Shelter Suitability Mapping using Geospatial Analysis: A case study of Chalakudy River Basin in Kerala

Antony Reshma[1]*, Abdu Rahiman K.U.[2] and Vishnudas Subha[2]
1. Division of Civil Engineering, School of Engineering, Cochin University of Science and Technology, Kochi, 682 022, Kerala, INDIA
2. Faculty of Civil Engineering, School of Engineering, Cochin University of Science and Technology, Kochi, 682 022, Kerala, INDIA
*reshmaantony@cusat.ac.in; reshmajismon2014@gmail.com

Abstract
Over the past few years, floods have become far more frequent worldwide. The Chalakudy River Basin (CRB) in the State of Kerala has been experiencing floods since 2018. This study analyses the flood-prone areas and identifies the most suitable locations for flood emergency shelters in the Chalakudy Taluk area of the basin employing geospatial techniques. To evaluate the suitability of the site, the study employs multicriteria analysis and a weighted sum approach in Geographic Information System (GIS). The study locates the position of emergency shelters based on elevation, land use type, flood inundation data, distance to road network and distance to flood-prone communities.

The investigation results show that 1.79% of the study area is most suitable, 9.08 % is suitable, 9.65% is moderately suitable, 14.05 % is medium suitable, 11.82% is moderately unsuitable, 25.1% is unsuitable and 28.27% is very unsuitable for locating flood shelters. By raising awareness about evacuation shelter locations within the study area, the research aids in the emergency response phase during flood incidents. The outcomes of this study help disaster management authorities, decision-makers, local people and planning committees for early planning of disaster mitigation activities.

Keywords: Emergency Shelters, Evacuation, Flood Risk management, GIS, Weighted Sum.

Introduction

Floods are among the most frequent natural catastrophes, causing significant harm including property loss and fatalities. Although it is impossible to eliminate natural calamities, their effects can be lessened with careful preparation and mitigation techniques. Flooding happens when the overflowing water submerges the normally dry terrain[29]. The United Nations defines disaster as "A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its resources"[25]. Early involvement and proactive preparation are essential for a prompt and successful reaction. Proactive readiness requires effective risk management[24]. Knowledge about flood inundation areas and emergency shelter locations helps Government agencies in making decisions, managing watersheds, formulating policies and implementing mitigation strategies in flood susceptible zones[1,8,10,27].

Emergency preparedness and response are the most important component of the set of activities related to flood-loss mitigation[26]. Creating an evacuation plan is a crucial pre-disaster procedure, since it effectively lowers the number of fatalities and injuries[7,30]. An emergency shelter is a kind of group housing that is set up by governmental or private groups, usually nonprofit organizations, to provide short-term or transitional accommodation to those who would not otherwise have a place to sleep[15].

Maps of areas affected by flooding that are updated in real-time are always beneficial for improved rescue operation management[18]. Advanced technologies such as hydrologic simulators, remote sensing, photogrammetry and geographic information systems, have been developed to help with flood risk mapping, monitoring and emergency management[9]. Basin topography is a valuable resource for flood mitigation, emergency response and modeling[26]. Many homes situated in low-lying regions get submerged and become unsafe for habitation during a flood incident. In this instance, those affected must seek emergency housing in temporary flood shelters[3,23]. For effective evacuation and relocation, the flood shelter needs to be readily accessible.

Despite this, the shelters must be constructed in a location that is not susceptible to flooding[2,5,23]. Establishing emergency response teams and emergency shelter planning, along with other mitigation activities assists in the capacity building process too. It is possible to inform the vulnerable population of what to expect in the case of an extreme event. Actions including the evacuation of people, materials and equipment can start as the situation becomes more certain[26].

Kerala, one of the most populous States in India, is particularly susceptible to natural calamities. The most frequent natural calamity in Kerala is flooding. In the 2018 Kerala flood, around 14 lakh people were sent to relief camps. In addition, many people migrated to the houses of their friends and relatives. About 1613 schools and 1.75 lakh buildings were affected by the flood event[14]. According to the Central Water Commission (CWC) study[4], Chalakudy was one of the most severely impacted basins in Kerala.

