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Determination of peak flood discharge and flood prone areas using HEC HMS and HEC RAS

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Abstract

A flood is defined as any moderately highwater flow which overtops the artificial or natural banks. It is one of world's most destructive natural disaster. During extreme rainfall events; flood water flow from all valleys towards the city, causing serious damage to public and private properties. In such situations; we have to identify the areas which with high risk of flooding. This study aims to analyze the peak discharge in Killi river basin based on 2,5, 10- year return periods and used for the identification of flood prone areas and to adopt appropriate plans to control and reduce the effect of floods. For this both hydrologic and hydraulic modelling are conducted using HEC HMS and HEC RAS. Peak flood discharge is estimated using HEC HMS and flow depth, velocity, water surface level is also determined by using HEC RAS. Depth of water, velocity distribution and water surface height obtained after 2D flow simulation are utilized to decide the degree of flooding. RAS-mapper is an effective tool in HEC-RAS, which can be utilized for inundation of research area. For unsteady flow analysis, each time step was done based on inflow hydrograph using RAS mapper tool in HEC-RAS, which gives the spatial distribution of the river flow. The model performance evaluation of HEC HMS was carried out by using co efficient of determination R^2 AND NRMSE. The outcomes from this study can be utilized for disaster management, flood management, early warning system by authorities in addition to infrastructure growth decisions.

Keywords: Flood; Peak Discharge; Return Periods; HEC HMS; HEC RAS; Hydrograph

1. Introduction

Flood is one of the major natural disasters which affects many parts of the world including developed countries. Large scale flooding is a global phenomenon that causes widespread devastation, economic damage and loss of human lives. Floods are caused by rainfall and storms, glacial lake overflow floods, dam floods, floods caused by infrastructure failures, sheet floods, or floods in lowland areas caused by imposing barriers to flow. The flood estimation that involves the development of hydrologic models is one of the non-structural measures that may help to reduce the number of damages incurred. It is very necessary for the identification of possible inundated areas so that a timely warning can be issued to the people in the affected areas. Flood studies mostly use HEC HMS model for various hydrological simulations in watersheds. HEC HMS runs program for studying watershed physical descriptions, meteorology descriptions, and hydrologic simulations (USACE 2018). The HEC HMS model is used to determine the peak flood discharge of a watershed, so that the input data used is simpler than the HEC RAS model because it does not require river geometric data. The peak, or maximum, rate of flow for a watershed will usually occur after the period of maximum rainfall intensity and when most of the watershed is contributing runoff. Peak discharges can also be caused by the melting of accumulated snow or by a combination of rain and snow melt in certain climatological regions. Peak discharge is also referred to as peak rate of discharge or peak rate of runoff. It is usually referred to in units of cubic feet per second, or cfs. And the flood hydrograph obtained from the HEC HMS model is in cfs unit. In this study, hydrological modelling system (HEC HMS) and the centre for hydrological engineering river analysis (HEC RAS) is used. HEC HMS is used to

