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EVALUATION OF GEOMORPHOLOGIC INSTANTANEOUS UNIT HYDROGRAPH METHOD IN FLOOD HYDROGRAPH SIMULATION

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A watershed is considered as a system consisting of different interrelated hydrologic units that react to rainfall. The present research was carried out to investigate the consistency, accuracy and reliability of a geomorphologic model in comparison with Snyder, SCS, Triangle, Rosso and geomorphoclimatic unit hydrographs in determination of the shape and dimensions of the outlet runoff hydrograph in the Kasilian basin located in the Mazandaran Province of Iran. For this purpose, the first twenty one equivalent rainfall-runoff events were selected and for each, a hydrograph of outlet runoff was calculated. Then the models were compared with the observed hydrograph, for peak time and peak flow of outlet runoff. The most efficient model for estimation of the hydrograph of outlet flow for similar regions was proposed. Comparison of calculated and observed hydrographs showed that the geomorphologic model had the most direct agreement in two parameters of peak time and peak flow of direct runoff. Also, the geomorphological model had the least amounts of main relative and square error. The result also showed that the efficiency of geomorphologic model ratio for Snyder, SCS, Triangle, Rosso and geomorphoclimatic hydrographs in the study basin are 91.06, 99.11, 88.642, 48.195 and 4.944, respectively. Comparing with other models, the geomorphologic and geomorphoclimatic hydrographs are the most efficient methods to estimate flood discharge.

INTRODUCTION

The Islamic Republic of Iran is the second largest country in the Middle East and almost 87% of the land area is located in arid and semiarid regions (Rangavar, 2004). The average annual rainfall is 240 mm, less than one-third of the global average value, hence it is among the world's dry areas (Mahdavi, 2005; Alizadeh, 2006). Recent studies show that the total volume of annual precipitation is almost 430 billion m^3, out of which about 20% is lost in the form of flash floods (Foltz, 2002; Ahmadvand and Karimi, 2008). In watershed planning and flood management, estimation of the maximum flood discharge is necessary for predicting the watershed hydrological behavior. The flood management in a basin would not be successful unless the hydrological behaviors are predicted (Bhadra et al., 2008). Lack or low accuracy of rain data, high cost, lack of information in catchments and long waiting time in obtaining results, are the major problems in hydrological prediction (Lopez et al., 2005; Vaes et al., 2001; J. Vahabi and M. Ghafouri, 2009; Maheepala et al., 2001;). A one common method in flood estimation is the use of unit hydrograph which is not only applied in peak flow estimation, but also for creation of complicated flood hydrographs (Heshmatpour et al., 2002). Catchments and storm characteristics are the parameters that mainly affect the complex process of watershed response to rainfall events (Agirre et al., 2005). Runoff production and its behavior is a function of different types of land use and land use changes (Rangavar et al., 2009). Hydrological response of a river basin is a function of relationship between basin geomorphology (catchments area, shape of basin, topography, channel slope, stream density and channel storage) and its hydrology (Snyder, 1938; Loukas et al., 1996; Shamseldin and Nash, 1998; Ajward et al., 2000; Hall et al., 2001; Jain and Sinha, 2003; Nourani et al., 2008). Many studies have been carried out about the efficiency of artificial unit hydrographs and Instantaneous Unit Hydrographs (IUHs) (Nash, 1960; Jeng and Coon, 2003; Wang and Chen, 1996). The IUH is defined as the probability density function (PDF) of the droplet travel time from the source to the basin outlet, in which the time spent in each state (order of the stream in which the drop is located) is taken as random variable with a exponential PDF (Liu et al., 2003). The concept of the Geomorphologic Instantaneous Unit Hydrograph (GIUH) was first introduced by Rodriguez-Iturbe and Valdes (1979) and later generalized by Gupta et al. (1981). In this approach, the excess rainfall is assumed to follow different probabilistic flow paths in the channel and overland areas to reach the basin outlet (Bhadra et al., 2008). Rodriguez-Iturbe et al. (1982) proposed a geomorphoclimatic instantaneous unit hydrograph (GCIUH) as a link between climate, geomorphologic structure and hydrologic response of a basin. They derived a set of basic equations for a third-order watershed. This quantitative conceptualization made it possible to generate a GIUH for an ungauged small watershed. Based on this result, the GIUH model was applied in semiarid regions and results were compared with traditional SCS approach to further verify model application. It is concluded that there is relative matching between the simulated runoff hydrograph and the recorded flows. Cudennec (2004) investigated the geomorphologic explanation of the unit hydrograph concept and concluded that use of geomorphologic parameters provides deterministic explanation of the assumption of the unit hydrograph and geomorphologic unit hydrograph theories. Sorman (1995) applied the GIUH model to estimate the peak discharges resulting from various rainfall events for basins in Saudi Arabia and concluded that the length ratio (R_L) significantly influenced the hydrologic response of a river basin and it must be considered for flood-forecasting studies of any river. Hall et al. (2001) did regional analysis using the GCIUH (geomorphoclimatic instantaneous unit hydrograph) in the southwest of England. In this study, the rainfall excess duration was divided into several time increments, with separate IUHs being generated for each interval. The results showed that fine time interval captures the shape of the runoff hydrographs. Jain et al. (2000) worked on rainfall-runoff modeling using GIUH in Gambhiri catchment in western India.

The results showed that the peak characteristics of the design flood are more sensitive to various storm patterns. The main objective of this research was to compare the recorded and computed hydrograph dimensions in simultaneous times and implement suitable methods for flood analysis in similar ungauged basins.

