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# Flood hazard assessment of Vamanapuram River Basin, Kerala, India: An approach using Remote Sensing & GIS techniques

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**ABSTRACT**

*In recent years humans have endured increasing number of natural disasters, of which flood is the greatest and most common throughout the world. Flood plains are thickly populated because of their economic significance. The present study area, Vamanapuram River basin in Kerala State, India presents a challenge in terms of repeated flash flood hazard in some parts. The present study aims to prepare Flood hazard risk zone maps of Vamanapuram River basin based on multi criteria assessment using remote sensing and GIS tools. Present study is limited to factors such as rainfall distribution, drainage density, land use, soil type, size of micro watershed, slope, and roads per micro watershed, to prepare Flood hazard risk zone map. The thematic maps of these factors are prepared using ArcGIS and ERDAS Imagine tools. By giving ranks and weights to these thematic maps, the weightage maps are created. In this study Weighted Overlay Analysis method is adopted to prepare the Flood hazard risk zone map. The hazard map thus prepared will show the total areas subjected to the hazards, as very low, low, moderate, high and very high risk zones. By preparing the risk zone maps, we can propose measures to reduce the risk of these hazards in Vamanapuram River Basin.*

**Key words**: Flood hazard Risk zone map, Multi Criteria Assessment, GIS, Weighted Overlay Analysis

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## INTRODUCTION

Hazard is the probability of the occurrence of a potentially damaging phenomenon within a given period of time and space (Varnes, 1984). Flood hazard is the chance that a flood event of a certain magnitude will occur in a given area within a given period of time. Flood hazard mapping is a vital component for appropriate land use planning in flood-prone areas. It creates easily-read, rapidly accessible charts and maps which facilitates the administrators and planners to identify areas of risk and prioritize their mitigation efforts. Floods are probably the most recurring, widespread, disastrous and frequent natural hazards of the world. Large parts of the world are subjected to one or more natural hazards, such as earthquakes, tsunamis, landslides, tropical storms (hurricanes, cyclones, and typhoons), coastal inundation, and flooding; although, many regions are also susceptible to artificial hazards (Li.,et al. 2012). India, a country with diverse hypsographic and climatic conditions, 85 percent of the land area is vulnerable to number of natural hazards and 22 States are categorized as multi hazards States. India is one of the worst flood affected countries, being second in the world and accounts for one fifth of global death count due to floods. India receives 75% of rains during the monsoon season (June – September). As a result almost all the rivers are flooded during this time resulting in sediment deposition, drainage congestion, invading into the main land. More than 8 million hectares of land in India are annually affected by floods. This means that nearly 32 million Indians experience the disasters associated with deluge. According to a Central Water Commission Report, nearly 37 million hectares (nearly 1/8th of India's geographical area) of fertile land are prone to floods at one time or another during the monsoon (Valdiya, 2004).

Although the Kerala state does not experience floods as severe as in the Indo-Gangetic plains, incidence of floods in the State is becoming more frequent and severe. Continuous occurrence of high intensity rainfall for a few days is the primary factor contributing to the extreme floods in the State. Other factors include wrong land use practices and mismanagement of the water resources and forests. The human interventions contributing to flood problems are predominantly in the form of reclamation of wetlands and water bodies, change in land use pattern, construction of dense networks of roads, establishment of more and more settlements, deforestation in the upper catchments etc. Increasing floodplain occupancy results in increasing flood damages. Urban floods result from blocked or inadequate storm sewers and due to increased urbanization. A number of extreme flood events occurred during the last century causing considerable damage to life and property highlight the necessity for proper flood management measures in the State. The flood problems are likely to worsen with the continued floodplain occupancy and reclamation of water bodies and wetlands. It is estimated that about 25% of the total geographical area accommodating about 18% of the total population of the State is prone to floods. Many parts within the present study area, Vamanapuram River basin experiences flash floods or had one in the past rainy season. The short duration intense rainfall, insufficient drainage etc. create conditions leading to flood. Flood proofing and identifying the flood prone areas are more important in managing the flood. Moreover most of the landscape diversity seen in Kerala is found in the Vamanapuram basin; hence a study in this basin will therefore help understanding the problems faced by the state.

Rachna and Joisy (2009) prepared flood hazard map of Vamanapuram River basin, a number of contributing factors including annual rainfall, size of watershed, slope of watershed, gradient of river and stream, drainage density, type of soil, land use, communication line and infrastructures were considered for rating the degree of hazard by means of weighting. Surjit and Kaushik (2012) assessed the risk and vulnerability of flood hazard in Ghaggar basin, India using GIS. The study attempted to propose a Flood Risk Index (FRI), based on factors such as hydrology, slope, soil type, drainage density, landform and land use. Tamilenthi, et al. (2011), Chiadikobi, et al. (2011), Ogah, et al. (2013), and Punithavathi, et al. (2011) also conducted studies on Flood Risk assessment or Flood hazard zonation based on various criteria.

Present study is an efficient methodology to accurately delineate Flood Hazards Risk Zones in Vamanapuram River Basin, using Geographic Information System and Remote Sensing techniques to derive a Hazard risk zone map, which can be used as base map for reallocation of facilities and infrastructure, formulation of plans for future expansion and emergency planning.

