



Flood vulnerability assessment using an integrated approach of multi-criteria decision-making model and geospatial techniques

K. S. Vignesh¹ · I. Anandakumar² · Rajeev Ranjan³ · Debashree Borah⁴

Received: 20 June 2020 / Accepted: 6 October 2020 / Published online: 27 October 2020
© Springer Nature Switzerland AG 2020

Abstract

Floods are one of the most devastating natural catastrophes, always associated with massive disruption to humans, land, and the economy. The current research focusses on the identification of Flood Vulnerable Zones (FVZ) of Kanyakumari district with the integration of Remote Sensing (RS) and Geographic Information System (GIS), and the Multi-criteria Decision-Making Analysis (MCDM)-based Analytical Hierarchy Process (AHP) model in the geospatial environment. The weights derived from 10 × 10 decision matrix of AHP model for the flood inducing factors are reflecting their varied priorities from high to low priority as rainfall (0.22), slope (0.124), drainage density (0.154), Land Use Land Cover (LULC) (0.153), Digital Elevation Model (DEM) (0.109), Soil (0.068), geology (0.052), geomorphology (0.048), Surface Runoff (0.042) and Topographic Wetness Index (TWI) (0.03), respectively. Consistency Ratio (CR) value obtained in this case is equal to 0.093 (< 0.1) signifies the acceptance of the derived weights. The more is the weightage given to the parameters, more significance is of the factor towards the occurrence of the flood hazard. The outcomes of the research found that the very high and highly vulnerable zones are spreading over a vast expanse of the district, which are situated in the south, south-east, south-west, and in some pockets of middle and north-east. The use of such a decision-making model-based approach is helpful in the identification and prediction of the susceptible sites, further helps the policymakers in hazard mitigation and decision-making planning.

Keywords Flood hazard · AHP · MCDM · Vulnerable zones · FVZ

Introduction

Humans are facing severe natural disasters such as floods, landslides, earthquakes, cyclones, etc., since the beginning of civilization (Nasiri et al. 2016; Sarkar and Mondal 2020). Over time, the potency and magnitude of all-natural hazards and disasters have increased manifold across the globe, attributing to a host of factors (Erena and Worku 2018). Physical factors, coupled with human activities,

have accelerated its pace posing large-scale devastation to the environment and ecosystem (Ali et al. 2019; Sarkar and Mondal 2020). Amongst the natural hazards, floods are the most common hydrometeorological and catastrophic event evoking immense risk to social, economic, and physical aspects (Indrayani et al. 2018; Panhalkar and Jarag 2017).

Criss-crossed by multiple rivers, India, aptly called the land of rivers, also experiences recurrent flood annually. Though high-intensity floods are regarded as a hazard but at the same time, these flood also helps in replenishing the river ecology and soil fertility, thus can be well-said that flood acts both as a boon and bane for the economy (Das et al. 2019; Gourav et al. 2020). According to Srivastava (2011), it is evident that the climatic and topographic features make various regions of India susceptible to several natural hazards. It is stated that 54% of land areas are highly prone to earthquakes, whereas about 40 million hectares of land areas are highly vulnerable to flood. Based on Andrew et al. (2018), India is ranked as the high-risk class for humanitarian crises and disasters with a risk management index of 5.7, while in terms of flood hazard index, the value was about 8.5, respectively. However, CWC

✉ K. S. Vignesh
ksvigneshphd@gmail.com

¹ School of Public Health, SRMIST, Chennai, Tamil Nadu 603203, India

² Centre for Natural Hazards and Disaster Studies, University of Madras, Chennai, Tamil Nadu 600025, India

³ Civil Engineering Department, Indian Institute of Technology (IIT), Delhi, Hauz Khas, New Delhi, Delhi 110016, India

⁴ Department of Geography, Guwahati University, Guwahati, Assam 781014, India

(2018) highlighted that the total land area inundated by flood in the country is around 5.74 million hectares, and the entire population affected was recorded as 18.64 million.

Eventually, the Indian sub-continent also possesses a longer coastline of 7517 km, witnessing several hazards, becoming one of the most vulnerable and potent zones (Vignesh and Madha Suresh 2018). It is noteworthy that coastal cities being regarded as dynamic interface zones experience significant coastal threats owing to rapid urban, industrial, and population growth aggravating the flood situation (Dhiman et al. 2019; Di Risio et al. 2017; Nayak and Bhaskaran 2014; Roy and Blaschke 2015). In this context, Kanyakumari is also worth mentioning as the region situated adjacent to the coastal belt has been encountering flood havoc since millennia (Vignesh and Madha Suresh 2018).

The term “vulnerability” indicates the measurement of potential risk with a combination of socio-economic ability to tackle the worst situation resulting from the disastrous event. The target of flood vulnerability assessment is to determine the probability and intensity of the flood hazard occurring for the protracted time (Al Baky et al. 2019; Hoque et al. 2019; Mundhe 2019). According to the (Cafiero and Vakis 2006) the vulnerability assessment aimed to determine the probability over the extended periods of decades to assist the activities of risk management. Though natural calamities cannot be stopped yet, its risk and effects can be reduced if proper planning and strategies are considered. Therefore, a vulnerability assessment is a challenging approach to map the potential vulnerable areas and initiate constructive efforts for managing sustainably (Danumah et al. 2016).

Amongst all approaches and techniques used to examine flood hazard and its aftermath, a comprehensible method propounded by Saaty 1980 developed within the framework of MCDM is Analytical Hierarchy Process (AHP). It is a structured technique and measurement involving a complex set of multiple decision-making criteria. These criteria are arranged in a hierarchical order based on decision maker’s preference that helps in determining the relative importance of the parameters applied in a precise and systematic manner (Al-Harbi 2001; Boulomytis et al. 2019; Chen et al. 2011; Gupta 2017; Lawal et al. 2012; Nandy et al. 2012; Saaty 1980; Seejata et al. 2018; Velasquez and Hester 2013). The present paper attempts to assess the flood vulnerable areas of the Kanyakumari district by the integration of the MCDM based AHP model and the geospatial techniques. Located along the coastline of the Indian Peninsula, Kanyakumari district also encounters severe annual floods posing more significant threats.

Study area

The study area is confined to the southernmost district of Tamil Nadu, i.e., Kanyakumari (Fig. 1), comprising a total geographical area of 1684 km². Its longitude and latitude extend from 77° 6' 1" to 77° 35' 26" East and from 8° 4' 36" to 8° 34' 43" North. The district is bounded by the Tirunelveli district on the North and East, while the Gulf of Mannar forms its South-eastern border. Moreover, the Indian Ocean and the Arabian Sea surrounds the district on South and South-west direction and Kerala state on West and North-west. The chief perennial river flowing through the central part of the district is Thamirabarani, along with Karaiyar and Paralayar as its tributaries. Being situated at the southern tip of peninsular India, the region receives rainfall from both South-west and North-east monsoon during summer and winter seasons. It also undergoes pleasant tropical climate all-round the year with summer temperature rising from 22 to 35 °C and winter temperature from 21 to 34 °C, respectively.

Materials and methods

Materials

The evaluation and mapping of the FVZ of Kanyakumari district, various datasets comprising sequential steps of methods have been followed. The present research has been carried out to framework the AHP model coupled with RS and GIS in the geospatial environment using ArcGIS 10.3. The formulation of the model requires the ten-flood influencing physical variables viz. rainfall, slope, drainage density, LULC, DEM, soil, geology, geomorphology, surface runoff, and TWI (Ali et al. 2019). The datasets used in this research are described accordingly in Table 1.

