

Flood Inundation Mapping of Harangi River Basin, Kodagu, Using GIS Techniques and HEC-RAS Model



M. R. Devanand and Subrahmanya Kundapura

Abstract Flood is the most common hydrologic event frequently experienced in India. The states of Kerala, UP, West Bengal, Karnataka and Assam were the mainly affected by flood in 2018. In Kodagu, the southern district of Karnataka, many people have been affected by heavy rains. Landslides in hilly terrain and flooding have worsened the lives of people and led to the destruction of 800 homes, 240 bridges collapsed, road networks of 2225 km damaged and 65 government buildings affected. The cost of rebuilding road infrastructure and buildings is approximately Rs. 3000 crores. While developing flood mitigation measures, flood inundation maps are an essential component, which will be useful for the planning stage. The mapping is expected to estimate the prone flood zone based on river flood stage without performing additional simulations and quantification of the flood risk with respect to different vulnerability parameters giving a clear picture of the planning stage. These are going to be achieved by both 1D hydrodynamic models and GIS environment. This study gives an insight about how unscientific development activities may increase the negative impacts of natural disasters. It can support the planners to correctly identify the non-vulnerable places while rebuilding the damaged infrastructure. This can help people to resettle permanently in a safer place, so that they will not be affected in the case of future disasters. Depending on the severity of the water levels, we can identify the area for construction of hydraulic structures for flood protection.

Keywords Hydrodynamic · Flood risk · Flood inundation

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1 Introduction

Flood is an overflow of a huge amount of water above its normal limits, generally over dry area. In central India, large-scale floods have been caused by climate change. Due to temperature variations in the Arabian Sea, an increase in the changes of the monsoon westerly winds has caused the rising number of extreme rain events especially in the southern region. The rainfall distribution in India is not uniform with respect to both time and space. The area which is getting inundated due to floods every year is about 4,00,000 km² provided by the flood statistics of India. Due to the heavy rains of high intensity, rivers may not be able to carry the excessive runoff which is caused by the rapid land use changes, encroachment and sedimentation. While developing flood mitigation measures, flood inundation maps are an essential component especially for non-structural measures. It is noticed that the reservoirs located upstream have a significant role in the flood happening in the downstream.

For hydrologic simulation, identification of the actual stream network in the river basin is obtained from the Google Earth images and should be georeferenced and mosaiced in ArcGIS software [1]. While performing flood inundation modeling, floods are prevented from entering the adjacent low lying areas caused by the presence of levees in the channel. Manning's *n*, which is an important parameter in hydraulic flood modeling, can extract along each cross-sectional cut line from satellite imagery [2]. A model is required to identify flood prone areas which can be used to predict spatially distributed estimates of the hydraulic variables such as flood inundated area extent and depth. For this purpose, one- and two-dimensional hydraulic models are used to compute water surface profiles in several different characterizations of the system [3].

In 2018, India has faced many flood events across the country. Kerala, UP, West Bengal, Karnataka and Assam are the states affected by flood. Kerala is the most affected in terms of lives lost, people displaced and property damaged. Disaster management division of the home ministry needs to get assess the events and take measures against it. Karnataka is also one of the most affected states. 161 people lost their lives and 3.5 lakh people got displaced with in the 11 districts.

In Kodagu, the southern district of Karnataka, many people have been affected by heavy rains. Landslides in hilly terrain and flooding have worsened the lives of people and led to the destruction of 800 homes, 240 bridges collapsed, road networks of 2225 km damaged and 65 government buildings affected. Cost of rebuilding road infrastructure and buildings is approximately Rs. 3000 crores. The affected regions are needed to be restored. Flood damage also includes psychological impacts and changes to natural ecosystem [4].

The planning for the infrastructure development should be at most care so that flood inundation mapping will be useful for the planning stage. The mapping is expected to approximate the prone flood zone based on river stage without performing additional simulations, and quantification of the flood risk with respect to different vulnerability parameters gives a clear picture to the planning stage.

So, Kodagu district of Karnataka has faced a flood event in month of August 2018. One of the river causes for the flood is Harangi. Flood inundation map has to be made for the Harangi River for identifying the flooded areas and damages estimation.