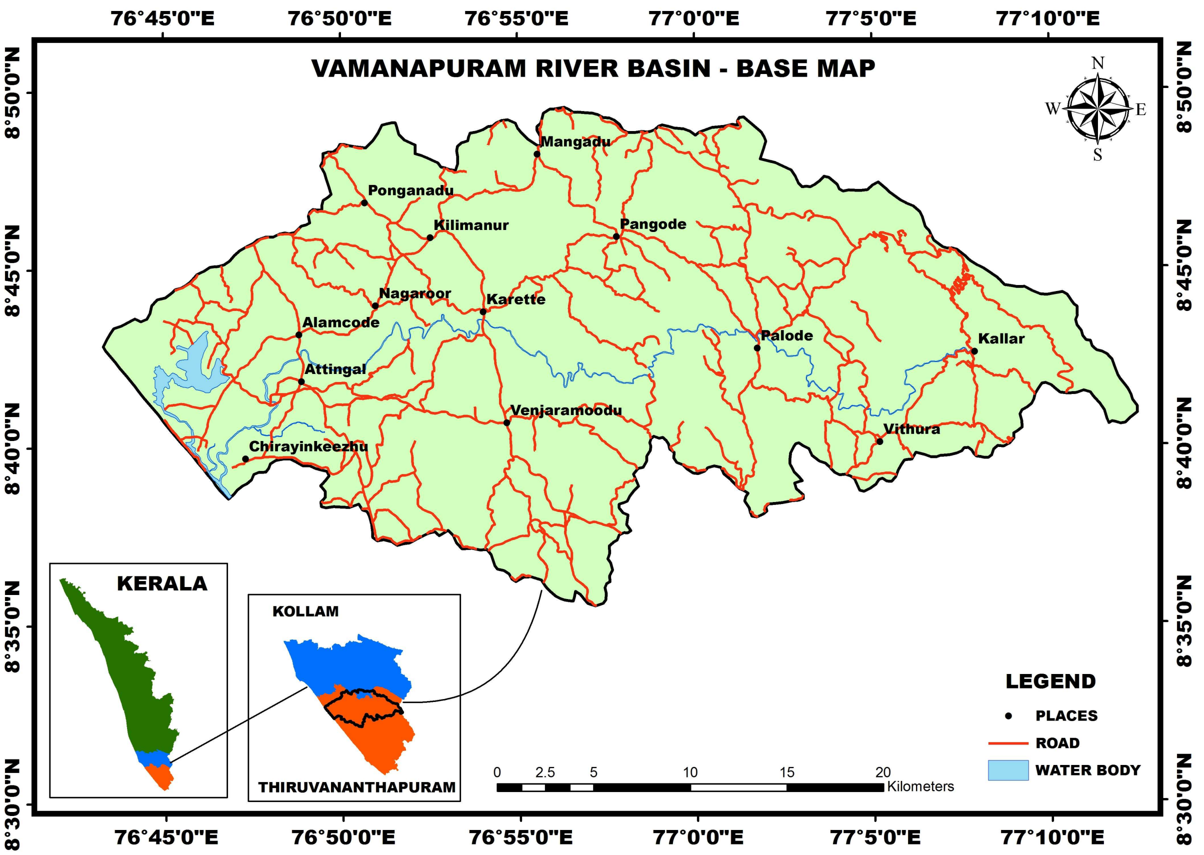


**Figure 1: Map showing the study area.**

**Study Area**
The Vamanapuram river basin with a catchment area of 787 sq. km. is located mainly in Thiruvananthapuram district and a small part falls in Kollam district of Kerala state. Vamanapuram River Basin is bounded by latitudes of 8˚ 35’ 24’’ N and 8˚ 49’ 13’’ N and longitudes of 76˚44’ 24’’ E and 77˚12’ 45’’ E. The Vamanapuram River Basin is bounded by Nedumangad Taluk of Thiruvananthapuram district in the South, Kottarakkara Taluk of Kollam districts in the North, Tamil Nadu in the East and Arabian Sea in the West. The area forms part of the midland terrain of the state, characterized by lateritic uplands with undulating topography and intermittent valleys. The altitudes vary from 40m in the northwestern parts to about 300m in the eastern and south-eastern parts. The river Vamanapuram is a major river in South Kerala with its network of tributaries. The trunk stream originates from the foothills of the Ponmudi hills (1074 m above msl) and the tributaries from the surrounding hills like Kallar. The river then flows onwards through Vamanpuram town and two-branch stream join at Attaramoodu where the main stream is called Kilimanur River. From there the master stream flows onward and joins the Kadinamkulam backwater at the northern most extremity. It debouches into the Arabian Sea at Mudalapallipozhi near Perumathura, 25 km north of Thiruvananthapuram city. The two tributaries of this river are the Upper Chittar & Manjaprayar streams. The major portion of the Vamanapuram River flows through midland terrain and the remaining through highlands and lowlands areas.

## MATERIALS AND METHODS

For the present study, the relevant maps were created using ArcGIS 9.3 and ERDAS Imagine 9.1 software tools. Satellite imagery was used as primary data source. The study area comprising Vamanapuram River Basin was delineated from Survey of India Topographic maps of scale 1:50000, numbered 58 D/10, 58 D/13, 58 D/14, 58 H/1, and 58 H/2. The micro watersheds, roads, water body, and drainage were digitized from SOI toposheets. The soil map was prepared by digitizing the Kerala State Land use Board (KSLUB) soil map. The rainfall distribution map was prepared from Indian Meteorological Department (IMD) data. The land use/land cover map was extracted from LANDSAT ETM+ satellite image and the data was classified using ERDAS Imagine 9.1 software. The contour map at 20 m interval was prepared from the NASA SRTM data, which in turn was used to prepare DEM and slope map. The Google Earth was used to modify the road network.

The present study was conducted using Multi criteria evaluation methods. A personal geodatabase was created in Arc Catalog and dataset was created for the Study area with the spatial reference of GCS_WGS_1984. Important places, Road, Streams, Water body, Soil, and Micro Watershed were digitized using ArcGIS tools. The thematic maps of Rainfall distribution, micro watershed size, slope drainage density, soil type, land use land cover, and Roads/micro watershed were prepared using Equal Interval Method in ArcGIS software by assigning weightage for each class. After digitizing and plotting the maps, the rank of each factor was given on the basis of its estimated significance in causing flooding. The data layers have been integrated in GIS environment by Weighted Overlay Analysis using Raster calculator.