Methods

FVZ preparation in this study involves the series of steps: identifying and defining the complex problem, generate the AHP model-based hierarchical structure for the selected criteria, perform the pair-wise comparison matrix analysis for the chosen influencing variables (binary comparison), assignment of priorities values and the determination of relative weights for each variable, measurement of consistency value for the evaluations and decisions, synthesize the conclusions on priority variables to identify the FVZ (Dandapat and Panda 2017; Danumah et al. 2016; Roy and Blaschke 2015; Sulaiman et al. 2015). The considered flood influencing factors were compared with the application of MCDM to compute the relative weights (or priorities) among the

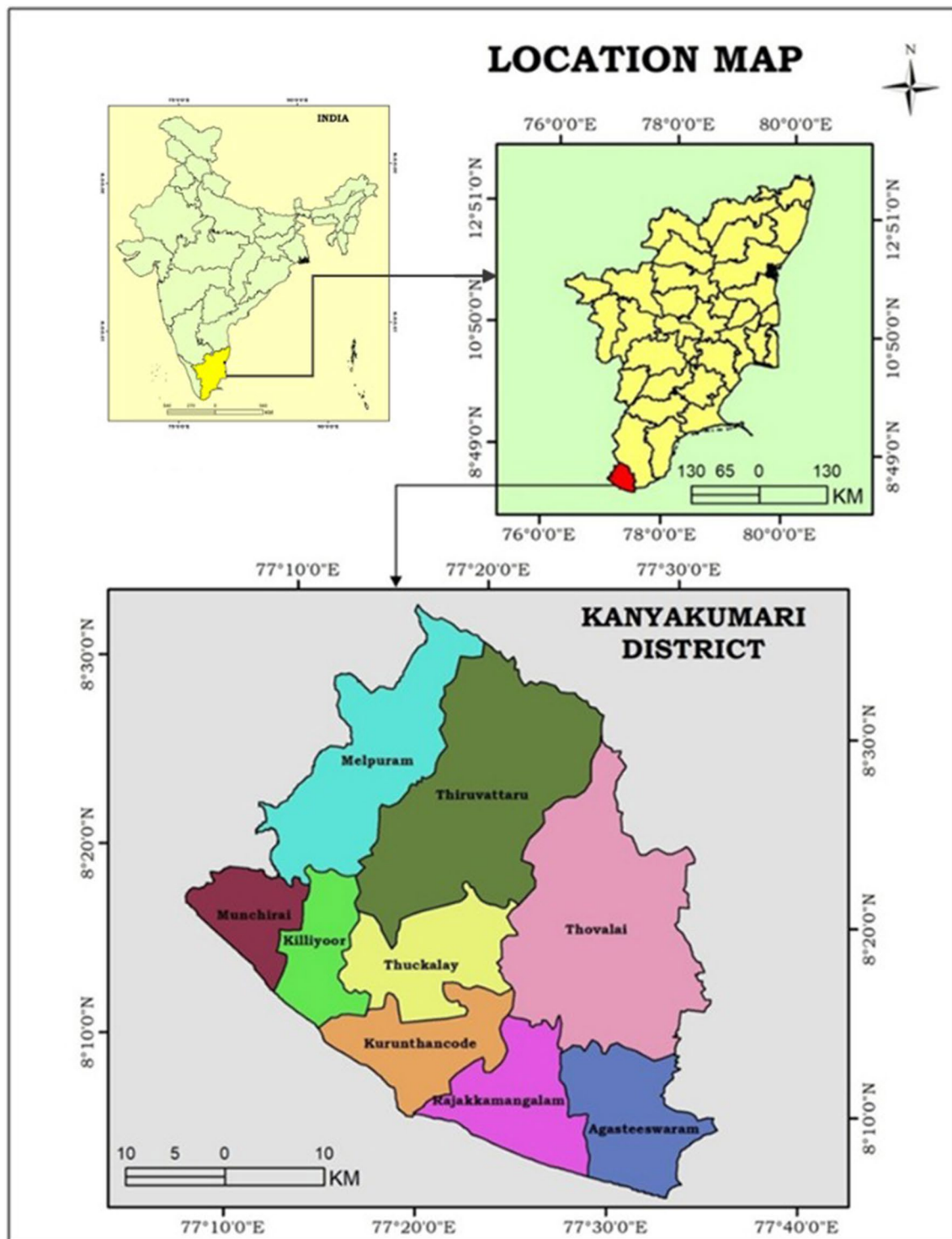


Fig. 1 Location map of Kanyakumari district, Tamil Nadu

factors to attain a significant outcome are discussed below in detail. MCDM-based AHP model was used to quantify the weightage of ten selected flood initiation factors, responsible for the determination of the potential of individual elements

in inducing the flood hazard (Chakraborty and Mukhopadhyay 2019; Lawal et al. 2012). The above influencing factors were further reclassified into the sub-classes according their

Table 1 Datasets used in the study

| S. no. | Datasets | Description | Resolution/scale | Source |
|--------|---------------------------------|---|------------------|---|
| 1 | Digital Elevation Model (DEM) | ASTER | 30 m | USGS earth explorer https://www.imdpune.gov.in/ |
| 2 | LANDSAT-8 | Downloaded | 30 m | USGS Earth Explorer https://www.imdpune.gov.in/ |
| 3 | Soil | Digitized from soil texture map of Kanyakumari District | | National Bureau of Soil Survey and Land Use Planning (NBSSLUP) |
| 4 | Rainfall | Using interpolation method | | Indian Meteorological Department (IMD) https://www.imdpune.gov.in/ |
| 5 | Slope | Derived from DEM | 30 m | DEM |
| 6 | Geology | Digitized from geological map of Kanyakumari | 1:500,000 | Geological Survey of India (GSI) |
| 7 | Geomorphology | | | Bhuvan |
| 8 | Surface Runoff | Derived from LULC, rainfall and hydrological soil group using NRCS Curve Number | | USGS earth explorer, https://earthexplorer.usgs.gov/ |
| 9 | Drainage Density | Extracted from DEM | | USGS Earth Explorer, https://www.imdpune.gov.in/ |
| 10 | Topographic Wetness Index (TWI) | | 30 m | DEM |

relative ranks for the computation of their relative weights (Danumah et al. 2016; de Brito and Evers 2016).

These relative ranks were allocated between 1 and 5, according to the Saaty 1980 preference descriptor (Table 3) for the construction of the thematic layers of each influencing factor. The maximum weightage value indicates very high vulnerability, followed by high, moderate, low, and very low, respectively (Table 5). All the obtained thematic layers have been combined and interpreted in the geospatial environment through the Weighted Linear Combination (WLC) approach using the geospatial platform to achieve the FVZ as the outcome. The flowchart of the proposed methodology is shown in Fig. 2.

Flood-inducing factors

Rainfall

It forms the most striking factor since the Kanyakumari district receives enough rainfall from both north-east and south-west monsoons. For the preparation of the rainfall distribution map, the rainfall data of all the rain gauge stations have been calculated through the Inverse Distance Weighted (IDW) interpolation tool in GIS platform. The district blocks witnessing high rainfall ranging from 75 to 190 mm are Thovalai, Thuckalay, Agasteeswaram, Kurunthancode, Munchirai, and Melpuram, constituting as high flood vulnerable regions. On contradictorily, lower rainfall of 0–75 mm is experienced by southern and

eastern parts of the Thiruvattar, northern part of the Thovalai, Killiyoor, and north part of the Rajakkamangalam intending to less flood vulnerability (Fig. 3a). The rainfall map was reclassified into four classes viz. 0–50 mm, 50–75 mm, 75–108 mm, and 108–190 mm.

Slope

The flood occurs in the low elevated area due to the downward inundation of water from the higher region. The slope map (Fig. 3b) has been created from the ASTER DEM satellite image of the study area wherein the area ranges from 0° to 75°. The southern region initiates by the least slope category from 0 to 15°, increasing towards the northern side of the district, indicating high proficiency to flood hazard. On the contrary, the steepest slope category from 60 to 75° covers a small portion in the northeast, extending up to the middle south-eastern part of the district. The slope map was grouped into five classes as 0–15°, 15–30°, 30–45°, 45–60°, and 60–75°, respectively.

