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Regional Planning Framework for Addressing Flood Vulnerability of a Metropolitan Region: The Case of Malappuram, Kerala, India

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Abstract. *Flood susceptibility is becoming increasingly important among the various natural disasters in terms of environmental, economic, and social consequences. The eco-regional planning approach, which incorporates the ecological boundary as a layer in the spatial planning process of settlements, is one of the most innovative concepts in recent research to address these problems. Hence, this research interrogated flood susceptibility mapping tools using an appropriate model for better settlement planning and management. A frequency ratio model was applied to a case region, Malappuram (in the State of Kerala, India), one of the world's fastest urbanizing metropolitan regions, using a three-tier assessment framework. A frequency ratio database for flood susceptibility mapping was created by combining historic flood locations with independent factors. The study region was divided into five flood-risk zones based on the computed flood susceptibility index, which varied from 0 to 18.38, i.e., very high, high, moderate, low, and very low. The results showed that the high and very high susceptibility classes accounted for 8.82% and 17.17% of the land, respectively. This paper highlights the requirement for a multi-level assessment of an ecologically oriented regional planning regime in India and estimates the success rate of flood prediction at 79.33%. The proposed regional planning framework is therefore essential for local government planners, researchers, and administrators when creating flood mitigation measures, and has the potential to become a substantial and essential instrument.*

Keywords. *Eco-regional planning, Flood Susceptibility, Frequency Ratio (FR) Model, Seed Cell Area Index (SCAI).*

Abstrak. *Kerentanan banjir menjadi semakin penting di antara berbagai bencana alam dalam hal konsekuensi lingkungan, ekonomi, dan sosial. Pendekatan perencanaan ekoregion, yang menggabungkan batas ekologis sebagai lapisan dalam proses perencanaan tata ruang permukiman, merupakan salah satu konsep paling inovatif dalam penelitian terkini untuk mengatasi masalah ini. Oleh karena itu, penelitian ini menginterogasi alat pemetaan kerentanan banjir menggunakan model yang tepat untuk perencanaan dan pengelolaan permukiman yang lebih baik. Model rasio frekuensi diterapkan pada wilayah kasus, Malappuram (di Negara Bagian Kerala, India), salah satu wilayah metropolitan dengan urbanisasi tercepat di dunia, menggunakan kerangka penilaian tiga tingkat. Database rasio frekuensi untuk pemetaan kerentanan banjir dibuat dengan menggabungkan lokasi banjir bersejarah dengan faktor independen. Wilayah studi dibagi menjadi lima zona rawan banjir berdasarkan perhitungan indeks kerawanan banjir yang bervariasi dari 0 hingga 18,38 yaitu sangat tinggi, tinggi, sedang, rendah, dan sangat rendah. Hasil penelitian menunjukkan bahwa kelas kerentanan tinggi dan sangat tinggi masing-masing sebesar 8,82% dan 17,17% lahan. Makalah ini menyoroti kebutuhan untuk penilaian multi-level dari rezim perencanaan regional yang berorientasi*

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ekologis di India dan memperkirakan tingkat keberhasilan prediksi banjir sebesar 79,33%. Oleh karena itu, kerangka perencanaan regional yang diusulkan sangat penting bagi perencana, peneliti, dan administrator pemerintah daerah saat membuat langkah-langkah mitigasi banjir, dan memiliki potensi untuk menjadi instrumen penting dan penting.

***Kata kunci**. Indeks Area Sel Benih (SCAI), Kerentanan Banjir, Model Rasio Frekuensi (FR), Perencanaan ekoregion.*

Introduction

Natural disasters are regarded as the most pressing issue that needs to be addressed on a local, regional, and global level. Climate change can increase the frequency, intensity, and seasonality of catastrophic disaster events like floods, making concurrent flood hazards critical to urban flood risk management (Homian Danumah et al., 2016). There is a possibility that flooding will occur more regularly in the future (Danumah et al., 2016). According to the World Health Organization (WHO), floods have caused severe damage to more than two billion people worldwide from 1998 to 2017. (*Economic Losses, Poverty & Disaster: 1998-2017*, 2018). Floods have resulted in notable harm to both the socio-economic fabric and physical infrastructure, posing a grave threat to human lives (Munir et al., 2022). The process of urbanization negatively affects the hydrological processes in urban areas by increasing the speed of runoff flow and intensifying peak flow, ultimately leading to higher risks of urban flooding (Chen et al., 2015). In India and other nations, alarmingly heavy rainfall has led to an upsurge in the occurrence and scale of urban flooding over the previous several decades. In flood-affected cities, this may result in massive harm to the local's life, assets, and livelihoods. Flooding is more likely to occur in coastal and urban areas due to the combined influence of intense downpours and high tides (Eldho et al., 2018). Hence, the need for scientific and accurate flood risk assessment cannot be overlooked for present and future human settlements.

Flood risk assessment is a scientific and specialized technical branch or procedure that deals with the quantitative analysis of flood susceptibility. Due to the increased production of scientific/technical research on this topic, it can be regarded as an emergent discipline (Díez-Herrero & Garrote, 2020). Susceptibility mapping is critical for examining storm surges besides their underlying flood risks; hence, choosing the right method is critical for determining flood susceptibility (Sahana et al., 2020). Various models in the domain of flood susceptibility mapping have been developed by many researchers and have evolved over time, adapting to new software platforms and improved data resources. The frequency ratio (FR) model is a relatively new approach that can generate scientifically accurate results to identify potential hazard areas within a study region (Lee & Kang, 2012). Numerous studies have indicated a gap between models and frameworks for evaluating flood vulnerability, which may be bridged by combining high-resolution data with a statistical approach to assess susceptibility and identify critical zones for planning and intervention.

Flood events are most destructive to those who reside in floodplains living in residences that are not flood-resistant. This vulnerable zone of residences does not have a flood alert system or is not aware of the potential risks. Intense rainfall events are becoming less common in large sections of North and Central India, while they are becoming more frequent in Northeast, East and peninsular India. Extreme weather events are becoming more common in the country, posing a greater risk of flooding (Guhathakurta et al., 2011). Kerala is a state[2] that has witnessed some of

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[2] "India is a federal union made up of 28 states and 8 union territories, totaling 36 separate entities" (*States Uts*, 2022).

the highest urbanization rates in India along with land use land cover (LULC) changes often leading to flash floods (Krishnan V. & Firoz C., 2021). The state also has a peculiar topography with cross-sections of high land, low land, and midlands (Cyriac & Firoz C, 2022). Hence, any change in the LULC anywhere in the topography can severely impact the downstream areas, especially the midlands and lowlands (Sonu et al., 2022). Perhaps, due to these factors, the frequency and intensity of the floods have been rising at an alarming rate since 2018.

The Malappuram region in Kerala, India, is ranked as one of the world's fastest growing metropolitan regions (T P Nijeesh, 2020). The consecutive floods and natural calamities in the state have also affected the lives in Malappuram, which witnessed a growth of 13.45% of the urban population in a decade in the district (Census of India, 2011). The city region has also witnessed several severe floods in the recent past, especially the 2018 and 2019 floods, as well as landslides, causing damage to life and properties, thus making it one of India's most vulnerable emerging urban centers. In most developing countries, studies intended to assess floods are mostly done non-scientifically and take a piecemeal approach by taking the city area as the boundary, whereas city boundaries are often decided based on some arbitrary choice. In fact, such studies must be ideally approached from a regional planning perspective by initially taking a broader region for the initial assessment. Using the inferences, a detailed assessment of the city area can be undertaken (Sonu et al., 2022). This way, one of the significant flood management problems in urban and regional planning amongst cities in India can be addressed. This approach contrasts with a conventional master planning approach based on administrative boundary limits.

Although the study area Malappuram is a metropolitan region, unfortunately, its spatial plans are developed only for the smaller statutory Urban Local Bodies[3] (ULBs), as per the present planning regime in Kerala (Sonu et al., 2022). Hence, this paper stresses the need to change the spatial planning process from the conventional approach to eco-regional based planning by superimposing eco-sensitive vulnerable regions within a larger metropolitan region onto the spatial plans. Hence, the primary objective of the present study was to demonstrate a regional planning approach by identifying the flood vulnerable zones via flood susceptibility mapping for a metropolitan region. It is imperative to provide strategies and solutions for better planning and management to counter such a high rate of urbanization and vulnerability to floods. The work sought to effectively analyze flood risk potential zones in the Malappuram metropolitan region to assist local authorities, such as the district[4] administration and ULBs, in developing flood mitigation strategies and proposing a framework for a regional planning approach based on flood susceptibility.

Therefore, the present study examined the relationship between the urbanization process, land-use changes, and flood susceptibility for the case region. The study also accentuates a need for a new framework for integrating a regional planning framework into the preparation of master plans for each local body and integration of local-area plans (zonal plans within a city) to address flooding. The proposed spatial scale of the research is given in Figure 1. A multi-level assessment and regional planning framework is formulated based on the output of the tier-1 level of assessment, which was the focus area of this study.

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[3] "Urban Local Bodies (ULBs) are small institutions formed under 74th Constitution Amendment Act that governs or administers a city or a town of specified population. Urban Local Bodies are vested with a long list of functions delegated to them by the state governments" (*Census of India: Administrative Divisions*, 2001).

[4] "Districts and smaller administrative entities are subdivided further inside the states and union territories" (*Census of India: Administrative Divisions*, 2001).

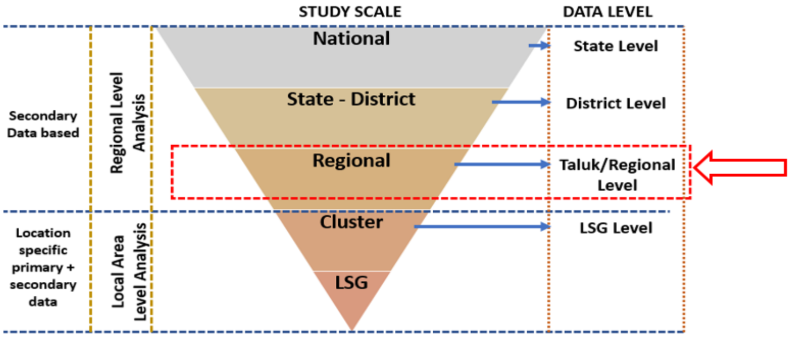


Figure 1 Scale of the present study.

This paper is divided into six sections. The first section is the introduction to the research, followed by a literature review of state-of-the-art research/assessment tools in the second section. The third section explains the methodology followed to get the results described in the fourth section, accompanied by its validation. A set of planning recommendations is discussed in the fifth section. The last section concludes the research, suggesting the need for multi-level assessment for regional planning based on flood susceptibility.

Literature Review

Ecological approaches in urban and regional planning gained significance in the 1960s and 1970s but were not yet widely accepted globally (Heymans et al., 2019; Wright, 2007). Even though ecosystems or eco-regions are intended to be viewed as a single entity for administrative convenience, their separation by administrative boundaries does not make them distinct entities that can be considered in isolation (Watershed Planning in Ontario, 2018). Recurrent disasters have highlighted the need for a different strategy to develop and conserve complex ecosystems that span administrative boundary limits, such as wetlands, forestry, creeks, and mangroves (Kohli, 2003). The best methods connect protected areas, preserve landscapes, and plan further developments without changing the city structure. Once defined, a plan must be viewed as a tool for enhancing the region’s coping capabilities rather than as a product (Margerum, 2011). A regional strategy should include a flood susceptibility assessment, a storm-water master plan, rising sea level forecasts, blue/green/grey infrastructure mapping, and other factors (*Watershed-Based Planning — Wetlands Watch*, 2021). Kerala’s current planning system is fragmented and fails to recognize the emergence of a developing mega-region along the coast, neglecting many ecological elements (Cyriac & Firoz C, 2022).

A comprehensive literature review was conducted to understand the critical works done in the related field, their takeaways and future research options, and the existing tools and methodological processes for conducting a flood susceptibility analysis based on the research area’s vulnerability scenario. Accordingly, the current section is divided into four sub-sections: background literature and research; literature on analyzing vulnerability scenarios; accessible tools and techniques; and existing models to perform flood susceptibility analysis

Existing Flood Susceptibility Scenario

In 2018, landslides caused widespread devastation in Kerala and Karnataka, resulting in the evacuation of 1.4 million people and 499 deaths (Viju B, 2019). Across the state of Kerala, landslides in 5,000 locations with distinctive intensities and characters, occurred nearly simultaneously. The result was catastrophic, as nearly one out of every six individuals in the state were affected (Directorate Central Water Commission, 2018). Three-quarters of villages in Kerala were hit by the disaster, displacing around 1.5 million people for a short time. Nearly 500 lives were lost, and the total cost of the losses and damages were estimated at USD 3.8 billion. Another spell of relentless rains in August 2019 resulted in heavy floods and landslides while the state was still recovering from the trauma of the 2018 disasters. Between 2006 and 2016, the change in Kerala's built-up regions in LULC increased by 139%. There was a significant loss of land cover in agriculture, barren land, and forest. The rise in built-up area has revealed a significant increase in the built-up rural category of 251% over a decade. During the same period, mining areas increased by 1,535%, resulting in accelerated land-use changes (Cyriac & Firoz C, 2022). The loss of agricultural land and forest land and growing urbanization and mining contributed to Kerala's devastating floods in 2018 and 2019 (United Nations Development Program, 2018). This situation is not different in most of the state's urban centers, including Malappuram, the case study metropolitan region.