REGIONAL SETTINGS

The Kasilian basin with an area of 68.8 km^2 was selected because of its hydro-climatology station, flood hydrograph, and hyetograph of its comparative precipitation. The research basin is located between the Setik mountains on the north, Chehar-Tab mountains on the east, Gatuja mountains on the west and Miruzad mountains to the south. It lies between 35° 58’ 30” to 35° 07’ 00” eastern longitudes and 53° 10’ 30” to 53° 18’ 00” northern longitude, south of the Caspian sea, Alborz mountains, Mazandaran Province, Iran, at an elevation of 3349 m above sea level. The average annual precipitation in the basin is about 791 mm. Climate is semi-humid and cool according to Demartonne method. Land type of the research area is mountainous and average slope is 15.8%. The length of its main river and its mean slope are 16.5 km and 13%, respectively. There are 12 climatological and one hydrometry station in the basin. Soil hydrological groups are D, C, B and its land use types are forest, range, agriculture and bare land with 38.06, 10.608, 18.396 and 0.711 km^2 areas, respectively. Figure 1 shows the study basin on the map of Iran. This study was conducted from winter (October) 2007 to winter (June) 2009.

MATERIALS AND METHODS

To achieve the study objective, an attempt has been made to compare the performance of the GIUH and GCIUH methods and validate them with recorded data of the watershed. Twenty one single events of rainfall-runoff (that were among other data and also snow melt that had no effect on the obtained flood) were selected for extraction of the geomorphologic instantaneous unit hydrograph. Data and information of equivalent rainfall-runoff events in season when snow is not melted were collected from graphs. After separation of base flow and calculation of curve area from each event, the direct runoff was obtained by dividing it by watershed area. The excess rainfall for 1 hour was then obtained.

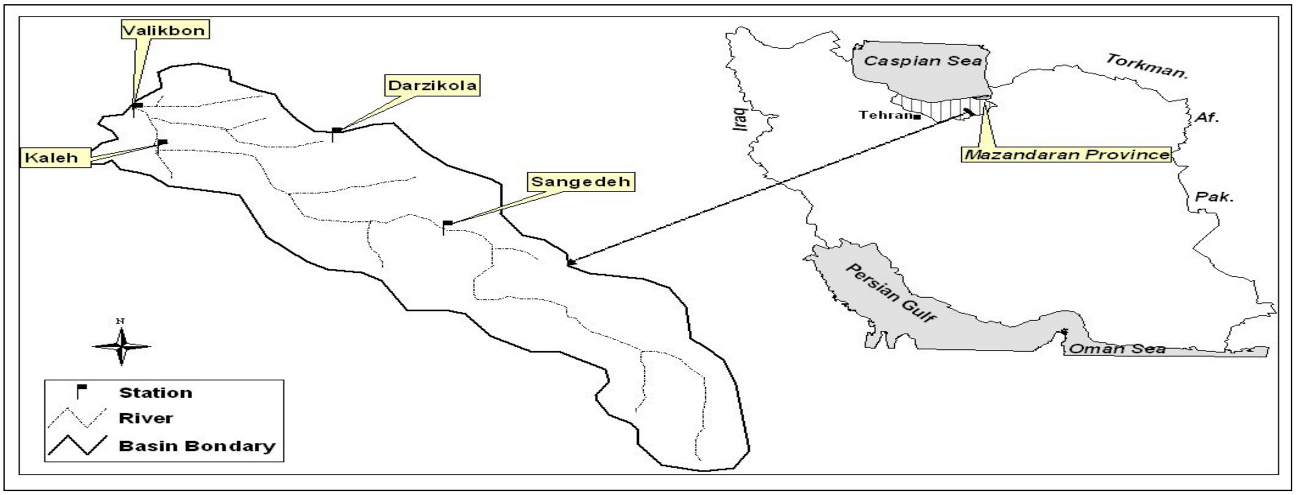

Figure 1. Location of the study basin.

The Arcview software was used extensively to prepare the model input data such as, area, slope and length of main river basin and also geomorphologic characteristics such as R_a (area ratio), R_b (bifurcation ratio) and R_l (length ratio). For stream order, Strahler's ordering system has been followed (Strahler, 1957). The model is relatively parsimonious in data requirements and most parameters can be obtained from DEM data. Flow velocity was obtained from calibration with historical data or methods appropriate for ungauged basins.

Model performance measures

To evaluate the suitability of the method for the basin of interest, three criteria were chosen to analyze the degree of goodness of fit. These criteria are Mean Relative Error (*MRE*) and Mean Square Error (*MSE*) based on following equations.

$$R_{Ei} = \frac{O-P}{O} \times 100 \tag{1}$$

$$RME = \frac{1}{n} \sum\nolimits_{i=1}^{n} R_{Ei} \tag{2}$$

$$SE = \left[\left(Q_{oi} - Q_{ci} \right) / Q_{oi} \right]^2 \tag{3}$$

$$MSE = \frac{1}{n} \sum\nolimits_{i=1}^{n} S_{Ei} \tag{4}$$

where, *MRE* is mean relative error percentage, *n* is number of estimation, R_E is the percentage of relative error in each estimation of the related parameter (here four parameters of peak time, base time, peak volume and discharge rate of flood have been considered). *O* is the observed values, *P* is the calculated values, *MSE* is mean of power 2 error, S_{Ei} is sum of squares of errors between observed and calculated hydrographs in each time interval, Q_{oi} is dimension of observed hydrograph and Q_{ci} is dimension of calculated hydrographs.