Drainage density (DD)

DD plays an influential role in the determination of flood vulnerability. DD map has been computed in the GIS environment from ASTER DEM (30 m) using the hydrological tools. The entire region is classified into three classes from low (0–0.016 km/km²), moderate (0.016–0.112 km/km²) and high (0.112–0.454 km/km²). Blocks with high drainage density are Thiruvattar, Thovalai, the eastern part

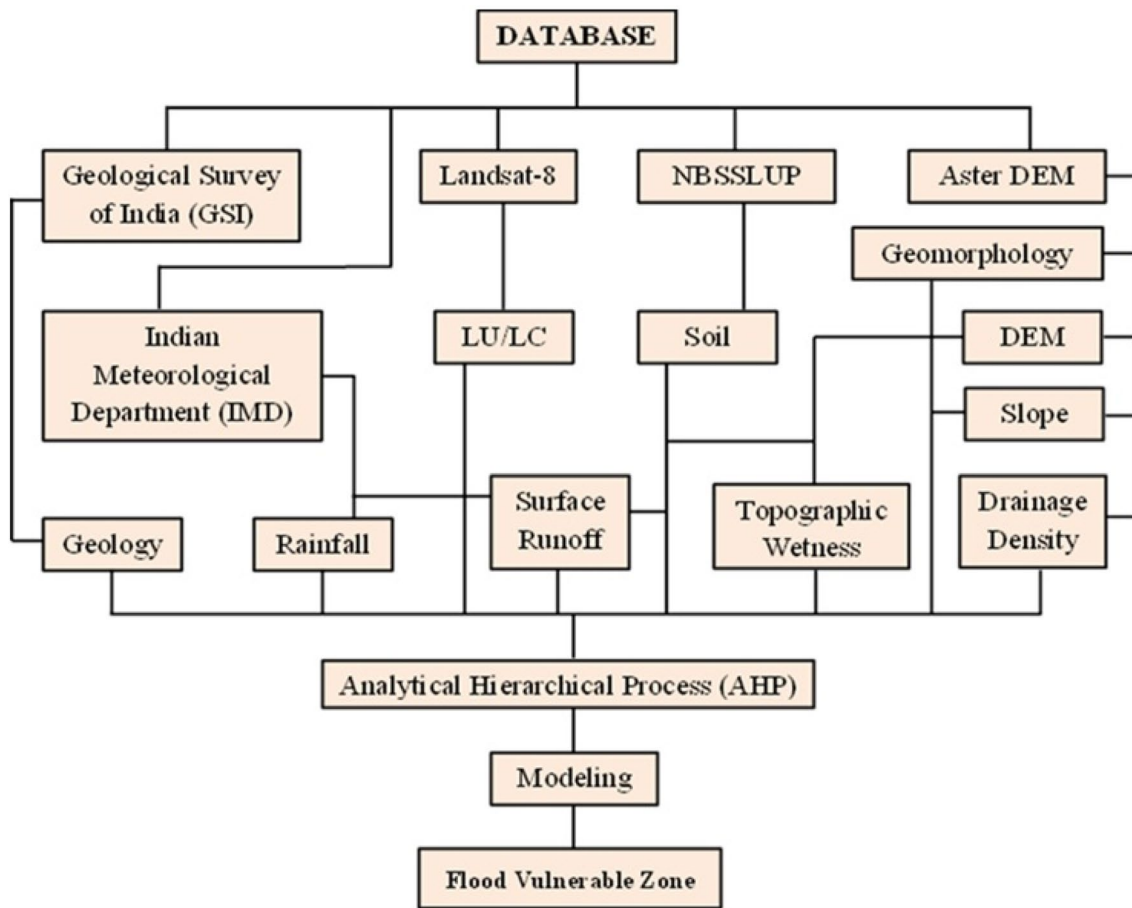


Fig. 2 Methodology flow chart

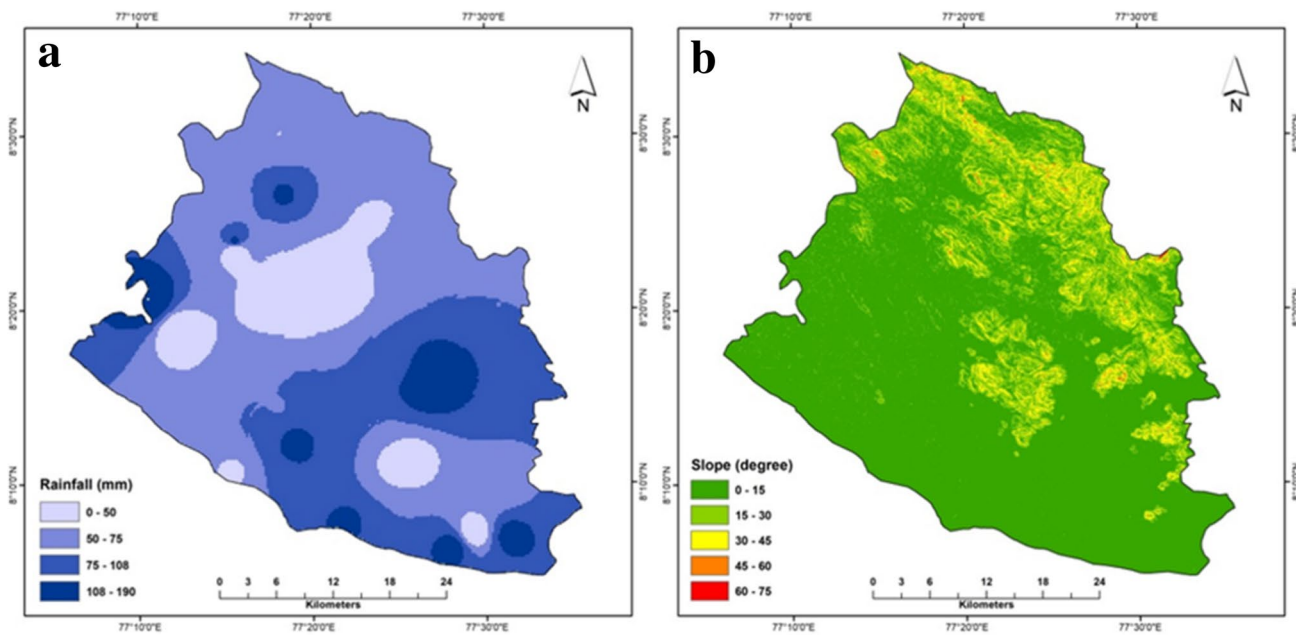


Fig. 3 a Rainfall map and b Slope map

of Thuckalay, and the northeastern part of Kurunthancode, which is very less vulnerable to flood. The lower density blocks such as Munchirai, Killiyoor, Rajakkamangalam, Agasteeswaram, and the southern part of the Melpuram are vulnerable to the flood. Adjacently, the regions such as Killiyoor, Kurunthancode, Rajakkamangalam, Agasteeswaram are highly vulnerable to flood because of the existence of coastal belt (Fig. 4a).

LULC

LULC is the primary driver in changing the landscape of a specific area. LULC map has been extracted from Landsat-8 using supervised classification wherein, four classes, such as agricultural land, built-up, forest, and waterbodies, are identified. Agrarian land constitutes 867.6 km², and forest covers about 545.09 km² while built up and waterbodies comprise 206.09 km² and 65.12 km², respectively (Fig. 4b). The study highlighted that the agricultural land, built up, and water bodies are regarded as highly susceptible, while forest-covered regions are least vulnerable to flood.

DEM

DEM (Fig. 5a) posturizes the elevation of the district ranging from 0 to 1816 m. The north and northeastern sides signify high altitude (1090–1816 m), whereas southern, southwestern parts belong to a low elevation (0–727 m) category. Thiruvattar, Melpuram, Thovalai blocks of 727–1090 m elevation are moderately vulnerable to flood while the low

elevation coastal blocks, namely Rajakkamangalam, Agasteeswaram, Kurunthancode, Killiyoor, and Munchirai leads to highly flood-prone region.

Soil texture

Soil texture has a sequential relationship with the rate of infiltration and surface runoff. The soil texture map and its classification has been generated based on the National Bureau of Soil Survey and Land Use Planning (NBSSLUP). The maximum traces compose of sandy clay covering 831.7 km², i.e., 50% of the total area followed by clay and sandy clay loam representing 400 and 238 km², indicating a high flood vulnerability along the district. While clay loam, loamy sand, and rock land cover 92.51 km² described as less flood-prone area (Fig. 5b). The produced map has been classified into eight soil texture classes such as clay, clay loam, loamy sand, rock land, sand, sandy clay, sandy clay loam, and sandy loam.

