One dimensional hydrodynamic modelling of pamba river for identifying the flood vulnerability

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Abstract. Hydrodynamic modelling is a powerful tool to understand and analyse a river flow and its conditions. The identification of flood vulnerability areas of Pamba river helps to minimize the damages associated with the flood. A hydrodynamic river model was customised and calibrated for the river Pamba in Kerala using MIKE HYDRO River model. The model was calibrated using Manning’s roughness coefficient. In this study, we utilize the time series of daily discharge and water level of different gauging station of Centre Water Commission at Kallooppara, Malakkara, Thumpamon and water level data of Thottappalli spillway. The SRTM DEM was used to generate the flood model for the period June to August 2010. The model performance was assessed by comparing observed and simulated water level at the upstream and downstream of the river. The correlation coefficient value obtained in the range of 0.53 to 0.94. The outcomes of the study can benefit future modelling effort through the provision of robust tool to predict water levels at various points of the river. This study can help the water resources policy makers for arriving at suitable mitigation measures.

1. Introduction
Flood was considered one of the natural disasters which can result in large losses and damages. These are usually caused by intense storms that create more runoff than an area can store or that a stream can hold in its normal path[1]. Floods have the greatest potential for damage from all natural disasters, and have great impact on people. Floods are caused not only by rain but also by human activities on the surface of the earth [2]. These may lead to increase in the runoff from rains by deforestation, and urbanization, thus storms that previously would have caused no flooding today inundate vast areas. The reckless building in vulnerable areas, poor management of watersheds, and failure to control the flooding also create the disaster condition [3]. The influence of human being has a great impact on the occurrence of flood events. Due to human influence the frequency and severity of the flood was increased and causes many problems. The extreme shift in land use pattern and rainfall trend, a thorough assessment of the magnitude of flood is essential. The key outputs of flood modelling are flood inundation and hazard maps that are used to measure floodwater’s magnitude, depth and velocity, all of which are critical for identifying and assessing areas at potential risk during a flood event[4]. Such maps form the basis for flood risk maps used to assess flood costs and impacts.

Kerala faced with devaluing flood in 2018 and 2019. Pamba river is one of the most affected regions in 2018 flood. Pamba river drain in to Kuttanad, where flood occurs even during normal rainfall. Pamba river basin being the most affected area in 2018 flood, detailed analysis and
understanding of the flood pattern is very essential. The detailed hydrodynamic study of Pamba River has not been conducted so far. Hence, there is a need for studying the pattern of flood in the study area.

2. Description of study area and data collection
Pamba River was taken for the study. The Pamba River enriches the lands of Pathanamthitta, Kottayam and Alappuzha Districts of Kerala covering an area of 2235 km². The total length of Pamba River is 176 km. The Pamba River originates at an altitude of 1,650 m above sea level from the Pulachimalai hill on the Peerumedu Plateau (Idukki District) in the Western Ghats region. The watershed lies between 9°10’ to 9°40’ in the north latitude and 76°15’ to 77°20’ east longitude [5]. It flows through many places including Kuttanad, an important rice cultivation centre, before emptying into the Vembanad River. The river shares its northern boundary with the Manimala basin, while it shares its southern boundary with the Achankovil basin [6]. There are three gauging stations maintained by Central Water Commission (CWC), Govt. of India stations, in the upstream side of the rivers. The river stretch considered for the study is between the CWC gauging stations; Malakkara, Thumpamon, Kalloopara and Thottappally spillway as shown in the Figure1.

![Figure 1. Location of pamba river in Google map view](image)

The stretch of Pamba River for the study is approximately 38 km. The length of Manimala River and Achenkovil River considered for the study are 15 km and 63 km respectively. The downstream of study area is Thottappally spillway. It consists of a 1310 m long, 365 m wide lead channel with a bridge cum regulator across the spillway channel [7].

