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Research Article

Numerical Modelling of Flood Inundation and Run-Up along the Banks of Pamba River, South West Coast of India

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A B S T R A C T

The state of Kerala was in the shadow zone of several natural disasters. But the disasters which happened during the last two decades changed our perceptions and preconceived notions. Before two decades, for Keralites the term disaster was a matter of strange science fiction books, Hollywood cinemas or the things which were happening on the other side of the globe or planet. The tsunami of December 26, 2004, Ockhi of 2017, Kerala Floods of 2018 and its replicated version in 2019 exposed our vulnerabilities. During the event of 2018 Kerala Floods, the need for a Flood Warning System (FWS) in Kerala was badly felt. Though there are many components for a FWS, the main component of a FWS is the prediction of inundation and run-up along the banks of rivers/ water bodies. This component can only be accomplished through the process of numerical modelling. Numerical modelling is an efficient tool for estimating the past events and predicting the future ones. Through numerical modelling different scenarios of possible flood generating permutations and combinations will be carried out and hence in the event of a real time flood warning a closest matching will be picked from these, which will be subsequently used for mitigation. The results of numerical modelling will be the base for creating vulnerability maps which will be used for mitigation and rehabilitation. This investigation numerically simulates the possible flood rising inundation and run-up along the banks of Pamba River situated on the south west coast of India. The model results suggest that extreme rain fall events alone cannot inundate the banks of Pamba River, whereas external discharges emanating from dams, tidal reflections from the oceans etc. could inundate the terrain. The investigation also recommends several components for successfully establishing a flood warning system in Kerala with specific reference to Kerala floods 2018.

Keywords: Flooding, Inundation, Run-up, Numerical Model, Flood Warning System

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Introduction

Unlike other natural disasters floods have a very rare peculiarity. The target area/ inundating area of natural disasters like tsunami, storm surge, earthquake, oil spill, and cyclones are all limited or confined to a particular domain. But floods can generate inundation beyond boundaries causing extensive damages to human life, property, devastating agricultural fields and yields as primary damage. When a large body of water rises and overflows into a normal dry land it is called as a flood, Mujumdar.[4] The discharge rate which exceeds a critical threshold value can also be called as a flood. Review of historical data related to floods suggests that prior to 2018 there were three flooding events in Kerala, Report of Central Water Commission - 2018.[6]

First was in 1341 due to a deluge in Periyar River. It was reported that the flood water breached the land mass, between the present Fort Kochi and Vypeen, and opened up the present Cochin estuary and harbor and helped in the formation of Vembanad Backwater. After this flooding, there happened a flood in July 1924, popularly known as Flood 99, named with reference to the Malayalam Calendar month 1099. Intense rain for three weeks and its subsequent inundation from the rivers Periyar, Meenachil, Pampa, Muvattupuzha and others originating from Sahyadri Mountains contributed towards this worst flooding. The year 1961 also witnessed heavy floods and rise in the water levels of reservoirs. But comparing with all these floods the floods which happened in 2018 was a great havoc. The Kerala Floods of 2018 stressed the need for establishing a flood warning system In Kerala, for which numerical modelling of flood characteristics based on different permutations and combinations of flood generating conditions are mandatory. Besides, flood modelling should be carried out extensively and exclusively for each river in Kerala based on various aspects like discharges, rainfall, inflows, tributaries etc. This investigation is carried out along the banks (Chenganoor-Kozhencherry) of Pamba River, Kerala located along the south west coast of India. Virgin model computations are carried out in this study. Virgin model means, model computations done with rainfall discharges alone and without considering any other external discharges.

Components Required for Setting-up an Effective Flood Warning System

Every state which are prone to floods should have an effective flood warning system. For setting up such units, lot of preliminary work has to be done so as to facilitate modelling outputs.