Geology

Based on the historical records, it is evident that the Kanyakumari district was formed during the Archaean period covered with Archaean metamorphic rocks. According to the Geological Survey of India (GSI), the Archaean gneisses are the most predominant rocks separating two districts, namely Kanyakumari and Tirunelveli. This separation occurred due to the formation of lofty ridges of Western Ghats. Prolonged erosion led to a reduction of gneiss in height that appeared

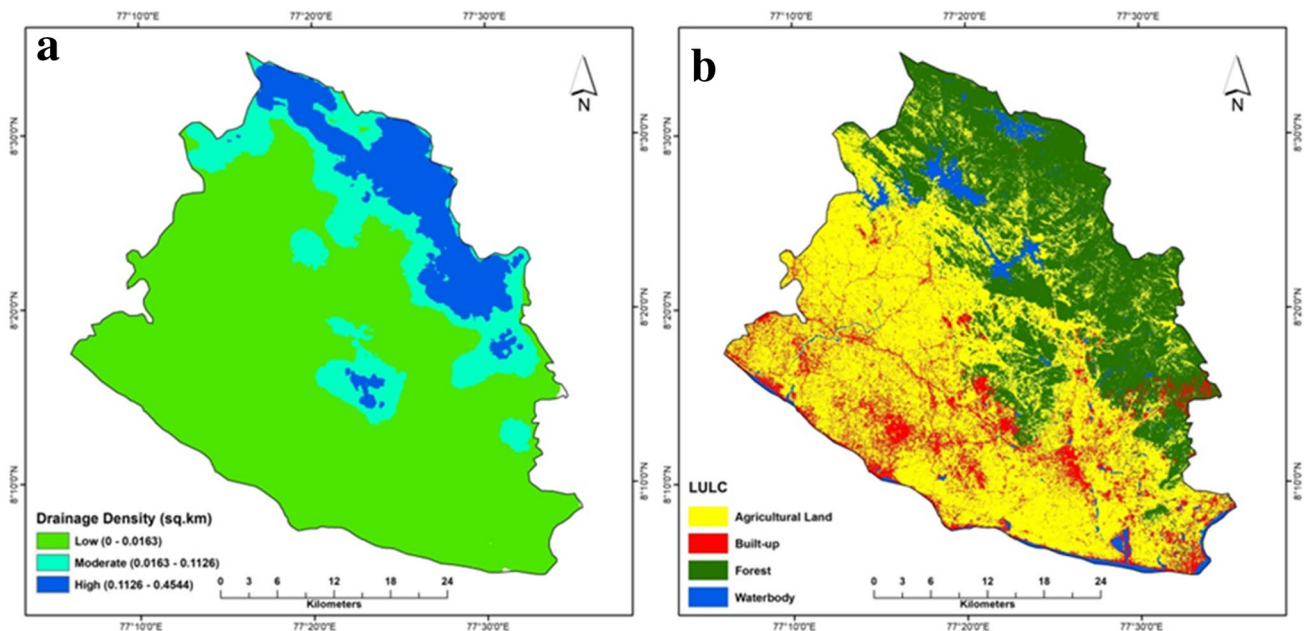


Fig. 4 a Drainage density map and b LULC map

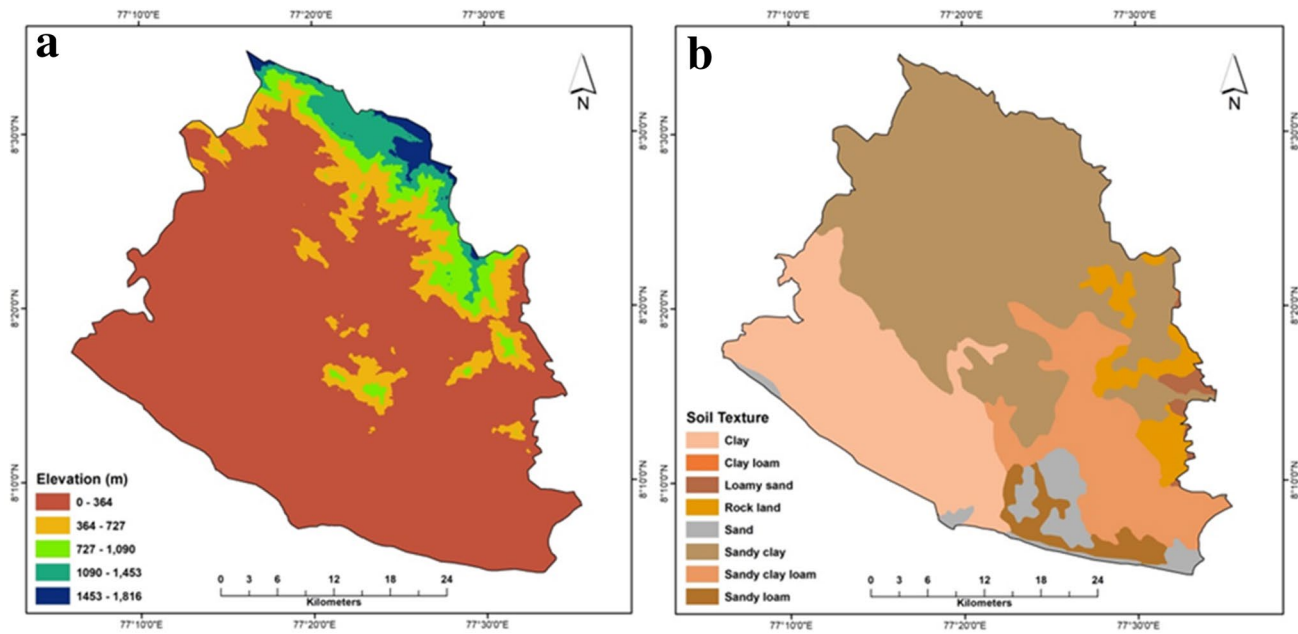


Fig. 5 a DEM map and b Soil texture map

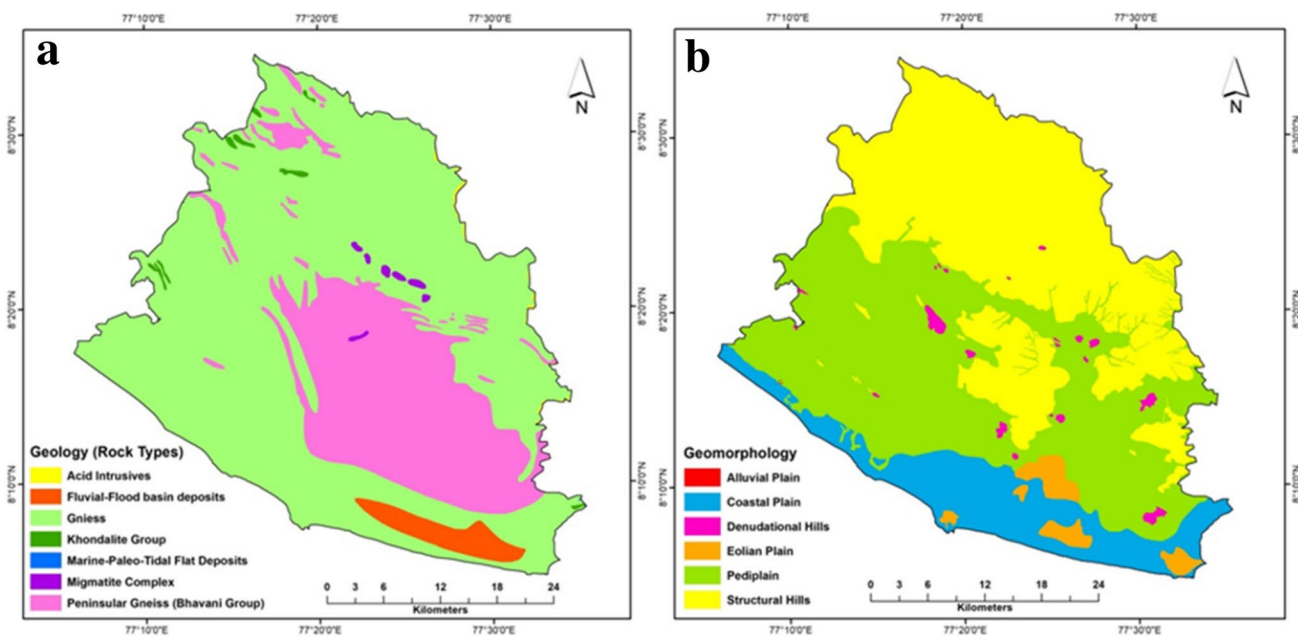


Fig. 6 a Geology map and b Geomorphology map

as subdued hills. Figure 6a depicts the geology map that has been prepared based on the GSI, where the plan was reclassified into seven categories. The middle parts of the district are covered with Peninsular gneisses and a considerable amount of Migmatite complex rocks. Subsequently, the south-eastern sides of the region comprise of fluvial

sediment deposits, whereas the western, northwestern sides of the district are covered with pockets of Khandolite groups of rocks.

Geomorphology

Geomorphologically, the entire district has been classified vividly as structural hills, denudational hills, coastal plains, alluvial plains, penplain, and aeolian plains. The middle and southern portion of the district comprises of aeolian, alluvial and coastal plains that are highly susceptible to flood. Contiguously, the northern, northeastern, and north-western part are covered by structural and denudational hills that is resistant to flood (Fig. 6b).