2 Study Area

The study area is Harangi River basin, which is located in Kodagu district (Fig. 1). Kodagu is one of the districts in the southern state of Karnataka which had hit by the southwest monsoon rains since June first week to till August 2018. Heavy rains lead to landslides and flooding across the district. The study area is in the Western Ghats mountain ranges; the heavy rain caused landslides across the area and made rescue operations difficult at that time, which increased the impact of damage. An overnight heavy rain at Madapur caused landslides and inundation of low-lying areas. Rescue teams had been deployed in Makkandur, besides Kalum and Devastur for that time. As many as 60 people were rescued from Mukkodlu, another badly hit region of the Kodagu.

The district comes between north latitude $11^{\circ} 56'$ to $12^{\circ} 56'$ and east longitude $75^{\circ} 22'$ to $76^{\circ} 11'$. It is having area of 4102 km^2 (Fig. 1). The district is covered by $134,597 \text{ ha}$ of forest area and comes with rich forest resources. In this district, the Harangi River basin extends from 76.50E to 76.0E in longitude and 12.660 – 12.1670 N latitude. The River Harangi IS going through Somwarpet and Madikeri taluks of Kodagu district and joins to River Kaveri. The watershed consist of five sub-basins, with an area of 442.746 km^2 and length of the basin is 345.4 km . The elevation of the basin ranges from maximum of 1636 – 824 m .

3 Objectives

- Relate the magnitude of extreme rainfall events to their probability of occurrence.
- Identification of the extent of flooding expected spatially over the area due to the extreme rainfall.

4 Methodology

The solutions for the two objectives are frequency analysis and flood inundation mapping. The primary step in designing engineering projects dealing with flood control, gully control, etc., is to find the probability of occurrence of a particular extreme rainfall. This information is determined by the frequency analysis of rainfall data. Frequency analysis estimates the chance of occurrence of an event over a specified period of time. There are different types of methods performing frequency

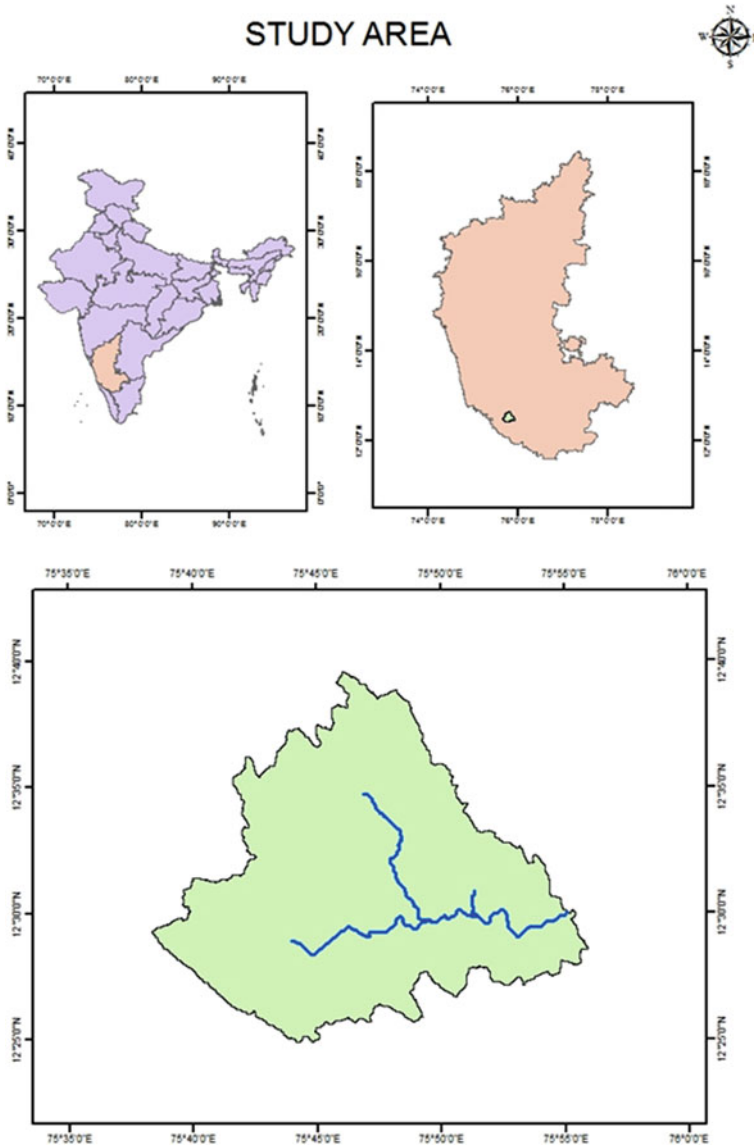


Fig. 1 Location of the study area (the Harangi River basin with stream network)

analysis. Before that, analyzing is important to obtain probability distribution. The terms return period and recurrence interval are used to denote the reciprocal of the annual probability of exceedance (Fig. 2).

