RESEARCH NOTE

GIUH-GcIUH COMPARISON FOR TWO WATERSHEDS IN IRAN

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Abstract Two representative watersheds, Ammameh and Kasilian, located in Southern and Nortern Elborz mountain in Iran respectively were considered. Fourteen events of rainfall-runoff in non-melling seasons were chosen and their storms and flood hydrographs were gathered from an automatic recording station. Base flow seperation was made by recession limb analysis while Philip equation was used for the calculation of effective rainfall. The ordinates of Instantaneous Unit Hydrograph (IUH) was determined by using the GcIUH and GIUH theory for each rainfall-runoff event seperately. Direct runoff hydrographs were determined by convoluting IUH and effective rainfall hyetograph. Mean flow velocity and kinematic wave parameter were correlated to peak discharge seperately. Therefore, these indices were estimated for each rainfall-runoff event, knowing its peak discharge. It is found that GcIUH shows a better results for all rainfall-unoff events. High sensitivity of GIUH to mean flow velocity and impossibility of accurate determination of its value may be the main reason for predicting less accurate results. GcIUH, on the other hand has lower sensitivity to kinematic wave parameter variations. Meanwhile for wide channels, this parameter does not depend on discharge.

Key Words IUH, GIUH, GcIUH, Flood Forecasting, Representative Watersheds

چکیده هیدرولوژیستها همیشه در جستجوی یافتن ارتباط بین خصوصیات مورفولوژیکی حوزه های آبریز و جریان های خروجی از آنها می باشند. تئوریهای آبنمود واحد لحظه ای ژئومورفولوژیکی (GIUH) و آبنمود واحد لحظه ای ژئومورفو-آب و هوائی (GcIUH) نتایج کوششهای جدید در این زمینه می باشند. ماهیت این تئوریها پویا است. مولفه پویائی در این مدل ها بترتیب متوسط سرعت آبراهه ای و هیتوگراف باران مازاد می باشد. تا بحال هیچ کوششی برای مقایسه این دو مدل به عمل نیامده است. به دلیل آمار دقیقتر و کاملتر، حوزه های آبریز معرف امامه و کسیلیان واقع در جنوب و شمال رشته کوههای البرز در ایران برای این مقایسه درنظر گرفته شد. اطلاعات ۱۴ واقعه بارندگی در فصول غیر ذوب برف و آبنمودهای مربوط به آنها جمع آوری گردید. عرضهای آبنمود واحد لحظه ای برای هر واقعه بارش-رواناب توسط دو تئوری فوق الذکر بطور جداگانه محاسبه شد. آبنمود جریان سطحی مستقیم توسط انتگرال پیچشی بدست آمد. این بررسی نشان داد که آبنمودهای بیشتری توسط تئوری GcIUH، در مقایسه با تئوری GIUH، بطور دقیقتر بازسازی شده است. حساسیت زیاد آبنمود واحد لحظه ای ژئومورفولوژیکی به تغییرات متوسط سرعت آبراهه ای و عدم توانائی برآورد دقیق آن از دلایل این امر می باشند. محاسبه باران مازاد یک مشکل مشترک برای هر دو تئوری می باشد.

INTRODUCTION

:reamflow synthesis from ungaged basins has long :en a subject of scientific inquiry. A survey of hydrologic literature [1,2] suggests three fundamental approaches: empirical, conceptual and, physically based. Pioneer works could be attributed to those of Sherman [3] and Snyder [4]. Rodriguez-Iturbe and

Valdes [5] introduced the idea of geomorphologic instantaneous unit hydrograph (GIUH), which led to the renewal of research in hydrogeomorphology. This theory has been verified for some basins in Venezuela [6]. Different theories have also been proposed by some other investigators [7, 8, 9], but with more excess parameters. GIUH methods have been compared to different IUH models for flood forecasting [10, 11, 12, 13] and found a priority over GIUH methods. A new approach to hydrologic similarity has been initiated by Rodriguez-Iturbe, et al. [14] under the concept of the geomorphoclimatic IUH (GcIUH). In this theory the IUH ordinates are a function of geomorphologic characterisics and a particular intensity and duration of rainfall. Rodriguez-Iturbe, et al. [15] have verified this theory for some watersheds. In this paper a comparison is made between GIUH [5] and GcIUH [14] for flood hydrograph simulations for two watersheds in Iran for the first time. Some modifications to GcIUH theory are also offered.

