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Research Article

Simulation Studies of Flood Along the Periyar River Basin, Central Kerala, India

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ABSTRACT

Kerala experienced a large flooding during August 2018. One of the worst affected river basin in Kerala is the Periyar river basin causing many damages to the buildings, electricity circuits and agricultural fields. These vulnerabilities indicated the need for establishing a Flood Warning System (FWS). The main component of a FWS is the prediction of inundation and run-up along the banks of a river. Numerical modelling using models like HEC - RAS is an efficient tool, which is used to predict the flood generating events and future flood events for different permutations and combinations. In this investigation, a virgin mode of model computation is used to calculate the run-ups in which, only the rainfall is taken as the input. In this investigation, study area is the Periyar river basin. The input data such as topographic and bathymetric data were taken from different satellite sources. Extreme Rainfall Events (ERE) were taken from the Central Water Commission (CWC) report. Rainfall was mainly categorized in to four modes. They are normal, moderate, heavy and hypothetical rainfall. The modelling results showed a varying pattern. The prominent locations from Cheranalloor to Aluva show no run-up for normal rainfall. There is a significant change in the run-up for moderate rainfall which increases to 0.5 m. The moderate and hypothetical run-up values are found to be around 1.25 m and 2 m respectively. The inundation pattern for the hypothetical rainfall showed drastically increased values coming in the range of 1650 m for the eastern locations. From this investigation, it is clear that a normal and moderate rainfall will not cause significant run-up and inundation, whereas continuous mode of heavy rainfall events contributing to extreme rainfall events can cause a significant run-up along the coast. This investigation will help the ongoing research and development trajectory to establish a FWS in Kerala with specific reference to Kerala floods 2018.

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

Introduction

The state of Kerala situated in the south western part of Indian Peninsular region, which is stretched in between the Western Ghats in the east and Arabian sea to the west. Kerala is the one of the highest monsoon rainfall regions in India with an annual rainfall of 3000 mm. The topography of the state can be divided in to three regions based on the climatic conditions. They are eastern highlands (rugged and cool mountain terrain), the midland (rolling hills) and lowlands (coastal plains). Kerala has particularly two monsoons - the south west monsoon (June - September) and the north east monsoon (October - December) and receives abundant rainfall during these two monsoon seasons.[7, 8, 12, 13-15, 17]

The occurrence of high intensity rainfall for continuous days during June - August 2018 resulted in flooding in most parts of Kerala. The floods of 2018 and 2019 exposed the urgent need for establishing a Flood Warning System (FWS) in Kerala. When a large body of water from sea, dam, rivers, canals, sewer or rain water rises and outflows into a normal dry land, it is called flood.[1, 8, 9, 12] Flooding is a temporarily occurring phenomenon and is a most devastating one in terms of property damage and human causalities. Floods can be widely classified as flash floods, coastal floods, urban floods, river floods and ponding. Besides, tidal inflows, tidal reflections can also lead to floods. The flood wave normally originates upstream and propagates too downstream. The heavy flooding during August 2018 in Kerala due to extreme rainfall affected many people, their assets and caused destruction of the agricultural fields. The reservoir reached to the Full Reservoir Level (FRL) and officials were forced to open the shutter of most of the dams. The rainfall which occurred during 15-17 August 2018, in Periyar, Bharathapuzha, Chalakkudy and Pampa was very high and is similar to that of 1924.[7, 8, 14, 15]

This investigation is an attempt to numerically model the run-up and inundation characteristics of floods along the Cheranalloor-Azheekode stretch on the banks of Periyar River, Central Kerala.