A significant collection of input data is needed for the customisation of MIKE HYDRO River. The daily water levels and discharges data recorded in the upstream and downstream of the river till 2017 is downloaded from the INDIA WRIS site. The observed water levels at different gauging stations in different years show that the water levels were high during the years 2007, 2010 and 2013. For this study, the year 2010 was chosen for the simulation of the model. Shuttle Radar Topography Mission digital elevation model (SRTM DEM) with a spatial resolution of 30 metre downloaded from USGS was used in the study. The cross sections are generated from MIKE HYDRO River model using DEM. The value of manning’s coefficient were inferred based on the study conducted by IITM and CWRDM [8].

3. Methodology
The purpose of this modelling study is to generate flood extent and depth at different cross sections. 1D modelling is carried out in MIKE HYDRO River software. It provides more accurate results within less time [1]. It is a one-dimensional, unstable, non-uniform flow simulation model developed by the Danish Hydraulic Institute which solves the 1D hyperbolic dynamic Saint – Venant equations using an implicit six-point Abbott – Ionescu finite difference scheme [9].
Continuity equation:
\[
\frac{\partial Q}{\partial X} + \frac{\partial A}{\partial t} = q
\]  
(1)

Momentum equation:
\[
\frac{\partial Q}{\partial t} + \frac{\partial \left[ y \frac{Q^2}{A} \right]}{\partial X} + gA \frac{\partial H}{\partial X} + \frac{gQ|Q|}{C^2AR} = 0
\]  
(2)

The MIKE HYDRO River setup requires mainly the creation of four modules. These module creating processes were described in detail below.

3.1 River network module
This is a central unit of the model. The river network had to be initially digitized using a topographic base map and DEM data. Here, the river is digitized using Google map and converted to shape file by ARC GIS platform. In GIS, we have to give specific TOPO ID and BRS ID in the attribute table of the river network. These shape file of river network is imported to MIKE HYDRO River. River Network module is also used to visualize the orientation of the inputs likes cross sections, river centre line, boundary condition, etc. so that it can be conformed that the provided inputs are arranged as desired [10].

3.2 River cross section module
Cross section module is one of the important modules of all these four modules. The cross-section data for the river contains two data sets, the raw and the data processed. The raw data defines a cross-section’s physical form by using (x, z) co-ordinates, usually obtained from a riverbed survey [11]. The data processed is derived from the raw data and contains corresponding values for stage, cross-section area, flow distance, radius of hydraulic / resistance. For generating cross section from DEM, the DEM is inserted as a background layer in the mike hydro and the location of cross sections were inserted as a shape file. Auto generate command is used for the generation of 37 numbers of DEM cross sections in all the three rivers considered for the study. Left bank, right bank and lowest bed level for all the cross sections can be defined simultaneously by updating markers for all the cross sections [12].

3.3 Hydrodynamic parameter module
To run a hydrodynamic computation an HD Parameter file must be created. For a variety of variables used during hydrodynamic computation, the HD parameter editor provides the possibility of defining user-defined values. All the parameters in this editor have default values and in most cases these values are found to be good for obtaining satisfactory simulation results. The manning’s coefficient or bed resistance can be applied different for different reaches of rivers [10].

3.4 Boundary condition module
The boundary editor dialog is where hydrodynamic limit conditions are defined. Selecting boundary conditions depends on the modelling area's data quality and physical situation. The Boundary Editor is used to define boundary conditions such as water levels, inflow hydrographs value as time series to the MIKE HYRO River model. Boundary conditions are defined through specifications made on boundary point locations, boundary types, etc. in the Boundary editor [11]. In this study we gave the time series of discharge of gauging stations as upstream boundary condition. The observed water level is taken as downstream boundary condition. For this we have to create dfs0 files of time series data.

3.5 Calibration of MIKE HYDRO River
The only parameter used for calibration at MIKE HYDRO River was the roughness coefficient of Manning, n. The Manning n is defined as Global and Local values in the hydrodynamic parameters for
MIKE HYDRO River. In calibration, the coefficient of roughness was modified to achieve the smallest possible difference between the water depths measured and simulated. The estimated water depth at the three rivers upstream was correlated with the respective observed values. By keeping the global coefficient of roughness as constant around the channel, the setup was simulated and the results compared with the observed values. Furthermore, the global river roughness coefficient was varied from the upstream of three rivers to the downstream of the channel, and the calibration setup was performed. The final value of the global coefficient of roughness was found to be within 0.03 to 0.06 ranges.