## RESULTS AND DISCUSSION

**Drainage density**
Drainage is an important ecosystem controlling the hazards as its densities denote the nature of the soil and its geotechnical properties (Pareta, 2004). The first step in the quantitative hazard analysis is designation of stream order. The stream ordering systems was first advocated by Horton (1945), but Strahler (1964) has proposed this ordering system with some modifications. The Stream ordering in the present study area was done using the method proposed by Strahler (1964). Streams up to $6^{th}$ order were noted in this basin. There are 22 fourth orders, 78 third orders, 343 second orders and 1478 first orders present in this basin. In this basin, the drainage pattern noted was dendritic type. Drainage density map could be derived from the drainage map. i.e., Drainage map is overlaid on watershed map to find out the ratio of total length of watershed to total area of watershed and it is categorized. The drainage density of the watershed is calculated as: **Dd = L/A**; Where, Dd = drainage density of watershed, L = Total length of drainage channel in watershed (km), A = Total area of watershed ($km^2$). Drainage density is an inverse function of infiltration. The less the infiltration of rainfall, which conversely tends to be concentrated in surface run-off. High drainage density values are favourable for runoff, and hence indicate low flood chance. A watershed with adequate drainage should have a drainage density ≥5 whilst the moderate and the poor ones have drainage density classes 1-5 and <1 respectively (Chankao, 1982). Higher weights are assigned to poor drainage density area and lower weights were assigned to areas with adequate drainage. The weighted drainage density map was created by assigning weights (Table. 1) to each class using ArcGIS spatial analyst tools. The prepared drainage density map is shown in Fig. 2.

**Table 1: Table showing the drainage density weight details**

| Class | Drainage Density | Weight |
|---|---|---|
| 1 | >5 | 2 |
| 2 | 3 - 5 | 4 |
| 3 | 1 - 3 | 6 |
| 4 | <1 | 8 |

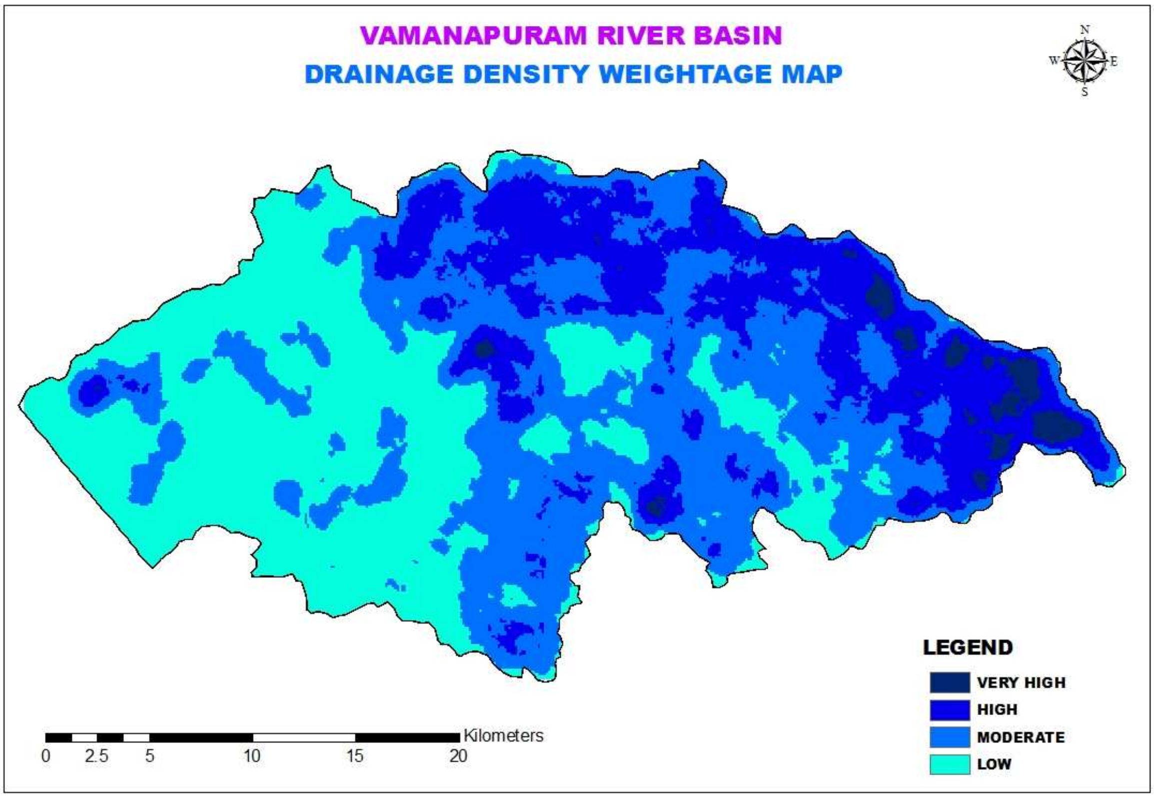


**Figure 2: Map showing the weighted drainage density**

## Land Use Land Cover (LULC)

The land use and management of the area is also one of the primary concerns because this is one factor which not only reflects the current use of the land, pattern and type of its use but also the importance of its use in relation to the living population and its relationship with the existing development. The vegetation cover of soils, whether that is permanent grassland or the cover of other crops, has an important impact on the ability of the soil to act as a water store. Runoff of rainwater is much more likely on bare fields than those with a good crop cover. The presence of thick vegetative cover slows the journey of water from sky to soil and reduces the amount of runoff. Impermeable surfaces such as concrete, absorbs almost no water at all. The land use land cover classes of the study area were prepared from Landsat 7 (ETM+) data. A supervised classification method was adopted using ERDAS Imagine 9.1 software and later analysed using ArcGIS spatial analyst tools. Land use classes in the area include: Built Up, Mixed Vegetation, Forest, Plantations, and Water Body. Land use types were grouped into different categories, weight is assigned to each class as shown in Table. 2. The prepared land use map is shown in Fig. 3.