Different Components of a Flood Warning System

A flood warning system has several components as mentioned by Praveen and Sajith (2018). They are:

- Identification of vulnerable areas
- Infrastructure Mapping
- Identification of flood prone water body
- Preparation of digital elevation maps
- Fine resolution bathymetry of rivers
- Mapping of land use/ land cover
- Rainfall data
- Inflows and outflows pertaining to river
- Geology of the terrain
- Dredging conditions

The main component of flood warning system is numerical modelling, which is used for the prediction of inundation and run-up along the banks of rivers/ water bodies. Numerical modelling will generate different situations of possible flood generating conditions and combinations. The main intention of developing a flood warning system is for issuing proper advisories in the event of any future flood generating events so as to mitigate the populations and to reduce the impact of destructions caused due to the flood.[10, 12] The setting up of flood modelling scenarios encompassing all possible permutations and combinations of flood generation should be carried out for modelling. The results emanating from the modelling will then be used for warning and for the mitigation of people from the vulnerable areas.[7, 8, 12, 13]

Study Area

The Periyar river basin lies between North latitude of 09°15’30’’ and 10°21’00’’, east longitude of 076°08’38’’ and 077°24’32’’. It flows from Western Ghats to Lakshadweep Sea. Periyar is known as the lifeline of Kerala because it is a back bone to the economy of Kerala. Periyar flows through some parts of Idukki, Ernakulam and Thrissur districts in Kerala and Coimbatore district in Tamil Nadu. The flooding in Periyar river basin is shown in Figure 1.

Figure 1.Flood in August 2018 along the Periyar River Basin

Periyar is the longest river in Kerala with a length of 244 km and has second largest river basin in Kerala. It originates from the Sivagiri group of hills in Sundara Mala in Tamil Nadu. The river flows to the village of Malayatoor, east Cheranalloor and Aluva. The catchment area of Periyar river is 5398 sq km. Its 98% (5284 sq km) lies in Kerala and rest (114 sq km) lies in Tamil Nadu. Periyar flows through some parts of Idukki, Ernakulam and Thrissur districts in Kerala and Coimbatore district in Tamil Nadu. Its major tributaries are Mullayar River, Cheruthoni river, Muthirapuzha, Perinjankutty river and Idamalayar. Periyar river basin has a tropical humid climate with wet and dry seasons. PRB is divided in to 144 sub basins. The selected area is shown in Figure 2.[7, 8, 14, 15]

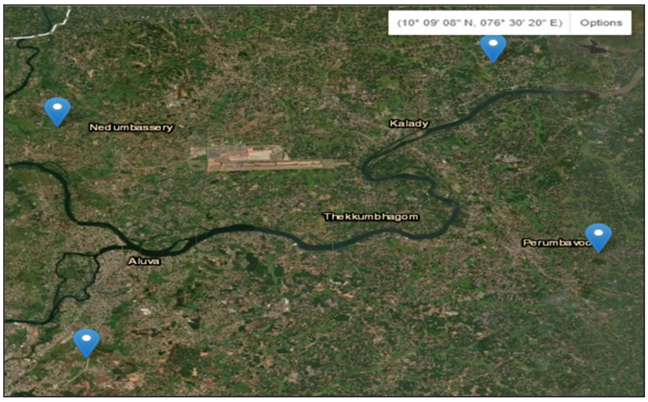

Figure 2.Study Areas Elected for this Investigation

Material and Method

The methodology adopted for this investigation can be explained based on data and the model.

Data Used

Based on the historic data of flood, the most vulnerable areas were selected. Rainfall data on the river basin was studied by using the past rainfall data obtained from Central Water Commission (CWC). The different categories of rainfall selected for this investigation can be categorized as normal, moderate, heavy and hypothetical.[14, 15]

The normal rainfall is 120 mm, moderate rainfall is 156 mm, heavy rainfall is 196 mm and the hypothetical rainfall is 210 mm. Bathymetric data is an important input of modeling. But the collection of bathymetric data is laborious, tedious and time consuming. Hence for the present study, alternate sources of data from satellite were taken. Topographic data for model computations were taken from various satellite sources. The Digital Elevation maps were downloaded from http://www.earthexplorer.usgs.gov/. The digital elevation maps pertaining to SRTM were downloaded in the format of SRTM 1Arc-Second (Figure 3). Figure 3, showing the selection procedure of DEM in SRTM 1 Arc-Second. An arc second indicates 30.87 meters.

