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Estimation of Runoff Peak Flow by El-Hames Empirical Method for Ungauged Catchments: A Case Study Iranshahr

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Abstract

In this paper, the El-Hames empirical method was used to determine the peak runoff flow in Iranshahr catchment. The El-Hames method is based on morphological parameters and SCS Curve Number of the studied area. In the current research, the implementing was processed by collecting the required data including soil type and vegetation cover, land use maps, digital elevation model and satellite images from the associated institutions such as Iran Water Resources Management Company (IWRM) and Iran Weather Organization. Then the all data was integrated by using geographic information system (GIS) in order to create different layers of required information. The generated layers were applied to determine the morphological parameters through SCS method and to develop the CN map of the study area. Afterward, daily rainfall statistics over the study catchment obtained from synoptic and rain-gauge stations were estimated for 2 to 200 year return periods. Finally, the developed curve number map and the rainfall statistics were imported in the El-Hames formula to estimate the maximum flood peak flow for return periods corresponding to flood events and the hydrographic graphs were plotted. This paper also assessed the validity of El-Hames formula to determine its accuracy. The obtained results of CE and RMSE with value of respectively, 0.97 and 55.95cms prove the accuracy of applied model. Results of this paper can be used as a basis for design and implementation of plans for sustainable development of water resources over the study area and to provide viable strategies for controlling floods and dealing with water crises in this region.

Keywords: Curve number, Peak flow, Runoff, El-Hames method, Iranshahr

Introduction

Determination of peak flow is the basic step of a range of hydrological studies such as those used for designing hydraulic structures and calibrating the rainfall-runoff models. This step is particularly critical for arid regions, especially regions where little or no runoff statistics are available (Sharma et al. 2000).

Lack of adequate rainfall, lack of runoff gauge stations, and possible changes in hydrological characteristics of arid and semi-arid regions can complicate the evaluation of

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runoff in these regions (Pilgrim et al. 988). There are a multitude of different methods for determination of maximum runoff in arid areas; these methods, which use physical and geomorphological characteristics or statistical techniques to achieve their objectives, have been presented by Hames et al. (1998), Jothityangkoon et al. (2001), Foody et al. (2004), Sevinç et al. (2007), Bracken et al. (2008), and McIntyre et al. (2009). Some of these methods calculate the ratio of average annual flooding to annual precipitation of a certain period (Bhatt et al. 2008; Al-Rawas et al. 2010). These methods however require careful calibration and validation by the data pertaining to previously recorded events; so in regions where there are no runoff gauging stations, results of these methods cannot be controlled and verified; in such circumstances, the more proper approach is to use empirical methods to determine the runoff. Limited extent of hydrology-related works on floods of arid and semi-arid regions suggests that those methods that are based on physical characteristics of the catchments cannot yet properly predict the required parameters without extensive calibration, therefore empirical and quasi-empirical methods can provide easier and more accurate solutions for this problem (Bahat et al. 2009; McIntyre et al. 2007).

In recent years, there have been extensive developments in the empirical approaches including Snyder's hydrograph (Snyder 1938), the Soil Conservation Service (SCS) curve number (CN) method (Soil Conservation Service (SCS) (1972) and a popular approach propose by Wang et al. (2011). These methods often use the flood peak flow, the empirical parameters, and geomorphological and hydraulic variables of the studied catchment to achieve their objectives. For example, theoretical methods can be used to obtain the flood peak flow and rainfall intensity of the catchment over different time periods. These methods however have been developed mainly for small urban catchments (Mulvaney 1851; Kuichling 1889; Ben-zvi and Arie, 1984); thus these empirical equations can only be used for small urban catchments with an area of less than 1 square kilometer (California Department of Transportation 2009.; Lumbroso and Gaume 2012; Burns et al. 2005) or for rural regions with an area of less than 25 square kilometers (Queensland Urban Drainage Manual, 2007).

One of the methods that can be used to determine the runoff coefficients is to obtain the catchment data pertaining to a long period of time. Determination of runoff coefficient is a difficult task and requires careful assessment of various factors and parameters such as soil moisture, rainfall intensity, rainfall duration, vegetation, and land use. However, as a well-known and suitable method, the SCS-CN can be used to predict the required parameters for different soil types through the standardized tables (Marek 2011).

The rapid development of remote sensing technology has enabled us to use GIS to map multiple layers of data, combine them and thus consider multiple hydrological perspectives to predict runoff parameters (Al-Ahmadi and El-Hames 2009; El-Hames and Al-Wagdany 2012; Green and Nelson 2002).