It is always vital to have an emergency relocation strategy, especially in flood-prone areas to prevent confusion, damage and injuries. Flood-prone areas of the Chalakudy River basin were mapped by Rema and Gopi[19] using HEC- RAS and

HEC- HMS models. The hydraulic routing results of the study show that Annamanada, Kadukutty, Meloor and Pariyaram LSGDs were in a high-risk zone, with 20m inundation depth. These flood-affected communities are located in the Chalakudy taluk area of the basin. The strategically placed emergency shelters to effectively meet the evacuation needs of people are essential components of a disaster management system in a city[12]. The objective of the current study is to map the possible and safe evacuation shelter sites in the Chalakudy taluk area using geospatial techniques.

Material and Methods

Study Area: Chalakudy taluk was selected for this study due to the frequent yearly floods that have occurred there recently. The study area includes a total of 12 local self-government departments (LSGD) lying within 10°10′–10°26′ North latitude and 76°13′–76°53′ East longitude. The Chalakudy River, the fifth longest river in Kerala, rises from the Anamalai Hills in the Western Ghats and it empties into the Periyar River at the Puthenvelikkara village of Ernakulam district. The river is the result of the convergence of the five streams Parambikulam, Kuriarkutty, Sholayar, Karappara and Anakkayam[17]. Chalakudy is the municipal town coming under the study area. The region lies between 3m to 1405m above sea level. The communities in low-lying areas experience floods frequently. The administrative boundary map of the study area is shown in fig. 1.

Data Source: The data used in the current research includes a flood inundation map of the Chalakudy taluk area for a 100-year return period, a Digital Elevation Model, road network data from the Open Street map website, Land use land cover map, location details of flood-affected communities and details of flood emergency shelters in 2018 Kerala flood event. To create an elevation map, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation model (DEM) of 30 m resolution was projected onto the World Geodetic system (WGS) 1984 Universal Transverse Mercator (UTM) zone 43N in GIS interface. The data was downloaded from the National Aeronautics and Space Administration (NASA) website.

Land Use/Land Cover 2021 was downloaded from the ArcGIS Living Atlas website of Esri. Esri Sentinel-2 of 10m resolution was used for this purpose. Road network data has been extracted using BBBike in Open Street Map (OSM) website. Before analysis, the data was carefully examined for mistakes relating to topology. Topology errors in road networks, including overlaps, dangles, multipart geometries and self-intersects, are eliminated by creating a geodatabase topology in ArcGIS[22]. Some features whose positions in the road network data do not correspond to their real locations need to be manually updated. Road geometry has been improved by overlaying the OSM data over the Street and Imagery base map in ArcGIS.

The base map served as a guide for fixing a few major errors. False lines and microsegments in the network data were manually removed[21]. In the current work, flood Inundation (1 in 100 Year return probability) data was obtained from Kerala State Disaster Management Authority (KSDMA)[13]. The location details of flood-affected communities were collected through personal communication with residents and officials. The details regarding the flood emergency shelters of the 2018 flood event were collected from the Chalakudy taluk office.

Methodology: The positioning of emergency shelters depends on many factors, both physical and social. The parameters required for locating the shelter camps depend on the type of disaster in question. Emergency evacuation locations are necessary for natural disasters including earthquakes, fires, hurricanes and flooding and they must be placed strategically[2]. In this study, five factors were selected to identify the appropriate locations of emergency evacuation sites during flood catastrophes.

