# Application of Geomorphic Direct Runoff Hydrograph Model for Arid Regions

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**Abstract**—Rainfall runoff models play a significant role in water resource engineering for future planning, management and development. This paper investigates the results obtained from two hydrologic techniques namely Nash Geomorphic Instantaneous Unit Hydrograph (GIUH) Model. Predictions are made for future use of Small Dams Organization Rawalpindi Division, Pakistan. Shahpur dam catchment was used as study area. Geomorphic parameters of Clark model were calculated using digital elevation model (DEM). Satellite imageries of catchment were processed using ArcGIS to estimate geomorphologic parameters. The model was applied for different storm events. Excess rainfall hyetograph was obtained from measured precipitation and direct surface runoff hydrograph was obtained by GIUH model. To check model efficiently two types of statistical parameters were used namely percentage error in peak (PEP) and percentage efficiency. The results from Nash GIUH were compared with those simulated by original Nash model and found that GIUH models are equally good even if the Nash model parameters are obtained by optimization.

**Index Terms**—Geomorphic, Model, PEP, Hydrograph, Events, Storms, Rainfall

## 1 INTRODUCTION

Water resource engineering is very old engineering as water is life. Water resource engineering projects are being given high importance word-wide. With population growth and development, the competition for water among agricultural, urban, industrial and environmental uses is increasing (Dawadi and Ahmad, 2013; Qaiser et al., 2013; Wu et al., 2013). Climate variability is resulting into extreme hydrologic events such as flash floods and hill torrents in some areas and drought in others, (Forsee and Ahmad, 2011; Ghumman et al. 2011, Ghumman et al. 2013 ). Water management can be improved by enhancing precipitation estimates (Kalra and Ahmad, 2012), flow estimates, sediment management, reservoir and delivery infrastructure operation, conservation, maintenance; and governing institutions ((Carrier et al., 2013; Kalra et al., 2013a; Kalra et al., 2013b; Kalra et al., 2013c); Mirchi et al., 2012).
The engineering related to rainfall and runoff is highly complex because of the unpredictability of hydrological processes and global climate change (Mikhailova et al. 2012, Yasinskii and Kashutina 2012) and Dobrovolski (2012) have noticed prospective impact of global climate changes on river runoff. In present scenario of global changes substantial adaptation is required to guarantee appropriate engineering, planning and management of water resources. Readily available runoff simulations are utmost important for this purpose. At the same time runoff prediction from a catchment is very complicated and is difficult to simulate accurately.

It is further aggravated in case of catchments lying in arid or semiarid regions such as Shah Pur Dam in Attock District, Pakistan. There are usually intense rainfall events having high spatial variability and short interval run offs in arid and semi-arid regions. Mostly the relevant rainfall runoff data is scanty in these circumstances due to which the rainfall-runoff models hardly simulate the real response of the watershed. Identification of model parameters for arid and semi arid regions is a big issue due to smaller number of rainfall runoff events as compared to those in humid regions. It is utmost important to explore new tools as well as to investigate application of the existing tools for solving problems related to the real life in developing countries like Pakistan. Developing countries need to take help from the work done by the researchers world-wide. Nguyen et al. (2009) have modeled the Can Le catchment (Vietnam) runoff with the help of the geomorphologic instantaneous unit hydrograph (GIUH). Ahmad et al. (2009), Ahmad et al. (2010), Ghumman et al. (2011) and Ghumman et al. (2012) has presented work using one of Clark, Nash or GIUH models. Troitskaya et al., (2012) have developed new tools related to satellite altimetry for investigating water resources. Design of hydraulic structures, river improvement works, run off mitigation schemes, run off estimation, management of water resources and sustainable water resources planning and development preferably require work on application of the existing rainfall runoff models to simulate runoff. The work of Johnston and Kummu (2012) and Ahmed (2012) is important regarding this field. Ghumman et al., (2014) has done work on GIUH models for a large catchment. Although the floods in large catchment areas may be dangerous but the peaks of flash floods and hill torrents from small catchment areas are high and time to peak is small. Such floods may be more dangerous. Hence investigations regarding runoff simulations by GIUH rainfall runoff models for small areas in developing countries should also be given high importance. The present paper deals with runoff simultaneous by application of two models for real life data of a small watershed in semi arid region of Pakistan having hill torrents and flash floods.