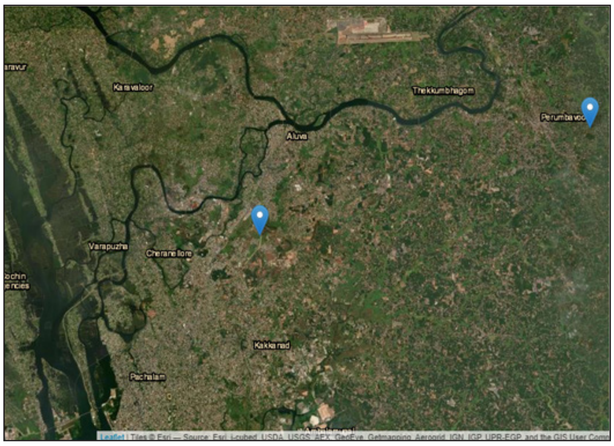

Figure 3.Collection of DEM data in SRTM

Model Used

Several models are available for flood inundation and run-up modelling such as HEC - RAS, HEC - HMS, MIKE II, MIKE FLOOD etc.

These models require fine resolution data for model computation. Collecting fine resolution data is time consuming, laborious and tedious. Purchasing of high-resolution numerical modelling will cost in the range of several lakhs to crore. So, purchasing a fine resolution model of this kind will be very costly. So alternate models like HEC - RAS model which is a globally accepted and well validated/ calibrated model is used in this investigation. HEC - RAS was developed by US Army Corps of Engineers in 1995 which is readily available and is used for simulating both steady and unsteady flow analysis which simulates in a two-dimensional mode.[1, 2, 4, 5, 7, 9, 11, 13]

Saint Venant equation provide the basic Physics of flood modelling.[9, 13]

Consider an elemental control volume dx. Sum of flow 'Q' entering to the control volume at the upstream and the lateral inflow q to the control volume gives the inflow to the control volume. Q is the flow per unit length. Therefore, the rate of lateral flow is qdx. The mass inflow rate and mass outflow rate can be represented as ρ(Q+qdx) and ρ(Q+) respectively where ρ is the density of the water. Volume of the channel element can be written as Adx. A is the cross - sectional area. The rate of change of mass stored within the control volume is written as ∂(ρAdx)/ ∂t. The flood modelling equations can be written in terms of Equation of continuity as:

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

According to Conservation of momentum:

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

Where is the momentum co-efficient; S_0-Bed slope and S_f -Energy slope/Friction slope.

First term in equation 2 represents the local acceleration term, which is the change in momentum due to change in velocity over time. Second term represents the convective acceleration in which the change in momentum is due to change in velocity along the channel. Third term is the pressure force, where the force proportional to the change in water depth along the channel. Next one is the gravity force, here the force is proportional to the bed slope. Bed slope is used to calculate the shear stress at the bed of an open channel which containing fluid that is steady or uniform. Last one is the friction force, where the force is proportional to the friction slope. Friction force is the rate at which the energy is lost along a given length of the channel.

These equations (1) and (2) are together called Saint Venant equation. These equations have various applications and are widely used to predict the flood arrival time and its magnitude. Solution of the Saint Venant equations gives the variation of discharge with time, along the length of the water body which is used for flood forecasting.[3, 6, 9, 12, 16]

The steps associated with the creation of a hydraulic model in HEC-RAS can be summarized as follows:

- Entering geometric data
- Entering the rainfall data
- Creating geometric data
- Creating boundary conditions
- Performing hydraulic calculations
- Collection of output

The main window of HEC - RAS model is shown in Figure 4.

