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Direct runoff hydrograph model's collation for a Pakistan's region

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K E Y W O R D S

Nash Model
Clark Model
GIUH Model
DSRO
DEM
ArcGIS
EFF
PETP
Q (PEP)
PEV

A B S T R A C T

Rainfall-Runoff modeling is among the classical applications of hydrology. This paper examines the results of 3 hydrologic approaches, particularly Clark Model, Nash Model, and Geomorphic Instantaneous Unit Hydrograph Model. Assumptions are forwarded for the long run use of the Rawalpindi Division, Pakistan's Small Dam Organization. The catchment of Shahpur Dam was an area under consideration for the study. The Digital elevation model (DEM) was implicated to measure the Nash and Clark model's geomorphic parameters. Using ArcGIS, catchment satellite imagery was processed to estimate geomorphological parameters. The models have been applied to multiple storm cases. Geographic Instantaneous Unit Hydrograph (GIUH) model gave direct surface runoff hydrograph, whereas, on measured precipitation excess rainfall hyetograph was obtained. Four types of statistical parameters, namely efficiency of the model (EFF), percentage defect in time to attain peak (PET_P), percent defect in attained peak Q (PEP), percentage defect in runoff rate (PEV) are used to check model's efficiency. The comparison is done between the findings of Clark and Nash GIUH models and the original Clark and Nash models. It was observed that GIUH models are equally good even when optimization is done for Clark and Nash model's parameters. Since the results obtained from these models are more credible, so, these models can be used in ungauged catchments to estimate the hydrographs.

1. Introduction

Water plays a vital role in the sustainability of the system of the earth. Environment, agriculture, energy, and human survival is intensely connected with water. Climate variations, growth, and encroachments in stream plains have sparked issues associated with water management worldwide. It is observed that irregularity of hydrologic processes and shifts in global weather give birth to unspeakable complexities in rainfall engineering [1,2] has observed potential influence on river runoff due to climate change worldwide. However, modeling of rainfall-runoff could be used to better estimate storm-water discharge. Rainfall-runoff simulations have the utmost importance in the scenario of global changes to assure appropriate forethought and management of water resources.

The Rainfall-runoff process is very complicated for watersheds of semi-arid areas i.e. Shahpur dam of Punjab, Pakistan. Characteristics of land-forms, soil properties, and precipitation dispersion are the pivotal aspects influencing the runoff of earth's surface from a watershed. Rainfall-runoff models have been used commonly for analyzing detention storage and hydraulic structures of small or large watersheds.

Further, it estimates the factors used in the development of fluid hydrographs. Todini (1988) described that in complex models, a lot of variables are required which is difficult and also takes time. Optimization of parameters which are larger in number is highly complex. Such as MIKE SHE, the need for large data and calculation of physical parameters makes its use limited to small catchments. Therefore, in the modern era, it is required to develop a relation of runoff models with physical parameters of the catchment with the requirement of a small number of parameters. Rainfall runoffs in semi-arid regions give relevant rainfall-runoff data to generate a model with minor input parameters, such as precipitation, surface runoff, evapotranspiration, interception, infiltration, and change in soil moisture etc.

There are many runoff models of precipitation in use. To model the cycle of precipitation-runoff Khaleghi and Ghodusi (2011) applied Geomorphologic Instantaneous Unit Hydrograph (GIUH) and also identify the form of the outlet hydrograph. [5] attempts to measure the rainfall/runoff relationship for basins that are ungauged on the grounds of hydrologic characteristics. Digital elevation models (DEMs) which are based on stream mapping are extensively used for hydrological uses (Lindsay and Evans, 2007). Nguyen *et al.*, 2009; used Geomorphological Instantaneous Unit Hydrograph (GIUH) to simulate the runoff of the Can Le Watershed (Vietnam). Clark, Nash and Geomorphologic Instantaneous Unit Hydrograph (GIUH) models have been mentioned by Ahmed *et al.*, 2009 *and* 2010; Ghumman *et al.*, 2011 and 2012. They concluded that Clark model gives quality results than Nash and Geomorphologic Instantaneous Unit Hydrograph GIUH models. For simulation of precipitation runoff processes, application of Nash Instantaneous Unit Hydrograph was done and it was found that the model efficiency varied from 87% to 95% (Masood *et al.,* (2010)). For ungauged catchments, the development of precipitation runoff models and estimation of models basic parameters are difficult tasks especially for the areas having fewer data. The point to be noted that the uncertainty in the drainage network or streams should be eliminated for reliable output.

Further complex models are the difficult and lengthy processes to apply. Therefore, exploring new technologies and researching the use of existing tools to solve rainfall-runoff related problems in the catchment is crucial for better water management planning and decision making. In water resources administration precipitation runoff models play the main role for long run use, advancement, and management. The present research on Shah Pur Dam Catchment (a semi-arid region of Pakistan) deals with comparison and development of four conceptual runoff models, (i) Clark, (ii) Clark Geographic Instantaneous Unit Hydrograph (Clark GIUH), (iii) Nash and (iv) Nash Instantaneous Unit Hydrograph (Nash GIUH). Further, estimate the efficiency of models, percentage defect in time to attain peak, percent defect in attained peak, percentage defect in runoff rate. Thus for evaluation of a more precise forecast model to calculate runoff for semi-arid catchment area by doing a comparison of all considered techniques.

1.1 Study Area

Shahpur Dam is a gravity dam located in Punjab Pothohar plateau (semi-arid region), having distance from the north of Fatehjang town is about 8 km and near the Kala Chitta hills range District Attock as shown in Fig. 1. The coordinates of the considered study area are East 72^{o}41’51” and North 33^{o}37’30”. The area’s topography with watershed has reduced levels of range from four hundred twenty-four meters to five hundred and forty meters. The watershed area sums up to approximately two hundred and two kilometer square and the total storage capacity is around 17.7 million m^3, out of this live storage capacity is 5.04 million m^3. The mean annual inflow to the dam is around 20.6 million m^3. The Shahpur dam provides about 289 mm/ha of gross water depth considering the command area of 17.4 Km^2. The rainfall station is Fatehjang station. The maximum inundation volume is 1008 m^3/sec. The soil at dam location is sandy silt clay. *(Shahid Ahmad, Muhammad Khan 2001)*

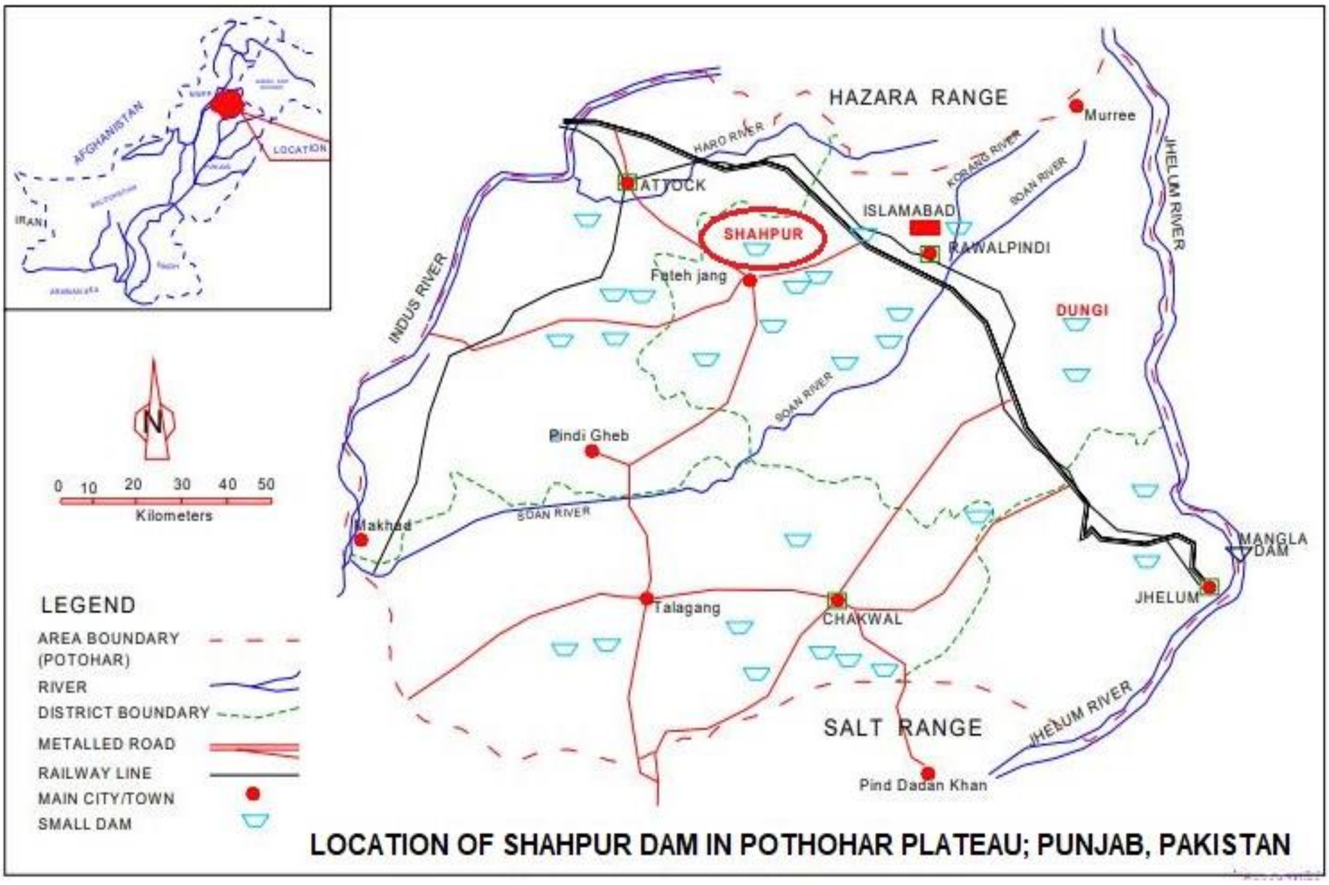

Fig. 1. Locality map of considered dam site

2. Materials and Methods

2.1 Clark Model:

Clark (1945) gave mathematical expression to calculate the instantaneous discharge which can be given by;