In this paper, the empirical method presented by EL-Hames (El-Hames 2012) is used to determine the flood peak flow in an arid/semi-arid region. There are little or no accurate statistics about the status of flood in this catchment, so in this paper aerial photographs, satellite images, and DEM maps are used to evaluate the required parameters. The data required for this method is acquired from satellite images through ArcGIS 10.1 software and without any fieldwork.

Materials and Methods

The method proposed by El-Hames (2012) uses the morphological parameters and SCS Curve Number of the catchment to predict the peak flow for the ungauged catchments located in arid and semi-arid regions. In this method, the morphological parameters influencing the peak flow are the area, slope and length of the main channel. Effective precipitation is another important factor which reflects the history of catchment moisture conditions and must be estimated from SCS Curve Number. the advantage of this method is that it can be used to determine the peak flow by only using a series of data that can be easily obtained from satellite images and GIS techniques, meaning that it does not require extensive fieldwork on the site of catchment. This method has been calibrated and verified for 76 rainfall-runoff events from 6 different countries. The area, slope, and length of main channel in these catchment have ranged from 2 to 16000 square kilometers, from 0.003 to 0.27 (m/m) and from 1500 to 37000 meters respectively. The total precipitation used in the tests performed on this method has been in a range of 4 to 744 mm. Comparison between the peak flow obtained from this method and those obtained from other developed methods show that in catchments larger than 45 square kilometers, results of this method has a correlation coefficient of 0.92 which points to its good performance; for catchments smaller than 45 square kilometers however, this coefficient has dropped to 0.67. But overall the method proposed by El-Hames can be a good alternative to other theoretical method.

According to El-Hames method, Equation 1 can be used to obtain the peak flow in catchments of arid and semi-arid regions with 0.92 correlation (with actual peak flow) and 95 confidence level:

$$Q_p = \frac{10\ P_e A\ Y^{0.65}}{L^{0.2} d^{0.2}} \tag{1}$$

In the above equation, P_e is the effective precipitation (mm), A is the area of catchment (square kilometers), Y is the average slope of catchment (m/m), L is the length of main channel (m), and d is the height of water retained in the catchment after the event of rainfall (mm).

Curve number (CN) of the catchment is required to estimate the effective rainfall (P_e) and water retention height (d).

As previously mentioned, Curve Number of the catchment for average moisture conditions (CN (II)) can be obtained by incorporating area's hydrologic soil group, vegetation and land use. Equations 2 and 3 can be used to estimate the Curve Number for dry conditions (DCN) and wet conditions (WCN):

$$\text{DCN or CN(I)} = \frac{4.2\ \text{CN}}{10-0.058\ \text{CN}} \tag{2}$$

$$\text{WCN or CN(III)} = \frac{23\ \text{CN}}{10+0.13\ \text{CN}} \tag{3}$$

Once the Curve Number of `catchment is determined, effective precipitation (P_e) can be calculated by Equation 4:

$$P_e = \frac{(P-0.2\ S)^2}{P+0.8\ S} \tag{4}$$

Water retention height (d) can be estimated by subtracting the effective precipitation from the precipitation (P in mm) (P_e millimeters), as shown in Equation (5):

$$d = P - P_e \tag{5}$$

Figure 1 shows the flowchart of method used for obtaining the parameters required for this study.