HEC-RAS: The floodplain modeling techniques are categorized into three major groups of 1D, 2D and 3D models. 1D models are more appropriate for planning,

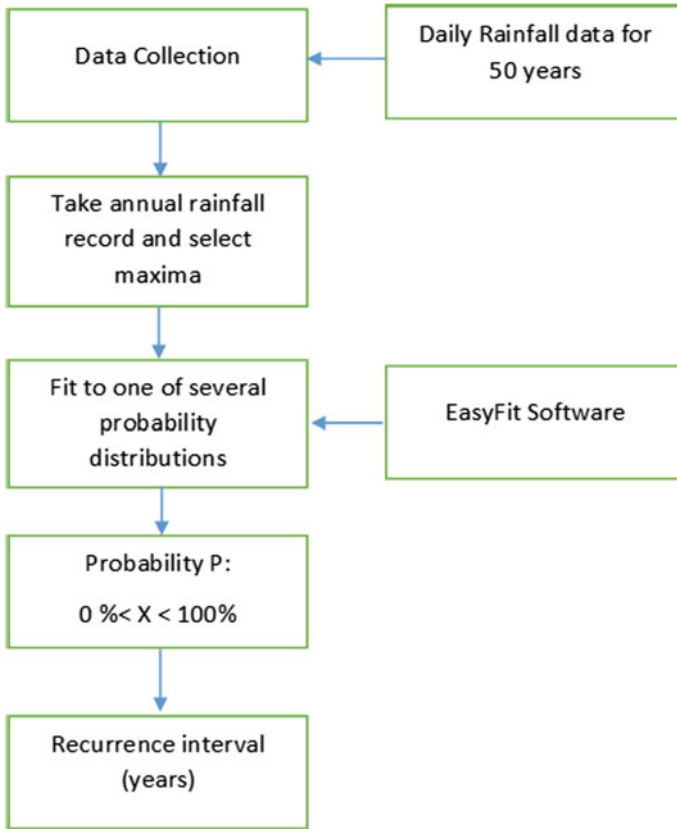


Fig. 2 Methodology for frequency analysis

management and flood protection purposes at big catchment and sub-catchment scales. The Hydrologic Engineering Center–River Analysis System (HEC-RAS) is a software package developed by the Hydrologic Engineering Center (HEC) of the USACE. It is dominantly used for 1D hydraulic modeling and one of the accepted hydraulics models for flood mapping. HEC-RAS is apt for performing 1D steady and unsteady flow hydraulic simulations on river channels and floodplains in a single river reach or a network of reaches [5]. Both historical data and newly measured information can be used for adopting the hydrological model parameters [6].

Field investigations and surveys should be performed before the development of the models for watershed. The main aim of this field study is relative to the stream channel geometry and structures [7]. HEC-RAS incorporates the data with geometry and generates solutions at the cross sections.

Thus, cross sections become the important part of the map. At least, two cross sections on each reach are required by a HEC-RAS model, which is generated from the TIN data.

Firstly, a conceptual model is stored as a series of coverages. Secondly, a numeric model is stored as a schematic of cross section which is organized into reaches. Watershed Modelling System (WMS) software involves with HEC-RAS using a HEC-GeoRAS geometry file containing the cross-sectional data in addition to three-dimensional georeferencing data. The conceptual model needs to be converted to a network schematic diagram for creating a geometry file in the river module. Modifications to this network schematic which can be used by HEC-RAS can be made directly in the river module or indirectly by editing the conceptual model in the map module and mapping to a new network schematic. Using the extracted cross-sectional data, the river is defined for running the simulation with the help of flow profile values.