MATERIALS AND METHODS

Location

For studing hydrologic behavior of the ungaged watersheds researchers need to survey representative areas. Unfortunately, representative watersheds are very limited in number in Iran and the data related to them are generally not accurate. Two suitable watersheds, Ammameh and Kasilian, located in Southern and Northern Elborz mountain in North of Tehran, Iran, were selected. Figure 1 shows the locations of these two watersheds. The main characteristics of these watersheds are summarized in Table 1. Detailed properties are present in literature [16, 17].

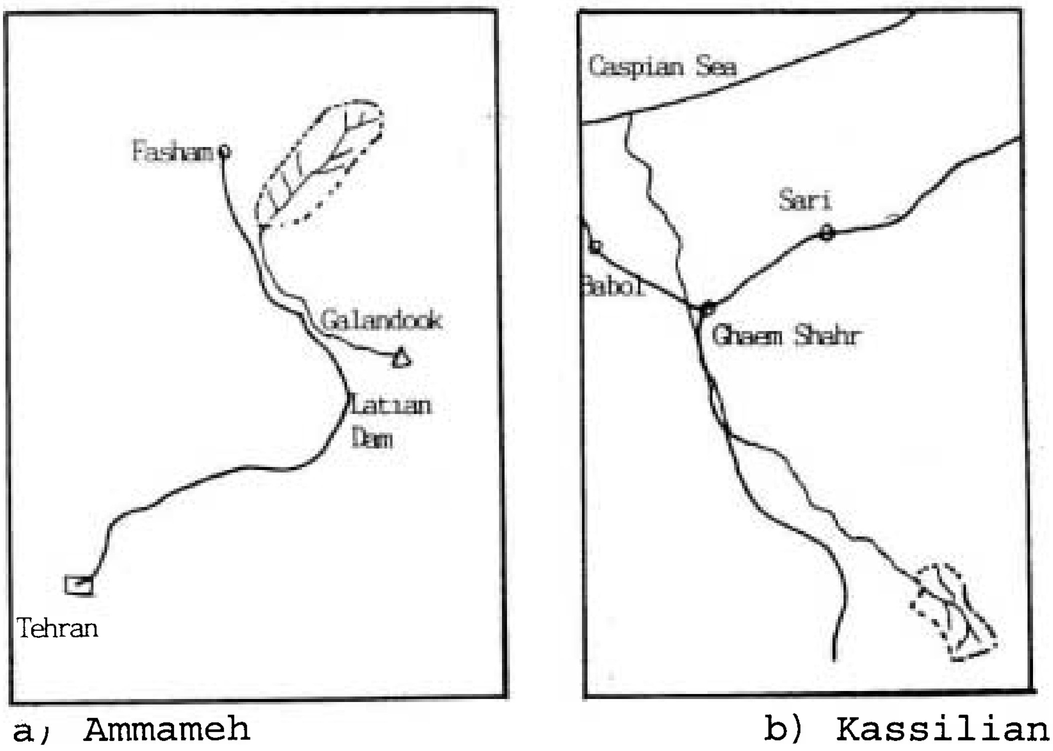


Figure 1. Relative locations of the watersheds under study.

TABLE 1. A Summary of Watersheds's Main Characteristics.

Parameters	Watershed	
	Kasilian	Ammameh
Altitude range (m)	1100-2700	1900-3870
Area (Sq. Km).	82.6	38.31
Hydrometric stations	1*	2**
Automatic raingauges	1	2
Non-automatic raingauges	8	3

* Valik-Bon
** Bagh-Tangeh in middle and Kamar-Khany at outlet

Effective Rainfall-Direct Runoff Events

Since nearly all rainfall-runoff models deal with direct relations of rainfall-runoff, the possibility of snow melt should be avoided in any selected events. Such storms which were well uniformly spatially distributed over each watershed were chosen. The number of raingauge stations in each watershed (Table 1) was utilized for this selection. Each event was distributed through time according to the automatic gauge (s) inside the watershed.

