Comparative Analysis of Flood Forecasting Techniques Using RRI, HEC-RAS & Gauge-to-Gauge Correlation Method for Delhi, INDIA

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ABSTARCT

The study aims at suggesting a suitable replacement of the existing Gauge-to-Gauge Correlation (GGC) method at Delhi by a hydrological model based flood forecasting system which increases the current forecast lead time from 15 to 24 hrs. Rainfall-Runoff-Inundation (RRI) and HEC-RAS are the two models taken into consideration in the study along with GGC method for doing the comparison. In the study, both the models have been calibrated and also a new correlation equation, correlating the gauges of upstream station Mawi and downstream forecasting station Delhi Railway Bridge (DRB) with the lag time of 24 hrs have been derived based on historical data. The models were further validated by doing flood water level forecasting for twelve different flood events. Finally, it was observed that RRI shows highest coefficient of correlation and coefficient of determination (0.91, 0.75) followed by HEC-RAS (0.84, 0.66) and GGC (0.79, 0.002). Based on the results obtained, the study has recommended implementing RRI model for flood forecasting at DRB.

Keywords: Flood Forecasting, Flood Inundation, HEC-RAS, RRI, Gauge-to-Gauge Correlation

INTRODUCTION

In India, flood causes considerable damage to human lives and property almost every year. On an average the total land and crop area that gets affected due to floods annually is about 186,000 km^2 and 37,000 km^2 respectively. River Yamuna brings recurrent floods in Delhi. It crossed its danger level of 204.83 meters fifteen times during the last 20 years. Recent floods in the year 2010 were the most severe that caused the maximum water level rise of 207.06 meters. Therefore, accurate and timely flood forecasts and advance warning is very important for providing valuable time to people and civil authorities in taking various preventive measures.

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The current practice used for flood forecasting by Central Water Commission (CWC) at Delhi and in India is GGC method which has some inherent drawbacks.

First, warning time it offers is short and limited. Second, it gives no information about the inundation extent and its depth and third, it does not offer smooth integration with the modern technology for the purpose of forecast formulation and its dissemination. The currently used flood forecasting technique is not only inadequate due to its inherent drawbacks but also has no hydrological basis. There is need to replace the existing setup at Delhi by a hydrological-model based flood forecasting technique to increase lead time to 24 hrs.

THEORY AND METHODOLOGY

The study compares the flood forecasting performance of RRI and HEC-RAS which are the Rainfall-Runoff and channel routing models respectively. Rainfall-Runoff-Inundation (RRI) model is a two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously (Sayama, 2012). The model deals with slopes and river channels separately. The flow on the slope grid cells is calculated with the 2D diffusive wave model, while the channel flow is calculated with the 1D diffusive wave models. For better representations of rainfall-runoff-inundation processes, RRI model simulates also lateral subsurface flow, vertical infiltration flow and surface flow. RRI couples 1D diffusive wave model for channel flow and 2D diffusive wave model for slope. HEC-RAS on the other hand is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. The unsteady flow simulation component of the HEC-RAS modeling system is capable of simulating one-dimensional unsteady flow through a full network of open channels which can also perform mixed flow regime (subcritical, supercritical, hydraulic jumps, and draw downs) calculations. HEC-RAS is used as a one-dimensional flood routing model based on dynamic wave equation in this study. GGC method is purely a statistical technique where the N^{th} hours stage of upstream base station and $(N+T)^{th}$ hour stage of downstream forecasting stations are correlated, where T is the travel time of flood wave between the base station and forecasting station.

Both RRI and HEC-RAS models in the study have been calibrated with 2010 flood event at DRB. Also, for GGC method, following correlation equation based on historical gauge data for Mawi-Delhi, 90 km reach, has been derived.

$$h_{DRB}(t) = 0.044 h_{Mawi}(t-24)^{1.5521}$$

Where,

$h_{DRB}(t)$ = Gauge at DRB at time (t) hrs

$h_{Mawi}(t-24)$ = Gauge at Mawi at (t-24) hrs

The methodology (**Figure 1**) entails application of calibrated RRI and HEC-RAS models and newly derived GGC correlation equation to forecast for 12 flood events. The general process followed is like simulated hydrograph was taken as output from RRI and HEC-RAS models. This simulated discharge was bias corrected to improve forecasting accuracy. Further this forecasted discharge at DRB was converted into forecasted water level by using the rating curve at DRB. For GGC method forecasted water level for DRB was obtained using the derived correlation equation. Further, forecasted water levels derived from the respective three methods were compared with the observed water levels at DRB. Finally the best performing method was suggested as the viable flood forecasting method for Delhi.