HEC-RAS requires Manning's roughness values for the materials found in the cross-sectional database. The value is taken as 0.03 for this clean and straight river with no rifts or deep pools [8]. Considering the 'steady flow' simulation for the study because of the flow and boundary conditions are taken as constant.

HEC-RAS takes that energy is constant and that the velocity vector is perpendicular at every cross-sectional line. After establishing the geometry of the river, flow values for each reach within the river network are entered. The model inputs for the hydraulic computations can be adopted from the channel geometry and flow rate values. Run the simulation and view the results in WMS by importing the file as 2D scatter data (Fig. 3).

5 Results and Discussion

The 50-year daily rainfall data has been applied and given from Karnataka State Natural Disaster Monitoring Centre (KSNDMC) for performing the frequency analysis. The hydrologic data is used to associate the extent of extreme events to their frequency of occurrence using probability distributions. Selection of the observations from same population can be used to achieve the assumption of independence and identical distributions. Selecting the annual maximum of the variable being analyzed as the successive observations from year to year fulfills the assumption of independence. Time series plot of the 50-year daily rainfall data shows the variation of rainfall over the years (Fig. 4).

The results obtained from EasyFit 5.6 professional software, a goodness of fit testing software, show the best fitting probabilistic distribution. Weibull distribution has the better rank combination than other functions.

The return period (T) of the event is calculated by $T = 1/P$. Return period is calculated using the Weibull formula. The maximum annual rainfall versus the return period is plotted (Fig. 5). From the graph, the rainfall occurred in the monsoon 2018 has return period of 8.5 years.

SRTM 1 Arc—Second Global elevation data of resolution 30 m for the year 2014 was downloaded from USGS Earth Explorer. The study area is lying in two tiles of

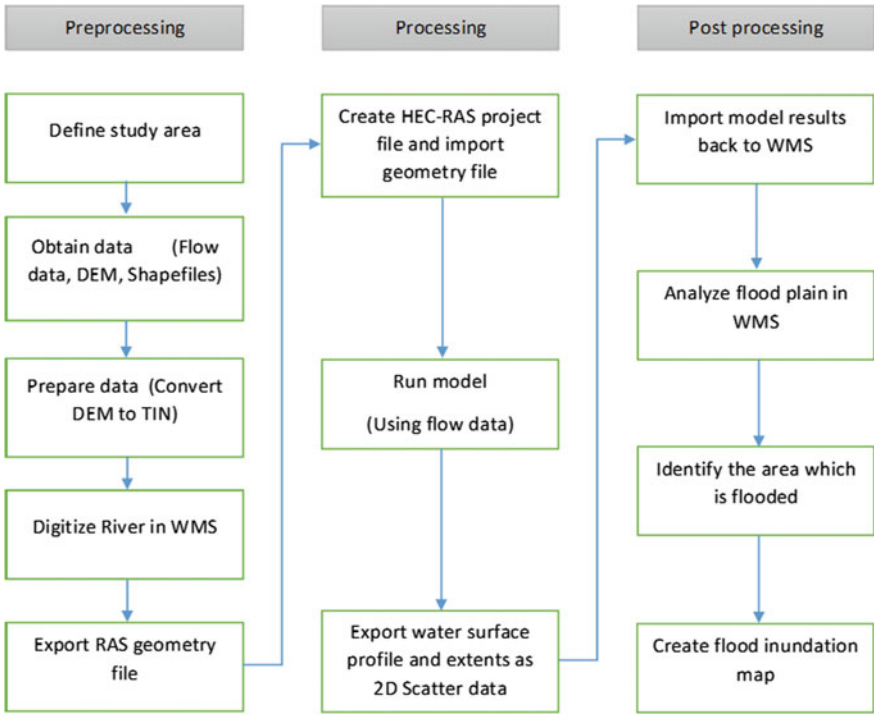


Fig. 3 Methodology for flood inundation mapping

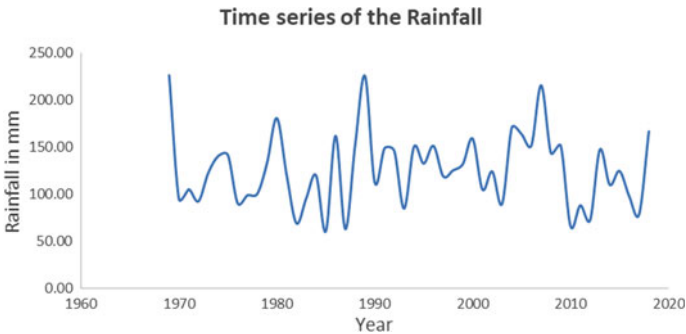


Fig. 4 Time series of the 50-year daily rainfall data

DEM, so that mosaic tool is used to merge the DEM and output is clipped using the basin shapefile of study area (Fig. 6).