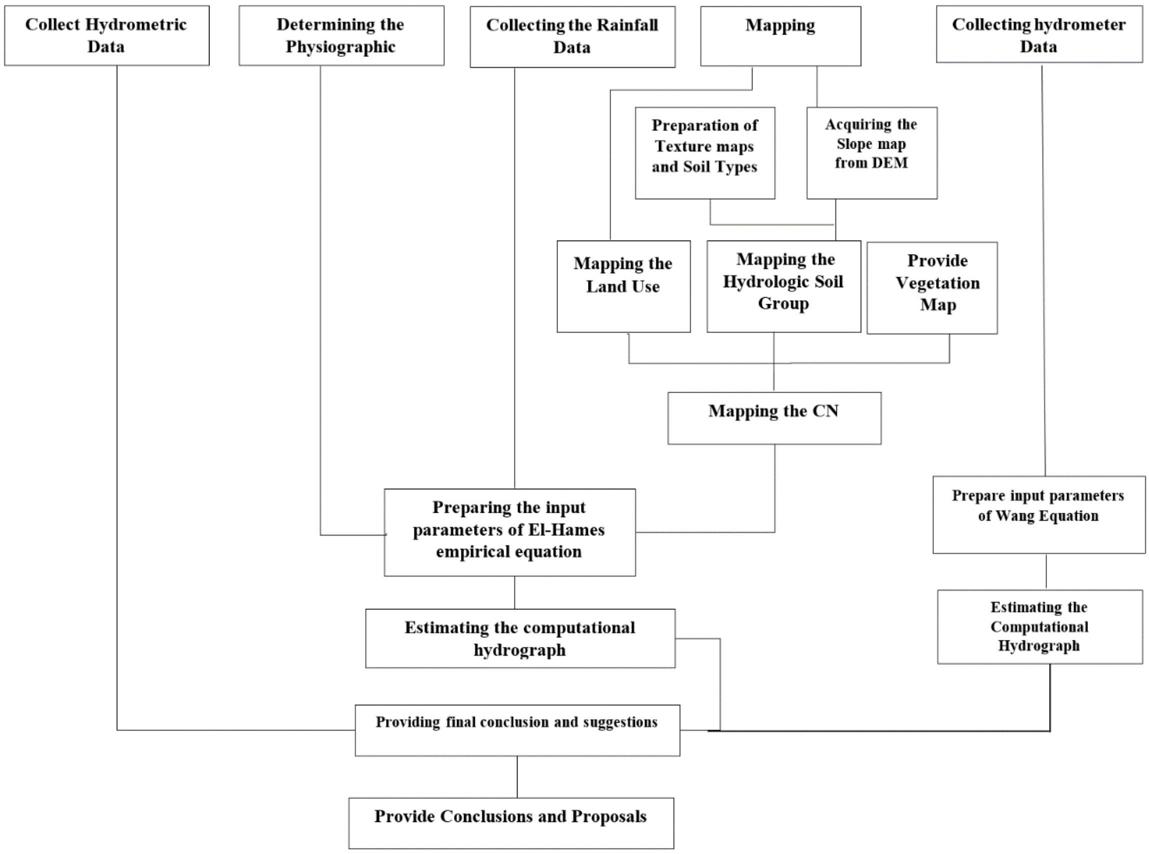

Figure 1. Flowchart of the research methodology

Study area

Iranshahr catchment is located in the far eastern boundary of Jazmurian catchment in eastern parts of Sistan-Baluchestan province in southeastern Iran. This catchment is located between 60˚ 25’ and 61˚ 25’ eastern longitudes and 26˚ 49’ and 27˚ 48’ northern latitudes. It has an area of about 9445 square kilometers, of which about 8107 square kilometers is covered by low mountains and the rest is covered by alluvial plains. This catchment has an average height of 770 meters above sea level. In terms of topography, this area is sloped from the North, East and South toward the central plains. The low latitude of this area means that this catchment is located in an arid climate with hot summers and temperate winters. Precipitation of this area is very low and irregular. On average, about 80 percent of annual precipitation occurs during late autumn and throughout winter, although region often see scattered showers coming from the Indian Ocean in July and August. According to reports collected from the gauge stations, Iranshahr catchment has an annual average precipitation of 112 mm and an annual evaporation of about 3343 millimeters (El-Hames 2012). The most important river of this catchment is Bampour, whose sources are Karavan and Daman streams in the north, Konar and Kavu streams in the east, Kahiri, Geronrud, and Kahan streams in the south, as well as several other minor water streams. This river has an east-west flow. Figure 2 shows the geographical location of Iranshahr catchment in Iran’s national catchment classification map where catchments are categorized into three classes. Zabol-Iranshahr-Bampour asphalt road provides access to different areas of this catchment. Figure 3 shows the access roads to Iranshahr catchment.

