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Full Length Research Paper

Regional model for peak discharge estimation in ungauged drainage basin using GIUH, Snyder, SCS and triangular models

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Due to the importance of instantaneous peak discharge estimation for watershed management study in countries like Iran, the search is ongoing to correlate geomorphologic and hydrologic parameters to present models. This paper describes the use of synthetic unit hydrograph at drainage basin of Mehran (Joestan River). The obtained results were compared with recorded peak discharge in outlet of watershed. The models of Relative Mean Error (RME) and Root of Mean Square Error (RMSE) in drainage basin in central Alborz watershed were compared with each other. The results indicate the RMEs of 20.43, 40.06, 133.082, and 135.72, and RMSEs of 16.08, 14.65, 25.37 and 25.82 for GIUH, Snyder, SCS and Triangular models respectively. The daily peak discharge model was derived by 177 recorded events of daily peak discharge.

Key words: Peak discharge, parameter, model, Mehran Basin.

INTRODUCTION

Considering the world average annual precipitation (860 mm), Iran is classified as a semi-arid area with an amount of 240 mm precipitation. But his amount of precipitation doesn't cover spatial agricultural needs (Hojjati and Boustani, 2010).To address the issue, it seems that the utilization of water should be modified according to daily rate of precipitation. One of the reasonable ways to get harmony with drought is useful application of available water resources (such as surface and ground water). This strategy can not be practiced without identification of district hydrology object. Because of the lack of identification and application of hydrology science in country, we experience dangerous floods and droughts in some sites. However, in recent years, more attentions have been given to water crisis, but still there are not any recorded data in this regard. It is clear that without studying of geomorphology and hydrology of drainage basin, execution of scientific plans for flood disaster can not be done. Drainage basin studies with attention to geomorphologic characteristics affect discharge characteristics of main rivers, their upstream and sediment generation (Nazari Samani et al., 2009). While, there is not any instrumentation for recording essential data and subsequent natural unit hydrograph, some methods can be used for determination of unit hydrograph.

Sherman (1932) concluded that the hydrograph shape must be the same for storms with same attributes. Snyder (1938) proposed a method in according with some of unit hydrograph attributes. This method is a result of researches in some cases of drainage basins in Appalachian Mountain. Some measurements were done by United States Soil Conservation Service (SCS) in different drainage basins and dimensionless hydrograph was presented (Mockus, 1957). These researches showed that if derived flood hydrograph axes in different conditions dimensioned, all of them will almost have a

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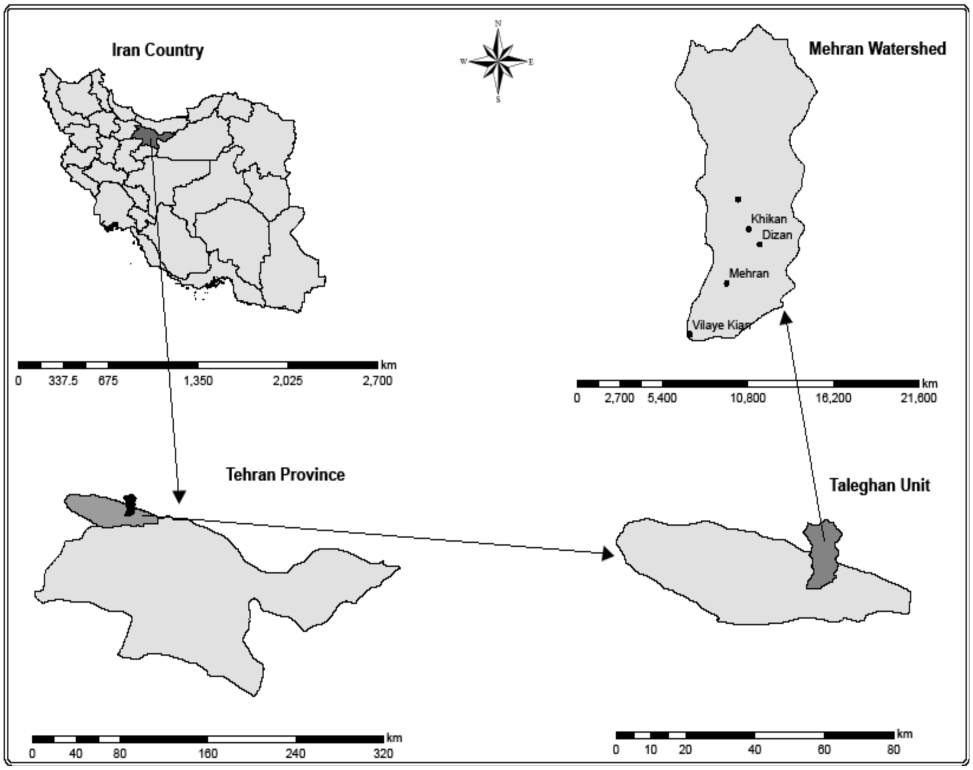

Figure 1. Location of Mehran basin.