Slope map is derived from DEM. The SRTM elevation data which was projected to UTM zone 43 N and subjected to a tool named ‘Slope’ in the ArcGIS toolbox. The output layer was then reclassified into five slope classes (Fig. 7).

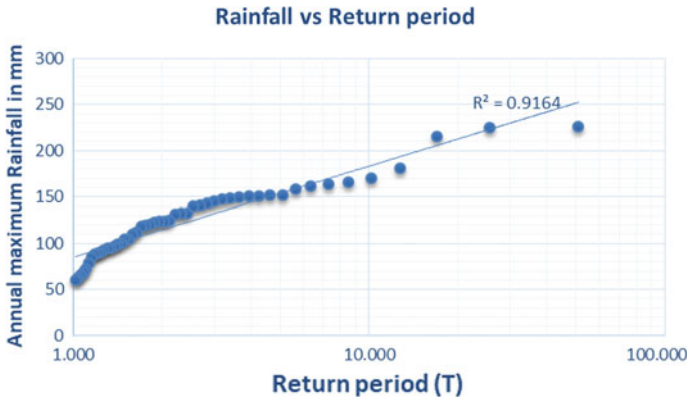


Fig. 5 Plot showing return period with rainfall values

LU/LC maps downloaded from SWAT Web site and Bhuvan Web site.

Bhuvan data set was much coarser than global land use data set, which obtained from SWAT Web site. The map is clipped and reclassified into nine classes using ArcGIS 10.3 tools (Fig. 8).

The soil map was obtained from National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) for the year 2003. The resolution of the map is 1:250,000 (Fig. 9). Soil is classified according to the hydrological soil group by using standard tables (TR55 manual). Here, the major portion of the area is coming under HSB C. Soil type C indicates the soil having slower infiltration and higher runoff potential.

The upstream reach of Harangi River was selected for finding the inundated extend. The delineated river stream had a length of 14.6 km. Figure 10 shows the location of the river reach from Harangi.

Channel is defined in WMS as coverage using the GIS layers obtained (Fig. 10). Channel cross section is extracted in WMS and imported in HEC-RAS. Channel parameters were specified in HEC-RAS model. The bed slope was entered (0.003 for upstream and 0.001) for downstream, and Manning's coefficients were set referring to Chow [8]. Flow profile was calculated with discharge 2205.88 cumec, which is the discharge measured on August 17, 2018. The model was run and expected to give conditions similar to the flood event. The model outputs were saved as shapefiles for further study.

Figure 11 shows the inundation map output from HEC-RAS model. HEC-RAS model is saved and imported in WMS to assess the flood extent. Then, the shapefile of inundated region overlaid on world topomap in WMS. Which is giving a better perception about the flood extent. Figure 11 shows the area consisting of vegetation and settlements covered under water.

