FLOOD HAZARD ZONE MAPPING IN THE TROPICAL ACHANKOVIL RIVER BASIN IN KERALA: A STUDY USING REMOTE SENSING DATA AND GEOGRAPHIC INFORMATION SYSTEM

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Received: 26.08.2017 / Accepted: 15.11.2019

Abstract: The large overflow or retention of water beyond the normal high water limits on flat or low-lying areas may be technically defined as flood. It is a widespread disaster repeatedly occurring throughout the world. Floods are more common in areas adjacent to a river, lagoon, or lake, occurring whenever the water level rises. This natural hazard is common in the low lying areas of the Achankovil River Basin in Kerala, which have been frequently affected by floods in the past. The objectives of the present study are to map the flood hazard zones of the Achankovil River Basin using Remote Sensing (RS) data and Geographic Information System (GIS) techniques, and to suggest suitable and effective methods for preventing and mitigating flood impact. The factors selected for this study are rainfall distribution, micro-watershed size, slope, drainage density, soil (drainage), geomorphology, land use/land cover, and roads per micro watershed. In order to prepare the map, a modified flood hazard index method is used. The area of the final flood hazard zone map is demarcated as five different hazard zones, viz. very low, low, moderate, high, and very high, depending on the level of flood occurrence. The prepared hazard zone map is validated using flood inundation data of the study area. To help the local communities understand the risk, this map shows the location of hazard areas. It can also be effectively used in disaster response planning and flood hazard management.

Keywords: Achankovil River Basin, flood, GIS, modified flood hazard index

Introduction:

Floods are among the most common of all natural hazards. Every year, they cause serious damages and loss of life and property over large areas in many countries. A flood is a natural phenomenon, which happens when a piece of land, or area, that usually remains dry, suddenly gets inundated, as a result of sustained heavy rainfall during monsoons, or tropical cyclones. Floods can occur suddenly and recede quickly or they can prevail for

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several days or even months. A flood can occur in coastal areas, low lying areas with poor drainage, or in urban locations with inadequate drainage systems (Jennings and Gruntfest 2003). Usually, natural causes like heavy rainfall, storm surges, and poor drainage together with human-induced causes like uncontrolled modification of flood plains and drainage congestion as a result of land reclamation lead to severe floods.

Floods are a very common hazard in Kerala, both because of natural as well as human-induced causes. A significant percentage of the total area of this state is prone to flooding. This is due to the widespread geographical distribution of river flood plains and low lying coastal plains in the state. During heavy rainfall, most of the rivers in Kerala reach their peak discharge levels. The low lying areas of Achankovil River Basin indeed have a history of devastating floods, which have caused considerable loss and damage to settlements, agriculture, and infrastructure.

RS data provides information that has proved to be very useful in a multitude of disaster management applications. RS data combined with GIS techniques offers an effective tool in the process of mapping areas prone to natural hazards. Many researchers have attempted to map flood prone areas using RS and GIS techniques (Islam and Sado 2000a; Islam and Sado 2000b; Brivio et al. 2002; Tanavud et al. 2004; Dewan et al. 2006; Kourgialas and Karatzas 2011; Paquette and Lowry 2012; Warghat et al. 2012; Clement 2013; Vinod et al. 2013; Daffi et al. 2014; Vinod et al. 2014). Chandran and Joisy (2009) prepared flood hazard zone map of Vamanapuram River Basin using RS data and GIS techniques. The factors they selected were annual rainfall, size of watershed, slope of watershed, gradient of the river and stream, drainage density, land use type, soil type, and communication line and infrastructure. Ajin et al. (2013) mapped flood hazard zones in Vamanapuram River Basin using RS and GIS techniques. The factors they selected for their study were rainfall distribution, micro watershed size, slope, drainage density, land use/land cover, soil, and roads per micro watershed.

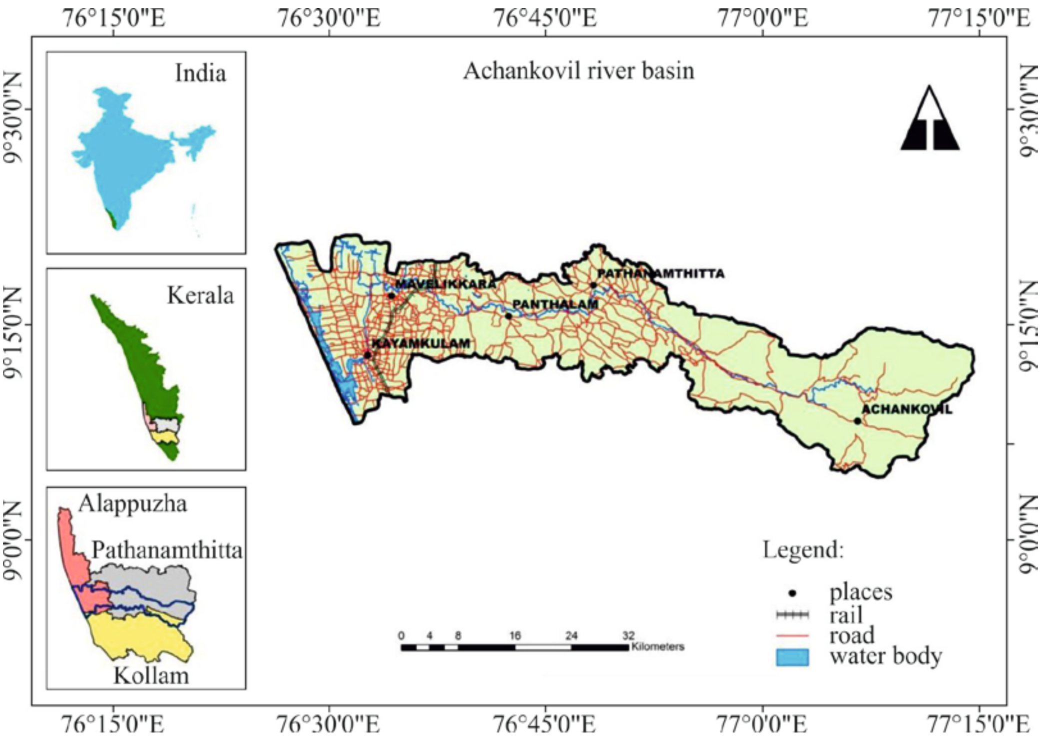
The objectives of this study are to map the flood hazard zones in the Achankovil River Basin using RS data and GIS techniques, and to suggest suitable and effective methods for preventing and mitigating flood impact. Factors such as rainfall distribution, micro watershed size, slope, drainage density, soil, geomorphology, land use/land cover, and roads per micro watershed are selected to map the hazard zones. A modified flood hazard index (MFHI) method is used to prepare the flood hazard zone map.

