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Estimation of Peak Discharge in an Ungauged Watershed Using GIUH Model Supported With GIS and RS

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Abstract
Geographical Information System (GIS) support based Geomorphological characteristics of Swarnamukhi river watershed located in Nellore district of Andhra Pradesh have been used to generate Geomorphologic Instantaneous Unit Hydrograph (GIUH). GIUH can be used as a transfer function for modelling the transformation of excess rainfall into surface runoff, in which excess rainfall is an excitation to the hydrologic system. The drainage network and slope map can be extracted from the Arc GIS software. The computation of Horton's ratios and their application in generating the Geomorphological Instantaneous Unit Hydrograph (GIUH) can provide a solution for ungauged watershed. The aim of this paper was to estimate the peak discharge of the swarnamukhi river basin located at Nellore district. Peak discharge is estimated on an event based approach during the period of 2009 - 2013, total ' 10 ' events are considered. The maximum and minimum elevation of the basin is 312 m and 29 m above MSL, respectively. Swarnamukhi River is the 5th order watershed comprised of about 957.92 km2 area. The slope of the watershed has maximum area covered nearly level (0-1)% and very gently sloping (1-3)%. Length of maximum order stream is 46.92 km, whereas Stream length ratio (Rl) is 2.29. The obtained results were compared with recorded peak discharge in hydro observation site of watershed. The models of Relative Mean Error (RME), Nash- sutlciff Error (NSE) and Root of Mean Square Error (RMSE) in watershed were compared with each other.

Keywords: Peak discharge, geomorphological parameters, digital elevation model (DEM), geographic information system (GIS), remote sensing