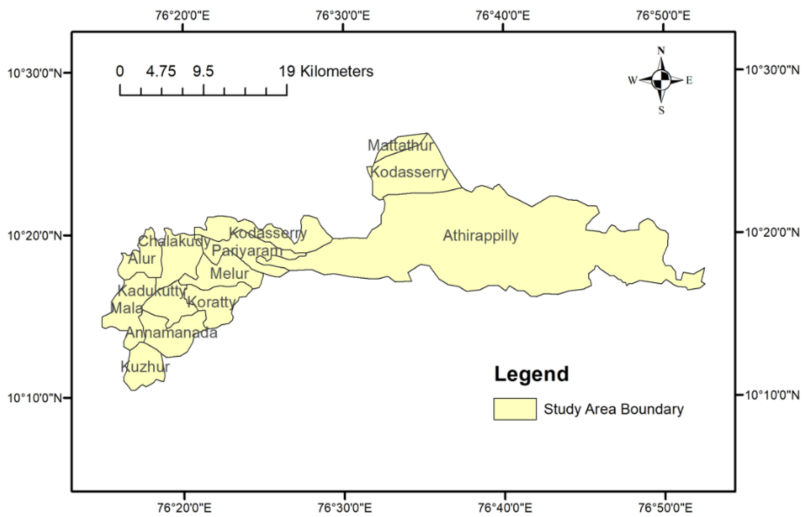

Fig. 1: Administrative boundary map of the study area
(Source: Boundaries delineated from the maps published in the website of chief electoral officer, Government of Kerala[6])

Since most of the research area is located in areas that are vulnerable to flooding, the topography of the region is the primary consideration when choosing a location for an evacuation center[28]. The flood-prone zones of the study area, land use patterns, distance to settlements and proximity to the road network were the additional variables taken into account[2,5,16,23]. To facilitate easy access, shelters have to be situated adjacent to buildings or roadways[20]. Flood polygons were digitized from the historic flood inundation map prepared by KSDMA. The obtained shapefile was then rasterized by using Polygon to Raster tool in ArcGIS. Euclidean technique in ArcGIS was used to map the distance to the settlement and proximity to the road network[20]. For the analysis, all of the collected data was transformed into raster data.

The thematic raster layers created for each variable in the multi-criteria analysis were reclassified by allocating scores ranging from 1 to 5 (Table 1), with 1 denoting areas with low favorability and 5 denoting locations that were advantageous for the placement of emergency shelters[5]. Ranks were assigned for each factor layer. The weighted maps were then multiplied with factor ratings or ranks and finally added together to locate suitable shelter sites[2]. Figure 2 displays a flow chart that explains the methodology adopted for this investigation. The suitability index for the location is given by equation 1.

$$\text{Suitability Index} = \sum_{a}^{n} R_a\, W_a \qquad (1)$$

where R_a = rating or rank given to each factor map and W_a = weightage given for various classes in the factor map.

$$\sum R_a = 100 \qquad (2)$$

In this work, elevation was given 50% rating, followed by land use (20%), distance to road network (10%), distance to settlements or flood-affected communities (10%) and flood-prone areas (10%). The topography of the study area is taken as a crucial factor in locating the emergency shelters, as it serves as a benchmark to identify secure locations in the event of flooding. Land use comes next in significance and not all land uses may be demolished to locate an evacuation center as each form of land use has a unique environmental value and function[2]. Flood inundation maps offer very efficient decision support for emergency response[32].

Results and Discussion

The elevation values of the study area are shown in figure 3a. Flooding is more likely to occur in low-lying areas[11]. Therefore, elevation is regarded as one of the crucial components in this study. Places that are less likely to experience flooding are given higher weights. The elevation map is reclassified in to 10 classes. Due to the significant risk of flooding, the contour areas with elevations below 15 meters are assigned least weight. Additionally, contours higher than 350 meters are not appropriate for flood shelters since they are difficult to access. Therefore, only contours that are between 15 and 350 meters are thought to be suitable for identifying flood shelters. Seven distinct LULC groups were found in the study area (Figure 3b).

Identifying the best locations for shelters is influenced by the urban layout and the ease of access to communities and infrastructure[28,31]. Sites that were within 100 meters of the road network, were given more weight, while those over 600 meters were given the least. Most of the eastern regions are not very appropriate for flood shelters since they lack adequate infrastructure (Figure 3c). In a similar way, areas greater than 4 km from flood communities were deemed less suitable, while those within 1.5 km were considered more suitable. The majority of flood communities are located in the western portion of the research area (Figure 3d). Waterways and forests are restricted in their ability to serve as evacuation sites, whereas built spaces, crop areas and barren land are considered to be more desirable locations[5].