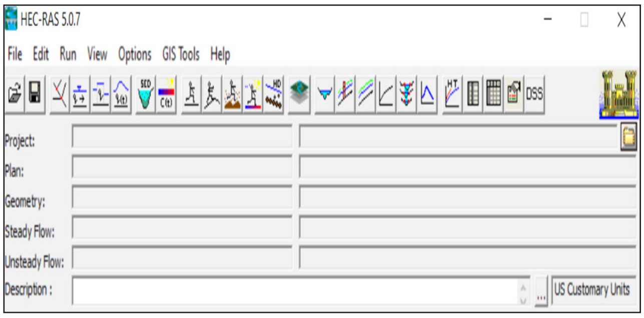

Figure 4.Main HEC - RAS Window

The other primary steps associated with this model computations are:

- Exporting of terrain
- Creation of unsteady flow data
- Creating two - dimensional area on this layer

Small areas are usually chosen for the better working of the HEC - RAS model. If the selected area is larger, computational time will also be larger.

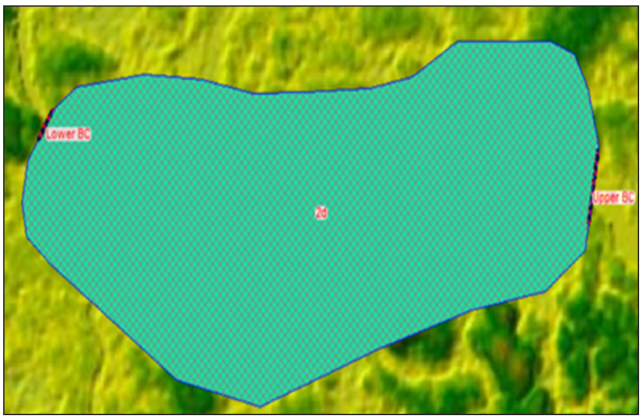

Figure 5.Creation of 2D area with Boundary Conditions

The model is formulated from the upstream direction to the downstream direction. Besides boundary conditions are provided which are necessary to identify the starting water surface and the internal locations with the river system.

Besides each river is having a specific upstream and downstream boundary conditions. By using the 2D area option it is possible to create a 2D area in that layer. After selecting the suitable area, a mesh is created with specific cell size. Above Figure 5, Shows the creation of two - dimensional area with specific cell size.

Subsequently unsteady flow will be generated with reference to the rainfall data which inturn will be giving the flow hydrographs leading to the final flood simulation.

Results and Discussion

The model can be run in two modes - virgin and non - virgin mode. In virgin mode rainfall was taken as the input and no other external discharge was considered. Whereas in non - virgin mode external discharges like dam discharge, tidal reflections, other external reflections etc. will also be taken as part of input.

In this investigation the model was exclusively simulated for virgin mode with reference to rainfall in four modes. The inundation and run-up mainly depend on the mode of rainfall normal, moderate, heavy and hypothetical. The run-up and inundation for all the four scenarios were generated and computed. Around fifteen places on the banks of Periyar were taken for the prediction of inundation and run-up.

Run-up

Run-up is the vertical extend of water which has gone upwards measured with reference to the Mean Sea Level (MSL). The obtained run-up and its graphical representation are shown in Table 1 and Figure 6. For normal rainfall no run-up is predicted by the model from Cheranalloor to Aluva. The prominent other locations like Mattoor, Kizhakkumbhagam, Thekkumbhagam, Kalady too showed zero run-up for normal rainfall. However, for moderate rainfall there was a small increase in the run-up pattern. The run-up value rose to around 0.5 m and is found to be consistently constant towards the entire stretch from Cheranalloor to Aluva. But the model showed a significant increase for heavy rainfall simulations which comes around 1.25 m. The simulated run-up depends on the rainfall data only. In heavy rainfall, the simulated run-up of Marampally, Chalakkal, Thekkumbhagam, Kuttamsserry, Thottumbhagam, Aluva comes to around 1.25 m height. The observed values are around 1.65 m, 2 m, 2.35 m, 1.85 m, 0.78 m and 1.28 m respectively. In the hypothetical mode the run-up values got drastically increased to 2 m in locations from Cheranalloor to Aluva. It should be noted that heavy and hypothetical rainfall can cause run-up along this terrain while comparing with that of normal and moderate rainfall simulations. From these run-up values, the higher run-up along Kizhakkumbhagam can be attributed to the low terrain elevation prevailing in that particular area. The model predicts no significant run-up along the stretch for normal rainfall and moderate rainfall. But it shows some significant run-up along the river bank for heavy and hypothetical source.