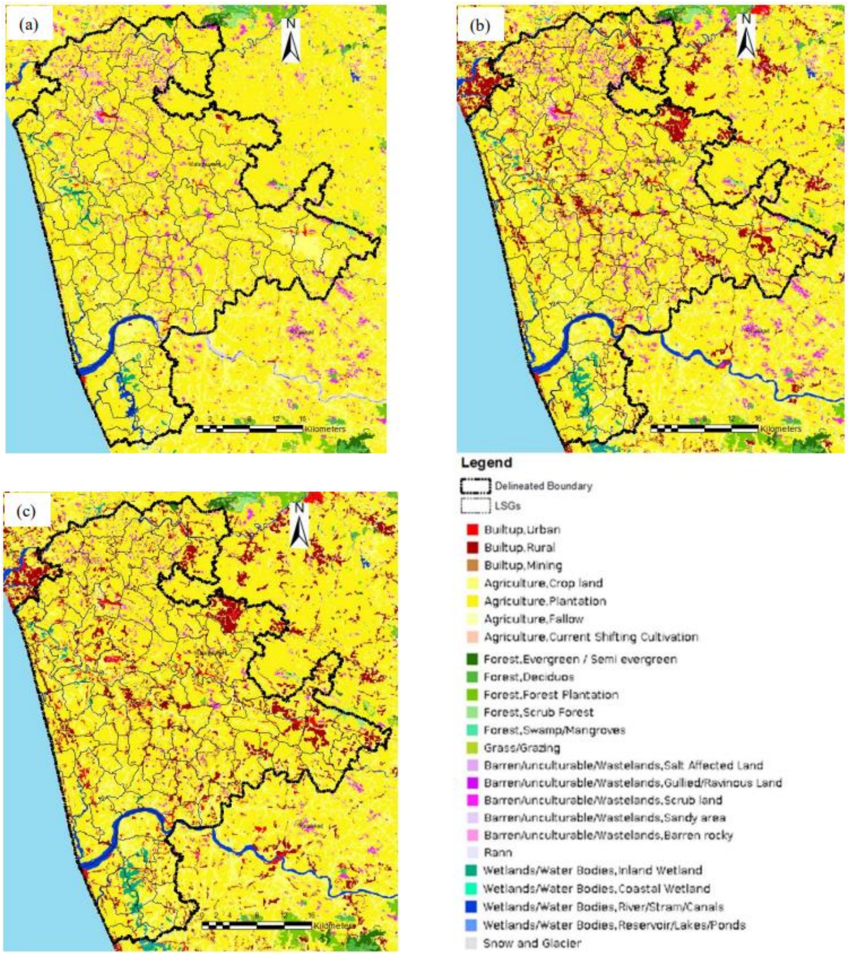


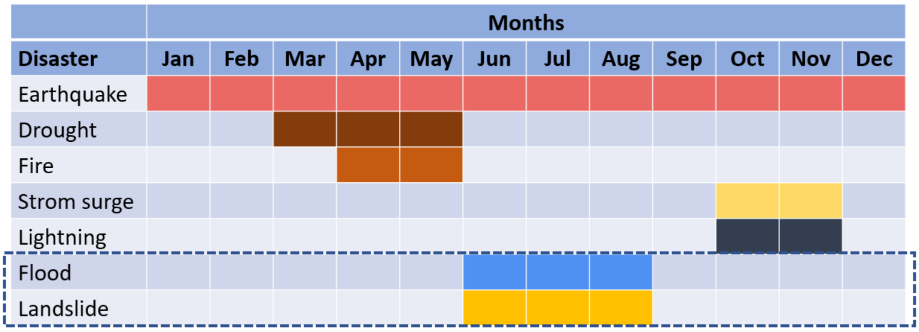
Figure 2 LULC map of Malappuram: (a) 2005-06; (b) 2010-11; (c) 2015-16 (Supervised Classification of Resourcesat 2 Imagery, Bhuvan).

Assessing the Malappuram metropolitan region, an increase of 5.73% was observed in built-up land use between 2005 and 2010 and an increase of 4.86% between 2010 and 2015. The conversion to rural built-up from agricultural land has substantially changed built-up land use in rural areas (Figure 2). Incessant rain and sporadic landslips in the forest regions of Nilambur triggered abrupt floods in the eastern regions of Malappuram, submerging various locations.

Figure 3 shows the seasonality of the hazards occurring in the Malappuram district as per the State Disaster Management Authority (SDMA) of Kerala. Significant precipitation in a short period throughout June, July, and August in the year 2018 pushed the runoff water above the capacity of the rivers. The steep landscape from the high-land Western Ghats to the low-lying western coast intensified the flood surges. In typical monsoon circumstances, the water level in Kerala's streams remains high throughout July and August (Directorate Central Water Commission, 2018). It shows that an extended/intense period of excess rainfall throughout these months, following a typical monsoon in June, can cause severe floods in Kerala's river basins. The rainfall data for 2013, 2018, 2019 and 2020 directly relate to the extent of flooding proportional to the annual rainfall (Figure 4).

Various studies have also shown that under optimum ocean-atmospheric conditions, such cloudburst events may leave a large area of the state exposed to landslides and flash floods throughout the monsoon period (Vijaykumar et al., 2021). The Gadgil report (Madhav Gadgil, 2011), published by the Western Ghats Ecology Expert Panel (WGEEP), is back in the spotlight after over three dozen people died in landslides and flash floods in October 2021. It predicted these disasters far in advance.

Unplanned changing land use patterns in Kerala are another primary reason that has changed the course of the water bodies and affected the seepage of water to recharge the underground resulting in increased surface runoff (Peter & Thummarukudy, 2019). LULC maps suggest reduced natural water bodies resulting in new flood risk zones and risks associated with residents' properties. Hence, there is a need to perform a flood susceptibility analysis in the case study region of Kerala, India, to determine the magnitude of sensitive human settlement territories and the possible risks. Various studies in flood modelling focused on a methodology for mapping flood susceptibility or conducting a comparative literature review of current models to propose generalist recommendations as broad interventions. In geographical areas like Kerala, where there is a high population density and a 'rurban'[5] settlement pattern, an urban planning and design paradigm based on ecology is pivotal (Sonu et al., 2022). The present research therefore aims to contribute a statistical approach and framework to identify flood-prone zones and delineate the group of local administrative bodies from a more significant regional planning perspective as a need for spatial planning and policy.



	Months											
Disaster	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Earthquake	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Drought			🟫	🟫	🟫							
Fire				🟧	🟧							
Strom surge										🟨	🟨	
Lightning										⬛	⬛	
Flood						🟦	🟦	🟦				
Landslide						🟨	🟨	🟨				

Figure 3 Hazard seasonality of Malappuram (District Disaster Management Authority, 2016).

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[5] The transition zone, which exhibits a distinct rural-urban continuum in which rural and urban uses mix and frequently clash. (Sonu et al., 2022).

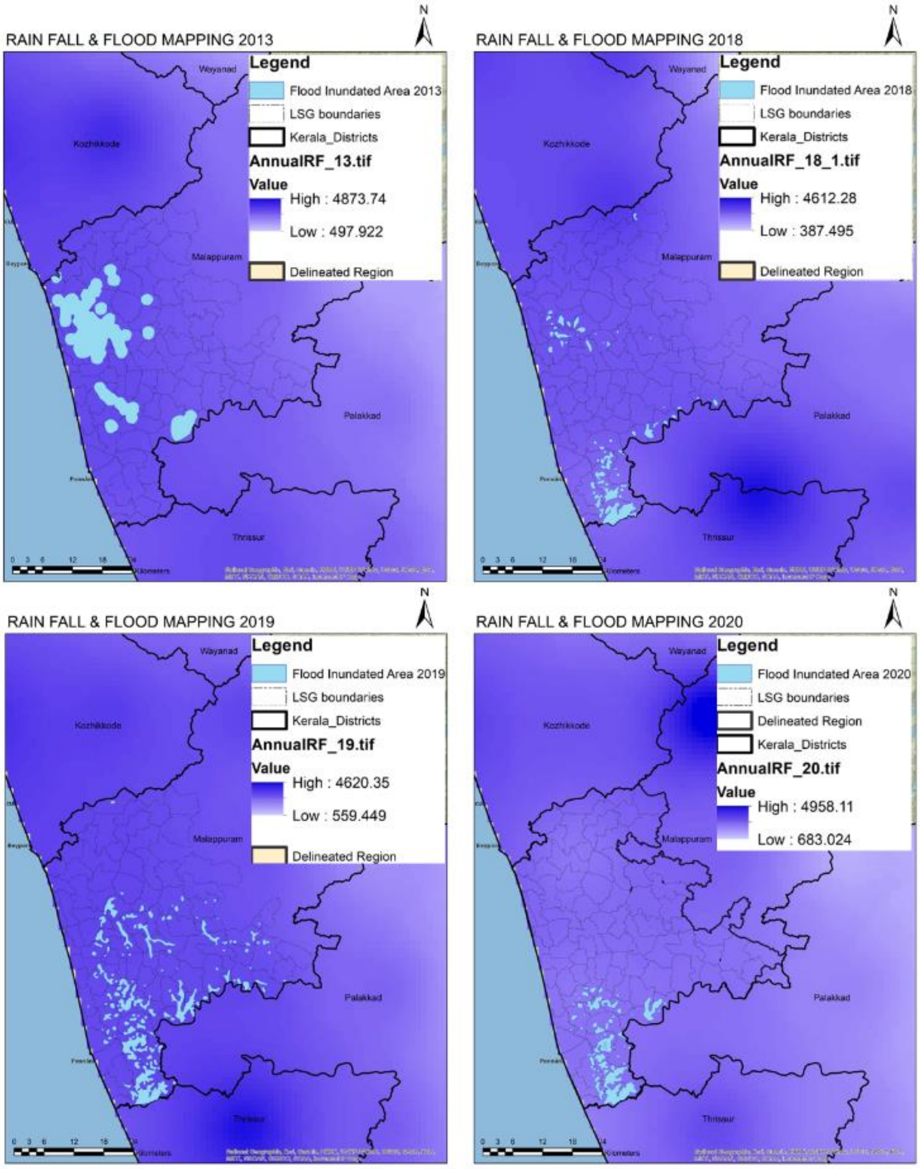

Figure 4 Rainfall and flood mapping for 2013, 2018, 2019 & 2020 (*Yearly Rainfall Data, IMD Pune*, 2021).

Tools and Techniques

Flooding is a large-scale natural calamity that is nearly impossible to stop entirely (Cloke & Pappenberger, 2009). Hence, it is indispensable to conduct flood vulnerability assessments and develop flood susceptibility mappings so that local governments can devise management strategies to reduce the damage caused by floods in the near future. Flood susceptibility mapping is a vital instrument for governments and planners to develop efficient flood management plans. The occurrence and intensity of a flood are contributed by physical factors such as climate, geomorphological structure, and human factors such as building construction, deforestation, etc. Flood susceptibility is a major cause of human misery, resulting in food security challenges, outbreaks of different waterborne diseases and infrastructure damages. Furthermore, as disasters account for 85% of the mortality among women and children, these are predominantly susceptible

(Neumayer & Plümper, 2007) and thus evaluating their susceptibility is an essential aspect of flood risk assessment. Numerous approaches have been in use to evaluate flood vulnerability for a long time. Understanding its various dimensions is critical for having a comprehensive comparative analysis. Geographic Information System (GIS) software tools and Remote Sensing (RS) have become increasingly widespread in recent years, as they add a new dimension to susceptibility assessment and validation. Satellite image analysis on RS and GIS platforms produces good results for mapping flood inundation and susceptibility, since it gives reliable information about an area (Ali et al., 2019). It provides a stable environment in which many models can run and data can be used to examine flood vulnerability, resulting in more rational and acceptable conclusions. RS and GIS methods to flood susceptibility are presently used effectively worldwide (Dewan et al., 2007; Haq et al., 2012; Khosravi et al., 2016). Flood susceptibility analysis has recently shifted to a greater emphasis on Advanced Land Imager (ALI) information and added high-resolution microwave data techniques for estimating turbidity and flood inundation (Amarnath, 2014). High-resolution airborne radar data, for example, has proven to be more beneficial in local flood inundation exploration (Murdukhayeva et al., 2013). Owing to their well-timed picture transmission, RADARSAT data, Sentinel 1 & 2 and Synthetic Aperture Radar (SAR) are given due consideration when investigating flood susceptibility. Furthermore, flood vulnerability evaluation by means of advanced machine learning techniques besides GIS-based modelling is gaining traction (Ahmadlou et al., 2018; Chapi et al., 2017; Hong et al., 2018; Khosravi et al., 2018; Shafizadeh-Moghadam et al., 2018).