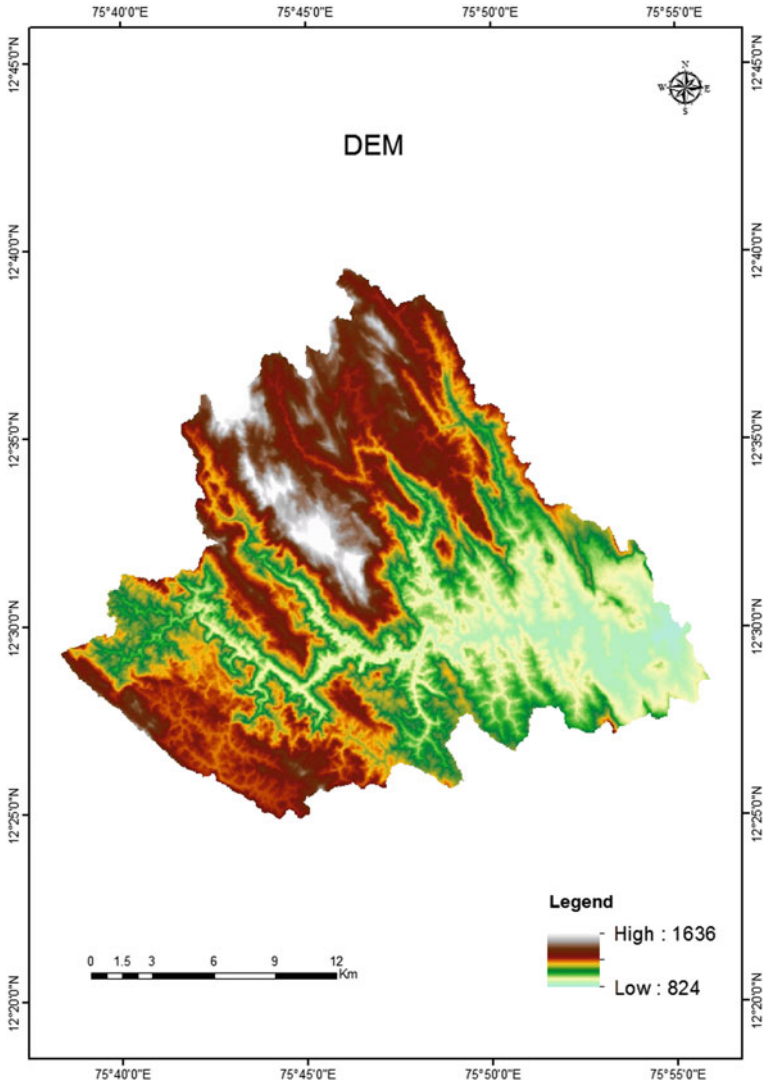


Fig. 6 DEM of the study area

6 Conclusion

Frequency analysis shows that this type of rainfall happened once in 8.5 years. Deforestation and unscientific development causes increased the impact this time. HEC-RAS was applied to a reach of 14.6 km of Harangi River. The model was fed with observed data of stream flow at Harangi gauging station. The HEC-RAS inundation model of the Harangi River reach showed that regions adjacent to the

