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Investigation and Comparison of Runoff Threshold in Different Climates of Iran

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Abstract

Determining the runoff threshold is a prerequisite for more accurate flood estimates, design and estimation of flood production potential, and knowing its extent can lead to optimal water resource management of watersheds. In this study, using the mean annual rainfall, a map of homogeneous climatic regions of Iran was prepared. Then, at least 30 stations with common statistical period in each homogeneous region were selected. Using a topographic map with a scale of 1: 50,000 and determining the location of the stations, the study area and each of the sub-watersheds were identified and the basic parameters of the watershed were extracted using the GIS. Runoff threshold was simulated using AWBM rainfall-runoff model and after calibration and obtaining optimal model parameters. Watershed zoning was performed based on the values obtained from the model and the percentage of surface cover of the watersheds was calculated according to the amount of runoff threshold for different climatic regions. The results showed that in all three climatic zones, almost half of the watersheds have runoff thresholds in a range of 0-5 mm and have the potential to convert rainfall into runoff and flood production. Watersheds with runoff threshold class (0-5 mm) were mainly located in the northern and central parts of West Azerbaijan province, north and northeast of Kerman province, and the northern and southern parts of Khuzestan province.

Keywords: Climatic zones, Flood, Permeability, Runoff threshold, Simulation.

1. Introduction

Runoff threshold is one of the most important features of the watershed. Determining the runoff threshold is a key component in flood designing estimates (Tularam and Ilahee (2007). Therefore, investigating and understanding the controls exerted by runoff thresholds is essential to understand stream responses at the catchment scale (Tetzlaff et al, 2008).

Runoff threshold is the amount of effective rainfall or excess that is required during a certain duration at a certain basin to start flooding at the basin outlet (Georgakakos et al. (1993). Gioia et al, (2008) concluded that typical floods occur when the amount of rainfall in an event exceeds the infiltration threshold. According to Modares Sanavi et al, (2011), the rainfall threshold determines the amount of rainfall that in a given duration creates a certain river flow in a section of the river. Threshold rainfall curves as a general tool in the flood warning system recommended by Sharafati and Zahabiyoun (2014). Toth (2015) referred to runoff threshold as flood flow that causes flood damage. Horton (1933) proposed the concept that surface runoff occurs when the intensity of rainfall exceeds the infiltration capacity of the ground. Ward and Bolton (1991) states that the duration of a storm is usually shorter than the time required to saturate the surface layer of most soils. Runoff threshold changes were investigated by Sadeghi et al, (2015) in small experimental scale in a forested watershed. The results indicated the temporal variability of runoff threshold during the experimental period. Schumm and Lusby (1963) examined temporal changes in infiltration and runoff capacity in eastern Colorado. Their results showed that in spring and summer, the average infiltration decreased and the runoff height increased. In winter, due to temperature changes and ice cracking of the soil surface, compacted surfaces are lost, infiltration is increased and runoff is decreased. Modares Sanavi et al. (2003) investigated the effect of different cultivation systems on runoff and erosion. The results showed that with the development of plant growth stages, the amount of water infiltration increased and runoff production decreased. The results of Sinoga et al, (2010) study showed that in the arid Mediterranean climates, there is a negative correlation between runoff and rock cover. Runoff threshold in karst lands was studied by Porhemmat et al, (2012). Their results showed that crushed limestone that has no soil cover, has high permeability, and lacks runoff formation conditions. Rainfall-runoff characteristics and their threshold behaviors on a karst hillslope were monitored for 43 rainfall events on a karst slope in southwest China by Wang et al. (2022). Their results showed that Soil depth exerted the greatest direct effect on Surface runoff, which increased as soil deepened.