**Table 2**: **Table showing the land use weight details**

| Class | Land Use Type | Weight |
|---|---|---|
| 1 | Water Body | 8 |
| 2 | Mixed Vegetation | 6 |
| 3 | Built up | 5 |
| 4 | Plantation | 4 |
| 5 | Forest | 2 |

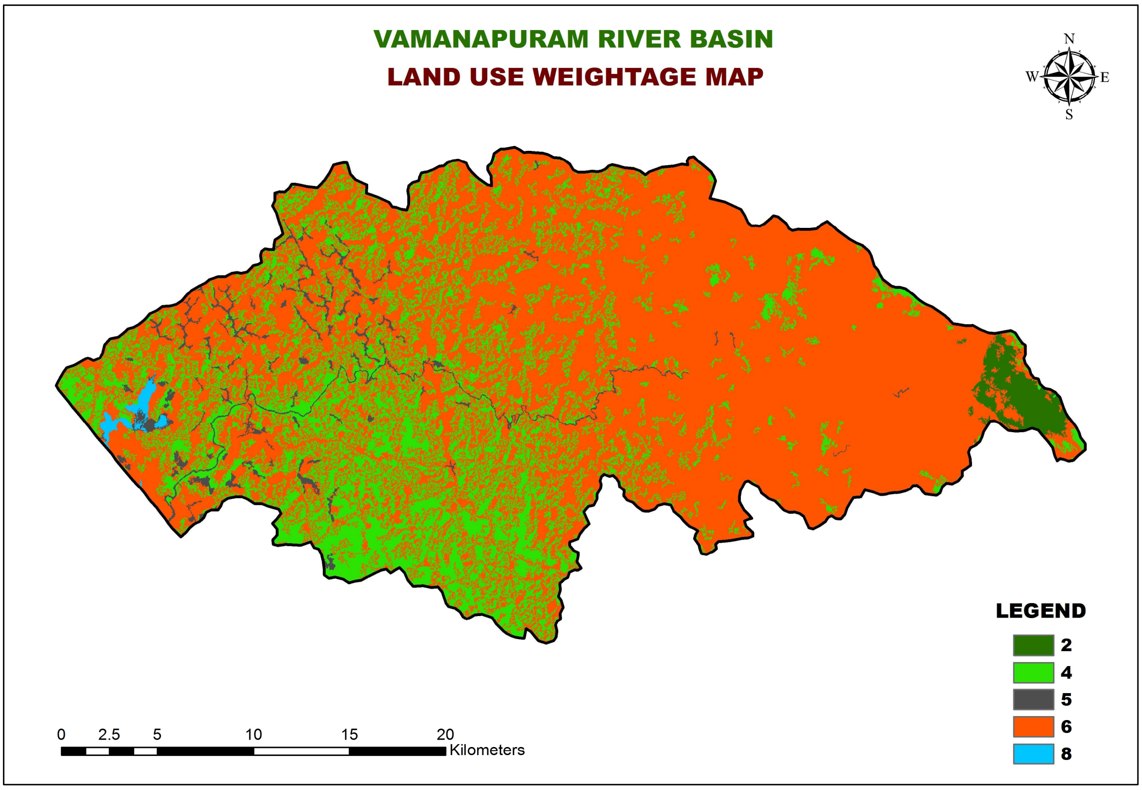


**Figure 3: Map showing the weighted land use**

## Soil type

The soil types in an area is important as they control the amount of water that can infiltrate into the soil, and hence the amount of water which becomes flow (Nicholls & Wong, 1990). Soil map was classified on the basis of infiltration capacity. On the basis of infiltration capacity, the soil types found in the basin include; highly infiltrated, moderately infiltrated, and less infiltrated. The structure and infiltration capacity of soils will also have an important impact on the efficiency of the soil to act as a sponge and soak up water. Different types of soils have differing capacities. The chance of Flood hazard increases with decrease in soil infiltration capacity, which causes increase in surface runoff. When water is supplied at a rate that exceeds the soil's infiltration capacity, it moves down slope as runoff on sloping land, and can lead to flooding (Lowery, et al, 1996). The weighted soil map was prepared by assigning weights to each soil classes as shown in Table 3. The prepared soil map is shown in Fig. 4.

**Table 3: Table showing the soil weight details**

| Class | Soil Type | Weight |
|---|---|---|
| 1 | High Infiltration | 4 |
| 2 | Moderate Infiltration | 6 |
| 3 | Low Infiltration | 8 |