A variety of techniques have been suggested for seperating base flow and direct runoff [18]. Recession limb analysis was preferred among the others, because of less dependency on subjective judgement [18]. Time distribution of rainfall losses during a storm can be made using a variety of technique [19]. The Philip type infiltration equation without the constant term was used among them:

$$f = 0.5 * s * t^{-1/2} \qquad (1)$$

where **f** is infiltration rate (mm/hr), **t** is time (hr) and s is a constant parameter (mm.(hr)$^{-1/2}$). Parameter **s** was determined by trial and error, similar to the method used by Jin [8].

GIUH and GcIUH Ordinates

Rodriguez-Iturbe and Valdes [5] used an embedded Markov process and derived some simple expressions for peak (qp, in 1/hr) and time to peak (tp, in hr) of an IUH in GIUH theory as follows:

$$qp = 1.31 * \{R_L^{0.43}\} * V/L \qquad (2)$$

$$tp = 0.44 * L * \{ [R_B/R_A]^{0.55}\}/V \qquad (3)$$

where R_A, R_B, and R_L are Horton area, bifurcation and length ratios respectively [20], L is the length of highest order stream (Km) and V is the mean channel flow velocity (m/s). For every rainfall-runoff event the value of mean channel velocity could be estimated by combination of hydraulic and geometric features of watershed outlet [21].

Rodriguez-Iturbe et al. [14] expressed analytically the mean flow velocity as a function of intensity and duration of effective rainfall, and geomorphologic characteristics of the higher-order watersheds. In this theory (GcIUH), peak and time to peak of IUH can be expressed as:

$$qp = 0.871/\{k^{0.4}\} \qquad (4)$$

$$tp = 0.585 * k^{0.4} \qquad (5)$$

where

$$k = L^{2.5}/\{i_r * A * R_L * \alpha^{1.5}\} \qquad (6)$$

$$\alpha = \sqrt{(s)}/\{n * b^{2/3}\} \qquad (7)$$

where i_r is the effective rainfall intensity (cm/hr), **A** is the watershed area (Sq. Km.), **n, b, s** are Manning roughness, bed width (m) and slope of river at watershed outlet, respectively, and α is called kinematic wave parameter. These equations were derived on the basis of RB/RA= 0.8 [14], which is shown by previous research to be approximately constant [6].

Probably the exact shape of an IUH is a two

TABLE 2. Horton Ratios and Other Physiographic Parameters of Watersheds Under Study.

Parameters	Station		
	Valik-Bon	Bagh-Tangeh	Kamar-Khany
Basin order	4	3	3
R_B	3.5	2.24	4.12
R_A	4.71	3.31	6.72
R_L	1.58	1.41	2.92
L_w(Km.)	4.63	3.30	10.84
A_w (Sq. Km.)	68.6	14.68	38.31
R_B/R_A	0.743	0.667	0.613

parameter gamma function. However, Henderson [22] showed that the most important characteristics of an IUH are the peak and time to peak, and as long as these two factors are correct, the exact form of the IUH is not very important, so a triangular approximation is quite satisfactory. Since this point has been verified recently [21], a simplified triangular form for the IUH shape is going to be accepted to be for the rest of this study.

RESULTS AND DISCUSSION

Horton's Laws

Topographic maps with scale of 1: 50000 (Geographical Division, Ministry of Defence, Islamic Republic of Iran) were used for deriving the necessary physiographic parameters as an input to Horton's laws computations. The results are depicted in Table 2. Although RB and RL ratios for Bagh-Tangeh station are not in complete agreement with reported literature [e.g. 20], the differences are negligible. The calculated RB/RA ratios (Table 2) show also negligible differences with the proposed value of 0.8 [6]. Due to some uncertainty existing in the whole process, the correct ratio of RB/RA must be used. Including this ratio in equation 5, the following modification would be made:

$$tp= 0.661*(K^{0.4})*([RB/RA]^{0.55}) \qquad (8)$$

Velocity Estimation

Leopold and Madock [23] performed the key studies of the hydraulic features of streams. On logaritmic scales, they proposed:

$$V= g*Q^h \qquad (9)$$

where Q is peak discharge (CMS) and g and h are constant parameters. These constant parameters were calculated by a method outlined by Ghahraman [21]. The results are presented in Table 3.