To determine percentage of superiority of the models in estimating of outlet hydrograph dimensions, the mean of power 2 of error of efficiency of each model with respect to other model has been used based on the following equation:

$(MSE_2/MSE_1) \times 100$ = Ratio of estimating 1 percentage efficiency of estimating 2 (5)

Sensitivity Analysis

Further work is continuing to analyze the influence of individual morphometric parameters on flood characteristics. In order to assess the GIUH model's sensitivity to different parameters, a series of sensitivity analyses were performed. Performing sensitivity analyses is a method to identify the input parameters that have the biggest impact on model predictions. As each variable was allowed to vary, all others were held constant. The 'base' scenario used for the sensitivity analyses is summarized in Table 1. As each parameter was evaluated, the impacts on the peak flow rate, the time to peak and the overall hydrograph shape were examined.

The channel flow velocities and geomorphologic ratios were investigated by multiplying the 'base' value by 0.5, 1.0, 1.5, and 2.0 in order to evaluate how the peak flow rate, time to peak and general hydrograph shape were affected by the changes in these parameters. In order to test the GIUH model's responsiveness to different excess rainfall intensities, unit hydrographs were developed for 0.03 cm/hr, 0.05 cm/hr, 0.1 cm/hr, and 0.15 cm/hr.

Table 1. Base values used in the sensitivity analysis.

Parameter		Value
channel velocity (m/s)	Rainfall intensity (cm/hr)	1.05
Precipitation Parameters	Rainfall duration (hr)	2.54
	Bifurcation Ratio (R_B)	2
Geomorphologic Ratios	Length Ratio (R_L)	4/02
	Area Ratio (R_A)	1/3
	Rainfall intensity (cm/hr)	3/9

RESULTS AND DISCUSSIONS

Dimensions of calculated outlet hydrographs by different methods were compared with observed hydrograph for 1h time durations (Figure 2). The performance of the model was also checked with respect to the peak discharge (*Qp*) and the time to peak (*tp*) of different storm events.

Table 2 presents physiographic and geomorphologic parameters of the basin which was studied. Detailed geomorphologic factors of basin are listed in Table 2, which are calculated by applying a DEM using a 30 m resolution raster elevation data set. It was found that the study basin is a sixth order basin. Also it is observed that the bifurcation ratio, length ratio and area ratio, which are non-dimensional characteristics, are 4.2, 1.03 and 3.9, respectively, for the study basin. These values are within the limits, which have already been reported in the literature.

Table 3 shows the rates of excess rainfall and their duration time for selective floods in the study basin. It was found that along with increased excess rainfall, peak flow and flow velocity are on

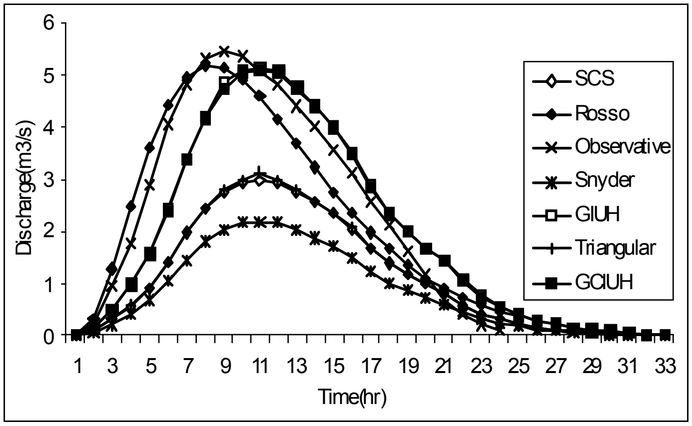

Figure 2. Comparison of observed and calculated hydrographs of different models for storm event of 2 October 2009.

Table 2. Geomorphologic characteristics of Kasilian basin.

Order	No. of streams	Average Length (km)	Average Area (km^2)	Value of constants
1	595	0.31171	0.21897	R_b=4.02
2	148	0.4545	1.1298	R_l=1.3
3	34	1.05625	4.4640	R_a=3.9
4	12	1.3942	6.3501	
5	3	0.885	24.7790	
6	1	8.55936	67.8	

Table 3. Rates of excess rainfall and their duration time for selective floods in Kasilian basin.

No	Date	*Qp* (m3/s)	*V*= 0.7859Q^0	Excess rainfall (mm)	Duration of Excess rainfall (hr)	*Qp* (hr^{-1})	t_p	Time to peak (hr)
1	91/05/12	12.1	2.06	7.31	8.00	0.35	1.54	7.54
2	92/06/20	1.68	0.960	0.0421	2	0.1626	3.29	4.79
3	93/06/04	2.043	1.035	0.12	2	0.1754	3.05	4.55
4	94/03/27	12.55	2.09	8.58	7.00	0.35	1.51	6.76
5	94/07/22	11.7	2.03	6.39	4.50	0.34	1.56	4.93
6	95/08/27	2.85	1.177	0.121	2	0.199	2.68	4.18
7	96/07/02	2.12	1.05	1.33	5.50	0.18	3.01	7.14
8	96/07/12	3.89	1.33	1.28	2.25	0.23	2.38	4.07
9	99/05/10	5.81	1.55	2.17	3.25	0.262	2.04	4.47
10	01/09/26	1.75	0.97	0.36	2	0.1652	3.24	4.74
11	02/08/20	3.66	1.297	0.19	3	0.2197	2.43	4.68
12	03/07/07	11.5	2.019	0.6618	3	0.3420	1.56	3.81
13	04/06/20	10.68	1.96	0.47	4	0.332	1.61	4.61
14	04/09/20	1.9	1.007	0.11	2.15	0.1705	3.14	4.75
15	05/04/30	2.2	1.065	0.1565	2	0.1805	2.96	4.46
16	05/07/12	8.3	1.78	0.5198	6	0.3015	1.77	6.27
17	05/09/21	3.3	1.24	0.22	9	0.2111	2.53	9.28
18	06/07/02	1.9	1.007	0.1041	1.5	0.1705	3.14	4.26
19	06/08/05	1.38	0.89	1.3371	3	0.1507	3.55	5.80
20	2007/08/	1.86	0.998	0.1731	1.45	0.1691	3.16	4.25
21	07/09/02	13.05	2.12	0.49	6	0.3591	1.49	5.99