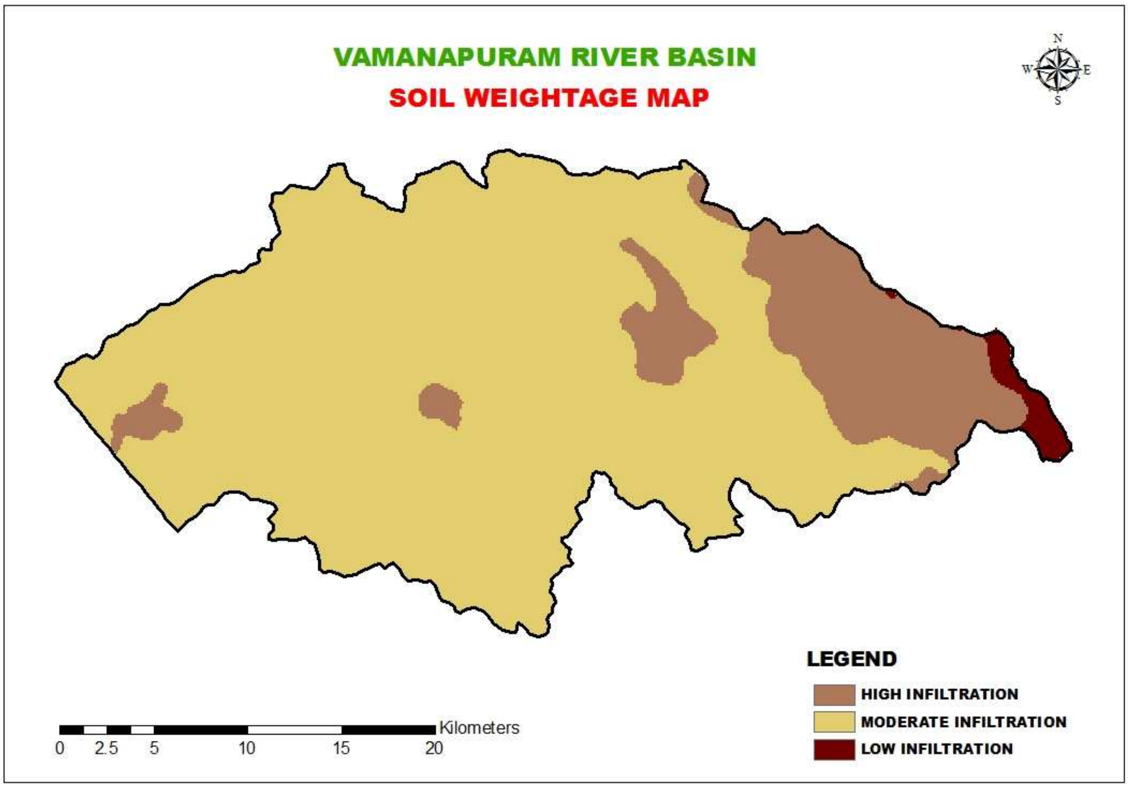


**Figure 4: Map showing the weighted soil type**

## Size of Micro-Watershed

Micro watersheds with larger drainage areas require runoff of longer duration for a significant increase in water level to become a flood. Therefore the micro watersheds with smaller area (size) are greatly affected by floods. Micro watersheds were delineated from the toposheet on the water divide basis. These were digitized and size of each watershed was computed, and the maps were prepared by classifying Micro watershed on the basis of size. The Size of micro watershed ranges from <1 to >44 sq. km. Weights are assigned as shown in Table 4. The prepared micro watershed size map is shown in Fig. 5.

**Table 4**: **Table showing the micro watershed (size) weight details**

| Class | Micro Watershed Size (Sq. Km) | Weight |
|---|---|---|
| 1 | 0 - 5 | 8 |
| 2 | 5 - 10 | 6 |
| 3 | 10 - 20 | 4 |
| 4 | 20 And Above | 2 |

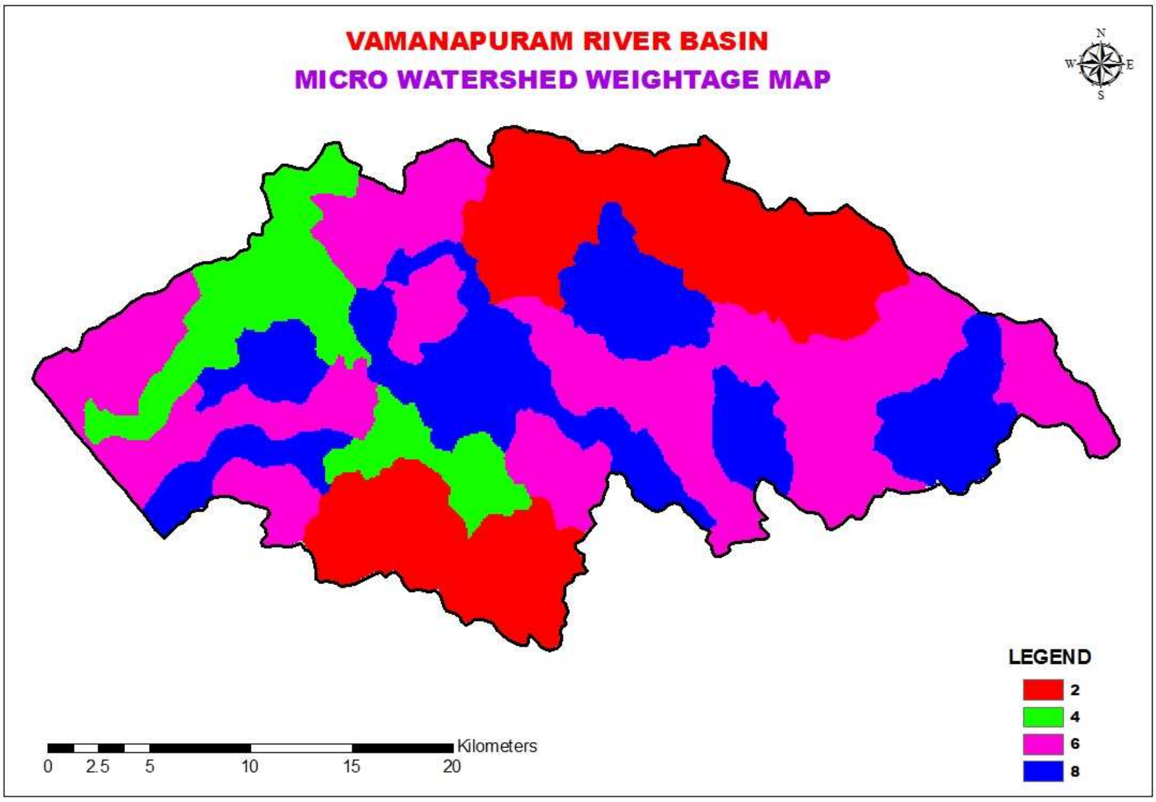


**Figure 5: Map showing the weighted micro watershed**

## Rainfall Distribution

Heavy rainfalls are one of the major causes of floods**.** Floods are associated with extremes in rainfall, any water that cannot immediately seep into the ground flows down slope as runoff. The amount of runoff is related to the amount of rain a region experiences. The level of water in rivers or lakes rises due to heavy rain falls. When the level of water rises above the river banks or dams, the water starts overflowing, this causes floods (Nicholls, 2001). The water overflows to the areas adjoining to the rivers, lakes or dams, causing floods or deluge. The flood water causes havoc and great destruction in the areas where it flows. There are 3 rain gauge stations in the catchment area. They are Braemore Estate, Valayinkil, and Varkala (Table. 5). The rainfall distribution map was prepared from the IMD data by Inverse Distance Weighted method using ArcGIS spatial analyst tool.