Surface runoff

Surface Runoff is directly proportional to slope condition, soil saturation, rainfall, and LULC types (Mu et al. 2015). Preparation of surface runoff map involves parameters such as LULC, soil texture, rainfall, additionally flow direction, flow accumulation, a watershed delineation that were extracted from ASTER DEM. Moreover, the Curve Number (CN) for Antecedent Moisture Condition (AMC) was assigned using the LULC and the Hydrological Soil Group (HSG), which determines the soil condition of the study area. The union of all these parameters concludes the surface runoff model for the Kanyakumari district, which has been reclassified into five classes Fig. 7a. The northern parts record very low surface runoff ranging from 0 to 31 mm, but due to the availability of forest cover, the water gets

infiltrated into the soil. Due to higher elevation, there is a chance of water getting discharged downwards to the lower region. Rajakkamangalam, Munchirai, Killiyoor, and Agas-teeswaram blocks are experiencing very low surface runoff that tends to be highly vulnerable to flood hazards. However, the presence of dense forest cover around Thovalai, Thiruvattar, and Melpuram causes these blocks to be less sensitive to flood accompanied by very low surface runoff.

TWI

TWI was prepared using the ASTER DEM, which excerpts the slope and catchment area, providing an accurate TWI for the study area. Most of the blocks in northern parts such as Melpuram, Thiruvattar, and individual pockets of Thovalai, Munchirai are less flood-prone because of less TWI that occurs due to higher slope recorded in the district towards the northern side. The inundated water can easily penetrate the unsaturated soil, and the nominal amount of water flows into the low-lying areas of the district. Adjacently, the blocks in the southern side of the region, such as Rajakkamangalam and Kurunthancode, indicates a higher value of TWI due to higher saturation of the soil and lower elevation of the terrain. During seasonal rainfall, these areas water does not tend to penetrate the ground and hence creates a havoc situation. The areas considerably far from the coastal zone are moderately vulnerable to flood. The primary area covering

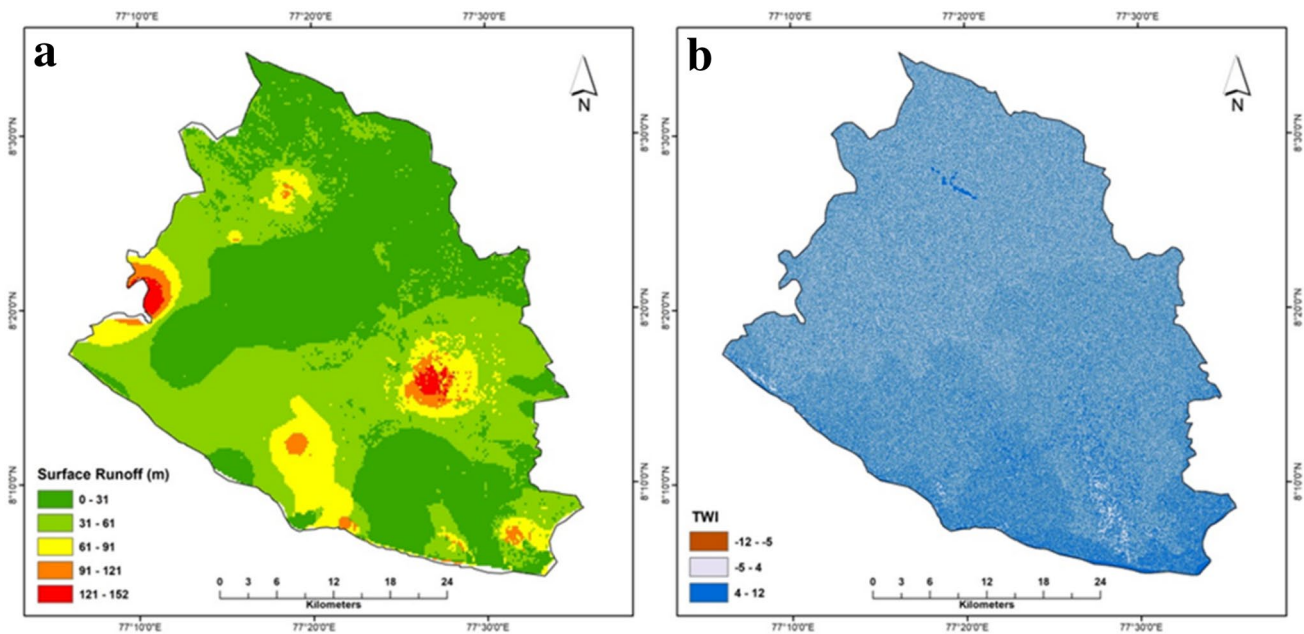


Fig. 7 a Surface runoff map and b TWI map

Table 2 Pair-wise comparison of 10×10 decision matrix

| Class | Rainfall | Slope | Drainage Density | LULC | DEM | Soil | Geology | Geomorphology | Surface Runoff | TWI |
|------------------|----------|-------|------------------|------|-------|-------|---------|---------------|----------------|-----|
| Rainfall | 1 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 5 |
| Slope | 1/3 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 3 |
| Drainage density | 1/3 | 1 | 1 | 1 | 3 | 3 | 3 | 5 | 5 | 5 |
| LULC | 1/2 | 1 | 1 | 1 | 3 | 5 | 3 | 5 | 3 | 3 |
| DEM | 1/3 | 1/2 | 1/3 | 1/3 | 1 | 5 | 3 | 5 | 3 | 3 |
| Soil | 1/3 | 1/3 | 1/3 | 1/5 | 1/5 | 1 | 1 | 3 | 3 | 5 |
| Geology | 1/3 | 1/3 | 1/3 | 1/3 | 1/3 | 1 | 1 | 1 | 3 | 1 |
| Geomorphology | 1/3 | 1/3 | 1/5 | 1/5 | 1/5 | 1/3 | 1 | 1 | 1 | 5 |
| Surface runoff | 1/3 | 1/3 | 1/5 | 1/3 | 1/3 | 1/3 | 1/3 | 1 | 1 | 3 |
| TWI | 1/5 | 1/3 | 1/5 | 1/3 | 1/3 | 1/5 | 1 | 1/5 | 1/3 | 1 |
| Total | 4.01 | 8.15 | 7.59 | 6.72 | 13.39 | 21.86 | 19.33 | 27.2 | 25.33 | 34 |

Table 3 Pair-wise comparison scale for AHP preferences (Saaty 1980)

| Numerical rating | Verbal judgments of preferences |
|------------------|---------------------------------|
| 9 | Extremely preferred |
| 8 | Very strongly to extremely |
| 7 | Very strongly preferred |
| 6 | Strongly to very strongly |
| 5 | Strongly preferred |
| 4 | Moderately to strongly |
| 3 | Moderately preferred |
| 2 | Equally to moderately |
| 1 | Equally preferred |

1005.5 km² represents a high topographic wetness index gradually decreasing to 674 km², while the lowest TWI is found in the minimal region of the district. The TWI map has been grouped into three classes depicted in (Fig. 7b).

Analytical hierarchy process (AHP)

AHP is the most reliable and flexible multi-criteria mathematical approach, was adopted in this current research to map the FVZ (Chen et al. 2011; Dandapat and Panda 2017; Zelenakova et al. 2015). Grouping the prepared thematic maps into five vulnerable categories, an AHP-based pair-wise comparison matrix of variables described above is

constructed (Table 2). Noteworthy, AHP is applied to assign varied weights for comparing the ten individual factors, and according to their relative importance, these ten factors are rated from 1 to 9 (Table 3) on an absolute number scale (Saaty 1980). The values of the size range from less to more flood-influencing factors. The priority scales were synthesized by dividing each element of the matrix by its column total. Moreover, the priority vector is derived by calculating the row averages.

Consistency check

To ratify the constructed pair-wise matrix and its allotted weightage (Saaty, 1980), evaluation through the Consistency Ratio (CR) was formulated where the acceptable CR must be below 0.1. In the present study, the consistency of the derived Eigen vector–matrix following the index below found is 0.093 concludes that the set of decisions considered is acceptable.

$$CR = \frac{CI}{RI}, \tag{1}$$

where CR is the consistency ratio, CI is the consistency index, and RI is the random index. RI refers to the consistency of the randomly evolved pair-wise matrix depicted in Table 4. The values provided in the table are subject to various parameters involved in AHP. Therefore, based on the ten variables, the derived RI obtained in the study is 1.49.