A flood management plan, in most circumstances, refers to measures for delivering aid and resettling flood victims. The fundamental four steps in flood management are flood prediction, flood preparedness based on flood predictability, flood strategy implementation, and overall damage assessment (Konadu et al., 2009). Univariate, Bivariate and Multivariate Analysis are the three types of assessment techniques available (Tehrany et al., 2014; Youssef et al., 2016). A Univariate analysis method is used when there is only one variable in the data and there are no cause-and-effect relationships. This technique employs frequency distribution pie charts, tables, histograms, frequency polygons, and bar charts as descriptive tools. Bivariate analysis is a great analytic technique to use when a data set contains two variables and experts want to compare two data sets. Correlation coefficients and regression analysis can be used to perform bivariate analysis. When there are more than two variables in a data set, a more complex statistical analysis method is performed, called multivariate analysis. (Hossain, 2019). Compared to a single-criteria-based flood susceptibility analysis, a multi-criteria assessment of flood risk and susceptibility will be far more precise and reliable (Sarkar & Mondal, 2020). Bivariate statistical analysis was used for this research as a primary analysis for a ‘preliminary probabilistic assessment’ of flood vulnerability; the mathematical easiness and data exploration in a limited time frame are important considerations for rapid assessment.

Flood susceptibility assessment models

Flood susceptibility research will be critical in the future for preventive measures and flood control. The models most often used are empirical, simplified, and hydrodynamic conceptual models for flood inundation (Teng et al., 2017). Empirical models include historical evidence, surveys, remote sensing, and research information (Smith, 1997; O’Connor & Costa, 2004; Schumann et al., 2009). Such models employ most data directly and are usually used in tandem with different models to improve decision making.

The most popular models for calculating flood inundation are hydrodynamic models, which simulate water movement by resolving the equations governing the underlying physical processes. Because they are computationally complex and time-consuming, they cannot be employed in applications that involve an extensive number of model runs (e.g., uncertainty analysis) or quick model responses (e.g., real-time forecasting) (Teng et al., 2017; Xie et al., 2021).

Simplified conceptual models have been developed as an alternate technique to increase the computing efficiency of flood inundation modelling (McGrath et al., 2019; Teng et al., 2017). These models run incredibly quickly since they do not attempt to represent the intricate process of water flow. They are typically only used to forecast the maximum flood inundation of certain flood occurrences because they are not physically derived, which limits their ability to replicate the adaptive process of water flow (Teng et al., 2017). Analytical hierarchy process (AHP), Multi-Criteria Decision Support Approach (MCDA), artificial neural networks (ANN), Weights of Evidence (WofE), and frequency ratio (FR) models are among the many comprehensive techniques utilized by various researchers that can be grouped under simplified conceptual models for flood vulnerability mapping (Teng et al., 2017).

Although the FR models and WofE are novel for flood susceptibility assessment, they are well-known for other natural disasters such as landslide mapping. For flood susceptibility mapping, both models get similar results (Rahmati et al., 2016), but the FR model has the upper hand with a better prediction rate, and a comprehensible input, output and calculation process with the possibility of obtaining quick results (Pirasteh & Li, 2017; Saha et al., 2021). This model is a bivariate statistical analysis (BSA) tool, where each class of individual parameters is given a value and its influence on the occurrence of flooding is measured. It can provide a flood susceptibility map that is scientifically valid. Flood-prone zones derived from this model can help to minimize floods and their consequences (Lee & Kang, 2012). A flood susceptibility assessment was conducted for the Markham River basin in eastern Papua New Guinea using MCDA (S. Samanta et al., 2018); the FR model outperformed the other method. This model is an adequate tool for susceptibility assessment with a high precision rate. Its simplicity makes it a practical and efficient approach for flood susceptibility mapping, especially in areas like Malappuram with limited data or resources. The present research used the frequency ratio method to develop a flood hazard map.

Model validation checks whether a trained model is reliable enough to be used as valid input for flood mitigation and future development planning. Validation tools such as Receiver Operating Characteristic (ROC), Training Stress Score (TSS), Seed Cell Area Index (SCAI), Accuracy testing, and others tests were used in previous studies (Chung & Fabbri, 2003; Natarajan et al., 2021; Sarkar & Mondal, 2020; Yodying, 2019). While there are no clear criteria for assigning flood points to validation and training data sets (Pradhan & Lee, 2010; Sarkar & Mondal, 2020), previous research projects generally used 70% of flood events as training data set for flood susceptibility model development and the remaining 30% for model validation (Pourghasemi & Beheshtirad, 2014; Tunusluoglu et al., 2008). In the present study, 30% of the validation locations were used to validate the model, while 70% of the training locations were selected at random for flood modelling (Haghizadeh et al., 2017; Rahmati et al., 2016). A validation technique known as Seed Cell Area Index (SCAI) compares the percentage of pixels in a particular flood susceptibility class to the percentage of pixels that have already experienced flooding at the designated site. (Arabameri et al., 2020; Sahana & Sajjad, 2017; Süzen & Doyuran, 2004; Yodying, 2019). The accuracy assessment and SCAI were used to weigh the method's accuracy and efficiency in the present study.

Materials & Methods

The present study aimed to understand the flood susceptibility situation of the study area to propose an appropriate regional planning framework. This section introduces the study area and its characteristics, followed by the various data sources required for the assessment. Subsequently, the detailed methodological process for the flood susceptibility analysis is explained.

Study Area

The fourth-largest urban agglomeration in the state of Kerala and the twenty-fifth-largest in India is the Malappuram Metropolitan Area (Figure 5) Malappuram is also one of the world's fastest-growing urban agglomerations, with a population of 1.6 million in 2011 compared to only 300,000 in 2001 (T P Nijeesh, 2020). Following the 2011 census, the urban areas in Kerala were redefined, leading to a rise in the number of municipalities and towns. The study area has 90 villages and 82 LSGs[6]. Incessant rain and sporadic landslips in the highland regions of Malappuram has impacted the midland and low-lying regions within the area of interest. The flood-affected areas of the Malappuram Metropolitan Region are represented in Figure 6.

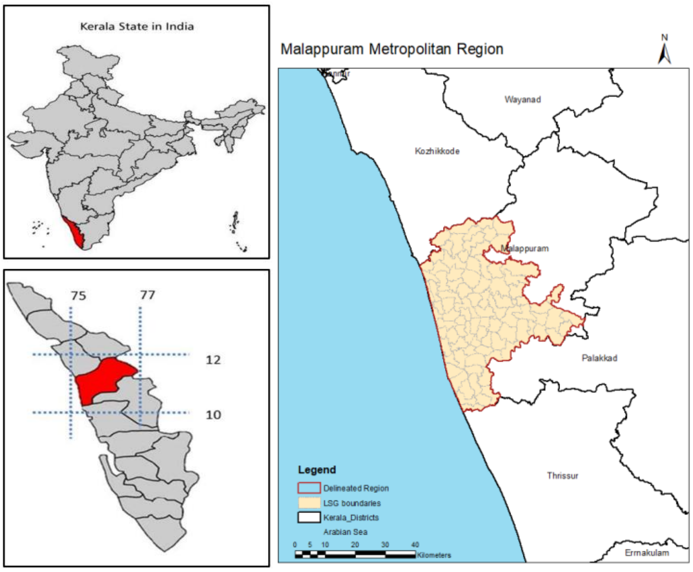

Figure 5 Location map of the Malappuram Metropolitan Region in the state of Kerala, India.

As discussed in Existing Flood Susceptibility Scenario Section, Kerala received plenty of rain between June 1 and August 19, 2018, more than 75% of the annual average rainfall and 42% more than usual. The massive rains soaked roughly the whole state, forcing the administration to release water from 35 dams even though the rains continued. In the state, more than 60% of the villages were affected. Wayanad, Malappuram, and Kozhikode in Kerala's northern regions in particular were notably affected. As can be seen in Figure 6, a large extent of the metropolitan region was affected by floods in 2013, 2018, 2019, and 2020. The series of consecutive floods started in 2018, affecting an area of 60.71 km^2 (3.5% of the metropolitan region), followed by the most intensive flooding in 2019, affecting an area of 147.94 km^2 (8.5% of the whole region). The flood of 2020 submerged an area of 71.92 km^2, affecting 4.1% of the area of the metropolitan region (*Event Specific Maps – Kerala State Disaster Management Authority*, 2021).

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[6] "73rd CAA gave power to the *gram panchayats* and empowered them as units of Local self-governments as the agency to determine and carry out policy in an area within a state. It is the lower most administrative unit within a state followed by black and district." (Local Government, Britannica, 2017)

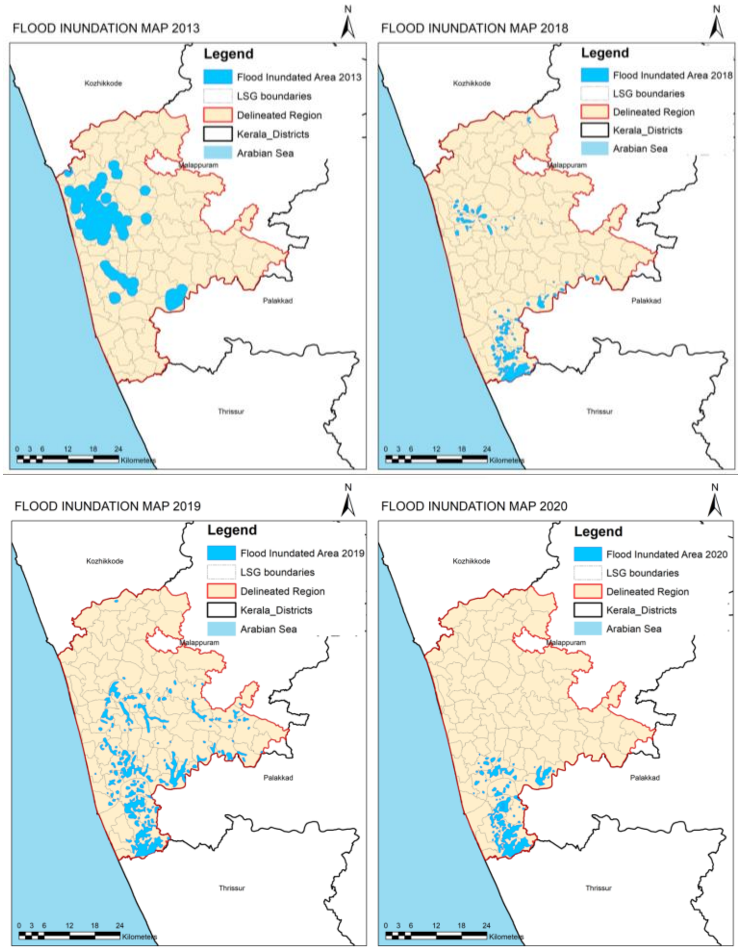


Figure 6 Flood inundation maps of 2013, 2018, 2019 & 2020 (Source: SDMA Kerala).

The Malappuram metropolitan region is spread over an area of 1,727 km². LULC change analysis was performed using digitized LULC maps from 2005-06, 2010-11, and 2015-16. The built-up region has grown significantly, which can be attributed primarily to the conversion of wetlands and agricultural land. Between 2005 and 2010, built-up land use surged by 5.73%, and between 2010 and 2015, it increased by 4.86%. The switchover from agricultural land to rural built-up has substantially changed built-up land use in rural areas. Future urbanization and new town centers could result from this. The locations identified with significant land-use changes and the recent flood-inundated areas are related, as highlighted in Figure 7. A significant relationship between increased urbanization and flooding is observed.