Materials and methods:

Study area

The study area extends from 9°0'0" N to 9°20'0" N latitudes and 76°20'0" E to 77°20'0" E longitudes. The head of the Achankovil River is located in the southern part of Devarmalai hills in the Western Ghats at the elevation of 700 m. The drainage basin covers an area of about 1484 km^2 and lies entirely in the Kerala state. This river basin is bound by the Pamba River Basin to the North, Kallada and Pallikkal River Basins to the South. The eastern boundary of this basin is formed by the Western Ghats, while the Arabian Sea forms the western boundary. Like all the river basins in Kerala, the Achankovil River Basin can also be divided into three different zones based on elevation – the lowland, midland, and highland. The lowland, located near the coastal area is generally swampy and is vulnerable to flood during monsoon months. The midland is characterized by gentle ascents and valleys interspersed with isolated low relict hills. The highland, located on the eastern side, is covered by dense forests and dissected by ravines and long spurs. The entire basin has a tropical climate without much variation in temperature and humidity. Along the low-lying areas, the climate is generally hot, with high humidity, while the highland, represented by the mountainous regions, generally has low temperature with high humidity. The study area map is shown in Figure 1.

Figure no. 1 Location map of the study area



The present study area was outlined from the Survey of India (SOI) topographic maps (Map Nos. 58 C/7, 58 C/8, 58 C/11, 58 C/12, 58 C/15, 58 C/16, 58 G/4, and 58 G/8) of 1:50,000 scale. In order to prepare the thematic maps of the area, ArcGIS 9.3 and ERDAS Imagine 9.2 software tools were used.

The drainage networks were digitized from the topographic maps, and the drainage density map was prepared using ArcGIS spatial analyst tools.

The road networks were also digitized from the SOI topographic maps and later updated using Google Earth data.

The micro watersheds were outlined from the topographic maps and the micro watershed size map was prepared by classifying the micro watersheds on the basis of area.

The geomorphology map was also prepared from the topographic maps.

The road per micro watershed map was prepared by categorizing the micro watersheds on the basis of the number of roads present in each micro watershed.

The soil map was prepared by digitizing NBSS&LUP (National Bureau of Soil Survey and Land Use Planning) soil map of 1:250000 scale.

The contour data was derived from the SRTM (Shuttle Radar Topography Mission) DEM (Digital Elevation Model). The contour data, having a 20 m interval was prepared using ArcGIS spatial analyst tools.

The slope map was prepared from the contour data using ArcGIS 3D analyst and spatial analyst tools.

The rainfall distribution map was prepared from the India Meteorological Department (IMD) annual average rainfall data for the years 2005 to 2010. This data was spatially interpolated by Inverse Distance Weighted (IDW) method to obtain the rainfall distribution map. IRS-P6 LISS-IV satellite image at 5.8 m resolution was used for the preparation of land use/land cover map.

The supervised classification was done using ERDAS Imagine software tools. These eight thematic layers were then converted into raster format and reclassified by equal interval classification. In order to prepare the hazard zone map, a MFHI model developed during this study was used.

Rank was assigned to each class of the selected factors and weight was assigned to each factor according to its influence on flood occurrence. The index was derived from the weight and rank (Index = Weight x Rank) (Tab. 1, Annexes).

The flood hazard zone map was prepared by overlaying the corresponding index maps using ArcGIS tools. Finally, the hazard zone map was validated using the available flood inundation data of the study area.

Results and discussion:

The present study has identified factors like rainfall distribution, micro watershed size, slope, drainage density, soil, geomorphology, land use/land cover, and roads per micro watershed which are significant in the flooding of the areas in Achankovil River Basin. Their significance is briefly discussed below.

Rainfall distribution

One of the most important factors of flood occurrence is the quantity of precipitation in a specific area during a specific period. Floods can be caused by a sudden sustained precipitation over an extended period, leading to super-saturation of the soils in a large region (Rodda 1970; Smith and Ward 1998). Floods can develop anywhere rain falls, if it brings more water than can be drained by channels or more than the infiltration capacity of the terrain. Short periods of intense rainfall may engender flash flooding and longer periods of widespread heavy rain can cause rivers to overflow. Heavy rain for a short period or moderate to light rain for several days or weeks can result in flood. Thus, heavy rains cause the river to overflow and submerge the surrounding flat areas, which results in flooding. The low lying areas or areas closer to the coast, studied here experience lower rainfall, whereas the highland areas experience heavy rainfall. Even though the low lying areas experience low rainfall, the chance of flooding is high because of the excess water supplied from the upstream highland, where there is excess rainfall. On the basis of rainfall received, the study area has been grouped into four classes, viz. 2868-2992 mm, 2992-3117 mm, 3117-3242 mm, and 3242-3367 mm. The rainfall distribution map is shown in Figure 2.

Micro-watershed size

Another very important factor that has a major influence in flooding is the micro watershed size. A watershed is the area of land, defined as a bounded hydrologic system, where all the water that is in excess of retention drains off from it and goes into a common waterway, such as a stream, river, lake, estuary, wetland, aquifer, or even the ocean (Ali 2011).

