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ESTIMATION OF DESIGN FLOOD HYDROGRAPH FOR AN UNGAUGED WATERSHED

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ABSTRACT: Determining flood features in unguaged watersheds has always been a challenge. The under study basin in this research, named Jongabad, is an ungauged basin with an area of 138.5 Km^2 in center of Iran on which a reservoir is going to be designed. So, the accurate estimation of peak and volume of floods entering the reservoir, as a result of heavy rainfalls, is essential. Due to not having flow data in the under study basin to determine hydrological parameters such as Curve Number (CN), a gauged neighbor watershed which is similar to the under study basin in terms of vegetation, geology and physiography was selected. Subsequently, the HEC-HMS model was applied to simulate a heavy storm in the neighboring basin for which rainfall and flow data were available. Simulating the flood, CN and storage coefficient which were assumed to be constant within the region were derived and then applied for the under study basin. To better simulate flood features, ArcGIS and HEC-GeoHMS were also employed to determine the physiographic features and input parameters of HEC-HMS for both basins. Also, instead of using SCS types of Rainfall Temporal Pattern (RTP) which are commonly used in similar studies in the region, the methods of average variability and consecutive blocks were applied to determine RTPs. Comparing the simulated flood hydrograph features in the representative basin with observed flow data indicated that the consecutive blocks method led to better results in terms of correspondency. Using the consecutive blocks method in target basin, the peak flows and flood volumes were computed with return periods of 2, 5, 10, 25, 50 and 100 years. Strength of the methodology used in this study is that it can be used to assess the impact of high-techs such as using ArcGIS to better simulate the basin and interrelated issues in it.

Keywords: Curve number, Rainfall temporal pattern, Ungauged, Unit hydrograph.

1. INTRODUCTION

Due to having one third of the average world precipitation, Iran is characterized among arid and semiarid regions of the world. Knowing this fact necessitates the building of structures which can store water during high-precipitated seasons and release it for consumption when droughts or low-flows occur. If these structures are not designed carefully and accurately, they will culminate in loss of many lives, let alone storage of water for consumption. The studies on natural disasters have shown that floods have had the biggest portion in terms of frequency and damages they did to human beings. Green et al. (2000) attributed more than 30 percent of damages in first half of the 20th century to floods. In Iran, it was estimated that 15 percent of human losses between 1977-1988 were due to floods (Jalalirad, 2002).

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2. DESIGN HYETOGRAPH

Design hyetographs should be based on observed storm events analysis (Chow et al., 1988). By analysis of observed storm events, the sequence of precipitation or rainfall temporal pattern (RTP) in typical storms can be determined. Since RTP directly affects the peak and volume of flow, it should be specified carefully. Such an analysis was performed by Huff (1967) for heavy storms on areas ranging up to 400 mi^2 in Illinois. RTPs can be classified into three classes in an arbitrary classification as follows: SCS type patterns, method of average variability and method of consecutive blocks.

The U. S. Soil Conservation Service (1986) developed synthetic storm hyetographs for use in United States. Soil Conservation Service studied a vast part of the United States with different climates and at the end suggested four types of patterns. For example, Types I and IA are for the Pacific climate with wet winters and dry summers. SCS patterns can be applied when there is no record of rainfall sequence available. The patterns can be applied only if the climate of the under study region is similar to the climate of the regions for which the SCS patterns were developed.

Average variability method is based on determining the real rainfall in each partial duration of the total specified duration and then ranking them based on their received precipitation. The more precipitation is received, the less the rank would be. In this way, the percentage of precipitation for each rank will be specified. Then, the percentages for each rank will be averaged. Also, the average of the ranks in each partial duration will be calculated and the more rank will be given to the more average. In the end, the average of percentages will be given to the ranks in accordance.

The method of consecutive blocks is the easiest way and can be applied easily when Intensity-Duration-Frequency (IDF) curves exist. In this way, also as default in some computer programs as the alternating block method or center-loaded storm, it has been used, the peak of the hyetograph is placed at the middle of the storm duration. Levy and McCuen (1999) reported that the actual data from six Maryland watersheds ($5<A<135$ sq. Km) suggested that center-loaded design storms are appropriate. Packman and Kidd (1980) also reported that center-loaded hyetograph was the most appropriate, based on the analysis of data from the United Kingdom.