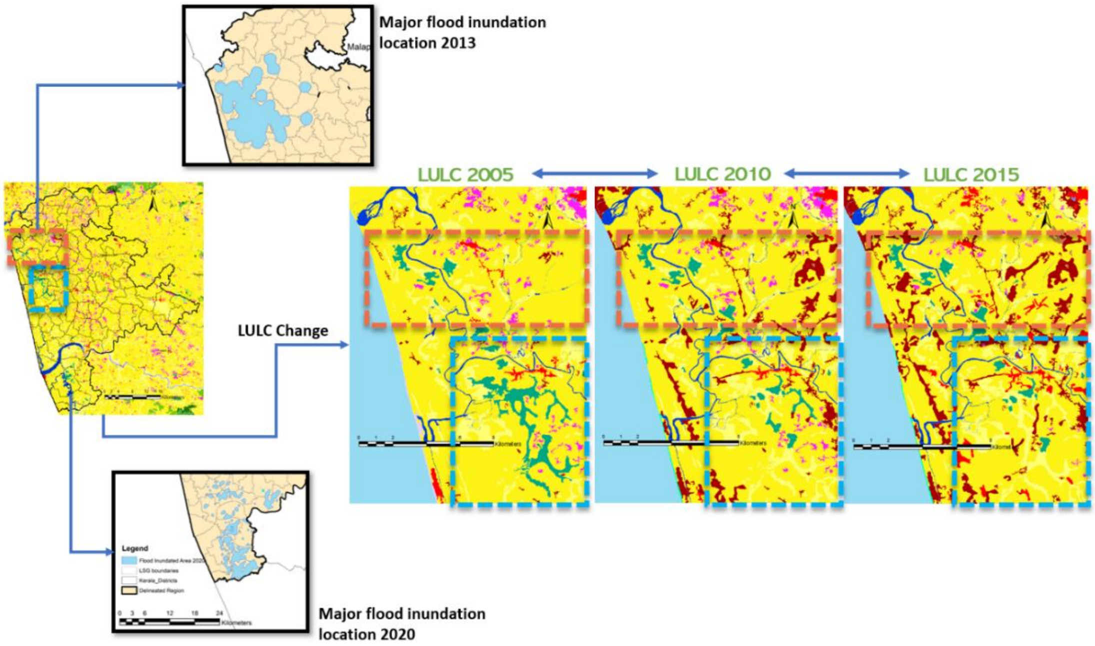


Figure 7 LULC change and flood inundation locations (Source: author-generated).

Data Sources and Collection

A flood susceptibility assessment was conducted using seven specific parameters frequently used in previous related studies: the LULC, Slope (Krishnan V & Mohammed Firoz, 2020), Elevation, Rainfall data, Topographic Wetness Index (TWI), soil type, and Lithology (Natarajan et al., 2021; Sarkar & Mondal, 2020; Yodying, 2019). The ArcGIS software was used to generate the geodatabase to integrate these layers.

It is critical to have scientifically validated previous flood occurrence data to anticipate future floods when analyzing flood vulnerability (Manandhar, 2010). The precision of previously documented flooding occurrences determines the accuracy and dependability of future flood risk (Merz et al., 2007). A flood inventory map was created using flood extent mapping from SDMA Kerala for 2013, 2018, 2019, and 2020. The Kerala SDMA flood event database yielded 325 historic flood locations that were plotted. 228 of 325 flood locations were used in the model construction, while 97 were used for validation, resulting in a 70:30 model building-to-validation ratio (Natarajan et al., 2021; Sarkar & Mondal, 2020; Yodying, 2019). The data set used for the flood susceptibility mapping is shown in Table 1. The 2015 LULC map was the most recent official map available from Bhuvan, a geo-portal of the Indian Space Research Organization (ISRO). It was derived from Resourcesat-2 LISS III with a spatial resolution of 30 x 30 m. Supervised classification is the most commonly used method for quantitative remote sensing image data analysis. Supervised classification was the method used for LULC preparation, employing the Maximum Likelihood Classification technique (Natarajan et al., 2021; R. K. Samanta et al., 2018; Sarkar & Mondal, 2020; Yodying, 2019). The most recent survey data, such as a lithological survey map (1996), came from the National Bureau of Soil Survey (NBSS). The soil survey information for 2016 came from the district survey report of minerals, Malappuram, 2016. The slope and elevation map were created in the ArcGIS spatial analysis tool using Shuttle Radar Topographic Mission (SRTM) Digital Elevation data for 2018, when the state experienced its worst floods since 2018.

Table 1 Flood susceptibility mapping data set.

Sl. No.	Data Description	Purpose	Year
1	SRTM DEM	Slope, elevation, TWI	2018
2	Meteorological data	Rainfall data	2018-2020
3	Resourcesat-2 LISS III	LULC	2015
4	Geological survey	Lithology	1996
		Soil type	2016

Methodology

Figure 8 explains the methodology used in the present study. All layers (as stated in Data Sources and Collection) were created and integrated into an ArcGIS environment to prepare the flood susceptibility mapping. The overall methodological process can be divided into three steps: frequency ratio analysis, Flood Susceptibility Index map, and model validation. The first step involved the creation of a flood inventory map that identifies the spatial distribution of flood events over a certain period. Then, the frequency ratio analysis was performed to determine the relationship between flood occurrences and several causative factors (parameters), such as slope, land use, soil, rainfall, Topographic Wetness Index (TWI), elevation and lithology. This analysis provides the weightage of each factor in contributing to flood susceptibility.

In the second step, a Flood Susceptibility Index (FSI) map was created by combining the weightage of each factor from the frequency ratio analysis. The FSI map provides an overall assessment of flood susceptibility for the study area, indicating the areas that are highly susceptible to floods based on a combination of causative factors.

The final step was the validation of the FSI map by comparing it with the actual flood events that occurred in the study area. This was done by using statistical methods such as accuracy assessment and Seed Cell Area Index (SCAI).

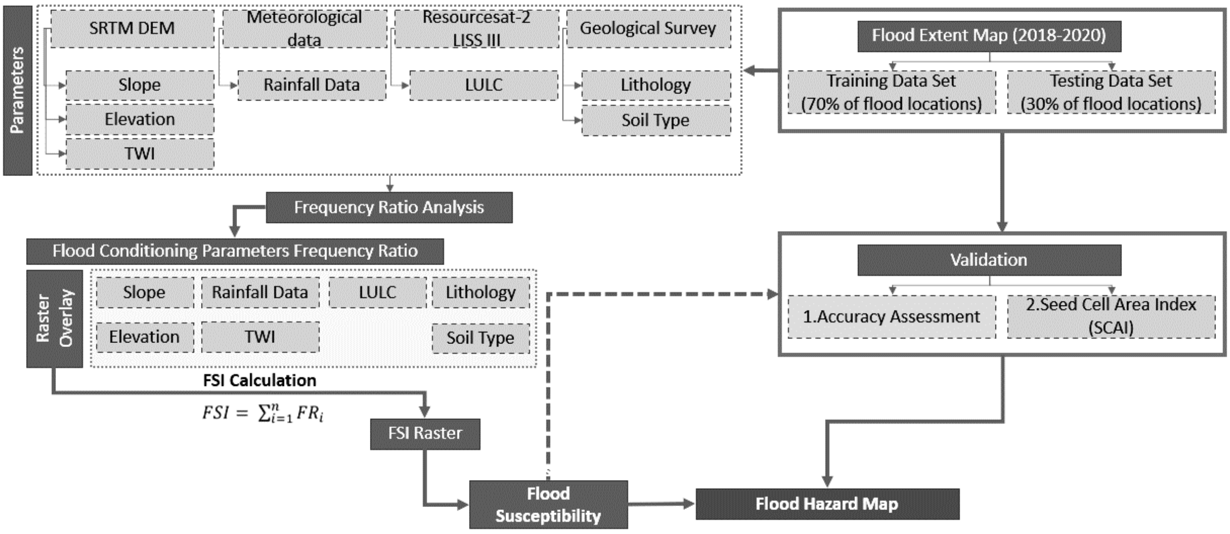


Figure 8 Methodological framework for flood susceptibility mapping.

Frequency Ratio Analysis

Elevation and slope are critical parameters for flood vulnerability mapping because elevation disparities impact climate features. Surface runoff and vertical percolation are both controlled by the slope of a region (Yodying, 2019). The ArcGIS spatial analysis tool created the slope and elevation map employing globally accessible Shuttle Rader Topographic Mission (SRTM) Digital Elevation Information. The resulting slope map was categorized into seven categories (up to 2.5°, 2.5°-5°, 5°-10°, 10°-15°, 15°-20°, 20°-25° and more than 25°). The elevation map was classified into eight classes (Less than 25 m, 25-50 m, 50-75 m, 75-100 m, 100-125 m, 125-150 m, 150-175 m and more than 175 m) (Natarajan et al., 2021; Sarkar & Mondal, 2020). The Topographic Wetness Index (TWI) is valid for estimating water accumulation in a region with varying elevations. It is determined by the slope and the contributing upstream area:

$$\mathrm{TWI} = \ln \frac{\mathrm{a}}{\tan \mathrm{b}} \qquad (1)$$

Where 'a' = contributing upstream area (m^2) and 'b' = slope in radians. Involved steps in the preparation of the TWI Map are:

- interpolate voids in a DTM
- calculate slope in degrees
- convert slope from degrees to radians
- calculate contributing upslope area
- calculate TWI (raster calculator)

Average rainfall data for 2018 to 2020 were sourced from the India Meteorological Department (IMD), and the data were interpolated for the entire assessment region. **Eq. 2** was used to calculate the FR index values (Sarkar & Mondal, 2020):

$$\mathrm{FSI} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{FR_i} \qquad (2)$$

where FSI stands for the flood susceptibility index and FR stands for the frequency ratio value for each factor, respectively.

The following formula (**Eq. 3**) was used to calculate the frequency ratio of the individual class of parameters (Sarkar & Mondal, 2020):

$$\mathrm{FR} = \frac{\mathrm{PH}}{\mathrm{PS}} \qquad (3)$$

In each class, PH represents the percentage of flood hazards, while PS represents the percentage of the case region area. The FR value shows the kinds of correlations between parameters and floods. A robust flood correlation is indicated by an FR value greater than 1, whereas a weak correlation is shown by an FR value less than 1 (S. Samanta et al., 2018).

Flood Susceptibility Index Map

Flood susceptibility mapping evaluation is critical for detecting flood-related elements. Previous flooding episodes and the factors that caused them could infer the correlation between flood and associated conditioning parameters that could trigger flooding. FR values of all variables were then transformed to a raster format, with a 30 m x 30 m pixel size spatial resolution of the individual raster layers. The database was consolidated using ArcGIS. This consolidated database was then categorized into five flood susceptibility classes using the Natural Break (Jenks) method (S. Samanta et al., 2018), i.e., very high, high, moderate, low, and very low flood susceptibility (Figure 8).

Model Validation

Validation of any model is critical in establishing the extent of authenticity and accuracy of the prediction. The first method used for validation was an accuracy assessment test using **Eq. ((4))**. This test checks the susceptibility classes identified within the flood inundated areas assigned for validation using 30% of the total flood location (Natarajan et al., 2021; Pradhan et al., 2010; R. K. Samanta et al., 2018).

$$\%\ \textbf{of accuracy} = \frac{\textbf{Number of pixels under High and Very High classes within the testing dataset}}{\text{Total number of pixels in the testing dataset}} \quad (4)$$

The Seed Cell Area Index (SCAI) method also validates flood susceptibility models. **Eq. (5)** illustrates this strategy by dividing the training and testing flood location data set by the percentage of flood susceptible areas (Sahana & Sajjad, 2017; Yodying, 2019).

$$\textbf{SCAI} = \frac{\textbf{Area of flood hazard classes}\ (\%)\ (\mathbf{A})}{\textbf{Flood hazard zone of training and testing set in each hazard class}\ (\%)\ (\mathbf{B})} \quad (5)$$

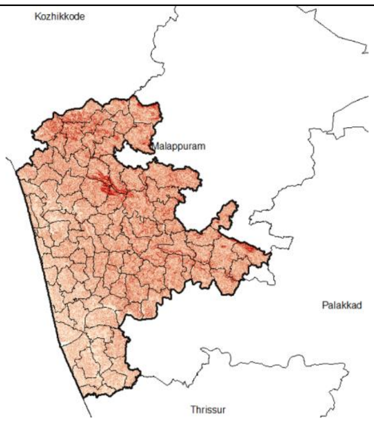
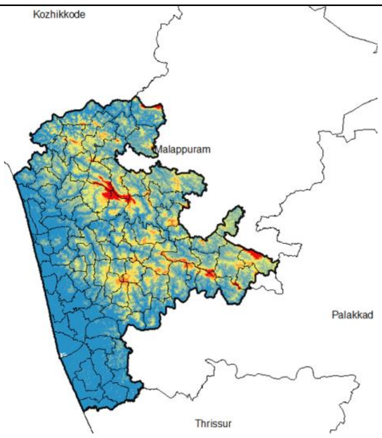
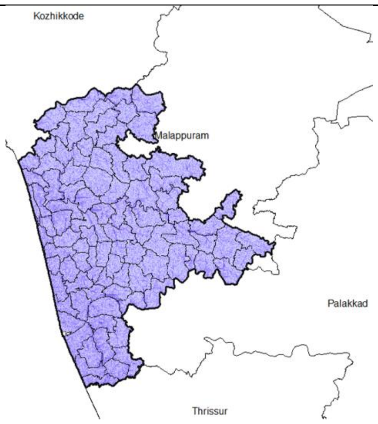
A substantial flood threat can be envisaged if the SCAI values for the model indices are lower. High SCAI values, on the other hand, indicate increasingly decreased flood threats (Liuzzo et al., 2019; Sahana & Patel, 2019).