Factors influencing runoff threshold in arid and semi-arid regions of Iran have been studied by Sharifi et al. (2004). The results showed that the effective variables are rainfall height, rainfall intensity, vegetation cover, sand, clay and slope percentage. The effect of slope and land use on runoff in the Kechik Watershed, Golestan Province of Iran was investigated using rainfall simulator by Abbasi et al. (2017). The results showed that organic matter and vegetation have a pivotal role in reducing runoff. Azmoudeh et al, (2010) investigated the effect of soil properties on runoff in forest lands using rainfall simulation. The results showed that previous soil moisture, organic matter, bulk density and percentage of sand particles had the greatest effect on runoff production. Simulation of daily runoff was investigated by Karnieli and Ben-Asher (1993) in four watersheds in Arizona, USA. Results showed that the runoff threshold is a function soil texture of each watershed. He stated that in the southwestern watersheds of the United States, the initial soil moisture has an important effect on runoff production. Poncea and Shetty (1995) simulate runoff and base flow changes in several watersheds of the United States, Africa, Canada, and India. The results showed; 1- The runoff threshold depends on the climate and the threshold in semi-arid areas is higher than in semi-humid areas. 2- The maximum runoff depends on the climatic conditions of each region. Sharifi and Boyd (1994) compared trivariate rainfall-runoff models AWBM and SFB in Australia. They concluded that the AWBM model simulates runoff better than the SFB model. Sharifi (1997) compared three models of SDI, AWBM and SFB in eight Australian watersheds. Results showed that the AWBM model works better than the SDI and SFB models.

In the semi-arid Mediterranean region of Spain, Martínez-Mena et al, (1999) studied the mechanism of runoff production in small catchments. In this study, two soil groups with different hydrological reactions were used. The results showed that micro-textured soils have higher runoff coefficient and lower runoff threshold than coarse-textured soils. Kirkby (2001) investigated the effect of soil properties on runoff threshold. He concluded that soil properties such as altitudes of soil and gravel shape are effective in the amount and spatial pattern of runoff. Kamphorst (1987) used a small rain-simulator to determine the soil erodibility factor (K) in the universal soil loss equation. The results showed; the amount of runoff and sediment concentrations for different soils changes drastically. Relationship between runoff and plant species was investigated by Gross et al, (1991). They reported that the presence of vegetation, even with low density, has a major effect on reducing the amount of sediment. Ward and Bolton (1991) investigated the effect of hydrological conditions of rangeland and forest soils on runoff and sediment production. The results indicate that the difference in runoff and sediment can be due to differences in initial soil moisture, organic matter and percentage of silt. Bissonnais and Singer (1993) investigated the formation of dike, runoff and furrow erosion on different soils. They concluded that the amount of clay, organic matter, iron and aluminum have an effective role on the amount of runoff and sediment. Also they reported that maximum runoff varies in different climatic conditions.

Giordanengo (2000) investigated the effect of vegetation density on runoff production. Results showed that the time of runoff onset is correlated with the total vegetation area and topography. Raeesiyan (2005) concluded that the runoff threshold has the highest correlation with rainfall depth and the lowest correlation with slope percentage. He was concluded that in agricultural lands, with increasing slope, runoff threshold decreases.

In this study, the AWBM runoff model has been used to simulate the runoff threshold and prepare a runoff threshold map in different climates of Iran and compare them.

2. Materials and Methods

2.1. Study Area

The study area in Iran and in three homogeneous climatic zones includes 86 watersheds located in arid climate in the center of the country and Kerman province, and 65 watersheds located in West Azerbaijan province of the "Humid and semi-humid" climatic zone. There are 44 watersheds located in the semi-arid climate of Khuzestan province. The code of studied hydrometric stations is presented in Table (1).

Table 1. Code of studied hydrometric stations

Climate	Code
Humid and semi-humid	2113, 2112, 1172, 1171, 1164, 1163, 1148, 1147, 1146, 1145, 1144, 1142, 1141, 1135, 115, 30112, 30121, 30114, 30113, 13252, 13243, 13224, 13223, 11621, 11432, 11431, 3072, 3071, 3062, 3061, 3043, 3017, 2114, 30221, 30214, 30213, 30212, 30211, 30163, 30162, 30163, 30152, 30151, 30142, 30141, 30133, 30131, 30132, 303231, 303224, 303223, 303222, 303221, 30333, 30331, 30321, 30313, 30312, 30311, 30222
Arid	469, 4432, 4441, 4442, 4444, 4511, 4514, 4521, 4651, 4542, 4666, 27154, 27155, 27156, 28232, 28242, 28243, 28244, 28245, 44243, 44431, 44433, 44432, 45122, 45123, 45131, 45132, 45133, 45134, 45141, 45142, 45143, 45145, 45153, 46411, 46421, 46521, 46413, 46522, 46523, 46524, 46525, 46531, 46533, 46612, 46611, 46613, 46614, 46615, 46616, 46617, 46621, 46622, 46623, 46631, 46771, 49122, 49123, 49124, 49132, 49133, 49134, 49135, 442421, 491251, 491252, 491261, 491262, 491263
Semi-arid	2211, 2212, 2213, 2214, 2215, 2311, 2312, 2413, 2414, 2415, 2421, 2422, 2424, 2511, 2512, 21631, 23211, 23212, 23213, 23214, 23215, 23216, 23217, 23218, 23221, 23222, 23231, 23242, 23311, 23212, 23313, 23322, 24111, 24112, 24121, 24123, 24124, 24231, 24233, 24234, 23411, 242321