3. UNIT HYDROGRAPH

Unit hydrograph is a familiar and convenient method to estimate the peak and volume of floods (Daniil et al., 2005). Many unit hydrographs have been proposed over the years. Synthetic Unit Hydrograph (SUH) is a kind of hydrograph which is based on physiographic features of a basin and is used to estimate the peak discharge and flood volume when there is no flow data. There are different methods on which SUH is built, yet three of them are common and could be easily applied. They are: 1) Snyder Unit Hydrograph 2) SCS Unit Hydrograph 3) Instantaneous Unit Hydrograph (IUH) [for more information on different types of unit hydrographs, refer to

Chow et al., 1988]. The principles of making a unit hydrograph are based on identifying physiographic features of the basin such as slope, concentration time and storage coefficient.

4. TIME OF CONCENTRATION

Time of concentration (*TC*) which is equal to the time that takes the farthest drop of water in the basin to reach the outlet of basin is a very important parameter in making IUH. It would be equal to the time between the end of rainfall and the turning point of hydrograph falling limb, provided that the resultant hydrograph of a rainfall is available.

A variety of methods have been developed to estimate the time of concentration. As the methods are empirical, some may overestimate *TC* and some others may underestimate *TC*. Since in this research, the SCS method led to better results in terms of correspondence with physiographic features of basin, its formula is explained as below. It is calculated as the following:

$$TC = 1.67(t_{lag}) \tag{1}$$

TC : time of concentration in hours

T_{lag} : the *lag* time (the time between the center of rainfall and the peak of the hydrograph) in hours

$$T_{lag} = \frac{L^{0.8}(S+1)^{0.7}}{1900Y^{0.5}} \tag{2}$$

L : length of the main watercourse (ft)

Y : the average of basin slope (%)

S : the index of water storage in the basin which is calculated as the equation (3):

$$S = \frac{1000}{CN} - 10 \tag{3}$$

CN : basin infiltration index

5. STORAGE COEFFICIENT

Storage coefficient which is the index of basin drainage is calculated by dividing the hydrograph discharge at falling limb turning point by the hydrograph slope at the same point.

Many studies have found that the storage coefficient, divided by the sum of time of concentration and storage coefficient, is reasonably constant over a region (HEC-HMS manual, 2000). In other words:

$$\frac{S_c}{S_c + TC} = \text{constant} \tag{4}$$

S_c : storage coefficient

So, if the resultant hydrograph of a rainfall exists, S_c and TC can be easily determined from it. Having them both, constant can be easily driven.

6. BACKGROUND IN FLOOD MODELING

Applications of simulating models which can simultaneously simulate the spatial relations of physiographic and hydrologic parameters are essential as well. Among different models which have been developed for rainfall-runoff simulation processes in ungauged watersheds, HEC-HMS (Hydrological Engineering Center-Hydrologic Modeling System), which is actually the modified version of HEC-1, has proved to be one of the most commonly used models due to its data requirements and being robust. Saeidian et al. (2009) employed HEC-HMS and evaluated the effect of converting rangelands to farming lands within a period of thirty years in Kardeh watershed located in north east of Iran and concluded that runoff volume and peak discharges rose due to an increase in curve number (*CN*) of the watershed. Daniil et al. (2005) applied HEC-HMS to estimate flood peak that can result from variation of rainfall distribution of given total height and duration. They proposed that SCS hyetographs are not reliable in all climatic situations and flood discharges derived from using those hyetographs should be compared with those discharges that have already occurred. Based on the physiographical features of an ungauged watershed in northern Ontario and the meteorological data of one nearby climatic station, Sui (2005) simulated the rainfall-runoff processes to estimate the desired peak flow through the combination of the regionalization of flood and the HEC-1 modeling. He introduced his method as an efficient one to be used in ungauged watersheds. Using HEC-HMS in Mohammad Abad basin in Golastan province, Shaghaie Fallah, (2000) simulated peak flows using HEC-HMS and compared the results with the observed data. He concluded that results produced by HEC-HMS were very close to the observed data.