**Table 5**: **Table showing the Rainfall distribution details**

| Sl. No: | Station Name | Average Annual Rainfall (mm) (1996 – 2010) |
|---|---|---|
| 1 | Varkala | 1452 |
| 2 | Valayinkil | 3124.20 |
| 3 | Braemore Estate | 3809.60 |

**Table 6**: **Table showing the Rainfall distribution weight details**

| Class | Average Annual Rainfall (mm) | Weight |
|---|---|---|
| 1 | >3500 | 8 |
| 2 | 3000 - 3500 | 6 |
| 3 | 2500 - 3000 | 4 |
| 4 | <2500 | 2 |

Flooding occurs most commonly from heavy rainfall when natural watercourses do not have the capacity to convey excess water. The present study area is characterized by hot tropical, wet climate. The southwest monsoon, from June to September is the principal rainy season. The second rainy season is the north-east monsoon from October to November. The area also gets thunderstorm rains in the pre-monsoon months of April and May. The average annual rainfall is about 1500 mm. The highest rainfall is recorded at Ponmudi, located in the south east border of this basin. Due to non availability of the daily rainfall data for such a long period (1996-2010), average annual rainfall values were used for the study. Weights are assigned to each class of average rainfall map as shown in Table. 6. The prepared rainfall distribution map is shown in Fig. 6.

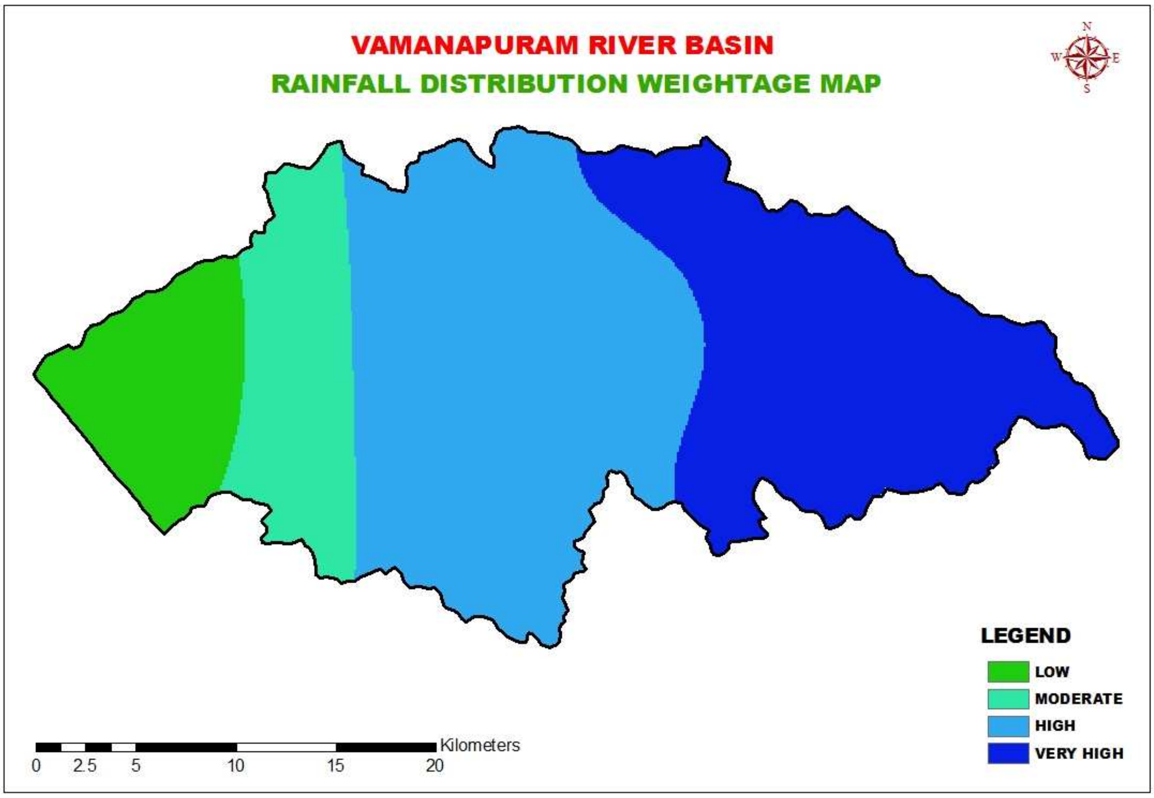


**Figure 6: Map showing the weighted rainfall distribution**

## Slope

Slope and height play an important role in governing the stability of a terrain. The slope influences the direction of and amount of surface runoff or subsurface drainage reaching a site (Dai, et al., 2002). The slope map was prepared using the DEM and slope generation tools in ArcGIS software. DEM is a digital representation of ground surface topography or terrain (Forkuo 2012). The use of DEM to observe topographic attributes, such as slope aspect and steepness allows researchers to comprehensively examine the variables affecting a hazard in a study area (Sawyer et al., 2004). Slope has a dominant effect on the contribution of rainfall to stream flow. It controls the duration of overland flow, infiltration and subsurface flow. Combination of the slope angles basically defines the form of the slope and its relationship with the lithology, structure, type of soil, and the drainage. A smooth/flat surface that allows the water to flow quickly is not desirable and causes flooding, whereas a higher surface roughness can slow down the flood response and is desirable (Krumbien, 1965). Steeper slopes are more susceptible to surface runoff, while flat terrains are susceptible to water logging. Slope angle of watershed ranges from 0 to >70, weights are assigned as shown in Table. 7. Class having less value was assigned higher rank due to almost flat terrain while the class having maximum value was categorized as lower rank due to relatively high run-off. The prepared slope map is shown in Fig. 7.

**Table 7: Table showing the slope weight details**

| Class | Slope (Degrees) | Weight |
|---|---|---|
| 1 | 0 - 20 | 8 |
| 2 | 20 - 40 | 6 |
| 3 | 40 - 60 | 4 |