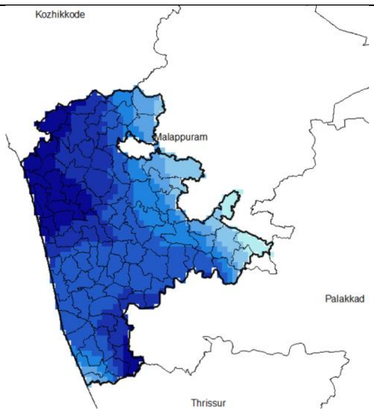
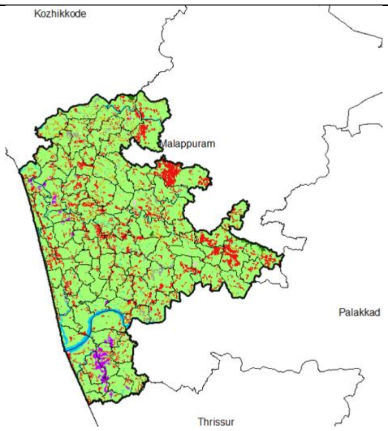
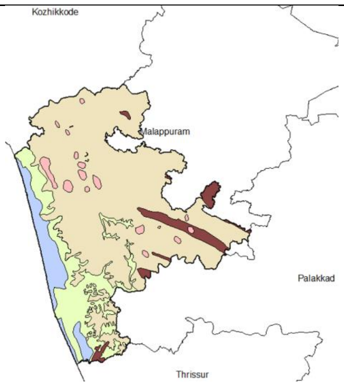
Results and Discussion

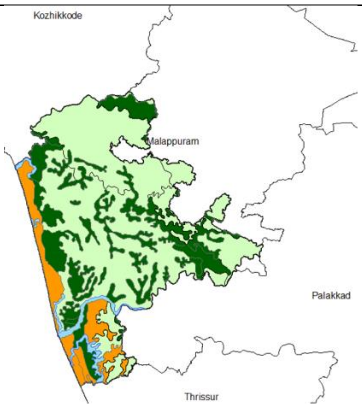
Frequency Ratio Analysis

The FR model used in the present study created a quantifiable correlation between flood occurrence and other flood determining parameters. Table 3 shows the FR value of individual flood conditioning parameters calculated using **Eq. (3)**. LULC, slope, elevation, rainfall data, Topographic Wetness Index, soil type, and lithology were the seven flood defining parameters. The slope map of the study area (Table 2(a)) shows that the FR value for the highest slope class (more than 25°) was 0.06. The lowest class (up to 2.5°), on the other hand, had an FR value of 1.95. The elevation of the region (Table 2 (b)) ranged from 0 to 512 meters. Less than 25 m, 25-50 m and 50-75 m classes of land were the most dominant categories, accounting for 30.29%, 32.1% and 21.09% of the metropolitan region, respectively. The maximum computed FR value was 2.65 for the less than 25m elevation class.

Table 2 Flood conditioning parameters.

Sl. No	Flood conditioning parameters	Map	Legend
a)	Slope		■ Up to 2.5 deg ■ 2.5 - 5 deg ■ 5 - 10 deg ■ 10 - 15 deg ■ 15 - 20 deg ■ 20 - 25 deg ■ More than 25 deg
b)	Elevation		■ Less than 25 m ■ 25 - 50 m ■ 50 - 75 m ■ 75 - 100 m ■ 100 - 125 m ■ 125 - 150 m ■ 150 - 175 m ■ More than 175 m
c)	TWI		■ Less than 10 ■ 10 - 15 ■ 15 - 20 ■ 20 - 25 ■ More than 25

Sl. No	Flood conditioning parameters	Map	Legend
d)	Rainfall		Rainfall in mm 🟦 2730.21 - 2950.06 🟦 2950.06 - 3057.26 🟦 3057.26 - 3112.82 🟦 3112.82 - 3159.64 🟦 3159.64 - 3200.54 🟦 3200.54 - 3242.14 🟦 3242.14 - 3341.26
e)	LULC		🟩 Agriculture ⬜ Barren Rocky 🟥 Built-Up 🟨 Fallow Land 🟩 Forest 🟧 Grassland 🟪 Industrial Area ⬛ Quarry Area 🟦 Water bodies 🟪 Wetland
f)	Lithology		⬜ Charnockite 🟨 Fluvial 🟫 Garnet-Graphite gneiss 🟥 Laterite 🟦 Marine 🟧 Pyroxene Granulite

Sl. No	Flood conditioning parameters	Map	Legend
g)	Soil Type		🟩 Clayey Soil 🟩 Gravelly Clay Soil 🟨 Loamy Soil 🟧 Sandy Soil 🟦 Water Bodies

Using ArcGIS, the TWI was calculated using **Eq. (1)** and reclassified into five categories, i.e., less than 10, 10-15, 15-20, 20-25 and more than 25 (Table 2 (c)). High TWI values are linked with a greater risk of flooding (Rahmati et al., 2016), and the FR value observed in the study validates this theory. The amount of rainfall is the most critical factor in causing flooding (R. K. Samanta et al., 2018; S. Samanta et al., 2018). The FR values were found to be high (greater than 1) in areas with heavy rainfall (more than 3159.64 mm), as shown in Table 2 (d).

The LULC represented in Table 2 (e) were categorized as Agriculture, Barren Rocky, Built-up, Forest, Grassland, Industrial Area, Quarry Area, Water Bodies and Wetland. The Wetland and Agriculture cover had high FR values, representing the greater chance of flood susceptibility. The lithology map in Table 2 (f) was divided into six categories: charnockite, garnet-graphite gneiss, fluvial, laterite, pyroxene, and marine. The fluvial area accounted for 15.66% of the site's total area, with an FR of 2.49. Lithology directly influences land permeability and, consequently, surface runoff. As a result, it is an essential criterion for flood susceptibility mapping (Haghizadeh et al., 2017; S. Samanta et al., 2018). Within the study region, Table 2 (g) depicts four soil type classifications: clayey soil, gravelly clayey soil, sandy soil, and loamy soil. Sandy soil, which makes up 9.03% of the metropolitan area, had the highest FR value of 2.38.

Table 3 Flood susceptibility mapping parameters used for FR model.

Parameters	Class	Number of total pixels in this study		Number of flood occurrence pixels		FR
		Total pixel	% of area	Flood pixel	% of area	
Slope	Up to 2.5 deg	298170	16.2063	42910	31.72925	1.957834
	2.5 - 5 deg	449898	24.4531	41090	30.38347	1.24252
	5 - 10 deg	661317	35.94427	39445	29.1671	0.811453
	10 - 15 deg	283438	15.40558	9950	7.3574	0.47758
	15 - 20 deg	97938	5.32318	1537	1.136515	0.213503
	20 - 25 deg	33519	1.821843	235	0.173768	0.09538
	More than 25 deg	15560	0.845726	71	0.0525	0.062077
Elevation	Less than 25 m	1056874	30.29891	108897	80.52249	2.657604
	25 - 50 m	1119948	32.10714	22325	16.50793	0.514152
	50 - 75 m	736000	21.09996	2891	2.137713	0.101314

Parameters	Class	Number of total pixels in this study		Number of flood occurrence pixels		FR
		Total pixel	% of area	Flood pixel	% of area	
	75 - 100 m	294713	8.448955	400	0.295775	0.035007
	100 - 125 m	133694	3.832795	290	0.214437	0.055948
	125 - 150 m	60563	1.736245	382	0.282465	0.162687
	150 - 175 m	25734	0.737753	0	0	0
	More than 175 m	60633	1.738252	53	0.03919	0.022546
TWI	Less than 10	931791	50.64522	44794	33.12235	0.654
	10-15	823663	44.76819	80146	59.26293	1.323
	15-20	76574	4.161992	9105	6.732575	1.617
	20-25	7196	0.391121	1180	0.872536	2.230
	More than 25	616	0.033481	13	0.009613	0.287
Rainfall (mm)	2730.21-2950.06	47462	2.450552	0	0	0
	2950.06-3057.26	120840	6.239196	2905	2.069265	0.331656
	3057.26-3112.82	157168	8.114879	2072	1.47591	0.181877
	3112.82-3159.64	237540	12.26464	8434	6.007636	0.489834
	3159.64-3200.54	678338	35.02386	64508	45.9498	1.311957
	3200.54-3242.14	417280	21.54495	42232	30.08234	1.39626
	3242.14-3341.26	278160	14.36192	20237	14.41505	1.003699
LULC	Agriculture	1534162	79.95499	120311	85.39478	1.068036
	Barren Rocky	1493	0.07781	0	0	0
	Built-Up	234667	12.23	9021	6.402958	0.523545
	Forest	6214	0.323851	0	0	0
	Grassland	39732	2.070689	717	0.508915	0.245771
	Industrial Area	4603	0.239892	1	0.00071	0.002959
	Quarry Area	24415	1.272422	148	0.105048	0.082558
	Water Bodies	51440	2.680867	2037	1.445829	0.539314
	Wetland	22056	1.149479	8653	6.141758	5.343079
Lithology	Charnockite	1357788	70.76453	70925	50.34784	0.711484
	Fluvial	300511	15.66188	55108	39.11976	2.497768
	Garnet-Graphite Gneiss	85241	4.442549	9965	7.073898	1.592306
	Laterite	42974	2.239698	3364	2.388017	1.066223
	Marine	131796	6.868879	1508	1.070491	0.155846
	Pyroxene	431	0.022463	0	0	0
Soil Type	Clayey Soil	515803	26.88237	40078	28.45034	1.058327
	Gravelly Clayey Soil	1176013	61.29087	65075	46.19507	0.753702
	Loamy Soil	0	0	0	0	0
	Sandy Soil	173417	9.038062	30329	21.52978	2.382123
	Water Bodies	53508	2.788704	5388	3.824803	1.371534

Flood Susceptibility Index Map

A flood susceptibility database was created by overlaying all the parameters with equal weightage using **Eq. (2)** in the GIS platform (Krishnan V et al., 2016). Assigning equal weightage is particularly useful in areas like the case study region Malappuram, where there is limited data or resources to conduct a more complex weighting method. This method is more effective for local administrations due to faster results along with a good level of accuracy, as noted by previous researchers such as (Natarajan et al., 2021; R. K. Samanta et al., 2018). The final FSI value database generated ranged from 0 to 18.38. Areas with a high FSI value have a high flood risk, and vice versa. Figure 9 depicts the reclassification of the generated database based on the natural break (Jenks) method, into five flood susceptibility classes: very low (less than 5.22), low (5.22-6.9), moderate (6.9-8.89), high (8.89-11.1), and very high susceptibility (more than 11.1). According to the findings, 26% of the research region were extremely susceptible to flooding, as 8.82% and 17.17% of land had very high and high susceptibility, respectively. Heavy rainfall in a short period of time caused runoff water to exceed the capacity of the rivers, and the sloping topography from the high hills of the Western Ghats to the low-lying west coast accelerates the flow of flooding waters. According to a survey of flood-prone areas in Malappuram, the district is extremely vulnerable to flooding. The Malappuram district's coastline tracts have been classified as important flood-prone locations (*Kerala State Disaster Management Plan*, 2016).

