Rainfall**	**TWI**	**Criteria Weights**
Flood Vulnerability	0.629	0.600	0.686	0.500	0.60
Flow Accumulation	0.126	0.120	0.086	0.214	0.14
Rainfall	0.157	0.240	0.172	0.214	0.20
TWI	0.090	0.040	0.057	0.071	0.06
SUM					1.00

Table 6. Random index (Dutta D., and Mahanty B., 2020).

n	**1**	**2**	**3**	**4**
Random index	0.00	0.00	0.58	0.9

Table 7. Criteria weights of factors for flood risk assessment.

Factors	**Weights**
Flood vulnerability	60
Flow accumulation	14
Rainfall	20
TWI	6

Here, consistency ratio obtained was 0.0431 < 10%, therefore the pairwise weight assignment for influencing factors was correct.

Weighted overlay analysis of different influencing thematic layers was performed of which the weighs obtained are given in Table 7. In this method, the cumulative flood risk score was derived similarly by using Equation 7:

$$\textit{Cumulative flood risk} = 60^{*}\,\textit{Flood vulnerability} + 14\,{*}\,\textit{Flow accumulation} + 20^{*}\,\textit{Rainfall} + 6^{*}\,\textit{TWI}, \quad (7)$$

Finally, the flood risk layer was generated through a weighted overlay; the values ranged from 2 to 5. The cumulative flood risk output thus generated was equally sized and then reclassified into three zones viz., High, Moderate, and Low as shown in Table 8.

3 Results and Discussion

Flood risk assessment is an important environmental management tool. It is very helpful in case of disaster risk reduction. In the present study flood risk assessment is carried out using AHP, which is an important multi-criteria decision-making tool widely used.

Cumulative flood risk zones, and their area extend in the entire Periyar river basin can be understood from Table 9. Cumulative flood risk in the range of 2 to 3 was considered as a high flood risk zone with 46.09 km2, which is 20.79% of the entire study area.

As seen in Fig. 5, the high flood risk areas are covered in Cochin and urban parts of Ernakulam district which was already recognized as very high flood vulnerable in the

Table 8. Cumulative Flood Risk

Cumulative Flood Risk	
2 – 3	High
3 – 4	Moderate
4 - 5	Low

Table 9. Flood risk zones

Flood risk zones	Percentage	Area (km^2)
High	20.79%	46.09
Moderate	71.35%	158.21
Low	7.86%	17.41

flood vulnerability study. The low elevation is one of the main reasons for the area being flooded. Another reason is that the area is adjacent to the backwaters of Vembanadu Lake along the coastline. There are chances that excess water gets gathered in low-lying areas and thus waterlogging can take place. The Ernakulam town center is very highly populated so there are more chances a lot of people get affected. Drainage block sites in the urban parts are another reason. The highland, mid-land, lowland regions of the land terrain is one most influential factor causing flood in Ernakulam.

Also, land use/land cover pattern change and rapid urbanization another potential reasons for making the area flood-prone. In the Idukki district, the portions of Mullaperiyar and Cheruthoni dam were identified in the High-risk zone. This may be due to more flow accumulation and TWI in the particular area. Other places under high flood risk zone include Idukki, Adimaly, Uputhara, Rajakumari, and Rajakkad.

Cumulative flood risk in the range of 3 to 4 was considered as a moderate flood risk zone with 158.21km2, which is 71.35% of the entire study area. In Ernakulam district, Aluva, Perumbavoor, Angamaly, Cochin International Airport Nedumbassery, Neeleshwaram, Vengoor, Kalamassery were identified under Moderate flood risk.

Cumulative flood risk in the range of 4 to 5 was considered as Low flood risk zone with 17.41 km2, which is 7.86% of the entire study area. This area includes the hilly regions of the Idukki district at the northern portion of the study area. The low flood vulnerability zones like Shivagiri hills, Chathurangappara, Idamalayar dam, etc., come under the high flood risk zone due to the higher values of flow accumulation and Topographic Wetness Index, also accompanied with the rainfall.

The flood risk map generated in the study helps to identify various flood vulnerable areas and places. This can be used to take measures of pre and post-monsoon disaster management in the study area.

4 Conclusions

Flood risk assessment is important to be carried out in areas susceptible to flood so that proper urban planning can be done. This can also be used in forecasting and warning of floods. In the Periyar river basin, the increasing number of flood events over years highlighted the need for flood-related studies. The geospatial approach was made use of in the preparation of flood vulnerability, flood risk maps. Flood risk map generated can be used to identify the high, medium, and low-risk areas. A combination of different