## 2 STUDY AREA

Shahpur Dam is a component of main small dam's chain in Punjab Barani Areas. The dam site is about 8 km north of

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Fatehjang town District Attock. The dam site is situated in Kala Chitta Range in Attock Distrcit, at about 50 km away from Islamabad and 10 km from Fatehjang, District Attock. The topography of the area includs the area ranging from reduced level (RL) 424 to 540 m. The total catchment area is about 202 $km^2$. The dam is of concrete gravity type and capacity of the spillway is 35600 $ft^3/s$. The dam was commissioned by Small Dams Organization, Government of Punjab in 1982 and was completed in 1986 at a cost of Pakistani Rupees 36.5 million (about 1 million US $ according to the currency rate at that time).

## 3 MATERIALS AND METHODS

### 3.1 Estimation of Geomorphologic Parameters

Geomorphologic characteristics of the Shahpur watershed were estimated using Arc GIS 10.1 software. The satellite imageries of Shahpur catchment was digitized and catchment area, stream order, stream areas and stream lengths were calculated. The maximum order of the streams in Shahpur dam watershed was 5. The corresponding length and area of the surface runoff of each channel order was measured. Using Horton's law geomorphologic parameters, such as bifurcation ratio (RB), stream length ratio (RL), and stream area ratio (RA), were calculated for the each order channels.

## 4 NASH AND GIUH-NASH MODELS

The original Nash's model is based on linear reservoir theory for input and output in a watershed. The ordinates of Nash's Instantaneous Unit Hydrograph are given as Nash (1958)

$$U_n(t) = \left[\frac{1}{k\,\Gamma(n)}\right]\left[\frac{t}{k}\right]^{n-1} e^{-\frac{t}{k}} \qquad (1)$$

Where 'n' and 'k' are parameters obtained from geomorphic characteristics of the catchment and 't' is the time and Γ(n)=(n-1)! for integer n. Nash's proposed equation is two parameter gamma function. The first parameter 'n' is the shape factor or degrees of freedom (number of linear cascades attenuating the IUH peak) and second parameter 'k' is the scale factor (time of storage, equal for all linear cascades).The parameters n and k are related as $\left[\frac{t}{k}\right] = n - 1$

So the right hand side (RHS) of equation of above equation can be written as

$$\left[\frac{(n-1)^n}{\Gamma(n)}\right] e^{1-n} = 0.58\left(\frac{R_B}{R_A}\right)^{0.55} R_L^{0.05} \qquad (2)$$

Rosso (1984) proposed expressions using regression analysis for estimation of Nash's model parameter 'n' and 'k' as:

$$n = 3.29\left(\frac{R_B}{R_A}\right)^{0.78} R_L^{0.07}$$

$$k = 0.7\left(\frac{R_A}{R_B R_L}\right)^{0.48}\left[\frac{L_\Omega}{V}\right] \qquad (3)$$

Where $R_A$, $R_B$, $R_L$ are Horton's ratios, $L_\Omega$ is length of highest order stream in kilometers and V is expected peak velocity in meters per second. k is in hours.

## 5 MODEL PERFORMANCE CHECK

To check efficiency of the models two error functions have been used as given below.

### 5.1 Model efficiency

$$EFF = \left(1 - \frac{\sum_{i=n}^{n}(Q_{oi}-Q_{si})^2}{\sum_{i=n}^{n}(Q_{oi}-\bar{Q}_{oi})^2}\right) \times 100 \qquad (4)$$

Here EFF is the percentage efficiency of the model, $Q_{oi}$ is the observed discharge of ith ordinate and $Q_{si}$ is simulated discharge of $i^{th}$ ordinate. And 'n' is the total no of ordinates.