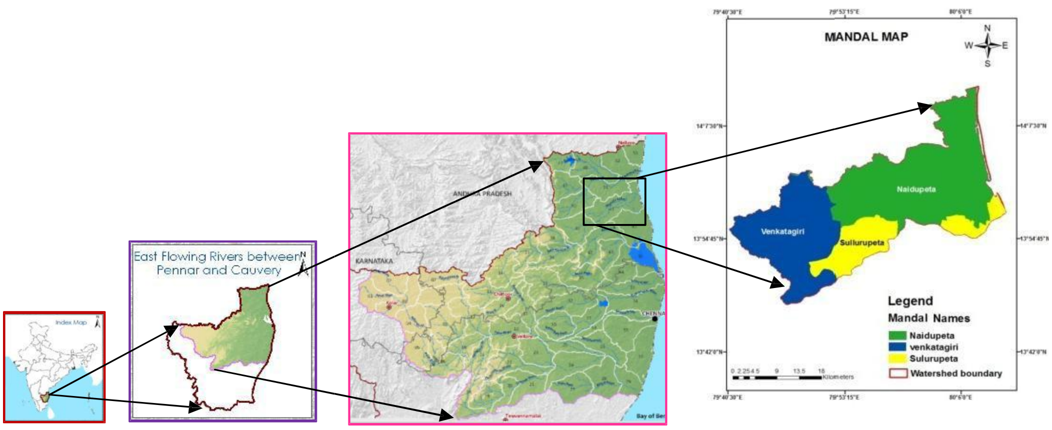
1. Introduction

Geomorphological Instantaneous Unit Hydrograph (GIUH) is a workable approach, which has directs applicability to an ungauged catchment for estimation of runoff response resulting from a rainfall response. It does not require conventional methods of regionalization of unit hydrograph; wherein, the historical rainfall runoff data of a number of gauged catchments are required to be analyzed. Because of these characteristics GIUH is gaining popularity and widespread acceptance among scientific community. Availability and accuracy of adequate runoff data for small and medium catchments is always under question, especially in developing countries like India. Changing climatic conditions are causing geo-spatial changes in catchment area and variation in rainfall pattern. Also, due to different anthropogenic and geoclimatic changes, the land use pattern is also undergoing a gradual shift and this has direct impact on rainfall characteristics of the catchment. Thus hydrological behaviour of ungauged catchment is evident on the coupling of hydrological characteristic of the catchment with the geomorphological parameters. The concept of the Geomorphologic Instantaneous Unit Hydrograph (GIUH) was introduced by Rodriguez-Iturbe and Valdes (1979) [15] as a first step in the direction of coupling the hydrologic characteristics of a catchment with the geomorphologic parameters. The GIUH approach has direct applicability for ungauged or scantily gauged catchments wherein rainfall data are available but runoff data are not given. The GIUH approach is more advantageous than the conventional IUH methods such as the Clark IUH model (Clark, 1945) [3] and the Nash IUH model (Nash, 1957) [13] since it avoids the requirement of stream flow data. Also, dynamic nature of the parameters of Clark and Nash IUH models requires regular revision because of changing land use and climatic conditions. Further, the GIUH approach is more beneficial than the regionalization techniques as it does not require any information about the other catchments in the hydro-meteorologically homogeneous region. It also eliminates use of stream flow data for the catchment for which it is to be applied. Geomorphological control on basin hydrology is evident on geomorphometry-hydrology relationship. The role of basin geomorphology in controlling the hydrological response of a river basin is known for a long time. Earlier works (Snyder, 1938; Horton, 1945; Taylor and Schwartz, 1952) [21, 4, 22] have provided an understanding of basin geomorphology- hydrology relationship through empirical relations. Snyder (1938) [21] proposed that catchment area, shape of basin, topography, channel slope, stream density and channel storage affects the shape of hydrograph. On that basis, he proposed an empirical equation of unit hydrograph (called synthetic unit hydrograph-SUH) based on catchment area, shape of the basin and averaging out other parameters with a coefficient. Further advancement was made by different workers notably by Clark (1945) [3], Nash (1960) [12] and Koutsoyiannis and Xanthopoulos (1989) [8]. Koutsoyiannis and Xanthopoulos (1989) [8] highlighted the advantage of parametric approaches for derivation of unit hydrograph in order to establish a relationship between the UH and catchment characteristics. However, these relationships are characterised by some constants, which represent the 'ensemble average' of geomorphological control on the river discharge.

Geomorphology of a river basin describes the status of topographic features of the surfaces and streams, and its relationship with hydrology provides the geomorphological control on basin hydrology (Jain and Sinha, 2003) [6]. Geomorphology reflects the topographic and geometric properties of the watershed and its drainage channel network. It controls the hydrologic processes from rainfall to runoff, and the subsequent flow routing through the drainage network. The role of basin geomorphology in controlling the hydrological response of a river basin is known for a long time. Moreover, for any infrastructural development, it is very useful tool for first hand overview of the basin. It is advantageous in case of laying out the urban drainage and irrigation canal system, aqueducts, study the physiographic impacts on environment, and selection of silt disposal site, hydropower site (Sarkar and Gundekar, 2007) [19], recharge zone, percolation tank, retention tank, dam site, etc. This drainage network of the river basin can provide a significant contribution towards flood management and water logging program (Jain and Sinha, 2003) [6]. The derivation of the GIUH uses the assumption that a stream of a certain order has a known linear response function of the familiar or complex probability distributions. (Rodriguez-Iturbe and Valdes, 1979; Kirshen and Bras, 1983; Rinaldo *et al*., 1991) [15, 7, 14]. The effect of linear channels in the hydrologic response was introduced by Kirshen and Bras (1983) [7]. Thus, the GIUH based transfer function approach is applicable in such a situation where rainfall data is available but runoff data are not, and it is a more powerful technique for the flood estimation than the commonly used parametric Clark model (Clark, 1945) [3] and Nash's cascade technique (Nash, 1957) [13] (Yen and Lee, 1997; Bhaskar *et al*., 1997; Jain *et al*., 2000; Lohani *et al*., 2001; Kumar *et al*., 2002; Sarangi *et al*., 2007; Bhadra *et al*., 2008; etc.) [23, 2. 18, 1]. Another advantage of GIUH technique is its potential for deriving the unit hydrograph (UH) using the geomorphologic characteristics obtainable from topographic map / remote sensing, possibly linked with geographic information system (GIS) and digital elevation model (DEM) (Rodriguez-Iturbe and Valdes, 1979; Rosso, 1984; Sahoo *et al*., 2006; Kumar *et al*., 2007; etc.) [15, 16, 10]. However, the GIUH technique is applicable for the estimation of the direct runoff component of the stream flow and hence, can be used to generate the direct runoff hydrograph (DRH). Once the DRH is computed, the flood hydrograph can be simply obtained by adding the base flow component. The main objective of this paper is to use GIS support based geomorphological Characteristics of Swarnamukhi river basin to GIUH approach for the estimation of Peak disc harge.