According to flood risk study conducted by Rema and Gopi[19], majority of communities in Annamanda, Kadukutty and Meloor, experienced inundation depths above 20 meters and many areas in Kuzhur, Mala and Chalakudy inundated in the range of 10 to 20m depth. The analysis of 100-year flood inundation map by KSDMA reveals that 97.76 km^2 (in a total of 628 km^2) of the study area was totally submerged under water. In this investigation, the optimal locations were those that were between 250 meters and 1 km from areas that had been inundated (Figure 3e).

Ideal Locations for Flood Emergency Shelters: The shelter suitability map was created by superimposing the five main indicators in ArcGIS based on their assigned weights and ranks (Figure 4). Due to the abundance of mountainous regions, lack of settlements and a lack of adequate transportation, the majority of the eastern region is an extremely unsuitable zone. The unsuitable and moderately unsuitable areas are mainly located within the administrative boundaries of Mala, Kadukutty and Annamanada local bodies as these areas are at high flood risk. Despite having medium-suitable locations, Chalakudy and Kuzhur local bodies are not safe for extreme flood risk since their elevation is below the 15-meter contour.

According to the study, the best locations for emergency shelters are those that fall within the 15 and 350 m contour zones, which have good transportation infrastructure. Since many locations in the Alur, Koratty, Meloor, Kodasserry and Pariyaram local bodies are above the 15-meter contour and are not impacted by flooding, they might be taken into consideration when organizing an emergency evacuation (Figure 5).

Figure 5 depicts the locations of flood shelters and flood affected communities during 2018 flood event. The results shows that 1.79% of study area is most suitable, 9.08 % is suitable, 9.65% is moderately suitable, 14.05 % is medium suitable, 11.82% is moderately unsuitable, 25.1% is unsuitable and 28.27% is very unsuitable for locating flood shelters. The significance of emergency sheltering locations for flood catastrophe response was established by many previous researches.

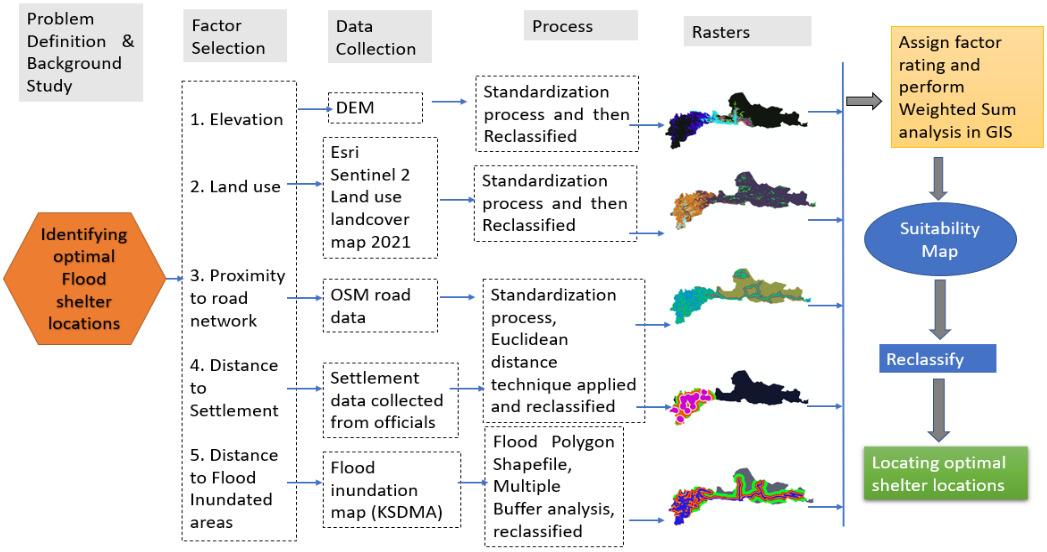

Fig. 2: Flowchart explaining the methodology

Table 1
Factor rating and Weightages assigned for each variable

Selected Factors	Classification	Weightage	Factor rating
Elevation (in meters)	3-15	1	50%
	15-50	3	
	50-100	5	
	100-150	5	
	150-200	5	
	200-250	4	
	250-300	3	
	300-350	2	
	350-400	1	
	>400	1	
Land use	Water	1	20%
	Trees	1	
	Flooded Vegetation	1	
	Crops	5	
	Built Area	3	
	Bare Ground	4	
	Range Land	2	
Buffer Distance to flooded area (in meters)	100	3	10%
	250	4	
	500	5	
	1000	4	
	2500	2	
	>2500	1	
Proximity to road network (in meters)	<100	5	10%
	100-300	4	
	300-400	3	
	400-600	2	
	>600	1	
Distance to settlements (in meters)	0 -1500	5	10%
	1500-2000	4	
	2000-3000	3	
	3000-4000	2	
	4000-49000	1	