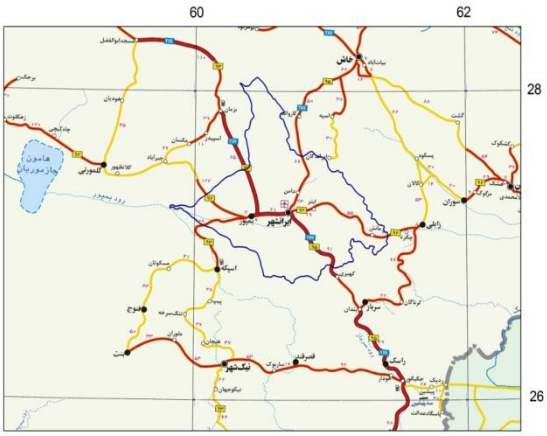

Figure 3. Access roads to different parts of Iranshahr catchment

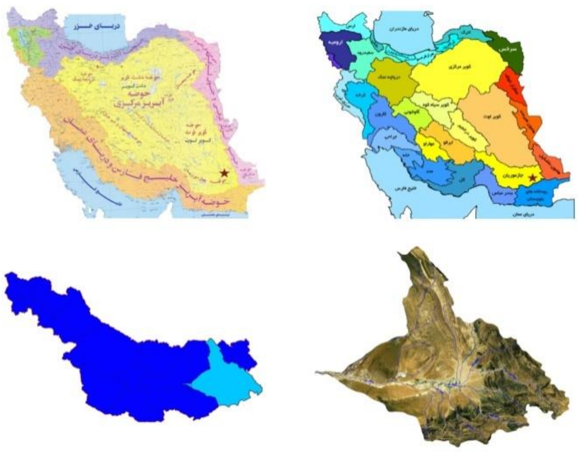

Figure 2. Geographical position of Iranshahr catchment

Results

After considering the climatic conditions, the geographical position and the area of Iranshahr catchment, El-Hames empirical method was selected to estimate the peak flow of runoff. In the El-Hames method, morphological factors affecting the peak flow are the area, slope and length of main channel; effective precipitation is another important factor which reflects the history of catchment moisture conditions and must be estimated by SCS-CN method (fig. 1).

Physiology of the catchment

Planimetric and physiographic characteristics of Iranshahr catchment were estimated by GIS with the help of digital elevation model (DEM) and SAS Planet satellite imagery. Table 1 shows the physiographic characteristics of Iranshahr catchment acquired from GIS. These physiographic characteristics include: area (A), perimeter (P), and length of the catchment (L_{max}), form factor (F_f), compactness factor (C), length of equivalent rectangle (L_e), width of equivalent rectangle (W_e), diameter of equivalent circle (D) and shape factor (S_f). Collected data show that Iranshahr catchment is in the category of large and stretched catchments.

Table 1. Physiographic characteristics of Iranshahr catchment

A (Km^2)	P (Km)	Lmax (Km)	F_f	C
9445	587.5	187	0.27	1.7
D(Km)	S_f	Le (Km)	We(Km)	
109.7	18.4	206	89.7	

Slope of the catchment

Slope of a catchment can somewhat control the water flow rate and thus the rate of water infiltration. It is obvious that in steeper areas, the higher speed of water limits the rate of its infiltration. To estimate the average slope of Iranshahr catchment, the isoclines map of the area was plotted, and was used in conjunction with two existing general formulas available in the literature. Figure 4 shows the isoclines map of Iranshahr catchment. According to this figure, most parts of Iranshahr catchment have a slope of between 0 to 3 degrees. Ultimately, the slope index of this catchment was estimated to 5.4 percent.

Channel density

Channel network refers to a set of drainage courses that collect and route water across the catchment. This means that a denser channel network spread over a larger portion of catchment will have a better performance in draining the runoff. Catchment and channel network level of development can be evaluated by a factor called drainage density index which is the total length of all channels in a catchment divided by the total area of that catchment. A larger drainage density index shows that there are more channels over each unit area and indicates that this channel system can drain the flood more quickly. To determine the drainage density index of Iranshahr catchment, the digital elevation model (DEM) of the area and the WMS software were used to identify the channel of this area (Figure 5) and the total length of channels (about 7966 km) was divided by the total area of this catchment (about 9445 square kilometers) resulting in a drainage density index of 0.84 kilometers per square kilometer. Also, the gross slope of Bampour river (the main river of Iranshahr catchment) was estimated to 0.52%.

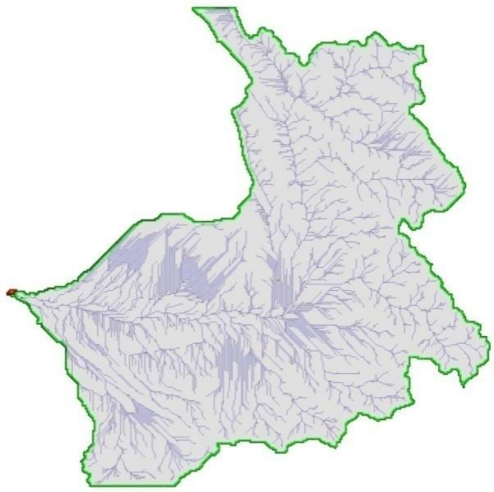

Figure 5. drainage system of Iranshahr catchment (tree pattern)

