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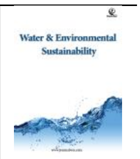

Rainfall prediction to evaluate the flood risk using remote sensing and geographical information system

Ciurea Maria
Associate Professor of University of Petrosani, Romania

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**Corresponding Author:*
Ciurea Maria
mariamacris2011@yahoo.com

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ABSTRACT

In this study, the runoff curve number map for Navrud watershed in north of Iran was determined based on the soil hydrological group, land-use and land-cover using remote sensing and geographical information system. For this objective, land-cover and Land-use situation maps were prepared using NDVI index and Landsat satellite data, respectively. Runoff curve number maps were determined using the overlay prepared maps in GIS and SCS table. For evaluating the accuracy of estimated curve numbers, runoff maximum discharge was calculated using HEC-HMS model and compared to the observed values. Furthermore, the climate change trend and probabilistic distribution functions were considered to predict the flood risk. The effects of climate change were defined by atmospheric general circulation models for A1B, A2 and B1 scenarios. Error analysis between calculated and observed discharge showed that watershed curve number was determined with acceptable accuracy.

Introduction

Necessity of accurate estimation of hydrological parameters for the optimal design of hydraulic structures is the main reason for various studies and different methods. One of the most important issues regarding decisions relevant to water resources is the estimation of peak discharge and runoff volume in zones with low or less data as like as most watershed of Iran. On the other hand, with attention to lack or deficit statistics and accurate data, application of experimental formulas could be considered as one of the sensible and useful ways for achieving of mentioned goals (Asadi et al., 2017, Melesse and Shih, 2002). Field measurements in the watershed scale may be time consuming and decision-making in this condition could be impossible. Development of remote sensing techniques and application of measuring devices in various fields could be prepared for large amounts of data in water engineering. Furthermore, geographical information system (GIS) is one of the most important tools for water resources data analysis in the previous studies (Schumann et al., 2000).

Hence, Remote Sensing (RS) and Geographic Information System (GIS) techniques are the appropriate tools in characterization and prioritization of watershed areas (Sharada et al., 1993, Saxena et al., 2000, Makhamreh, 2011, Magesh et al., 2012). Land- cover is a category in RS which has made the major impact to maximize the technological capabilities (Garbrecht et al., 2001, Pandey and Sahu, 2002). Moreover, RS and GIS can be successfully utilized to improve accuracy in estimation of curve number for a watershed from its land use data and digitized soil map (Cheng et al., 2006, Pandey et al., 2002, Still and Shih, 1985, White, 1988).

The curve number method of the U.S. Soil Conservation Organization was used for determination of depth of the runoff of the sub-watershed S-65A of Kissimmee Watershed of U.S (Melesse and Shih, 2002). For more description, the effect of land use changes was investigated on the runoff during the decades of 1980, 1990 and 2000. Landsat satellite images ETM + and TM, MSS were implemented to determine the land use and land cover maps. Land cover map of the area was prepared by satellite images and NDVI index (Melesse et al., 2003, Mishra et al., 2006, Nossin, 2005). Also, they determined that land use changes in the period of 20 years lead to changes in spatial distribution of curve number (CN) and runoff volume. Land use change may show some changes of urban construction that these changes may be lead to increase runoff volume or peak discharge. Payraudeau et al. (2003) determined the effect of land use changes on watershed hydraulic response to utilize SCS-CN method in Pallas, southern France. GIS could be incorporated as a suitable tool for obtaining spatial characteristics of watershed such as soil, land use and topography. The results showed that land use change and the type of classification could be affected significantly on hydrological modeling (Payraudeau et al., 2003).

RS and GIS techniques were implemented for preparation of curve number and runoff volume map for Amameh watershed in northern of Tehran, Iran (Gholami et al., 2017). Land cover maps were provided using third and fourth bands of Landsat TM satellite images and NDVI index. The land-use was obtained by Landsat satellite images and soil hydrological group map was determined based on permeability, slope and soil texture. Finally, obtained curve number by RS and GIS was compared with measured curve number of the storm rainfall with 88% accuracy (Schumann et al., 2000, Sereda et al., 2011).