Kinematic Wave Parameter

Equation 7 is valid only for a wide rectangular channel [14]. The channel width at Valik-Bon, Bagh-Tangeh, and Kamar-Khany stations are 5, 1, and 1.2 meter respectively; which are not wide enough.

TABLE 3. Constant Parameters in Equations 9 and 11 for Stations Under Study.

Parameters	Station		
	Valik-Bon	Bagh-Tangeh	Kamar-Khany
No.	72	399	532
z	0.6841	1.6678	4.9269
x	-0.0513	-0.5577	-0.5009
r*	-0.8	-0.85	-0.82
No.	72	192	192
g	0.7963	1.5511	2.6530
h	0.3693	0.1397	0.2045
r*	1	0.644	0.75

*correlation coefficient

Meanwhile Bagh-Tangeh and Kamar-Khany do not have simple rectangular corss sections. For a kinematic wave the acceleration and pressure terms in the momentum equation are negligible. So in this case the momentum equation can be expressed as follows (after Chow et al. [24]):

$$Q = \alpha . A^{c} \quad (10)$$

Addressing the fact that $S_0 = S_f$, by the definition of a kinematic wave, Manning formula can be written as:

$$Q = [S_0^{1/2} / (n.p^{2/3})].\ A^{5/3} \quad (11)$$

where p is the wetted premeter of cross section (m). Comparing these two equations leads to:

$$\alpha = \sqrt{(s)} / \{n.p^{2/3}\} \quad (12)$$

This equation is equivalent to Equation 7 only when the condition p#b satisfies. Therefore Equation 7[14] is not valid for watersheds under study and Equation 12 should be used instead. Combination of the existing hydraulic relationships [23] yields to:

$$\alpha = z^{*}Q^{x} \quad (13)$$

where z and x are constant parameters, the value of which could be determined by method outlined by Ghahraman [21]. The results are also presented in Table 3.

Surface Flow Hydrograph

Some important characteristics of selected rainfall-runoff events in non-melting seasons which their storms were uniformly spatially distributed over the relevant watershed are summarized in Table 4. Peak and time to peak of GIUH was made by Henderson's simplification [22] and surface flow hydrograph was made by using convolution integral [20]. The results are shown in Figures 2 to 15.

All these figures show that by using the GcIUH

TABLE 4. Characteristics of Selected Rainfall and Runoff Events.

Flood No.	Station	Data	Runoff mm	Rain mm	Runoff coefficient	Peak discharge CMS
1	Valik-Bon	3-30-1371	0.31	20.00	0.015	1.68
2		7-04-1370	0.32	16.38	0.019	1.75
3		3-05-1362	1.28	8.33	0.153	14.1
4		3-29-1370	2.10	10.68	0.197	12.73
5		5-09-1353	6.08	23.55	0.258	35.40
6		3-03-1370	2.74	25.28	0.109	10.68
7		9-09-1363	1.02	21.55	0.048	2.40
8		7-15-1363	4.81	55.70	0.086	11.40
9		5-20-1371	1.58	15.20	0.104	12.90
10		7-10-1369	0.84	16.00	0.053	1.74
11		4-03-1361	1.46	8.75	0.167	4.56
12	Bagh-Tangeh	2-29-1351	0.43	10.21	0.042	2.32
13		4-16-1353	1.00	15.75	0.063	2.15
14		4-28-1353	1.12	10.01	0.112	2.89
15		5-01-1355	6.37	25.05	0.254	5.39
16		4-15-1353	3.06	32.45	0.094	2.62
17	Kamar-Khany	7-02-1353	0.16	7.10	0.023	1.00
18		5-12-1351	0.13	8.85	0.015	1.02
19		5-01-1355	1.79	25.05	0.072	10.40
20		4-16-1353	0.98	15.75	0.062	4.68
21		8-13-1351	4.95	59.21	0.084	6.56

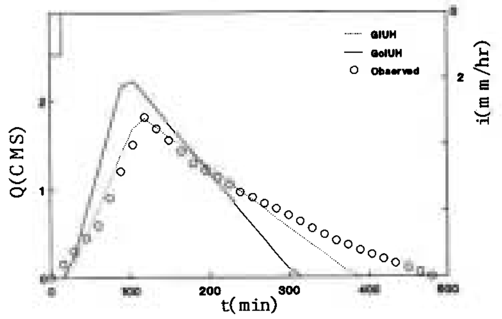


Figure 2. Flood hydrograph for 3-30-1371 (Valik-Bon station)