2.2. Methodology

First, using mean annual rainfall data, the map of homogeneous climatic regions of the country was divided into three regions: arid, semi-arid, Humid and semi-humid. Then, by evaluation the daily river flow data of hydrometric stations in the region, a minimum of 30 stations with appropriate and same statistics period and were selected from a province located in the climatic regions of the country. Using a topographic map with a scale of 1:50000 and determining the location of stations, the study area and each of the sub-watersheds were identified and the basic parameters of the watershed were extracted using the GIS. Table (1) shows the watersheds used for the research. The map of the location of hydrometric stations in the watersheds of the selected provinces is shown in Figure 1. In order to estimate the surface runoff of the country's watersheds, river flow information of hydrometric stations was prepared and after classifying the stations based on statistical years, stations with 5 to 14 years data were reconstructed and the statistical years of all of them were extended to 15 years. Runoff threshold was simulated using AWBM runoff simulator model. To use the model, calibration has been done in each watershed and the optimal model parameters in each watershed were determined. Then, model verification in predicting the behavior of the watersheds was performed using data that was not used in the calibration step, and using the parameters calculated in the previous step, the outflow of each watershed was obtained. Finally, the sensitivity analysis of model was performed in order to determine the effective parameters of the model. Then, zoning of watersheds was performed based on the values obtained from the model and the percentage of surface cover of the watersheds was calculated according to the runoff threshold. Finally, the results in different climates were compared and analyzed.

2.3. Division of homogeneous regions

Iran has very different climatic conditions, so that it can be seen from very arid to Humid areas. In general, the country can be divided into three regions based on mean annual rainfall: arid, semi-arid, humid and semi-humid. This study was conducted in provinces that are in arid, semi-arid and humid-semi-humid conditions in terms of moderate rainfall. Figure (1) shows the division of the country into three homogeneous regions of the same climate in general (adapted from Sharifi, 2017).