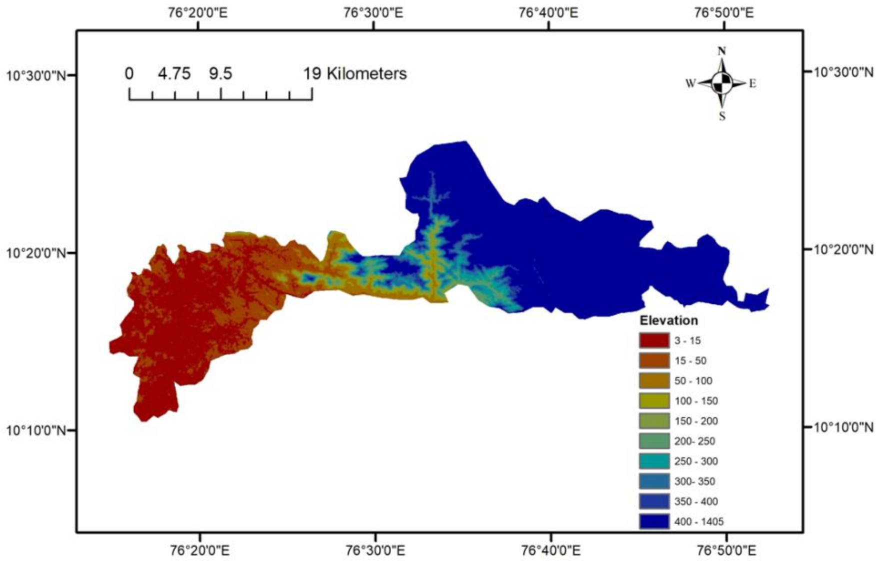

Fig. 3(a): Elevation

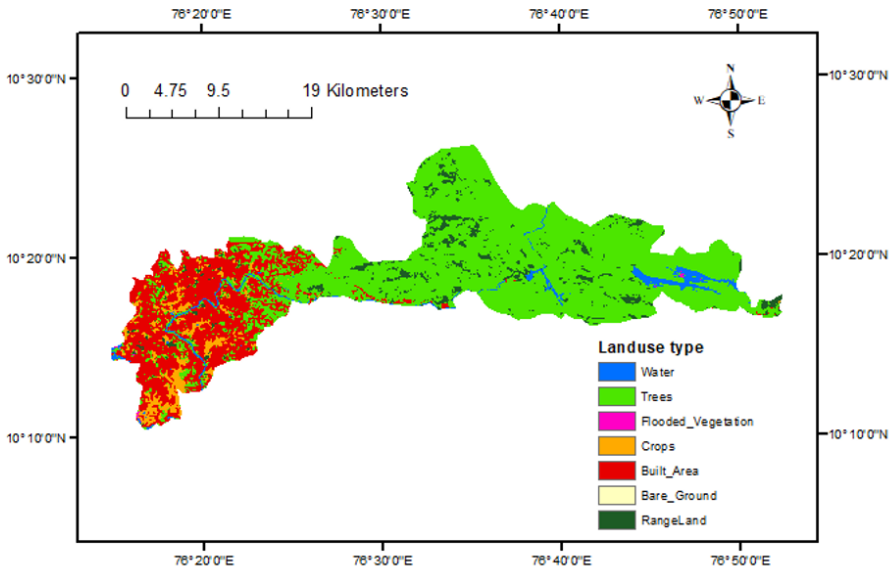

Fig. (3b): Landuse

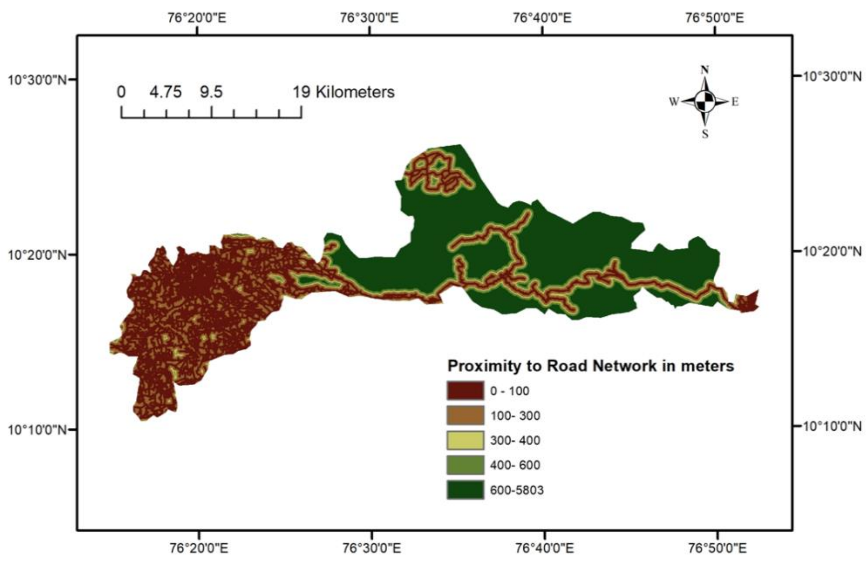

Fig. 3(c): Proximity to road network

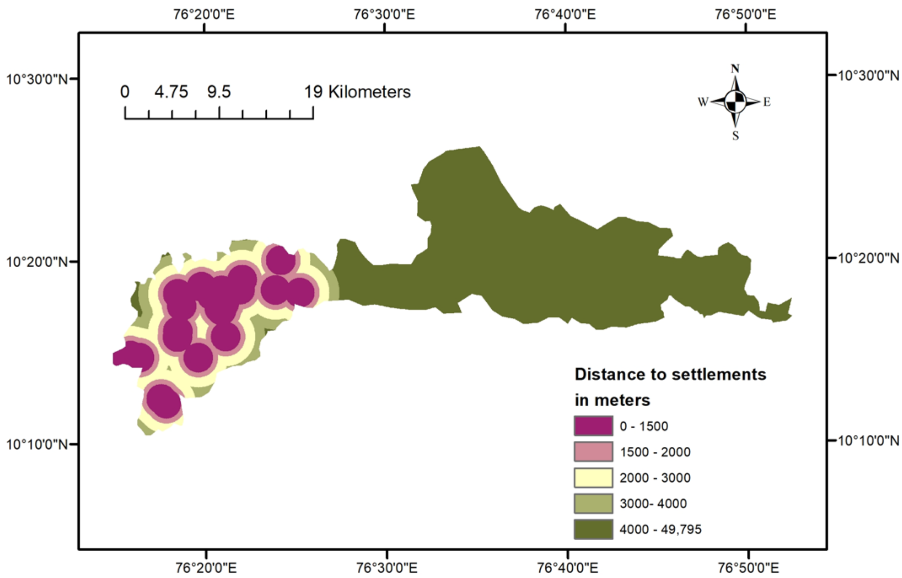

Fig. 3(d): Distance to settlements

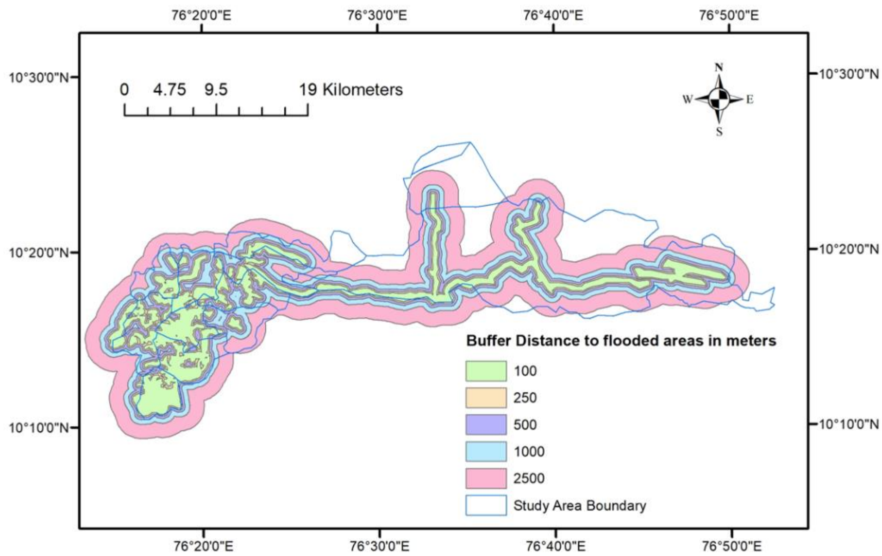

Fig. 3(e): Buffer distance to flooded areas

Fig. 3: Factor Maps of the study area

(a) Elevation (b) Landuse (c) Proximity to road network (d) Distance to Settlements (e) Buffer distance to flooded areas

Uddin and Matin[23] used GIS and multicriteria analysis to map the best places for emergency shelters in Bangladesh and they say that the optimal location should not be under water during floods; rather, it should be in an area that is prone to flooding and should be quickly accessible by people. In addition, shelters built in remote locations or too far from communities could not reduce the risk of flooding disasters[20]. The method employed in the current study