The smallest hydrological unit is known as a micro-watershed. Our study consists of 87 micro watersheds. Micro watersheds with larger drainage areas require a longer runoff for a significant increase in water level to become a flood (Ajin et al. 2013). Depending upon the areal extent of micro watersheds, the study area has been grouped into four classes, viz. 0.39-14.58 sq. km, 14.58-28.77 sq. km, 28.77-42.96 sq. km, and 42.96-57.14 sq. km. The micro watershed size map is represented in Figure 3.

Figure no. 2 Rainfall distribution map

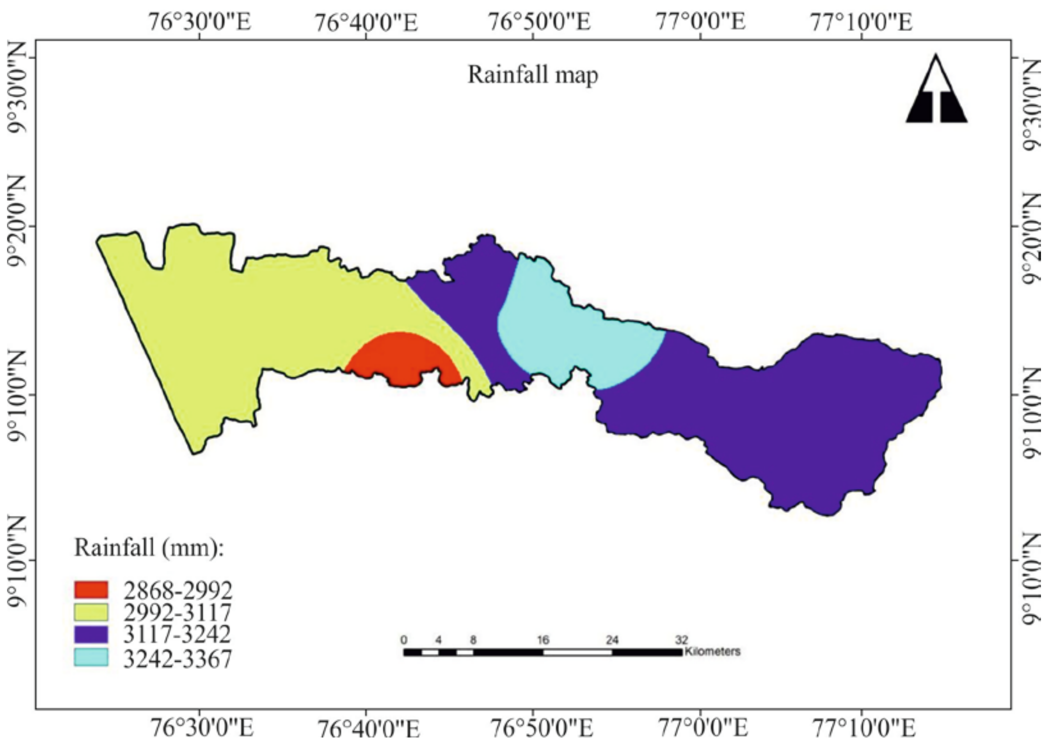
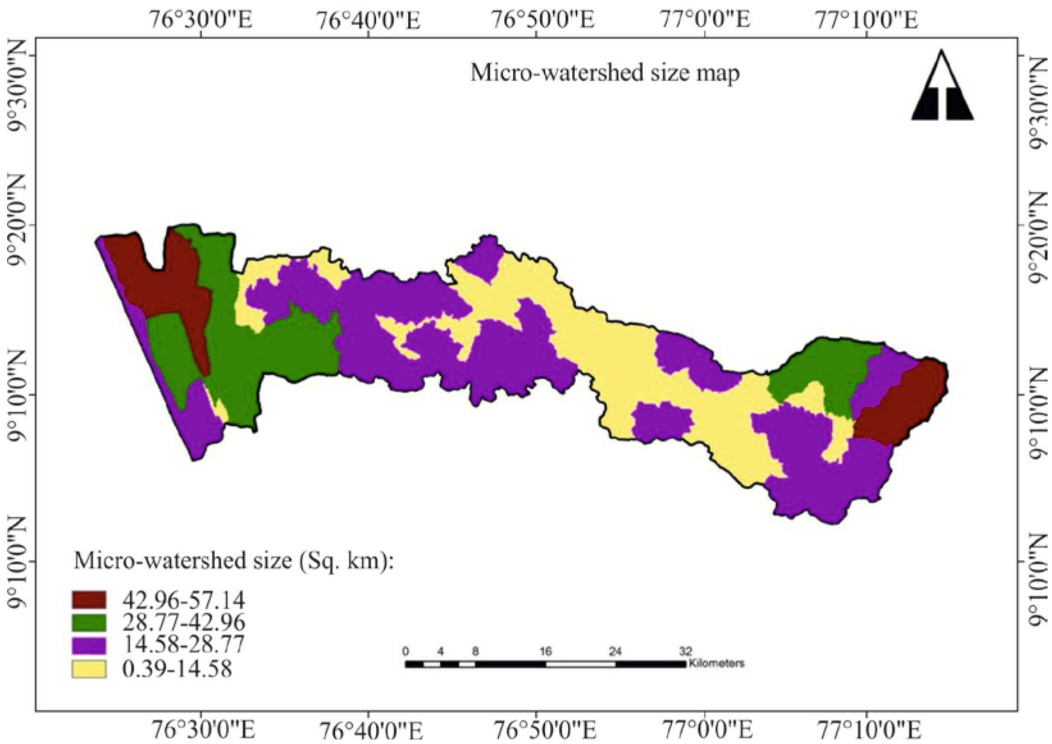


Figure no. 3 Micro watershed size map



Slope

Slope, the degree of inclination of the land surface, also has a significant influence on flooding. The lower the inclination, the flatter the terrain and higher the inclination, steeper the terrain (Warghat et al. 2012). If there is a higher ground adjacent to a lower ground, the lower area is likely to experience floods during heavy rains. The chance of flood is also more in areas with lower slopes, as those areas are more susceptible to water logging (Tanavud et al. 2004). There is general agreement that steeper slopes would be beneficial since they do not allow water accumulation in depressions, thus preventing ponding of water (Fernández and Lutz 2010; Ramlal and Baban 2008). Major portion of the study area is characterized by lower slopes. In this river basin, steeper slopes are found only on the eastern side. The slope of the study area is grouped into three classes: 0-10°, 10-20°, and 20-30°. The pattern of slope distribution is represented in Figure 4.