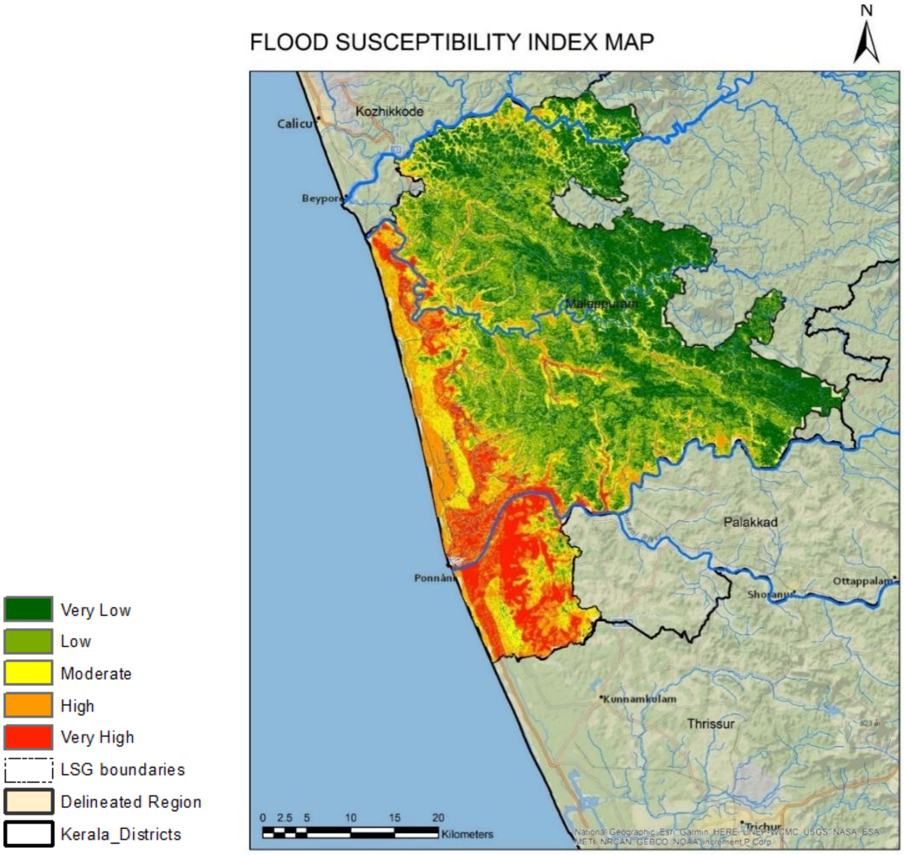


Figure 9 Flood susceptibility map of Malappuram Metropolitan Region

Model Validation

Utilizing a model for practical, academic or research purposes is not scientific without first verifying its precision and reliability (Chung & Fabbri, 2003). The calculated accuracy rate (**Eq.**

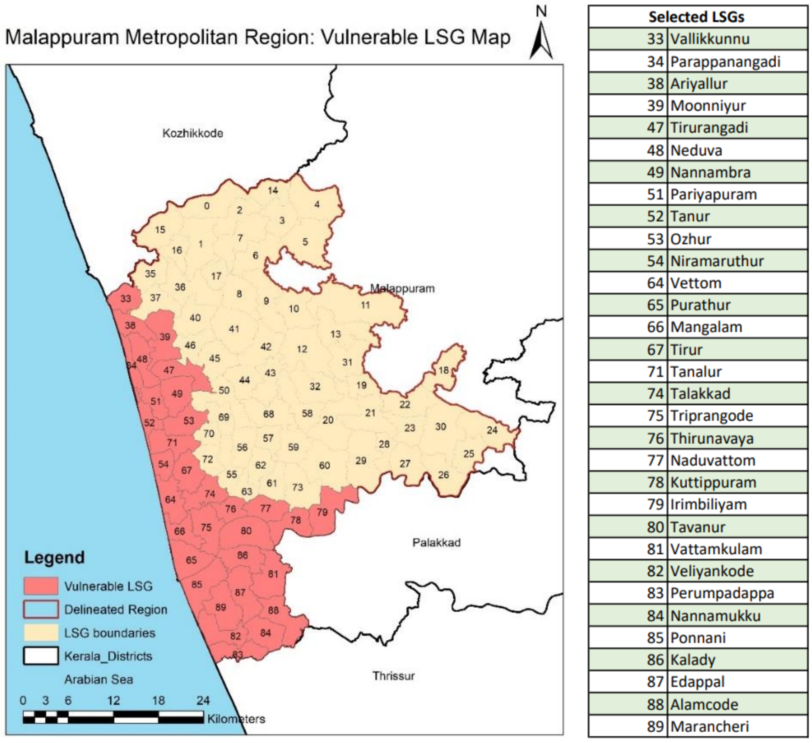
(4)) for flood prediction was 0.79. The FR model is suitable for flood susceptibility study as it has a prediction accuracy of 79.33%.

As the SCAI values (calculated using **Eq. (5)**) are high for low and very low flood hazard classes and extremely low for high and very high hazard classes, the flood susceptibility map produced by the FR model exhibits sufficient accuracy (Table 4).

32 LSGs out of 89 were the most vulnerable to floods, as identified in Figure 10 for flood mitigation activities with the highest significance. The flood susceptibility analysis, based on this model, will be a valuable and effective tool for local government officials, research scholars, and city planners in formulating flood mitigation strategies.

Table 4 SCAI calculation.

Flood Hazard Zones	Percentage of flood hazard area (A)	Percentage of training and testing data set (B)	SCAI
Very Low	24.75%	4.14%	5.979491
Low	31.87%	16.53%	1.928282
Moderate	17.40%	19.34%	0.899482
High	17.17%	33.37%	0.51458
Very High	8.82%	26.63%	0.331228



Selected LSGs	
33	Vallikkunnu
34	Parappanangadi
38	Ariyallur
39	Moonniyur
47	Tirurangadi
48	Neduva
49	Nannambra
51	Pariyapuram
52	Tanur
53	Ozhur
54	Niramaruthur
64	Vettom
65	Purathur
66	Mangalam
67	Tirur
71	Tanalur
74	Talakkad
75	Triprangode
76	Thirunavaya
77	Naduvattom
78	Kuttippuram
79	Irimbiliyam
80	Tavanur
81	Vattamkulam
82	Veliyankode
83	Perumpadappa
84	Nannamukku
85	Ponnani
86	Kalady
87	Edappal
88	Alamcode
89	Marancheri

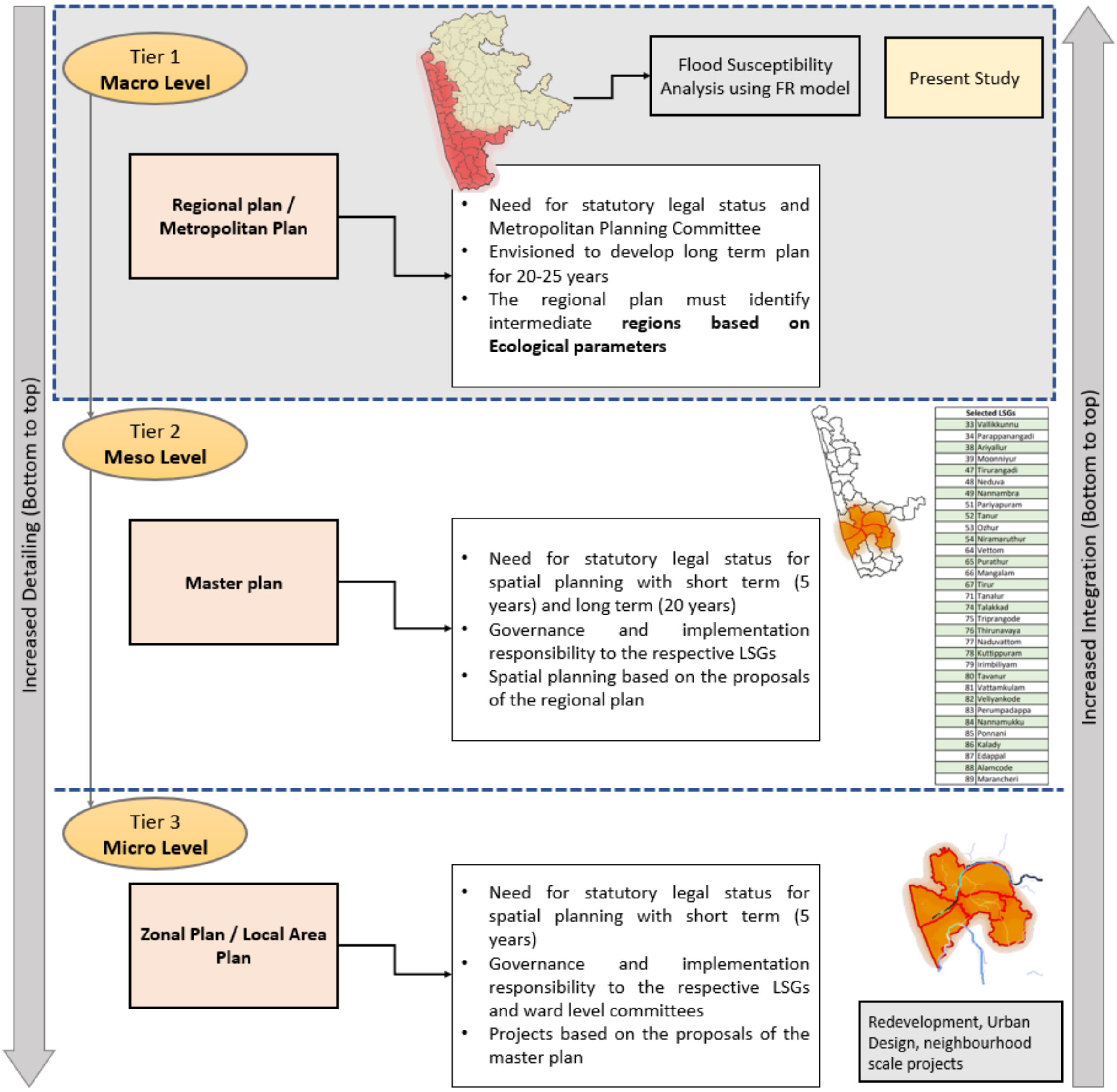
Figure 10 Villages highly vulnerable to floods.

Planning Recommendations

There is a need to develop a new urban planning approach that prioritizes harmonious interactions between people and the environment, values the landscape, and considers cities as complex socio-ecological systems (Wright, 2007). The present study utilized a scientifically accurate frequency ratio model to evaluate the flood susceptibility of a specific area from a regional planning perspective and proposes a multi-level assessment framework future regional planning (Figure 11) (Krishnan V & Firoz C., 2023). The tier-1 assessment in the proposed framework involves two stages. In the first stage, the flood vulnerability of a larger metropolitan region will be evaluated based on flood-causing parameters that are identified through their correlation with historical flood data. The accuracy of the results will be determined through model validation and will serve as the foundation for the subsequent levels of assessment. The results obtained in stage-1 assessment were used to classify the metropolitan region from most vulnerable to least vulnerable to floods (Figure 9). The stage-2 assessment identifies the LSGs within the metropolitan region that are most vulnerable to floods (Figure 10) and require immediate planning intervention. The proposed multi-level assessment framework for regional planning is based on overlaying the results of stage 1 and 2 onto a spatial scale to address issues at tier 1 (metropolitan regional level), tier 2 (metropolitan sub-regional level), and tier 3 (LSG level). This multi-level assessment framework is then expanded to propose a regional planning framework for flood mitigation, representing the scope of this study (tier-1/macro level) and the future scope (tier-2/meso level and tier-3/micro level). This work serves as the tier-1 level of assessment within the overall proposed framework for regional planning based on flood susceptibility mapping and spatial planning based on the output. The study revealed a direct relationship between the increase in built-up areas by 10.59% and human activities, such as mining between 2005 to 2015, and LULC changes that cause frequent flood events and related disasters (Figure 7). The reduction in agricultural land by 9.05% and wetlands by 0.35% in Malappuram due to urbanization between 2005 and 2015 was a major reason for floods since 2018. In Kerala, the administration follows demarcated boundaries of ULBs when formulating master plans or statutory plans, which may need to be revisited. A piecemeal approach to spatial planning does not benefit people or cities facing increasing challenges caused by disasters like floods. Therefore, a regional planning approach based on flood susceptibility mapping is essential to formulate effective spatial plans and policies at various levels of intervention.

To implement holistic regional planning for metropolitan regions, a bottom-up approach should be followed, starting from the micro-level (ULB level plans) to the macro-level (regional/perspective plan) (Figure 11). A flood susceptibility map (Figure 9) should be used to identify the broader flood-prone region, where a regional plan for ecological regions with common characteristics needs to be drafted. Subsequently, the severity of the flood risk in each of the areas must be evaluated based on the level of susceptibility indicated on the map as well as information on the vulnerability of buildings or infrastructure. Land-use decisions such as zoning, building permits or infrastructure planning must be examined. Upstream and downstream measures should be put in place to control river flow and margins against floods to limit runoff in urban areas, where a regional plan for ecological regions with common characteristics needs to be drafted. To avoid catastrophic disasters, an increase in green space and permeable surfaces and infrastructure protection in terms of accessibility, connectivity, and supply system (Naia Landa Mendez, 2014) must be implemented at this regional scale. Floodproofing standards must be identified and implemented as part of policy guidelines that focus on community-based strategies for reducing conventional flood damage on a building- or local-area scale. Flood early warning systems are vital to decrease losses by providing advantages in flood-vulnerable communities if the strategies are correctly implemented.