same shape. The problems of geomorphologic instantaneous unit hydrograph (GIUH) were demonstrated in 1979 by Rodriguez- Iturbe. Recent progress in finding run off topographic was made by aid of GIUH. In previous two decades, many hydrologists (Gupta et al., 1980; Rodriguez-Iturbe et al., 1982; Krishen and Bars, 1983; Troutman and Karlinger, 1985; Agnese et al., 1988; Chutha and Dooge, 1990; Yen and Lee, 1997; Olivera and Maidment, 1999; Berod et al., 1999) were interested in run off simulations using drainage basin attribute geomorphology. The primary idea describing the engineering of stream network and results of geomorphologic responses was derived and named geomorphologic instantaneous unit hydrograph (Karvonen et al., 1999). A mathematical method and its efficiency were proposed by (Lee and Chang, 2005) as a result of studying the northern Taiwan. The results shows since the run off primarily occurs in low portions of a watershed near streams of a precipitation run off model, only the surface run off is recognized as being inadequate. And as a result, by correction of GIUH the better results can be derived. The surface flow IUH of this study could adequately reflect the variation of surface roughness conditions, and the subsurface flow IUH could reveal different soil conditions. The concept of GIUH is utilized in calculating the influence of the channel network on the delay and the shape of the hydrograph (Karvonen et al., 1999). The quantitative analysis of drainage networks has gone through dramatics advances since 1690, mainly after Shreve's (1966) classical paper which led the way for a theoretical foundation of Horton's empirical laws. This has provided a new perspective for many other problems in fluvial geomorphology (Rodrigues-Iturb and Valdes, 1979). This article describes the most optimized model of instantaneous peak discharge estimation. To achieve this, four models including GIUH, SCS, Snyder and Triangular have been taken into account. With regards to recorded peak discharge in Mehran basin and measured data in above mentioned models, regional model for discharge estimation is earned.

MATERIALS AND METHODS

Study area

Mehran drainage basin is one of the sub basins of the Central Alborz basin. It is located in Tehran province and its Taleghan unit situated 50° 53' 24.0" to 50° 59' 19.0" East longitudinal and 34° 10' 48.0"to 36° 20' 21.0" North latitude and covers 99.71 km^2 (Figure 1).

There were rain gauge station and hydrometric station in outlet for extraction of discharge and rain statistics in the study area. In this basin, one rain gauge station: Joestan and also one hydrometric station named Mehran- Joestan were considered (Figure 2).

Main precipitation in the study area is related to Mediterranean circulation that influences the area from west in autumn through

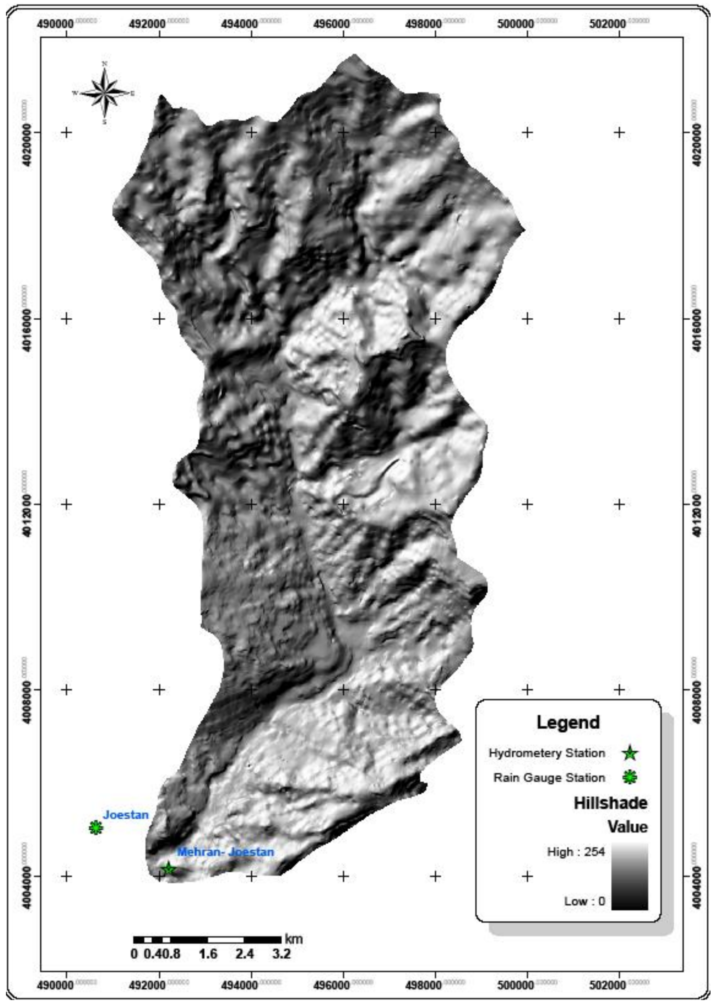

Figure 2. Location of rain gauge station and hydrometric station In Mehran basin.

spring. Since the watershed is located on the southern slopes of central Alborz, semiarid climate is predominating. Different drainage patterns can be observed, the main of which is dendritic (Figure 2).