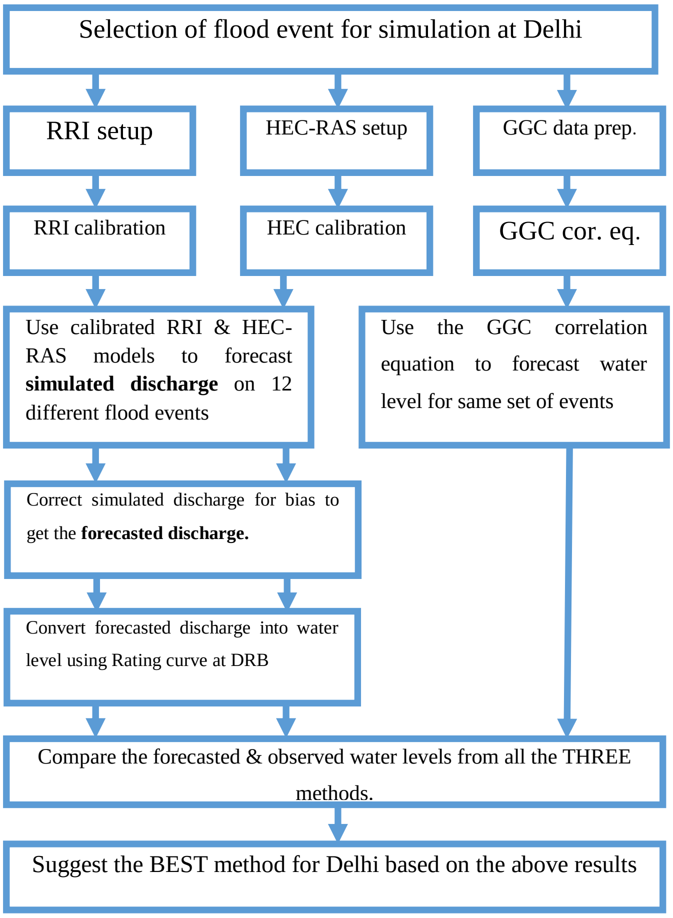

Figure 1: Methodology

DATA

For RRI model 30 arc-second DEM, flow direction and flow accumulation HydroSHEDS have been used as geometric data input. In the study gauged rainfall data from ten stations spread all over the upper Yamuna basin is used as input. The rainfall of June, July, August, September and October for the year 2010 is taken into consideration. The method of Thiessen polygon interpolation is used for creating input rainfall for RRI simulation. The soil data for the study has been taken from the

Harmonized World Soil Database of the FAO soil portal, which is a 30 arc-second raster of 1:5000000 scale. For HEC-RAS 90 km reach of Yamuna River from Mawi to Delhi is taken into consideration with simulation period taken from 25th July, 2010 to 22nd September, 2010. Further river cross section data at 10 km interval has been used in the study which was further interpolated into 500 meter interval by the model. At Mawi station upstream boundary condition was given in the form of discharge. The DRB station is selected as downstream station for forecasting targeting point where downstream boundary condition (in this study, Rating curve) is given for HEC-RAS model.

RESULTS & DISCUSSION

After completing the calibration of RRI and HEC-RAS models and deriving the correlation equation for GGC method, all the three methods were applied on the same set of 12 flood events, taken from 10 years data. The forecast lead time for the study was taken as 24 hrs. The result obtained in the form of forecasted water levels were compared with the observed water levels for the respective flood events and plotted as shown below in **Figure 2**