4. Results and discussion
The cross sections of rivers were generated by using DEM in MIKE HYDRO River. These are used as the inputs in flood modelling of river. Then the calibration of MIKE HYDRO River results and the graphs of observed and stimulated water level graphs were shown. The output from the MIKE HYDRO River model in the form of flood depth and discharges of each cross section were also obtained.

4.1 MIKE HYDRO River-Calibration
Initially, the MIKE HYDRO River was developed and simulated with default hydrodynamic parameters. The initial value given to manning’s coefficient was 0.033. The model is calibrated by changing Manning’s coefficient (n). It is changed for different stretches of different rivers, as the n value is not uniform throughout the length of the river. Figure 2 shows the graph plotted with observed and simulated time series (TS) water level of Manimala, Pamba Achenkovil Rivers and Thottappally spillway at downstream.

![Figure 2](image-url)

**Figure 2.** Observed and simulated water level after calibration at a) Manimala River b) Pamba River, c) Achenkovil River d) Thottappally spillway
The observed and stimulated water level at downstream of the river are very close to each other compared to the upstream of the river. The correlation coefficients obtained are given the Table 1.

| Points          | From DEM C/S |
|-----------------|--------------|
| Manimala        | 0.941        |
| Pamba           | 0.923        |
| Achenkovil      | 0.529        |
| Thottappally    | 0.969        |

The obtained correlation coefficient values are higher except for Achenkovil River. The highest value of correlation coefficient was obtained in downstream of the rivers at Thottappally. The observed water level is measured with respect to mean sea level (MSL) but the stimulated water level is with respect to another datum from DEM. This may be the reason for the variation in the observed and stimulated water levels at different location of river.

4.1 1D flood model

After calibration, we run the model. The 1D result of the MIKE HYDRO River is described below. The flood depth, water level and discharge at different location of river are simulated. The simulated flood at each cross section of the river is given in Figure 3.

The model developed using DEM cross sections, shows no flooding at the downstream end, which may not a correct depiction. The maximum flood depth obtained by the model is in the range of 8.55 m to 10.9 m as indicated by the yellow colour. The simulated water levels at different location of river are simulated using MIKE HYDRO River model is given in Figure 4.
The maximum water level obtained in the range of 11.96 m to 13.46 m as indicated by the brown colour in the above Fig.4. The downstream of the river Thottappally shows a water level of 1.48 m. The computed discharge at different location of river was simulated and the obtained graph is given in Figure 5 showing the simulated discharge with respect to different colours.

The discharge obtained in between 0 to 332 m$^3$/s. The upstream of Manimala, Pamba and Achenkovil shows a maximum of 155.82 m$^3$/s discharge. The downstream of the rivers have minimum of 199.20 m$^3$/s discharge.
5. Conclusions
The study is about the flood modelling of Pamba river and at each cross section stage, discharge and flood depth values were obtained using the one dimensional model MIKE HYDRO River. The model developed for Manimala, Pamba and Achenkovil gives correlation coefficient values as 0.94, 0.92, and 0.53 respectively at the upstream of the river. The water level and discharge simulated is satisfactory with the observed values at the upstream and downstream of the rivers. The downstream correlation coefficient values obtained is higher compared to upstream. The variations in observed and stimulated water levels are due to different datum used for measurement. The observed water level is based on mean sea level and the stimulated water level is based on a different datum. A correction was made in the topographic data with known values to get more accurate results. From the study, we can understand that, the model developed using DEM cross sections can be used for the simulation of one dimensional model when the measured cross sections were unavailable. This study will help the water resources policy makers to identify the vulnerable zones of flood and for arriving at suitable mitigation measures.

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