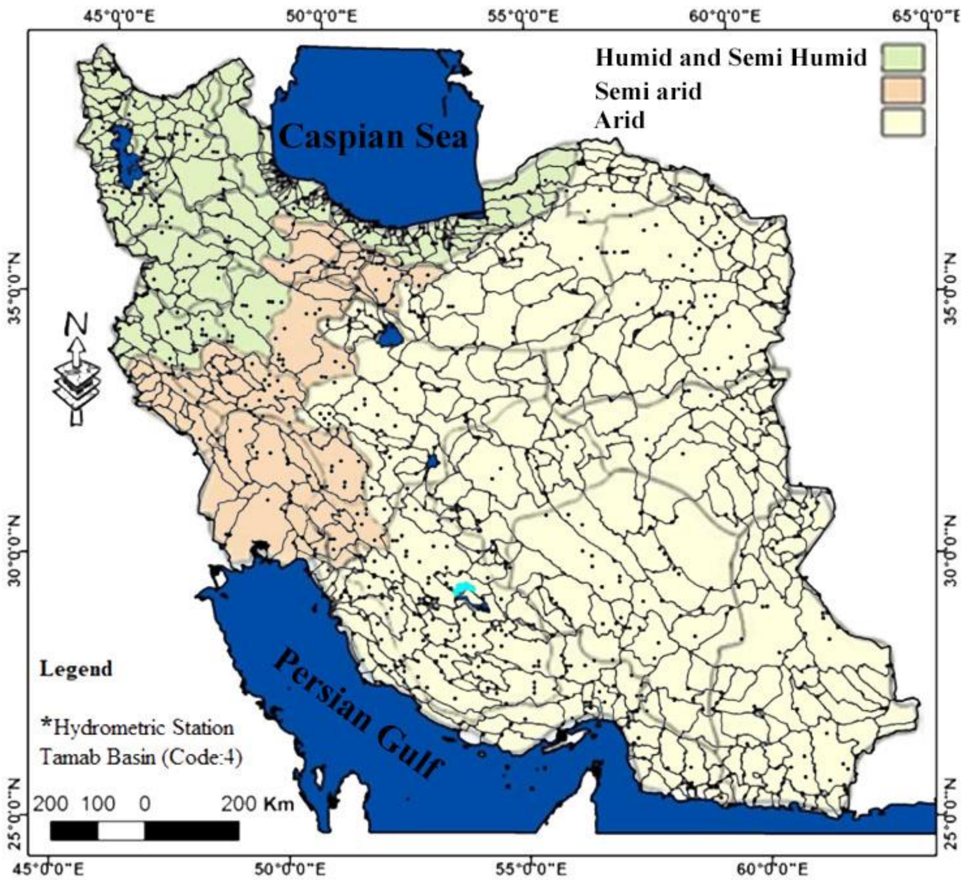

Fig. 1. Dividing the country into three regions with the same climate (adapted from Sharifi, 2017)

2.4. AWBM model structure

The AWBM model, is a water balance computer model for rainfall-runoff simulation first proposed by Boughton (1993). This model is an area partial models of saturated surface flow that uses daily and hourly rainfall and mean monthly evaporation to calculate daily and hourly runoff. This model is developed based on partial area runoff theory, which is similar to saturated surface flow theory, and its advantages over other rainfall-runoff simulation models are: The model has trivariate and in seasonal rivers that do not have a base flow, the model becomes univariate. The structure of the model is relatively simple and calculates runoff at different times from different regions. The AWBM model uses surface storage capacities ($Store_1$, $Store_2$, and $Store_3$) with areas (A_1, A_2, and A_3) to simulate runoff levels, and the water balance calculates each storage surface independently of the others at daily (or hourly) time steps. The water balance equation of each surface is such that rainfall is added to the surface storage and evapotranspiration is reduced. Therefore, the water balance equation in the case where n is the number of stores in the watershed is as follow:

$$Store_{n+1}=Store_n+Rain-Evap \quad n=1, 2, 3, \dots \quad (1)$$

In this equation, if the amount of storage moisture is negative, it is considered zero, and if the storage moisture exceeds the reservoir capacity, the excess moisture is converted into runoff and the storage moisture remains equal to the reservoir capacity (Boughton et al, 2002). Runoff is supplied from two main sources of surface runoff and base flow.

The parameters of the model are:

- Base flow index
- Recession Constant

3. Results and discussion

The results of the intersection of the border map of the country's watersheds with the homogeneous climatic map of Figure (1) show that in terms of the amount of watersheds in each climatic zone, arid zone with approximately 58.31%, semi-arid with about 23.75% and humid and semi-humid zone with about 17.94% have formed country's watersheds.

3.1. Humid and semi-humid climatic zone:

The results of the intersection of the country's watershed map and climatic map in digital environment, showed that the "humid and semi-humid" climatic zone is located in the north and west of the country and covered areas of Gilan, Mazandaran, Golestan, Kurdistan, East and West Azerbaijan, Hamedan, and Kermanshah and approximately 17.94% of the country's watersheds are located in this climate. For the analysis of this study, the watersheds located in the province of West Azerbaijan have been selected. The parameters of the AWBM model were determined according to the research method for determining the runoff threshold. Then in the model, by dividing the effect of variability of watershed storage capacity into three storage capacities (C1, C2 and C3) and estimating the levels of each of these storage capacities (A2, A1 and A3), runoff from each of these levels was simulated. The results of estimating the runoff threshold using AWBM model showed that most of the province has a runoff threshold between 5 to 10 mm. This range of runoff threshold in West Azerbaijan province is about 51.72% of the total watersheds of the province. Therefore, considering that the lower the runoff threshold, the less infiltration and consequently more flooding, most of the watersheds of the province are able to turn rainfall into runoff. Figure (2) shows the zoning map of runoff threshold classes in the seventh-order watersheds of West Azerbaijan Province and Figure (3) shows the percentage areas of runoff threshold classes. Watersheds with runoff threshold (0-5 mm) are mainly located in the northern and central parts of the province and second class watersheds (5-10 mm) are distributed in the southern parts. The results also showed that the maximum value of the runoff threshold of maximum instantaneous discharge in the Balanshrood watershed (30162) is equal to 15 mm and the maximum instantaneous discharge is estimated to be 0.14 cubic meters per second per square kilometer. Also, the lowest amount is in Aghchai watershed (1142), Mahlezan (1144), Sarab Qatur (1148), Qaresu (1172) Tasuj (3062), Qaranqu (13223), Chehriq-e Olya (30113), Nazloo (30131) and Simineh rood is obtained with 2 mm that the maximum specific flow rate is from 0.07 in Qarahsu Watershed (1172) to 0.97 cubic meters per second in Sarab Qatur Watershed (1148).