is economical, easy to use and take less time to map the appropriate locations for evacuation shelters in any area that is vulnerable to flooding. The research has a few limitations too. Only secondary data and geospatial approaches are used to determine the best places for shelters. Future studies in this area could combine a field study with more variables that affect emergency preparation. As a whole, the research subsequently assisted to lessen the flood catastrophe in Chalakudy taluk area by providing a novel mitigation plan to identify the sites most suitable for flood shelters.

Conclusion

Evaluating the spatial distribution of places to evacuate during the flood events is crucial in crisis management. In this study, flood emergency shelter locations in the flood-prone areas of Chalakudy taluk were mapped by integrating geospatial techniques with multicriteria analysis. As the majority of the areas are flood-prone, the research gave the greatest focus on the topography of the region for locating suitable spaces for emergency shelters. Land use, the distance to the flood-affected communities, the proximity to road networks and distance to the inundated regions were the other factors considered for the analysis.

The shelter suitability map was classified into seven classes: very unsuitable (28.27%), unsuitable (25.1%), moderately unsuitable (11.82%), medium suitable (14.05%), moderately suitable (9.65%), suitable (9.08%) and most suitable (1.79%). The results shows that there are many ideal locations for flood shelters around the communities of Alur, Koratty, Meloor, Kodasserry and Pariyaram local bodies.

The authorities can use the findings as key resources to manage floods and incorporate them into mitigation strategies. Additionally, the research offers relevant information for upcoming studies of risk assessment and mitigation in the research area. The methodology mentioned in this work can be applied to other regions too, with the same kind of issues.