The preliminary work includes:

- Identification of vulnerable flood affected areas and its causative water bodies/ rivers
- Preparation of high-resolution digital elevation on the banks of these rivers
- Fine resolution bathymetry of rivers
- Mapping of Land use/ Land cover terrains
- Mapping of river bank structures
- Demarcation of administrative terrain
- Collection of Ground water table
- Acquiring of rainfall data in hourly resolution
- Inflows and outflows pertaining to river
- Geology of the terrain
- Locating hydraulic structures
- Conditions of soil
- Trajectory and dimensions of rivers
- Flow conditions
- Dredging conditions and bathymetric variations
- Collection of historical flood data
- Tidal data & Tidal patterns with variations
- Features of Dam and its connectivity
- Knowledge about canal networks, tributaries and its draining pattern
- Survey of rehabilitation centers
- Channels of easy mitigation
- Identification of a numerical model capturing the hydrodynamics of flow

The above-mentioned datasets should be collected, processed and incorporated into computer models. Thereafter simulations should be carried out incorporating several different permutations and combinations of all possible flood generating conditions. The results of modelling should be stored in digital vulnerability maps and in the event of a possible flood arising conditions a nearest matching scenario should be picked from the results, based on which advisories and warnings can be issued for accelerating the mitigation efforts. But collecting all the above data is laborious, time consuming and tedious. So, alternate sources for modelling flood characteristics should be sought. In this investigation numerical simulation is carried out effectively using such alternate sources of data.

Materials and Methods

This investigation is an attempt to numerically model the run-up and inundation characteristics of floods along the Chenganoor-Kozhencherry stretch on the banks of Pamba river. This area was selected as it was the worstly affected area during 2018 Kerala Floods. Two numerical models were selected for computations. HEC-RAS and TN2 models were specifically used for flood generation and estimating run-up and inundation. The models were bifurcated in such a way so as to capture the discharge rate and for estimating the final characteristic patterns. The bathymetry data and topographic data for model computations were taken from satellite data source (*earthexplorer.usgs.gov*). The other

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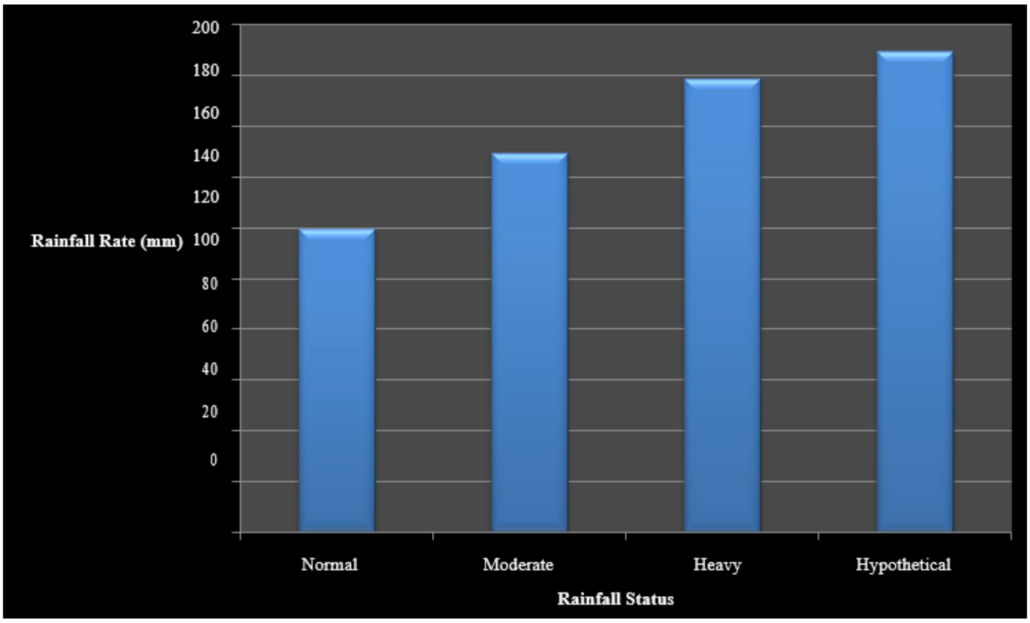

Figure1.Classification of different modes of Rain fall (Base Data:CWC Report)

Figure 2.Study area taken for model computation

data regarding Extreme Rainfall Event (ERE) was taken from the Kerala Flood Report of Central Water Commission. Historic data related to rainfall was also referred from Sudheer KP et al.[1] and Krishnakumar KN et al.[2] before initiating model runs.

The model run was initiated in four different modes viz. Normal Flooding, Moderate Flooding, Heavy Flooding. Besides a hypothetical flooding scenario was also initiated to capture the potentially worst-case scenario. Normal mode shows a rainfall depth of 120 mm rainfall and moderate rainfall shows a rainfall rate of 150 mm. Heavy rainfall was the exact replicated version of August 2018 Kerala floods as mentioned in the report of Central Water Commission. The data used in this investigation include rainfall data, friction coefficients, bathymetric data and topographic data. The rainfall data taken from the report of Central Water Commission, was further interpolated to bifurcate and classify the different modes of rainfall and to compute its rate (Figure 1).