### 5.2 Percentage error in peak

$$Q_{pep} = \left(1 - \frac{Q_{ps}}{Q_{po}}\right) \times 100 \qquad (5)$$

Where $Q_{pep}$ is percentage error in discharge in $ft^3/s$. $Q_{ps}$ is the calculated peak discharge and $Q_{po}$ is the observed peak discharge in $ft^3/s$. Similarly errors can be found in time to peak (PETp) and volume of runoff (PEV).

## 6 SUMMARY, RESULTS AND DISCUSSIONS

The parameters of Nash GIUH model (n and k) are calculated from the geomorphic characteristic of the watershed area where as the original Nash model parameters were determined by hit and trial optimization. The model was applied to four rainfall events of 2013 and simulated runoff was compared with observed direct runoff hydrographs. The peak velocity was calculated using the equations mentioned above and time of concentration was obtained from geomorphic parameters. The kinematic wave coefficient was estimated to be 0.7 ($s^{-1}.m^{-1/3}$). The length of longest stream was 23.47 km. The parameter values of both the models are given in table 2. It is observed that he parameters estimated from geomorphic characteristics are close to the best parameters calculated by hit and trial for Nash model. The runoff generated by the two models for different events is shown in Figs. 1 to 10. The model efficiency and the error between the observed and simulated peak runoff (QPEP), time to peak (PETp) and volume of runoff (PEV) is given in table 3. It is observed that results of both the models Nash and Nash GIUH are very close. This shows that in case the data is scanty and calibration/validation of the runoff model is not possible then the GIUH model can be used. The efficiency of GIUH model ranges from 44% to 99%. In Nash GIUH model storm event 2 is most efficient. Same is the case with time to reach the peak discharge.

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Table 1: Geomorphologic parameters and stream order for Shahpur catchment.

| Horton Stream Order | Total stream numbers | Mean Stream Length (Km) | Mean stream area (Km2) | (RB) | (RL) | (RA) |
|---|---|---|---|---|---|---|
| 1 | 113 | 0.93 | 1.8 | 5.13 | - | - |
| 2 | 22 | 2.14 | 7.07 | 3.66 | 2.30 | 3.92 |
| 3 | 6 | 4.57 | 20.56 | 3 | 2.13 | 2.90 |
| 4 | 2 | 4.61 | 61.69 | 2 | 1.00 | 3.00 |
| 5 | 1 | 8.81 | 202 | - | 1.90 | 3.27 |
| Mean | 3.44 | 1.80 | 3.20 | | | |

Table 2: Nash and Nash GIUH model parameters

| Model | Nash | | Nash GIUH | |
|---|---|---|---|---|
| Event No./parameters | n | k | N | K |
| 1 | 1.74 | 1.217 | 1.41 | 1.14 |
| 2 | 2 | 2.2 | 1.41 | 2.1 |
| 3 | 2 | 1.17 | 1.41 | 2.98 |
| 4 | 1.74 | 1.65 | 1.41 | 1.17 |
| 5 | 2 | 1.85 | 1.41 | 2.00 |
| 6 | 2 | 2.1 | 1.40 | 2.20 |
| Arithmetic Mean | 1.91 | 1.69 | 1.40 | 1.93 |
| Geometric Mean | 1.90 | 1.64 | 1.40 | 1.82 |



