Flood modelling and breach analysis of karuvannur river in kerala state

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Abstract. India is one among the countries around the world, where continuous variations in climate and rainfall amount causes severe economic damages and threat to human lives. High amount of rainfall causes drastic changes in the normal flow of a river and leads to heavy flood. During the catastrophic flood occurred in the year 2018, Karuvannur River overflowed and collapsed the bund road connecting Arattupuzha and Karuvannur. It had deviated from its original course and subsequently the low lying areas near the river were completely flooded. This incident indicates the need for conducting hydrologic and hydraulic analysis of Karuvannur River for adopting an effective river management plan to prevent the future flood events. In this study, hydrologic analysis is done using HEC-HMS model and hydraulic modelling is done using HEC-RAS model. From the analysis, the maximum flow, velocity and shear stresses on the banks of river are determined. Flood mapping is also done. As per the results of flood modelling, construction of a levee on the river bank is proposed to avoid overflow and diversion of flow hereafter.

1. Introduction

The analysis of the flow properties of a river is termed as hydraulic analysis and that of watershed characteristics is termed as hydrological analysis. The hydrological and hydraulic properties include the rainfall distribution, watershed characteristics, velocity, discharge, depth, stage etc. The continuous variation in the flow properties due to the unexpected hydrological changes causes morphological changes subsequently in the river and its basin. So, the hydrological and hydraulic analysis of a river has a significant role in taking measures for the mitigation of river induced problems like flood. The hydrological and hydraulic modelling can be done using several models and the commonly used ones are HEC-HMS, HEC-RAS etc. Validation of the result from these models is then carried out using the required field measurements. During the disastrous flood in the year 2018, Karuvannur River which is the fourth largest river in Thrissur district of Kerala changed its course of flow destroying the bund road from Arattupuzha to Karuvannur. The spate of river spread to several kilometres, submerging hundreds of houses and acres of cropland. Hence an attempt is made to explore and identify the possible reasons for such an unprecedented tragic event. The main objective of this study is to conduct a simulation model study of the river using the state-of-the-art hydraulic and hydrologic models in order to identify the causes for the river diversion and to propose a river management plan for the
protection of river banks so as to prevent out-of-bank flows to the neighbouring low lying areas. Figure 1 shows the diverted Karuvannur River during flood.

![Diverted Karuvannur River during flood 2018](image)

**Figure 1.** Diverted Karuvannur River during flood 2018

2. **Literature review**
Mondal et al. (2016) has conducted a study to understand the hydro dynamic changes in Ichamati River using HEC-RAS model. The changes of channel capacity width, depth, meander, rating curve for the Ichamati River are determined by HEC RAS Model. Thakur et al. (2017) has conducted a research to evaluate the extend of flood plain in copper slough watershed (CSW) in Champaign, Illinois; utilizing the known precipitation and land use. He used HEC-HMS software for rainfall runoff modelling and HEC –RAS software for flood modelling. Ingale and Shetkar (2017) conducted a study on flood analysis of Wainganga River using HEC-RAS model. Here 2D modelling of the river was done using HEC-RAS 5.0.3. The water surface elevations are computed for various flood discharges and return period (25years, 50 years and 100 years).

Devmurari et al. (2015) has conducted a detailed study on river training works in which various types of protection works for the river bank is discussed and detailed. According to them it is desirable to conduct detailed physical model studies before implementing any kind of major river training works. Haddad et al. (2016) has conducted an investigative study titled “Levee Layouts and Design Optimization in Protection of Flood Areas”. They have suggested that it is possible to lessen the flood damages by constructing levees and identified its best possible location and designed its height in high risk areas.

3. **Study area**
The study area selected for this work is Karuvannur River basin. It is located within the Thrissur district of Kerala. River has a drainage area of 1054 sq. km and main stream length of 48 km. It has an average annual discharge of 44.33 cum/sec. Figure 2 shows the stream network map of Karuvannur river basin.

![Stream network map of Karuvannur Basin](image)

**Figure 2.** Stream network map of Karuvannur Basin
4. Methodology
To identify the causative factors of river breach and to study the river system behaviour, 2D flood modelling is done. Only 5.460 km long stretch of river, in which the bund breach has occurred is selected for flow modelling. Figure 3 shows the river network and the enlarged depiction of the highlighted study reach. Red dot indicates the point of bund breach.