Study Area

Pamba, the third longest river in Kerala with a length of 176 km and connected to 8 Dams was the worstly affected region during the floods of 2018 (Figure 2). Other than numerous deaths, there was devastation to property and infrastructure along 26 km length of Pamba River which is thickly populated. It is the river which is flowing through three different districts of Kerala based on topography.

Besides, there are two larger religious congregations happening on the banks of this river annually viz. Maramon Convention and Hindu Maha Summit. The banks of Pamba also is an interim shelter house for lakhs of Sabarimala

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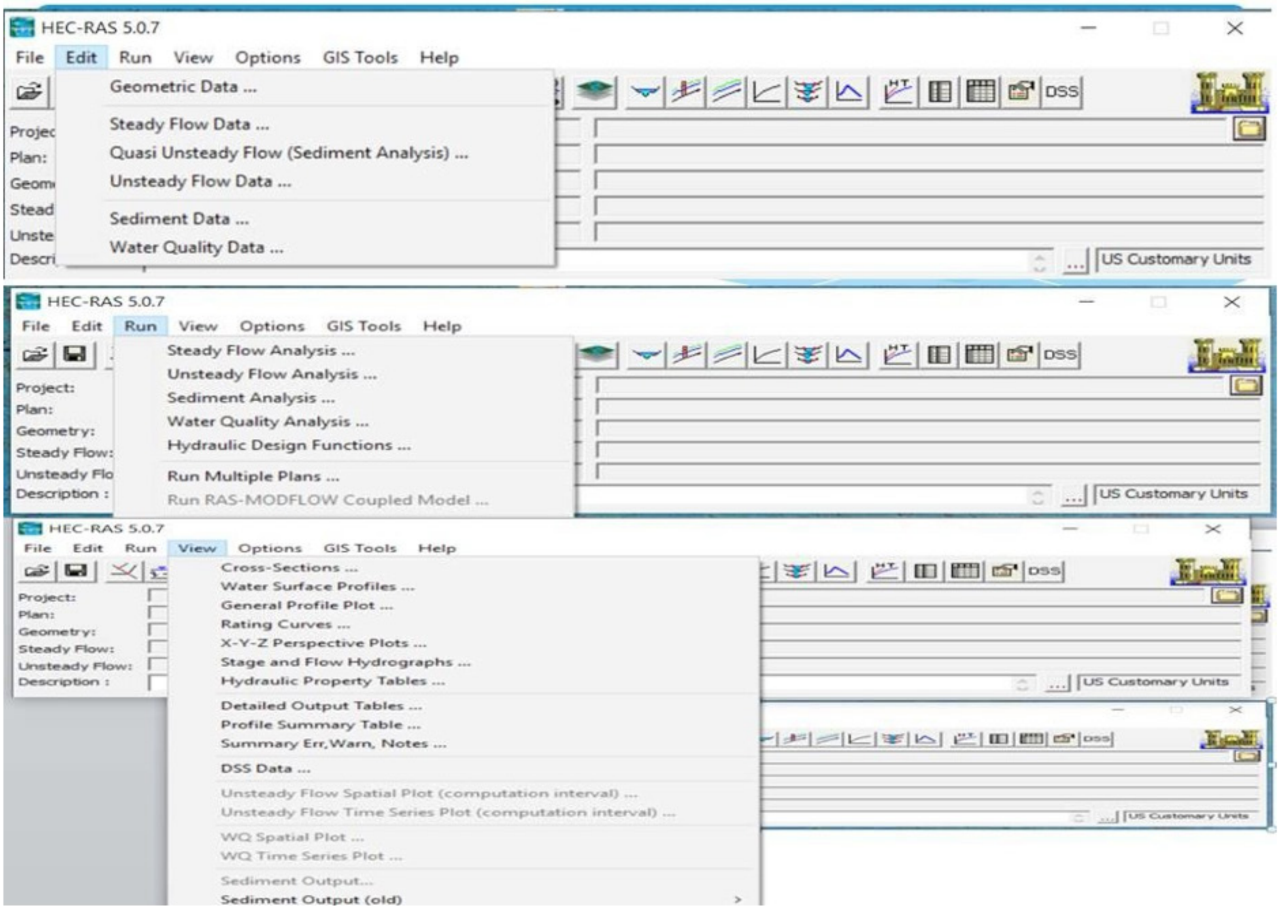

Figure 3.Different Model Run Scenarios of this Investigation

Pilgrims. Banks of Pamba is also a terrain for various literary fests and academic festivals. Pamba river is selected for this study considering the socio-economic, demographic and religious importance of this region.