$$Q_{i+1} = 2C_0R_i+C_1Q_i \tag{1}$$

In this equation, i **is** index having a value range of 1-N, co-efficient of storage is R which is in hrs. $(i+1)^{th}$ x-axis value of the hydrograph of Clark's model is represented in the equation as Q_{i+1}. Coefficients of weight C_o and C_1 were given by Mushkingham as;

$$C_o = \frac{0.5t}{(R+0.5t)}, C_1 = \frac{(R-0.5t)}{(R+0.5t)} \tag{2}$$

Here R is the coefficient of storage and t is the computational time interval.

To develop the Clark model, 2 criteria, coefficient of storage R and time of concentration T_c are required. Usually, the slope of the recession curve at the point of inflection is used to obtain R-value. In Clark's model concentration-time (T_c) is termed as the required time in hours taken by a specific runoff for traveling between hydraulically extreme remote points and outlet in the catchment. The most common method to find the time of concentration by the use of geomorphic parameters is Kinematic wave formula and is given by;

$$T_c = \frac{0.93\, L^{0.6} n^{0.6}}{i^{0.4} S^{0.3}} \tag{3}$$

In equation 3, L is overland flow length in kilometers, n is Manning's co-efficient, i is the intensity of rain-fall in centimeters per hour and S is the slope in meter per meter. The optimization technique is used in this research to get the best set of values of R and $T_{c.}$

2.2 Nash Conceptual Model:

Nash proposedthat by routing the prompt influx through a cascade of linear reservoirs (*n* numbers) having the similar coefficient of storing K Instantaneous Unit Hydrograph (IUH) is computed; Ahmed (2012). From the initial reservoir the outflow is taken into account as flow into the next reservoir, and so on. From the *n*th reservoir the outflow which can be represented by the formula

$$Q_{IUH}(t) = \frac{0.2778\, At^{n-1}e^{-t/k}}{(n-1)!k^n} \tag{4}$$

Where Q_{IUH} (*t*) is the flow rate at time *t* for instantaneous unit hydrograph and n is called shape parameter in equation. *K* is the wait period in hrs. Direct surface runoff (DSRO) hydrograph is computed by the convolution process of additional rainfall hydrograph with instantaneous unit hydrograph. Shape parameter and wait period are important hydrologic parameters of the Nash model where ‘n’ represent the number of linear waterfalls and k represents the coefficient of storage. The two basic hydrologic parameters used in the Nash model are ‘n’ and ‘k’. The major difficulty is finding the most efficient pair of parameters that gives efficient output result. To find these parameters is a very difficult task. Simulated and observed results are optimized to get these parameters. The optimization technique maximizes or minimizes a function; this function is called the objective function.

2.3 Geographic Instantaneous Unit Hydrograph Model (GIUH) Model

Using regression analysis Rosso in 1984 found the relationship between Nash model parameters and geomorphic parameters as given below.

$$n = 3.29\left(\frac{R_B}{R_A}\right)^{0.78} {R_L}^{0.07} \tag{5}$$

$$k = 0.7 \times \left(\frac{R_A}{R_B R_L}\right)^{0.78} \left[\frac{L_\Omega}{V}\right] \tag{6}$$

Where R_A represents stream area ratio, R_B represents the bifurcation ratio, R_L represents the stream length ratio, and L_Ω represents maximum stream order’s length (km) in these equations. V (m/s) is the expected velocity at peak discharge. The coefficient of storage ‘k’ is given in hours in the above equations.

In Clark GIUH the parameters hydrologic parameters R and T_c are evaluated by considering topographic parameters. Kinematic wave formula was considered for estimation of concentration time. The calculation of Slope for catchment and watersheds was done. Arc GIS 10.1 is used regarding the calculation of required parameters.

Geomorphic features of the Shahpur watershed were calculated using Arc GIS 10.1 software. The satellite imageries (30 m) of Shah Pur reservoir were numbered and then the calculation of area of catchment, the order of stream, areas of stream and lengths of the stream was done. Fig. 2 shows the picture of Shah Pur Dam Catchment finalized by ArcGIS 10.1 software.

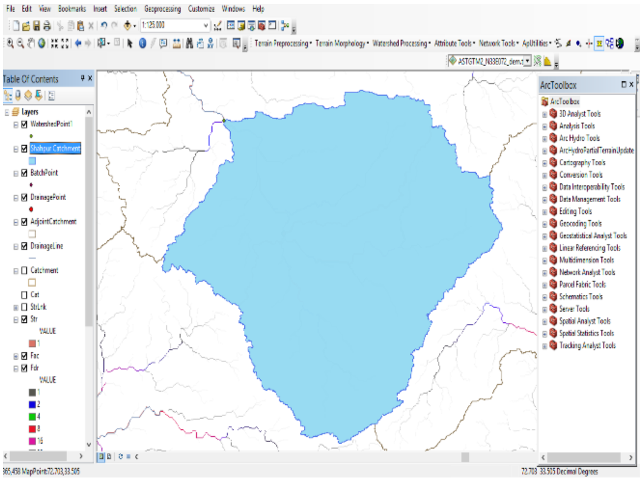

Fig. 2. The picture of Shah Pur dam catchment finalized by ArcGIS 10.1 software

The highest order of stream for considered catchment was five. The area of surface runoff and the lengths of each stream were calculated. Horton’s law of topographical parameters is used to evaluate, the ratio of bifurcation, the ratio of stream length, and the ratio of stream area for each channel order and given by following formulas.

$$R_B = \frac{1}{antilog\ (m)} \tag{7}$$

$$R_L = antilog\ (m) \tag{8}$$

$$R_A = antilog\ (m) \tag{9}$$

For ratio of bifurcation (R_B), the slope of order of stream vs log of corresponding stream order line is represented by *m*, for ratio of stream length (R_L) the slope of order of stream vs log of average length of stream of given order line is represented as *m* and for ratio of stream area (R_A) the slope of corresponding stream order vs log of average space drained by the off stream-line is represented as *m*. In Fig.3 it can be seen that the highest order of stream of the catchment is 5.

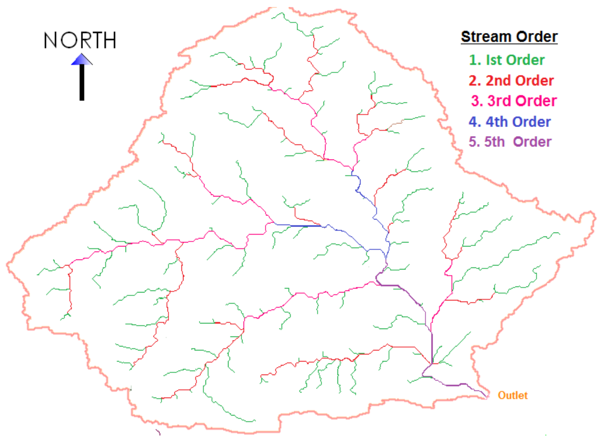

Fig. 3. Horton’s stream ordering for considered catchment

The number of streams (N) calculated against stream order 1-5 are 113, 22, 6, 2, and 1. The corresponding values of mean length, mean area can be seen in table 1. with other estimated values.