Drainage density

Drainage density is the ratio of the total length of the stream network in a watershed over its contributing area (Horton 1945). The more the drainage density, the higher the runoff coefficient. The chance of flood is higher in the areas with a low drainage density, because the rate of drainage is much less than the rate of precipitation. In the study area, the drainage density is higher in the upstream eastern segment and very low in the downstream western segment. The drainage density is grouped into three different classes, viz. 0-2.33 km/km^2, 2.33-4.66 km/km^2, and 4.66-7.00 km/km^2. The drainage density map of the Achankovil River Basin is shown in Figure 5.

Soil (drainage)

Soil is another important factor used in the process of flood hazard zone mapping. Generally, a portion of the water infiltrates the soil during rain. When all pores are filled with water, the soil becomes saturated and the zone of aeration disappears. If the rain continues, pools may form on the soil surface. Soil drainage refers to the soil's natural ability to transmit water through it, depending on its permeability. Loose soil allows water to pass through quickly. Similarly, the permeability of the underlying rock types also affects the rate of runoff. The lesser the permeability, the greater the runoff. Watersheds with more permeable soils are generally less prone to flooding than those with impervious soils (Schultz and Leitch 2008). In the study area, soils are classified into three different groups, depending on their drainage capacity. They are excessively drained, well-drained, and moderately drained soils. Moderately drained soil types are represented by clay and gravelly clay; well-drained soil types are loam and gravelly loam; whereas the excessively drained soil is sandy. In this river basin, the probability of flood is higher in areas with moderately drained soil containing clay and gravelly clay. This type of soil is very dense, causes less water infiltration, and thus increases the amount of surface water which leads to flood. A major part of this basin is composed of well-drained soil represented by loam and gravelly loam. The map with different soil categories, depending on their drainage capacity, is shown in Figure 6.

Geomorphology

Geomorphology, the study of characteristics, origin, and development of landforms is another factor taken into account in flood hazard zone mapping. The shape of the landscape affects floods. For example, water tends to run off very quickly into streams in regions with steep slopes instead of infiltrating into the soil, whereas in fairly flat regions, water runs off much more slowly, allowing more time for infiltration. However soil gets saturated very fast, which then results in flooding. Flat areas are highly susceptible to flood than steeper ones. The geomorphologic classes in this basin are represented by denudational structural hills, denudational hills, piedmont zone, residual hills, plateau, pediplain, alluvial plain, coastal plain, marshy land, and water body. In the upper part of the Achankovil River Basin are present the denudational structural hills, followed by a piedmont zone, which delineates its upper and central parts. Plateaus and pediplains are found in the center of the basin, whereas the lower part is characterized by the presence of coastal and alluvial plains. The map showing the spatial distribution of all these geomorphologic classes is given in Figure 7.

Land use/land cover

Land use/land cover (LU/LC) is represented by the vegetative material and modifications on the surface of the earth that influence the flow of water. Watersheds with LU/LC that promote infiltration are less prone to flooding (Schultz and Leitch 2008). The infiltration rate is higher in the areas with thick vegetation. Thus, a vegetated landscape is less susceptible to flooding than a bare one. Vegetation slows down overland flow too, thus promoting infiltration. The impermeable built-up areas can cause water logging, as the infiltration rate remains low. The LU/LC classes found in the Achankovil River Basin are forest, plantation, mixed vegetation, open area, built-up area, and water body. Mixed vegetation and forest cover a major portion of this area. Figure 8 shows the LU/LC map.