Model Used and Data

Though there are several different global flood models available for flood inundation and run-up modelling, the need of fine resolution data is of utmost importance while dealing with such investigations. Besides several other components are required for establishing an effective flood warning system. As collection of those components are very much tedious and laborious the only option was to go for satellite data sources as an alternative to field data and to use an open source model as both are very much cost effective and are readily available.

For numerical modeling HEC-RAS model developed by Hydrologic Modeling System of Hydrologic Engineering Centre, US Army Corps of Engineers (HEC-HMS) was used for model computations (Figure 3). The data for model computations like the bathymetry and topographic data was taken from the website of earth observer.[7] The Shuttle Radar Topographic Machine (SRTM) data with a resolution of 90 m was used for simulation studies (Figure 4).

Equations of Flood Modelling

A French Engineer Saint Venant (1797-1886), who worked deeply on hydraulics and floods, developed a set of equations which was later named as a Saint Venant (SV) equations as an honor to him. Saint Venant equations provide the basic physics of flood modelling. The governing equations in differential form are

$$\frac{dQ}{dx}+\frac{dA}{dt}-q=0 \qquad (1)$$

$$\frac{1}{A}\frac{dQ}{dt}+\frac{1}{A}\frac{d}{dT}\left(\frac{Q^2}{A}\right)+g\frac{dy}{dx}-g\,(S_0-S_F)=0 \qquad (2)$$

$$I_F-O_F=\frac{dS}{dt} \qquad (3)$$

The above equations 1, 2 and 3 are called Saint Venant Equations.[4] There are two methods of flood routing suggested by Rajat Pandey et al.[5] are:

- Hydrologic routing
- Hydraulic routing

Hydrologic routing uses equation of continuity for basic model computations, whereas hydraulic routing uses both continuity equation and Saint Venant equations for model predictions.

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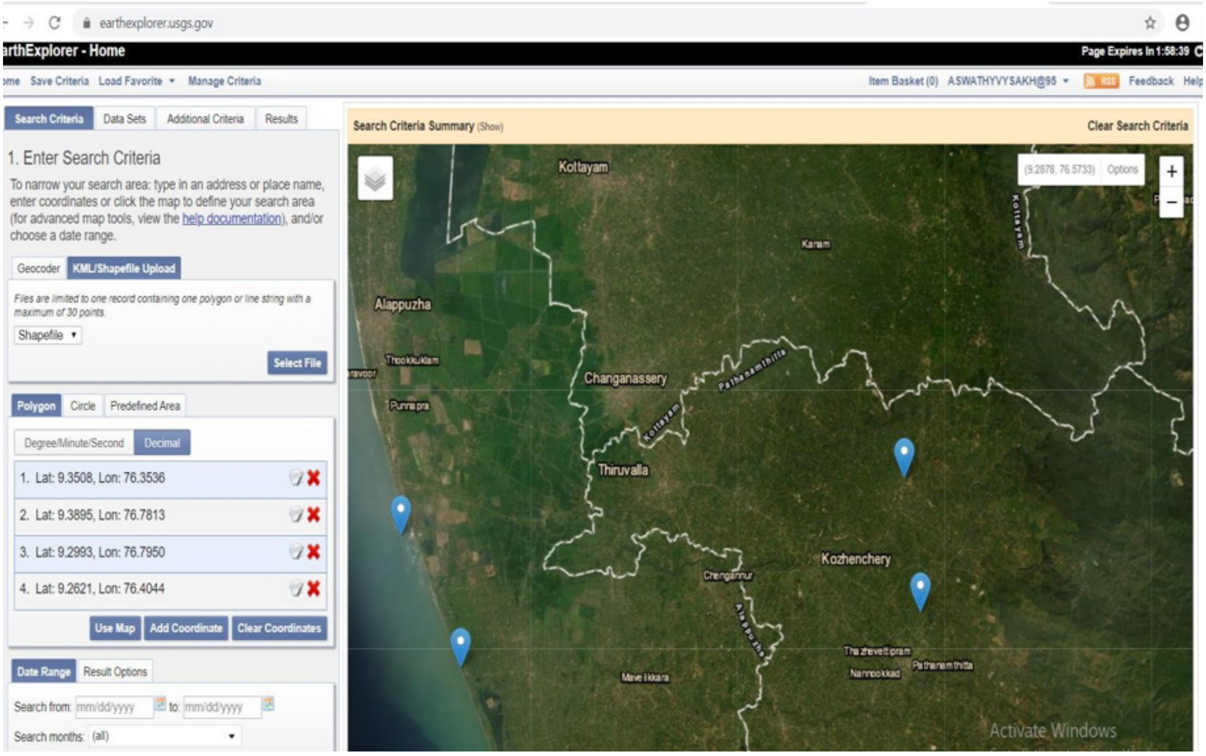