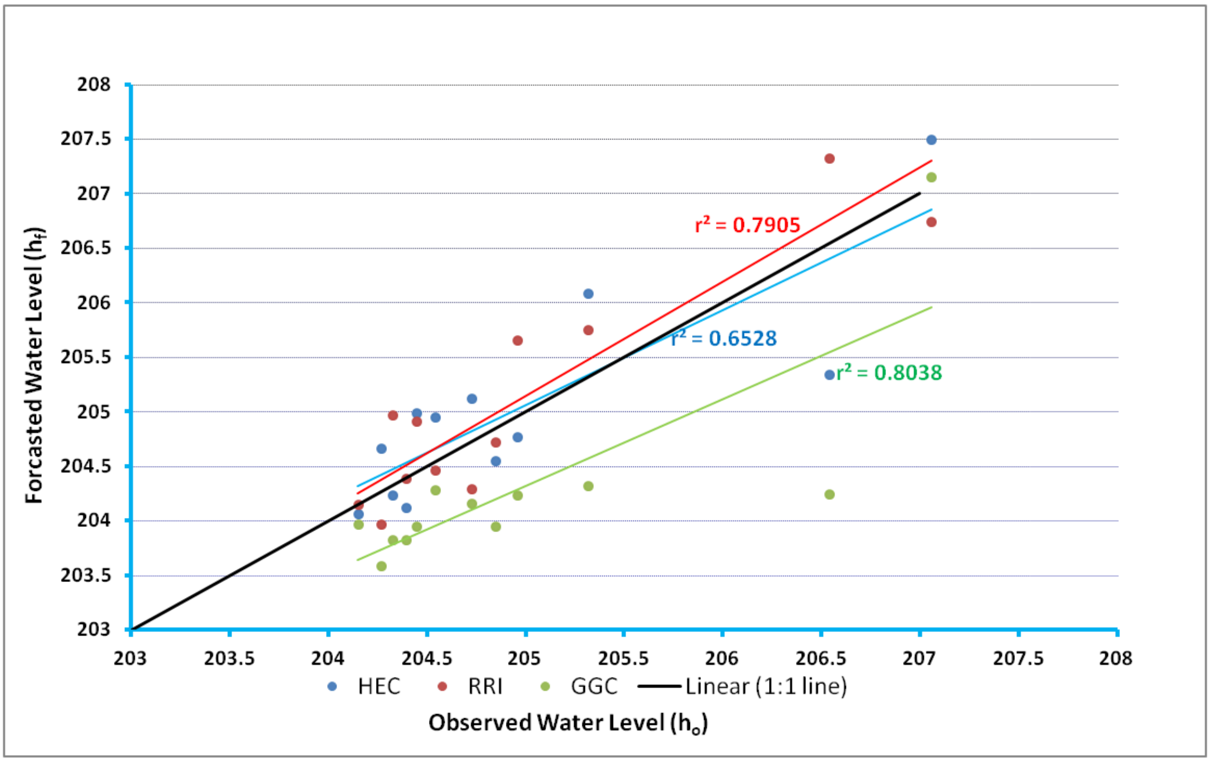

Figure 2: Graphical representation of RRI, HEC-RAS & GGC results at DRB

The graph not only shows the scatter plot for all the three methods but also sketches their respective trend lines. A line (1:1) is also drawn as the reference line for comparing the three trend lines.

The key findings from the figure are summarized as follows.

- The red line for RRI is above the 1:1 line which implies that RRI is generally overestimating. Since the line is only slightly above the 1:1 line, the degree of overestimation is relatively small.
- It could also be seen from the RRI line that the degree of overestimation is smaller at lower gauge value and tends to get larger at higher gauges.
- The blue line for HEC-RAS is above the 1:1 line at lower gauges and crosses it to get below it at higher gauge values. This implies that HEC-RAS generally overestimates at lower gauge values and tends to underestimate at higher gauges.
- The line for HEC-RAS shows larger forecasting error, from underestimation at lower gauges to overestimation at higher gauges, though the degree of over or under estimation is not large.
- The green line for GGC is below the 1:1 line, implying that the derived GGC method is consistently underestimating.
- Since the GGC line is much below the 1:1 line, the degree of underestimation tends to be large. As GGC method is purely statistical technique and has no hydrological basis, there could not be a hydrological explanation for such underestimation or overestimation forecasting errors.
- The underestimation by GGC method can be attributed to the errors in the data used for deriving the correlation equation in the study.

Two performance indices, correlation (r) and Coefficient of Determination (CoD) is used to measure the performance of the results obtained from the three methods under the study and is shown in the **table-1** below

Table 1: Performance Index for RRI, HEC-RAS & GGC : *r* is correlation coefficient, R^2 is coefficient of determination

Index		**RRI**	**HEC-RAS**	**GGC**
r	**:**	**0.91**	0.84	0.79
R^2	**:**	**0.75**	0.66	0.002

For all the three methods discussed in the study, forecasted water levels are closer to the observed ones at lower stage flows and tend to scatter away as the flood level increases. It is seen that maximum R^2 (0.75) is observed in case of RRI results followed by HEC-RAS and GGC.

Though, the correlation coefficient for all the three methods are relatively high and in the same range, coefficient of determination varies from highest for RRI to lowest for GGC with HEC-RAS in between. Since coefficient of determination is the measure of goodness of fit for a model, its highest value for RRI implies that RRI fits best among the three methods and its reliability of forecast is maximum among the three. Apart from the performance indicator as mentioned above, there are other advantages of using RRI. First, RRI takes hydrological inputs (rainfall, topography, land use etc.) therefore better hydrological representation of a catchment. Second, For whole basin as a unit, RRI should be preferred. HEC-RAS being a dynamic wave model is used only for small reaches. For long reaches and larger basins HEC-RAS simulation tends to go unstable. Finally, GGC, with no hydrological basis, should be avoided as far as possible.

1. RECOMMENDATIONS

In the study the performance of RRI with respect to HEC-RAS and GGC methods is better and may be recommended for installation for flood forecasting at Delhi. Implementation of the RRI model for flood forecasting at Delhi will have following benefits

1. It will increase the forecast lead time from 15hrs to 24 hrs. This will be a great advantage for concerned administration in carrying out various preventive measures in flood disaster mitigation.
2. It will add more reliability to the forecast issued than the existing forecast based on GGC method.
3. RRI gives not only water level forecast in the channel but also inundation depths and their extents. The performance of RRI model for inundation simulation may be further investigated. Such information will be useful for a metropolitan city like Delhi where stakes are very high. Early information about inundation will help in targeted and effective evacuation of people.

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3. REFERENCES

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