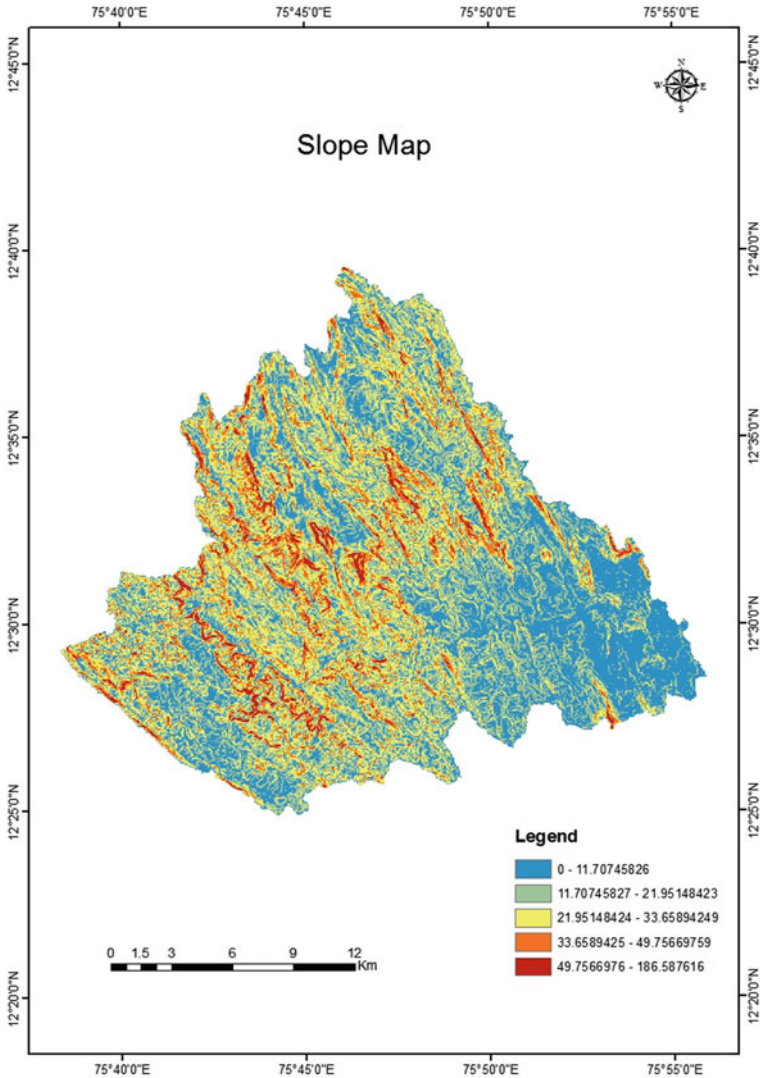


Fig. 7 Slope map of the study area

river are likely to get inundated during a flood event. This region is characterized by settlements and cultivation of crops. Based on the flood plain obtained, flood hazard mapping could be done for the same. It helps the planners to correctly identify the non-vulnerable places while rebuilding the infrastructure. Depending on the severity of the water levels, we can identify the area for construction of hydraulic structure.