Table 3:Nash and Nash GIUH model's parameters

| Event Number | Nash GIUH | | | | Nash | | | |
|---|---|---|---|---|---|---|---|---|
| | EFF | Q(PEP) | PETp | PEV | EFF | Q(PEP) | PETp | PEV |
| 01 | 90.00 | -7.11 | 0 | 3.6 | 89.93 | -7.10 | 0 | 3.3 |
| 02 | 99.56 | 3.41 | 10 | -2.2 | 99.10 | -0.68 | 10 | -9.3 |
| 03 | 98.85 | 8.24 | 0 | 0.50 | 99.99 | -0.43 | 0.5 | 1.68 |
| 04 | 96.67 | -2.43 | -6.6 | -0.01 | 99.70 | -50.73 | 0.5 | -0.5 |
| 05 | 75.19 | -38.01 | 5.2 | 5.76 | 70.91 | -28.01 | 5.2 | 5.03 |
| 06 | 44.21 | 2.20 | 0.5 | -5.866 | 44.14 | 1.20 | -5.2 | -5.66 |
| 07 | 70.41 | 8.47 | -0.09 | -6.12 | 71.71 | 4.47 | 4.5 | 15.21 |
| 08 | 80.21 | 14.1 | 40 | -5.67 | 89.21 | 4.1 | 20 | -5.88 |
| 09 | 78.12 | -8.47 | 1.5 | 28.20 | 81.62 | -6.70 | 4.5 | 15.21 |
| 10 | 84.32 | 6.11 | 0.5 | -27.33 | 83.23 | 6.10 | 0.4 | -15.8 |
| Mean | 78.88 | -1.24 | 5.12 | -1.27 | 79.162 | -8.642 | 3.826 | 1.068 |

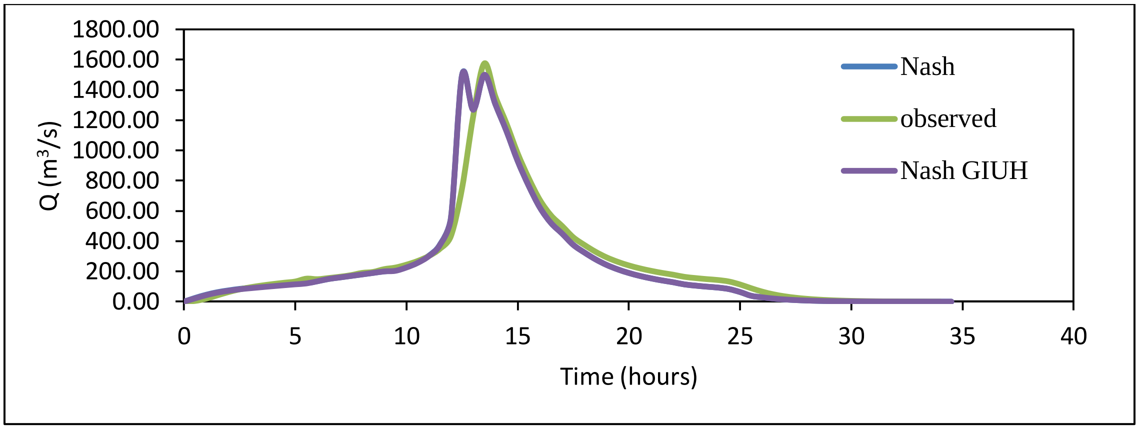


Fig. 1:The Calculated DSRO hydrographs at outlet by the Nash , Clark, Nash GIUH and Clark GIUH models, and observed outlet DSRO hydrograph for Event No.1