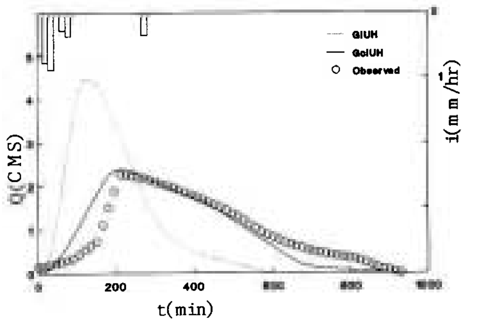


Figure 6. Flood hydrograph for 9-9-1363 (Valik-Bon station)

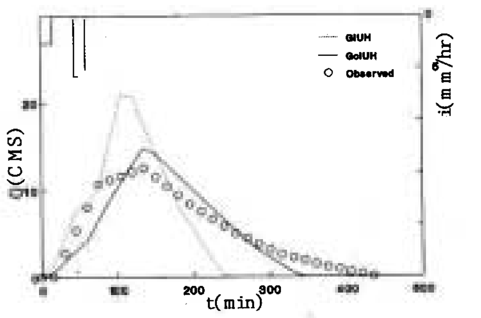


Figure 3. Flood hydrograph for 3-29-1370 (Valik-Bon station)

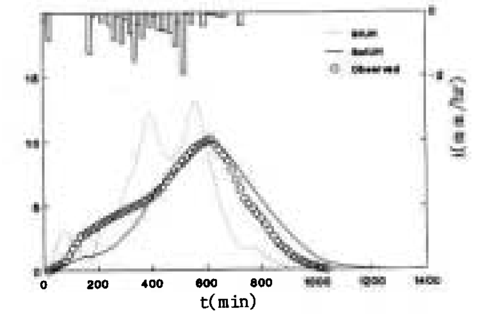


Figure 7. Flood hydrograph for 7-15-1363 (Valik-Bon station)

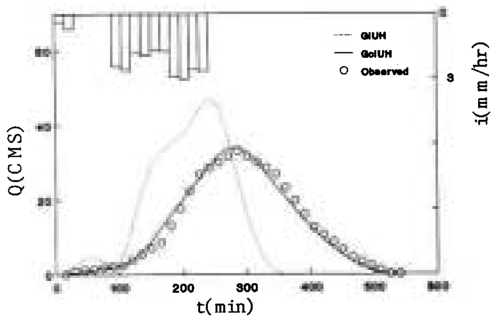
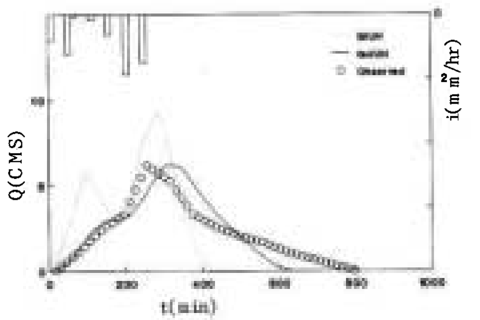


Figure 4. Flood hydrograph for 5-9-1353 (Valik-Bon station)



Fiugre 8. Flood hydrograph for 5-20-1371 (Valik-Bon station)

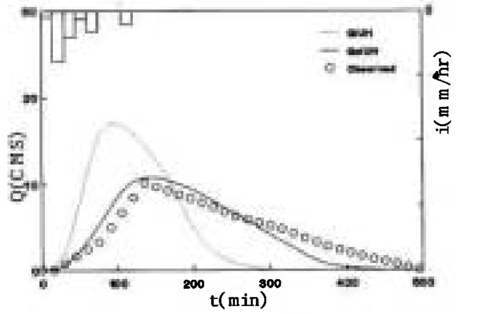


Figure 5. Flood hydrograph for 3-3-1370 (Valik-Bon station).