The length of its main river is about 22 km. The maximum and minimum elevations are 4390 and 1940 m respectively. Mehran drainage basin contains poor range lands and farming terrains and a small part of the watershed is garden. The total precipitation changes from 635 to 768 mm in different places of the watershed.

Extraction of rain and discharge data coincide with flood

We used flood discharge statistics and recorded rain in the station of local water institute of Tehran province and organization of water resources research. For Mehran drainage basin 15 coincidence events of rain and discharge were extracted for these events (15), 7 of which was recognized to be good (Figure 3).

Digital topographic map

Supply digital topographic map was extracted from National Cartographic Center (N.C.C.). We also extracted the followings: stream map study drainage basin, mean slope of drainage basin area, mean weighted slope of main stream in outlet of drainage basin, main stream length from centroid to outlet of drainage basin (Figure 4)

Slope of highest stream order, stream number in each order (for determination of bifurcation ratio, R_b), stream lengths in order (for determination of length ratio, L_u) and drainage basin area in each order (for determination of area ratio, A_u). The estimation of these parameters can be handled easily and more accurately using GIS.

It is observed that the design flood is more sensitive to the design storm pattern and its time distribution (Jain et al., 2000). Lin and Oghochi (2006) have obtained the most common method implemented in major commercial GIS software, assuming minimum contributing area to determine channel head locations. However, minimum contributing areas should vary even within a small watershed according to local factors such as topography and litho logy. The infinite form and variety of drainage basins respond to the known basic geomorphologic laws exists in nature. It is expected that in the structure of the hydrologic response of a basin, a basic order should also be present which reflects the deep symmetry in formal relations between the parts involved in Horton's geomorphologic laws (Rodriguez- Iturbe et al. 1982).

It must be mentioned that bifurcation ratio ($R_B=N_u/N_{u+1}$), Length

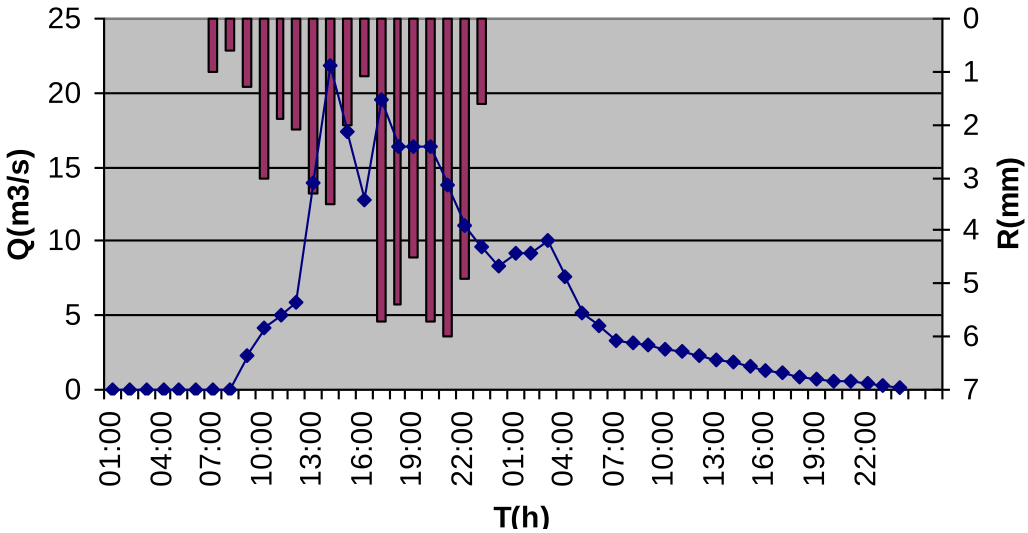

Figure 3. Observed Hydrograph at 7, 8 Nov. 2006 .