Table 4 Random Index (RI) value

| Size of Matrix (n) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|--------------------|---|---|------|-----|------|------|------|------|------|------|
| Random Index (RI) | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

CI is computed using Eq. 2

$$CI = \left(\frac{\lambda_{\max} - n}{n - 1} \right), \quad (2)$$

where λ_{\max} stands for the maximum eigenvalue of the comparison matrix, n for number factors. Furthermore, the Flood Vulnerability Zone (FVZ) map has been generated using the Flood Vulnerability Index (FVI) values obtained from Eq. 3

$$FVI = \sum_{i=1}^n W_i \times R_i, \quad (3)$$

where W_i is the weights for individual flood conditioning factors, and R_i is the rating class.

Finally, the obtained FVZ was reclassified into five groups viz. very high, high, moderate, low, and very low using natural breaks (Rocha et al. 2020).

Results and discussion

Current research emphasized on the FVZ preparation of Kanyakumari district using the MCDM AHP model. The 10×10 decision matrix was formed, where diagonal elements are equal to 1 (Kazakis et al. 2015) using the inducing variables with the derived $CR = 0.093$ (< 0.1 thresholds) as indicated in Table 2. The CR value obtained in the AHP analysis signifies that the weightage derived for the flood influencing factors such as rainfall (0.22), slope (0.124), drainage density (0.154), LULC (0.153), DEM (0.109), soil (0.068), Geology (0.052), Geomorphology (0.048), Surface Runoff (0.042) and TWI (0.03), respectively, are in acceptable range (Table 5) and can be used in the FVZ preparation using the WLC.

Table 6 shows the resultant normalized pair-wise comparison, wherein each element of the 10×10 decision matrix was divided by the total sum of inter-comparison of priority rankings (Saaty 1980) of the considered parameters. Normalization indicates the scaling of the ten parameters from 0 to 1.

FVI values of the flood vulnerable zone map range from 2.23 to 4.75 obtained using Eq. 3 and reclassified into five classes such as very low, low, medium, high, and very

high to generate the FVZ map (Fig. 8) of the Kanyakumari district.

Assessment of flood vulnerable zone map is represented in Table 7 where its respective areas along with percentages covering under distinctive FVZ categories have been derived through the AHP application. Considering the total area of the district, about 102.82 km^2 (6.11%) falls under a very highly vulnerable zone while 813.48 km^2 (48.31%) are recognized as highly sensitive regions. On the other hand, a total area of 305.94 km^2 representing 18.17% is recorded as moderately vulnerable areas. Accordingly, low sensitive and very low vulnerable regions occupy a total of 337.78 km^2 and 123.97 km^2 , respectively.

Additionally, the block-wise flood vulnerability zone is also shown in Table 8. The nine administrative blocks constituting the Kanyakumari district have been analyzed individually based on the differential vulnerable categories. The result highlights that 89.64 km^2 (22.31%) of Kurunthancode block have been delineated as a very highly sensitive zone followed by Agasteeswaram (15.99%) and Munchirai (14.71%). Meanwhile, most of the blocks excluding Thiruvattaru, Thoivalai and Melpuram are categorized as high vulnerability regions wherein chronologically, 97.64% area of Killiyoor, 87.03% area of Rajakamangalam, 85.14% area of Munchirai, 74.79% area of Agasteeswaram and 73.24% area of Kurunthancode block are identified as highly flood vulnerable regions. This can be attributed due to adjacency to the coastal belt, torrential downpour, high population density, gentle slope coupled with haphazard urban growth, injudicious anthropogenic activities, sparse vegetation and forest cover, etc. On the contrary, the moderately vulnerable blocks involve Melpuram representing 30.42%, followed by Thoivalai (28.54%) and Thiruvattaru (21.27%). Similarly, the very low and low sensitive blocks are recorded as Thoivalai and Thiruvattaru, respectively. These regions witness less exposure towards flood as it is dominated by dense vegetation and forest cover, presence of extensive plains as a hindrance for settlement, and other developmental activities.

Table 5 Weights of sub-classes using AHP comparison matrix

| Sl. no. | Parameter | Sub classes | Vulnerability | Rank |
|---------|----------------------------|----------------------------------|---------------|------|
| 1 | Geology | Migmatite Complex | Very low | 1 |
| | | Khondalite Group | Low | 2 |
| | | Peninsular Gneiss | High | 4 |
| | | Gneiss | Very high | 5 |
| | | Acid Intrusive | Low | 2 |
| | | Marine-Paleo-Tidal Flat Deposits | Low | 2 |
| | | Fluvial flood basin deposits | Moderate | 3 |
| 2 | Soil texture | Clay | High | 4 |
| | | Clay loam | Very low | 1 |
| | | Loamy sand | Low | 2 |
| | | Rock land | Low | 2 |
| | | Sand | Low | 2 |
| | | Sandy clay | Very high | 5 |
| | | Sandy clay loam | High | 4 |
| 3 | Land use land cover (LULC) | Sandy loam | Moderate | 3 |
| | | Waterbodies | Very high | 5 |
| | | Built up | High | 4 |
| | | Agricultural land | Low | 2 |
| 4 | Geomorphology | Forest | Very low | 1 |
| | | Structural Hills | Very low | 1 |
| | | Denudational Hills | Low | 2 |
| | | Piedplain | Moderate | 3 |
| | | 4. Coastal Plain | High | 4 |
| 5 | Slope | Alluvial Plain | Very high | 5 |
| | | Aeolian Plain | Very high | 5 |
| | | 0–7.5° | Very high | 5 |
| | | 7.5–17° | High | 4 |
| | | 17–35° | Moderate | 3 |
| 6 | Digital elevation model | 35–60° | Low | 2 |
| | | 60–75° | Very low | 1 |
| | | 0–364 mm | Very high | 5 |
| | | 364–727 mm | High | 4 |
| | | 727–1090 mm | Moderate | 3 |
| 7 | Drainage density | 1090–1453 mm | Low | 2 |
| | | 1453–1816 mm | Very low | 1 |
| | | 0–0.0163 km/km ² | Very high | 5 |
| 8 | Topographic Wetness Index | 0.0163–0.1126 km/km ² | Moderate | 3 |
| | | 0.1126–0.4544 km/km ² | Low | 2 |
| | | 0–4 | Low | 2 |
| 9 | Rainfall | 4–9 | Moderate | 3 |
| | | 9–12 | Very high | 5 |
| | | 0–50 mm | Low | 2 |
| | | 50–75 mm | Moderate | 3 |
| 10 | Surface runoff | 75–108 mm | High | 4 |
| | | 108–190 mm | Very high | 5 |
| | | 0–31 mm | Very high | 5 |
| | | 31–61 mm | High | 4 |
| | | 61–91 mm | Moderate | 3 |
| | | 91–121 mm | Low | 2 |
| | | 121–152 mm | Very low | 1 |

Table 6 Normalized pair-wise comparison

| Class | Rainfall | Slope | Drainage density | LULC | DEM | Soil | Geology | Geomor-phology | Surface runoff | TWI | Priority Vector |
|------------------|----------|-------|------------------|-------|-------|-------|---------|----------------|----------------|-------|-----------------|
| Rainfall | 0.249 | 0.368 | 0.395 | 0.297 | 0.224 | 0.137 | 0.155 | 0.11 | 0.118 | 0.147 | 0.22 |
| Slope | 0.082 | 0.122 | 0.131 | 0.148 | 0.149 | 0.137 | 0.155 | 0.11 | 0.118 | 0.088 | 0.124 |
| Drainage density | 0.082 | 0.122 | 0.131 | 0.148 | 0.224 | 0.137 | 0.155 | 0.183 | 0.197 | 0.147 | 0.154 |
| LULC | 0.124 | 0.122 | 0.131 | 0.148 | 0.224 | 0.228 | 0.155 | 0.183 | 0.118 | 0.088 | 0.153 |
| DEM | 0.082 | 0.061 | 0.043 | 0.04 | 0.074 | 0.228 | 0.155 | 0.183 | 0.118 | 0.088 | 0.109 |
| Soil | 0.082 | 0.04 | 0.043 | 0.029 | 0.014 | 0.045 | 0.051 | 0.11 | 0.118 | 0.147 | 0.068 |
| Geology | 0.082 | 0.04 | 0.043 | 0.049 | 0.024 | 0.045 | 0.051 | 0.036 | 0.118 | 0.029 | 0.052 |
| Geomorphology | 0.082 | 0.04 | 0.026 | 0.029 | 0.014 | 0.015 | 0.051 | 0.036 | 0.039 | 0.147 | 0.048 |
| Surface runoff | 0.082 | 0.04 | 0.026 | 0.049 | 0.024 | 0.015 | 0.017 | 0.036 | 0.039 | 0.088 | 0.042 |
| TWI | 0.049 | 0.04 | 0.026 | 0.049 | 0.024 | 0.009 | 0.051 | 0.007 | 0.013 | 0.029 | 0.03 |

