



Evaluation of WMS model in basins without statistical data in southwestern Iran using Dicken's experimental method (case study: Kuhgel Basin of Khuzestan Province)

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Abstract

Floods are important in studies related to water resources utilization, dam construction, basin management and hydrological studies. Therefore, to a large extent, the accuracy of these studies and the safety of water facilities depends on the flood study methods. The aim of this study was to investigate the WMS model in determining the maximum flood discharge in three sub-basins with areas of 10.3, 1.5 and 7.3 square kilometers in the Kuhgel region located in southwest of Iran. Comparing the results of the model with the results of the Dicken's experimental method in the region showed that the maximum flood discharge and flood volume estimated by the WMS model are well consistent with the values of the Dicken's experimental method. Therefore, the relative error percentage index, root-mean-square error and Nash–Sutcliffe coefficient of the model were calculated equal to 6.12, 0.51 and 0.82, respectively. The results also revealed that the mean of model estimates was approximately 0.16% higher than Dicken's experimental method. Based on Student's t-test, the difference between the model values and Dicken's experimental method was not significant at the level of one percent. The results show that the WMS model simulates flood values with appropriate accuracy for basins with no statistical data in southwest of Iran. Due to the high sensitivity of the SCS method in the WMS model to rainfall distribution, rainfall analysis in the study area is necessary to achieve the desired results and the rainfall distribution and its time distribution should be as close as possible to the actual values in the region.

Keywords Precipitation pattern · Curve number · Validation · Runoff · Land use

Introduction

Various factors are involved in runoff and flooding. These factors include rainfall intensity, basin slope, soil permeability, topographic conditions, topographic characteristics, vegetation characteristics and soil saturation (Al-Zahrani et al. 2017). Therefore, the development of integrated flood prevention, control and utilization programs for appropriate application management measures is inevitable. The role of mathematical-hydrological models in determining the flooding of basins is very important (Badri et al. 2017). So that hydrological models are used in different issues including

accurate flood forecasting to design water structures and extreme value hydrological event prevention policies (Yousefi Mobarhan et al. 2016). To predict floods in basins without sufficient statistics data, some research has been done that has used WMS and GIS models to estimate floods. Fathy et al. (2020) have proposed a method for estimating flood volume in Sinai. They also studied flood risk reduction methods using open canals and small dams. In a study by Jenna and Knut (2020), the maximum flood discharge was calculated using experimental relationships based on the area of the basin on the Mahanadi River in India. The results showed that by considering the area of the upstream basin on the river, floods can be predicted with acceptable accuracy. In a study conducted by Melinski et al. (2019) on the Vistula River in Poland, the maximum annual river flow was examined by physiographic parameters of the upstream basin for 41 stations. The results showed that the most important physiographic parameters of the basin affected by floods included sub-basin area, altitude difference, and

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waterway network of the basin. Abbas et al. (2020) also obtained flood volume and permeability in the Wadi Umm Sidr region of Egypt using field measurements and the WMS model. Yousif and Hussien (2020) from geophysical data and remote sensing and satellite imagery provided methods to reduce flood risk in Sharm El Sheikh, Egypt. He suggested using Calvert to support the roads.

Nowadays, using the model in precipitation-runoff simulation has become common to access flood characteristics such as peak discharge time. In this regard, calibration and evaluation of these models and different methods of flood estimation in these models has become necessary and inevitable. In another study conducted by Hoseini (2011), TR-20, TR55 and HEC-1 methods in the WMS model were used to determine the flood discharge of basins located in Khuzestan Province. The results were compared with experimental values and manual calculations. The results showed that the use of HEC-1 method in WMS model is most consistent with the experimental values in Dicken's Method in Khuzestan Province. Saghafian et al. (2016) presented a new mathematical model of precipitation-inflow runoff-flow using combined models of Modclark precipitation-runoff and SCS infiltration. In this study, three different spatial patterns of curved numbers (uniform, decreasing downstream and increasing) have been used with two scenarios with and without input current. The results showed that in all cases where the inflow was effective, the volume of surface runoff and peak flow was lower. Especially in areas with low curve numbers, there were fundamental differences between simulated hydrographs with and without inlet flow. Kowalik and Walega (2015) conducted a study in four small agricultural basins in Poland using asymptotic functions and concluded that there is a strong correlation between the number of observational curves and the amount of rainfall. Satheeshkumar et al. (2017) in an article estimated the runoff rate using CN-SCS method in GIS environment in north of India. Based on the results, they approved the application of this model and method to estimate runoff in their study area. Mirzaei et al. (2017) conducted a study in Amuqin watershed in Ardabil Province. They use six types of precipitation patterns including Huff method, Meteorological Organization method and SCS method by Clark runoff precipitation models, curved number and Schneider to estimate flood discharge with return period of 2, 5, 10, 25, 50 and 100 years. The results showed that WMO precipitation model with SCS rainfall-runoff model with minimum values of percentage-relative error and root-mean-square error, equal to 7% and 1.57 m³/s, respectively, was introduced as the proposed model for the Amuqin basin.