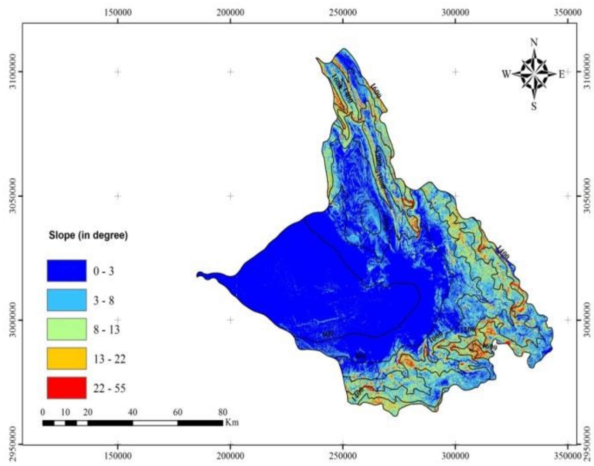

Figure 4. Isoclines map of Iranshahr catchment

Determination of runoff curve number

Curve number (CN) must incorporate the soil hydrology group, vegetation and land use of assessed catchment, thus CN of a catchment must be calculated by using the weighted average of these parameters. Figure 6 shows the 1:100000 geological map of Iranshahr catchment. According to this map, plains of this region have a relatively coarse grained soil texture with alternating bands of clay and sand and large boulders, which are the results of sedimentations caused by plain rivers. In general, the presence of clay-based materials in soil texture increases from the northeast and east to west and central regions of the plain. The map presented in Figure 7 shows the soil orders of Iranshahr catchment. According to this map, the soil covering this area includes Arid sols, a combination of Arid sols and Enti sols, sand dunes and salt marshes.

Merging the geological map (from which soil texture can be extracted) with layer-slope features extracted from digital elevation model gave the infiltration rate and soil hydrology group of the region. Figure 8 shows the soil hydrology groups of Iranshahr catchment. As this figure shows, study area is mainly comprised of soil hydrology group C.

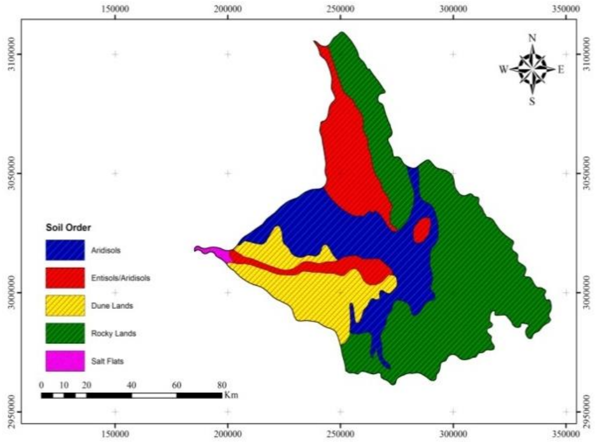

Figure 7. Soil orders of Iranshahr catchment

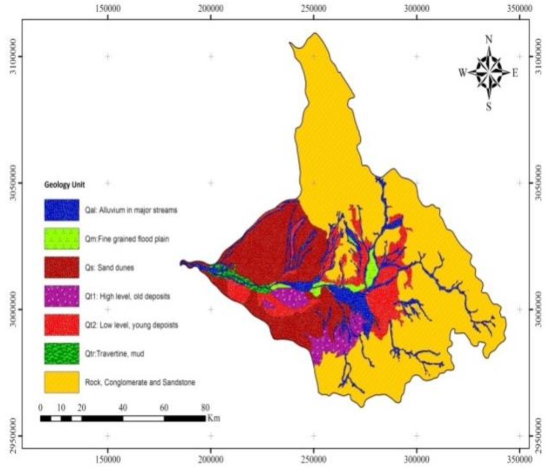

Figure 6. Geological map of Iranshahr catchment

Land use map of Iranshahr catchment, which was collected from the Iran's natural forests and rangelands organization (Fig. 9), shows that there are 10 different types of land use in the study area.

