Geomorphological Aspects for Runoff Prediction in a Himalayan Catchment

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Abstract: The present study was undertaken to explore the geomorphological characteristics of the catchment of river Bino, a tributary of Ramganga river, located in the Himalayan region to develop a geomorphological instantaneous unit hydrograph (GIUH). The prediction performance of the developed GIUH was evaluated by comparing the peak discharge (q_p) and time to peak (t_p). It was observed that the absolute prediction error (APE), absolute percentage error (PE) for all estimated values of peak discharge and time to peak were, in general, well within the acceptable limits. It was also found that the extent of the map scale has a significant effect on the prediction performance of the developed model as it affects the values of some of the geomorphological parameters of the catchment.
Keywords: geomorphological characteristics, ramganga river, geomorphological instantaneous unit hydrograph, instantaneous unit hydrograph

1 Introduction

Accurate and easy estimation of runoff from catchments is a primary requirement for water resource planning for controlling the adverse impacts of floods and draughts in an area. The traditional techniques for the design-flood estimation not only require lengthy and reliable rainfall-runoff records, but also a sustainable procedure for updating the model parameters from time to time. Because of the high cost involved in setting up and maintenance of gauging stations, it is not possible to set up and maintain the stations over many locations for a long period of time. Thus, although many large catchments are gauged, a lot of small catchments still remain ungauged. Since long, scientists and engineers have been trying to synthesize stream flow from ungauged catchments. In this direction, the most popular approach has been the use of empirical relationships for determination of the parameters of conceptual models, like the synthetic unit hydrographs and instantaneous unit hydrographs. Some relationships have also been developed by researchers for estimation of some of the important characteristics of stream flow hydrographs, such as, lag time, peak discharge, time to peak and hydrograph duration. However, such relationships do not appear to be very accurate, since variations in global atmosphere may bring about changes in the rainfall patterns.

The most commonly used approach for rainfall-runoff modeling has been the determination of instantaneous unit hydrographs (IUH) for a basin through the application of linear theories. The IUH, which is equivalent to the unit impulse response function of a basin, describes the link between geomorphologic laws and hydrologic response of the basin. In recent times, geomorphologic techniques have been developed to link runoff with geomorphological characteristics of the catchment, obtainable from readily available toposheets, aerial photographs etc. of catchment under consideration. The linking of geomorphological parameters with the hydrological characteristics of a basin is likely to provide a more realistic representation of the hydrologic behaviour of different types of catchment, particularly the ungauged ones. With this in view an attempt has been made to explore the geomorphoological characteristics of the watershed and develop geomorphological instantaneous unit hydrograph (GIUH) to predict the runoff on storm basis for a Himalayan sub catchment.

2 Study area

The Ramganga is a springfed river having its origin in the middle Himalayas of Uttar Pradesh. The Ramganga river catchment, upstream to Kalagarh dam, comprises of an area of about 3,134 km^2, covering Almora, Chamoli, Pauri Garhwal and Nainital districts. The Bino watershed, a sub-watershed of Ramganga catchment, has been taken as the study area for carrying out hydrological and geomorphological analysis in the present study. The Bino watershed is a hilly catchment of the river Bino, a tributary of Ramganga, and is located between 29° 47′ 0″ and 30° 2′ 15″ N latitude and 79° 6′ 15″ E and 79° 17′ 15″ E longitude in the Ranikhet forest subdivision of Ramganga catchment. The soil texture varies from gravelly loamy sand to silt loam. Soil pH is mostly on the acidic side, varying from 5 to 7 with medium to high organic matter depending on the land use. The water holding capacity of the soil is generally low because of the dominance of coarser fractions. The watershed is divided into three groups on the basis of land use pattern namely, forest, cultivable and grazing land, waste and barren land. The cultivable lands, in general, are under poorly managed terraces and are susceptible to severe erosion. The grazing and wastelands have a poor vegetation cover and are severely eroded.