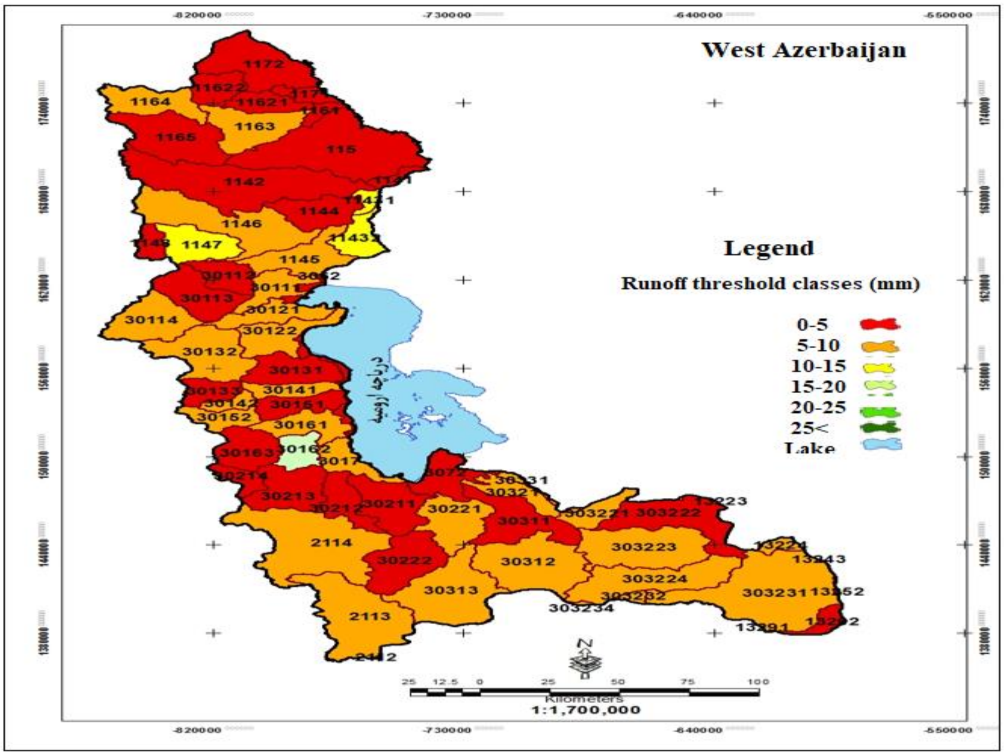

Fig. 2. Zoning map of runoff threshold classes in the seventh-order of West Azerbaijan province