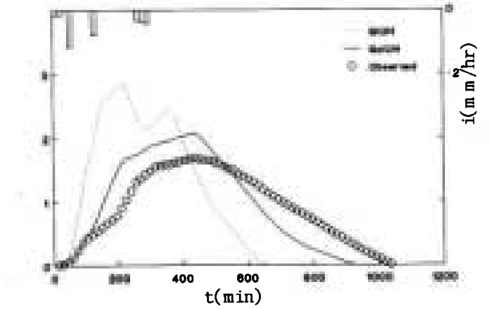


Figure 9. Flood hydrograph for 7-10-1369 (Valik-Bon station)

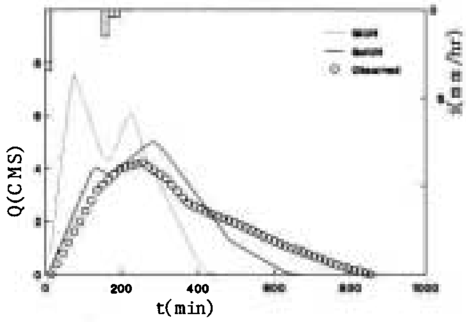


Figure 10. Flood hydrograph for 4-3-1361 (Valik-Bon station)

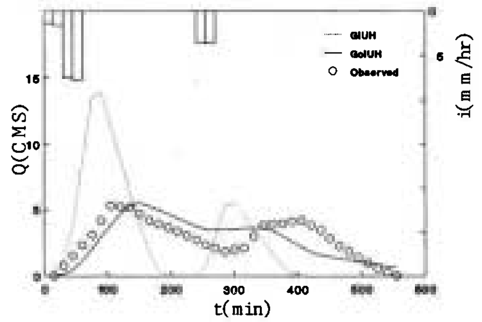


Figure 13. Flood hydrograph for 5-1-1355 (Bagh-Tangeh station)

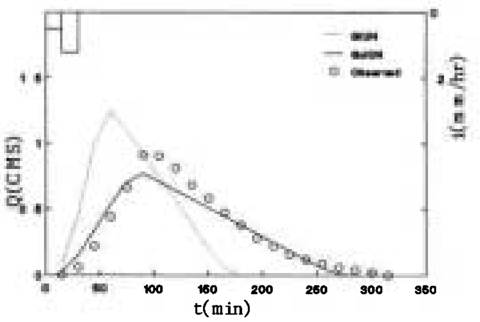


Figure 11. Flood hydrograph for 2-29-1351 (Bagh-Tangeh station)

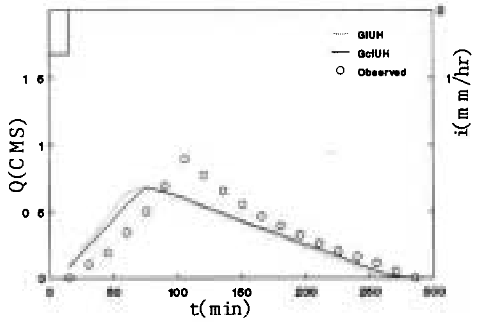


Figure 14. Flood hydrograph for 7-2-1353 (Kamar-Khany station)

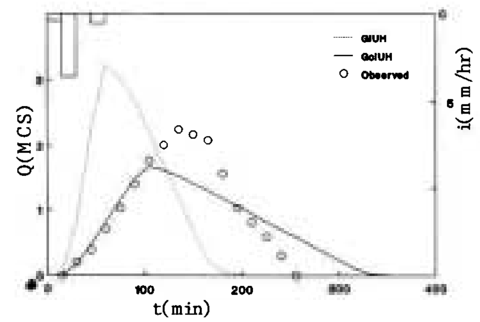


Figure 12. Flood hydrograph for 4-28-1353 (Bagh-Tangeh station)

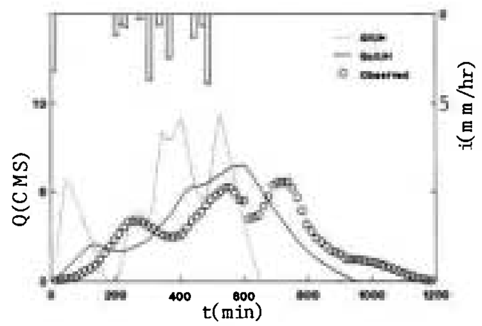


Figure 15. Flood hydrograph for 8-13-1351 (Kamar-Khany station)

method the flood hydrographs have been simulated nearly in an exact form. On the other hand an acceptable flood hydrograph simulation (except one) is the result of using the GIUH method. Although in complex and intermittent rainfall events in difference between observed and GcIUH method-simulated flood hydrograph grows up, in more uniform and continuous ones a complete perfect agreement exists.