Geographical Information Systems (GIS) are increasingly being used for spatial and temporal data handling in flood analysis (Townsend and Walsh, 1996; Dutta et al., 2000; Al-Sabhanet al., 2003). The advent of GIS and its usage in water resources issues, helped hydrologists to make a better view of watersheds and its features such as streams, drainage network and slope. Maidment and Djokic (2000) have discussed specific interfaces and algorithms integrated in a GIS to account for the spatial influence in hydrologic and hydraulic modeling. Previous studies (Tate et al., 2002; Whiteaker et al., 2006) have also established the use of GIS for floodplain mapping. Kloub et al. (2010) employed GIS and remote sensing for monitoring of water resources degradation at Al-Azraq Oasis, Jordan. GIS application also helped to analyze raster data and shift from lumped models to semi/fully distributed models. By applying mathematical and statistical models, Kiyani (1999) showed that spatial rainfall distribution which is a significant factor in water related issues can be easily done with the help of GIS. He also concluded that using GIS resulted in better and more accurate results.

This study describes an attempt to incorporate GIS into flood modeling. It also indicates how flooding simulation in representative basins could be accomplished and how the results can be employed for determining flood features in ungauged basins. Furthermore, the efficiency of Snyder unit hydrograph is emphasized for application in similar situations.

7. MATERIALS AND METHODS

Jongabad basin with the area of 138.5 square kilometers is located between the 31°14'-31°27′ north latitude and 51°38′-51°48′ east longitude. It is located in Isfahan province and the nearest city to the basin is Semirom. Figure 1 gives a schematic view of the basin and its adjacent basin, a part of which has been taken as the representative of Jongabad basin.

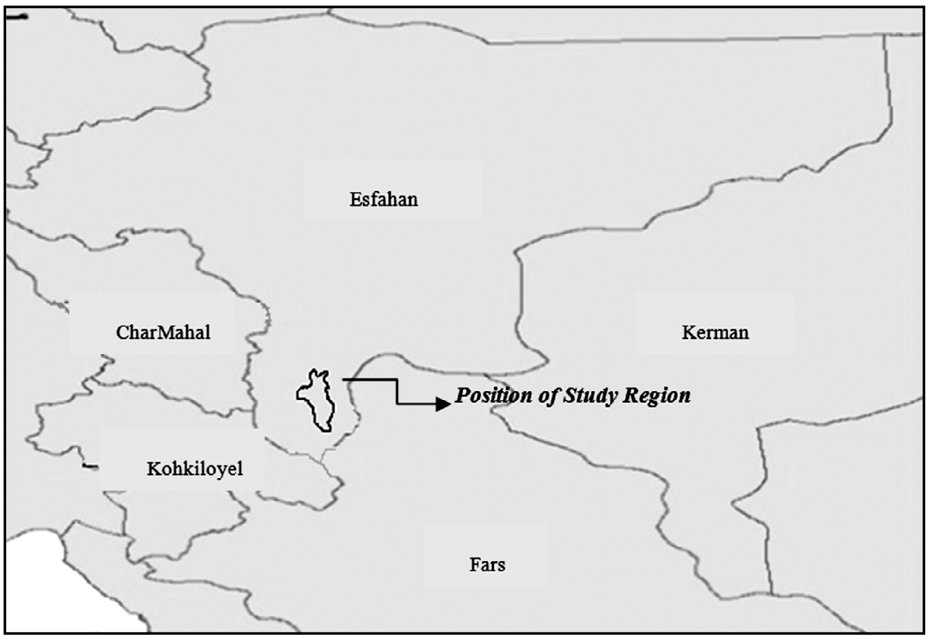

Figure 1: Geographic Position of Jongabad Basin in South of Isfahan Province

In this research, IUH method was applied, regardless of time effect. Different methods have been suggested to make IUH. However, lag and route technique which is also known by the name of Clark is the most efficient of them (Chow, 1988) and was used in this study. To determine the required parameters of Clark hydrograph, i.e. time of concentration and storage coefficient, equations (1) to (4) were applied.

There are only two rain-gauge stations called Hanna and Khosroshirin in the region (Figure 2). The only pluviograph, which is required for determining RTP, in the region is located in Hanna rain-gauge station. So, RTP derived from Hanna station was used for the design rainfall in Jongabad basin.

As no flow data has been recorded in Jongabad basin to estimate design flood features with them, the flood occurred on Feb10th in 2005 with a peak flow of $17m^3/s$ in the representative basin called Ghale-Eslamabad was first simulated. To get results closer to the observed data, the recorded depth precipitation in both of the so called rain-gauge stations was used. However, to input hyetograph of Feb10th precipitation as the RTP of the flood, data recorded in Hanna Station was employed.

