RESEARCH NOTE

GIUH-GelIUH COMPARISON FOR TWO WATERSHEDS IN IRAN

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Abstract Two representative watersheds, Ammaragh and Kasitian, located in Southern and Northern Elborz: mountain in Iran respectively were considered. Fourteen events of rainfall-runoff in non-melting 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 GelIUH and GIUH theony for each rainfall-runoff event separately. Direct runoff hydrographs were determined by convoluting IUH and effective rainfall hyetograph. Mean flow velocity and kinematic wave parameter were correlated to peak discharge separately. Therefore, these indices were estimated for each rainfall-runoff event, knowing its peak discharge. It is found that GelIUH shows a better results for all rainfall-runoff events. High sensitivity of GIUH to mean flow velocity and impedance of accurate determination of its value may be the main reason for predicting less accurate results. GelIUH, 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, GelIUH, Flood Forecasting, Representative Watersheds

INTRODUCTION

Runoff synthesis from ungauged basins has long been 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 characteristics 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 studying 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.](image)
TABLE 1. A Summary of Watersheds's Main Characteristics.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Kasilian</th>
<th>Ammameh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude range (m)</td>
<td>1100-2700</td>
<td>1900-3870</td>
</tr>
<tr>
<td>Area (Sq. Km.)</td>
<td>82.6</td>
<td>38.31</td>
</tr>
<tr>
<td>Hydrometric stations</td>
<td>1*</td>
<td>2**</td>
</tr>
<tr>
<td>Automatic rain gauges</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Non-automatic rain gauges</td>
<td>8</td>
<td>3</td>
</tr>
</tbody>
</table>

* Valik-Bon
** Bagh-Tangeh in middle and Kamar-Khani 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 rain gauge 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 separating 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:

\[ f = 0.5 * s * t^{-1/2} \]  

(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 (\( q_p \), in l/hr) and time to peak (\( t_p \), in hr) of an IUH in GIUH theory as follows:

\[ q_p = 1.31 \times \left( R_{L}^{0.43} \right) \times \frac{V}{L} \]  

(2)

\[ t_p = 0.44 \times L \times \left( \frac{R_{y}/R_{h}^{0.55}}{V} \right) \]  

(3)

where \( R_{A} \), \( R_{h} \), 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:

\[ q_p = 0.871/[k^{0.4}] \]  

(4)

\[ t_p = 0.585 \times k^{0.4} \]  

(5)

where

\[ k = \frac{L^{1/2}}{(i_s \times A \times R_{L} \times \alpha^{1/3})} \]  

(6)

\[ \alpha = \sqrt{(s)/(n^{*}b^{2/3})} \]  

(7)

where \( i_s \) 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 \( \alpha \) 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.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Valik-Bon</th>
<th>Bagh-Tangeh</th>
<th>Kamar-Khany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin order</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>$R_b$</td>
<td>3.5</td>
<td>2.24</td>
<td>4.12</td>
</tr>
<tr>
<td>$R_a$</td>
<td>4.71</td>
<td>3.31</td>
<td>6.72</td>
</tr>
<tr>
<td>$R_s$</td>
<td>1.58</td>
<td>1.41</td>
<td>2.92</td>
</tr>
<tr>
<td>$L_e$(Km.)</td>
<td>4.63</td>
<td>3.30</td>
<td>10.84</td>
</tr>
<tr>
<td>$A_e$(Sq. Km.)</td>
<td>68.6</td>
<td>14.68</td>
<td>38.31</td>
</tr>
<tr>
<td>$R_b/R_s$</td>
<td>0.743</td>
<td>0.667</td>
<td>0.613</td>
</tr>
</tbody>
</table>

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.

Velocity Estimation

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

\[ V = g^*Q^a \]  

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.

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

*correlation coefficient

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Meanwhile Bagh-Tangeh and Kamar-Khany do not have simple rectangular cross 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]):

\[ Q = \alpha A^c \]  \hspace{1cm} (10)

Addressing the fact that \( S_0 = S_r \), by the definition of a kinematic wave, Manning formula can be written as:

\[ Q = \left[ \frac{S_0^{1/2}}{(n \cdot p^{0.6})} \right] A^{5/6} \]  \hspace{1cm} (11)

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

\[ \alpha = \sqrt{s} / (n \cdot p^{0.6}) \]  \hspace{1cm} (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:

\[ \alpha = z^*Q \]  \hspace{1cm} (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 GIUH

### TABLE 4. Characteristics of Selected Rainfall and Runoff Events.

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

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

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

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

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

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

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

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

Excluding 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 respectively.

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 2 m/s. This is favorite for hydrologists, since they are interested in forecasting design discharges at return periods in ungaged watersheds. In these cases the high velocity lowers 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 moment 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) GeIUH

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 diminish as GeIUH 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 GeIUH as is compared to GIUH method for flood hydrograph simulation in ungaged watersheds.

CONCLUSIONS

a) Two modifications to GeIUH 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, GeIUH would be prior to GIUH model. GeIUH 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 ungaged 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.

ACKNOWLEDGEMENT

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