Upstream flood hydrograph prediction of Chalakkudy River

A J Jeslin\(^1\) and K S Sumam

Department of Civil Engineering, Government Engineering College Thrissur, Kerala, India

\(^1\)E-mail: jeslin23@gmail.com

Abstract. Flood routing is an important step in any flood modelling study. When the upstream river station data is available the flow of flood water can be routed to downstream and flood inundation studies can be carried out. Flood hydrograph forms the crucial part of any flood routing study. But in certain cases the upstream flow data may not be available where one can use reverse flood routing technique to determine the upstream flood hydrograph, from the available downstream flow data. Reverse flood routing studies involve errors due to its inversing nature and any such reversing techniques are seldom available. Artificial intelligent techniques like genetic algorithm is a better resort where there is data deficiency to perform normal routing or reverse routing techniques. In the present study reverse routing model solved using genetic algorithm, is applied to one of the most flood affected river in Kerala, India during the flood in 2018.

1. Introduction

Flood is considered to be one of the most frequent natural disasters across world. Every flood is associated with loss of lives, damages to cultivated areas, damages to personal property or creation of dangerous public health issues. Flood hydrograph is a crucial element in every flood related studies. In such studies flood routing software can be used to prepare flood inundation maps that may be helpful for an emergency evacuation plan.

1.1. Reverse Flood Routing

Flood routing is the process of determining the downstream hydrograph based on the flow data available at upstream. Owing to the lack of gauge stations, upstream hydrographs are scarcely available in most developing countries. Reverse routing process is a method of determining the upstream hydrograph based on the available downstream flow data and the characteristics of the river. The reverse routing process has all the difficulties of an inverse problem; it is ill posed and computations always subject to instability [1]. Due to these reasons, only limited researches are found in this area.

1.2. Soft computing techniques

In past decades many engineers have attempted to solve problems in water resources engineering field with the help of empirical or regression-based or numerical models. Either Empirical models or regression based models are not universal. The numerical models may require substantial data measurement or parameter estimation. Hence, the models which are reliable, user friendly and realistic and those do not have the limitations of existing methods are to be employed. Artificial intelligence (AI) methods meet this need [2]. Major AI methods that have wide applications in water resources
engineering are Genetic Algorithm, Artificial Neural Network, and Fuzzy Logic. Genetic Algorithm is an optimization technique developed from the evolutionary theory of natural selection by survival of fittest. GAs have fewer assumptions and do not depend on mathematical properties like differentiability, continuity etc. and this make it widely acceptable [3].

This paper attempts to determine the upstream hydrograph from the observed downstream hydrograph for an Indian river using the reverse routing technique achieved by applying the artificial intelligent solving method of genetic algorithm.

2. Literature Survey
In literature various studies regarding reverse routing methods can be seen, especially attempts for reversing Muskingum model and St Venant equations. Most of the studies report the occurrence of errors during inverting due to instability of computations [1,6].

A model for reverse routing by using genetic algorithm was proposed in literature [4]. Three different configurations of hydrometric monitoring of a river reach with considerable lateral inflow were considered, however no precipitation data available, was selected for the study. Values of exponents, coefficients and parameters for all reaches were obtained using genetic algorithm method. Procedure was validated by employing these models in various branches of River Tiber in Italy.

As a continuation to this, a flood modelling study on a river in Turkey with no upstream gauged stations by adopting the methodology suggested in the above study was conducted [5]. The upstream hydrograph was determined by using the genetic algorithm iterations. From the obtained hydrograph, the flood inundation study was conducted using HEC RAS software. It was reported that the model could predict the flooded areas with almost 80% accuracy. Through this paper an attempt to find the adaptability of a reverse routing method using genetic algorithm as suggested in the literature [4,5] in Indian condition by selecting one of the most flood affected river during Kerala flood of 2018 (Chalakkudy River) is performed.

3. Study Area
The Chalakkudy was one of the most effected regions in the flood of 2018. From 14th to 18th August 2018, Chalakudy city, located on the right bank of Chalakudy River faced a massive destruction due to heavy flood. Chalakudy market itself experienced a loss of more than 300 crores due to drowning of food grains stored for the upcoming festival – Onam. Further in 2019 also there was heavy rainfall in Chalakudy area but it was not ended up in heavy floods as in 2018. The occurrence of flood in consequent years indicates its chance in future. So in consideration of the flood happened in 2018, Chalakudy was selected as the study area. Fig.1 shows the major areas of town during flood in 2018.

![Figure 1. Impact of flood in Chalakudy in 2018](image-url)
Chalakudy river is a tributary of Periyar River, and also it is the fifth largest river in Kerala having length of about 145.5 km. It flows through three districts in Kerala; Palakkad, Thrissur and Ernakulam. Even though Chalakudy river is a tributary of the Periyar, for all practical studies it is treated as a separate river by Government or other agencies. Chalakudy river has a catchment area of 1,704 km², out of which 1,404 km² lies in Kerala and the remaining, in Tamil Nadu [7].