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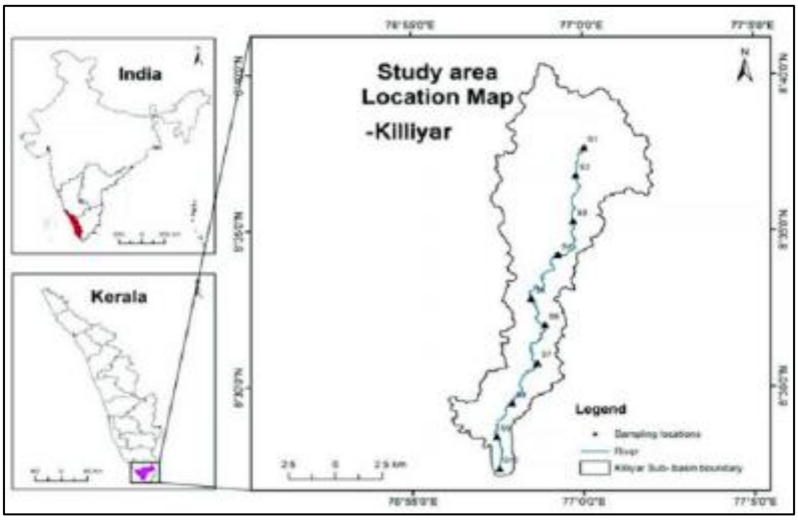
determine peak flood discharge of Killi river basin. After obtaining the output from the HEC HMS is given as input to HEC RAS for the identification of flood prone areas. The most recent capacities of RAS mapper in HEC RAS are used for the improved mapping of the floodplain by using flood information of the Killi River. The objective of the study is to determine peak flood discharge corresponding to different return periods of 2, 5 and 10 year and to set up a flood inundation map of the Killi river basin located in Kerala. For the preparation of flood inundation map two-dimensional unsteady flow analysis is carried in HEC RAS. The HEC HMS and HEC RAS models can assess the extent of flooded areas. And the main objectives of this study are to determine flood peak discharge in Killi river basin using HEC HMS and to identify the extent of flood inundated area and inundation depths using HEC RAS.

2. Methodology

The generalized methodology of the study comprises of watershed delineation from the DEM, estimation of peak discharge using HEC-HMS model and prediction of flood hazard areas using HEC-RAS model.

2.1. Study Area

The Killiyar (latitudes 8º40’30"N, 8º27’0"N and longitudes 76º 57’E, 77º 2’0"E) is a ground fed or spring fed rivulet forms major tributary of Karamana river and originates from Ottakompukunnu and Karimchathimala at Theerthankara, in Nedumangadu taluk of Thiruvananthapuram district (Kerala state). The river enters Thiruvananthapuram city at Vazhayila and flows through Mannammoola, Maruthankuzhi, Edapazhinji, Jagathy, Killippalam, Attukal, Kalady south and merges with Karamana River at Pallathukadavu near Thiruvallam flowing a total stretch of 35km in North West direction towards the Arabian Sea which is shown in Fig. 1.



(source: Evaluation of Radon Distribution and its Implications vis-à-vis Water Quality of Killiyar river, Kerala,India)

Figure 1 Study area

2.2. Data Collection

The meteorological data required for the study were rainfall data observed in Killiyar from January 1983 to December 2018. Daily rainfall data in mm of for the required period was obtained from the website of Central Water Commission (CWC). The spatial data required for the study were Digital Elevation Model (DEM) which is shown in fig.2, Land Use Land Cover (LULC) map and soil map are shown in fig.3 and in fig.4. The DEM of India of 30 arc second resolution was obtained from United States Geological Survey (USGS) Earth Explorer site. The LULC map of the Trivandrum was obtained from Bhuvan, a site under Indian Space Research Organisation (ISRO) and the soil map of the world was obtained from the website of Food and Agricultural Organisation (FAO).