The hypothetical mode of simulation which is in tune with extreme rainfall events showed an alarmingly high run-up value of 2 m for the entire stretch.

The simulations of extreme rainfall events expose the vulnerability of prolonged rainfall events along this stretch.

Validation with Field Data

Table 1, summarizes the results of simulation and the observed field signatures. It should be pertinently noted that the observed field data shows a variation from the simulated field data. The difference between the observed and simulated run-up is due to external discharges like dam discharge, tidal reflection, backwater effect, water absorbing properties of soil and its characteristics etc. The simulated results are from virgin simulation where no external discharges are considered. But the observed field data emanates from several external reflections, tidal reflections and that attributes to the variation with simulated data.

Inundation

Inundation is the horizontal extend of water along a land area and is measured with reference to the shoreline of the river. The results of inundation obtained from numerical simulation studies are shown in Table 2 and the plot of inundation is shown in Figure 7.

Here it should be particularly noted that no inundation is predicted by the model for normal rainfall whereas for moderate, heavy and hypothetical rainfall shows some inundations. Locations in the entire stretch starting from Cheranalloor in the east to Aluva in the west with the middle locations like Mattoor, Kottayam, Kalady, Chengal, Thuruthukadavu, Thekkumbhagam, Kanjoor, Kuttamsserry, Thottumbhagam showed no inundation for normal rainfall. In Thottumbhagam the inundation comes around 900 m whereas in Chengal, it is around 800 m for heavy rainfall.

Table 1.Simulated Run-up Values obtained from Numerical Simulation

Locations	Normal rainfall (m)	Moderate rainfall (m)	Heavy rainfall (m)	Hypothetical rainfall (m)	Observed (m)
Cheranalloor	0	0.5	1.25	2	2.16
Mattoor	0	0.5	1.25	2	1.48
Kottamam	0	0.5	1.25	2	1.1
Onampilly	0	0.5	1.25	2	2.07
Kalady	0	0.5	1.25	2	1.85
Chengal	0	0.5	1.25	2	1.79
Thuruthukadavu	0	0.5	1.25	2	1.7
Kanjoor	0	0.5	1.25	2	0.95
Kizhakkumbhagam	0	0.5	1.25	3	3
Marampally	0	0.5	1.25	2	1.67
Chalakkal	0	0.5	1.25	2	2
Thekkumbhagam	0	0.5	1.25	2	2.35
Kuttamssery	0	0.5	1.25	2	1.85
Thottumbhagam	0	0.5	1.25	2	0.78
Aluva	0	0.5	1.25	2	1.25

Table 2.Simulated Inundation Values for Different Modes of Rainfall

Locations	Normal rainfall (m)	Moderate rainfall (m)	Heavy rainfall (m)	Hypothetical rainfall (m)
Cheranalloor	0	150	750	1500
Mattoor	0	150	750	1300
Kottamam	0	150	750	1500
Onampilly	0	150	750	1110

Kalady	0	150	750	1110
Chengal	0	200	800	1110
Thuruthukadavu	0	150	750	1110
Kanjoor	0	150	750	1110
Kizhakkumbhagam	0	150	750	1110
Marampally	0	150	600	1500
Chalakkal	0	150	750	1500
Thekkumbhagam	0	200	750	1500
Kuttamssery	0	150	750	1650
Thottumbhagam	0	250	900	1500
Aluva	0	150	750	1500