Table 1

Assessed values of number of streams (n), mean length (l) and mean area (a) for each stream order

Sr. No.	Mean Length (L) km	Mean Area (A) Km^2	Log (N)	Log (L)	Log (A)
1	0.93	15.79	2.054089	-0.03241	1.198568
2	2.09	35.09	1.351312	0.330513	1.546332
3	4.47	61.59	0.767242	0.659927	1.790314
4	4.59	105.66	0.30204	0.664802	2.013084
5	8.79	204.79	0	0.945985	2.3214

Table 2

Assessed geomorphic parameters of shah pur watershed

Horton Stream Order	Total Stream numbers	Bifurcation Ratio (R_B)	Stream Length Ratio (R_L)	Stream Area Ratio (R_A)	Stream Length of the highest order (L_X)
5	144	3.25	1.59	1.85	8.79

2.4 Computation of Model Performance Criteria:

The objective function used to optimize the simulated and observed results were efficiency of model and peak weighted root mean square error (RMSE) and is given by the formulas;

$$\eta = \left(1 - \frac{\sum_{i=1}^{i=NQ}(Q_{oi} - Q_{ci})^2}{\sum_{i=1}^{i=NQ}(Q_{oi} - \overline{Q_o})^2}\right) \times 100 \quad (10)$$

$$RMSE = \sqrt{\left\{\frac{1}{NQ}\left[\sum_{1}^{NQ}(Q_{oi} - Q_{ci})^2\left(\frac{Q_{oi} + \overline{Q_o}}{2\overline{Q_o}}\right)\right]\right\}} \quad (11)$$

In above equations, η is efficiency of model, NQ represents the total number of ordinates of the hydrograph, i is index varying from 1 to NQ, the observed ordinate i of hydrograph is represented by Q_{oi}, Q_{ci} is ordinate i of the hydrograph which is calculated or simulated, $\overline{Q_o}$ represents mean observed hydrograph ordinates and RMSE is Root Mean Square Error (RMSE) at peak and is weighted. These objective functions were used to find the performance and efficiency of the models at different sets of hydrologic parameters e.g. n and K.

In this research, the first four different conceptual models, namely, Clark, Clark Geographic Instantaneous Unit Hydrograph (Clark GIUH), Nash and Nash Instantaneous Unit Hydrograph (Nash GIUH) were developed and then results from these models were compared for a semi-arid area of Pakistan. The literature of Ahmed (2012) and Jhonston and Kummu (2012) are connected with this field and worth studying. The efficiency of the model, percentage defect in time to attain peak, percent defect in attained peak, percentage defect in runoff rate are used to check the efficiency of model. They were evaluated for all considered events data by using formulas in equations 12, 13, 14 and 15 and then the results of four models were compared with observed DSRO hydrograph.

$$EFF = \left(1 - \frac{\sum_{i=n}^{n}(Q_{oi} - Q_{si})^2}{\sum_{i=n}^{n}(Q_{oi} - \bar{Q}_{oi})^2}\right) \times 100 \quad (12)$$

$$Q_{pep} = \left(1 - \frac{Q_{ps}}{Q_{po}}\right) \times 100 \quad (13)$$

$$\mathrm{PET}_p = \left(1 - \frac{T_{ps}}{T_{po}}\right) \times 100 \quad (14)$$

$$\mathrm{PEV} = \left(1 - \frac{V_s}{V_o}\right) \times 100 \quad (15)$$

In the above equations 12, 13, 14 and 15, EFF represents the percent efficiency of the model, Qoi represents ordinate i of the discharge which is observed and Qsi represents ordinate i achieved after simulation. n represents a cumulative number of ordinates. Q_{pep} is a percent error in discharge in cumecs. Q_{ps} is the evaluated discharge at a peak and Q_{po} represents discharge which is observed at peak in cubic meter per second. PETp is a % error in discharge (Q) in cubic meter per second. T_{ps} represents evaluated time to discharge at a peak after simulation and T_{po} represents evaluated time to discharge at a peak which is in hours. PEV represents the percent error discharge of total volume in cubic metres per second. V_s represents evaluated discharge volume and V_o represents observed discharge volume.

3. Results and Discussion

Overton and Meadows (1976) narrated that uncertainty is always present in rainfall-runoff model. Rainfall data which is used as an input of the runoff model have uncertainty in it. But these models can be used for estimating in ungauged areas and watersheds. However, accurate measurements of runoff are very difficult but these models can give maximum information. McPherson (1978) observed input data accuracy as the most important criterion to check the reliability of simulation analysis. Distribution of rainfall over the whole catchment and losses are important to develop a runoff model. Lindsay and Evans (2007) focused on geomorphological parameters and error was measured in geomorphic parameters with necessary changes in elevation of the digital elevation model (DEM). Kuldeep (2011) computed watershed parameters in India by using used ArcGis and realized that ArcGis software-based geomorphic analysis is a competent hydrological modeling method. Khazaei and Zahabiyoun (2014) implemented an automatic runoff calculation technique. Here is the comparison of models named Nash, Nash GIUH, Clark and Clark GIUH for rainfall events

Table 3

Validation comparison for Nash model

Sr. No.	Nash Geographic Instantaneous Unit Hydrograph Model				Original Nash Model			
	Efficiency of model	Percent defect in attained peak	Percent defect in time to attain peak	Percentage defect in runoff rate	Efficiency of model	Percent defect in attained peak	Percent defect in time to attain peak	Percentage defect in runoff rate
1	89.99	-7.09	0	3.59	89.90	-7.09	0	3.29
2	99.57	3.39	9	-2.19	98.99	-0.57	9	-9.29
3	98.86	8.22	0	0.57	99.98	-0.32	0.47	1.57
4	95.68	-2.36	-6.8	-0.04	99.60	-50.62	0.49	-0.49
5	75.20	-37.99	4.4	5.74	70.89	-27.99	5.4	5.00
6	98.98	2.02	0.49	-5.755	98.6	1.09	-5.1	-5.55
7	70.42	8.36	-0.1	-6.23	71.61	4.36	4.49	15.10
8	81.22	13.99	39.99	-5.56	89.10	4.09	19.99	-5.77
9	77.13	-8.37	1.49	28.19	81.51	-6.61	4.49	15.10
10	85.33	5.99	0.49	-27.23	83.12	6.09	0.39	-15.79
Average	87.23	-1.384	4.9	-0.89	88.33	-7.757	3.962	1.25

From the above table, it can be seen that the efficiency of the model is greater than 85% for the first four precipitation events deducing the result that the model is quite efficient. Fig.4 to Fig.13 shows the comparison between observed discharge values and simulated discharge values. In Fig.5 for event number 2, it can be seen that Nash and Nash GIUH have the same time to reach the peak and the peak value is nearly equal to the observed one. The Maximum discharge was observed to be 66 m^3/sec. Peak discharge obtained from Nash and Nash GIUH was 66 m^3/sec and 63 m^3/sec respectively. Ninety-nine percent efficiency was estimated for this event. The efficiency of the model, percentage defect in time to attain peak, percent defect in attained peak, percentage defect in runoff rate is shown in table 3. Similarly, many cases depicted efficiency more than seventy percent. Separate efficiency of model calculations were done for both models. In addition, estimated peak discharge defect is below fifteen percent in most of the cases which can be neglected. The calculations of remaining standards were also done to check the efficiency of models that represented praise able model performance.

Table 4

Validation comparison for Clark model

Sr. No.	Clark Geographic Instantaneous Unit Hydrograph Model				Original Clark Model			
	Efficiency of model	Percent defect in attained peak	Percent defect in time to attain peak	Percentage defect in runoff rate	Efficiency of model	Percent defect in attained peak	Percent defect in time to attain peak	Percentage defect in runoff rate
1	99.81	-3.49	0	-10.99	98.99	-4.49	0	-5.9
2	97.48	3.6	9	-4.79	98.00	6.54	9	2.3
3	93.99	9.43	0	2.749	91.24	10.58	0	2.19
4	96.10	-5.57	0	1.91	96.25	-7.9	0	3.1
5	96.69	1.99	0	17.09	98.29	0.98	0	-12.02
6	91.49	4.59	-5.19	-15.46	90.19	3.1	0	-2.1
7	95.73	7.19	-4.48	-12.77	91.09	6.79	-4.48	-6.34
8	91.65	-5.59	20.03	-18.56	89.38	-4.88	20.03	-14.14
9	89.5	-7.10	-4.47	-8.10	85.63	3.12	-4.47	-6.34
10	93.7	3.78	0	-6.63	91.76	7.57	0	-2.22

Table 4 represents the efficiency of the model, percentage defect in time to attain peak, percent defect in attained peak, percentage defect in runoff rate for 10 rainfall cases and comparison of observed and simulated discharges are shown in Fig. 14 to Fig.23. Fig.14 for event 1 shows that Clark and Clark GIUH have the same time to the reach peak. Observed discharge for this event was 1575 m^3/sec and simulated discharges by Clark and Clark GIUH were 1560 m^3/sec and 1568 m^3/sec respective depicting percentage efficiency of 99% for this event. Similarly, it can be deduced that the efficiency of the model in many cases is above eighty-five percent. The implementation of the model can be done to evaluate direct runoff from a given rainfall event. Peak value error is below ten percent. And the volume error is below seventeen percent. The defect in time to attain peak is 0% in most of the rainfall cases. The highest value for the defect in time to attain peak is twenty percent.