Chalakudy town is located at upstream of the river gauging station of Central Water Commission (Arangaly gauging site). At upstream, State Irrigation Board has a gauging station in Chalakudy River, but it is too far from the town. Also, the data of state irrigation department’s gauging station located at Vettilapara is not available due to interstate water conflicts. However, in order to perform flood routing, the discharge at upstream location of Chalakudy town is required. Since it is not available, can be accomplished by using reverse routing technique. Figure 2 shows Google earth image of the Arangaly station (pinned) with a 10 km stretch upstream of the river.

Figure 2. Google Image showing Arangaly station and river stretch

4. Data collection
The data required for reverse routing is basically the downstream data. The River Gauging station selected for the study is Arangaly station of Central Water Commission (CWC), which is located downstream of Chalakkudy town in Chalakkudy River. The data of this station was collected from CWC Office Coimbatore and Bangalore. Discharge data from the gauging station includes the observed and interpolated flow values in m³/s for the year 2018; hydrograph for the period is shown in Figure 3. The peak of the hydrograph is observed from 12th August to 23rd August 2018; this period is selected for the modelling. Also the details regarding the Arangaly station like location, coordinates are obtained from Water Year Book of CWC [8].

Figure 3. Hydrograph at Arangaly for the year 2018-19
5. Reverse Flood Routing

The unknown upstream hydrograph will be obtained by reverse flood routing process by adopting the iteration procedure of Genetic Algorithm. Downstream hydrograph, stage data and velocity data are used for GA iterations. Parameters and coefficients that result in the best solution will be used to calculate the upstream hydrograph.

5.1. Objective Function

Through optimization, GA can minimize (or maximize) an objective function under given constraints. In this study the objective function selected is to minimize the Mean Absolute Error (MAE) (as given in Equation 1) by adopting suitable values for parameters and coefficients that are unknown in the routing equations.

\[
\text{Mean Absolute Error (MAE)} = \frac{1}{n} \sum_{i=1}^{n} |Q_d(\text{model}) - Q_d(\text{observed})| \tag{1}
\]

- \(n\) is the number of observations,
- \(Q_d(\text{model})\) downstream discharge predicted by model,
- \(Q_d(\text{observed})\) is the downstream discharge observed.

5.2. Reverse Routing Equations

The reverse flood routing model used in this study is taken from published literature [4, 5]. The first part of the model is the formulization of the upstream hydrograph. For this, Pearson Type III distribution equation is employed [9]

\[
Q_u(t) = Q_{pu} * \left( \frac{t}{t_{pu}} \right)^{\frac{1}{y-1}} * e^{\left( \frac{1}{y-1} \right) \left( \frac{1}{y-1} \right)} + Q_b \tag{2}
\]

where \(Q_u(t)\) is flow discharge at upstream, \(Q_{pu}\) is peak discharge at upstream, \(Q_b\) is base flow rate, \(t_{pu}\) is time to peak and \(y\) is the hydrograph shape parameter. The following basic routing equation can be obtained on the basis of the continuity equation [4].

\[
[Q_u(t - T_l) + q_l(t)L] - Q_d(t) = \frac{ds}{dt} \tag{3}
\]

where \(Q_u(t)\) is the downstream discharge, \(q_l(t)\) is unit lateral inflow rate, \(L\) is river reach length, \(S\) is storage, \(T_l\) is wave travel time and \(t\) is time. From Equation (3), the downstream discharge can be stated as:

\[
Q_d(t) = [Q_u(t - T_l) + q_l(t)L] - \frac{s(t) - s(t - T_l)}{T_l} \tag{4}
\]

The next two equations of the model are the auxiliary components to Equation (4). The storage \((S)\) can be related to the downstream flow stage as follows.

\[
S(t) = \eta WLh_d(t) \tag{5}
\]

where \(\eta\) is storage coefficient, \(W\) is channel width, \(h_d(t)\) is downstream flow stage. The model relates to the lateral flow to the downstream discharge as follows:

\[
q_l(t)L = \alpha Q_d(t)^\beta \tag{6}
\]

where \(\alpha\) and \(\beta\) are coefficients.

5.3. Reverse Routing Technique

The sequence of using these equations for the reverse flood routing model using Genetic Algorithm technique can be explained by using a flow chart as shown in Figure 4.