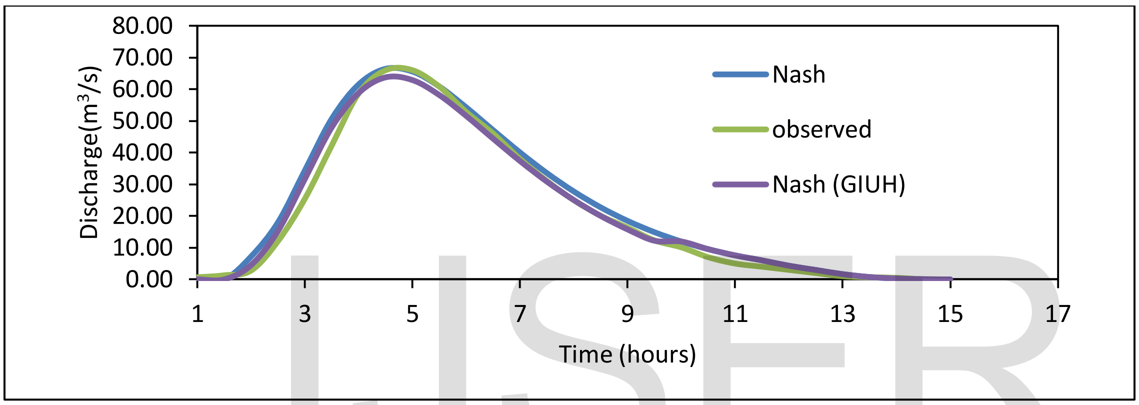




Fig. 2:The Calculated DSRO hydrographs at outlet by the Nash , Clark, Nash GIUH and Clark GIUH models, and observed outlet DSRO hydrograph for Event No.2

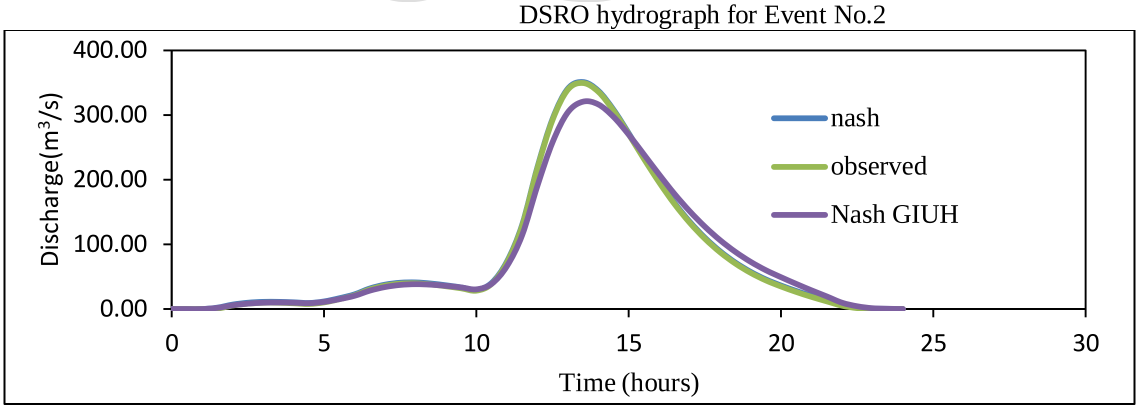


Fig. 3:The Calculated DSRO hydrographs at outlet by the Nash , Clark, Nash GIUH and Clark GIUH models, and observed outlet DSRO hydrograph for Event No.3

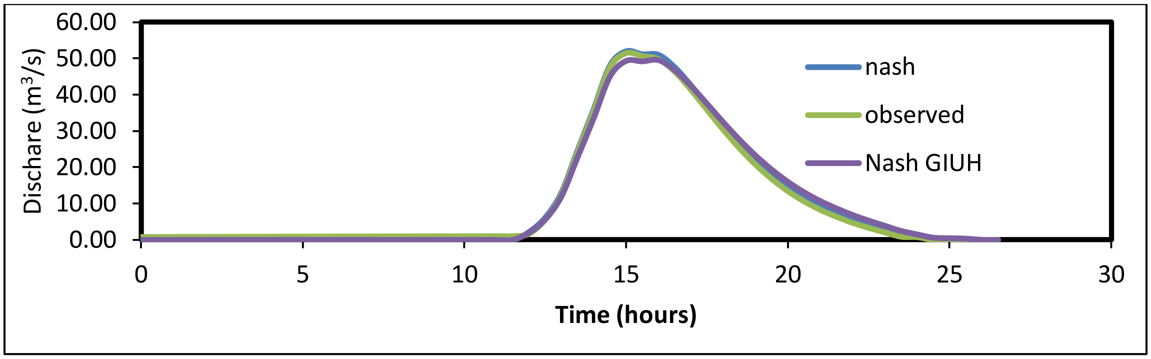


Fig. 4:The Calculated DSRO hydrographs at outlet by the Nash , Clark, Nash GIUH and Clark GIUH models, and observed outlet DSRO hydrograph for Event No.4