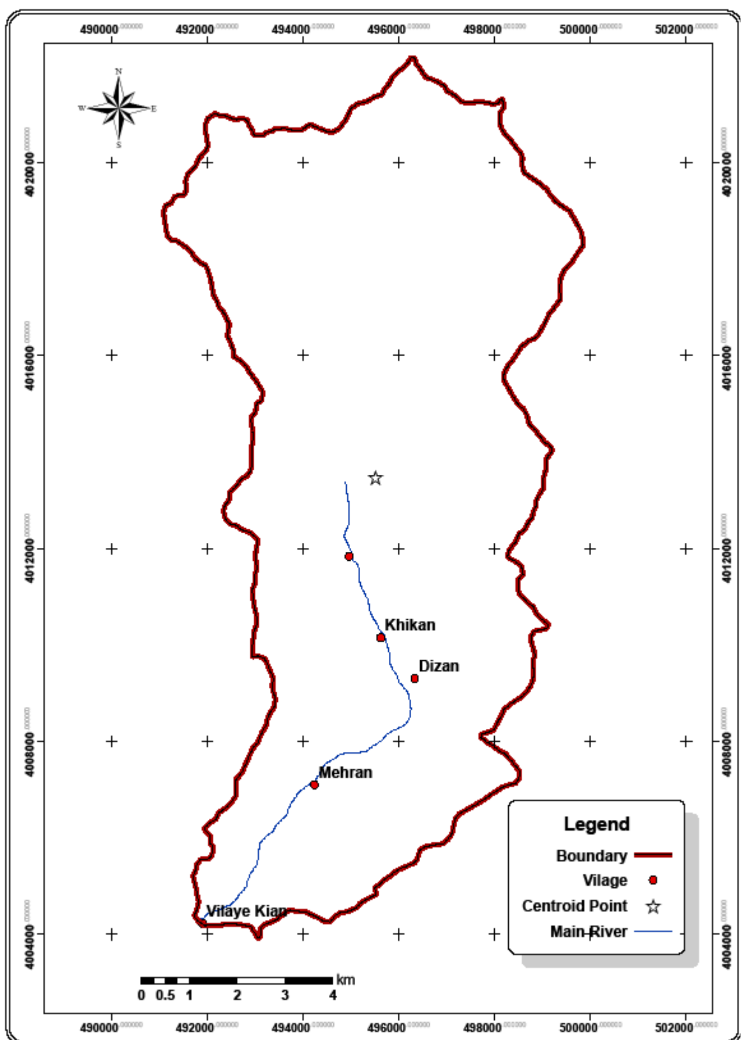

Figure 4. The main stream from centroid to outlet of Mehran basin.

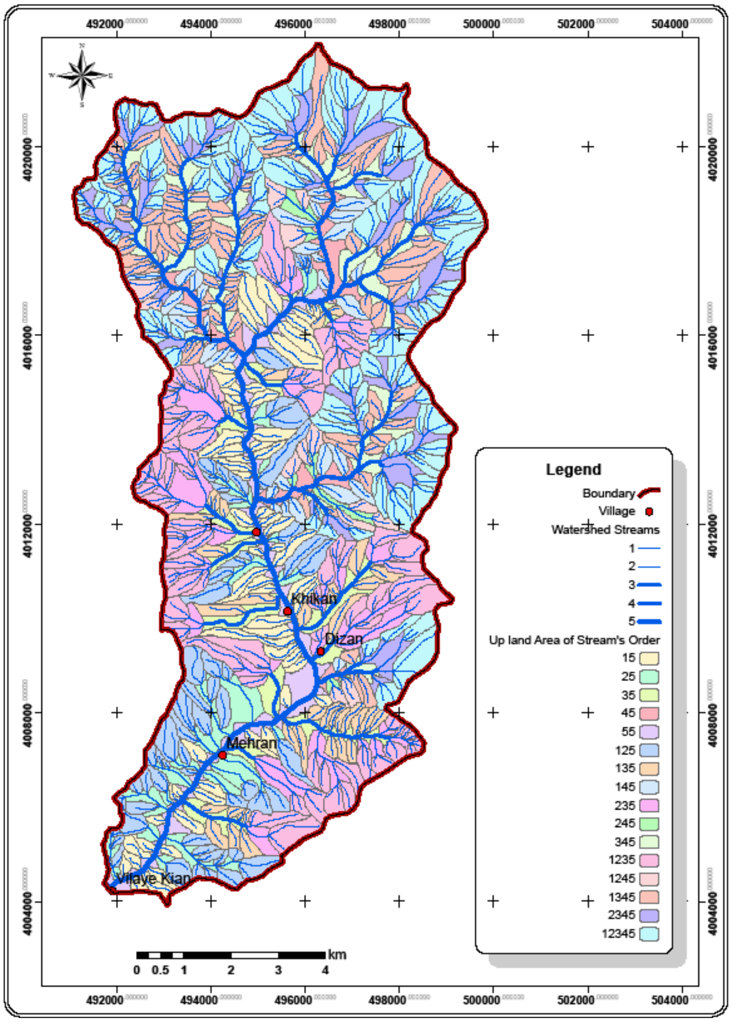

Figure 5. Up land area for each order of stream.

ratio ($R_l=L_u/L_{u-1}$) and area ratio ($R_A=A_u/A_{u-1}$) from this relation were calculated. N_u, N_{u+1}: are the numbers of stream of orders U and U+1; L_u, L_{u-1}: are the mean length of streams of orders U and U-1; A_u, A_{u-1}: are the mean area of the basins of orders U and U-1

A river basin is made up of two interrelated systems: the channel network and the hill slopes. The hill slopes control the production of storm water runoff which, in turn, is transported through the channel network towards the basin outlet. The runoff- contributing areas of the hill slopes are both a cause and an effect of the drainage network growth and development. This cause-and-effect relationship may be visualized through the following consideration taken from Gupta et al. (1980) and Rodriguez- Iturbe (1993). It must be attended to each water ways including stream area with spatial order that entered to stream and with stream by upper order, and then it needs to be reached to outlet. For instance water way 245 in Mehran drainage basin consists of a stream area of order two that is entered to streams with order four and then entered to stream of order five. Therefore for each basin, there exist at most $2^{\Omega-1}$ water ways (Ω is the biggest stream order in each of basin) (Zhang and Govindaraju, 2003). In Mehran drainage basin, there are 16 water ways. For earning each order's area, tables of different water way gained and for earning each water way, the upper entered water way area must be attended (Figure 5).