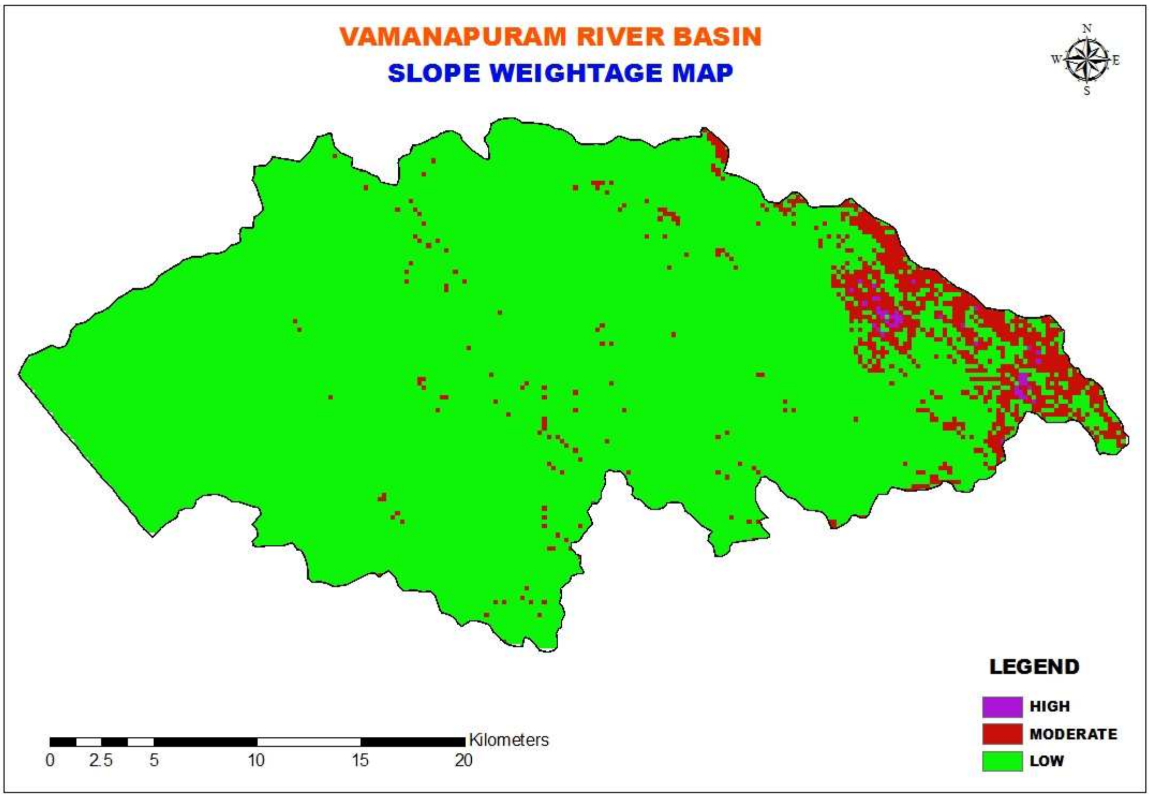


**Figure 7: Map showing the weighted slope**

## Roads per Micro Watershed

Road is one of the important anthropogenic factors inducing flood hazard, a road map was generated, with metalled, un-metalled roads and tracks (footpath) of the study area. It was observed that the roads were very well identified on the scanned image. All the roads were mapped initially from the toposheets and modified using the Google Earth data in vector form. After converting it to shape file, the road map was generated in Arc map. The roads per micro watershed map was derived when road network map was overlaid on micro watershed. The purpose of this map is to find the obstructions caused by the constructions of roads, which disturbs the free flow of water. Obstructions caused by the construction of structures in the ways of floodwaters, considerably impede the free flow of rivers (Valdiya, 2004). Roads, bridges, etc in the watershed restrict the passage of flood discharge. Roads and infrastructures which cover much of the land surface have less capacity to store rainfall and snowmelt (Konrad, 2003). Construction of roads and buildings often involves removing vegetation, soil, and depressions from the land surface. The permeable soil is replaced by impermeable surfaces such as roads, bridges, railway tracks, etc that store little water, reduce infiltration of water into the ground and accelerate runoff. The Number of Roads per Micro Watershed ranges from 0 to 43. Weights are assigned as shown in Table. 8. The prepared Roads per watershed map is shown in Fig. 8.

**Table 8**: **Table showing the Roads per watershed map weight details**

| Class | No: Of Roads Per Micro Watershed Map | Weight |
|---|---|---|
| 1 | 0 - 10 | 2 |
| 2 | 10 - 20 | 4 |
| 3 | 20 - 30 | 6 |
| 4 | 30 And Above | 8 |