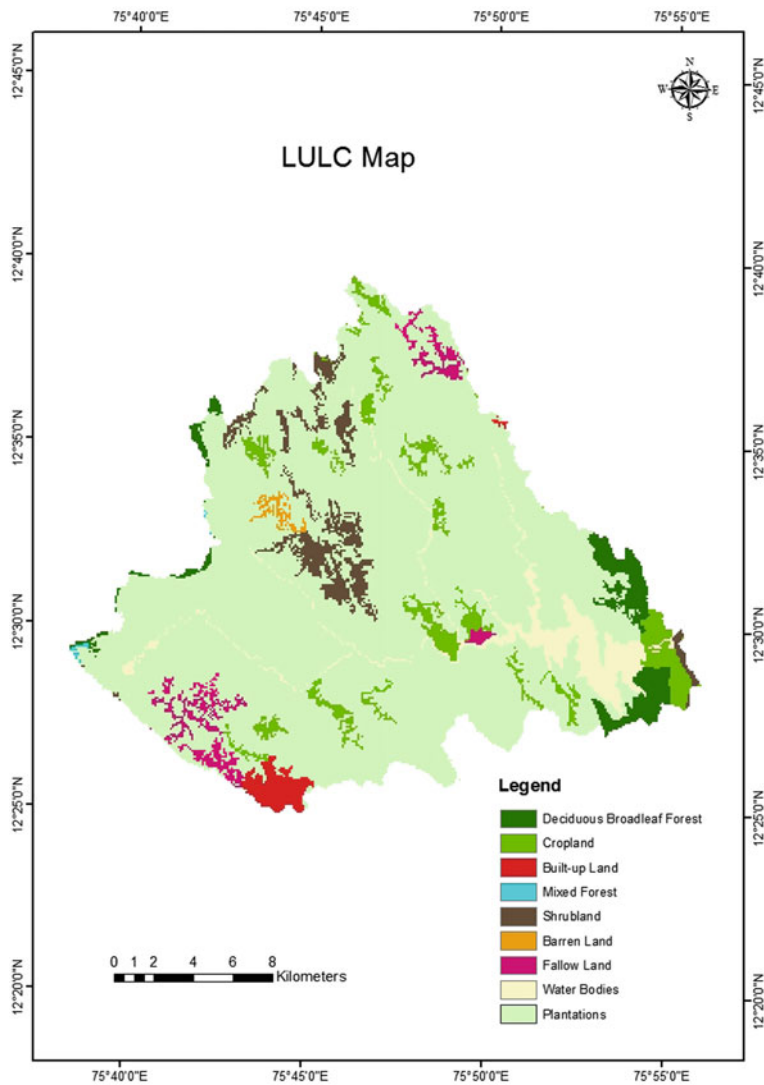


Fig. 8 LU/LC map of the study area

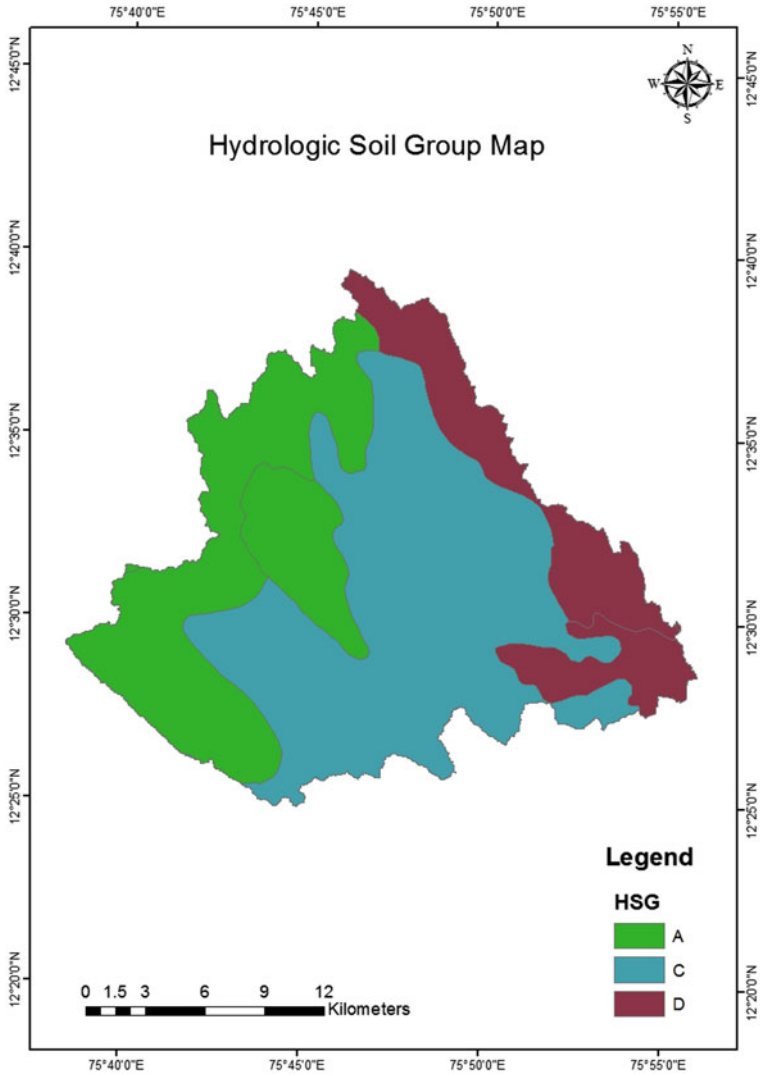


Fig. 9 Map showing HSGs in the study area

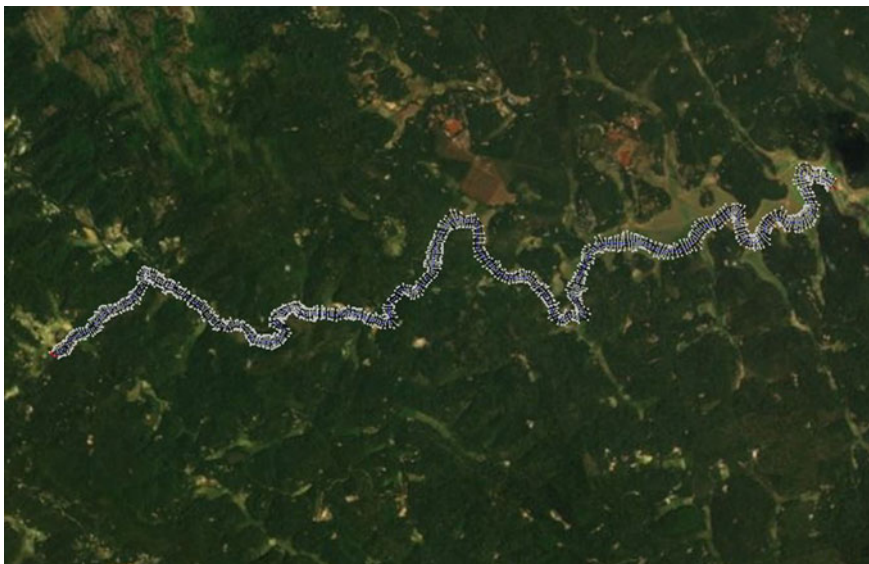


Fig. 10 Channel cross sections in WMS



Fig. 11 Inundated regions shown in WMS with world topomap

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