Study Area

The area of investigation in this research study is the major part covers Naidupeta and remaining area covers Venkatagiri, sullurupeta in Nellore district, Andhra Pradesh. It is located 13°90' and 14° 25' N and 79° 89' and 80° 12' E and covering an area of 957.92 sq.km. The Study area falls under Palar Sub-basin the area was delineated from India Water Resources Information System (IWRIS) C18PAL41. The study area it is a part of east flowing river between pennar and caurey basin and the river draining into the bay of Bengal. In the study area main river is Swarnamukhi and the length of the river as 56.90 km. In the study area has one hydro observation station and 11 rain gauge stations are located. The hydro observation site is located in naidupeta in Nellore district.



Methodology

GIUH stands for Geomorphological Instantaneous Unit Hydrograph. Rodriguez-Iturbe and Valdes (1979) [15] introduced the geomorphological instantaneous unit hydrograph (GIUH), also called geomorphological unit hydrograph (GUH), to link hydrograph shape to channel network characteristics. To determine the Horton's Ratio as given in following. Three of Horton's ratios namely bifurcation ratio (RB), stream-lengths ratio (RL) and stream area ratio (RA) are unique representative parameters for a given watershed and are fixed values for a given watershed system. Values of bifurcation ratio, the length ratio, and the area ratio in nature are normally between respectively.

Peak discharge

3 and 5 for RB, 1.5 and 3.5 for RL and 3 and 6 for RA, The following formula is used to estimate the peak discharge in GIUH Model as:

$$Q_p = t_r \times q_p \times \left(1 - t_r \times \frac{q_p}{4}\right) \times Q_e$$

Where, Qp = Peak discharge (m3/s) ;
Time of effective rainfall, tr = 0.133× tc (hr) ; qp = peak flow per unit time (hr-1) ;
Effective discharge, Qe = ir × A (m3/s) ;

Rainfall intensity $i_r = \frac{p}{t}$ (cm/hr) ;

A= Area of the watershed (sq.km);

Time of effective rainfall

It is defined as the time it takes for rain water to travel from one location to another location in a watershed.

$$t_r = 0.133 \times t_c$$

Where, tc, is time of concentration (hrs)

Time of Concentration

Time of concentration is a concept used in hydrology to measure the response of a watershed to a rain event. It is defined as the time needed for water to flow from the most remote point in a watershed to the watershed outlet. It is a function of the topography, geology, and land use within the watershed.
According to Kirpich formula the time of concentration is given as follows,

$$t_c = K \times \frac{L^{0.77}}{S^{0.385}}$$

Where,
k = unit conversion coefficient
L= main stream length (m)
S= slope (m/m)

Peak flow per unit time

Rodriguez-Iturbe and Valdes (1979) [15] derived the peak and time to peak for the IUH as a function of Horton's order ratios (Horton, 1945) [4], and are given as:

$$q_p = 1.31 \times R_L^{0.43} \times \frac{v}{L_\Omega}$$

Where,
qp = peak flow per unit time (hr-1) ;

$$R_L = \frac{L_i}{L_{i-1}};$$

Li = average length of stream of ith order ;
V = Flow Velocity (m/s) ;
LΩ = Length of the highest order stream in the basin (km)

Flow Velocity

Flow Velocity in fluids is the vector field that provides the velocity of fluids at a certain time and position. To indicate rate and direction of movement of water per unit time.

$$V = \frac{L}{t_c}$$

Where, L= main stream length (m);
tc= time of concentration (hrs);

Models calibration

Watershed models are powerful tools for simulating the effect of watershed processes and management on soil and water resources. However, no comprehensive guidance is available to facilitate model evaluation in terms of the accuracy of simulated data compared to measured flow and constituent values.