Note: $Q_p(m^3/\sec) = q_p/3600 \times \frac{ir}{100} \times A$, $Q_p(hr^{-1}) = \frac{1.31}{L_\Omega} RL^{0.43} V$, $T_p = t_p + 0.75tr$.

number of events, calculation of excess water with more efficient methods which can calculate rain loss as a function of time. This is in agreement with results obtained by Mojaddadi et al. (2009).

Table 4 gives hydrograph dimensions in SCS, Snyder and Triangle methods in the study basin. It demonstrates that a comparable level of performance was achieved for all methods. Also agreement between hydrographs with respect to the peak discharge has negligible errors while with regards to peak arrival time, it shows more differences. This may be because of the peak flow dependence to excess rainfall intensity. These results are not in agreement with those of Heshmatpour et al. (2002).

Table 5 shows amounts of *MSE* and *MRE* of each method for the study basin. The results show the efficiency of extracted hydrographs in different methods by two indices of *MRE* and *MSE*. As we can see the performance of the methods on the largest events is better. Amounts of *MSE* for geomorphologic, Snyder, SCS, Triangle, Rosso and GCIUH models in the study basin are 0.215, 19.634, 21.37, 19.11, 10.39 and 1.065 percent, respectively. Amounts of*RME* for geomorphologic, Snyder, SCS, Triangle, Rosso and GCIUH models in the study basin are 8.524, 72.04, 77.64, 73.63, 56.73 and 21.57 percent, respectively. The result shows the efficiency of extracted hydrographs in different methods by two indices of *MRE* and *MSE*.

Table 6 presents relative efficiency of methods in estimating dimensions of outflow in the study basin. For this purpose, *MSE* of each model was used. The results show the efficiency of GIUH method ratio to other models. A comparison of the estimated hydrographs of studied models with observed hydrographs showed that the efficiency of geomorphologic model ratio to Snyder, SCS, Triangle, Rosso and GCIUH in the study basin are 91.06, 99.11, 88.642, 48.195 and 4.94,

Table 4. Hydrograph dimensions in SCS, Snyder and Triangle methods in Kasilian basin.

No	Date	Methods							
		Flood		SCS		Snyder		Triangle	
		Qp	*tp*	*Qp*	*tp*	*Qp*	*tp*	*Qp*	*tp*
1	1991/05/12	12.1	8.3	18.33	5.69	17.33	9.67	17.83	5.69
2	1992/06/20	12.55	8.1	3.35	3.14	2.35	5.17	2.85	3.14
3	1993/06/04	11.7	6.5	6.35	3.49	2.35	5.17	5.85	3.49
4	1994/03/27	2.12	8.2	19.13	5.32	1.813	8.92	18.63	5.32
5	1994/07/22	3.89	5.7	17.49	4.13	2.049	7.05	20.99	4.13
6	1995/08/27	5.81	5.84	3.35	3.71	2.35	5.17	2.85	3.71
7	1996/07/02	2.85	5.9	3.47	4.50	1.94	7.79	4.97	4.50
8	1996/07/12	1.75	6.11	5.21	3.34	2.32	5.36	6.71	3.34
9	1999/05/10	1.9	6.23	8.91	4.64	2.19	6.11	9.41	4.65
10	2001/09/26	11.5	4.65	3.35	2.94	2.356	5.17	2.85	2.95
11	2002/08/20	1.86	4.53	5.22	4.60	2.22	5.92	6.72	4.60
12	2003/07/07	1.38	6.24	23.22	4.77	2.22	5.92	22.72	4.77
13	2004/06/20	3.3	8.88	16.03	4.94	2.10	6.67	21.53	4.94
14	2004/09/20	3.66	5.94	3.33	2.64	2.33	5.28	2.83	2.64
15	2005/04/30	13.05	6.87	5.356	3.35	2.35	5.17	4.85	3.35
16	2005/07/12	10.68	5.47	14.005	4.75	1.900	8.17	19.50	4.75
17	2005/09/21	1.68	6.31	6.66	7.44	1.66	10.42	6.15	7.44
18	2006/07/02	1.9	5.21	3.43	4.10	2.43	4.79	2.93	4.10
19	2006/08/05	2.2	5.7	3.22	4.28	2.22	5.92	3.72	4.28
20	2007/08/08	8.3	6.13	3.43	3.14	2.43	4.76	2.93	3.14
21	2007/09/02	2.043	5.76	18.005	4.63	1.90	8.17	19.50	4.63

Table 5. Amounts of (*MSE*) and (*MRE*) for Kasilian basin.