In contrast to the original Nash model, which had parameters that were obtained by hit-and-miss optimization, the Nash GIUH model's parameters (n and k) are computed from the geomorphic characteristics of the watershed region. Four rainfall events in 2013 were subjected to the model's use, and the simulated and actual direct runoff hydrographs were compared. The aforementioned formulae were used to calculate the peak velocity, and geomorphic characteristics were used to determine the time of concentration.

The analogy between Original Nash Model and Nash Geographic Instantaneous Unit Hydrograph Model (Nash GIUH) with observed direct surface runoff hydrograph for some of the rainfall events.

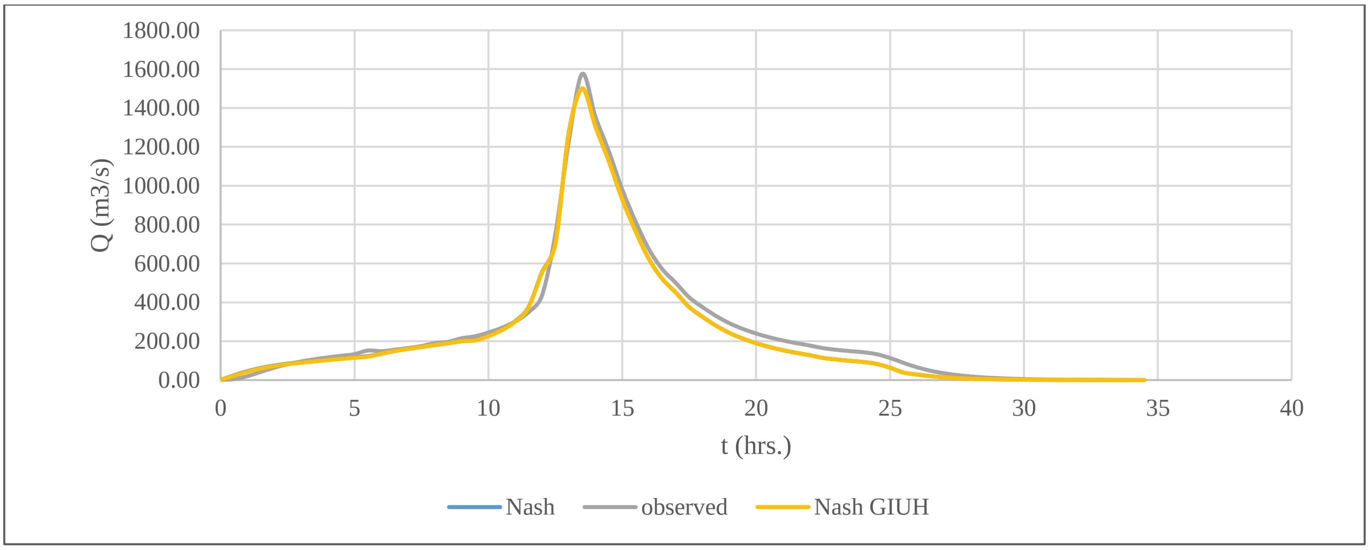