1. Comparison between observed and calculated discharges
2. Linear Regression analysis
3. Performance evaluation indices

Performance evaluation indices

a. Nash-sutcliffe efficiency (NSE)

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(y_i^{obs} - y_i^{sim})^2}{\sum_{i=1}^{n}(y_i^{obs} - y^{mean})^2}\right]$$

Where Yi obs is the ith observation for the constituent being evaluated, Yi sim is the ith simulated value for the constituent being evaluated, Y mean is the mean of observed data for the constituent being evaluated, and n is the total number of observations.

b. Rmse-observations standard deviation ratio (RSR)

RSR is calculated as the ratio of the RMSE and standard deviation of measured data, as shown in equation

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\sum_{i=1}^{n}(y_i^{obs} - y_i^{sim})^2}{\sum_{i=1}^{n}(y_i^{obs} - y^{mean})^2}$$

c. Statistical Errors

Statistical errors such as Relative Mean Error (RME), Root Mean Square Error (RMSE) are determined by using the following equations

1. $RME = \sum_{i=0}^{n}\left[\frac{y_{obs} - y_{sim}}{y_{obs}}\right] \times 100$
2. $RMSE = \frac{1}{n}\left\{\sum\left[y_{obs} - y_{sim}\right]^2\right\}$

n i=0 yobs

Where,
yobs= observed past data;
ysim= simulated or predicted data;
n= total number of observed data;

Results and discussions

By using these model is estimated on an event based approach. Peak discharge is estimated on an event based approach during the period of 2009 - 2013. Total ' 10 ' events are considered and it was shown in table 1.

Table 1: Numbers and dates of events studied in an ungauged watershed

S. NO	Date of events	Precipitation P in mm	Events number
1	12-February-2009	3.2	10
2	5,6 -September-2009	18.9	
3	13,14-March-2010	30.8	
4	28,29,30,31-October-2010	221.2	
5	22,23-February-2011	16.4	
6	22,23,24-August-2011	120.4	
7	04-January-12	5.2	
8	3,4,5-November-2012	176.2	
9	19,20-March-2013	95.4	
10	19,20,21,22,23-October-2013	185.2	