3 Development of giuh model

The geomorphological characteristics of the Bino watershed were analysed by using a combination of the survey of India topo-sheets, 53 N/4, 53 N/8, 53 O/1, 53 O/5 on an inch scale (1 inch = 1 mile, i.e., 1:63,360) and 53 N, 53 O on a quarter inch scale (1 inch = 4 mile, 1:253,440) scale. The watershed was found to be a sixth order basin with total number of streams as 921 on inch scale map. The hydrological data for the study were obtained from the Divisional Forest Soil Conservation Department, Ranikhet (Uttaranchal). Single peaked six storm events, which occurred simultaneously at Bino watershed as well as at the Naula rain gauge station, adjacent to the boundary of the Bino watershed, on June 27, 1973; July 26,1973; June 24—25, 1979; July 23—24, 1979; August 28—29, 1980 and July 31-August 1, 1982 were selected for the study. The streams of the watershed were delineated and ordered according to Strahler's ordering scheme(1957). Stream lengths were measured and converted into actual lengths in meters by multiplying them with suitable conversion factor. Similarly, the measured drainage areas for each stream in mm^2 were converted into km^2 by multiplying it with a suitable conversion factor. The maximum and the minimum elevations on the inch scale were found to be 1,075.9 m and 840 m respectively, while on the quarter inch scale the respective values were 987.5 and 840 above the mean sea level.

An attempt was then made to develop an instantaneous unit hydrograph from recorded rainfall-runoff data (storm IUH) and a geomorphological instantaneous unit hydrograph (GIUH) by using geomorphological information for the Bino watershed. The ordinates of Ithe IUHs and GIUHs for different storm events were derived by adopting the following equation given by Nash (1957).

$$U(T) = \frac{1}{K\,\Gamma(n)} \left(\frac{T}{K}\right)^{n-1} e^{-(T/K)} \qquad (1)$$

where, $U(T)$ is the ordinate of the IUH, cm/h; n is the shape parameter; K is the scale parameter, h; t is time, h and Γ is the gamma function.

By knowing the total volume of direct runoff [L^3], the rainfall excess [L] could be estimated by dividing it with the total watershed area [L^2], where [L] indicates the length dimension. From the property of IUH, the first and second moments (M_1 & M_2) of the IUH about the origin t=0 are given, respectively by the following equations:

$$M_1 = n\,K \qquad (2)$$

and

$$M_2 = n(n+1)K^2 \qquad (3)$$

Using equations (2) and (3) the values of n and K for a catchment were estimated adequately with the known excess rainfall hyetograph and a corresponding direct runoff hydrograph. Now by substituting the values of n and K in Eqn.(1), the ordinates of the storm IUH were estimated at one hour regular time interval.

The storm wise GIUHs were also developed by using the Eqn. (1) where the values of parameters n and K were estimated with the help of the geomorphological parameters and characteristics of the watershed. Geomorphological parameters viz.; bifurcation ratio (R_B), stream length ratio (R_L) and stream area ratio (R_A) between consecutive orders of the streams were estimated using Horton's laws. The average values of bifurcation ratio (R_{BA}), stream length ratio (R_{LA}) and stream area ratio (R_{AA}) for the entire basin were determined by fitting linear regression equations respectively, between log values of the number of streams (N_w), main stream length (L_w) and the mean stream area (A_w) as the dependent variables and order of the stream as the independent variable. The parameters R_{BA}, R_{LA} and R_{AA} were estimated by taking antilog of slope values of the respective regression lines. Then the values of the Nash's parameter n and K were estimated by using the following relationships proposed by Bhaskar *et al.*, (1997).

$$\frac{(n-1)}{\Gamma(n)} e^{-(n-1)} (n-1)^{n-1} = 0.5764\, R_{BA}{}^{0.55}\, R_{AA}{}^{-0.55}\, R_{LA}{}^{0.05} \tag{4}$$

and

$$K = \frac{0.44}{V} L_{\Omega}\, R_{BA}{}^{0.55}\, R_{AA}{}^{-0.55}\, R_{LA}{}^{0.38}\, x \frac{1}{n-1} \tag{5}$$

where the peak velocity (V) of main stream was estimated by using the expression proposed by Sorman (1995).