No.	Event	Geomorphologic	Snyder	SCS	Triangular	Rosso	GCIUH
1	1991/05/12	0.082	27.358	38.819	32.83	24.16	2.02
2	1992/06/20	0.001	0.456	2.808	1.38	2.80	0.017
3	1993/06/04	0.065	10.97	18.60	7.912	2.47	0.001
4	1994/03/27	0.022	31.128	43.28	36.95	27.83	1.80
5	1994/07/22	0.307	33.52	33.52	39.56	48.83	2.64
6	1995/08/27	0.534	0.244	0.255	3.04	1.605	0.87
7	1996/07/02	0.045	5.549	1.838	8.15	2.40	0.15
8	1996/07/12	0.737	5.387	1.74	7.95	0.56	1.32
9	1999/05/10	0.440	9.657	9.657	13.01	0.161	1.34
10	2001/09/26	0.022	0.367	2.578	1.22	2.75	0.001
11	2002/08/20	0.008	6.590	2.456	9.40	0.76	0.071
12	2003/07/07	1.192	115.07	137.52	52.23	19.76	4.38
13	2004/06/20	0.950	18.99	28.71	78.47	14.59	3.64
14	2004/09/20	0.017	0.1891	2.058	0.874	2.617	0.09
15	2005/04/30	0.022	4.647	9.959	7.05	2.04	0.005
16	2005/07/12	0.030	22.139	32.5	27.09	4.39	0.91
17	2005/09/21	0.029	5.569	11.28	8.17	1.096	0.026
18	2006/07/02	0.048	0.279	2.336	1.057	2.619	0.14
19	2006/08/05	0.069	3.395	3.39	5.48	2.99	0.011
20	2007/08/08	0.045	0.3318	2.48	1.158	2.65	0.138
21	2007/09/02	0.063	35.465	24.55	41.67	32.27	2.198
Sum		4.743	431.951	470.1	420.48	228.61	23.45
RME		8.524	72.04	77.64	73.63	56.73	21.57
MSE		0.215	19.634	21.37	19.11	10.39	1.065

Table 6. Relative efficiency of estimator (1) to estimator (2) in estimating runoff in Kasilian representative basin.

Estimator(2) Estimator(1)	Geomorphologic	Snyder	SCS	Triangular	Rosso	GCIUH
Geomorphologic	1	0.0109	0.0100	0.0112	0.0207	0.202
Syder	91.060	1	0.9187	1.0272	1.889	18.418
SCS	99.114	1.0884	1	1.1181	2.056	20.047
Triangular	88.642	0.9734	0.8943	1	1.839	17.929
Rosso	48.195	0.529	0.4862	0.5437	1	9.748
GCIUH	4.9438	0.0542	0.0498	0.0557	0.102	1

respectively. This is in agreement with results obtained by Mojaddadi et al. (2009). Compared with other models (based on this study) in the study basin the result of geomorphologic model is the most efficient models to estimate flood discharge. Also the results showed high agreement of GIUH, SCS, Snyder, Triangular and GCIUH methods with observed hydrograph in parameter of outlet runoff. Generally, the comparison of obtained results of the methods under study shows that GIUH method is more efficient than other methods. As a result, the difference between GIUH and GCIUH is negligible and one can say that the two methods have similar efficiencies. This is in agreement with results obtained by Mojaddadi et al. (2009). Thus the GIUH model can be adapted as a standard tool for modeling rainfall-runoff transformation process in basins with no data. This is in agreement with results obtained by Bhadra et al. (2008).

The channel velocity estimate is an important variable in estimating the time-area curve and the resulting runoff hydrograph. While keeping the geomorphic parameters fixed, the channel velocity was varied from 50% to 200% of the base channel velocities calculated in Table 6. Despite the large changes in the channel velocities, the peak flow rate varied less than 30% (Figure 3). The changes in the channel velocity did have an impact on the hydrograph timing. As the channel velocity increased, the hydrograph shifted to the left and occurred earlier. As the channel velocity increased, the time to the peak discharge decreased from 2.75 hours to 2 hours. Lower velocity values are corresponding to low stage indicating the lean period. Higher velocity values indicate higher stage period. Figure 3 shows that increase in average channel velocity causes significant increase in the peak of hydrograph (Q_P) with less time to peak (t_P). This research is in agreement with the results of Kilgore (1997) and Jain et al. (2003).

Because there is a good deal of uncertainty in the estimate of the rainfall excess intensity, the effects of different rainfall excess intensities was investigated by allowing the intensity to vary

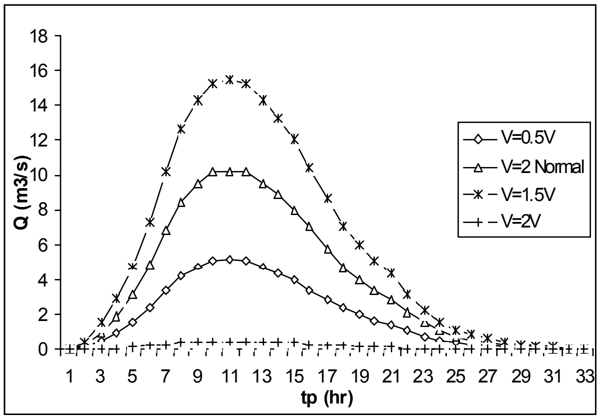

Figure 3. Sensitivity of model response to variations in channel velocity.

from 0.03 cm/hr to 0.15 cm/hr. As the intensity of rainfall excess increased, the resulting hydrographs showed less attenuation and a higher, faster peak flow rate (Figure 4). As the rainfall excess intensity increased, the time to peak decreased from 2.5 hours to 1.5 hours. This research is in agreement with the results of Kilgore (1997).