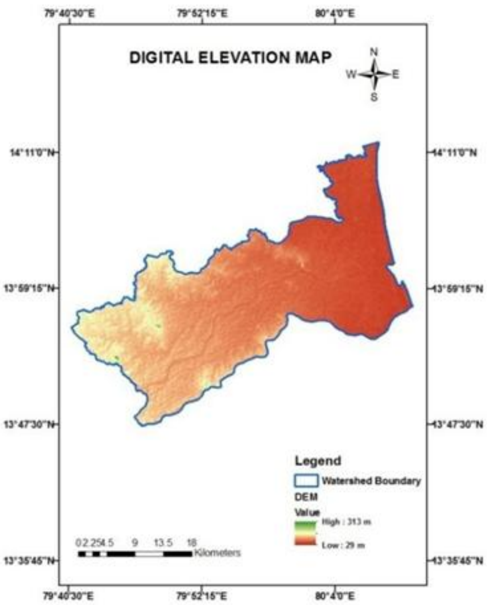


Fig 2: Digital Elevation Map of the study area

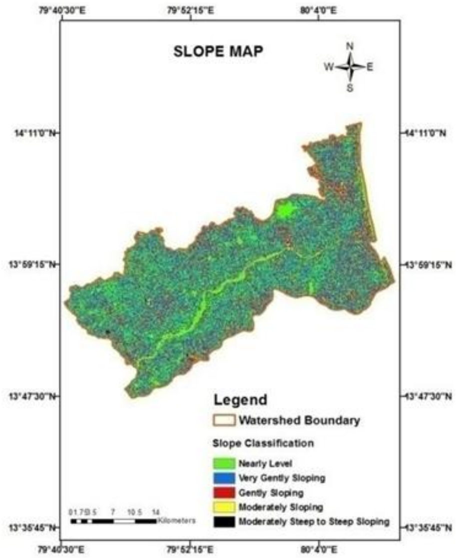


Fig 3: Slope Map of the study area

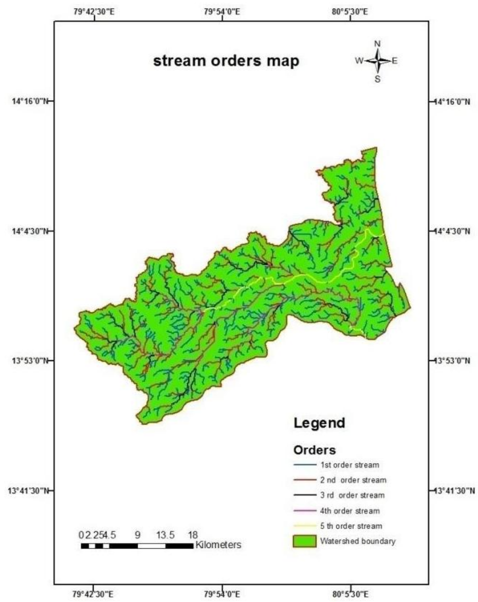


Fig 4: Stream Orders Map of the study area

To calculate the geomorphological parameters based on stream orders map and calculating the stream lengths, length ratio.

Table 2: Geomorphological Parameters in the watershed

Stream Order	Number of Streams	Length of Streams (km)	Mean Length of Streams (km)	Length Ratio RL=Lu/Lu-1	Average Length Ratio of a Watershed
1	452	590.71	1.30	1.30	
2	96	260.415	2.71	2.07	
3	25	95.023	3.80	1.40	2.289
4	5	105.926	21.18	5.57	
5	2	46.256	23.12	1.09	

Table 3: Estimation of peak discharge using GIUH Model

Event	Dates	Precipitation P, (mm)	Rainfall P intensity, ir = t (cm/hr)	Qe = ir × A, (m3/s)	Qp Qp = tr × qp × (1 − tr × 4) × Qe (m3/s)
1	12-February-2009	3.2	0.133	29.54	8.36
2	5,6 -September-2009	18.9	0.013	75.47	15.31
3	13,14-March-2010	30.8	0.230	112.45	7.09
4	28,29,30,31-October-2010	221.2	0.641	341.480	140.11
5	22,23-February-2011	16.4	0.034	31.82	34.21
6	22,23,24-August-2011	120.4	0.167	211.879	99.81
7	04-January-2012	5.2	0.244	30.53	12.41
8	3,4,5-November-2012	176.2	0.021	257.65	125.62
9	19,20-March-2013	95.4	0.154	151.10	64.01
10	19,20,21,22,23-October-2013	185.2	0.198	177.70	138.32