The solution of Eqn. (4) by the Newton-Raphson method of non-linear optimization yielded the value of shape parameter "n". Now knowing the value of n, V, R_{BA}, R_{LA} and R_{AA}, the scale parameter, K was obtained by using Eqn.(5). Thus, on substitution of values of n and K in Eqn.(1), the ordinates of GIUH were estimated at one hour regular time interval.

4 Results and discussion

The values of R_B, R_L and R_A along with other geomorphological characteristics viz; stream orders, total number of streams, mean stream length and mean stream area are given in Table 1. The average values of bifurcation ratio (R_{BA}), stream length ratio (R_{LA}) and stream area ratio (R_{AA}) for the entire basin were found as 3.7184, 1.981 and 4.0144 respectively. The reliability of a model is judged by the goodness of fit between observed and predicted values for a model. In this study the following statistical measures were employed for performance evaluation of the GIUH model.

Table 1 Geomorphological characteristics for different stream orders

Stream order	Total number of streams	Mean stream length (m)	Mean stream area (km^2)	Bifurcation ratio	Stream length	Stream area ratio
(w)	(N_w)	(L_w)	(A_w)	R_B	R_L	R_A
1	720	778.45	0.28	4.897	-	-
2	147	899.17	1.64	3.868	1.175	5.896
3	38	1 300.41	6.75	4.222	1.445	4.117
4	9	3 885.25	31.46	3.000	2.913	4.540
5	3	5 637.83	97.47	3.000	1.450	3.100
6	1	25 401.93	304.76	-	4.505	3.130

Absolute prediction error (APE)

The following equation proposed by the World Meteorological Organisation Statistics (1975) has been used to determine the absolute prediction error values in percent.

$$APE = \frac{\sum_{i=1}^{n}(O_i - P_i)}{\sum_{i=1}^{n} O_i} \times 100 \qquad (6)$$

Absolute percentage error (PE)

The absolute percentage error, which reflects the performance of model for individual observations has also been used to evaluate the performance of the developed GIUH model and is determined by,

$$PE = \frac{(O_i - P_i)}{O_i} \times 100 \qquad (7)$$

where, O_i and P_i are observed and predicted values of runoff at corresponding time i.

The performance of GIUH model for the study area was judged by considering the storm IUH as the basis for the comparison. The performance of the model was also checked with respect to the peak discharge (q_p) and the time to peak (t_p) of different storm events. The peak discharge (q_p) and time to peak (t_p) values for the selected storm events, obtained using IUH and GIUH models, are shown in Table 2 along with APE and PE values. The absolute prediction error of the GIUH model on inch scale for the prediction of peak runoff rate (q_p) and time to peak (t_p) are 34.88% and 24% respectively. It can be seen that absolute percentage error values for the prediction of q_p and t_p vary from 0% to 40%, except for the storm event of July 31-August 1, 1982, where it was 94% in case of q_p prediction. The above results clearly confirm the applicability of the GIUH model on the inch scale for the study area. As a test case the ordinates of IUH & GIUHs on inch and quarter inch scales for the storm event of August 28-29,1980 are shown in Fig.1 along with the observed IUH to establish the applicability of the model on the study area. It can be observed from Fig 1 that the model on inch scale (GIUH-IS) performs excellently well and has a definite edge over the model on quarter inch scale (GIUH-QIS) in predicting the runoff for the study area.