Flow velocity

Following formula was introduced by Rodriguez- Iturb et al. (1979) to calculate the flow velocity for one special storm:

$$V_\Omega = 0.665\alpha_\Omega^{0.6}(i_r A)^{0.4}$$
$$\alpha_\Omega = S_\Omega^{0.5}/nB^{2/3}$$
(1)

Where V_Ω is the flow velocity (m/s), i_r is rain intensity (cm/h), A is drainage basin area (km^2), S_Ω is slope of the main river in drainage basin outlet (%), n is Mannig's roughness coefficient and B is the mean flow width in outlet of drainage basin (m).

Instantaneous peak discharge estimation

The classical theory of the instantaneous unit hydrograph (IUH) relates the rainfall excess over catchments to the direct runoff at the catchments' outlet rests based on three basic assumptions: lumped system, linearity, and time invariance (Rooso, 1984). GIUH model and relations presented by Rodriguez- Iturb et al. (1979) (Formula

2).

$$q_p = {}^{1.31}/_{L_\Omega} \, [R_L^{0.43} V] \qquad (2)$$

Where L_Ω is the biggest length of Main River (km), V is flow velocity (m/s), q_p is peak discharge in (hr^{-1}) (Formula 3).

$$Q_P/_{Q_e} = t_r . q_p \left(1 - t_r * {}^{q_p}/_4\right) \qquad Q_e = i_r . A$$

$$\rightarrow \quad t_b \geq t_r \qquad (3)$$

Q_p: is the exited peak discharge (m^3/s), Q_e is the effective discharge (m^3/s), q_p is the peak discharge of geomorphologic instantaneous unit hydrograph (hr^{-1}), t_r is the time of effective precipitation (h), i_r is rain intensity (cm/h) and A is the drainage basin area (km^2).

Peak discharge estimation

Other models such as Snyder, SCS and Triangular have also been studied using relations presented in references such as Snyder (1938) and SCS Engineering- ing Handbook. Washington. D. C. (1968).

SCS model

The method of peak discharge estimation employed by the Soil Conversion Service (SCS), U. S. Department of Agriculture, uses an average number of natural UHs for watersheds varying widely in size and geographical location. In the SCS model, the lag time, Tl, shall be determined using watershed physical properties such as the area, main river length, average slope and CN (Curve Number). The synthetic unit hydrograph can then be computed. The SCS model permits computing the peak discharge for a watershed that has insufficient observed rainfall–runoff data.

A Unit Hydrograph (UH) is defined as the direct runoff hydrograph (DRH) produced by 1 unit (inch) of effective rain (runoff) uniformly distributed over a basin. Unit hydrographs can be combined with precipitation data and basin data to determine the DRH for a particular basin. The curve number was determined with respect to land use and soil hydrological group maps in different antecedent moisture conditions (dry, average and moist) and hydrological conditions. The losses estimation is the sum of the interception, infiltration, and transmission of the soil and surface (in mm). The runoff calculation is given below:

$$S = \frac{25400}{CN} - 254 \qquad (4)$$

Runoff was calculated using the following formula (5):

$$Q = \frac{(P - 0.25)^2}{P + 0.85} \qquad (5)$$

Q: Run off (mm), S: Losses (mm) and P: Maximum precipitation in 24 h (mm).

After calculating runoff caused by a storm event, the maximum flood discharge was calculated using the following formula (6):

$$Q_{\max} = \frac{2.083AQ}{t_p} \qquad (6)$$

Q_{max}: maximum flood discharge (m^3/s), A: Basin area (km^2), Q: Run off (mm) and tp: time of flood crest which is evaluated by time of concentration (tc) in minute.

Snyder model

Snyder (1938) was the first to propose a unit hydrograph technique that could be used on un gauged basins. His method was based on a number of watersheds in the Appalachian Highlands ranging in size from 10 mi^2 to 10,000 mi^2. Snyder's equations are:

$$T_P = C_t (L.L_c)^{0.3} \qquad (7)$$

Where t_p is basin lag, L is length of the main stream from the outlet to the divide, L_c is Length along the main stream to a point nearest the watershed centroid and Ct is coefficient usually ranging from 1.8 – 2.2 (Ct has been found to vary from 0.4 in mountainous areas to 8.0 along the Gulf of Mexico).

$$Q_P = 640 \left({}^{C_P A}/_{t_p} \right) \qquad (8)$$

Where Q_p: peak discharge, A: drainage area and C_p: storage coefficient ranging from 0.4 to 0.8 where larger values of Cp are associated with smaller values of Ct.