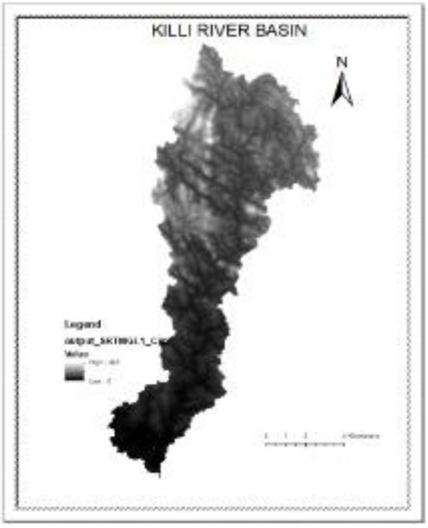


Figure 2 DEM of Killi river basin prepared in ArcGIS 10.8

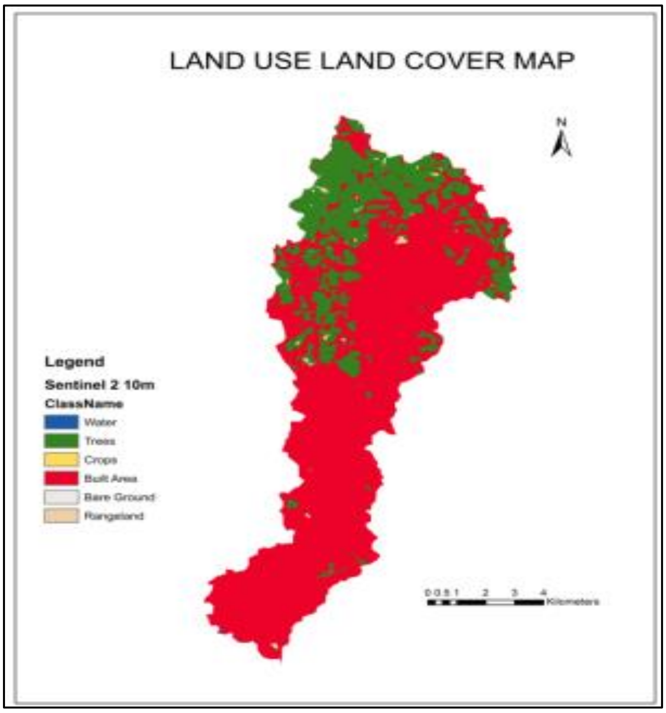


Figure 3 LULC of Killiyar

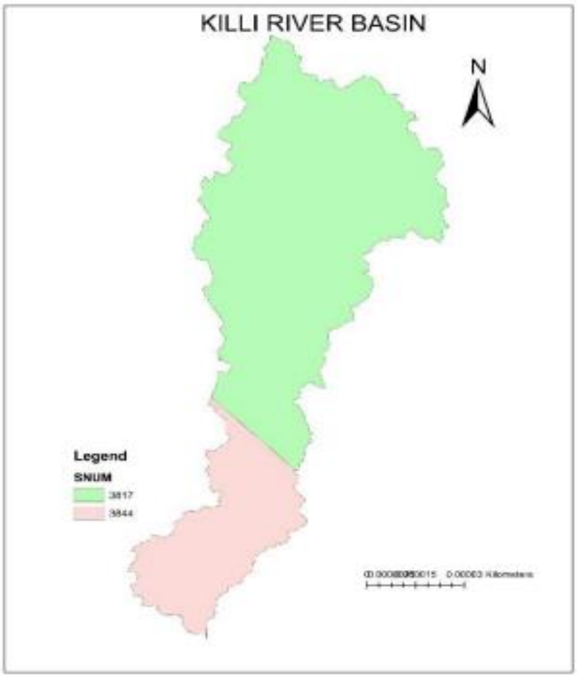


Figure 4 Soil map of Killiyar

The Curve Number grid of the basin was prepared from the soil map and LULC map was joined to form the soil-land use poly in ArcGIS 10.8. The soil-land use poly is shown in figure.

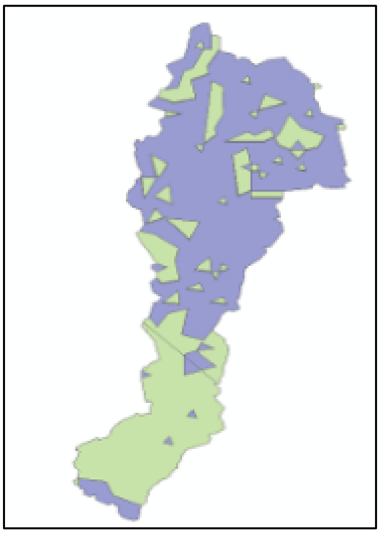


Figure 5 Soil land use poly

2.3. Watershed delineation of Killi river basin

Watershed delineation of Killi river basin Watersheds or catchments are physically delineated by the area upstream from a specified outlet point. In this study watershed delineation is done using the DEM. The step wise procedure is as follows:

- Import DEM into Arc GIS
- Create depression less DEM
- Select fill from options: The fill tool is used to remove any imperfections in DEM.
- Create a flow direction grid: A flow direction grid assigns a value to each cell to indicate the flow direction. This is an important step in delineation, as the direction of flow will determine the ultimate destination of the water flowing across the surface of the land.