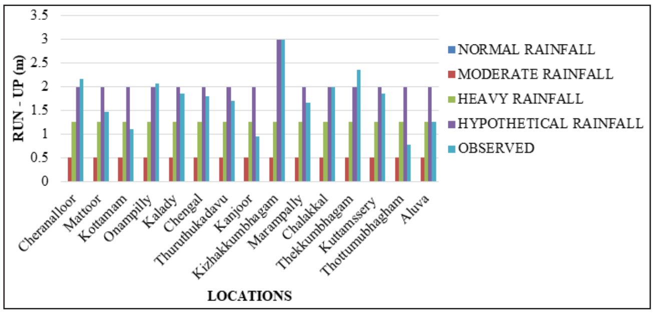

Figure 6.Simulated run-up values along Cheranalloor to Aluva

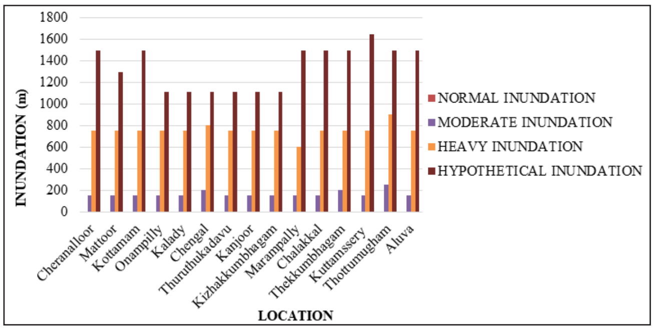

Figure 7.Simulated Inundation Values along Cheranalloor to Aluva

Discussion

The results of investigation can be summarized as follows. The rainfall in Kerala can be classified into normal, moderate and heavy. The vulnerability on the banks of Periyar river is very much dependent on the prevailing topography of the banks. From the modelling results it is clear that a normal or moderate kind of rainfall won't inundate the Periyar banks. Heavy mode of rainfall can cause significant inundation on the banks. But prolonged heavy rainfall will lead to extreme rainfall events leading to the scenario of extreme vulnerability associated with run-up and inundation as simulated by the hypothetical simulation. The variation of simulated and observed inundation can be attributed towards the mode of model, namely virgin model simulation.

In this investigation virgin model simulation was used and no other external discharges like dam discharge, tidal reflections were incorporated. But the observed inundation on the field emanates from external discharges and that underscores the variation in the simulation results.

This investigation recommends the need for simulations involving external discharges for an in-depth vulnerability analysis along this terrain.

Conclusion

Flood is one of the most dangerous natural hazards in the world. Hydrological modelling is a useful tool for determining the dynamic behavior of the flood including run-up and inundation. Hydraulic analyses of the study were carried out using the HEC - RAS software version of 5.0.7. The model showed good performance, which indicates its capability of accurately and efficiently determining run-up and inundation. The obtained result of HEC - RAS model is encouraging and shows that HEC - RAS model is able to simulate the inundation and run-up along the river banks.

The simulated flood run-ups and inundations were compared with field signatures. The computed run-up was very much less than the observed run-up of the field which can be attributed towards the mode of simulation namely virgin simulation. The observed field signatures emanated from several external discharges like dam discharge, boundary reflections, real time tide fluctuation and many other external catalytic factors. Those external factors contributed to heavier run-up whereas the input to our model was exclusively rainfall alone.

The results of these kinds of investigations should be used for mitigation so that intensity of flooding can be reduced. This study also recommends the need for successfully establishing a flood warning system in Kerala with specific reference to the Kerala floods 2018. Besides this investigation recommends the need of simulations involving external discharges with fine resolution real time data on a larger scale. This investigation suggests that these kinds of modelling will be very helpful to generate digital run-up and inundation maps for different permutations and combinations. So, in the event of real time flood warning these maps can be used for giving proper advisories to the people who are living on the banks of Periyar river.

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