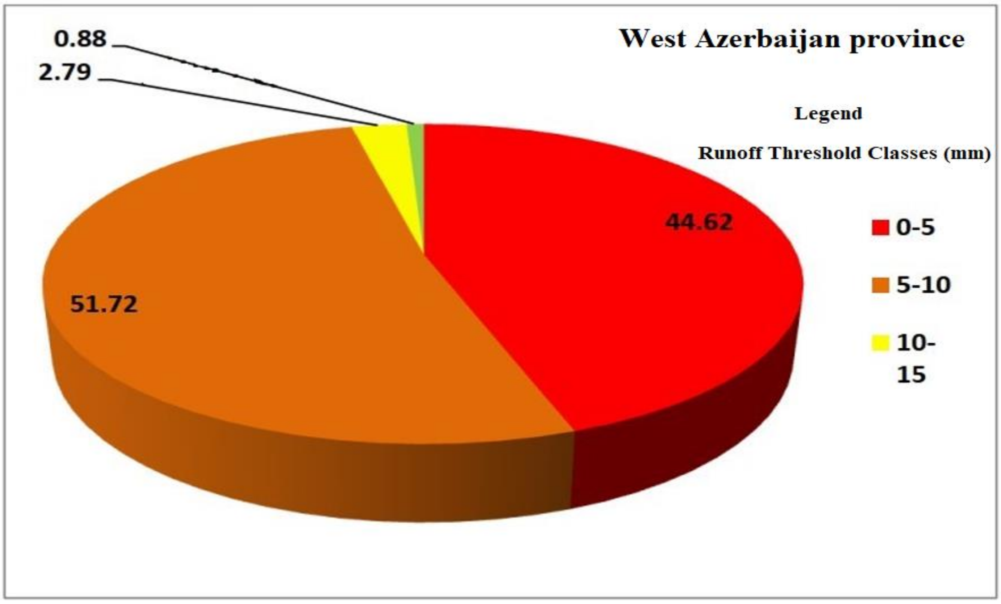

Fig. 3. Percentage areas of runoff threshold classes (mm) in West Azerbaijan province

3.2. Arid climatic zone:

The results of the output maps of the intersection of the watersheds with the climatic map showed that this climatic zone has the largest range in the geography of the country and covers the entire central, southern, eastern and southeastern regions. The watersheds located in this region comprise approximately 58.31% of the country's watersheds. For this study, selected 29 watersheds located in Kerman province. The output results of the simulation model showed that the amplitude of runoff threshold obtained for the watersheds located in this province is 0-25 mm, which in five classes including 0-5 mm, 5-10 mm, 10-15 mm, 15-20 mm and more than 20 mm is divided and based on this, the zoning map of the runoff threshold of the province is divided into seven ranks (figure 4) and the percentage of surface cover of runoff thresholds in the province is presented in Figure (5). As it is known, the values of runoff threshold in this province are in the range of 0 to 25 mm. Also, Figure (3) shows that the runoff threshold of the province is mainly zero to five mm with 44.9% of the areas, which mainly covers the northern and northeastern regions of the province. Class of 5 to 10 mm with an areas coverage of 43.65% is estimated. This class covers the central regions of the province. In addition, a runoff threshold of 10 to 15 mm with an areas of 8.46% has been observed. This class is spread in the southern and southwestern part. Runoff threshold of 15-20 with areas of 0.8% and runoff threshold of class 20-25 and above with surface coverage of 2% is located in the center of the province.