Climate change is one of the main components to consider the uncertainties in the rainfall amounts. Gholami et al. (2017) evaluated the effect of climate change on precipitation in Ghaemshahr plain, Iran using WG-LARS model under A1B, A2, and B1 scenarios. The results showed that the flood and drought could be happened by precipitation variations in future. The same study was carried out in Kermanshah, Iran using WG-LARS by (Salahie et al., 2017). The results showed that the warming and drought events are the common phenomena for future decades (Golrang et al., Inci Tekel et al., 2006).

In this study, new techniques such as GIS and RS were used for preparation of runoff curve map for Navrud watershed in a humidity region of Iran. Then, for evaluating the calculated curve number, maximum of flood discharge is simulated using rainfall-runoff models HEC_HMS. Furthermore, climate change can affect flood generation, as the most important factor in the water management by changing precipitation patterns. Therefore, it is essential to assess the impact of climate change on flood risk. This study was aimed to evaluate the impacts of future climate change on flood risk in Navrud watershed, located in west of Gilan province, North of Iran. Finally simulated discharge will be compared to the maximum values of observed flood discharge.

Materials and Methods

Study area is Navrud watersheds in west of Gilan province, Iran. Navrud watershed is located in the geographical coordinates between ˚48 ′35 to 454 ˚48 east and ′36 ˚37 to ′45 ˚ north (Fig. 1). This area has an area of about 260 km^2 and its land cover consists of two types of forests and pastures (Asadi et al., 2017). The physiographic characterizations of the Navrud watershed is shown in Table 1. For preparing curve number map of runoff for watersheds were used from sensor data ETM + Landsat satellite. In this study, digitized topographic map with 1:25000 scale and other existing digitized and printing information of these areas were used. Also, for analyzing of the images and to collect the necessary data for preparing curve number map some software such as ERDAS, ArcView, ArcGIS and ILWIS were used.

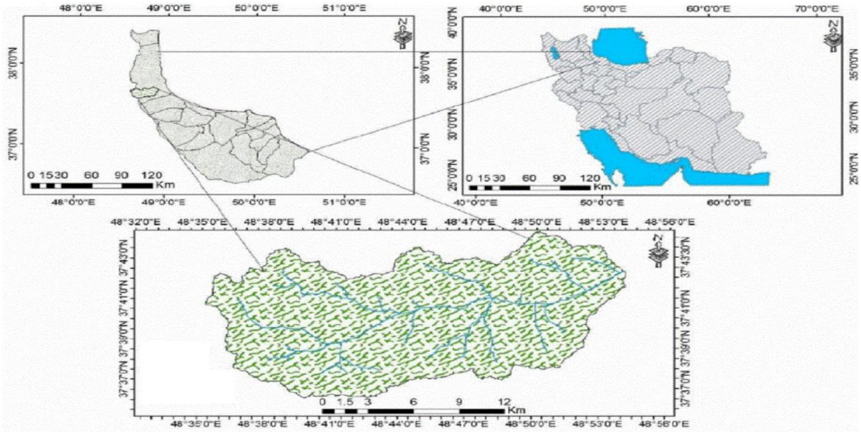

Fig.1. Location of studied area in the related province and country (Iran)

Table1. Physiographic characterizations of studied area

Watershed	Watershed Area (km2)	Watershed Perimeter (km)	Average Watershed Rainfall(mm)	Watershed Average height (m)	Watershed Average slope (%)	Watershed Climate Type
Navrud	265	117	853	1390	43	humid

Land use map

The basic field map was provided using topographic condition and the final land-use map was obtained from Landsat satellite images. To geometric correction of satellite images, 1:25000 topographic maps and survey points with the appropriate distribution area were used. Geometric matching of the images were performed by second-degree polynomial equation.