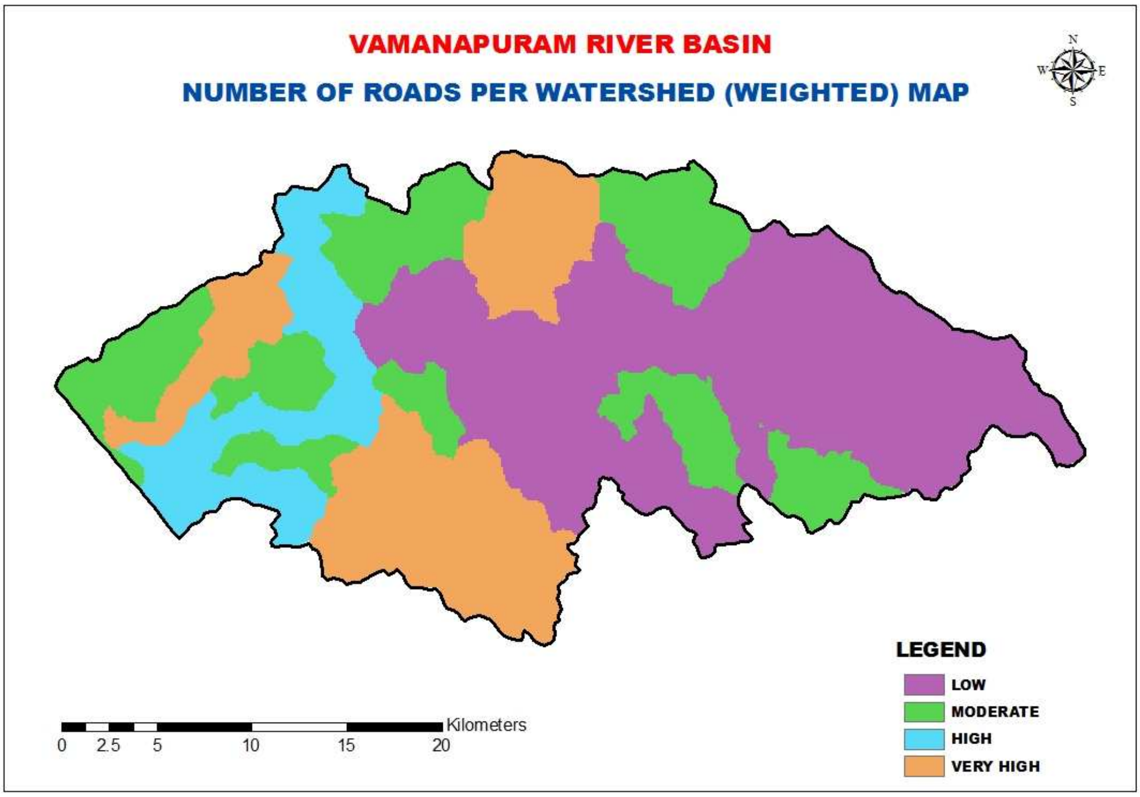


**Figure 8: Map showing the weighted roads per micro watershed**

## Flood Hazard Risk Zone

The net probability of occurrence of flooding in each flood hazard zone is estimated from the total sum of the weight of each contributing factor considered. To obtain this total sum weight, all of contributing factor maps was overlaid. The total weight for estimating the probability of flooding in a particular flood hazard zone = the sum of every contributing factor (Pramojanee, et al, 1997). GIS allows the decision maker to identify a list meeting a predefined set of criteria with the overlay process (Heywood et al., 1993). All of these processes, the compilation of contributing factor maps, the overlaying of all maps and the calculation of hazard areas were obtained by using Raster Calculator in ArcGIS Spatial Analyst tool. The factors which contribute to the floods are given in the Table. 9. The flood hazard map was prepared by giving suitable ranks (7 being highest; 1 being lowest) to these contributing factors and the prepared map is shown in Fig. 9.

**Table 9**: **Table showing the Contributing factors to flood**

| Sl. No. | Contributing Factors | Rank |
|---|---|---|
| 1 | Rainfall Distribution | 7 |
| 2 | Size of Micro Watershed | 6 |
| 3 | Slope | 5 |
| 4 | Drainage Density | 4 |
| 5 | Land Use Land Cover type | 3 |
| 6 | Soil type | 2 |
| 7 | Roads Per Micro watershed | 1 |

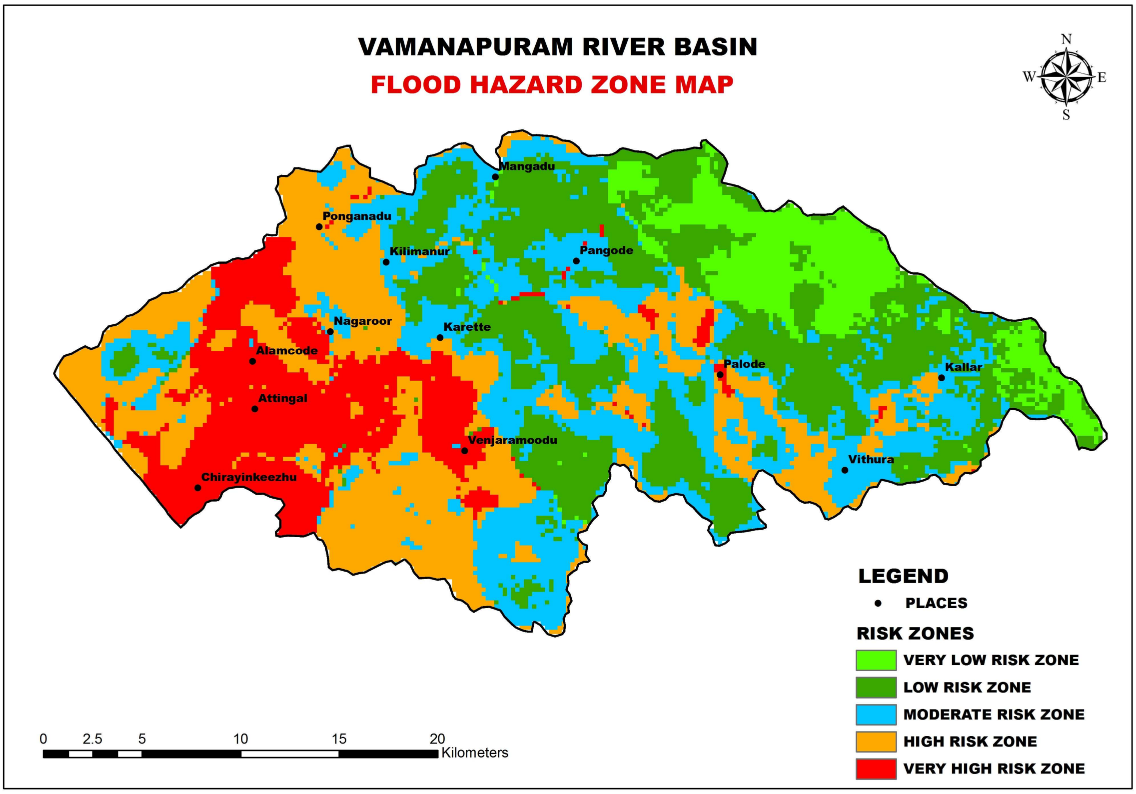


**Figure 9: Map showing the Flood hazard risk zones**

## CONCLUSION

GIS techniques and analysis are valuable tools for various fields. This has been used for mapping, modelling and analysis of variety of applications in disaster management at various levels and scales. Floods are natural phenomena which cannot be prevented. However, human activity is contributing to an increase in the likelihood and adverse impacts of extreme flood events. Firstly, the scale and frequency of floods are likely to increase due to climate change, which will bring higher intensity of rainfall and rising sea levels as well as to inappropriate river management and construction in flood plains which reduces their capacity to absorb flood waters. Secondly, the number of people and economic assets located in flood risk zones continues to grow. The present study shows a simple and cost effective way of using geographical information system for creating flood hazard map from the available data base. In this study, an attempt has been made to prepare flood hazard map using ArcGIS and ERDAS Imagine software tools. Using the flood hazard map, flood prone areas can be identified, which will assist in appropriate planning of development works.

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