$\Sigma = 1.000$

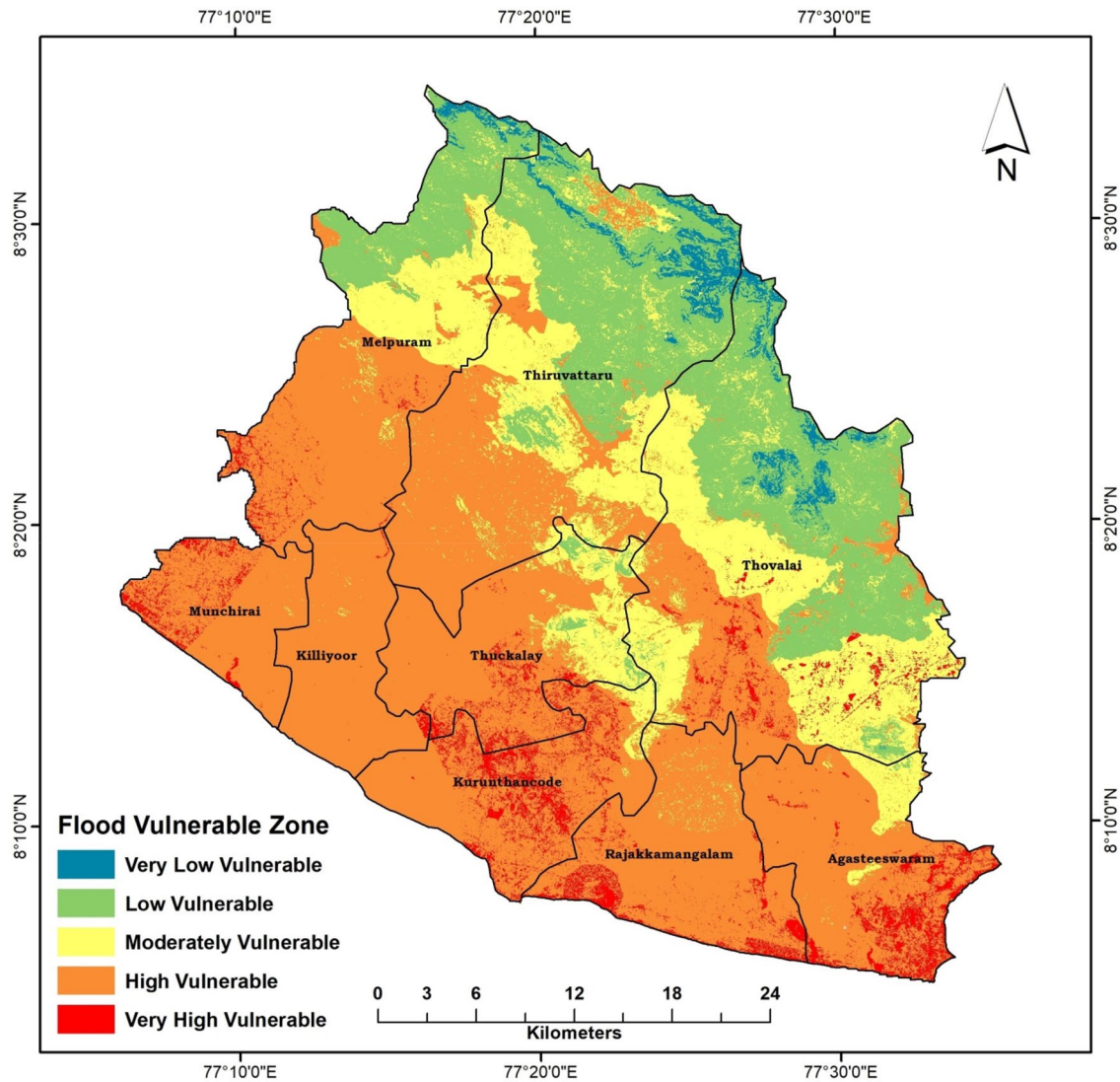
**Fig. 8** Flood vulnerable zone map

Table 7 Flood vulnerability status

| Sl. no. | Flood vulnerable zones | Area in km ² | Area in % |
|---------|------------------------|-------------------------|-----------|
| 1 | Very low vulnerable | 123.97 | 7.36 |
| 2 | Low vulnerable | 337.78 | 20.05 |
| 3 | Moderately vulnerable | 305.94 | 18.17 |
| 4 | Highly vulnerable | 813.48 | 48.31 |
| 5 | Very highly vulnerable | 102.82 | 6.11 |

Conclusion

The present research elucidates flood vulnerability mapping as a prerequisite approach in identifying and predicting the degree of susceptibility of various regions towards the natural calamity. Being the most efficient and widely acceptable technique, MCDM-based AHP model approach was used to carrying out the flood vulnerability analysis of the Kanyakumari district. In this regard, according to the decision maker’s preference, the weights are allotted to the ten influencing variables that represent their respective priorities. Amongst all the variables, rainfall with (0.22) weightage is highly significant, while TWI is of least significance (0.03) that substantially contributes to occurrence of flood in the region. Similarly, the layers of the parameters have also been reclassified into five groups (Table 5) from 1 to 5, wherein one indicates very low, and five shows very high that represents their priorities in causing such hazard. Thus, the study reveals that a majority of Kanyakumari district has been delineated as very high to high vulnerability zones covering an area of 916.3 km². However, the southern parts of Kurunthancode, coupled with the southwestern part of Rajakkamangalam, south and south-east part of Agasteeswaram, south and western part of Thuckalay, south part of Killiyoor and southwestern part of Munchirai are regarded as highly susceptible blocks to the flood havoc. The total area found under the obtained five classes in percent (Tables 7, 8 and Fig. 8) is represented as very high (6.11), high (48.31), moderately (18.17), low (20.05), and very low (7.36) vulnerable.

The most causative factor behind the presence of vast flood vulnerable zones is its adjacency to the coastlines triggered by coastal floods. Unplanned urbanization, aided by rampant population growth, is also another notable factor that needs to be addressed in the study area. Such type of modeling and mapping of selected sites enhances to recognize the flood-prone regions that could be assumed as the foremost step in preparing flood plans. Moreover, the executed analysis might provide a baseline for planners, civil engineers, Non-Governmental Organization (NGOs), government officials, policymakers as it would help to implement manifold strategies required for effective planning so that these natural hazards could be monitored and

Table 8 Block-wise area of flood vulnerability

| Block name | Flood vulnerable zones | | | | | | | | | |
|-----------------|-------------------------|-----------|-------------------------|-----------|-------------------------|-----------|-------------------------|-----------|-------------------------|-----------|
| | Very low vulnerable | | low vulnerable | | Moderately vulnerable | | Highly vulnerable | | Very highly vulnerable | |
| | Area in km ² | Area in % | Area in km ² | Area in % | Area in km ² | Area in % | Area in km ² | Area in % | Area in km ² | Area in % |
| Agasteeswaram | 0 | 0 | 0.38 | 0.27 | 12.47 | 8.95 | 104.34 | 74.79 | 22.32 | 15.99 |
| Killiyoor | 0 | 0 | 0 | 0 | 0.18 | 0.21 | 85.67 | 97.64 | 1.89 | 2.15 |
| Kurunthancode | 0 | 0 | 0.19 | 0.16 | 5.25 | 4.29 | 89.64 | 73.24 | 27.31 | 22.31 |
| Melpuram | 14.71 | 6.28 | 61.63 | 26.29 | 71.31 | 30.42 | 86.55 | 36.92 | 0.21 | 0.09 |
| Munchirai | 0 | 0 | 0 | 0 | 0.12 | 0.15 | 68.06 | 85.14 | 11.76 | 14.71 |
| Rajakkamangalam | 0 | 0 | 0 | 0 | 2.81 | 2.13 | 114.98 | 87.03 | 14.32 | 10.84 |
| Thiruvattaru | 63.51 | 17.25 | 124.37 | 33.77 | 78.35 | 21.27 | 101.87 | 27.66 | 0.17 | 0.05 |
| Thovalai | 45.75 | 12.01 | 146.43 | 38.43 | 108.74 | 28.54 | 62.55 | 16.41 | 17.57 | 4.61 |
| Thuckalay | 0 | 0 | 4.78 | 3.45 | 26.71 | 19.27 | 99.82 | 72.03 | 7.27 | 5.25 |

mitigated to a certain extent. Thus, multi-criteria-based models could further help in executing the unpredictable hazards in a sustainable manner.