The effects of different rainfall excess durations were investigated by allowing the duration to vary from 2 to 8 hours. As the duration of rainfall excess increased, the resulting hydrographs showed a higher, faster peak flow rate (Figure 5). As the rainfall excess duration increased, the time to peak decreased from 2.5 hours to 1.8 hours.

The effects of different geomorphologic ratios (R_L, R_A and R_B) were investigated by allowing the geomorphologic ratios to vary from 1.5 to 6. Our preliminary results suggest that out of the three Horton morphometric ratios, R_L influences the Q_P and t_P most significantly. Our analysis predicts higher Q_P for higher R_L. This demonstrates the influence of particular morphologic parameters on flooding behavior of individual basins. As the length ratios (R_L) increased, the resulting hydrographs showed a higher, faster peak flow rate (Figures 6, 7 and 8). As the length ratio increased, the time to peak decreased from 2.5 hours to 2.1 hours. This research is in agreement with the results of Sorman (1995) and Jain et al. (2003). Also, as the area ratio and the bifurcation ratio increased, the time to peak increased from 2.5 to 2.8 hours.

In general, this research is in agreement with the results of Heshmatpour (2002), Jain and Sinha (2003), Jain et al. (2000), Hall et al. (2001) and Cudennec (2004).

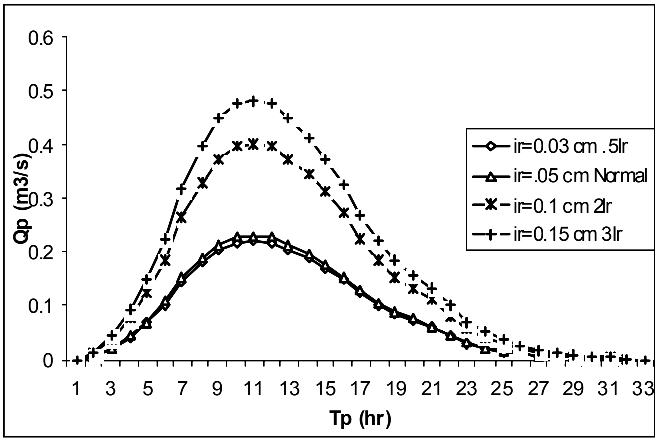

Figure 4. Sensitivity of model response variations in rainfall excess intensity.

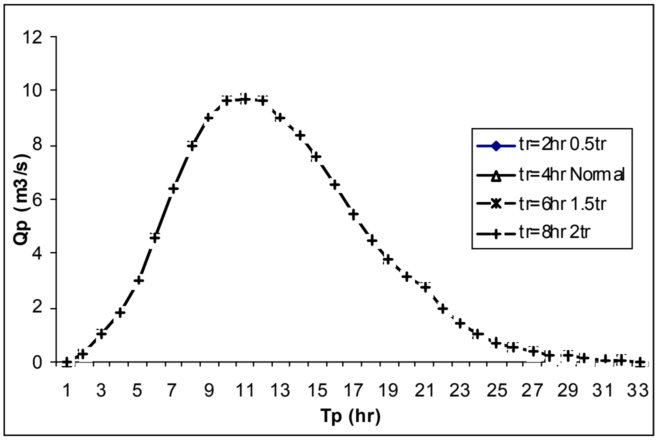

Figure 5. Sensitivity of model response to variations in the time to recession.

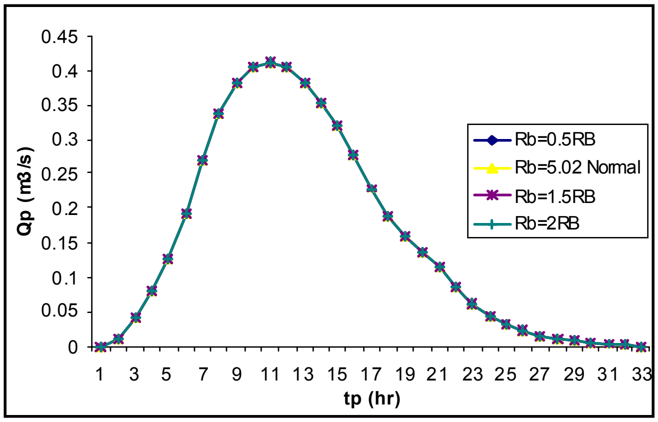

Figure 6. Sensitivity of model response to variations in the bifurcation ratio.

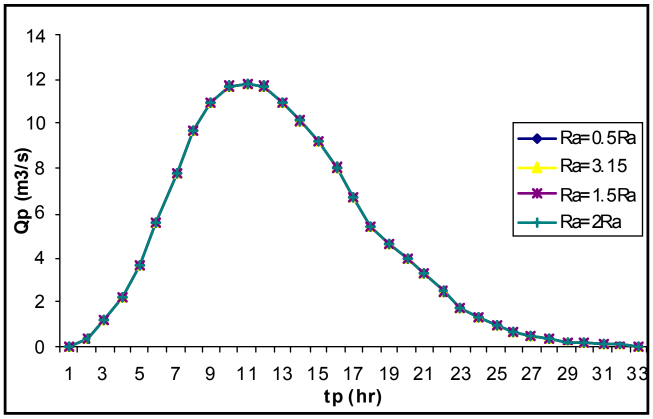

Figure 7. Sensitivity of model response to variations in the area ratio.