The analysis of the generated FSI Map helped to identify the urban local bodies prone to floods (Figure 10), where detailed local-area plans need to be developed. Zoning restrictions and land-use patterns seen as being in the public interest rather than directed toward economic interests should be used to limit future expansion (Moreau, 2016; Nguyen, 2019). Similarly, generalized coastal zone regulations may not have to apply in all circumstances. Because of the state's limited land availability and dense population, an amendment was passed stating that a 100-m or similar creek width would be maintained as the construction line. At the tier-3 level of the planning framework, the local-area plans have to optimize the land-use pattern, facilitating compact development and more green cover for the percolation of water and curb surface runoff. At this scale, urban design projects and streamflow enhancement projects should be done by the LSGs. Hence, integrating the existing planning regime of development plans to local-area plans with the proposed regional planning framework will significantly improve sustainable and context-specific development.



- Need for statutory legal status and Metropolitan Planning Committee
- Envisioned to develop long term plan for 20-25 years
- The regional plan must identify intermediate **regions based on Ecological parameters**

- Need for statutory legal status for spatial planning with short term (5 years) and long term (20 years)
- Governance and implementation responsibility to the respective LSGs
- Spatial planning based on the proposals of the regional plan

Selected LSGs	
33	Vallikkunnu
34	Parappanangadi
38	Ariyallur
39	Moonniyur
47	Tirurangadi
48	Neduva
49	Nannambra
51	Pariyapuram
52	Tanur
53	Ozhur
54	Niramaruthur
64	Vettom
65	Purathur
66	Mangalam
67	Tirur
71	Tanalur
74	Talakkad
75	Triprangode
76	Thirunavaya
77	Naduvattom
78	Kuttippuram
79	Irimbiliyam
80	Tavanur
81	Vattamkulam
82	Veliyankode
83	Perumpadappa
84	Nannamukku
85	Ponnani
86	Kalady
87	Edappal
88	Alamcode
89	Marancheri

- Need for statutory legal status for spatial planning with short term (5 years)
- Governance and implementation responsibility to the respective LSGs and ward level committees
- Projects based on the proposals of the master plan

Figure 11 Proposed planning framework for metropolitan region planning.

Conclusion

The objectives of the present research were to identify flood vulnerable settlements and integrate them into a regional planning framework. Accordingly, a case application was attempted in the Malappuram metropolitan region of Kerala, India. In the integration framework, three tiers of assessment were proposed. The present study fell under the tier-1 assessment, giving broader recommendations for regional development and planning from the perspective of flood vulnerability. The natural hazards and vulnerabilities do not follow administrative boundaries, which have been arbitrarily delineated in view of human and economic prosperity. Hence, developing a new design and urban planning paradigm is essential based on a harmonious human-environment interaction, identifies landscape value, and views cities as sophisticated, dynamic socio-ecological entities. FR modelling, a statistically significant assessment technique, was used to map flood susceptibility of the case region, which helped identify the list of LSGs in Malappuram that are highly vulnerable as part of the tier-1 assessment. Subsequently, tiers 2 and 3 of the assessment followed to integrate the recommendations into the master plan, development plan, and local-area plans. The study revealed a high correlation between increasing urbanization, land-use changes and land conversion rates with the increasing flood inundation in the case study region. The study's primary contribution was to integrate a spatial planning framework into the regional planning process, especially from the flood assessment perspective. The scope of this research may be further expanded to tier-2 (sub-regional level) and tier-3 (LSG level) assessments with more detailing, either using the same or slightly different variables. The current study was limited to Kerala's flood vulnerability and spatial planning context. It was based on a thorough assessment of a group of local administrative bodies chosen from the fastest growing and emerging metropolitan region of Malappuram using the tier-1 stage (macro level) of analysis. The method proposed in this study proved to be a valid primary analysis for identifying the most vulnerable settlements through an FR model.

The study's future scope can be broadened by assessing a more significant watershed boundary to establish an accurate flood mitigation plan and spatial planning policies. Also, it could be used as a background study to quantify the associated risk in terms of economy, environment, and human lives in flood-prone areas. The findings of this study will help decision-makers in selecting optimal areas for future large-scale development and disaster management planning, such as rescue routes, service centers, and shelters, to implement adequate flood mitigation and management plans.

References

Ahmadlou, M., Karimi, M., Alizadeh, S., Shirzadi, A., Parvinnejhad, D., Shahabi, H., & Panahi, M. (2018). Flood susceptibility assessment using integration of adaptive network-based fuzzy inference system (ANFIS) and biogeography-based optimization (BBO) and BAT algorithms (BA). *Https://Doi.Org/10.1080/10106049.2018.1474276*, *34*(11), 1252–1272. https://doi.org/10.1080/10106049.2018.1474276

Ali, S. A., Khatun, R., Ahmad, A., & Ahmad, S. N. (2019). Application of GIS-based analytic hierarchy process and frequency ratio model to flood vulnerable mapping and risk area estimation at Sundarban region, India. *Modeling Earth Systems and Environment*, *5*(3), 1083–1102. https://doi.org/10.1007/s40808-019-00593-z

Amarnath, G. (2014). An algorithm for rapid flood inundation mapping from optical data using a reflectance differencing technique. *Journal of Flood Risk Management*, *7*(3), 239–250. https://doi.org/10.1111/JFR3.12045

Arabameri, A., Saha, S., Roy, J., Chen, W., Blaschke, T., & Bui, D. T. (2020). Landslide susceptibility evaluation and management using different machine learning methods in the Gallicash River Watershed, Iran. *Remote Sensing*, *12*(3). https://doi.org/10.3390/rs12030475

Census of India. (2011). https://censusindia.gov.in/2011census/dchb/3205_part_b_malappuram.pdf

Census of India: Administrative Divisions. (2001). https://censusindia.gov.in/census_and_you/administrative_division.aspx

Chapi, K., Singh, V. P., Shirzadi, A., Shahabi, H., Bui, D. T., Pham, B. T., & Khosravi, K. (2017). A novel hybrid artificial intelligence approach for flood susceptibility assessment. *Environmental Modelling & Software*, *95*, 229–245. https://doi.org/10.1016/j.envsoft.2017.06.012

Chen, Y., Zhou, H., Zhang, H., Du, G., & Zhou, J. (2015). Urban flood risk warning under rapid urbanization. *Environmental Research*, *139*, 3–10. https://doi.org/10.1016/j.envres.2015.02.028

Chung, C.-J. F., & Fabbri, A. G. (2003). Validation of Spatial Prediction Models for Landslide Hazard Mapping. In *Natural Hazards* (Vol. 30).

Cloke, H. L., & Pappenberger, F. (2009). Ensemble flood forecasting: A review. In *Journal of Hydrology* (Vol. 375, Issues 3–4, pp. 613–626). https://doi.org/10.1016/j.jhydrol.2009.06.005

Cyriac, S., & Firoz C, M. (2022). Dichotomous classification and implications in spatial planning: A case of the Rural-Urban Continuum settlements of Kerala, India. *Land Use Policy*, *114*, 105992. https://doi.org/10.1016/j.landusepol.2022.105992

Danumah, J. H., Odai, S. N., Saley, B. M., Szarzynski, J., Thiel, M., Kwaku, A., Kouame, F. K., & Akpa, L. Y. (2016). Flood risk assessment and mapping in Abidjan district using multi-criteria analysis (AHP) model and geoinformation techniques (Côte d'Ivoire). *Geoenvironmental Disasters*, *3*(1). https://doi.org/10.1186/s40677-016-0044-y

Dewan, A. M., Islam, M. M., Kumamoto, T., & Nishigaki, M. (2007). Evaluating flood hazard for land-use planning in greater Dhaka of Bangladesh using remote sensing and GIS techniques. *Water Resources Management*, *21*(9), 1601–1612. https://doi.org/10.1007/s11269-006-9116-1

Díez-Herrero, A., & Garrote, J. (2020). Flood risk assessments: Applications and uncertainties. In *Water (Switzerland)* (Vol. 12, Issue 8). MDPI AG. https://doi.org/10.3390/W12082096

Directorate Central Water Commission, H.-S. (2018). *Kerala Floods of August 2018*. https://reliefweb.int/sites/reliefweb.int/files/resources/Rev-0.pdf

District Disaster Management Authority. (2016). *District Disaster Management Plan, Malappuram 2015*.

Economic losses, Poverty & Disaster: 1998-2017. (2018). www.unisdr.org

Eldho, T. I., Zope, P. E., & Kulkarni, A. T. (2018). Urban flood management in coastal regions using numerical simulation and geographic information system. *Integrating Disaster Science and Management: Global Case Studies in Mitigation and Recovery*, 205–219. https://doi.org/10.1016/B978-0-12-812056-9.00012-9

Event Specific Maps – Kerala State Disaster Management Authority. (2021). https://sdma.kerala.gov.in/event-specific-maps/

Guhathakurta, P., Sreejith, O. P., & Menon, P. A. (2011). *Impact of climate change on extreme rainfall events and flood risk in India*.

Haghizadeh, A., Siahkamari, S., Haghiabi, A. H., & Rahmati, O. (2017). Forecasting flood-prone areas using Shannon's entropy model. *Journal of Earth System Science*, *126*(3). https://doi.org/10.1007/s12040-017-0819-x

Haq, M., Akhtar, M., Muhammad, S., Paras, S., & Rahmatullah, J. (2012). Techniques of Remote Sensing and GIS for flood monitoring and damage assessment: A case study of Sindh province, Pakistan. *Egyptian Journal of Remote Sensing and Space Science*, *15*(2), 135–141. https://doi.org/10.1016/j.ejrs.2012.07.002

Heymans, A., Breadsell, J., Morrison, G. M., Byrne, J. J., & Eon, C. (2019). Ecological urban planning and design: A systematic literature review. *Sustainability (Switzerland), 11*(13). https://doi.org/10.3390/SU11133723

Homian Danumah, J., Nii Odai, S., Mahaman Saley, B., Szarzynski, J., Thiel, M., Kwaku, A., Koffi Kouame, F., & You Akpa, L. (2016). *Flood risk assessment and mapping in Abidjan district using multi-criteria analysis (AHP) model and geoinformation techniques, (cote d'ivoire)*. https://doi.org/10.1186/s40677-016-0044-y

Hong, H., Panahi, M., Shirzadi, A., Ma, T., Liu, J., Zhu, A. X., Chen, W., Kougias, I., & Kazakis, N. (2018). Flood susceptibility assessment in Hengfeng area coupling adaptive neuro-fuzzy inference system with genetic algorithm and differential evolution. *Science of The Total Environment, 621,* 1124–1141. https://doi.org/10.1016/j.scitotenv.2017.10.114

Hossain, S. (2019). *What is Univariate, Bivariate and Multivariate analysis? – HotCubator | Learn| Grow| Catalyse*. https://hotcubator.com.au/research/what-is-univariate-bivariate-and-multivariate-analysis/

Kerala State Disaster Management Plan. (2016). www.disasterlesskerala.org

Khosravi, K., Nohani, E., Maroufinia, E., & Pourghasemi, H. R. (2016). A GIS-based flood susceptibility assessment and its mapping in Iran: a comparison between frequency ratio and weights-of-evidence bivariate statistical models with multi-criteria decision-making technique. *Natural Hazards, 83*(2), 947–987. https://doi.org/10.1007/s11069-016-2357-2

Khosravi, K., Pham, B. T., Chapi, K., Shirzadi, A., Shahabi, H., Revhaug, I., Prakash, I., & Tien Bui, D. (2018). A comparative assessment of decision trees algorithms for flash flood susceptibility modeling at Haraz watershed, northern Iran. *The Science of the Total Environment, 627,* 744–755. https://doi.org/10.1016/j.scitotenv.2018.01.266

Kohli, K. (2003). *Eco-regional planning - Frontline*. https://frontline.thehindu.com/environment/article30214896.ece

Konadu, D. D., Fosu, C., & Yanful, E. K. (2009). *Digital Elevation Models and GIS for Watershed Modelling and Flood Prediction-A Case Study of Accra Ghana*.