Acknowledgements The authors sincerely acknowledge the Centre for Natural Hazards and Disaster Studies, the University of Madras, for conducting their research work successfully. We are also thankful to Binod Kumar Nath, Faculty for Modern Survey, Assam Survey and Settlement Training Centre, Guwahati and Aswathi P.V., Indian Institute of Remote Sensing, Dehradun for their consistent help and guidance.

Author contributions All the authors have contributed to the study conception and design. Material preparation, data collection and analysis were performed by KSV, and IA. The first draft of the manuscript was written by KSV, and all authors commented on previous versions of the manuscript. The first draft of the manuscript was revised by the RR and DB technically as well as grammatically during the manuscript revision process of the Journal. All authors read and approved the final manuscript.

References

- Al Baky MA, Islam M, Paul S (2019) Flood hazard, vulnerability and risk assessment for different land use classes using a flow model. *Earth Syst Environ* 4:1–20
- Al-Harbi KMA-S (2001) Application of the AHP in project management. *Int J Project Manage* 19(1):19–27
- Ali SA, Khatun R, Ahmad A, Ahmad SN (2019) Application of GIS-based analytic hierarchy process and frequency ratio model to flood vulnerable mapping and risk area estimation at Sundarban region, India. *Model Earth Syst Environ* 5(3):1083–1102
- Andrew T, Luca V, Montserrat MF, Brian D (2018). INFORM GLOBAL RISK INDEX. <https://doi.org/10.2760/754353>
- Boulomytis VTG, Zuffo AC, Imteaz MA (2019) Detection of flood influence criteria in ungauged basins on a combined Delphi-AHP approach. *Oper Res Perspect* 6:100116
- Cafiero C, Vakis RN (2006) Risk and vulnerability considerations in poverty analysis: recent advances and future directions. World Bank, Social Protection, Washington
- Chakraborty S, Mukhopadhyay S (2019) Assessing flood risk using analytical hierarchy process (AHP) and geographical information system (GIS): application in Coochbehar district of West Bengal, India. *Nat Hazards* 99(1):247–274
- Chen Y-R, Yeh C-H, Yu B (2011) Integrated application of the analytic hierarchy process and the geographic information system for flood risk assessment and flood plain management in Taiwan. *Nat Hazards* 59(3):1261–1276
- CWC (2018) Central water commission annual report 2018-2019. <http://cwc.gov.in/sites/default/files/arcwc2018-19.pdf>. Accessed 22 Sep 2020
- Dandapat K, Panda GK (2017) Flood vulnerability analysis and risk assessment using analytical hierarchy process. *Model Earth Syst Environ* 3(4):1627–1646
- Danumah JH, Odai SN, Saley BM, Szarzynski J, Thiel M, Kwaku A et al (2016) Flood risk assessment and mapping in Abidjan district using multi-criteria analysis (AHP) model and geoinformation techniques, (cote d'ivoire). *Geoenviron Disasters* 3(1):10. <https://doi.org/10.1186/s40677-016-0044-y>
- Das B, Pal SC, Malik S, Chakraborty R (2019) Living with floods through geospatial approach: a case study of Arambag CD Block of Hugli District, West Bengal, India. *SN Appl Sci* 1(4):329
- de Brito MM, Evers M (2016) Multi-criteria decision-making for flood risk management: a survey of the current state of the art. *Nat Hazards Earth Syst Sci* 16(4):1019–1033
- Dhiman R, VishnuRadhan R, Eldho TI, Inamdar A (2019) Flood risk and adaptation in Indian coastal cities: recent scenarios. *Appl Water Sci* 9(1):5
- Di Risio M, Bruschi A, Lisi I, Pesarino V, Pasquali D (2017) Comparative analysis of coastal flooding vulnerability and hazard assessment at national scale. *J Marine Sci Eng* 5(4):51
- Erena SH, Worku H (2018) Flood risk analysis: causes and landscape based mitigation strategies in Dire Dawa city, Ethiopia. *Geoenviron Disasters* 5(1):16
- Gourav P, Kumar R, Gupta A, Arif M (2020) Flood hazard zonation of Bhagirathi river basin using multi-criteria decision-analysis in Uttarakhand, India. *Int J Emerg Technol* 11(1):62–71
- Gupta AK (2017) A study on urban flood vulnerability in Vrishabhavathi Valley Watershed, Bengaluru, Karnataka using AHP, GIS and RS techniques. *Int J Adv Remote Sens GIS* 6(1):2325–2342
- Hoque MA-A, Tasfia S, Ahmed N, Pradhan B (2019) Assessing spatial flood vulnerability at Kalapara Upazila in Bangladesh using an analytic hierarchy process. *Sensors* 19(6):1302
- Indrayani P, Mitani Y, Djamaluddin I, Ikemi H (2018) Spatial-temporal vulnerability and risk assessment model for urban flood scenario. *ASM Sc J* 11(Special Issue 3):233–245
- Kazakis N, Kougiaris I, Patsialis T (2015) Assessment of flood hazard areas at a regional scale using an index-based approach and analytical hierarchy process: application in Rhodope-Evros region, Greece. *Sci Total Environ* 538:555–563
- Lawal DU, Matori AN, Hashim AM, Wan Yusof K, Chandio IA (2012) Detecting flood susceptible areas using GIS-based analytic hierarchy process. *Int Proc Chem Biol Environ Eng* 28:1–5
- Mundhe N (2019). Multi-criteria decision making for vulnerability mapping of flood hazard: a case study of Pune city. *J Geograph Stud* 2(1):41–52. <https://doi.org/10.21523/gcj5.18020105>
- Nandy S, Kushwaha SPS, Gaur P (2012) Identification of Swamp deer (*Cervus duvauceli duvauceli* Cuvier) potential habitat in Jhilmil Jheel Conservation Reserve, Uttarakhand, India using multi-criteria analysis. *Environ Manag* 49(4):902–914
- Nasiri H, Yusof MJM, Ali TAM (2016) An overview to flood vulnerability assessment methods. *Sustain Water Resour Manag* 2(3):331–336
- Nayak S, Bhaskaran PK (2014) Coastal vulnerability due to extreme waves at Kalpakkam based on historical tropical cyclones in the Bay of Bengal. *Int J Climatol* 34(5):1460–1471
- Panhalkar SS, Jarag AP (2017) Flood risk assessment of Panchganga River (Kolhapur district, Maharashtra) using GIS-based multicriteria decision technique. *Curr Sci* 112(4):785
- Rocha C, Antunes C, Catita C (2020) Coastal vulnerability assessment due to sea level rise: the case study of the Atlantic Coast of Mainland Portugal. *Water* 12(2):360
- Roy DC, Blaschke T (2015) Spatial vulnerability assessment of floods in the coastal regions of Bangladesh. *Geomatics Nat Hazards Risk* 6(1):21–44
- Saaty TL (1980) The analytic hierarchy process. McGraw-Hill, New York
- Sarkar D, Mondal P (2020) Flood vulnerability mapping using frequency ratio (FR) model: a case study on Kulik river basin, Indo-Bangladesh Barind region. *Appl Water Sci* 10(1):17

- Seejata K, Yodying A, Wongthadam T, Mahavik N, Tantanee S (2018) Assessment of flood hazard areas using analytical hierarchy process over the Lower Yom Basin, Sukhothai Province. *Proc Eng* 212:340–347
- Srivastava RK (2011) Disaster management of India. UNDP, MHA (GOI), Delhi
- Sulaiman NA, Mastor TA, Mat MSC, Samad AM (2015) Flood hazard zoning and risk assessment for Bandar Segamat sustainability using analytical hierarchy process (AHP). In: 2015 IEEE 11th international colloquium on signal processing and its applications (CSPA), pp 72–77. IEEE
- Velasquez M, Hester PT (2013) An analysis of multi-criteria decision making methods. *Int J Oper Res* 10(2):56–66
- Vignesh KS, Madha Suresh V (2018) AN assessment of flood vulnerability using risk matrix method-a case study of Kanayakumari district, Tamil Nadu. *J Global Resour* 4(01):102–106
- Zelenakova M, Blistan P, Purcz P, Fijko R (2015) Multicriteria analysis for flood vulnerable areas in southeastern Slovakia. *Eurasian J Environ Res* 1(2):8–19

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.