Rauf and Habibi (2015) studied the WMS model in Hirchai basin of Ardabil Province. The results showed that with increasing the return period from 2 to 100 years, the difference between the calculated and observed values increases

from 4.49 to 13.69% and the SCS method in the model provides more accurate results. Hoseini et al. (2017) in a study examined the methods TR-20, TR55 and HEC-1 in the WMS model to determine the maximum flood in basins located in Khuzestan Province. The results showed that the use of TR55 method in the WMS model is most consistent with the experimental values. Moghadasi et al. (2017) studied the effect of land use change on flooding potential of Bustan Dam watershed using WMS model between 1996 and 2006. The results showed that the total area of rangeland has increased in the study period. While the good rangeland has decreased, the average rangeland has increased and the area related to the poor rangeland has remained almost constant, which indicates a decrease in the quality of rangelands in this watershed. Therefore, the study of flood status and its values and hydrography is of great importance. Therefore, in this study, due to the global increase in flood events in recent years, the WMS model and the hydrographic method of the SCS unit hydrograph will be investigated to determine the peak flood discharge of three sub-basins of Kuhgel located in southwest of Iran.

Materials and methods

The area of the study

This research has been carried out in Khuzestan Province in Kuhgel region, which is located in the geographical position of 49° 43' 59" to 50° 20' 34" east longitude 31° 42' 5" to 32° 10' 32" north latitude. The study region with an area of about 17 square kilometers, in the southwestern foothills of the Zagros Mountains, located in northeast of Khuzestan and close to the city of Izeh. Izeh city is one of the cities in the east of Khuzestan Province and is located in northeast of Ahvaz city. Izeh city is limited to Chaharmahal and Bakh-tiari Province from the north and east, Baghmalek from the south and Masjed Soleiman from the west. Izeh city, which has been studied in the west of the region, is located 950 km southwest of Tehran and 175 km northeast of Ahvaz. Izeh area, which is located under the middle Karun basin, is about 402 square kilometers. Figure 1 shows the location of the study area on a map of Iran.

Physiographic studies

Physiography or morphology of the catchment is one of the basic topics of hydrology and important parameters such as area, slope and concentration time of the basin along with the longitudinal slope of the main river will be the result of this Sect. 1: 25,000 basin maps and WMS software were used for physiographic studies. Figure 2 shows the range of Kuhgel basin and its sub-basins and