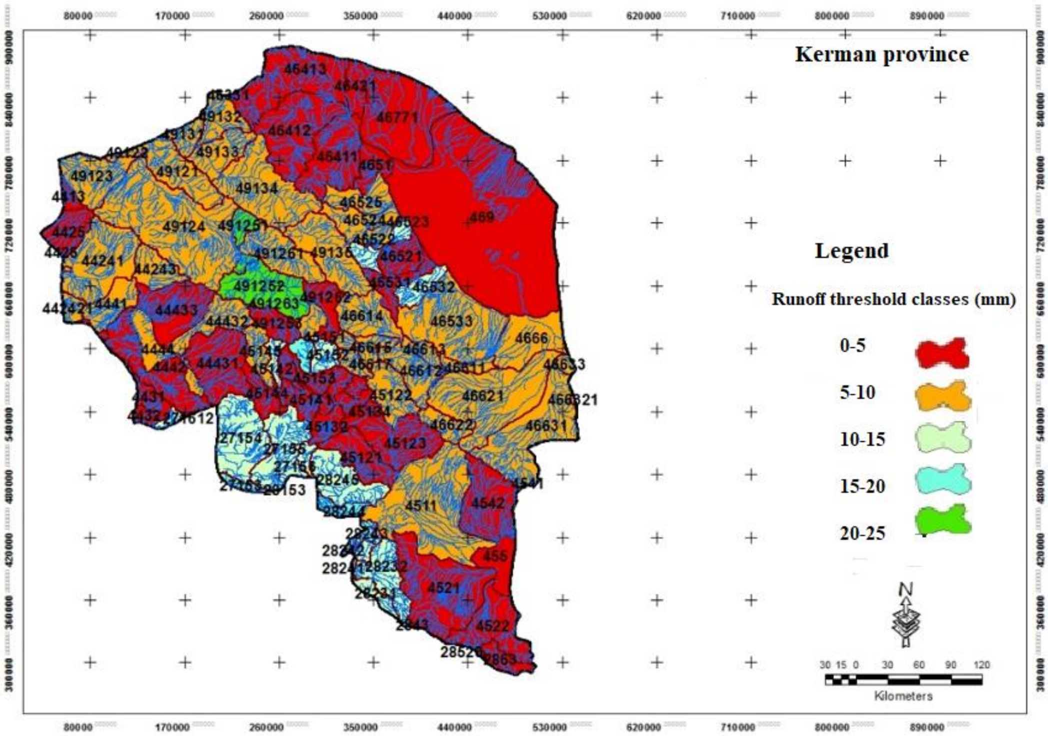

Fig. 4. Zoning map of runoff threshold classes in the seventh-order watersheds of Kerman province

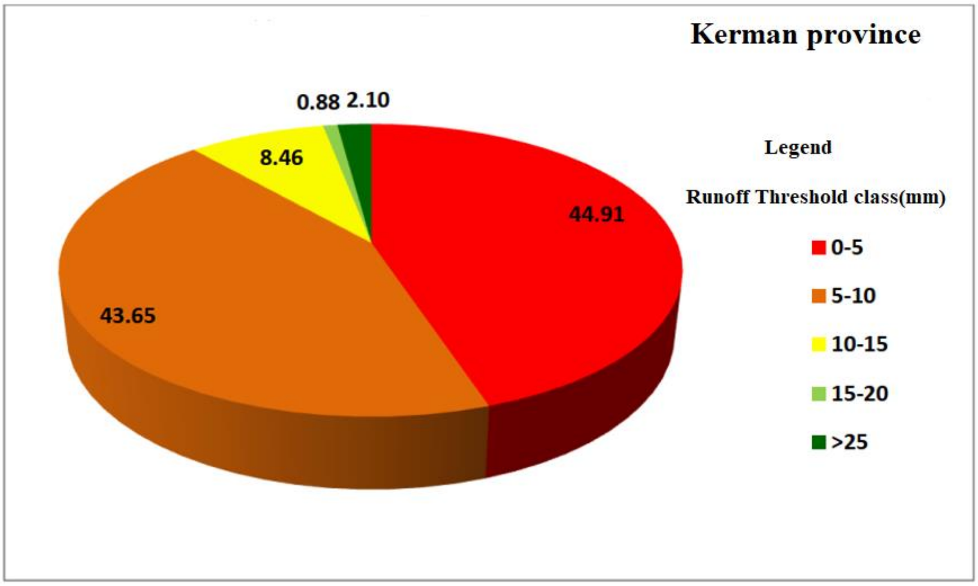

Fig. 5. Percentage areas of runoff threshold classes (mm) in Kerman province

3.3. Semi-arid climatic zone:

The output results of the intersection of homogeneous climatic maps and the boundaries of watersheds showed that this climatic zone is scattered in the west and northwest of the country and in parts of Markazi, Qazvin, Tehran, Alborz, Lorestan, Ilam, Khuzestan, Chaharmahal and Bakhtiari

Province and Kohgiluyeh and Boyer-Ahmad Province are expanding. About 23.75% of the country's watersheds are located in this climate. We selected 47 watersheds with appropriate statistics and a same period in Khuzestan province for analysis. The results of research in estimating runoff threshold using AWBM model showed that most of Khuzestan province has runoff threshold between 0 to 5 mm. This range in Khuzestan province is 59.82% of the total area of the province's watersheds. This range of runoff thresholds are spread in the central, southern, northern and northeastern parts of the province. The second class, which covers the range of 5-10 mm, mainly covers the eastern watersheds of the province. Considering that the lower runoff threshold showed the lower infiltration and consequently the more flooding, most of the watersheds of the province are able to convert the rainfall to runoff. The results also showed that the highest value of runoff threshold in Dez 3 watershed (code 23313) is equal to 12 mm that the maximum instantaneous flow rate is estimated at 0.95 cubic meters per second per square kilometer. The lowest values are obtained in watersheds 2311, 2415, 2421, 2424, 23212, 23312, 24124, 24233 equal to 2 mm tat the maximum instantaneous flow rate is from 0.19 in watershed 2311 to 1.47 cubic meters per second per square kilometer in watershed 24124.