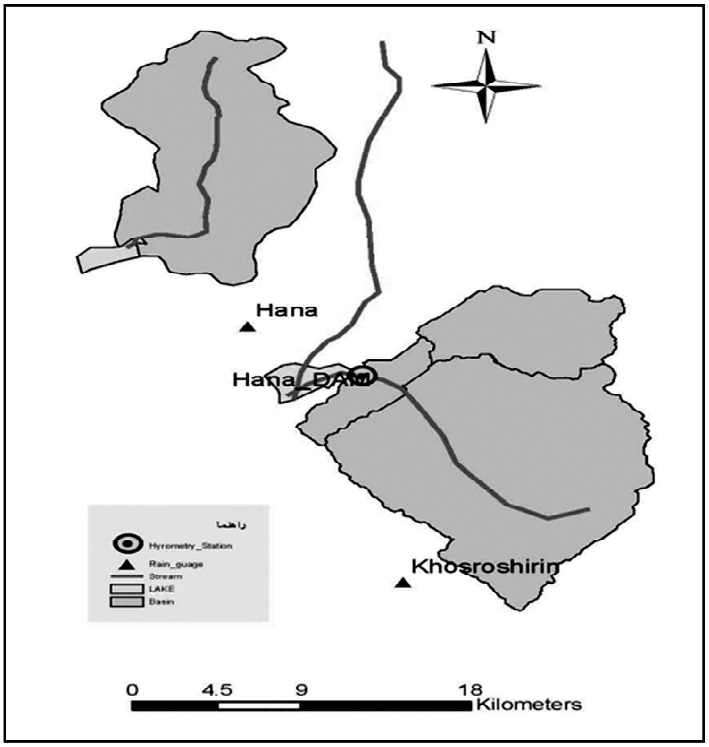

Figure 2: Position of Rain-Guage Stations and Representative Basin with Flow Data

8. RESULTS AND DISCUSSIONS

Introducing the primary parameters of the Clark Unit Hydrograph for Ghale-Eslamabad basin which itself is made of three sub basins (Figure 2), HEC-HMS was applied. In the calibration process, Sum Square Error was assumed to be the objective of optimization process. The results of Feb10th flood simulation in Ghale-Eslamabad are shown in Table 1.

Table 1
Results of Feb10th Flood Simulation in Ghale-Eslamabad

Parameter	*Simulated*	*Observed*	*Difference*	*Percentage of difference*
Volume (MCM)	2.19	2.36	-0.12	-5.2
Maximum discharge (m^3/s)	15.9	17	-1.1	-6.5

9. SENSITIVITY ANALYSIS

The sensitivity analysis results (Table 2) indicate that the objective function is most sensitive to *CN*. It is also shown that the initial values of coefficient storage and time of concentration are very close to the calibrated values. They prove that the SCS method for estimating concentration time is reliable.

Table 2
The Results of Sensitivity Analysis

Sensitivity of Final Function	*Optimization Value*	*Initial Value*	*Parameter*	*Sub-basin Area (km²)*
-0.47	2.07	2.04	Storage Coefficient (hr.)	23.85
-0.16	2.75	2.7	Time of Concentration (hr.)	
7.17	71	77	Curve Number	
-1.82	2.59	2.55	Storage Coefficient (hr.)	56.9
-1.39	3.45	3.39	Time of Concentration (hr.)	
18.76	75	78	Curve Number	
-0.34	4.57	5.4	Storage Coefficient (hr.)	212.2
-0.95	8	7.1	Time of Concentration (hr.)	
-9.15	79.7	76	Curve Number	

10. PHYSIOGRAPHIC FEATURES OF TARGET BASIN

Using ArcGIS and Hec-GeoHMS, the physiographic features of Jongabad basin such as area, circumference, height of weight center and length of the longest stream were determined (Table 3). It was assumed the *CN* value of Jongabad basin equals the weighting average of *CN*s in sub basins of the representative basin, i.e Ghale-Eslamabad due to the hydrological similarities of both basins.

Knowing *CN* equals 78.1, time of concentration and storage coefficient were calculated based on equations (3) and (4), respectively.