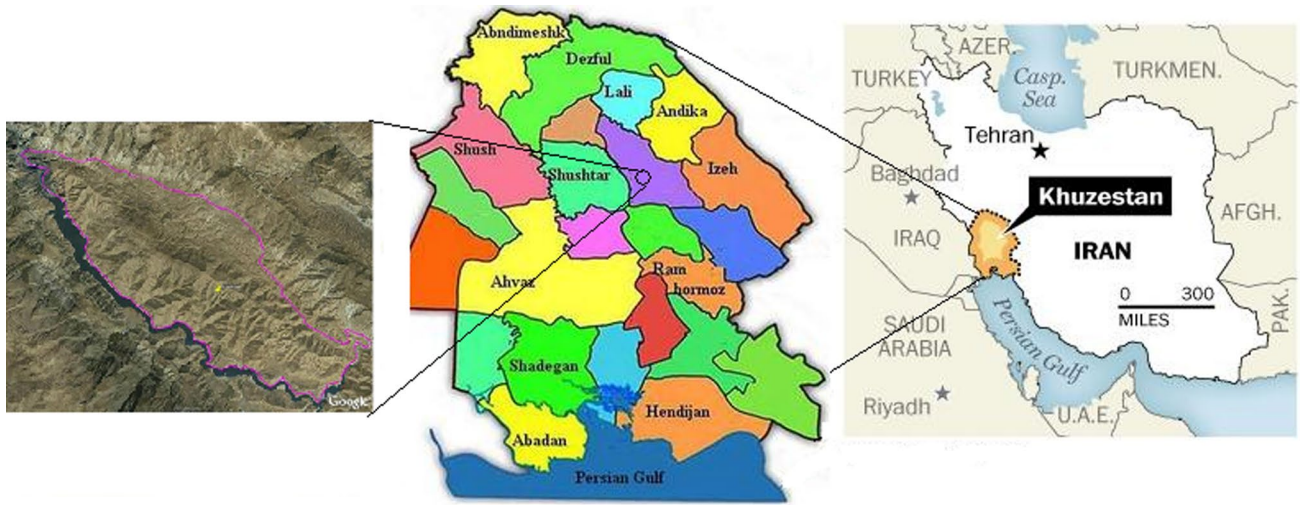


Fig. 1 Location of Koohgel watershed in Ardabil Province and country

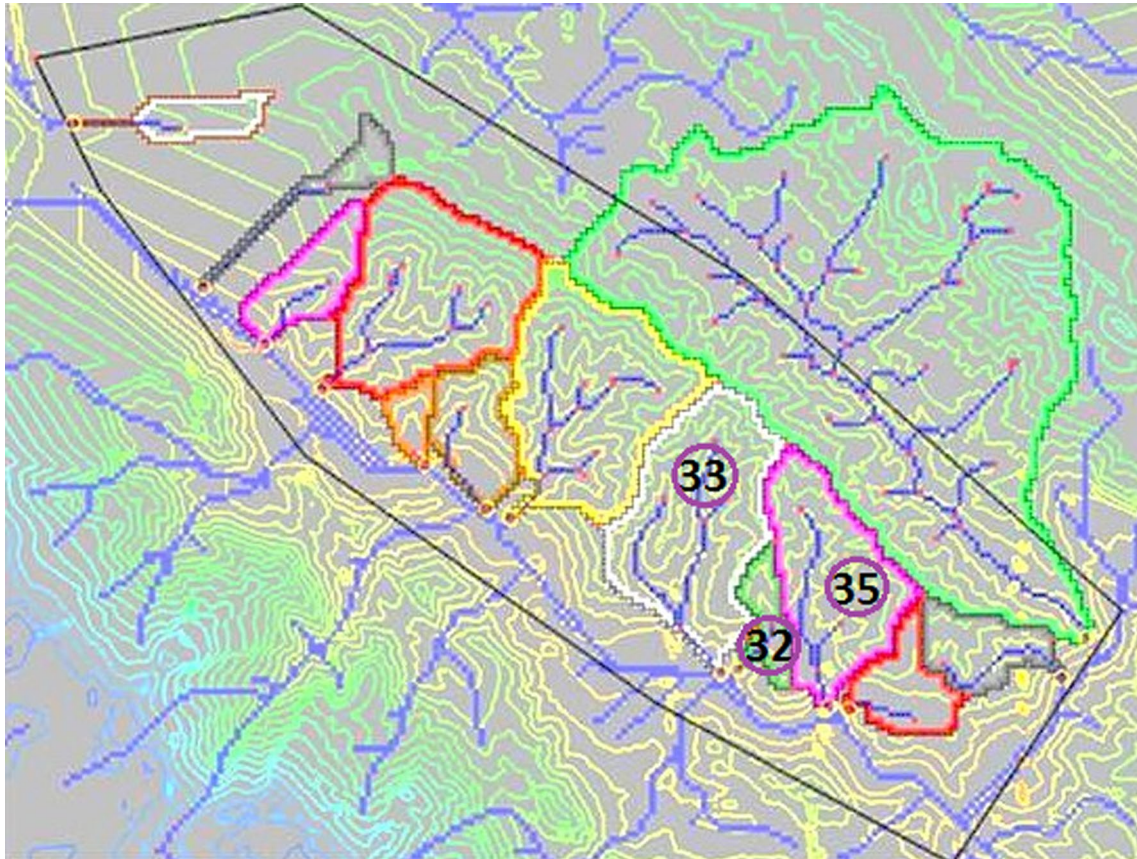


Fig. 2 Area of Kuhgel basins

Fig. 3 Area of sub-basins No. 32–33–35 of Kuhgel basin

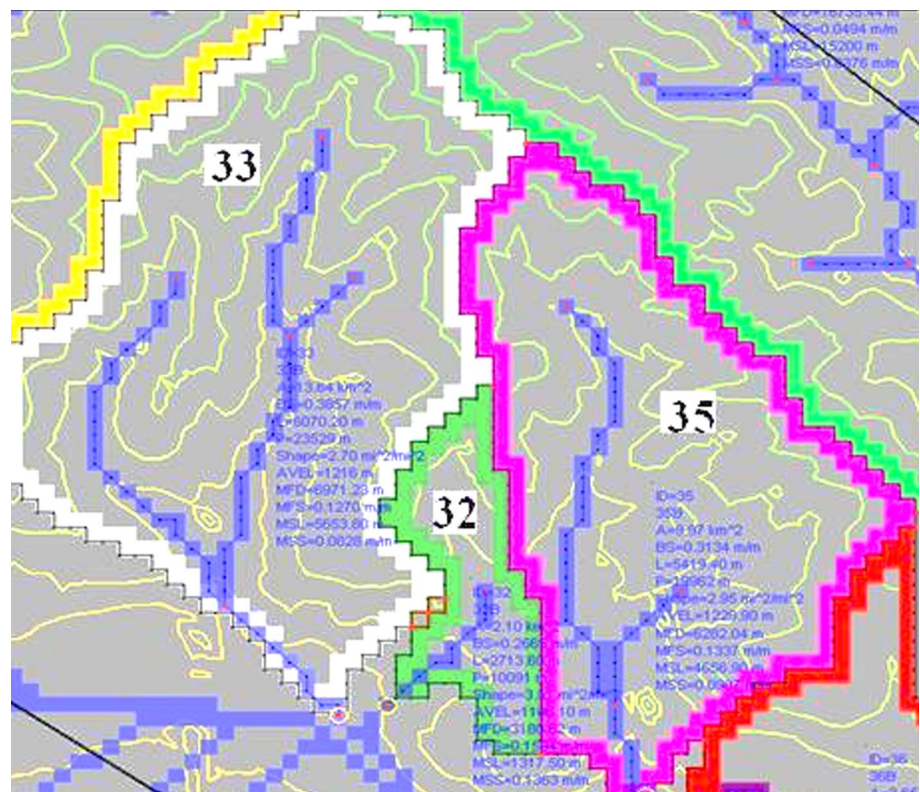


Table 1 Physiographic characteristics of the studied sub-basins

Basin names	Area (km ²)	Shape factor	Mean elevation (m)	Concentration time (hrs.)	Main stream slope (%)	Curve number	Perimeter (km)	Main stream length (km)
33	10.3	2.7	1216	0.65	0.08	74	23.5	6.9
32	1.5	3.51	1106	0.33	0.13	75	10	3.18
35	7.3	2.95	1229	0.55	0.09	72	19.9	6.2

Fig. 3 shows the sub-basins under study. Also, the physiographic characteristics of the studied sub-basins of Kuhgel basin are presented in Table 1.

Estimation of peak flood discharge using SCS method

The US Soil Conservation Service (SCS), now called Natural Resources Conservation Service (NRCS), developed a Dimensionless Unit Hydrograph based on the analysis of large number of watersheds. The X-axis consists of dimensionless time units and Y-axis consists of dimensionless discharge units. The Dimensionless UH is very useful for constructing a synthetic unit hydrograph for a wide variety of watersheds. Dimensionless unit hydrographs based on a study of a large number of unit hydrographs

are recommended by various agencies to facilitate construction of synthetic unit hydrographs. Since there was no stream gauge (hydrometric station) in the studied area, the US, Soil Conservation Service method, SCS was used to extract the unit hydrography (UH) of sub-basins. The concentration time of the basin was derived from the following relation:

$$T_c = \left(\frac{0.871L^3}{\Delta h} \right)^{0.385} \quad (1)$$

where T_c : Time of concentration (h); L : Flow length (m); Δh : The difference between the minimum and maximum heights of the region.