Exluding the similar parameters, determination of uncommon parameter is the main source of differences between these two models for accuracy of flood hydrographs simulations. These parameters are mean flow velocity and kinematic wave parameter for GIUH and GcIUH respectivley.

a) GIUH

Indirect methods were used for velocity determination for all rainfall-runoff events. Except for Valik-Bon station, there exists a more or less variable stage-discharge relationship for Bagh-Tangeh and Kamar-

Khany due to unstable cross section. The lower correlation coefficients in these stations show this point (Table 3). Mean flow velocity is a parameter which reflects the effect of the catchment dynamic characteristics on the GIUH. Even very small changes in V cause relatively large changes in the shape of GIUH [5, 6, 8, 13]. Rodriguez-Iturbe, et al. [6] showed that in spite of high dependency of GIUH ordinates on velocity, this dependency diminishes at velocities greater than 2m/s. This is favorite for hydrologists, since they are interested in forecasting design discharges at high return periods in ungaged watersheds. In these cases the high velocity loweres the sensitivity of GIUH to mean flow velocity. In all, an engineer must compute the peak discharge at various velocities and take the optimum of each via an engineering judgment [6]. Although it seems that for a given rainfall-runoff event the stream flow velocity should approximately be the same at any momemt through the whole watershed [5, 14, 23, 25], Ghahraman [26] has shown that this assumption may not be correct for some selected rainfall-runoff events in Ammameh watershed. Changes of velocity may be a reason for incomplete match between observed and computed flood hydrographs.

b) GcIUH

Due to narrow width of the rivers under study, in contrast to the view of Rodriguez-Iturbe et al. [14], the kinematic wave parameter is not constant. Although indirect methods were used for α determination, (1) sensitivity of IUH ordinates to its variations is less pronounced than the effect of velocity changes, and (2) the effect of probable errors in α determination would remarkably diminishe as GcIUH ordinates depend on excess rainfall characteristics. In wide rivers, the water depth may be ignored in comparison to bed width and a constant value for α would result from local considerations. The latter point magnifies the priorities of GcIUH as is compared to GIUH method for flood hydrograph simulation in ungauged watersheds.

CONCLUSIONS

a) Two modifications to GcIUH theory have been offered. One of them is attributed to the inclusion of RB/RA ratio, and the other deals with managing non-wide channels.

b) In general both methods will be helpfull for flood hydrograph simulation, while related parameters are accurately determined. But due to uncertainty in velocity prediction and high dependency of GIUH on V, GcIUH would be prior to GIUH model. GcIUH is more advantageous in wide rivers, where the kinematic wave parameter is constant.

c) Computing excess rainfall is a common problem for both methods. Its determination not only remains as an unsolved problem in ungauged watersheds [2], but in gauged watersheds some different problems arise. Selection of a suitable method, amongst the existing methods [19], is dependent on engineering judgment and the experience of researcher.

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REFERENCES

1. J. C. I. Dooge, "Problems and Methods of Rainfall-runoff Modelling". In: T. A. Ciriani, U. Maione and J. R. Wallis, eds. Mathematical Models for Surface Water Hydrology, John Wiley and Sons, New York, (1976).
2. V. P. Singh, "Military Hydrology"; Report 17, A Quasi-Conceptual Linear Model for Synthesis of Direct Runoff with Potential Application to Ungaged Basins, Miscellaneous Paper EL-79-6, Prepared by Mississipi State University, Starkville, MS, for the US Army Engineer