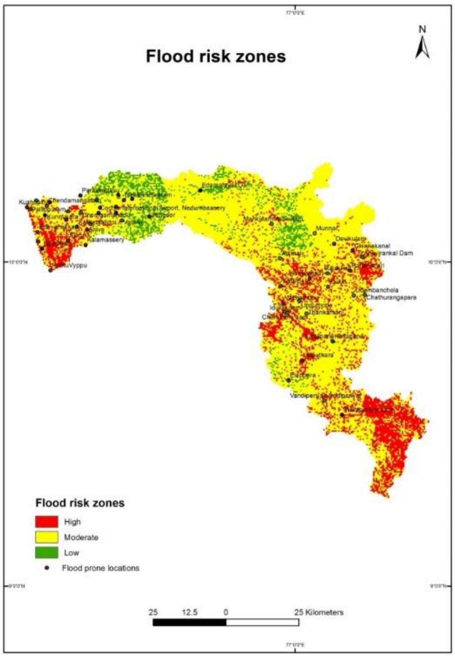

Fig. 5. Flood risk zones.

influencing factors like flood vulnerability, rainfall, TWI, flow accumulation gave a realistic picture which finally led to the computation of flood risk. In the Periyar river basin, 20.78% of the area as per the study comes under high flood risk, 71.35% under moderate flood risk, and 7.86% under low flood risk.

Extreme floods cannot be prevented but a lot of investment in the reducing flood risks is absolutely necessary. In the present study, flood maps generated are useful for emergency management. The areas with high flood risks can undergo several mitigation strategies. In the urban area, the permission of new constructions in the high or moderate risk zones must be given only after ensuring the flood safety measures. Locations for the operation of flood relief camps, i.e., low flood risk areas, can be identified through the flood map generated through the study. The present study is very useful for emergency disaster management, disaster preparedness, readiness, and responses.

References

1. Ghosh A., Kumar Kar, S.: Application of Analytical Hierarchy Process (AHP) for Flood Risk Assessment: A Case Study in Malda District of West Bengal, India. Natural Hazards, 94, pp. 349–368 (2018)
2. Ameen-Salam, A., Rubeena, T.A.: Damage Assessment and Changing Nature of Land Use with Special Reference to the Flood Plain Areas of Aluva and Paravur Taluks, Kerala. Journal of Aquatic Biology & Fisheries, 6, pp. 1–8 (2020)

3. Kumar-Saha A., Agrawal, S.: Mapping and Assessment of Flood Risk in Prayagraj District, India: A GIS and Remote Sensing Study. Nanotechnology for Environmental Engineering, 5(11), pp. 1−18 (2020)
4. Krzywoszanska, A., Mrowczynska, M., Tronte, S.: GIS Technology, 3D Models and Mathematical Models as a Tool for Assessing Development Capabilities of Flood Risk Land to Make Arrangements of Municipal Planning Documents. Journal of Ecological Engineering, 20, pp. 25–33 (2019)
5. Springer: LNCS Homepage (2020) http://www.springer.com/lncs.
6. Censusindia: Census of India 2011. Kerala, Series-33, Part XII-B, District Census Handbook Idukki, Directorate of Census Operations Kerala, Government of India (2020)
7. Censusindia: Census of India 2011, Kerala, Series-33 Part XII-B, District Census Handbook Ernakulam, Directorate of Census Operations Kerala, Government of India (2020)
8. CWC: Study Report Kerala Floods of August 2018. Government of India Central Water Commission Hydrological Studies Organization Hydrology (S) Directorate, Government of India (2019)
9. Dutta, D., Mahanty B.: Role of Consistency and Random Index in Analytic Hierarchy Process - A New Measure. Numerical Optimization in Engineering and Sciences, 979, pp. 233–239 (2020)
10. Mousavi, S., Roostaei, S., Rostamzadeh, H.: Estimation of Flood Land Use/Land Cover Mapping by Regional Modelling of Flood Hazard at Sub-Basin Level Case Study: Marand basin. Geomatics, Natural Hazards and Risk, 10(1), pp. 1155–1175 (2019)
11. Soils of Kerala: http://www.keralasoils.gov.in/index.php/2016-04-27-09-26-39/soils-of-kerala, Department of Soil Survey and Soil Conservation, Government of Kerala (2017)
12. Xiao, Y., Yi, S., Tang, Z.: Integrated Flood Hazard Assessment Based on Spatial Ordered Weighted Averaging Method Considering Spatial Heterogeneity of Risk Preference. Science of the Total Environment, 599-600, pp. 1034–1046 (2017)
13. Wondim Y.K.: Flood Hazard and Risk Assessment Using GIS and Remote Sensing in Lower Awash Sub-basin, Ethiopia. Journal of Environment and Earth Science, 6(9), pp. 69−86 (2016)
14. Wondim, Y.K.: Flood Hazard and Risk Assessment Using GIS and Remote Sensing in Lower Awash Sub-basin, Ethiopia. Journal of Environment and Earth Science, 6, pp. 7–86 (2016)
Zulkhairi, M.D., Azman T.: A Multicriteria Index and Analytical Hierarchy Process on Flood Risk Assessment: Application in Niger State, Nigeria. International Journal of Innovative Technology and Exploring Engineering, 8(8S), pp. 674–678 (2020)