However, the difference between the minimum and the maximum heights of the region is derived from the following relation:

$$\Delta h = H_{max} - H_{min} \tag{2}$$

To estimate the basin flood using the SCS approach, the following steps were utilized.

Statistical indicators

Relative error percentage

This parameter is expressed as a percentage and is calculated through the following equation. In this regard, Q_i is the observational value and Q_m is the predicted value where $i = 1 \dots, n$ where n is the number of observational data.

$$RE = \frac{\sqrt{\sum (Q_i - Q_m)^2}}{\sum Q_i} \tag{3}$$

Calculate the root of the average square error

This criterion is calculated through the following equation.

$$RMSE = \sqrt{\frac{\sum (Q_i - Q_m)^2}{n}} \tag{4}$$

Q_i is the observational value and Q_m is the predicted value where $i = 1 \dots, n$. Where n is the number of observational data.

Calculation of NS index (Nash–Sutcliffe)

To evaluate the model, which is as follows.

$$NS = 1 - \frac{\sum_i^n (Q_{mi} - Q_{si})^2}{\sum_i^n (Q_{mi} - \bar{Q}_{mi})^2} \tag{5}$$

In these relationships, \bar{Q}_m is the average observed flow rate in cubic meters per second, Q_{mi} is the observed flow rate, and Q_{si} is the computational flow rate during the simulation period (Nash–Sutcliffe, 1970).

Results and discussion

Estimation of maximum flood flow using experimental method (Dicken's experimental method)

In the studies that have been done in the watersheds of Khuzestan Province, different experimental equations have been obtained to calculate the peak flood discharge for the basins without statistics. Shahidi and Behnia (2007) obtained 11 new hydrometric stations in the province and after reconstructing and completing their statistics using the correlation between area and flood with a return period of 500 years in the Dicken's experimental equation obtained a new equation in terms of area and return period. This equation can be used in Khuzestan with 99% confidence level for catchments up to 10,000 square kilometers. Their equation is as follows.

$$Qm^3 / s = (2.59T_r^{0/5235})A_{km^2}^{(0/692 T_r^{0.0388})} \tag{6}$$

In this regard, T_r is the return period in terms of year and A is the area of the basin in terms of square kilometers. By placing the area under Kuhgel basins and the return period of 50 and 100 years in this equation, the maximum flood discharge for these sub-basins was estimated, which is shown in Table 2.

Estimation of basin floods with different return periods using WMS model and SCS method

Instead of using flood statistics, rainfall data is used in this method. Usually in rainwater basins, the rain gauge network is denser than the flow measurement network, so in the SCS method, flood hydrograph is estimated using rainfall statistics. The method proposed by the US Soil Conservation Organization (SCS) was used to extract the hydrograph of the sub-basin unit, because there were no hydrometric stations in the study area (Eard 1975, Alizadeh 2011). The rainfall runoff of the basin is divided into two components, part of it flows at the basin level (surface runoff) and the other part is lost in the form of infiltration or evaporation. The part of the precipitation that flows on the surface of the basin and causes floods is called excess precipitation and its amount for each precipitation is

Table 2 Estimated discharge of sub-basins based on Dicken's experimental method

Basin names	32	33	35			
Area (km ²)	1.5	10.3	7.3			
Return period (Year)	50	100	50	100		
Peak flow (m ³ /s)	27.8	40.3	131.2	198.7	99.4	149.4

calculated according to the SCS method by the following equations. The results showed that for sub-basins in the Kuhgel River basin, the Wakeby distribution pattern can be considered as the selected distribution. According to the statistical study of rainfall in the study area, the maximum rainfall of 6 h with a return period of 50 and 100 years was estimated to be 52 and 58 mm, respectively.

$$S = \frac{25,400}{CN} - 254 \tag{7}$$

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{8}$$

S: It is a parameter that represents the potential for losses (in millimeters), *CN*: The number of curves related to the surface of the basin, *Q*: Height of excess precipitation in millimeters, *P*: Rainstorm height in millimeters.