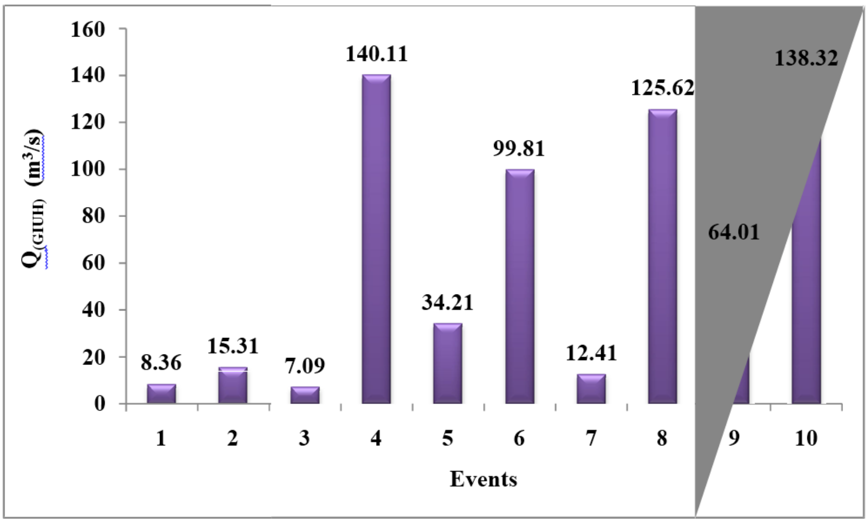


Fig 4: Ordinate graph on GIUH Model

The ordinate graph on GIUH Model is plotted on the variations of peak discharge values (Q (GIUH)) for various events. By the plot, the Peak discharge values for the events 4, 6, 8 and 10 can be observed being comparatively high because the corresponding events belong to monsoon period.

Comparison between observed and calculated discharges

Table 4: Comparison between observed and calculated peak discharges on three models

Events	Dates	Q (observed)	Q (calculated)
1	12-February-2009	11.18	8.36
2	5,6 -September-2009	17.32	15.31
3	13,14-March-2010	7.85	7.09
4	28,29,30,31-October-2010	145.72	140.11
5	22,23-February-2011	37.41	34.21
6	22,23,24-August-2011	104.84	99.81
7	04-January-2012	13.10	12.41
8	3,4,5-November-2012	126.63	125.62
9	19,20-March-2013	69.22	64.01
10	19,20,21,22,23-October-2013	145.57	138.32

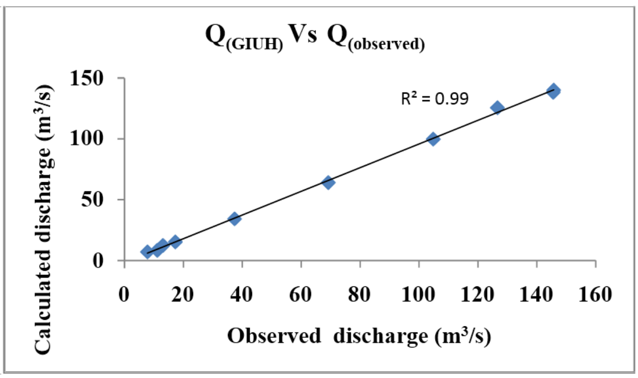


Fig 5: Graph drawn on QGIUH Vs Qobs

A correlation graph is plotted between the observed and calculated discharges from GIUH Model to get the R2 value. By observation, as the R2 (0.99) value is more nearer to 1.0, it can be stated that the GIUH Model is fit for ungauged watershed.

The Performance evaluation indices values were also calculated and given in below Table 5 it can observed in models calibration the GIUH is the better one to estimate the peak discharge an ungauged watershed.

Table 5: Performance evaluation indices on the three Models

S. No	Models	RME	RMSE	NSE	RSR
1	GIUH	8.06	0.39	0.89	0.61

Conclusions

It was established successfully in this study that remote sensing and GIS can provide the appropriate plateform for convergent of large volume of multi-disciplinary data. Many watersheds of the Indian as well as of developing countries do not have sufficient historical records and detailed watershed information needed for physically based distributed models. In these cases GIUH can provide a better solution for flood management programs. The technique of GIUH based design flood estimation is very useful in forecast of the temporal variation of the surface runoff at the outlet of the ungauged basin, which is useful in the hydrologic engineering applications. The described technique is economical and has high accuracy in determining the flood hydrograph for an basin ungauged watershed.