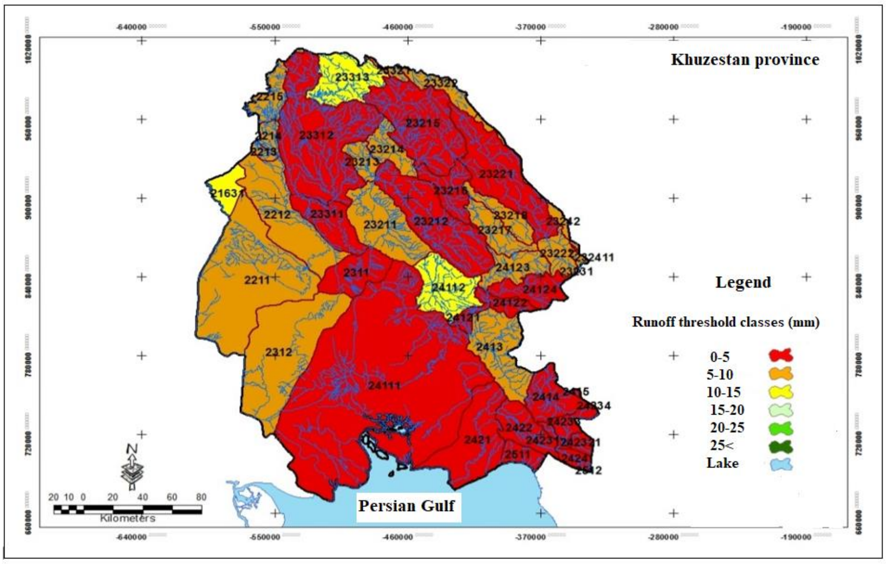

Fig. 6. Zoning map of runoff threshold classes in the seventh-order watersheds of Khuzestan province

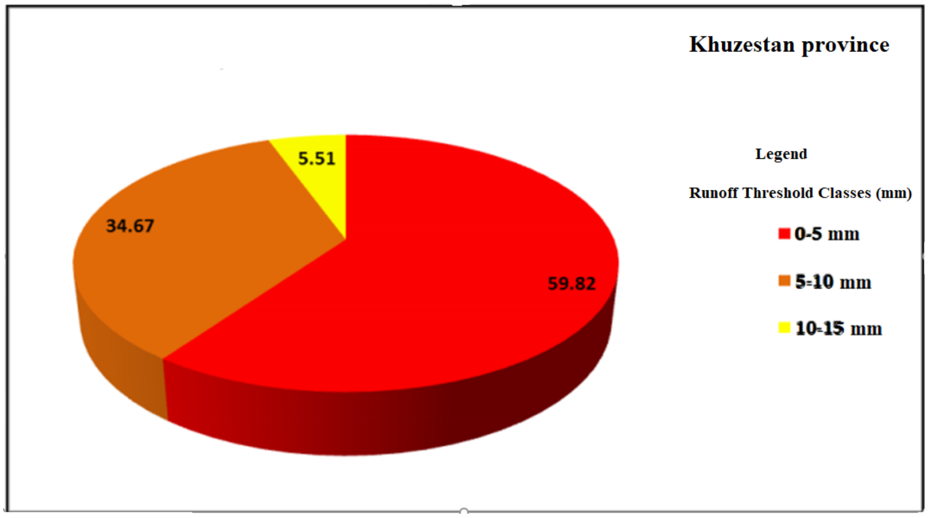

Fig. 7. Percentage areas of runoff threshold classes (mm) in Khuzestan province

4. Conclusion

In summarizing and comparing the simulation results of runoff threshold in the watersheds of three provinces located in different climatic zones, it is noteworthy that in all three climatic zones, almost half of the watersheds have runoff thresholds in the 0-5 mm class and have the potential for rainfall to runoff and flood production. These results can be analyzed in this way, considering that these simulations have been performed in the watersheds that have appropriate data, which are mainly located in mountainous areas and in rivers upstream. Therefore, most of the watersheds have shown a high potential for conversion of rainfall into runoff.

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6. Conflicts of Interest

No potential conflict of interest was reported by the authors

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