The results obtained from this method are shown in Figs. 4, 5 and 6. Also, the results of the model and the floods estimated by the WMS model and the SCS method with return periods of 50 and 100 years are expressed in Table 3.

Fig. 4 Flood hydrograph with return period of 50 and 100 years for sub-basin 32

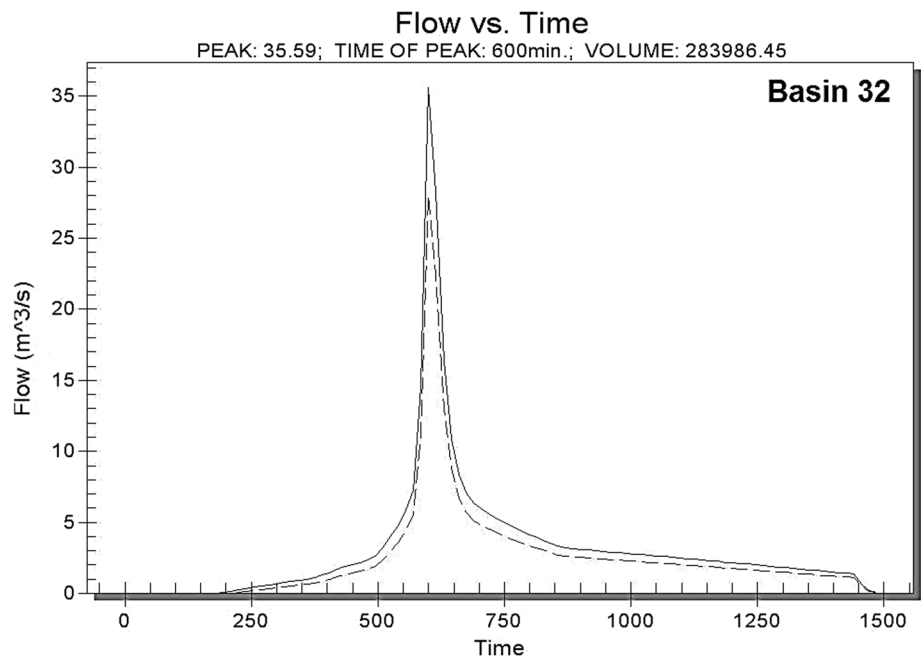


Fig. 5 Flood hydrograph with return period of 50 and 100 years for sub-basin 33

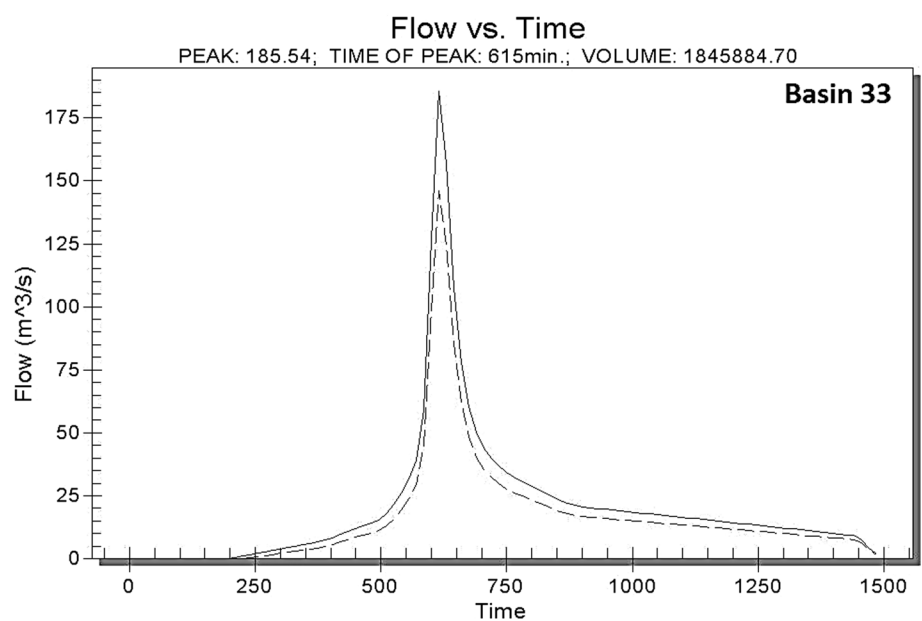


Fig. 6 Flood hydrograph with return period of 100 and 50 years for sub-basin 35

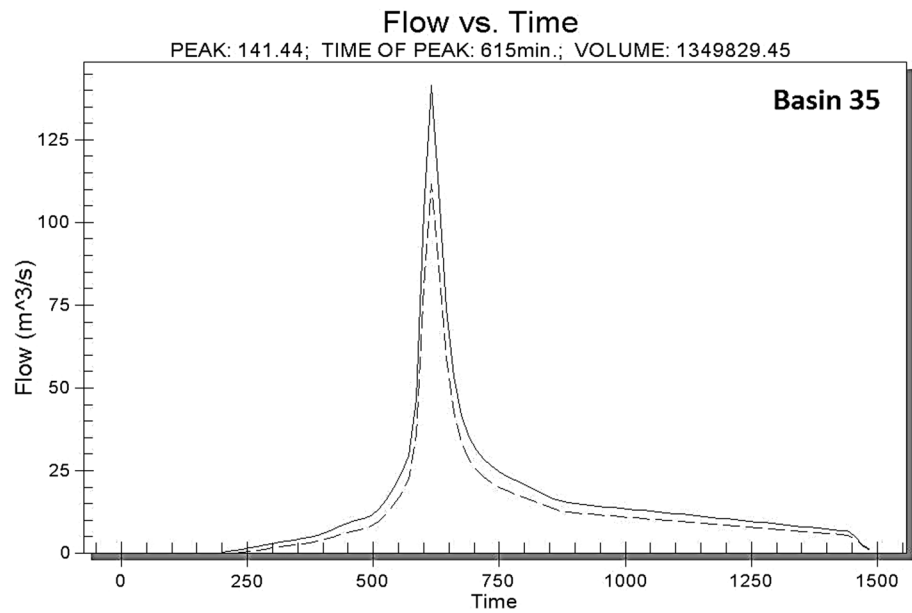


Table 3 Peak flow and volume with different return periods in study sub-basins using WMS model and SCS method

Basin names	32	33	35			
Area (km ²)	1.5	10.3	7.3			
Return period (Year)	50	100	50	100	50	100
Peak flow (m ³ /s)	28.04	35.59	146	185.5	111.5	141.5
Flood volume (MCM)	0.22	0.28	1.45	1.84	1.06	1.3

Table 4 Observational error values estimated by WMS model

Relative error percent-age (%)	Root mean squared error (m ³ /s)	Nash–Sutcliffe index
0.23	10.1	0.96

Table 5 Results of variance equality test and comparison of means of WMS and Dicken's experimental model results

Statistical index	Flood (m ³ /s)	
	Dicken's experimental model	WMS
Mean	107.84**	108.02**
variance	4313	4044
F (Computational)	0.93	
F (Table)	0.09	
T (Table)	0.005	
T (Computational)	3.16	

Symbols ** and n.s by means, significant and non-significant mean differences in the level of one percent