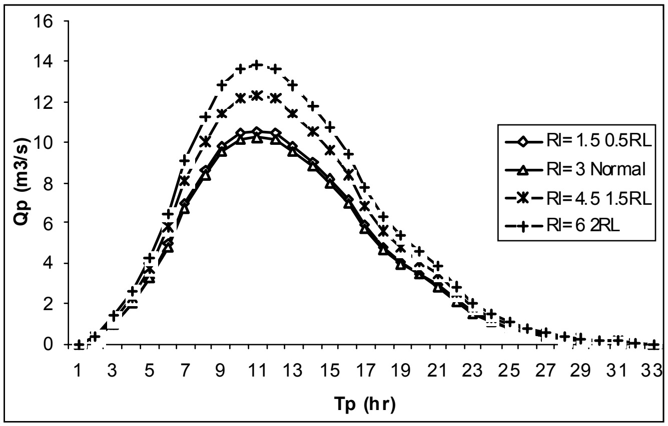

Figure 8. Sensitivity of model response to variations in the length ratio.

CONCLUSIONS

1- In case of outlet runoff values, all of tested methods have high agreement with observed hydrograph.

2- When the number of events increases, the estimation accuracy, and the efficiency and precision of excess water estimation increase. Our results are validated by comparison with the result of flood frequency analysis based on observed data.

3- Due to simplicity of proposed method in comparison with other methods in flood estimation and since lower design risk is desired, it can be used for a watershed with no data.

4- Compared with synthetic unit hydrographs, these methods (GIUH & GCIUH) have better estimation of time to peak and peak discharge. Hence, the prediction performance of the developed GIUH was evaluated by comprising the peak discharge (Q_p) and time to peak (t_p).

5- Compared to traditional methods, the proposed method can be used for precise investigation of the morphogenetic characteristics and their effects on basin hydrology.

6- Using the proposed method, the contributions and participations of different tributaries to flood hazard in river basin can be well understood.

7- The effect of individual morphogenetic parameters on flood discharge can be provided by the proposed method.

8- In order to identify the input parameters that had the biggest impact on the GIUH model, a series of sensitivity analyses were performed.

The channel velocity and rainfall excess intensity had the biggest influence on the peak flow rate. Also the channel velocity and rainfall excess intensity had the greatest effect on the time to peak prediction. When a sensitivity analysis was performed, the channel velocity had the most influence over the time to peak. It appeared that changes in channel velocity affected the time to peak to a much greater extent than the peak flow rate. The higher the channel velocity, the lower the cumulative travel time and eventually the lower the time to peak. On the other hand, changes in the overland flow velocity had more impact on the peak flow rate than on the time to peak. Hence it is worth mentioning that the geomorphologic unit hydrograph is not linear because its main characteristics Q_p and t_p vary with the velocity V of the main river course. The effect on velocity on GIUH reflects the dynamics of hydrological response of basin.

Excess rainfall intensity was found to have a big impact on both the time to peak flow rate and the peak flow rate. Increasing the excess rainfall intensity caused an earlier and larger peak flow rate. The rainfall excess intensity is an important parameter for estimating the peak flow rate and the time to peak. Care should be taken when selecting a technique to estimate the rainfall excess.

The length ratio (R_L) is an important parameter for estimating the peak flow rate and the time to peak in the GIUH model. The length ratio significantly influenced the hydrologic response of a study basin. Area ratio (R_A) and bifurcation ratio (R_B) are important parameters only for estimating the time to peak in the GIUH model.

9- Variation in GIUH parameters with respect to velocity reflects the dynamic behavior of hydrological response of Kasilian river basin in different periods.

10- The developed model when applied to predict storm runoff on Kasilian basin, performed well as it yielded the model estimated values in reasonably close agreement to the corresponding observed values.

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REFERENCES

Agirre, U., M. Goni, J.J. Lopez and F.N. Gimena. 2005. Application of a unit hydrograph based on sub watershed division and comparison with Nash instantaneous unit hydrograph, Catena. 64(2-3): 321-332.

Ahmadvand, M., and E. Karimi. 2008. A social impact assessment of the floodwater spreading project on the Gareh-bygone plain in Iran: A causal comparative approach, Environ Impact Asses Rev (2008)

Ajward, M.H., and I. Muzik. 2000. A Spatially Varied Unit Hydrograph Model, Journal of Environmental Hydrology, Vol. 8, Paper 7.

Alizadeh, A. 2006. Principles of Applied Hydrology, 20th edn. Emam Reza University Publications, Mashhad, Iran, pp: 808.

Bhadra, A., N. Panigrahy, R. Singh, N.S. Raghuwanshi, B.C. Mal and M.P. Tripathi. 2008. Development of a gemorphological instantaneous unit hydrograph model for scantily gauged watersheds. Environmental Model Software, 23(8): 1013-1025.

Cudennec, C., Y. Fouad, I. Sumarjo Gotot and J. Duchesne. 2004, A Geomorphological Explanation of the Unit Hydrograph Concept, Hydrological Processes, 18: 603-621.

Foltz, R.C. 2002. Iran's water crisis: Cultural, political and ethical dimensions. Journal of Agricultural Environment Ethics, 15(4): 357-380.