5.4. Evolver 8.0

Reverse routing model explained in the above section was employed by using suitable software that utilizes the principle of Genetic Algorithm for optimization problems. In this study trial version of Evolver 8.0 developed by Palisade Corporation is being used. ‘The Decision Tools Suite (DTS) 8.0’ is a collection of decision analysis and statistical analysis add-ins developed by Palisade Corporation and
designed for use with Microsoft Excel 2010 or higher. There are six individual add-ins included in the suite: @RISK, Evolver, Neural Tools, Precision Tree, Stat Tools, and Top Rank. Evolver is one among them. This software uses the ‘Recipe Solving Method’ for selection of new off springs for every iteration to minimize the objective function under specified constraints.

6. Result

The Evolver software needs a table of constant values whose values cannot be altered and a table of adjustable cells (Table 1) whose values can be varied within the given range so as to meet the objective function i.e. to minimize the mean absolute error. Constant values are length of reach = 12 km and width of reach = 90 m. Trials were carried out several times by creating a sequence of iterations as per method explained in flowchart (Figure 4) in MS Excel and the one resulted in best output was chosen (Table 2). Graphs obtained as output of computations are shown in Figure 5 and 6.

![Figure 4. Reverse Routing Model (Source: Kaya et al., 2017)](image-url)
Table 1. Adjustable Cells

| Adjustable cells                                      | Min  | Max  | Units |
|-------------------------------------------------------|------|------|-------|
| Upstream discharge                                     | $Q_{pu}$ | 4601 | 5000  | m$^3$/s |
| Time to peak                                           | $t_{pu}$ | 432000 | 604800 | seconds |
| Hydrograph shape parameter--rising limb                | $y_1$ | 1    | 65    | No unit |
| Hydrograph shape parameter--falling limb               | $y_2$ | 1    | 65    | No unit |
| Coefficient-eta                                        | $\eta$ | 0    | 10    | No unit |
| Coefficient—alpha                                      | $\alpha$ | 0    | 1    | No unit |
| Coefficient–beta                                       | $\beta$ | 0    | 10    | No unit |

Table 2. Reverse routing model in MS Excel

![Figure 5. Observed Qd (ob) and computed Qd (comp) downstream hydrograph](image-url)
The results obtained after performing reverse routing iteration in Evolver 8.0 can be summarized as below:

- The variation of discharge between upstream and downstream hydrographs is about 300 m$^3$/s and time lag comes to 2 hours. (From graph and computations)
- Hydrograph shape parameter:
  - For the rising limb the value lies between 1 and 1.5
  - For the falling limb the value lies between 1 and 1.1
- Storage coefficients $\eta$
  - Value lies between 1 and 1.1
- Lateral flow constants $\alpha$ and $\beta$
  - Value lies between 0 and 0.1
- Mean Absolute Error: 84.65 m$^3$/s
- Error observed: 5 %

7. Conclusions

This study was conducted on Chalakudy River with an objective to determine the unknown upstream hydrograph from the available downstream flow data. Reverse routing model used in this study could predict the upstream hydrograph with a Mean Absolute Error = 84.65 m$^3$/s and this error is less than 5%. The range of parameters and coefficients suited for the Chalakudy River was also identified.

The study has certain limitations related to assumptions adopted in equations used in model building. When there is no upstream gauging stations or when upstream flow data is not available for public, to conduct various flood related studies like flood modelling, flood mapping etc., this artificial intelligent technique of genetic algorithm to solve reverse routing problem can be applied for a more reliable result.

References

[1] Dooge J C I and Bruen M 2005 Problems in reverse routing Acta Geophysica Polonica53 4.
[2] Tayfur G 2012 Soft Computing in Water Resources Engineering: Artificial Neural Networks, Fuzzy Logic and Genetic Algorithms, WIT Press Southampton.
[3] Liong S Y, Chan W T and Shree R J 1995 Peak-Flow Forecasting with Genetic Algorithm and SWMM Journal of Hydraulic Engineering121 8.
[4] Zucco G, Tayfur G, and Moramarco T 2015 Reverse Flood Routing in Natural Channels using Genetic Algorithm Water Resources Management 29 12.

[5] Kaya C M, Tayfur G and Gungor O 2017 Predicting flood plain inundation for natural channels having no upstream gauged stations Journal of Water and Climate Change 10 2.

[6] Das A 2009 Reverse stream flow routing by using Muskingum models Sadhana 34 3.

[7] Maya K 2005 Studies on the nature and chemistry of sediments and water of Periyar and Chalakudy rivers Cochin University of Science and Technology Kerala India.

[8] Water Year Book June 2017– May 2018 West Flowing Rivers Basin Volume I Stream Flow & Suspended Sediment Data CWC.

[9] Moramarco T, Pandolfo C and Singh V P 2008 Accuracy of Kinematic Wave Approximation for Flood Routing II Unsteady Analysis Journal of Hydrologic Engineering 13 11.