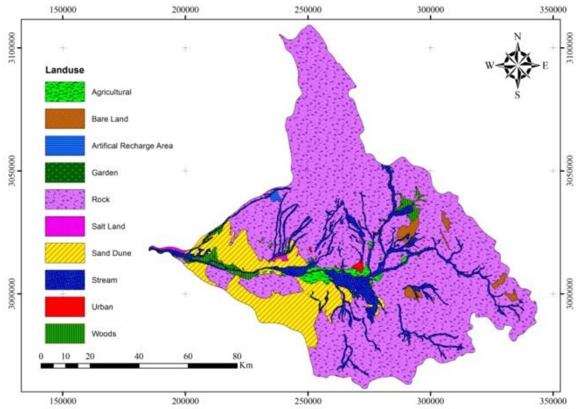

Figure 9. Land use map of Iranshahr catchment

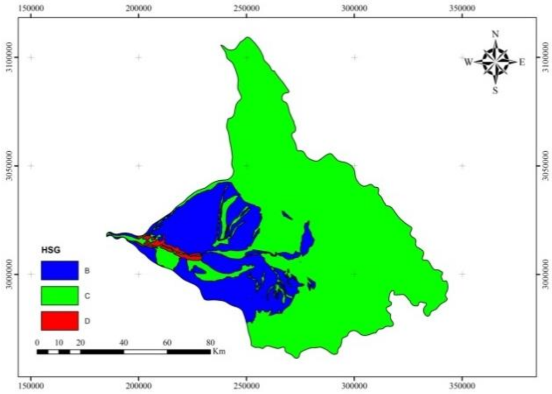

Figure 8. Soil hydrology groups of Iranshahr catchment

Figure 10 shows the vegetation density map of Iranshahr catchment. In this map, color green represents sparse vegetation cover and color yellow represents desert expanses. These expanses are parts of Iranshahr- Jazmurian desert which is stretched along east-west axis and starts with a width of about 40 km near the city of Iranshahr and continues for about 170 km toward Jazmurian pit. Toward the west, width of this desert reaches up to about 70 kilometers and continues into the Kerman province.

Ultimately the CN values were selected according to maps of hydrologic soil group, land use and vegetation density. These CN values are listed in Table 2. The CN vector layer was produced by using the values presented in Table 2 as well as an overlay of hydrologic soil group map and land use map created in GIS environment (Figure 11).

Table 2. Curve Numbers selected with respect to hydrologic soil group, land use and vegetation density of Iranshahr catchment

Soil hydrology group / Land use	B	C	D
Agricultural lands	86	91	94
Barren lands	-	91	-
Horticultural lands	55	70	77
Artificial recharge zones	0	-	-
Rocky outcrops	98	98	98
Salt marsh	84	90	92
Sandy hills	77	85	88
Waterways	-	0	-
Urban areas	80	88	-
Sparse vegetation	66	77	83

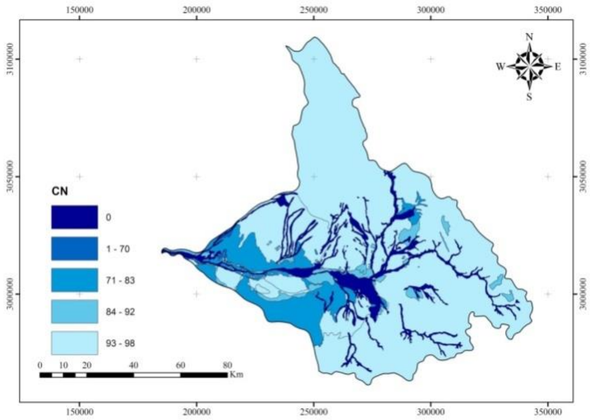

Figure 10. Curve Number map of Iranshahr catchment

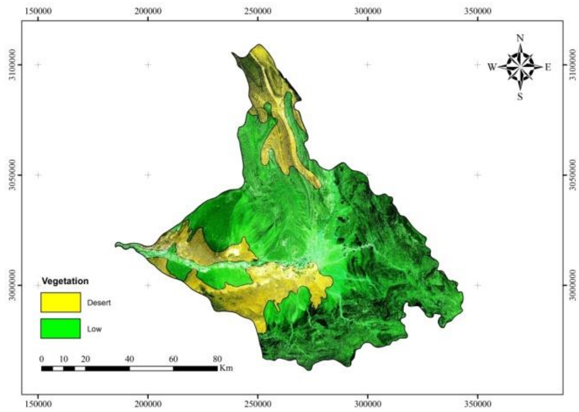

Figure 11. vegetation density map of Iranshahr catchment

Soil surface retention

To estimate the effective precipitation (P_e), which is an important parameter of El-Hames method, one must determine the Curve Number and consequently the soil surface retention (S) of the studied catchment. Based on the CN vector layer of Iranshahr catchment, weighted average of CN in average conditions was calculated to 83. Thus, using Equation 1, the average soil surface retention of this catchment was estimated to 52 mm.

Runoff peak flow

The morphological parameters involved in the El-Hames, method, which include the area, slope and length of main channel, were estimated to 9445 km^2, 0.005 m/m, and 187000 m respectively. Having the average soil surface retention (S) and the maximum 24-hour rainfall of the catchment for 2 to 200 year return periods, the value of effective precipitation (P_e) and water retention height (d) and subsequently the value of maximum flood peak flow for these return periods were estimated. Results of these estimations are presented in Table 3 and the graph corresponding to these results is presented in Figure 12. According to Table 3, for the 2 year return period a 26 mm rainfall event continuing for 24 hours creates a runoff with peak flow of 515 cubic meters per second. According to El-Hames empirical method, having an estimated probable maximum precipitation of 234 mm causes the probable maximum flood (PMF) to be about 21894 cubic meters per second.