Fig. 4. Rainfall case 1

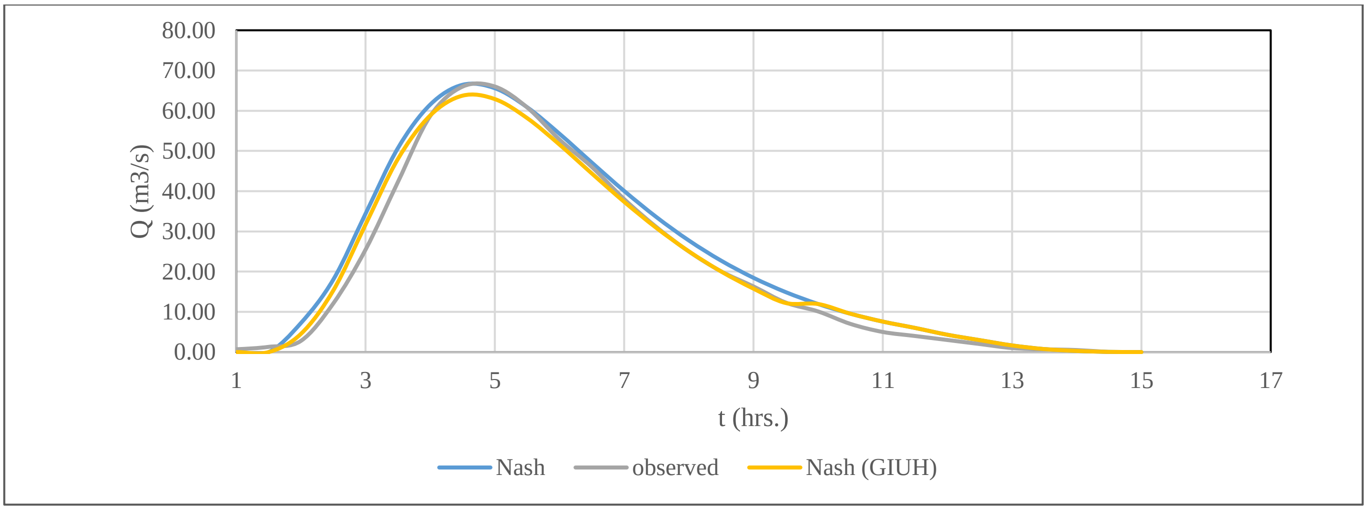

Fig. 5. Rainfall case 2

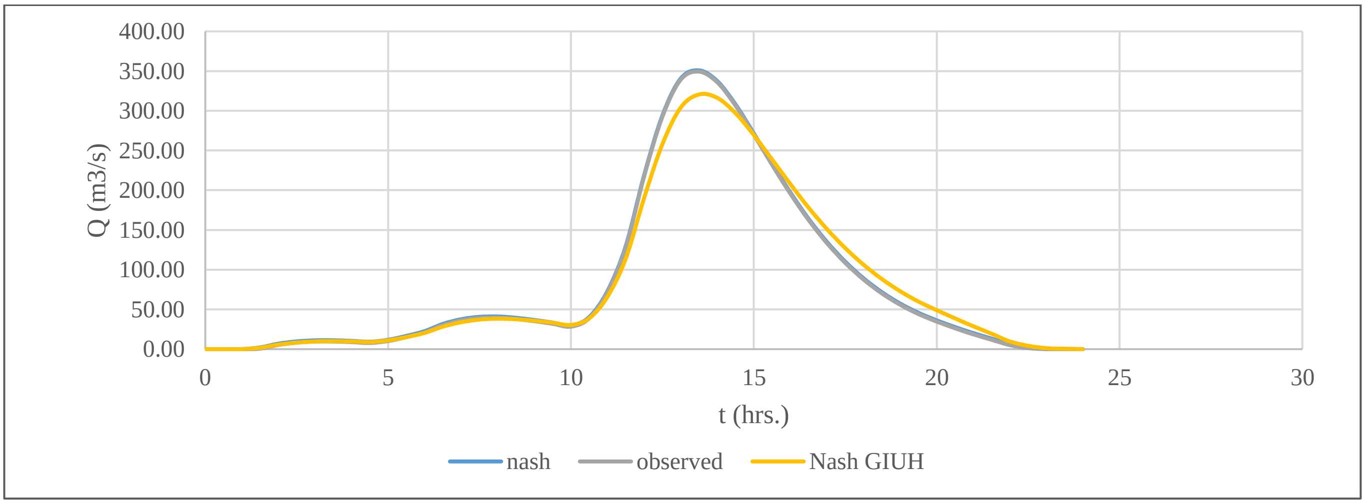

Fig. 6. Rainfall case 3

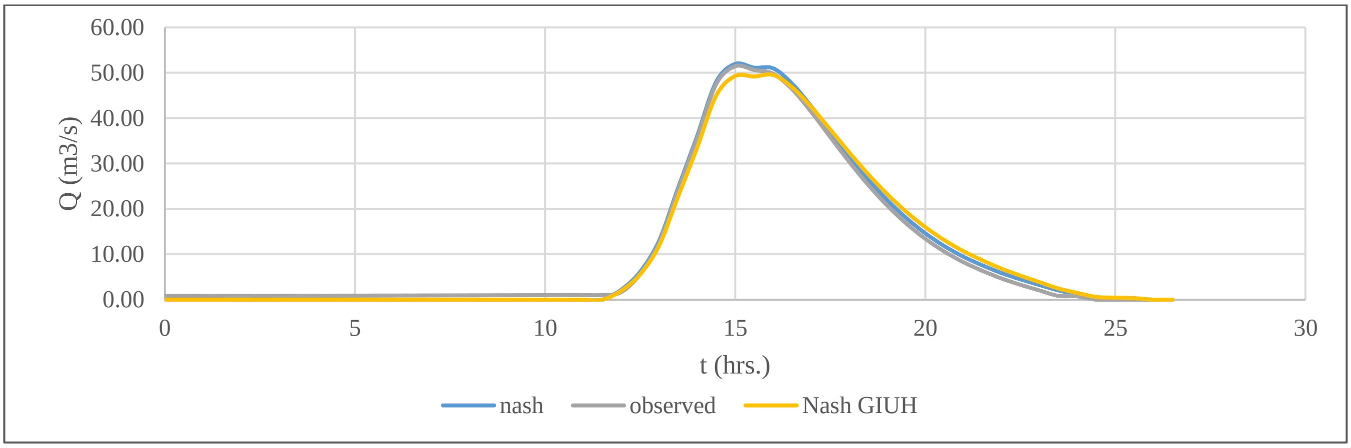

Fig. 7. Rainfall case 4

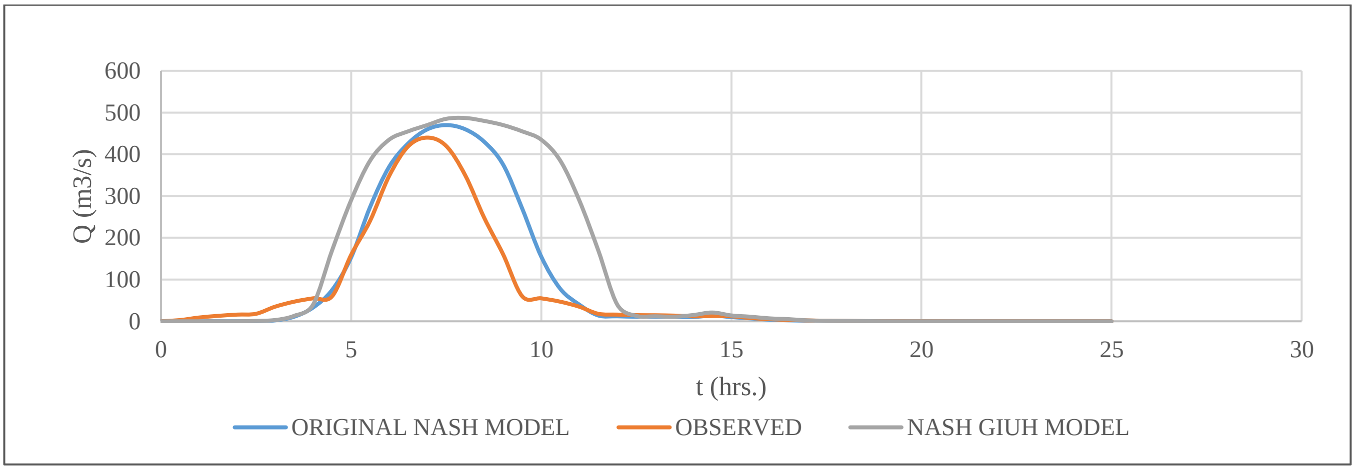

Fig. 8: Rainfall case 5

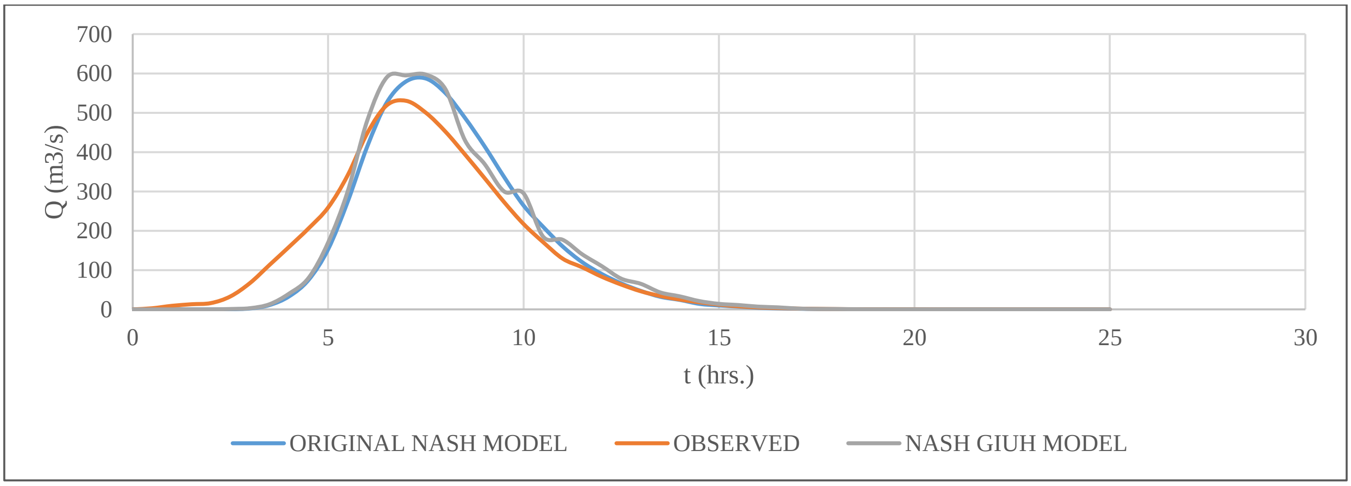

Fig. 9. Rainfall case 6

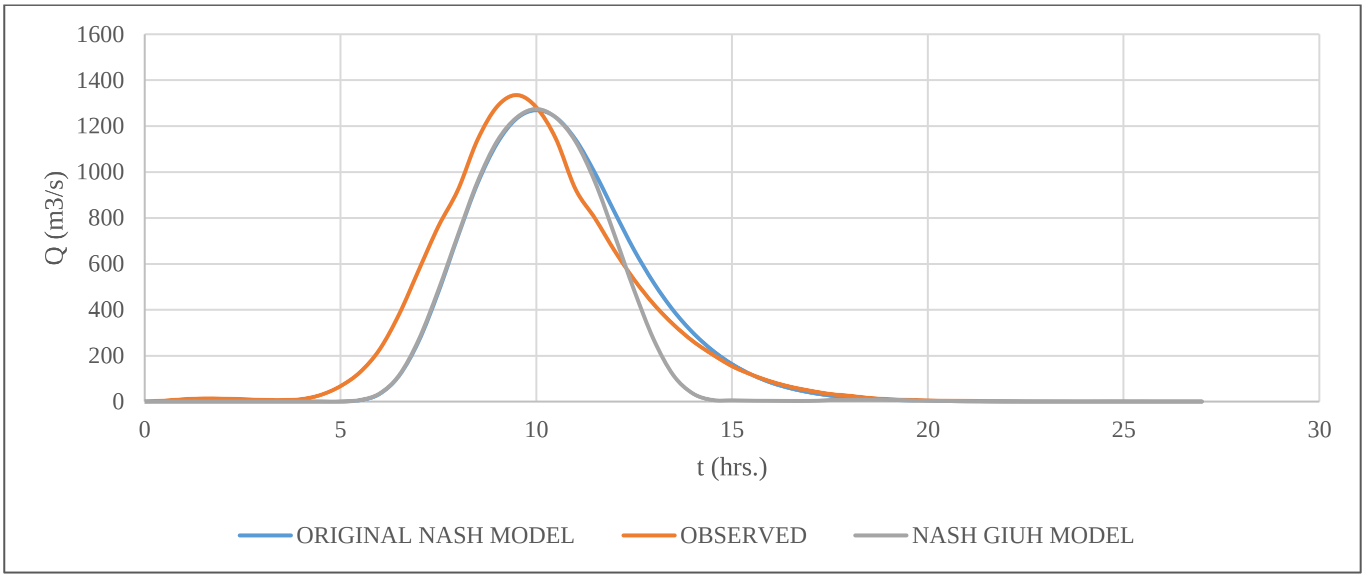

Fig. 10. Rainfall case 7

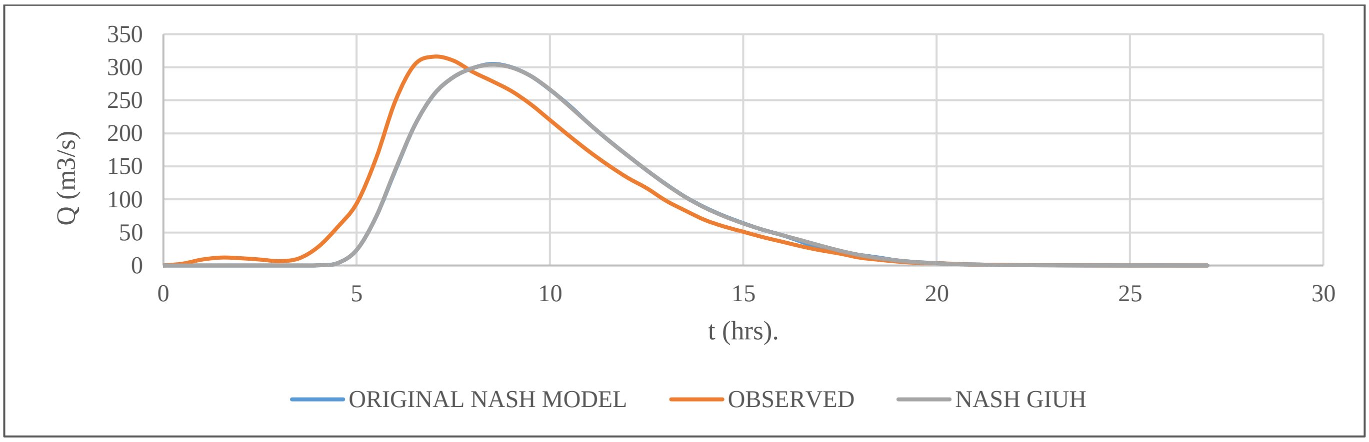

Fig. 11. Rainfall case 8

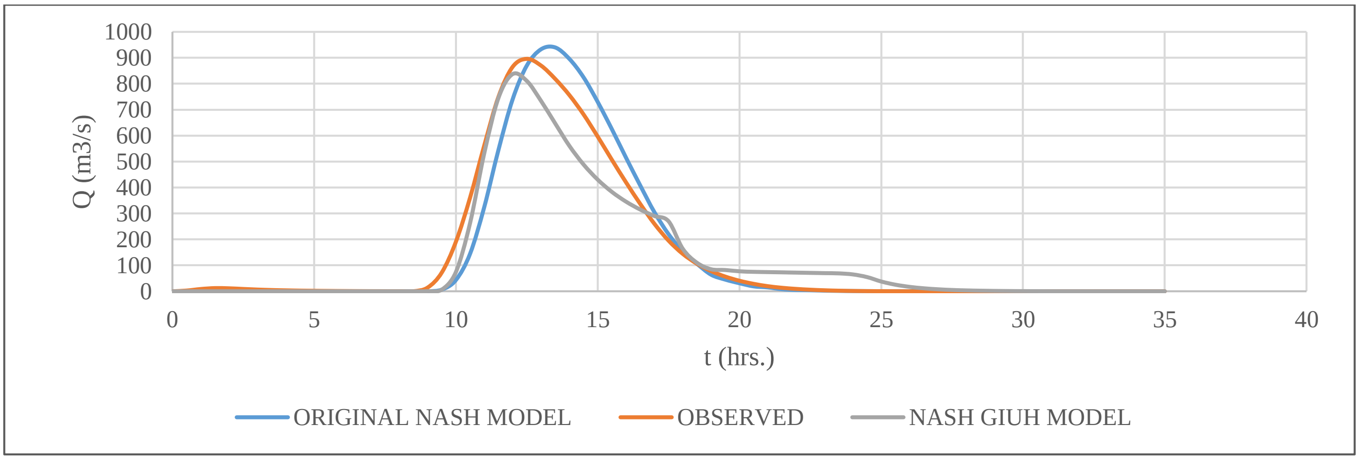

Fig. 12. Rainfall case 9

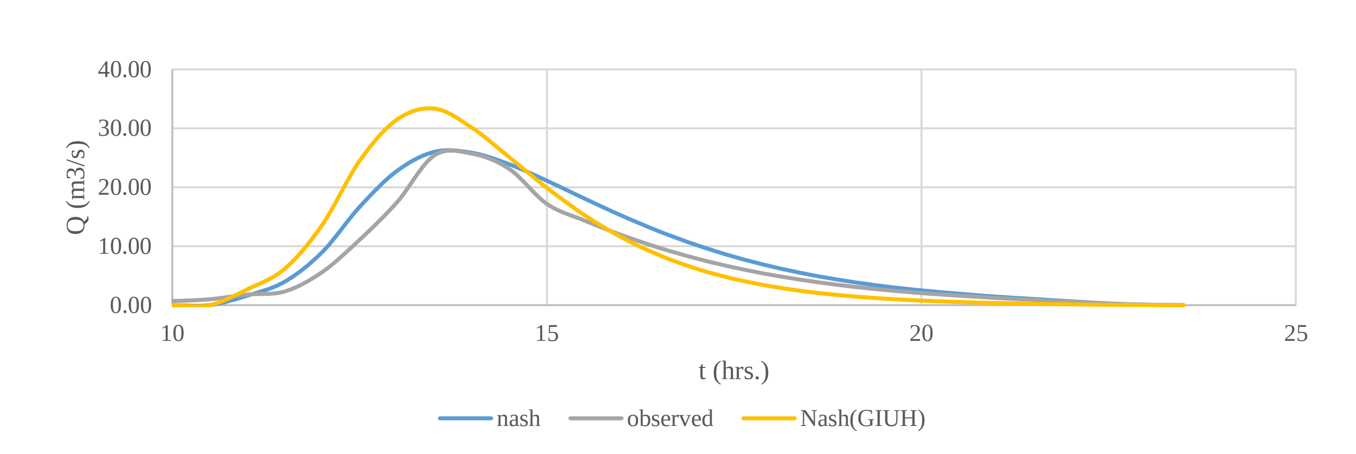

Fig. 13. Rainfall case 10

The kinematic wave coefficient was estimated to be 0.7 (s−1.m−1/3). The length of longest stream was 23.47 km. It is observed that he parameters estimated from geomorphic characteristics are close to the best parameters calculated by hit and trial for Nash model. Figs. 4 to 13 display the runoff produced by the two models for various events. Results from the Nash and Nash GIUH models are found to be fairly similar. This demonstrates that the GIUH model can be utilized if there is insufficient data to calibrate or validate the runoff model. The GIUH model's efficiency ranges from 70% to 99%. Storm event 2 is the most effective one in the Nash GIUH model. The same is true of the peak discharge's arrival time.

Comparison of Clark and Clark Geographic Instantaneous Unit Hydrograph (Clark GIUH) with observed direct surface runoff hydrograph for events 1-10.