References

1. Bhadra A, Pnigrahi N, Singh R, Raghuwanshi NS, Mal BC, Tripathi MP. Development of geomorphological instantaneous unit hydrograph model for scantly gauged watersheds, Environmental Modelling & Software. 2008; 23:1013-1025.
2. Bhaskar NR, parida BP, Nayak AK. Flood estimation for ungauged catchments using the GIUH. J Water Resour Plng and Mgmt. 1997; 12(4):228-238.
3. Clark CO. Storage and the unit hydrograph, Trans. Am. Soc. Civ. Engr. 1945; 110:1945-1946.
4. Horton RE. Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology, Bull. Geol. Soc. Amer. 1945; 56:275-370.
5. Jain SK, Singh RD, Seth SM. Design flood estimation using GIS supported GIUH Approach' Water Resour. Manage. 2000; 14:369-376.
6. Jain V, Sinha R. Hyperavulsive-anabranching Baghmati river system, north Bihar plains, eastern India', Zeitschriftfür Geomorphologie. 2003; 47(1):101-116.
7. Kirshen DM, Bras RL. The linear channel and its effect on the geomorphologic IUH. J Hydrol. 1983; 65:175-208.
8. Koutsoyiannis D, Xanthopoulos T. On the parametric approach to Unit Hydrograph identification, Water Res. Manage. 1989; 3:107-128.
9. Kumar R, Chatterjee C, Lohani AK, Kumar S, Singh RD. Sensitivity analysis of the GIUH based Clark model for a catchment, Water Resour. Manage. 2002; 16:263-278.
10. Kumar R, Chatterjee C, Singh RD, Lohani AK, Kumar S. Runoff estimation for an ungauged catchment using geomorphological instantaneous unit hydrograph (GIUH) model', Hydrol. Process. 2007; 21:1829-1840.
11. Lohani AK, Singh RD, Nema RK. Comparison of geomorphological based rainfall-runoff models, CS (AR) Technical Rep., National Inst. of Hydrology, Roorkee. 2001.
12. Nash JE. A Unit Hydrograph study, with particular reference to British catchments, Proc. Inst. Civil Engg. 1960; 17:249-282.
13. Nash J. The forms of instantaneous unit hydrograph', Int. Ass. Sci. and Hydrol. Pub. 1957; 1:45(3):114-121.
14. Rinaldo A, Marani A, Rigon R. 'Geomorphological dispersion', Water Resour. Res. 1991; 27:513-525.
15. Rodriguez-Iturbe I, Valdes JB. The geomorphologic structure of hydrologic response, Water Resour. Res. 1979; 15(6):1409-1420.
16. Rosso R. Nash model relation to Horton order ratios' Water Resour. Res. 1984; 20:914-920.
17. Sahoo B, Chatterjee C, Raghuwanshi NS, Singh R, Kumar R. Flood estimation by GIUH based Clark and Nash models. J Hydrologic Engrg. 2006; 11(6):515-525.
18. Sarangi A, Madramootoo CA, Enright P, Prasher SO. Evaluation of three unit hydrograph models to predict the surface runoff from a Canadian watershed' Water Resour. Manage. 2007; 21:1127-1143.
19. Sarkar S, Gundekar HG. Geomorphological parameters: are they indicators for installation of a hydropower site?' International Conference on Small Hydropower, Kandy, Srilanka. 2007, 225.
20. Singh VP. Hydrologic Systems, Watershed modeling, Prentice-Hall, New Jersey 07632, USA. 1989, II.
21. Snyder FF. Synthetic Unitgraphs, Transactions of American Geophysics Union, 19th Annual Meeting, Part 2. 1938, 447.
22. Taylor AB. Schwartz HE. Unit-hydrograph lag and peak flow related to basin characteristics', Transact. Amer. Geophys. Union 1952; 33:235-246.
23. Yen BC, Lee KT. Unit hydrograph derivation for ungauged watersheds by stream-order laws.' J. Hydrologic Engrg. 1997; 2(1):1-9.