Figure no. 4 Slope map

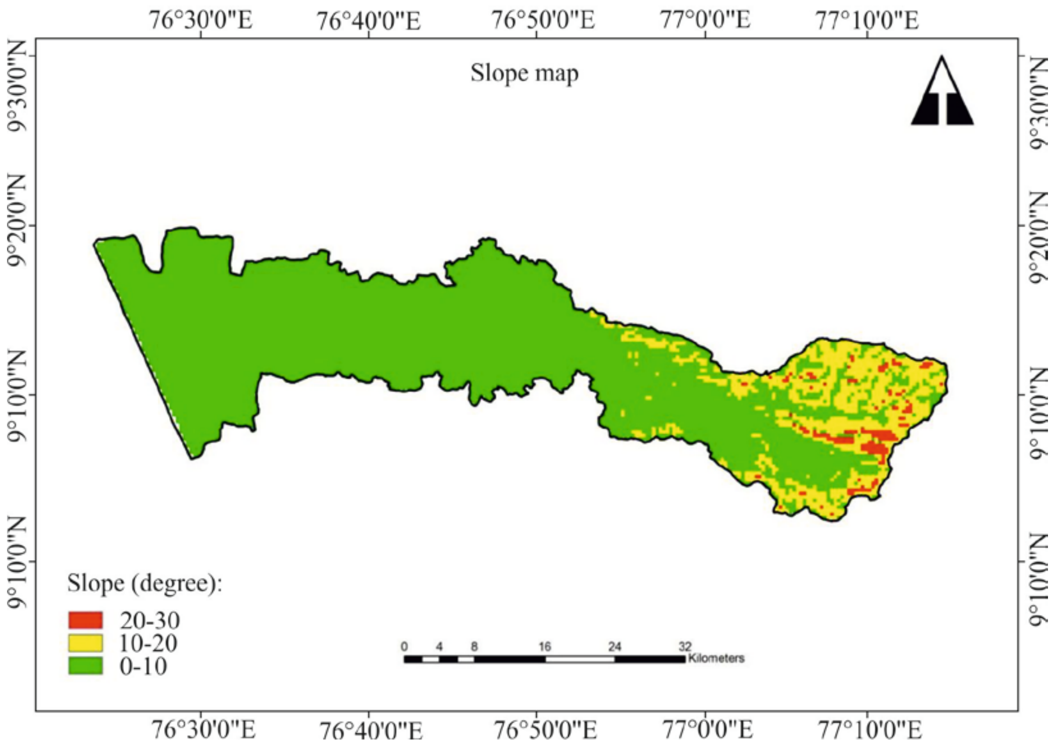


Figure no. 5 Drainage density map

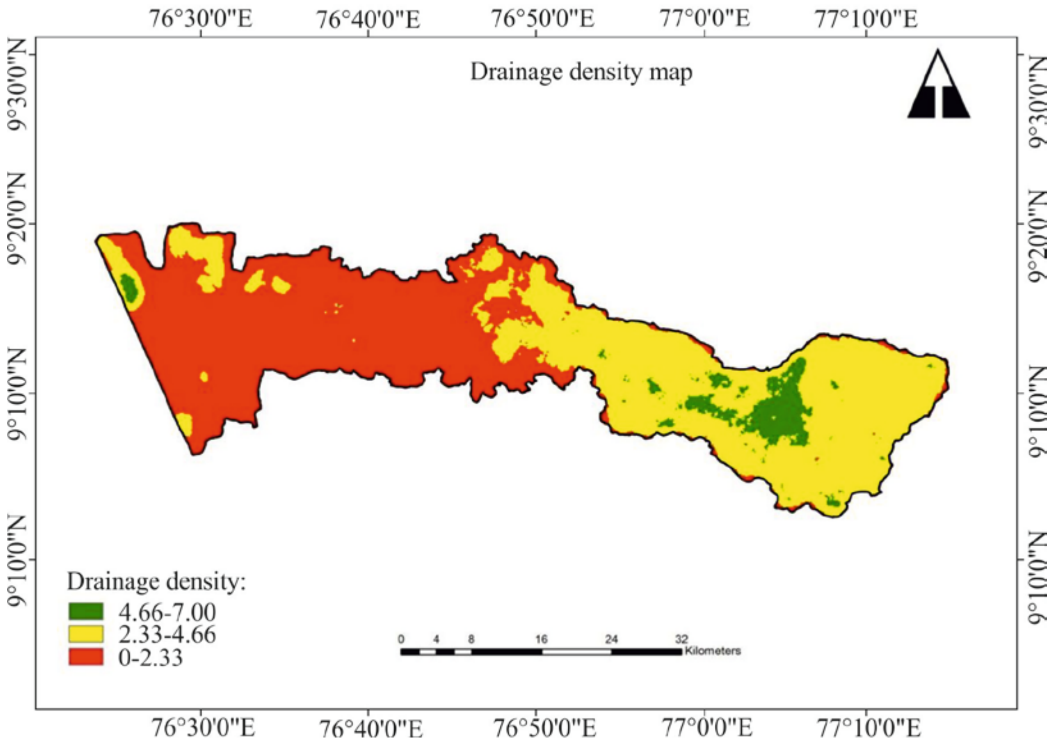


Figure no. 6 Soil map