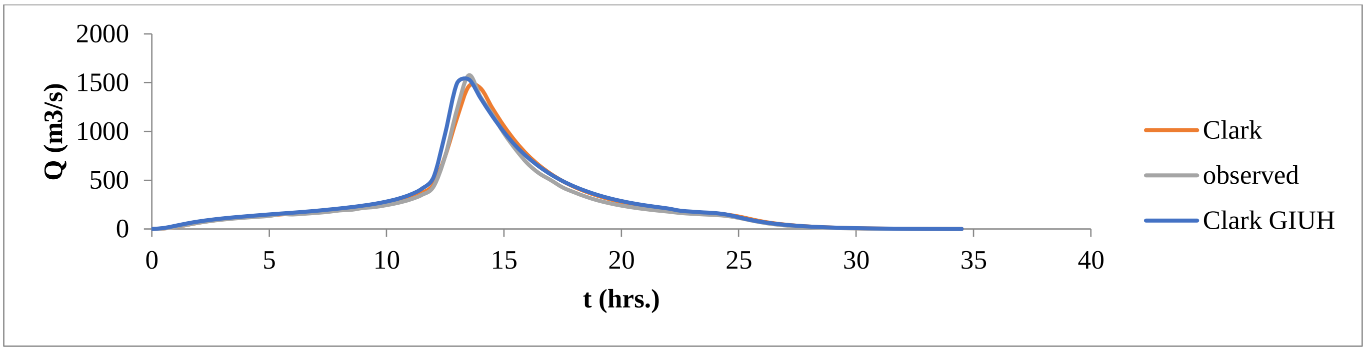

Fig. 14. Rainfall case 1

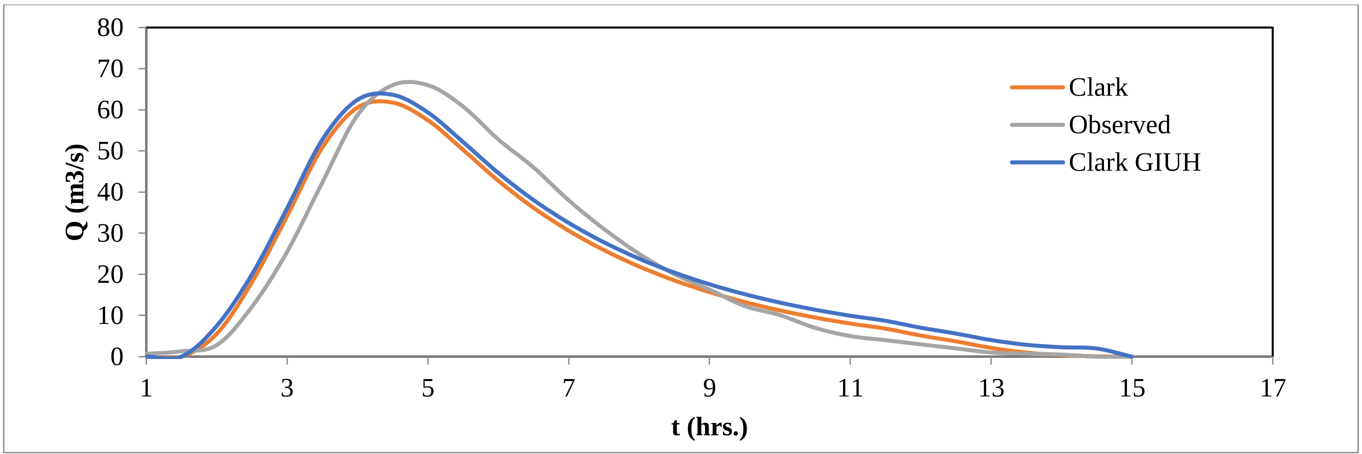

Fig. 15. Rainfall case 2

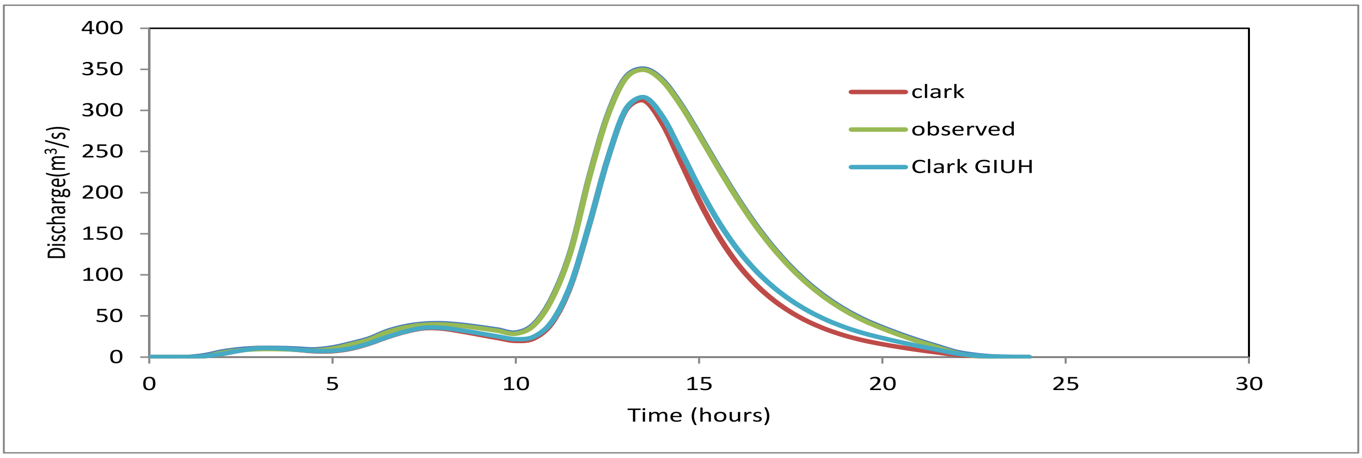

Fig. 16. Rainfall case 3

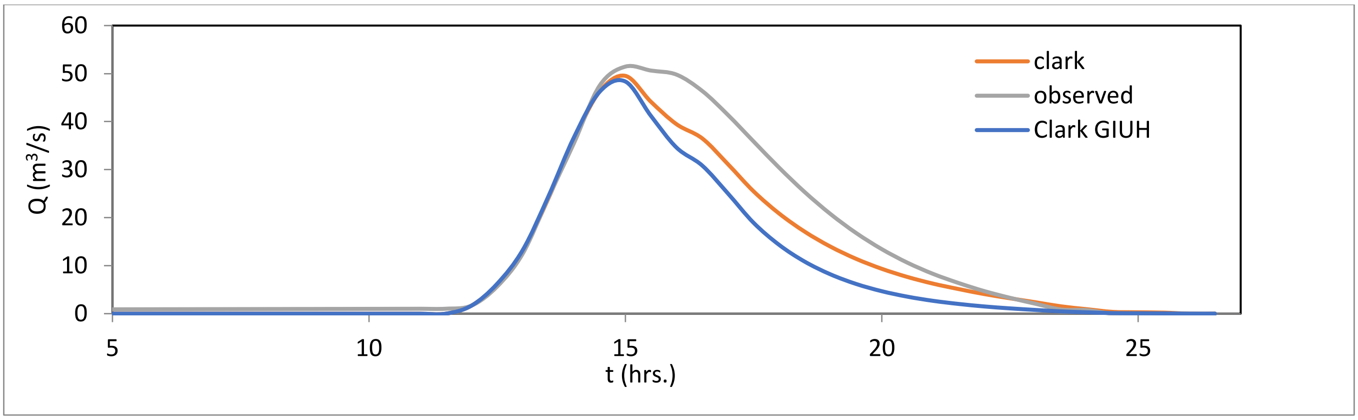

Fig. 17. Rainfall case 4

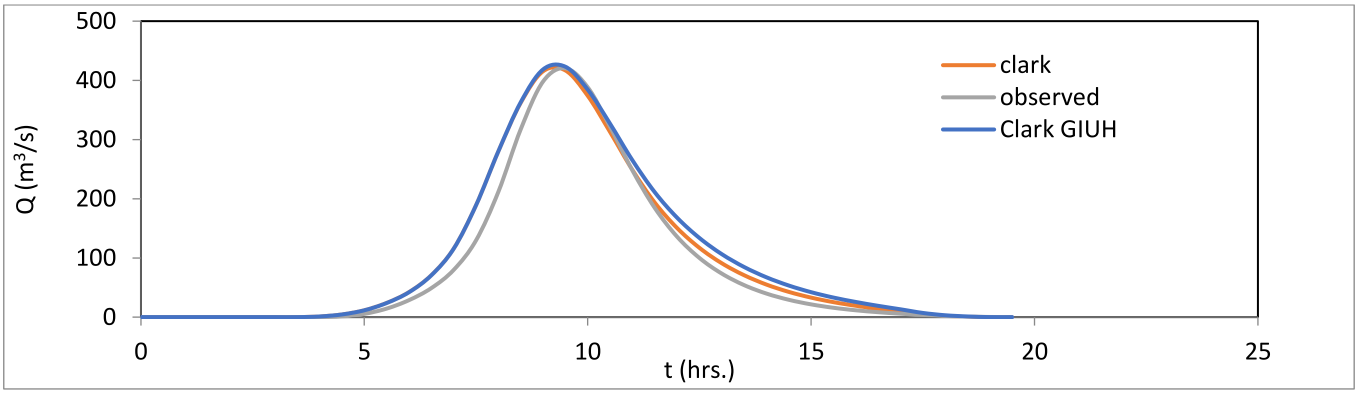

Fig. 18. Rainfall case 5

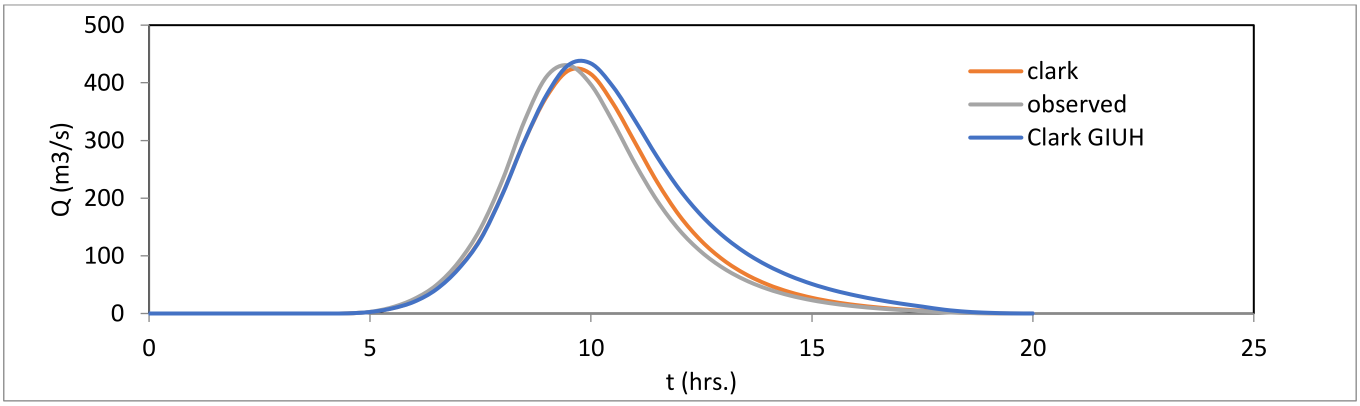

Fig. 19. Rainfall case 6

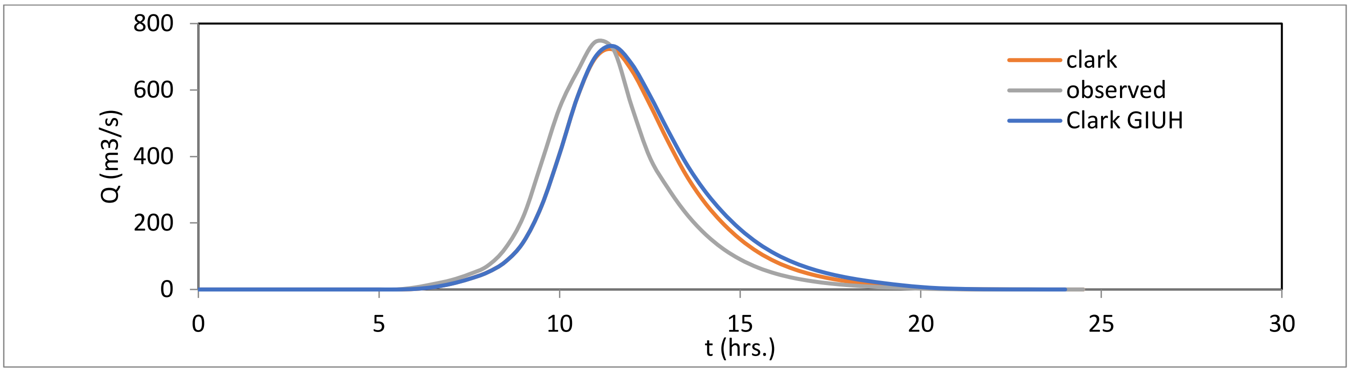

Fig. 20. Rainfall case 7

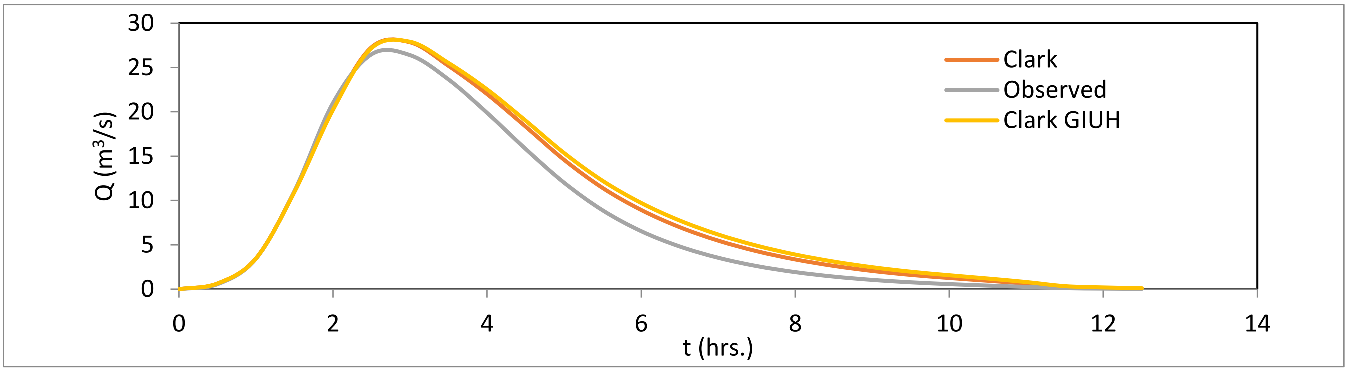

Fig. 21. Rainfall case 8

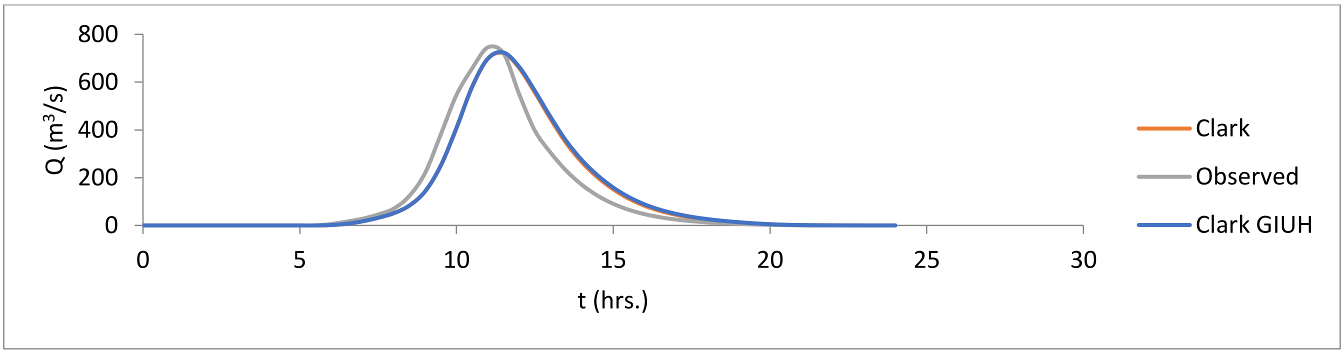

Fig. 22. Rainfall case 9

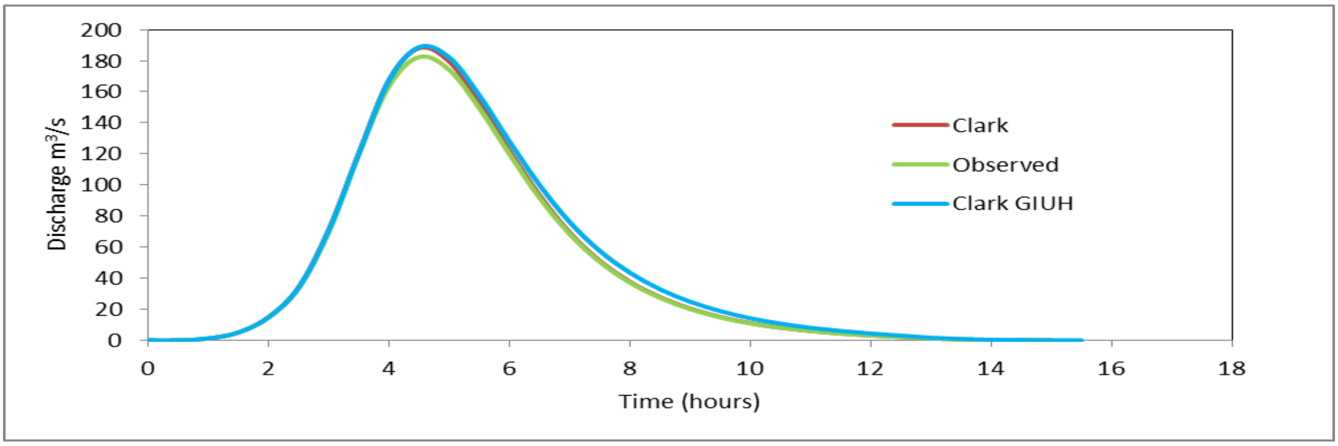

Fig. 23. Rainfall case 10

This chart contrasts the Clark and Clark GIUH models. The Clark model's efficiency is greater than 90%. Then, for each storm occurrence, the peak percentage inaccuracy was less than 10%. The maximum percentage inaccuracy for volume is 18%. Similar to percentage error, the maximum error in peak time is 20%. Similar findings are obtained using the Clark GIUH model using the four efficiency criteria.

4. Conclusion

The parameters of the Nash Geographic Instantaneous Unit Hydrograph (Nash GIUH) model (n and K) were evaluated from geomorphic features of the watershed area, whereas, optimization by hit and trial method was used to estimate original Nash model parameters. It is observed that the best parameters evaluated in Nash model by hit and trial are near to the best parameters determine from geomorphic features. And the findings of both models Nash and Nash GIUH are very close. This shows that the Nash GIUH model can be implemented for the calculation of runoff when there is meager data for evaluation. It has more than 95% model efficiency. In Nash GIUH