- Create flow accumulation grid: Flow accumulation tool is used to calculate the flow into each cell by identifying the upstream cells that flow into each downstream cell.
- Create and snap pour points: After identification of streams, the entire catchment was delineated into 54 subbasins and 29 reaches.

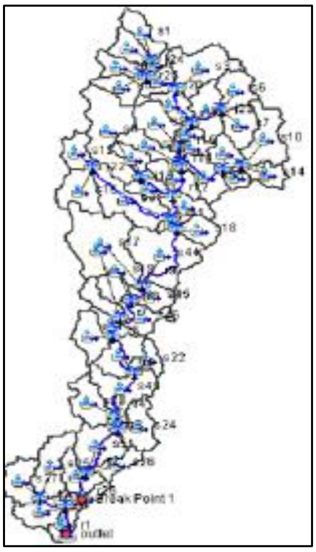


Figure 6 Killiyar basin model

Peak discharge estimation in HEC HMS For the estimation peak discharge for different return period in Killi river basin; first we have to select different processes included in the study. The processes selected for the study are: Precipitation Loss Estimation: SCS Method of Abstraction Rainfall - Runoff Transformation: SCS Unit Hydrograph Method Routing Method for Reaches: Lag Routing method

After the delineation of watershed; the basin model was created, the mean curve number values obtained for each subbasin from the CN grid in ArcGIS was given as input to the HEC HMS model. After that initial abstraction values are calculated using the equation $\mathrm{I}a = 0.2S$ Lag time t = 0.6*tc Where l is the length of the longest flow path in metres and Y is the basin slope in % which are the subbasin characteristics obtained directly from HEC-HMS. After putting all these parameters into the basin model, another important thing is metrological model setup. In metrological model rainfall depth in mm corresponding to different return periods 2,5,10 years are given. The model performance was evaluated using Coefficient of determination R^2 and NRMSE.

2.4. Development of Flood Inundation Map

The flood inundation map of Killiyar region is prepared by using DEM of Killiyar and providing the flood hydrograph and the river normal depth as boundary conditions.2 D unsteady flow simulation is done and the water level for different return periods is generated in HEC-RAS for a particular cross section. In 2D modelling a 2D mesh is created over the terrain of the basin. After the creation of the terrain model, the 2 D flow area and the upstream and downstream boundaries are specified. The flow hydrograph for 10 year return period is given as the upstream boundary condition and normal depth at a friction slope of 0.000011is given as the downstream boundary condition.

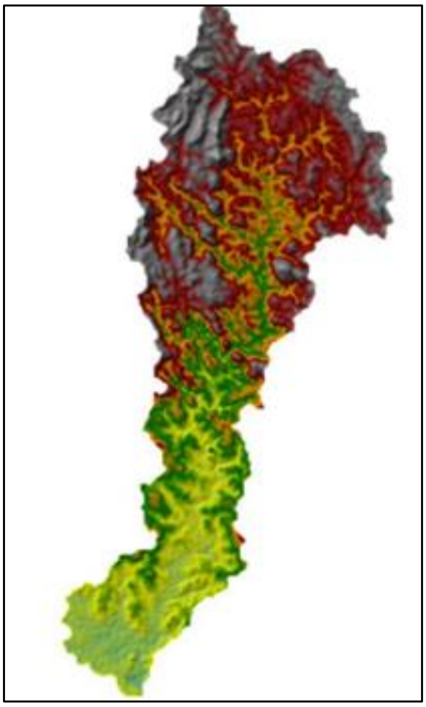


Figure 7 Terrain model

3. Results and discussions

The peak discharge value of the Killiyar watershed for the return period of 2 year is shown in the figure. The obtained peak discharge value is 4873.2 m^3/s.