Figure 4.Bathymetric and Topographic Data Selection Procedure for Model Computations

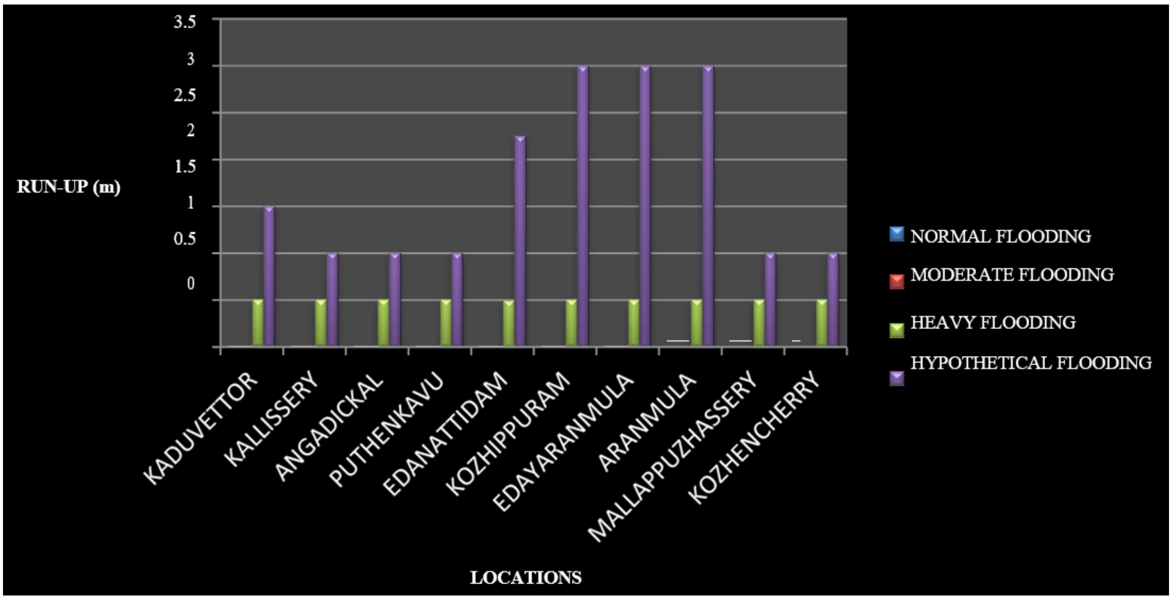

Figure 5.Simulated Run-up patterns along the banks of Pamba River

Results and Discussion

The results of numerical modeliing in terms of run-up and inundation are discussed below.

Run-up

Run-up is the vertical extend of water that has gone upwards and it is measured with reference to Mean Sea Level (MSL). Figure 5, shows the run-up due to flooding along Chenganoor Kozhencherry banks of Pamba River.

The run-up shows a varying pattern along the banks. The model predicted no significant run-up along the stretch for three scenarios of flood modelling viz. normal, moderate and heavy flooding. But the potentially worst-case simulation showed some significant run-up along the banks. A maximum run-up of 3 m was observed along Kozhipuram, Edaranmula and Aranmula whereas a height of 2.25 m was simulated for Edanattidam. These places are the locations where terrain elevation is considerably