Waterways Experiment Station, Vicksburg, MS, (1989).
3. L. K. Sherman, "Stream-flow from Rainfall by the Unit Graph Method", Eng. News Rec. (1932), 108, 501-505.
4. F. F. Snyder, "Synthetic Unit Graph", *Trans. Am. Geophys. Union.*, 19, (1938), 447-454.
5. I. Rodriguez-Iturbe, and J. B. Valdes, "The Geomorphologic Structure of Hydrologic Response", *Water Resour. Res.* 15(6), (1979), 1409-1420.
6. I. Rodriguez-Iturbe, G. Deveto, and J. B. Valdes. "Discharge Response Analysis and Hydrologic Similarity, the Interrelation between the Geomorphologic IUH and the Storm Characteristics", *Water Resour. Res.* 15(6), (1979), 1435-1444.
7. V. K. Gupta, E. Waymire, and C. T. Wang, "A Representation of an Instantaneous Unit Hydrograph from Geomorphology". *Water Resour. Res.* 16(5), (1980), 855-862.
8. C. X. Jin., "A Deterministic Gamma-type Geomorphologic Instantaneous Unit Hydrograph based on Path Types", *Water Resour. Res.* 28(2), (1992), 479-489.
9. M. R. Karlinger and B. M. Troutman. "Assessment of the Instantaneous Unit Hydrograph from the Theory of Topologically Random Networks", *Water Resour. Res.*, 21(11), (1958), 1693-1702.
10. A. Q. Karim, "Flood Forecasting Using Geomorphologcal Instantaneous Unit Hydrograph". M. E. thesis, University of Roorkee, Rorkee, India, (1992).
11. R. K. Panigrahi, "Derivation of Nash Model Parameters from Geomorphological Instantaneous Unit Hydrograph". M. E. thesis, University of Roorkee Rokee, India, (1991).
12. V. P. Singh, C. Corradini, and F. Melone, "Comparison of Some Methods of Deriving the Instantaneous Unit Hydrograph", *Nordic Hydrology*, 16, (1985), 1-10.
13. J. B. Valdes, Y. Fiallo and I. Rodriguez-Iturbe, "A Rainfall-runoff Analysis of the Geomorphologic IUH" *Water Resour. Res.*, 15(6), (1979) 1421-1435.
14. I. Rodriguez-Iturbe, M. Gonzales-Sanabria and R. L. Bras, "A Geomorphoclimatic Theory of the Instantaneous Unit Hydrograph", *Water Resour. Res.* 18(4), (1982a), 877-886.
15. I. Rodriguez-Iturbe, M. Gonzales-Sanabria, and G. Caamano, "On the Climatic Dependence of the IUH: A Rainfall-runoff Analysis of the Nash Model and the geomorphoclimatic Theory," *Water Resour.* Res. 18(4), (1982b), 887-903.
16. S. Ansari-Fard, "Evaluation of SCS Methods in Representative Basins of Iran", M. Sc. thesis, College of Agriculture, Tehran University, Tehran, Iran, (1971), (in Persian).
17. M. B. Nahvi, "Evaluation of CN Methods for Runoff Prediction due to Rainfall in Ammameh Basin". M. Sc. thesis, College of Agriculture, Tehran University, Tehran, Iran, (1371) (in Persian).
18. R. K. Jr. Linsley, M. A. Kohler and J. L. H. Paulhus. "Hydrology for Engineers", 3rd ed., New York: McGraw-Hill, (1982).
19. D. Hillel, "Applications of Soil Physics, "Academic Press, New York, (1980).
20. R. L. Bras, "Hydrology: An Introduction to Hydrologic Science", Addison-Wesley Publishing Company, Inc. USA, (1990) 643.
21. B. Ghahraman, "Flood Forecasting as Affected by Complete Shape of IUH". *Iran. J. of Sci. and Tech.* 19(3), (1995), 289-300.
22. F. M. Henderson, "Some Properties of the Unit Hydrograph". *J. Geophysic. Res.*, 68(16), (1963), 4785-4793.
23. L. B. Leopold, and T. Jr. Maddock. "The Hydraulic Geometry of Stream Channels and some Physiographic Implications". U. S. Geological Survey Professional paper No. 252, Washington, D. C. (1953).
24. V. T. Chow, D. R. Maidment and L. W. Mays," Applied Hydrology", McGraw-Hill Inc, (1988) 572.
25. D. H. Pilgrim, "Isochrones of Travel Time and Distribution of Flood Storage from a Tracer Study on a Small Watershed", *Water Resour. Res.*, 13(3), (1977), 587-595.
26. B. Ghahraman, "Velocity Analysis in GIUH Theory" *Iran J. of Sci. and Tech.*, (Accepted), (1995).