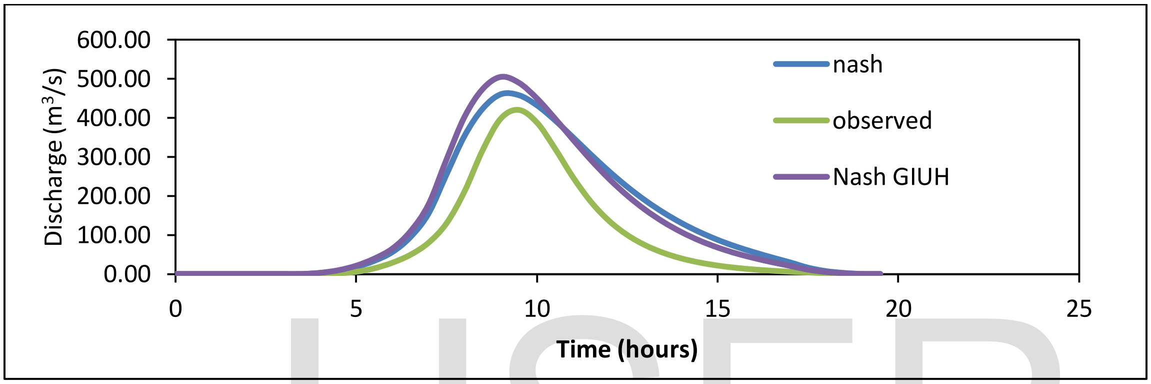




Fig. 5:The Calculated DSRO hydrographs at outlet by the Nash , Clark, Nash GIUH and Clark GIUH models, and observed outlet DSRO hydrograph for Event No.5

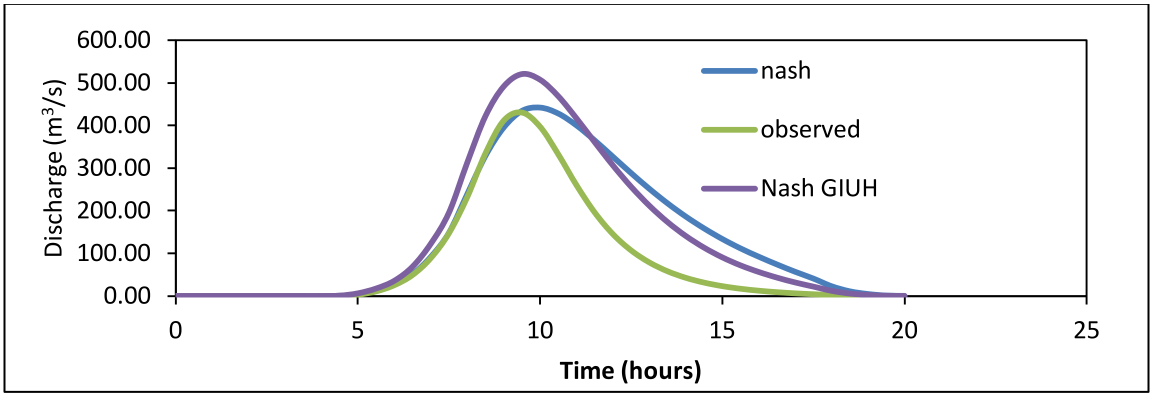


Fig. 6:The Calculated DSRO hydrographs at outlet by the Nash , Clark, Nash GIUH and Clark GIUH models, and observed outlet DSRO hydrograph for Event No.6