Studies by Dile and Srinivasan (2014) and Hejazi and Marzbani (2015) showed that basin level and rainfall can be the most important factor in runoff flow. In the southwestern parts of the Kuhgel Basin, there are areas that are suitable for agriculture. According to the research of Hanson et al. (2008), the result is the effects of natural disasters such as flood runoff and its primary effects on agriculture in the region, so the correct simulation and modeling of flood runoff is one of the important parameters in flood management in the region. Therefore, according to different methods of flood estimation, it is necessary to choose the method that provides more accurate results to be used in the management of the output of the basins, which are generally agricultural lands. Statistical analysis of the results is shown in Table 4. Also the results of variance comparison and mean comparison test obtained from the model are shown in Table 5. As the results of the statistical study show, no significant difference was observed between the flood estimated by Dicken

method and WMS model at the level of one percent. This indicates that the estimated unit hydrograph of the Kuhgel Sub-Basins and its rainfall distribution is very close to the curves presented in the SCS method in the WMS model. The results show that the flood estimated by the model in different return periods has a higher mean than the Dicken's experimental method. This overestimation can be considered as a minor error of the WMS method. Since the average slope of the sub-basins is low and this issue increases the

time required for runoff to leave the basin (hydrograph base time), so one of the reasons for the high hydrograph base time of the basins can be due to the low general slope of the basin.