Krishnan V., S., & Firoz C., M. (2021). Impact of land use and land cover change on the environmental quality of a region: A case of Ernakulam district in Kerala, India. *Regional Statistics, 11*(2), 102–135. https://doi.org/10.15196/RS110205

Krishnan V, S., & Firoz C., M. (2023). Assessment of regional environmental quality using cluster analysis. *Environmental Development, 45*. https://doi.org/10.1016/j.envdev.2023.100832

Krishnan V, S., Mandla, V. R., & Pannem, R. M. R. (2016). A Geospatial Approach for the Development of Hazardous Building Zonation Mapping. *Arabian Journal for Science and Engineering, 41*(4), 1329–1341. https://doi.org/10.1007/s13369-015-1873-9

Krishnan V, S., & Mohammed Firoz, C. (2020). Regional urban environmental quality assessment and spatial analysis. *Journal of Urban Management, 9*(2), 191–204. https://doi.org/10.1016/j.jum.2020.03.001

Lee, M.-J., & Kang, J.-E. (2012). Predictive Flooded Area Susceptibility and Verification Using GIS and Frequency Ratio. *Journal of the Korean Association of Geographic Information Studies, 15*(2), 86–102. https://doi.org/10.11108/kagis.2012.15.2.086

Liuzzo, L., Sammartano, V., & Freni, G. (2019). Comparison between Different Distributed Methods for Flood Susceptibility Mapping. *Water Resources Management, 33*(9), 3155–3173. https://doi.org/10.1007/s11269-019-02293-w

Local Government, Britannica. (2017). Britannica. https://www.britannica.com/topic/local-government

Madhav Gadgil. (2011). *Report of the Western Ghats Ecology Expert Panel*. https://ruralindiaonline.org/en/library/resource/report-of-the-western-ghats-ecology-expert-panel/

Manandhar, B. (2010). *Flood Plain Analysis and Risk Assessment of Lothar Khola*. https://doi.org/10.13140/2.1.1664.1289

Margerum, R. D. (2011). *Integrated Watershed Management: Comparing Selected Experiences In The U.S. And Australia*.

McGrath, C., Palmgren, P. J., & Liljedahl, M. (2019). Twelve tips for conducting qualitative research interviews. *Medical Teacher*, *41*(9), 1002–1006. https://doi.org/10.1080/0142159X.2018.1497149

Merz, B., Thieken, A. H., & Gocht, M. (2007). Flood risk mapping at the local scale: Concepts and challenges. In *Advances in Natural and Technological Hazards Research* (Vol. 25, pp. 231–251). Springer Netherlands. https://doi.org/10.1007/978-1-4020-4200-3_13

Moreau, A.-L. (2016). *Planning in urban flood prone areas: Focus on six principles to reduce urban vulnerability*.

Munir, A., Ghufran, M. A., Ali, S. M., Majeed, A., Batool, A., Khan, M. B. A. S., & Abbasi, G. H. (2022). Flood Susceptibility Assessment Using Frequency Ratio Modelling Approach in Northern Sindh and Southern Punjab, Pakistan. *Polish Journal of Environmental Studies*, *31*(4), 3249–3261. https://doi.org/10.15244/pjoes/145607

Murdukhayeva, A., August, P., Bradley, M., Labash, C., & Shaw, N. (2013). Assessment of inundation risk from sea level rise and storm surge in northeastern coastal national parks. *Journal of Coastal Research*, *29*(6 A), 1–16. https://doi.org/10.2112/jcoastres-d-12-00196.1

Naia Landa Mendez. (2014). *Adaptation to Urban Floods by Planning and Design: Guidelines for an Adaptive Management to Urban Floods and Storm Water use taking as a Case Study the City of Bilbao*. www.kth.se

Natarajan, L., Usha, T., Gowrappan, M., Palpanabhan Kasthuri, B., Moorthy, P., & Chokkalingam, L. (2021). Flood Susceptibility Analysis in Chennai Corporation Using Frequency Ratio Model. *Journal of the Indian Society of Remote Sensing*, *49*(7), 1533–1543. https://doi.org/10.1007/s12524-021-01331-8

Neumayer, E., & Plümper, T. (2007). The Gendered Nature of Natural Disasters: The Impact of Catastrophic Events on the Gender Gap in Life Expectancy. *Annals of the Association of American Geographers*, *97*(3), 551–566. https://doi.org/10.1111/j.1467-8306.2007.00563.x

Nguyen, H. T. (2019). *Spatial Planning in Flood-prone Areas*. https://tuprints.ulb.tu-darmstadt.de/id/eprint/9266

O’Connor, J. E., & Costa, J. E. (2004). Spatial distribution of the largest rainfall-runoff floods from basins between 2.6 and 26,000 km2 in the United States and Puerto Rico. *Water Resources Research*, *40*(1). https://doi.org/10.1029/2003WR002247

Peter, B., & Thummarukudy, M. (2019). *Leaving No One Behind: Lessons from the Kerala Disasters*. http://repo.floodalliance.net/jspui/handle/44111/3341

Pirasteh, S., & Li, J. (2017). Probabilistic frequency ratio (PFR) model for quality improvement of landslide susceptibility mapping from LiDAR-derived DEMs. *Geoenvironmental Disasters*, *4*(1). https://doi.org/10.1186/S40677-017-0083-Z

Pourghasemi, H. R., & Beheshtirad, M. (2014). Assessment of a data-driven evidential belief function model and GIS for groundwater potential mapping in the Koohrang Watershed, Iran., *30*(6), 662–685. https://doi.org/10.1080/10106049.2014.966161

Pradhan, B., & Lee, S. (2010). Landslide susceptibility assessment and factor effect analysis: backpropagation artificial neural networks and their comparison with frequency ratio and bivariate logistic regression modelling. *Environmental Modelling and Software*, *25*(6), 747–759. https://doi.org/10.1016/J.ENVSOFT.2009.10.016

Pradhan, B., Oh, H. J., & Buchroithner, M. (2010). Weights-of-evidence model applied to landslide susceptibility mapping in a tropical hilly area. *Geomatics, Natural Hazards and Risk*, *1*(3), 199–223. https://doi.org/10.1080/19475705.2010.498151

Rahmati, O., Pourghasemi, H. R., & Zeinivand, H. (2016). Flood susceptibility mapping using frequency ratio and weights-of-evidence models in the Golastan Province, Iran. *Geocarto International*, *31*(1), 42–70. https://doi.org/10.1080/10106049.2015.1041559

Saha, S., Sarkar, D., & Mondal, P. (2021). Efficiency exploration of frequency ratio, entropy and weights of evidence-information value models in flood vulnerability assessment: a study of raiganj subdivision, Eastern India. *Stochastic Environmental Research and Risk Assessment*. https://doi.org/10.1007/S00477-021-02115-9

Sahana, M., & Patel, P. P. (2019). A comparison of frequency ratio and fuzzy logic models for flood susceptibility assessment of the lower Kosi River Basin in India. *Environmental Earth Sciences*, *78*(10). https://doi.org/10.1007/s12665-019-8285-1

Sahana, M., Rehman, S., Sajjad, H., & Hong, H. (2020). Exploring effectiveness of frequency ratio and support vector machine models in storm surge flood susceptibility assessment: A study of Sundarban Biosphere Reserve, India. *Catena*, *189*. https://doi.org/10.1016/j.catena.2019.104450

Sahana, M., & Sajjad, H. (2017). Evaluating effectiveness of frequency ratio, fuzzy logic and logistic regression models in assessing landslide susceptibility: a case from Rudraprayag district, India. *Journal of Mountain Science*, *14*(11), 2150–2167. https://doi.org/10.1007/S11629-017-4404-1

Samanta, R. K., Bhunia, G. S., Shit, P. K., & Pourghasemi, H. R. (2018). Flood susceptibility mapping using geospatial frequency ratio technique: a case study of Subarnarekha River Basin, India. *Modeling Earth Systems and Environment*, *4*(1), 395–408. https://doi.org/10.1007/s40808-018-0427-z

Samanta, S., Pal, D. K., & Palsamanta, B. (2018). Flood susceptibility analysis through remote sensing, GIS and frequency ratio model. *Applied Water Science*, *8*(2). https://doi.org/10.1007/s13201-018-0710-1

Sarkar, D., & Mondal, P. (2020). Flood vulnerability mapping using frequency ratio (FR) model: a case study on Kulik river basin, Indo-Bangladesh Barind region. *Applied Water Science*, *10*(1). https://doi.org/10.1007/s13201-019-1102-x

Schumann, G., Bates, P. D., Horritt, M. S., Matgen, P., & Pappenberger, F. (2009). Progress in integration of remote sensing-derived flood extent and stage data and hydraulic models. *Reviews of Geophysics*, *47*(3). https://doi.org/10.1029/2008RG000274

Shafizadeh-Moghadam, H., Valavi, R., Shahabi, H., Chapi, K., & Shirzadi, A. (2018). Novel forecasting approaches using combination of machine learning and statistical models for flood susceptibility mapping. *Journal of Environmental Management*, *217*, 1–11. https://doi.org/10.1016/j.jenvman.2018.03.089

Smith, L. C. (1997). Satellite remote sensing of river inundation area, stage, and discharge: A Review. In *Ltd. Hydrol. Process* (Vol. 11). John Wiley & Sons.

Sonu, T. S., Mohammed Firoz, C., & Bhagyanathan, A. (2022). The impact of upstream land use land cover change on downstream flooding: A case of Kuttanad and Meenachil River Basin, Kerala, India. *Urban Climate*, *41*, 101089. https://doi.org/10.1016/J.UCLIM.2022.101089

States Uts. (2022, September). Know India: National Portal of India: Https://Knowindia.India.Gov.in/States-Uts/.

Süzen, M. L., & Doyuran, V. (2004). Data driven bivariate landslide susceptibility assessment using geographical information systems: A method and application to Asarsuyu catchment, Turkey. *Engineering Geology*, *71*(3–4), 303–321. https://doi.org/10.1016/S0013-7952(03)00143-1

T P Nijeesh. (2020, January 9). Malappuram tops list of world's fastest-growing urban areas. *Times of India*. https://timesofindia.indiatimes.com/city/kozhikode/malappuram-tops-list-of-worlds-fastest-growing-urban-areas/articleshow/73163346.cms

Tehrany, M. S., Pradhan, B., & Jebur, M. N. (2014). Flood susceptibility mapping using a novel ensemble weights-of-evidence and support vector machine models in GIS. *Journal of Hydrology, 512*, 332–343. https://doi.org/10.1016/j.jhydrol.2014.03.008

Teng, J., Jakeman, A. J., Vaze, J., Croke, B. F. W., Dutta, D., & Kim, S. (2017). Flood inundation modelling: A review of methods, recent advances and uncertainty analysis. In *Environmental Modelling and Software* (Vol. 90, pp. 201–216). Elsevier Ltd. https://doi.org/10.1016/j.envsoft.2017.01.006

Tunusluoglu, M. C., Gokceoglu, C., Nefeslioglu, H. A., & Sonmez, H. (2008). Extraction of potential debris source areas by logistic regression technique: A case study from Barla, Besparmak and Kapi mountains (NW Taurids, Turkey). *Environmental Geology, 54*(1), 9–22. https://doi.org/10.1007/S00254-007-0788-5/FIGURES/10

United Nations Development Program. (2018). *Kerala Post Disaster Needs Assessment Floods and Landslides*. https://www.ilo.org/newdelhi/whatwedo/publications/WCMS_660139/lang--en/index.htm

Vijaykumar, P., Abhilash, S., Sreenath, A. V., Athira, U. N., Mohanakumar, K., Mapes, B. E., Chakrapani, B., Sahai, A. K., Niyas, T. N., & Sreejith, O. P. (2021). Kerala floods in consecutive years - Its association with mesoscale cloudburst and structural changes in monsoon clouds over the west coast of India. *Weather and Climate Extremes, 33*. https://doi.org/10.1016/j.wace.2021.100339

Viju B. (2019). *Flood and Fury: Ecological Devastation in the Western Ghats*. Penguin Random House India Private Limited.

Watershed Planning in Ontario. (2018). https://prod-environmental-registry.s3.amazonaws.com/2018-02/013-1817_DraftGuidance.pdf

Watershed-Based Planning — Wetlands Watch. (2021). https://wetlandswatch.org/watershed-based-planning/

Wright, J. M. (2007). *Floodplain management principles and current practices*.

Xie, S., Wu, W., Mooser, S., Wang, Q. J., Nathan, R., & Huang, Y. (2021). Artificial neural network based hybrid modeling approach for flood inundation modeling. *Journal of Hydrology, 592*. https://doi.org/10.1016/j.jhydrol.2020.125605

Yearly Rainfall Data, IMD Pune. (2021). India Meteorological Department. https://www.imdpune.gov.in/Clim_Pred_LRF_New/Grided_Data_Download.html

Yodying, A. (2019). *Assessment of Flood Hazard Using Geospatial Data and Frequency Ratio Model In Sukhothai Province, Thailand* (Issue 1). https://earthexplorer.usgs.gov/

Youssef, A. M., Pradhan, B., & Sefry, S. A. (2016). Flash flood susceptibility assessment in Jeddah city (Kingdom of Saudi Arabia) using bivariate and multivariate statistical models. *Environmental Earth Sciences*, *75*(1), 1–16. https://doi.org/10.1007/s12665-015-4830-8