$$T_b = 3 + {}^{t_p}/_8 \qquad (9)$$

Where T_b: the time base of the hydrograph. For small watersheds, Eq 9 should be replaced by multiplying tp by a value of from 3 to 5 as a better estimate of Tb. Eqns. 7,8 and 9 define points for a unit hydrograph produced t_p an excess rainfall of duration D = tp/5.5. For other rainfall excess durations D', an adjusted formula for tp becomes:

$$T_{p'} = t_p + 0.25(D' - D) \qquad (10)$$

Where tp' is the adjusted lag time for duration D'. Once the three quantities tp, Qp, and tb are known, unit hydrograph can be sketched so that the area under the curve represents 1,0 in of direct runoff from the watershed.

In this application the two items of data are: C_p is Storage coefficient plus and T_p is catchments' lag times.

Triangular model

Since the height and base-width of the triangular are constrained to be simple functions of its time to peak, *Tp*, the triangular UH is a parameter model. Employing a statistical relationship between *Tp* and catchments' characteristics, the triangular model can be applied in regionalization mode for catchments un gauged for flow.

Table 1. Numbers and dates of events studied in drainage basin.

Date of events	Intensity i_r (cm/h)	Events Num.
20, 21 Apr 2003	2.55	7
29, May, 2003	3.8	
24, 25 Apr 2004	2.225	
26, 27 Apr 2005	3.55	
19, 20 May 2005	0.66	
7, 8 Nov 2006	0.66	
27, 28 Apr 2007	3.28	

The triangular model is widely employed for flood hydrology. For hydrological analysis of lower flows, or for characterizing whole flow regimes, the parameter triangular model is, not surprisingly, limited by its conceptual simplicity (e.g. hydrograph recessions are not characteristically linear)

Models calibration

Relative Mean Error (RME)

Relative Mean Error relation for calculated peak discharge from observed peak discharge is presented in Formula (11, 12):

$$RME = {}^{1}/_{n} \sum RE_i \quad (11)$$ and

$$RE_i = {[(Q_{op} - Q_{cp}) * 100]}/{Q_{op}} \quad (12)$$

Where RE_i is the relative error percentage for each of events, Q_{op} is the observed peak discharge and Q_{cp} is the calculated peak discharge.

Root of Mean Square Error (RMSE)

Root of Mean Square Error of peak discharge is presented in Formula (13, 14):

$$RMSE = \left[{}^{1}/_{n(\sum_{i=1}^{n} SE_i)}\right]^{1/2} \quad (13)$$

and

$$SE_i = (Q_{op} - Q_{cp})^2 \quad (14)$$

In which SE_i is the relative error for each event, Q_{op} is the observed peak discharge and Q_{cp} is the calculated peak discharge.

Models presentation for daily and instantaneous peak discharge

Geomorphologic parameters can be derived from digital model easily. Geomorphologic parameters are also used in rainfall- run off modeling (Fleurant and Ronald, 2006). In this section, with regards to factors in studied models and recorded daily and instantaneous peak discharge data in Mehran- Joestan hydrometer station, attempted to present regional model for peak discharge estimation.

RESULTS

As mentioned before, from 15 coincident events of rain and discharge, 7 events were recognized to be good. The results of rainfall and discharge coincidence extraction were presented in Table 1.

With regard to geomorphologic factors for each of these models, using Geographic Information Systems (GIS), Digital Elevation Model (DEM) production and stream nets for Mehran basin were earned (Table 2).

Two important preferences of study models (especially GIUH model) beside geomorphologic factors are flow and rainfall factors. GIUH model's factors such as Mannig's roughness coefficient, slope of the main river in basin's outlet, mean flow width in outlet of basin for flow velocity calculation in Formula (1) were considered. (Table 3).

After earning factors of each study model we can apply them. Beside the results of each model, events date and observed discharge for accidental comparison are also presented (Table 4 and Figure 6).

To check the validity of each model, error functions are determined. The results of Relative Mean Error (RME) and Root of Mean Square Error (RMSE) investigations are presented in Table 5. The results indicate that GIUH model with the RME of 20.43 and RMSE of 16.089 has the lowest error among other study models.

The results of this research show that it is not possible to create the regression model for instantaneous peak discharge, because there are not enough recorded events. Therefore we have attempted modeling to present daily peak discharge. For Mehran drainage basin, 177 daily flood events with regarding to harmony between rain hyetograph and flood hydrograph were recognized to be good and applicable. With calculated factors in studied models in this research and other measured parameter, the regression equation is calculated (Formula 15). Within the last two decades or

Table 2. Geomorphologic calculated parameters in Mehran drainage basin.