Table 3. The results of estimation of runoff peak flow in Iranshahr catchment for return periods of 2 to 200-year, obtained by El-Hames empirical method

Return period T (years)	precipitation P (mm)	length of main channel L (m)	Area A (km^2)	Slope Y (mm)	Soil surface retention (mm)	Effective precipitation P_e (mm)	Water retention height d (mm)	Peak flow Q_p (m^2/s)
2	26					5	21	515
3	32					9	23	869
5	38					13	26	1319
10	46					18	28	1956
25	57	187000	9445	0.005	52	26	30	2844
50	64					32	32	3530
100	72					39	33	4253
200	79					45	34	4987

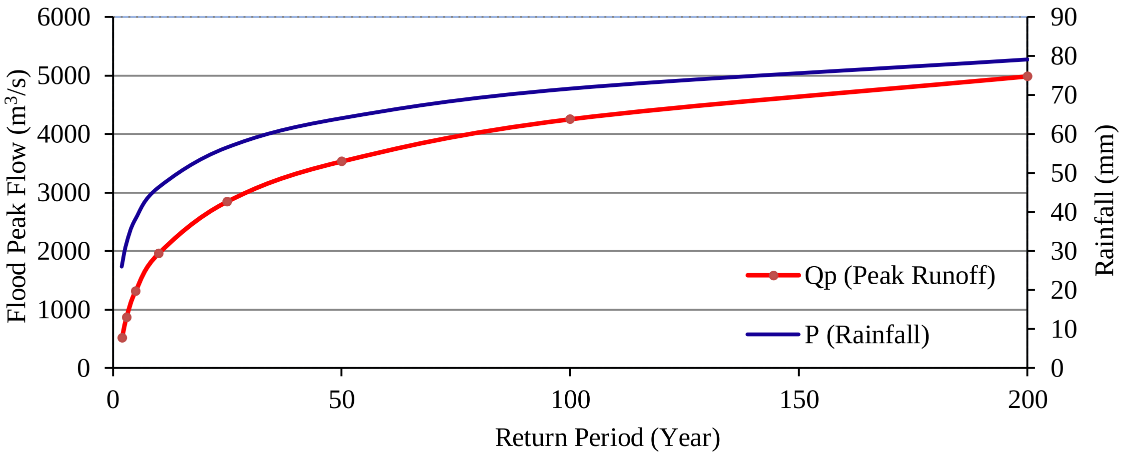

Figure 12. Graph of maximum 24-hour rainfall in Iranshahr catchment and its corresponding flood peak flow for return periods of 2 to 200 years

Discussion and Conclusion

To evaluate and verify the validity of El-Hames method for Bampour sub-catchment (Fig. 13), first the data pertaining to peak flows recorded in Bampour gauging stations were gathered and then the amount of precipitation corresponding to each flood event was determined. The daily precipitation data recorded by rain gauge station of Bampour dam was used for this task. After obtaining the parameters of El-Hames formula, peak flow values of Bampour catchment were calculated and then were compared with the values measured by Bampour gauging stations (Table 4).

Figure 14 shows the correlation graph for peak flows measured by Bampour gauging stations and those calculated by El-Hames method. The results of this study show that the values estimated by El-Hames method have a 99% correlation with peak flow values measured at Bampour gauging station, and this shows the high accuracy of this formula.

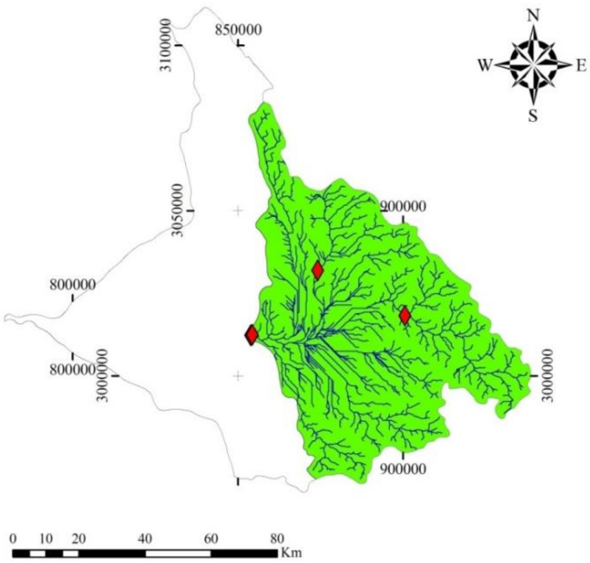

Figure 13. Position of Bampour sub-catchment in Iranshahr catchment

To determine the sensitivity of each parameter of El-Hames formula, the error caused by changing the initial value of each parameter was determined. MAE (Mean Absolute Error) and RMS (Root Mean Square Error) were used as the metrics of this assessment. This assessment, which is known as sensitivity analysis, determines the most sensitive input parameters, namely those in which the slightest change cause the greatest error in estimations. It should be noted that in the course of analyzing the sensitivity of a single parameter, the other parameters should be kept constant.