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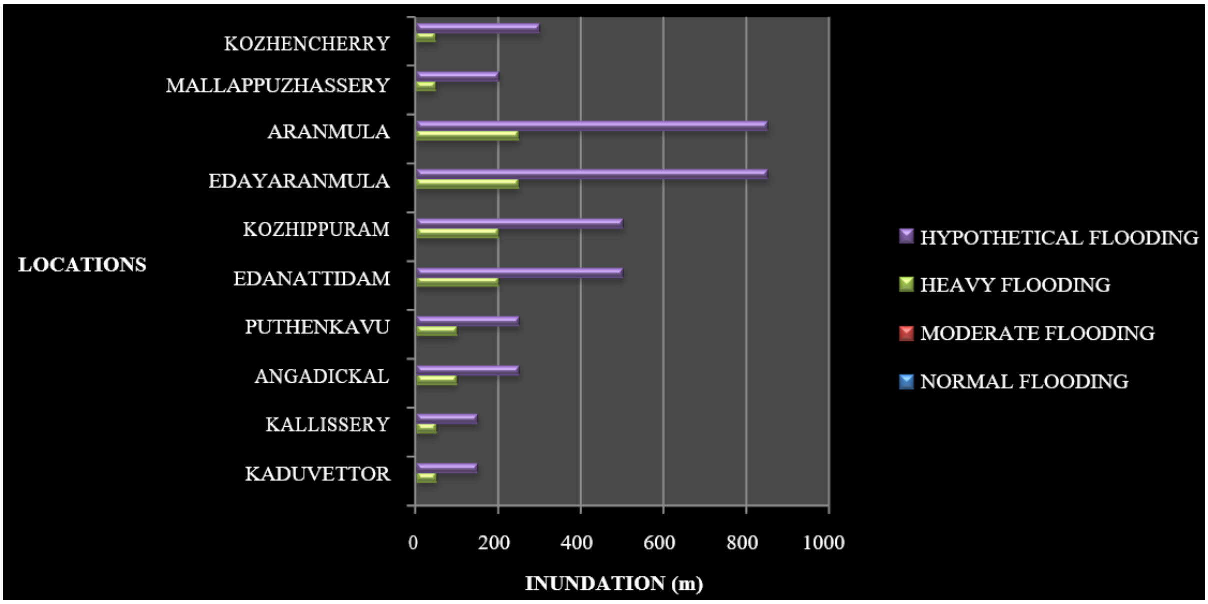

Figure 6.Simulated inundation patterns along the banks of Pamba River

low in the range of 0.5 m to 1.25 m above mean sea level. All other stretches like Kallissery, Angadickal, Puthenkavu, Mallapuzhassery and Kozhenchery showed a run-up of 1 m.

Inundation

Inundation is the horizontal extend of water which is measured with reference to the shoreline of water body on both sides. Figure 6, shows the simulated inundation along the stretch. The model predicted significant inundation only for the potentially worst-case simulation incorporating heavy rainfall and other triggering sources. A maximum extend of 850 m was simulated for Aranmula and Edayaranmula. Other locations like Kozhippuram and Edanattidam showed a maximum of 500 m inundations. The locations like Kozhencherry and Mallapuzhassery got an inundation pattern in the range of 200-400 m inundation. The most pertinent thing from the simulation is that, significant inundation was predicted by the model only for the potentially worst-case scenario. The other simulations showed no significant inundation though the terrains were of lesser elevation from mean sea level.

Conclusion

The model computations showed varying results for the stretch. The normal flooding scenario and moderate flooding couldn't contribute to significant inundation or run-up along the stretch, whereas the hypothetical source of flood generation can cause some run-up and inundation along the banks of Pamba River. The inundation pattern of heavy flooding scenario is less while comparing with that of hypothetical source. The results of numerical modelling indicate that the banks of Pamba will not be inundated exclusively due to extreme rainfall events alone. The normal, moderate and heavy rainfall did not make much of inundation along that terrain. Only the potential worst-case scenario of model computation showed some inundation. It can be attributed towards the fact that, inundations can only be caused by external discharges like dam discharge, tidal reflections emanating from high tide at the coast and other inflows through estuaries. Even the heavy flooding scenario which was the replicated version of Kerala floods 2018 also could not inundate the the terrain. So, it can be concluded that the banks of Pamba River are less vulnerable to floods arising due to extreme precipitation of rainfall alone.

The results of these kinds of investigations should be used for mitigation and the intensity of flooding can be reduced. But however, the quality of model output is directly dependent on several components which are to be fed as input to the model. The effective collection of such data can contribute to good model predictions. This study also recommends certain specific components for successfully establishing a flood warning system in Kerala with specific reference to Kerala Floods 2018.

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