Streams order	Number of streams	Length of streams (km)	Mean Length of streams (km)	Upstream drainage basin area (km^2)	Mean Upstream drainage basin area (km^2)	Mean stream length from upstream to outlet (km)	Main stream distance from outlet to centroid of drainage basin (km)	Mean slope of drainage basin (m/m)	Mean slope of main stream in outlet of drainage basin (m/m)
1	598	286.21	0.4786	67.67	0.11				
2	120	72.330	0.6027	59.28	0.49				
3	27	36.998	1.3703	65.99	2.44	22.07	11.749	0.244	0.01955
4	5	9.352	1.8704	48.53	9.70				
5	1	16.548	16.548	99.71	99.71				

Table 3. The required parameters for measurement flow velocity from kinematic wave parameters.

Drainage basin	Mannig's roughness coefficient (n)	slope of main river in drainage basin outlet S_{Ω} (%)	drainage basin area (km^2)	Rain intensity I_r (cm/h)	mean flow width in Outlet of drainage basin B (m)
Mehran	0.0382	1.95	99.71	It's different for any events in drainage basin	7.089

Table 4. Date of events and peak discharge estimation (m^3/s) from using models in Mehran drainage basin.

Events Date	Mehran drainage basin				
	Qp (o.)	Qp (Tri.)	Qp (SCS)	Qp (Sny.)	Qp (GIUH)
20,21 April 2003	55.46	48.483	47.893	21.39	18.73
29 May, 2003	23.51	54.83	54.145	22.09	23.366
24, 25 April 2004	8.97	58.67	57.92	22.45	9.052
26, 27 April 2005	18.54	33.66	34.108	22.45	16.94
19, 20 May 2005	34.054	32.77	32.35	22.1	12.59
7, 8 Nov. 2006	22.57	31.136	31.54	21.73	22.83
27, 28 April 2007	22.35	51.46	50.827	21.73	21.803

so, one of the simplest approaches to the problems of rainfall-runoff modeling has been through the application of linear theories (Dooge 1973).

$$Q_p = 2.416V + 1.336A - 0.039B - 2.591 \quad (15)$$

$$R^2 = 0.952 \qquad R = 0.97$$

Where V is the flow velocity, A is discharge area and B is wetted perimeter in discharge area.

Discussion and conclusions

With regards to (Table 5), it can be concluded that the GIUH, Snyder, SCS and Triangular models could provide better estimation respectively. With regards to Tables 4 and 5, the GIUH and Snyder models have the same results to some extent.

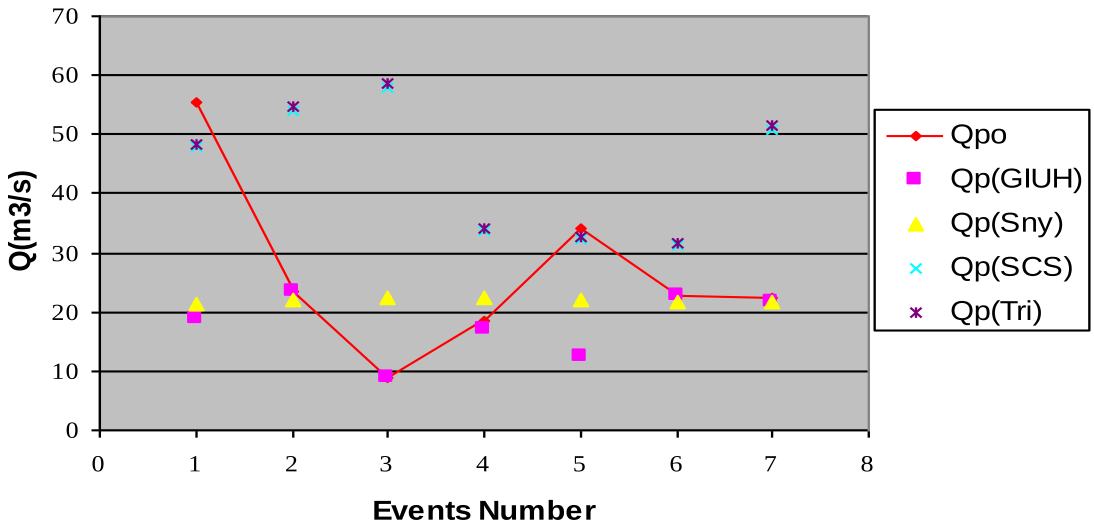

Figure 6. Observed discharge and peak discharge estimation from using models.

Table 5. Comparison of study models in drainage basin with index of Relative Mean Error (RME) and root of mean square error (RMSE).

Study models	Mehran drainage basin	
	RMSE	RME
GIUH	16.089	20.43
Snyder	14.65	40.062
SCS	25.371	133.082
Triangular	25.828	135.722

Kumar et al. (2002) have modeled the unit hydrograph and correlated GIUH model parameters with Clark model parameters. But in our study, besides GIUH model parameters, we also used SCS, Snyder and Triangular models parameters to model peak discharge estimation. Mossa (2008), studied hydrologic characteristics such as stream and slope nets, flow hydraulic and spatial rainfall distribution of GIUH model in seven basins of south west of France. Results shows that splitting the basin to sub basins in two points of stream nets for GIUH model determination is sufficient but we did split the basin to 16 sub basins on the upper stream’s order ($2^{\Omega-1}=2^{5-1}=16$). Also the analysis shows that the GIUH model has more sensitivity to stream topology, spatial rainfall distribution and characteristics of flow hydraulic. Thus, with regards to Fig (5), characteristics of flow hydraulic have been improved by our study.