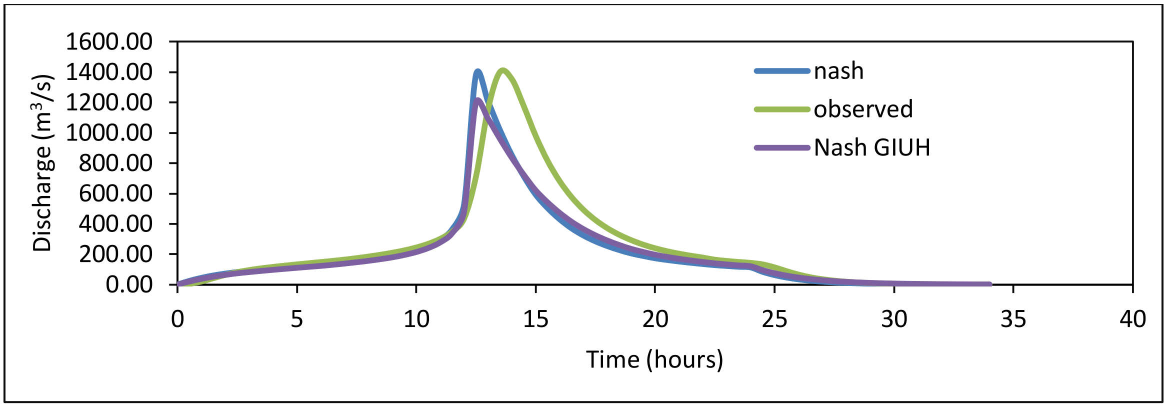


Fig. 7:The Calculated DSRO hydrographs at outlet by the Nash , Clark, Nash GIUH and Clark GIUH models, and observed outlet DSRO hydrograph for Event No.7

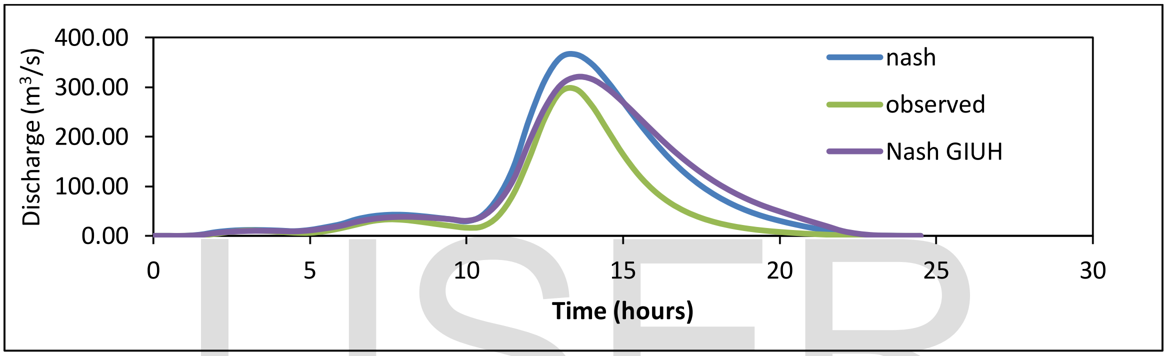


Fig. 8: The Calculated DSRO hydrographs at outlet by the Nash, Clark, Nash GIUH and Clark GIUH models, and observed outlet DSRO hydrograph for Event No.8.



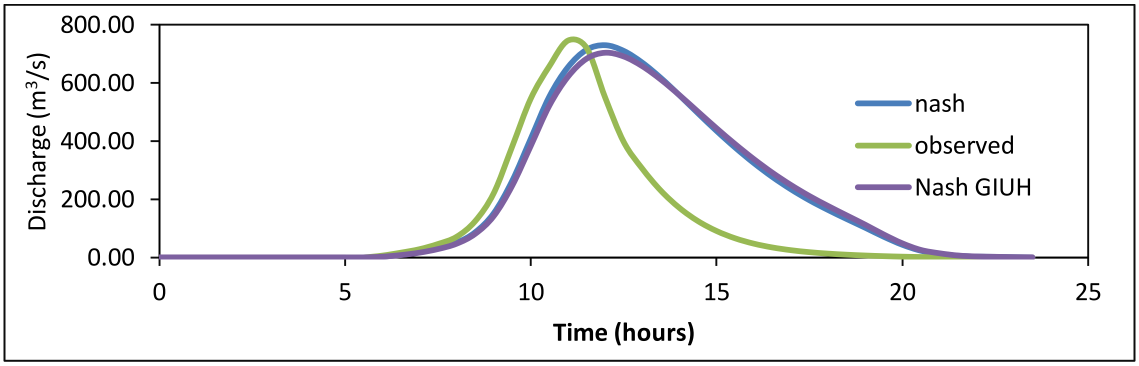


Fig. 9: The Calculated DSRO hydrographs at outlet by the Nash , Clark, Nash GIUH and Clark GIUH models, and observed outlet DSRO hydrograph for Event No.9