Table 2 Performance evaluation of the GIUH model for the prediction of peak discharge rate (q_p) and time to peak (t_p)

Sl.No	Storm Events	Peak discharge (cumec)		Absolute difference in peak discharge	Absolute percentage error (PE)	Time to peak (h)		Absolute difference in time to peak	Absolute percentage error (PE)
		Observed	Predicted			Observed from IUH	Predicted from GIUH		
1	June 27, 1973	98.361	117.89	19.530	19.85	5	4	1	20
2	July 26, 1973	105.691	147.779	42.000	39.73	5	3	2	40
3	June 24—25, 1979	104.950	134.522	29.570	28.17	6	4	2	33.33
4	July 23—24, 1979	164.759	185.952	21.193	12.86	3	3	0	0
5	August 28—29, 1980	126.238	137.161	10.923	8.65	4	4	0	0
6	July 31—Aug 1,1982	145.585	282.744	136.886	94.00	3	2	1	33.33
APE=34.88%						APE = 24%			

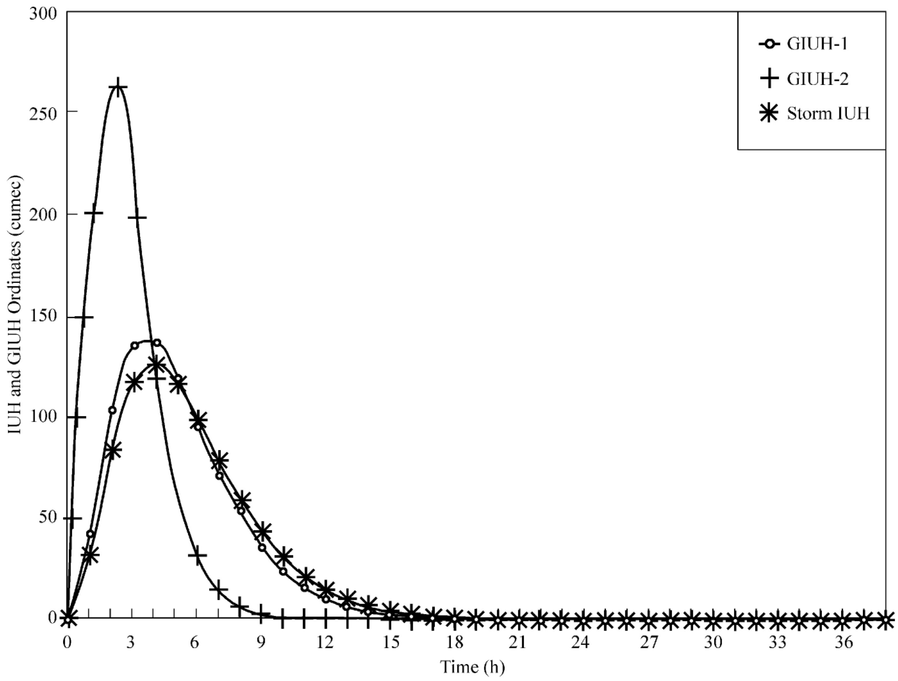

Fig. 1 Comparison of IUH and GIUHs for the storm event of August 28—29, 1980

References

Bhaskar, NR., Parida, B.P. and Nayal, A.K. 1997. Flood estimation for ungauged catchment using the GIUH. Journal of Water Resources Research Planning and Management. 7: 228-238.

Nash, J.E. 1957. The form of instantaneous unit hydrograph. International Association of Science and Hydrology. Pub. 145, 3: 114-121.

Sinha, J. 1999. A study on geomorphological response for runoff prediction in a Himalayan catchment. M.Tech. Thesis in Agricultural Engineering (Soil and Water Conservation Engineering), G.B. P.U.A.T., Pantnagar (India). p. 107.

Sorman, A.U. 1995. Estimation of peak discharge using GIUH model in Saudi Arabia. Journal of Water Resources Planning and Management. 7: 287-293.

Strahler, A.N. 1957. Quantitative Analysis of watershed geomorphology. Trans of American Geophysical Union. 38: 913-920.