Gupta, V.K., E. Waymire, and C.T. Wang. 1980. A representation of an Instantaneous Unit Hydrograph from Geomorphology. Water Resources Research, 16(5): 855-862.

Hall, M.J., A.F. Zaki and M.M.A. Shahin. 2001. Regional analysis using the Geomorphoclimatic Instantaneous Unit Hydrograph. Hydrological Earth System Sciences, 5(1): 93-102.

Heshmatpour, A., M. Saravi, A. Saaddin, and M. Erfanian. 2002. An investigation of efficiency of geomorphologic and geomorphoclimatic instantaneous unit hydrograph in estimation of flood discharge rate. Journal of Natural Resources., 55(1): 3-22. (In Farsi)

Jain, S.K., R.D. Singh, and S.M. Seth. 2000. Design flood estimation using GIS supported GIUH approach. Water Resources Research, 14: 369-376.

Jain, V., and R. Sinha. 2003. Derivation of Unit Hydrograph from GIUH Analysis for a Himalayan River. Water Resources Management, 17: 355–376.

Jeng, R.I., and G.C. Coon. 2003. True form instantaneous unit hydrograph of linear reservoirs, Journal of Irrigation and Drainage Engineering., 129(1): 11-17.

Kilgore, J.L. 1997. Development and Evaluation of a GIS-based spatially distributed Unit Hydrograph Model. M. S. thesis, Biological Systems Engineering Dept., Virginia Tech, Blacksburg.

Liu, Y.B., S. Gebremeskel, F. De Smedt, L. Koffmann, and L. Pfister. 2003. A diffusive transport approach for flow routing in GIS-based flood modeling. Journal of Hydrology, 283: 91-106.

Lopez, V., F. Napolitano, and F. Russo. 2005. Calibration of a rainfall-runoff model using radar and raingauge data. European Geology advances, University of Geosciences, 2: 41–46.

Loukas, A., M.C. Quick, and S.O. Russell. 1996. A physically based stochastic-deterministic procedure for the estimation of flood frequency. Water Resources Management, 10(6): 415-437.

Mahdavi, M. 2005. Applied Hydrology, 2nd Volume. 4rd edn., University of Tehran, Publications, Iran, pp: 441stimation of flood discharge rate. Iran. Journal of Natural Resources, 55: 3-22.

Maheepala, U.K., A.K. Takyi, and B.J.C. Perera. 2001. Hydrological data monitoring for urban stormwater drainage systems. Journal of Hydrology, 245: 32–47.

Mojaddadi, H., M. Habibnejad, M.Z. Ahmadi, K. Solaimani, and M.A. Hadian-Amri. 2009. An Investigation of Efficiency of Outlet Runoff Assessment Models: Navroud Watershed. Journal of Applied Sciences, 9(1): 105-112. (In Farsi)

Nash, J. 1960. A unit hydrograph study, with particular reference to british catchments. Hydraulics Research Station, 17: 249-282.

Nourani, V., V.P. Singh, M.T. Alami, and H. Delafroz. 2008. Geomorphological Runoff Routing Modeling Based on Linear Reservoirs Cascade. Journal of Applied Sciences, 8(9): 1660-1667.

Rangavar, A., V.A. Rojkov., M.G. Nurberiew, and M. Azizi. 2009. The use of Surface Runoff to Improve Degraded Rangelands by Creating Shrub Pastures. Research Journal of Environmental Sciences, 3 (5): 543-551.

Rangavar, A., M. Nurberdiev, and V. A. Rojkov. 2004. Rainwater harvesting for establishment of artificial pastures on eroded lands in arid regions (Case study in Khorasan, Iran). In: International workshop on water harvesting and sustainable agriculture. Moscow, Russia, 7 September 2004. 55th IEC Meeting,

Rodriguez-Iturbe, I., and J. Valdes. 1979. The Geomorphologic Structure of Hydrologic response, Water Resources Research, 15(6): 1409– 1420.

Rodríguez-Iturbe, I., M.G. Sanabira, and G. Caamaño. 1982. On the Climatic Dependence of the IUH: A Rainfall-Runoff Analysis of the Nash Model and the Geomorphoclimatic Theory. Water Resources Research, 18(4): 887–903.

Rosso, R. 1984. Nash Model Relation to Horton Order Ratios. Water Resources Research, 20(7): 914–920.

Shamseldin, A.Y., and J.E. Nash. 1998. The geomorphological unit hydrograph-a critical review. Hydrol. Earth system Sci., 2(1): 1-8.

Snyder, N.P., K.X. Whipple, G.E. Tucker, and D.J. Merritts. 2002. Interactions between onshore bedrock-channel incision and near-shore wave base erosion forced by ecstasy and tectonics, Basin Researches, 14: 105– 127.

Sorman, A.U. 1995. Estimation of peak discharge using GIUH model in Saudi Arabia, Journal of Water Resources Planning and Management, 121(4): 287-293.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Transaction of American Geophysical Union., 38(6): 913-920.

Vaes, G., P. Willems, and J. Berlamont. 2001. Rainfall input requirements for hydrological calculations, Urban Water, 3(1-2), 107-112

Vahabi, J., and M. Ghafouri. 2009. Determination of Runoff Threshold Using Rainfall Simulator in the Southern Alborz Range Foothill-Iran. Res. J. Environ. Sci., 3(2): 193-201.

Wang, G.T., and S. Chen. 1996. A linear spatially distributed model for a surface rainfall-runoff system. Journal of Hydrology, 185(1-4): 183-198.

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