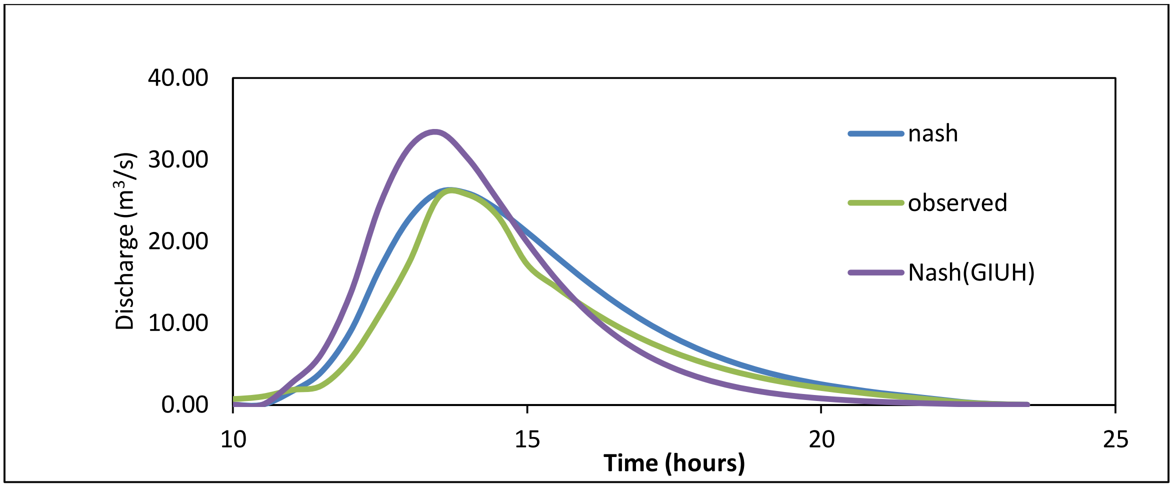


Fig. 10: The Calculated DSRO hydrographs at outlet by the Nash , Clark, Nash GIUH and Clark GIUH models, and observed outlet DSRO hydrograph for Event No.10

Table 03: EFF and PEP of the Nash and Nash GIUH models for 10 storm events.

| Event Number | Nash | | Nash GIUH | |
|---|---|---|---|---|
| | EFF | PEP | EFF | PEP |
| 01 | 82.65 | 21.85 | 99.85 | -3.5 |
| 02 | 96.82 | 6.6 | 98.88 | 9.09 |
| 03 | 78.26 | -17.12 | 96.57 | 12.64 |
| 04 | 56.29 | -50.73 | 96.14 | -5.56 |
| 05 | 75.19 | -38.01 | 96.73 | 2.00 |
| 06 | 44.4 | 2.20 | 92.5 | 4.61 |
| 07 | 70.41 | 8.47 | 95.74 | 7.2 |
| 08 | 80.21 | 14.1 | 91.67 | -5.6 |
| 09 | 78.12 | -8.47 | 89.45 | -7.11 |
| 10 | 84.32 | 6.11 | 93.7 | 3.76 |

## 7 CONCLUSION

From the results obtained it is concluded that Nash-GIUH model gives equally good results as compared to the original Nash model. In Nash GIUH model efficiency of the model ranges from 96% to 44% in first six events. The next four events have efficiency of more than 70% which means that the model is efficient and can be applied to any rainfall runoff event. In case of % error in peak discharge this error ranges from -38% to 21% which means that there is variation but in case of next four events mostly a lower value of error in peak discharge is obtained.

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