As shown in Figs. 4, 5 and 6, the baseline time of the flood hydrograph is the same in all cases and does not change with the return period as the peak flow time remains constant at about 25 h. This issue has also been observed in the research of Shannani et al. (2016). They stated that although with a slight change in the curve number due to land use change, the maximum amount of flooding changes, but the time to reach the peak discharge does not increase. The results of this study are consistent with the research conducted by Sanyal et al. (2014) in this field. The SCS method is used in the WMS model for basins with an area of less than 65 square kilometers and a concentration time of less than 10 h and rainfall of less than 125 cm and a duration of rainfall of less than 24 h. All of these factors are true in basins 32, 33, and 35. The closeness of the results of this method to the Dicken's method may be that all the necessary conditions in the SCS method are met. Also, among the studied sub-basins, sub-basin No. 32, which has the smallest area, has a more accurate estimate which is consistent with the results of research by Hoseini (2011). In this study, since the precipitation distribution was not available, the same precipitation distribution provided by SCS was used in the WMS model. Studies by Ghaffarijegilandeh et al. (2016) have shown that the use of a single precipitation distribution model alone cannot produce acceptable results from simulation of maximum instantaneous flow and hydrograph. Precipitation characteristics are one of the most important factors in hydrograph simulation. Due to the lack of statistics of synoptic stations in the region, it is usually not possible to take into account the distribution of rainfall in the model. The results showed that the average peak discharge values obtained from the model were estimated to be 0.16% higher than the values of the Dicken's experimental method. A number of studies in Iran have shown that the SCS method in the WMS model has more accurate results for focus times of more than six hours, but does not provide suitable answers for smaller amounts. For concentration times less than six hours, the concentration time should be corrected (Jena and Nath 2020) which does not correspond to the results of this study. In this study, although the concentration time of each sub-basin is less than six hours, but the results of the WMS model as shown in Table 4 are very close to the experimental results in the region. By examining the shape coefficient of sub-basins, the values of which are equal to 3.51, 2.7 and 2.95 for basins 32, 33 and 35, respectively, it can be concluded that the shape of the basin did not deviate much from the circular shape. This reduces the focus time and latency of the basin. In a study by Hoseini (2020), SCS method was more accurate in estimating flood discharge and volume in the basin than other methods in WMS model. However, the accuracy of the model decreased with increasing

the return period, which contradicts the results of this study because the amount of error in predicting the accuracy of the model did not show a significant relationship with increasing the maximum flow.

Conclusion

According to the obtained results, it can be said that in using different methods to estimate flood discharge in southwestern Iran, the results of the WMS model are close to Dicken's experimental values. Considering that the characteristics of most sub-basins of southwest of Iran in terms of small basin area and its concentration time as well as low slope, is consistent with the SCS artificial hydrograph method. This method gives better results than other methods. If the concentration time of the basin is calculated more accurately, the results of this method can be closer to the real values. The results showed that due to the high sensitivity of this method to the distribution of rainfall in the region, to achieve the desired results, the need for rainfall analysis in the region. Precipitation distribution and its time should be close to precipitation distribution in the study area. The results showed that the WMS model for return periods of 50 and 100 years, with a high coefficient of explanation, has good accuracy and can calculate the amount of flood in different sub-basins of this area, which covers a large area of Khuzestan Province. The results of this study can be used in flood estimation with different return periods in sub-basins of the Khuzestan Province that do not have stations to record floods data. In particular, in most of the areas located at the outlet of the sub-basins of southwestern Iran, there are no recorded statistics for estimating flood data with different return periods. Therefore, if the estimates are based on the physiographic characteristics of each basin and with using of the WMS model, it can be used to determine the maximum flood with appropriate confidence level.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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