In the study done in Paskohak drainage basin by Rahimian and Zare (1995) to compare the results of GIUH with SCS, Snyder and Triangular methods, it has been concluded that GIUH has a better coincidence with observed hydrograph. That was the reason that our study utilizes this result. Jain and Sinha (2003) studied Horton laws with their applications in GIUH model on UN gauged basin with fifth order in Himalayan Mountains. The results shows discharge with 50 years return period have good accomplishments with observed data. Their study confirms our results. Kumar et al. (2007) have used GIUH model for extraction run off hydrograph in Ajar basin of India. Results comparisons from error functions (such as root mean of standard error) in six events have the best results. Their study also confirms our results.

Ghiassi (2004) has estimated the hydrograph by GIUH and GCIUH methods, and by other synthetic methods such as Snyder, SCS and Triangular, he has compared the results. This study has been done in reprehensive basins of Kassilian in northern Iran and Lighvan in northwest of Iran. It is mentioned that the GIUH by ROSSO method also acquired. After then these methods compared with observed hydrograph, the results were acceptable and they have no significant differences. The other results of this research project show that for peak discharge estimation, hydrographs of GIUH, Triangular, SCS and Snyder methods have the best estimation respectively. Therefore Ghiassi's results for GIUH are matched with our results. Montazeri et al (2004) showed

Table 6. Events analysis of Geomorphology model in Mehran drainage basin

Model	Drainage Basin	Date of events	Problem	Reason
GIUH	Mehran	20, 21 April 2003	Qpo>Qpe	Snow melt and rainfall with up continuous

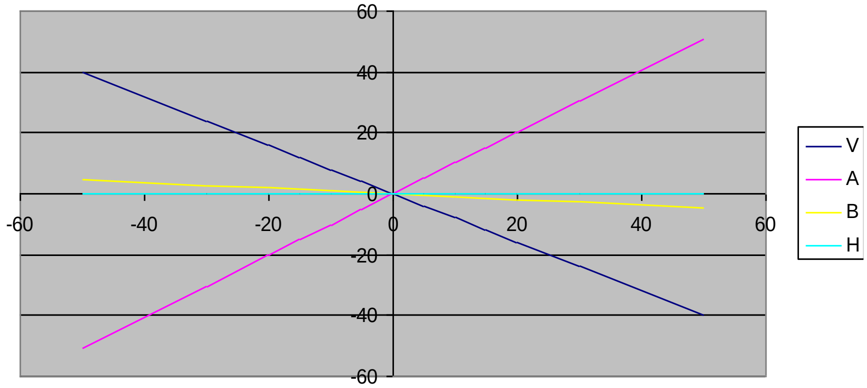

Figure 7. Sensitivity analysis of daily peak discharge model's factors in Mehran basin.

that using GIS technique for extraction of required parameters for Clarck synthetic hydrograph and comparing them with observed hydrograph in outlet will result in a good harmony between them. Therefore for this study also used this technique.

Based on the results obtained the GIUH model is the best model for the estimation of instantaneous peak discharge. Data obtained for each of the events in the Mehran drainage basin demonstrate that in one of the events in 20 and 21 April, 2003, the observed discharge (Qp_o) was greater than the estimated discharge by model (Qp_e). The reason is presented Table 6.

Sensitivity analysis of daily peak discharge model's factors (Formula 15) in Mehran drainage basin in Figure 7 demonstrates that the factors like flow velocity and discharge area have the major effects on model's sensitivity. So, accurate measurement of these parameters enhances the efficiency and will provide a more accurate model.

For many drainage basin in the world, that do not have hydrometric station or have an incomplete data, it is recommended that if there is a gauge rain station, the Geomorphologic model for peak discharge estimation to be used. Is it does not exist, the Snyder model is recommended.

For the same kinematical conditions, size and scale in the GIUH model are not reflected through the area on the basin but through the length of the storms (L_Ω). Two basins may be considered hydrologicaly similar when they have identical $R_L^{0.43}/ L_\Omega$ which controls q_p. Due to the values of R_L existed in nature, we may assume that $R_L^{0.43} \approx R_L^{0.38}$, two basins will be similar when they have equal values of ($R_L^{0.43}/ L_\Omega$) and (R_B/R_A), (where L_Ω is in Kilometers when comparing different values of $R_L^{0.43}/ L_\Omega$ Rodriguez- Iturbe and Valdes, 1979). With regards to above mentioned problems for further confidence of GIUH model, it is recommended that this model is used in other drainage basins in the world and the results analyzed.

In the end, with regard to the need for these models in the world, it is recommended that models with these characteristics are presented.

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