model precipitation case two has high efficiency. The same is true for time to attain the maximum discharge. For multiple storm cases, Original Clark and Clark Geographic Instantaneous Unit Hydrograph (Clark GIUH) is developed and analogy is done with DSRO hydrograph. Optimization is done for calculation of model parameters (R and T_C); to build the model its best pair is selected. In the case of Clark GIUH, the parameters are geomorphically evaluated. Clark model depicted a high efficiency of more than ninety percent in most of cases. Percent defect in the peak was also not more than ten percent. Percent defect in the rate was also below 20%. Similarly, percent defect in time to attain peak was also less than 20%. Clark GIUH model depicted the same behavior; the best results were obtained from the four performance criteria. Mostly simple Clark Model provided effective results. Models obtained using the Clark method were more accurate as compared to Nash method.

5. Recommendation

The obtained results are effective and it is suggested that these models need to use instead of installing the instruments in range of catchment, which are expensive and time consuming. Meanwhile runoff models of precipitation include a few parameters and the results obtained from these models are credible so these models can be used in ungauged catchments. The installation of gauging instruments is costly and access to these gauging stations is difficult work to do. So, it is possible to use these models for estimation of hydrographs. Digital models of elevation should be easily accessible for hydrologist so that runoff models can be easily created. This will cut down both time and cost.

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