Figure 3. River Network and enlarged view of the study reach

Flood modelling is done using HEC-RAS software. Input data required for HEC-RAS software are DEM, cross section data and boundary conditions. The cross section data is prepared using HEC-GEORAS which is an extension of Arc-GIS software. Figure 4 shows the geometry of the river reach created by HEC-GeoRAS.

Figure 4. Geometry of the river reach created by HEC-GeoRAS

To run the HEC-RAS model, the upstream boundary conditions can be any one of flow hydrograph, stage hydrograph and rating curve. Since the flow hydrograph at the upstream side of the river is not available, the same is obtained by running the rainfall-runoff model prepared using HEC-HMS software. Normal depth is given as the downstream boundary condition. Required input data for the HEC-HMS is prepared by use of Arc-Hydro tool and HEC-GeoHMS 10.1. Result from HEC-HMS model is then calibrated and validated. Flow hydrograph from HEC-HMS is used in HEC-RAS model. Figure 5 shows the terrain model of the Karuvannur river basin prepared in HEC-RAS.

Figure 5. Terrain model of Karuvannur basin
HEC-RAS model results are then calibrated and validated using the discharge and stage data at the Karuvunnur bridge station. From the flood model, the maximum height up to which the water would rise can be ascertained and thus the height up to which the banks of the river need to be protected can be estimated. Thus from the observations collected from flood modelling, suitable river training works can be identified and designed to prevent overflowing of rivers to side banks and to the nearby low lying areas.

### 4.1. Calibration and validation of HEC-HMS and HEC-RAS models

The HEC-HMS model is calibrated by changing the parameters like Muskingum K, X, curve number and lag time. A scatter plot of observed versus simulated discharge is plotted and the Coefficient of determination is computed. From the available daily discharge data from 3rd August to 15th August 2018, received from Irrigation Design and Research Board (IDRB), Trivandrum, discharge values from 03 to 11th August 2018 are taken for calibration and remaining for validation. The Coefficient of determination during calibration and validation are obtained as 0.75 and 0.87 respectively. Figure 6 shows the calibration and validation results.

Noticeable variation between the observed and simulated discharges are apparent in the graph as the observed discharge values are calculated from the measured stage value and interpolated from the discharge curve as the Dept. was unable to take direct discharge data during these days due to incessant rain and torrential flow in the river.

**Figure 6.** Calibration and validation graph of HEC-HMS model

The calibration and validation of HEC-RAS model is done using the discharge data obtained from the gauging station at Karuvunnur Bridge for the period 3rd August 2018 to 15th August 2018, collected from IDRB. The calibrated value of Manning’s ‘n’ value is considered as 0.04 for rivers and 0.06 for banks. The coefficient of determination from calibration and validation of the model are obtained as 0.55 and 0.64 respectively. Figure 7 shows calibration and validation graph of HEC-RAS model.

**Figure 7.** Calibration and validation graph of HEC-RAS model

### 4.2 River System Review

Many windings or meandering stretches of river can be observed from upstream to downstream in the Karuvunnur River. In the Kerala Flood 2018, the river breach has occurred in one of such winding
portion itself. Usually breaches occur when the water levels or water level durations exceed a threshold. Figure 8 shows the elevation profile across the river in the reach where diversion took place.

![Elevation profile across the river](image)

**Figure 8.** Elevation profile across the river

During that disastrous flood, the river changed its usual course and flowed towards the right bank and overtopped, destructing the bund road. From the elevation profile, it can be noted that, area beyond the bund road on right bank of the river is at a lower elevation than the river itself. This terrain profile enhanced the spreading of water over those low lying areas. River training works such as Levee, Guide banks etc. can be proposed and designed for the protection of river bank and the discharge regulating structures also can be built to prevent such calamities. In this case too, the wide spreading of water and the resulting inundation in these area could have been reduced by constructing a levee or similar protective structures on the right bank of the river. So in this study, location and hydraulic design of a levee to prevent overtopping is incorporated to evade further occurrence of river breach.

5. **Results and discussions**

Hydrologic and hydraulic modelling of the study area is done in HEC-HMS and HEC-RAS respectively. Calibration and validation of both the models gave promising results indicative of their good performance. The peak flow due to rainfall is observed between the periods 16th to 17th August 2018. The total drainage area for each sub basins is obtained from rainfall runoff modelling. From the river network, it can be seen that the starting point of the Karuvannur River is the confluence of Kurumali and Manali River. So the outflow at this confluence point is taken as the upstream boundary condition of the reach in the study. Flow hydrograph at 1 hour interval is obtained. From the outflow hydrograph at the junction, it can be observed that the flow at the junction was normal till 14th August 2018. But due to the heavy incessant downpour since 15th August 2018, the river discharge multiplied rapidly. The peak flow observed due to the rainfall is observed as 699.5m³/s. Figure 9 shows the outflow hydrograph at the junction point of Manali and Kurumali River.