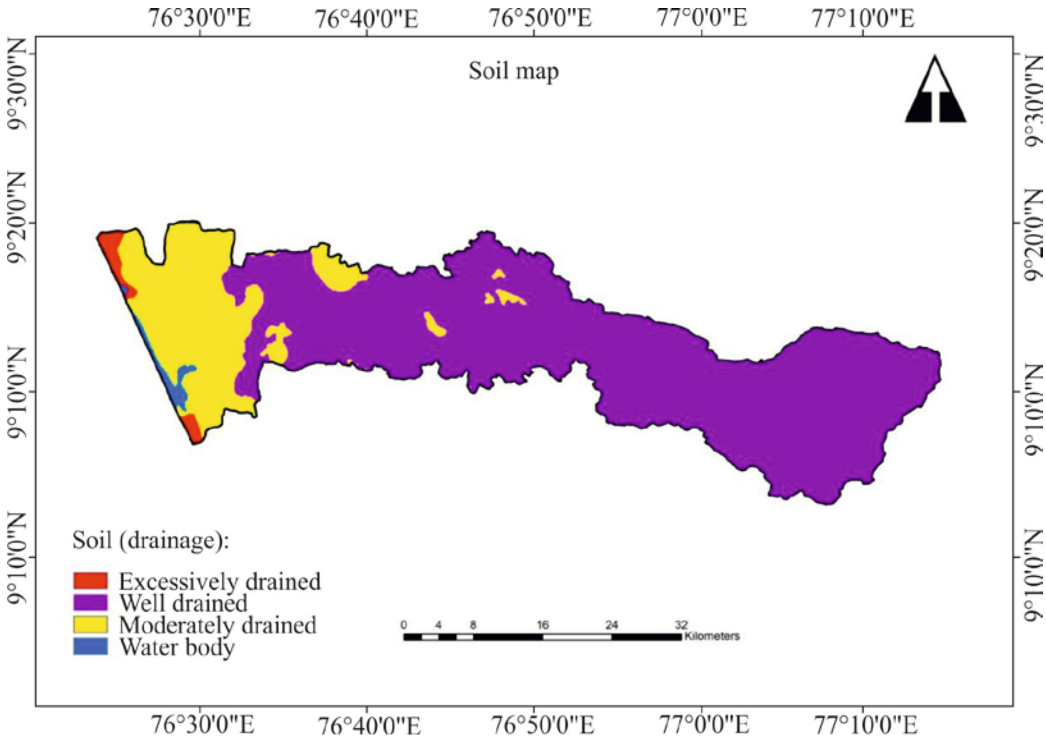


Figure no. 7 Geomorphology map

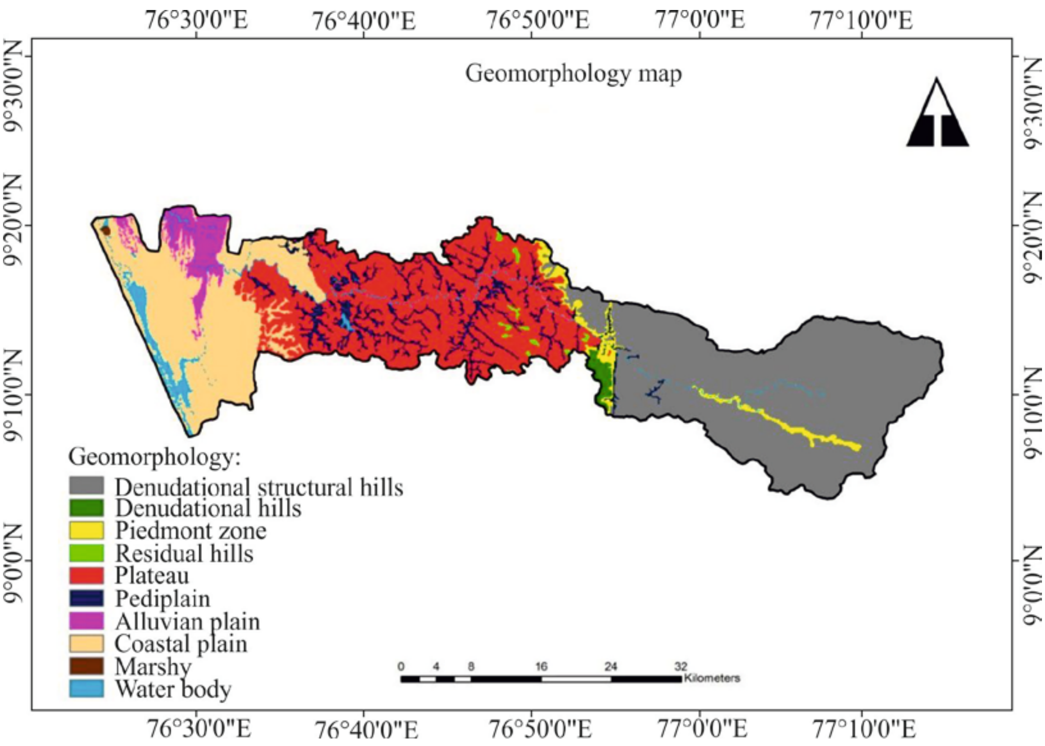
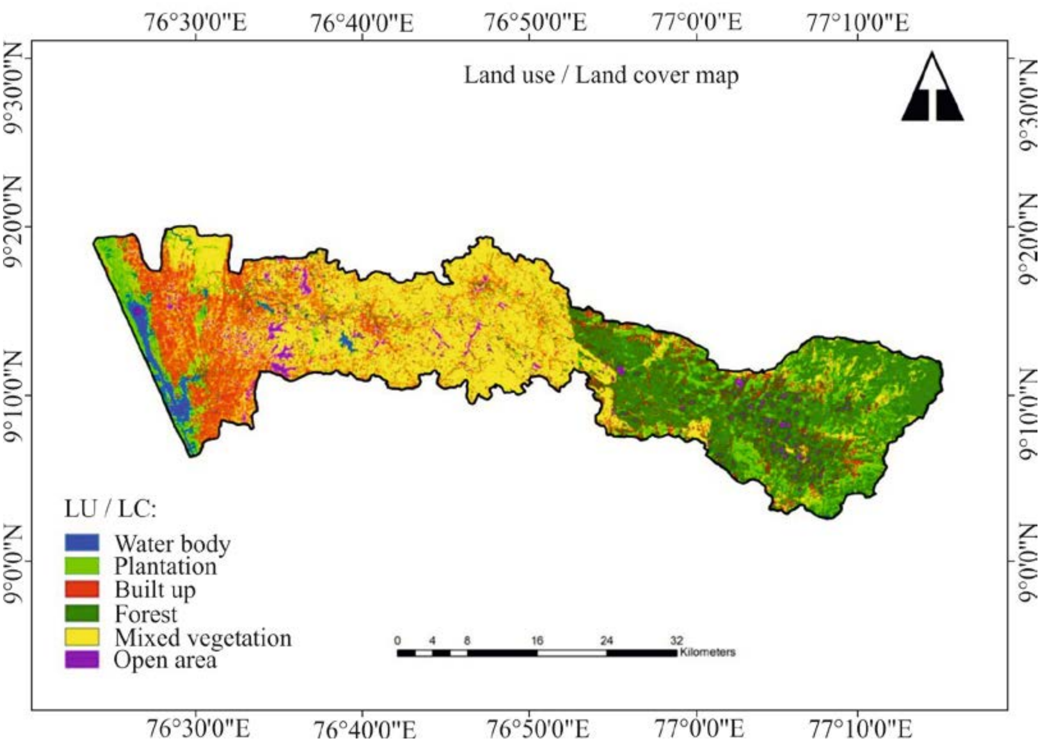