Table 3
The Physiographic Features of Jongabad Basin

CN	*Longest Stream (km)*	*Height of Weight Center (m)*	*Perimeter (km)*	*Area (km²)*	*Time of Concentration (hr)*	*Storage Coefficient*
78.1	24.154	2360	81.760	138.5	3.45	2.6

11. DESIGN RAINFALL

Since Jongabad basin concentration time equals 3.45 hours and the value is less than 6 hours, the duration of design rainfall was assumed to be 6 hours (Chow, 1988). Also, to determine the depth of this 6-hour rainfall with different returning periods, maximum 24-hour rainfalls were applied with a reduction factor of 1.48, according to the following equation.

$$P_{6,T} = \frac{P_{24,T}}{1.48} \quad (5)$$

To determine $P_{24,T}$, the distribution of rainfall in Hanna station was used. As the topography of the basin does not vary too much and height of center of weight in Jongabad (2360 m.a.s.l) is very close to the height of pluviograph which is located in Hanna rain-guage station (2329 m.a.s.l), it seems reasonable to assume that the distribution of rainfall in Jongabad basin is similar to the one recorded in Hanna rain gauge station. To specify the statistical distribution which best fits maximum 24-hour rainfalls recorded within the period of 1986–2005 in Hanna, four probability distributions named Normal, three parameters Log-normal, two parameters Gamma and Gumbel were applied. For goodness of fit, the least square method was employed. Fitting the above-mentioned distributions, it was revealed that Gumbel resulted in the best fit. The results of statistical storm analysis are shown in Table 4.

Table 4
Statistical Analysis of Storms, Recorded in Hanna

Return Periods (year)	2	5	10	25	50	100
Peak Flow (m^3/s)	37.9	50.1	58.2	68.4	76	83.5

To specify the RTP in Jongabad, the methods of average variability and consecutive blocks were applied. First, storms with durations close to 6 hours were extracted. Second, the RTPs were derived, using the two-previously mentioned methods. Also, to better compare the RTPs, the method of consecutive blocks was employed with the peak coefficient of 33%, 50% and 75%. Then, the storm occurred on Feb10th in 2005 in Ghale-Eslamabad was again simulated, using the new derived RTPs. Finally, the simulated values, i.e volume of flood and peak flow, were again compared with the observed values (Table 5). The results indicate that method of consecutive blocks leads to better results for peak flow and volume of flow (Table 4).

Knowing the depth, RTP, duration of design rainfall and also the parameters of IUH, Jongabad basin was simulated and the peak and volume of flow were computed for return periods of 2, 5, 10, 25, 50 and 100 (Table 6).

Table 5
The Results of Average Variability and Consecutive Blocks Methods

Precipitation Pattern Distribution	*Peak Coefficient (%)*	*Calculated Volume of Flood (MCM)*	*Observed Volume of Flood (MCM)*	*Calculated Peak Discharge (m^3/s)*	*Observed Peak Discharge (m^3/s)*
	33	2.03		15	
Consecutive Blocks	50	2.19	2.31	16.2	17
	75	2.01		17.8	
Average Variability	-	2.19	2.31	16	17

Table 6
Peak and Volume of Discharge for Different Return Periods

Volume of Flood (MCM)	*Peak Discharge (m^3/s)*	*Return Period (year)*
6.34	41.3	2
12.5	82.6	5
17.4	114.5	10
24	159.8	25
29.3	195.8	50
34.8	232.8	100

12. CONCLUSIONS

Since Iran is located in an arid region and its annual average precipitation is about one third of the average precipitation in the world, the necessity of applying and building the structures which can prevent the loss of water in high-precipitated years is a must. What is of great importance is the correct estimation of peak and volume of floods entering these structures, as a result of heavy rainfalls. Unfortunately, most of the basins whose runoffs have not yet been brought under control are those that either lack sufficient data or have no flow data at all.

The target basin in this research is one of those basins for which no flow data has been recorded. Nevertheless, building a dam which can prevent the loss of water in this high consuming basin has proved to be a necessity. To estimate features of floods which enter this basin, a nearby and hydrologically-similar basin was chosen to be used as the representative of the under study basin. During the simulation processes, Snyder unit hydrograph was proved to be a nice choice in similar conditions, for its parameters can be easily driven provided that at least a rainfall hyetograph and a flood hydrograph are available. The results presented in this research must be viewed in the context of the amount and quality of the information that was available. The results also have to be seen in the context of possible alternative approaches and the results that may be expected. Strength of the methodology used in this study is that it can be used to assess the impact of high-techs such as using ArcGIS to better specify the required parameters such as physiographic parameters.

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