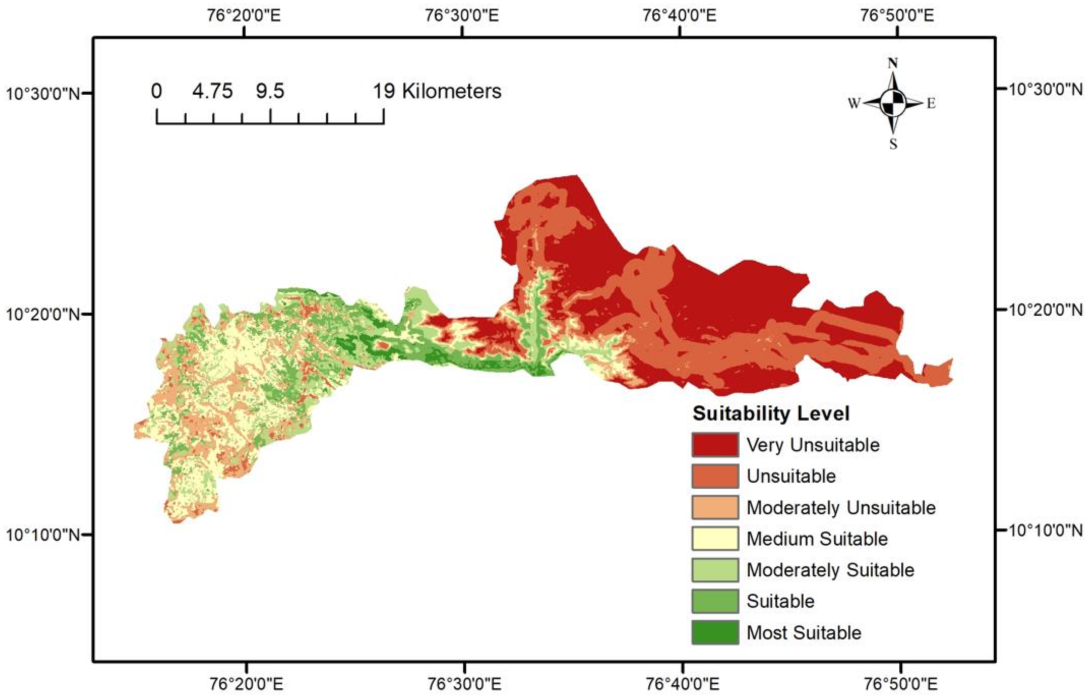

Fig. 4: Shelter Suitability Map

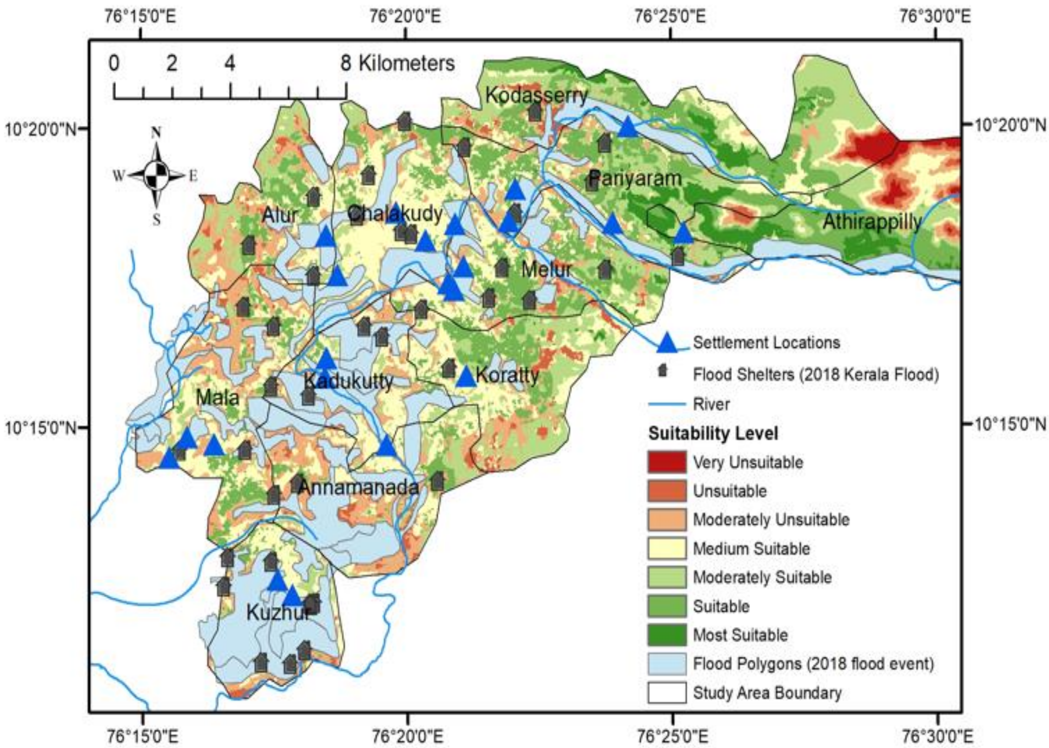

Fig. 5: Optimal shelter locations for various local bodies in the study area

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