Figure 15 and Figure 16 show the plots depicting the result of sensitivity analysis performed on each input parameter of El-Hames formula. According to these figures, El-Hames formula is most sensitive to precipitation parameter; this means that considering an overestimated value for precipitation parameter will create a very significant error in estimated peak flow.

Table 4. Comparison between the peak flows measured by Bampour gauging stations and those calculated by El-Hames method

Peak flow (El-Hames method) (cms)	Peak flow (cms)	Precipitation (mm)	Date of event
110.8	97.74	19.5	30-Jan-72
97.7	94.38	19	18-Jul-73
336.8	324.52	26	20-Feb-74
379.4	306	27	26-Jan-76
113.9	112.5	6	07-Aug-83
93.5	110.25	7	15-Mar-87
45.3	60	8	30-Oct-89
357.8	328.8	26.5	01-Feb-91
423.7	445	28	06-Feb-92
1656.1	1472	49	30-Dec-93
891.3	919.37	37	11-Jul-94
124.6	92.5	20	22-Mar-95
220.7	197.4	23	07-Dec-95
446.6	438.44	28.5	02-Mar-05

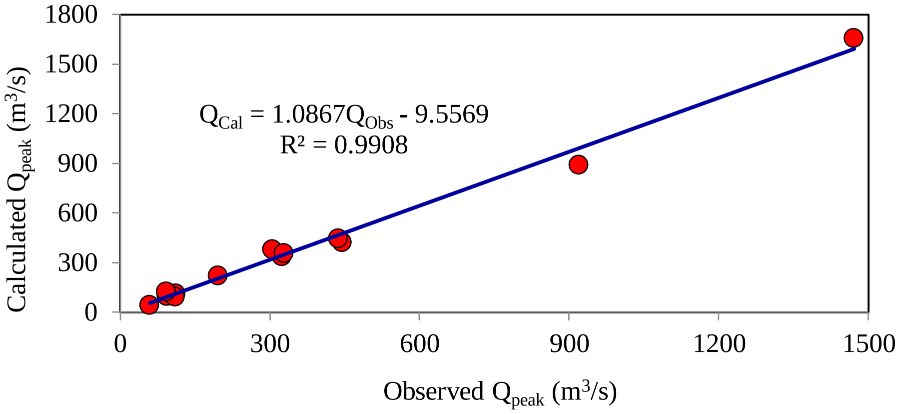

Figure 14. The plot of correlation between peak flows recorded by Bampour gouging station and those calculated by El-Hames formula

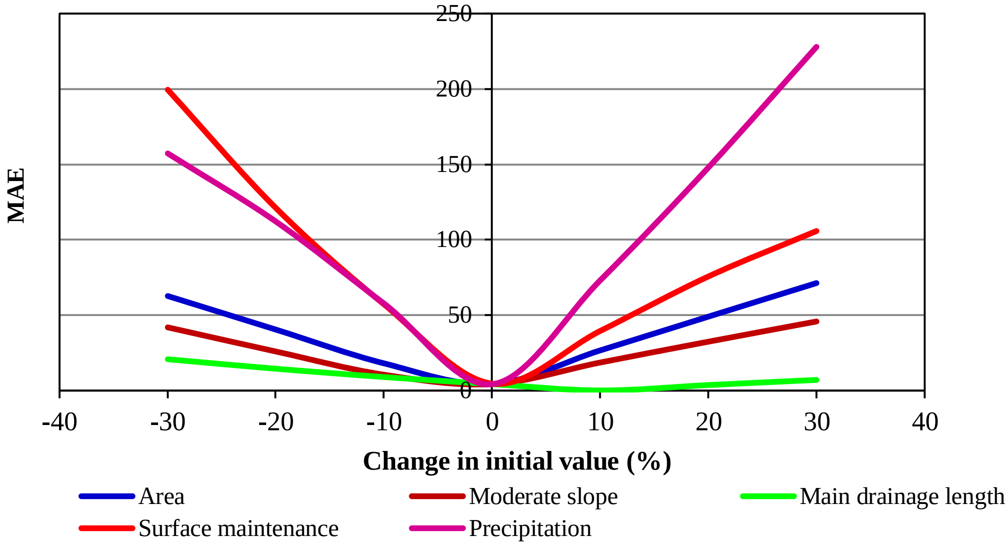

Figure 15. Results of sensitivity analysis performed on input parameters of El-Hames formula

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