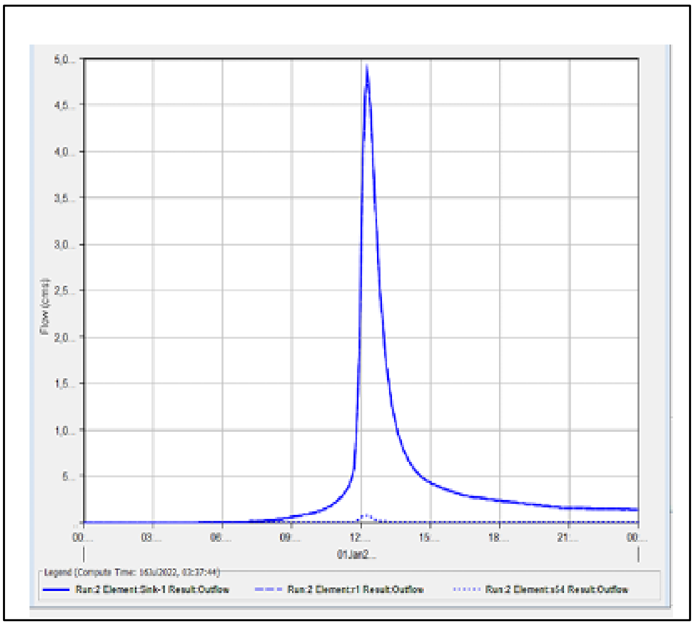


Figure 8 Flood hydrograph for 2 years return period

The peak discharge value for the return period of 5 years is shown in figure. And the obtained peak value is 7729.7 m^3/s.

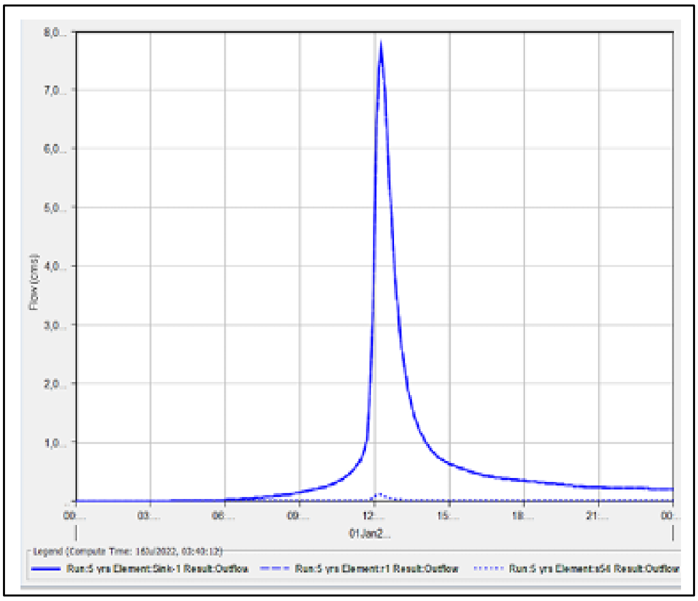


Figure 9 Flood hydrograph for 5 years return period

The peak discharge value for the return period of 10 years is shown in figure. And the obtained peak value is 9929 m^3/s.