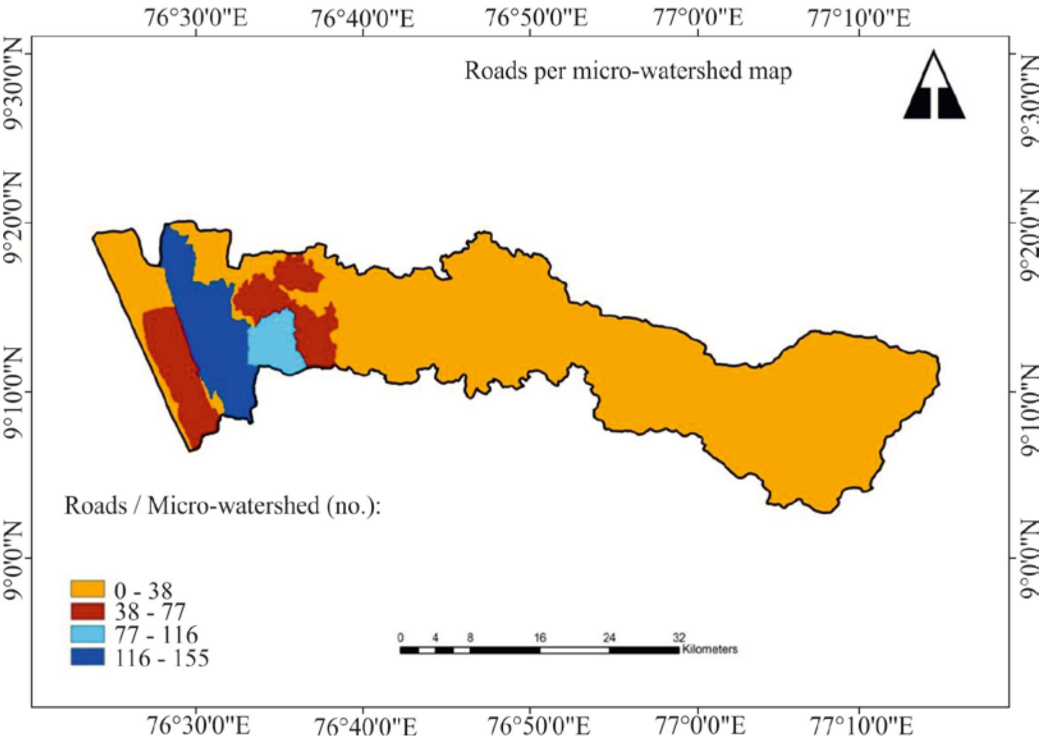
Figure no. 8 Land use/land cover map



Roads per micro watershed

As a part of road construction, a large quantity of earth material is removed and relocated. Extraction of earth material can affect the stability of the terrain and the dumped material may obstruct free flow of water. Such modifications can cause water logging. Also the permeable soil is replaced by impermeable road building materials, which will reduce infiltration and, in this manner, raise the water level. The number of roads per micro watershed is more in the lower plains of this river basin, and thus increases the potential for flooding. Depending on the number of roads per micro watershed, the entire study area is grouped into four different classes, viz. 0-38, 38-77, 77-116, and 116-155. The road per micro watershed map is shown in Figure 9.

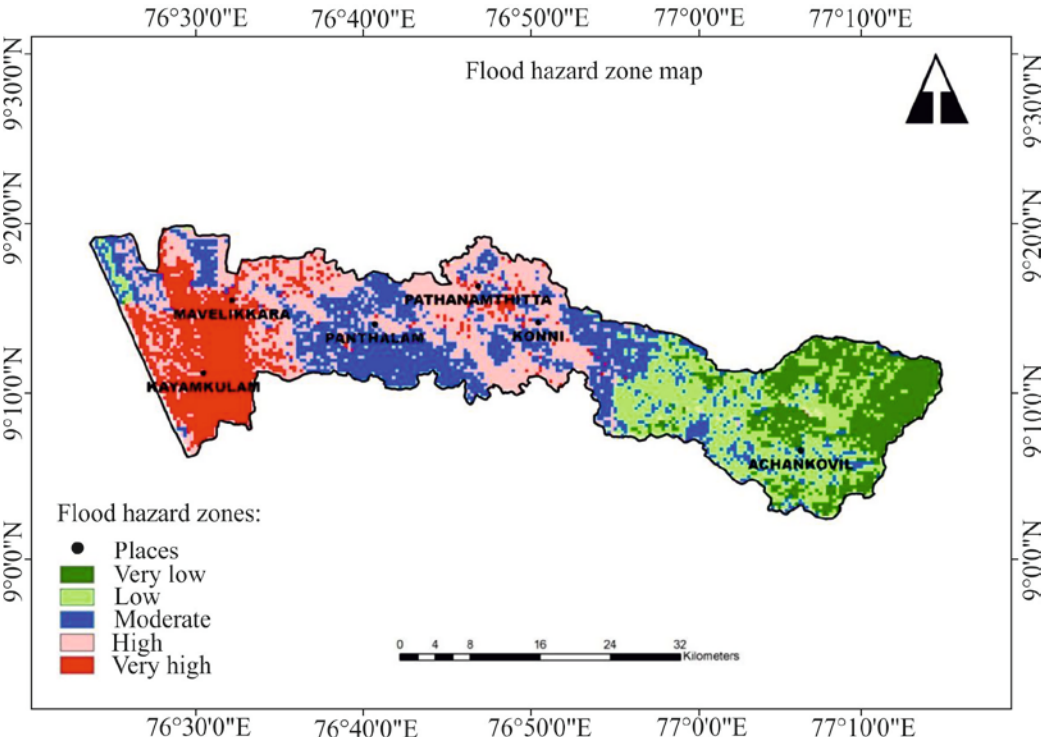
Figure no. 9 Roads per micro watershed map



Flood hazard zones

For the flood hazard zone mapping, eight factors have been taken into consideration. The flood hazard zone map is prepared by combining the index map layers of the selected factors using GIS techniques. Flood hazard zones in our study are divided into five classes, viz. very low, low, moderate, high, and very high, depending on the severity of flood hazard. Finally, the prepared flood hazard zone map is validated using the data collected during the field survey, related to previous floods in this area. Analysis of the statistical data on the frequency and intensity of flood has shown that most of the past flood occurrences are spatially over the very high hazard zone. The flood hazard zone map is shown in Figure 10. Lower parts of this basin belong to the high and very high flood hazard zones. This is due to the low gradient in the lower plains, where a vertical rise in the water level can inundate large areas. These areas are composed of low drainage soil types and the cross-sectional areas of the streams are insufficient to effectively drain out the excess influx of rain water, which results in flooding. This shows that geomorphology, soil, and drainage density play important roles in flooding. Our study reveals that the present methodology can provide accurate result, and can be successfully and effectively used in flood hazard zone mapping.