![Outflow hydrograph at the junction point](image)

**Figure 9.** Outflow hydrograph at the junction point
Since the HEC-HMS results gives the discharge or runoff from the basin due to rainfall, average daily flow observed in the river is to be added to the result obtained from HEC-HMS. From 2D flood model study, it is observed that the maximum flow occurred on 16 August 2018 midnight at each cross sections of the river reach. When the model results were examined, it is seen that the total peak flow in the study reach during flood is in the range 750 to 755 m$^3$/s. Figure 10 shows the flood mapping from 15th August to 18th August 2018. The Red arrow in the figure shows the direction of diversion of river due to breach during flooding.

![Figure 10. Flood mapping on 15-08-2018, 16-08-2018, 17-08-2018 and 18-08-2018](image)

For further investigation on breaching mechanism and system behaviour, the region between the river section A and B is considered, because the sudden variation in the river system and flow properties due to its winding nature between these sections has triggered the breaching mechanism. Figure 11 shows the region between river cross sections under consideration.

![Figure 11. Region between river cross sections under consideration](image)

The maximum flow passing through sections A and B are noted. The maximum flow of water passing through the sections A and B is almost equal to 750 m$^3$/s. The discharge through these sections started to rise rapidly by 15th night and continued to flare up till 17 August 2018. Figure 12 shows the flow hydrograph in the sections A-B.

![Figure 12. Flow hydrograph at cross sections A and B](image)
The enormous discharge between these two river sections caused the water to flow over the right bank, as the height of bank was less than the flood depth. In the curved portion of the river, the weakening of the side bank due to the scouring action of the tangential force developed by the curvilinear flow might have further aggravated the problem. The water flowed over the right bank of the curved portion turned into a cascaded torrent and struck down the bund road. Also, bed shear stress is one of the important parameters to be examined. Because; the changes in bed shear stress is the main reason for scouring on bank. As the bed shear stress increases with increase in velocity, the lower bank of the river starts to erode and gradually the entire bank fails. Here the bed shear stress ranged between 38.0 N/m² to 100 N/m² and velocities also much above the normal one. An entire 20m stretch of the road was washed away and the low lying areas like Cherpu, Ettumana and nearby area was inundated severely. Maximum depth of water in the river went up to 13.5 m with 1.5 m of water above the right bank at the breach location. Figure 13 shows the bed shear stress graph at sections A and B.

Figure 13. Bed shear stress graph at sections A and B

Considering the river cross sectional features and the flood characteristics, a levee is proposed on the right bank so as to prevent the overtopping of flow to the right bank and further down to the low lying areas. Figure 14 shows the proposed levee where \( h_L \) is the total height of levee which may vary according to the river bank line and soil conditions. A free board of 1.5m is provided to account for any other factors which are not envisaged in the design.

Figure 14. Proposed levee
6. Conclusions
It is found that abrupt variation in discharge, velocity and bed shear stress have caused the river diversion and ultimately the bund breach. Maximum flow, velocity, stage and bed shear stress on the cross sections A and B are examined by conducting the model study. High amount of rainfall in the basin increased the runoff in the Karuvannur River. Runoff started to rise from 15th August 2018 and peak flow occurred on 16th August 2018 in the midnight. Overflow of river toward the right bank has occurred on the highly curved portion of the river. Here a tangential force developed by the curvilinear flow scoured and breached the right bank of the curved portion of the river and the nearby bund road. Using the results of flow modelling, construction of a levee on the right bank is proposed to prevent the overflow and thereby preventing the wide spreading of water in the nearby low lying areas. Top level of levee is at 16.5 m from the channel bottom including free board of 1.5 m.

Although both the calibrated and validated models performed well, there could be some discrepancy in the results obtained due to data insufficiency. Neither the discharge nor the stage-discharge relationship at the upstream side of the river was available. Hence simulated discharge values obtained from rainfall runoff modelling using HEC-HMS are used as the upstream boundary condition in the HEC-RAS model. Also modelling is done by assuming same value for manning’s coefficient and uniform cross section for the entire river stretch which is far from the reality.

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