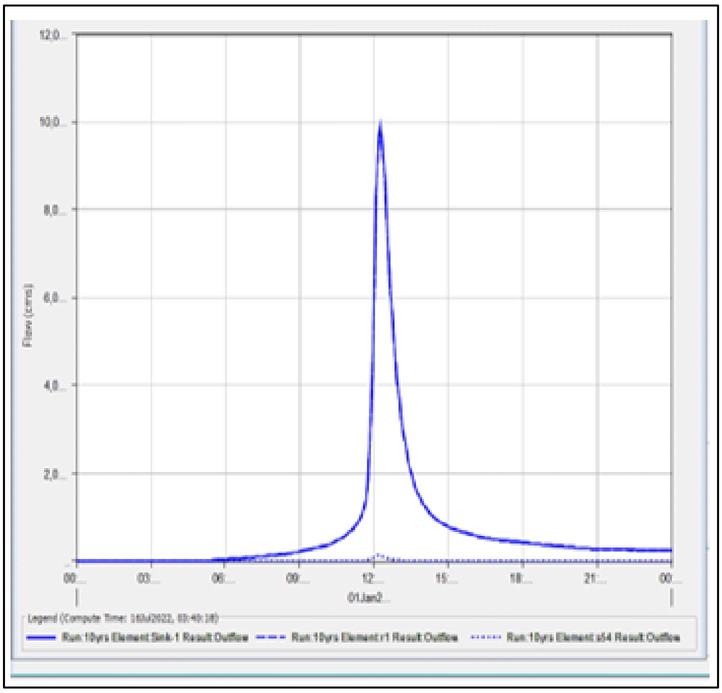


Figure 10 Flood hydrograph for 10 years return period

3.1. VALIDATION OF HEC-HMS MODEL

The model was validated by using observed and simulated peak discharge values corresponding to different return periods of 2,5,10 years in the Maruthankuzhy region. The following R2 and NRMSE values obtained are:

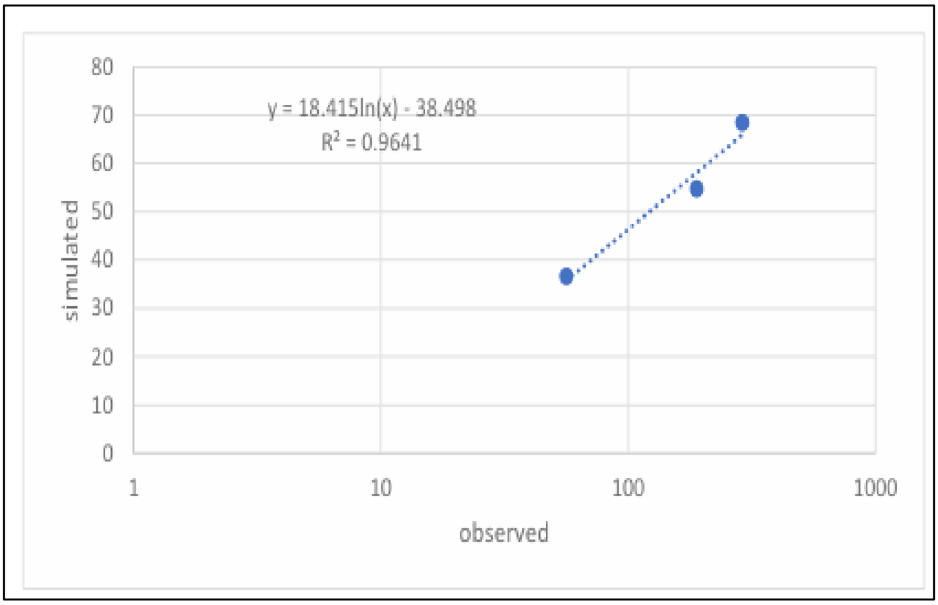


Figure 11 Correlation curve

$$R^2 = 0.9641 \qquad NRMSE = 0.063679$$

It is found that even though R^2 value is satisfactory, NRMSE value is also satisfactory.

3.2. Maximum water surface elevation in hecras

The average depth of the Killiyar is about 3.48m during 10 years return period. From the continuous simulation performed, it is found that during this return period the maximum flood depth of the basin is found to be 17.47m. From the flood inundation map of 10-year return period, it is found that the downstream parts of the basin include regions of Jagathy, Edapazhanji, Maruthankuzhy etc. were found to be flood prone areas.

Figure 12 Maximum water surface elevation

4. Conclusion

In this project, HEC-HMS is used to determine the peak flood discharge in the Killi river basin. The obtained results are validated by using R2 and NRMSE values. And it shows satisfactory results. Hydraulic modelling is very much useful for determining the flow characteristics of Killi river. In this study hydraulic modelling of Killi river basin was carried out using HEC RAS then the maximum flood depth in the basin is found to be 17.74m. From the flood inundation map, the maximum flood depth is found to occur on the basin that include the regions of Jagathy, Edapazhanji, Maruthankuzhy etc. Proper river management plans should be adopted with a special focus to the flood prone areas to prevent future flood events.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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