Figure no. 10 Flood hazard zone map



Based on the flood hazard zone mapping, preventive and mitigation measures for floods can be designed and implemented. To mitigate flood and related disasters, human intervention causing environmental and geomorphological degradation must be avoided. Some of the preventive and mitigation measures that can be carried out in the present study area are:

- controlling or banning constructions that block the natural flow of water and also the encroachments of flood plains and drainage channels;
- conservation and maintenance of stream channels, including, retaining the size and clearing the present obstructions in the channel, in order to facilitate easy water drainage;
- watershed treatment, including slope management like contour bunding, slope reversal, and afforestation to prevent soil erosion and to increase water retention capability of the soil.

Conclusions:

Floods are common natural hazards experienced all over the world. They cause loss of life, property, and infrastructure. Floods cost many millions of dollars every year due to property damage, lost production, lost wages, and lost business. The cost of building and maintaining dykes, dams, and other flood defenses are high. Further, there is an incalculable human cost. Thus, the prevention, control, and management of flood hazards are critically important components of public safety and quality of life. The identification of high and very high flood hazard zones in the Achankovil River Basin is to show the critical zones, which are prone to floods for effective disaster prevention, preparedness, and planning. The geospatial technology plays an important role in mapping flood prone areas.

In this study, to prepare the flood hazard zone map of the Achankovil River Basin, a RS and GIS based analysis has been carried out. The study shows that geomorphology, drainage density, and soil are the most important factors influencing flood hazard occurrence in this area. The flood hazard zone map will serve as valuable data and guideline for the planners, decision makers, and emergency services in assessing flood hazard and to mitigate loss or damage in future.

Rezumat:

CARTAREA ZONELOR DE RISC LA INUNDAȚII ÎN BAZINUL TROPICAL AL RÂULUI ACHANKOVIL DIN KERALA: UN STUDIU DE UTILIZARE A TELEDETECȚIEI ȘI A SISTEMULUI DE INFORMAȚII GEOGRAFICE

Revărsarea mare sau reținerea apei dincolo de limitele normale ridicate ale apei pe zonele plane sau joase, pot fi definite tehnic ca inundații. Este un dezastru larg răspândit în mod repetat în întreaga lume. Inundațiile sunt mult mai întâlnite în zonele adiacente ale unui râu, lagune sau lac, apărând oricând nivelul apei crește. Acest dezastru natural este comun în zonele joase din bazinul râului Achankovil din provincia Kerala, care a fost frecvent afectată de inundații în trecut. Obiectivele acestui studiu au fost de a carta zonele de risc la inundații din bazinul râului Achankovil folosind tehnicile de teledetecție (RS) și Sistemul de Informații Geografice (GIS) și pentru a sugera metodele cele mai adecvate și eficiente pentru prevenirea și atenuarea impactului inundațiilor. Factorii selectați pentru acest studiu au fost distribuția precipitațiilor, mărimea microbazinelor hidrografice, pantele, densitatea drenajelor, solurile (drenate), geomorfologia, folosirea terenurilor / acoperirea terenurilor și drumurile de acces din microbazinele hidrografice. În vederea pregătirii cartărilor s-a folosit o metodă de indici de risc la inundații modificată. Harta finală de risc la inundații a arealului studiat a fost delimitată în cinci zone de risc: foarte scăzut, scăzut, moderat, ridicat și foarte ridicat, depinzând de nivelul de apariție a inundațiilor. Harta riscului la inundații a zonei a fost validată folosind datele despre inundații din arealul studiat. Pentru a ajuta comunitățile locale să înțeleagă riscul, acestă hartă indică localizarea zonelor de risc. De asemenea, poate fi folosită eficient în planificarea răspunsului la dezastre și managementul riscului la inundații.

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ANNEXES

Table no. 1 Rank, Weight, and Index assigned for different factors

Sl. No.	Factor	Class	Rank	Weight	Index
1	Rainfall distribution (mm)	2868 - 2992	1	20	20
		2992 - 3117	2		40
		3117 - 3242	3		60
		3242 - 3367	4		80
2	Micro-watershed size (sq. km)	0.39 – 14.58	4	18	72
		14.58 – 28.77	3		54
		28.77 – 42.96	2		36
		42.96 – 57.14	1		18
3	Slope (degree)	0 - 10	3	15	45
		10 - 20	2		30
		20 - 30	1		15
4	Drainage density (km/sq. km)	0 – 2.33	3	12	36
		2.33 – 4.66	2		24
		4.66 – 7.00	1		12
5	Soil (drainage)	Excessively drained	1	12	12
		Well drained	2		24
		Moderately drained	3		36
		Water body	4		48
6	Geomorphology	Denudational structural hills	1	10	10
		Denudational hills	2		20
		Piedmont zone	3		30
		Residual hills	4		40
		Pediplain	5		50
		Plateau	6		60
		Alluvial plain	7		70
		Coastal plain	8		80
		Marshy land	9		90
		Water body	10		100
7	Land Use/Land Cover (LU/LC)	Forest	1	8	8
		Plantation	2		16
		Mixed vegetation	3		24
		Open area	4		32
		Built up	5		40
		Water body	6		48
8	Roads per Micro watershed (Nos.)	0 – 38	1	5	5
		38 – 77	2		10
		77 – 116	3		15
		116 – 155	4		20