Root mean square error (RMSE) of geometric correction was obtained less than 0.1. The satellite bands expect 6 and 8 bands were merged to producing color images and then contrast improvement operations and enhancement was performed on color images. The obtained image of mergence Landsat bands had a resolution less than 30 meters. By PAN band of Satellite (Band 8), a resolution capability was enhanced to 14 meters. The Navrud watershed were classified to five classes that the classification was supervised and performed by maximum probability method. Then majority filter was tested to improve results and the elimination of single pixels with 3*3 and or 5*5 dimensions. Residential region class and road class had removed of classification algorithm due to lower accuracy of the classification algorithms.

For accuracy assessment of generated maps using ERDAS software, quite randomly 50 samples were selected on the classified map, and their accuracy is confirmed by the ground truth. Thus using ERDAS software user's accuracy criteria, overall accuracy and Kappa coefficient were calculated. The Kappa coefficient (K) is applied in order to summarize information produced by an error matrix. This coefficient is calculated by (Biron et al., 1999):

$$K = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} x_{+i} - x_{+i}}{N - \sum_{i=1}^{r} x_{i+} - x_{+i}}$$

(1)

Where, X_{ii} is the diameter entrances in the error matrix, x_{i+} is total "I" row of the error matrix, x_{+I} is total "I" column in the error matrix and N is the number of elements in the error matrix. Value of a Kappa criteria is showed perfect match between the obtained information of classification and ground information. Tables 2 showed the results of Landsat images classification using the maximum probability method.

Table 2. Landsat image classification for Navrud watershed

	Forest			Agriculture	
	High density	Relatively high density	Low density	Good pasture	Average pasture
Area (%)	45.9	12.1	8.7	11.3	22
User accuracy	71.43	57.14	100	90.91	71.43
Total accuracy	76				

Kappa coefficient	0.59

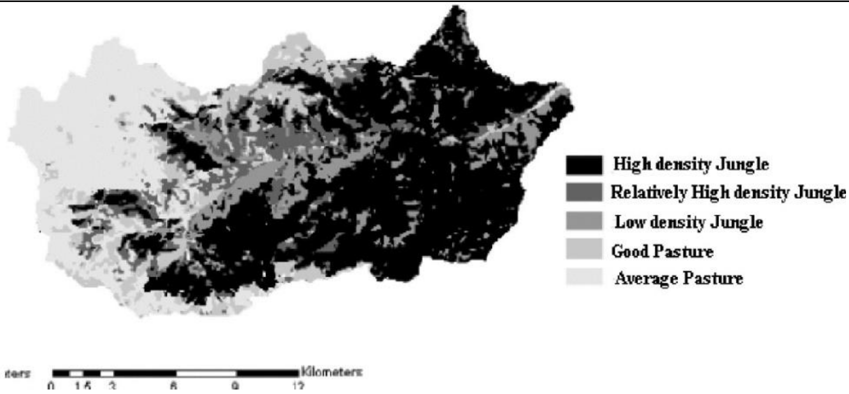

Fig.2. Land use map of Navrud watershed

Classification results showed that overall accuracy and Kappa coefficient obtained from accuracy assessment of land use map were equal to 76% and 0.7, respectively. High density of forest in Navrud map significantly led to decrease in estimated classification accuracy and kappa coefficient of images. Navrud watershed include about 46% of the high density forest that these will be affected potentially on the curve number and runoff results. Fig. 2 showed land use map for the studied watershed.

Watershed land cover map

Hydrological situation have shown potential production of a runoff in the region and if this potential was low, Hydrological situation will be fine. Land cover map were prepared using NDVI index. Application of NDVI index was performed by bands of 3 and 4 of Landsat satellite in the ILWIS software. Estimated land-cover map must be converted to digital files to entering ArcGIS environment and this conversion needs a classification. The classification was done supervised and by maximum probability method using ERDAS software. Land cover map of Navrud watershed was classified into three classes: excellent, good and middle. For accuracy assurance of resulting map, the accuracy assessment was done on the map. Also, the accuracy and precision of prepared maps and classification were evaluated. The percentage of covered good pasture was less than 40%. Navrud watershed is in excellent situation of vegetation cover (Table 3). Fig.3 show the land cover situation for Navrud watershed.

Table 5. Area percentage of land cover condition of studied watersheds

	Excellent	Good	Average	Poor
Land cover	41.56	38.34	20.09	-

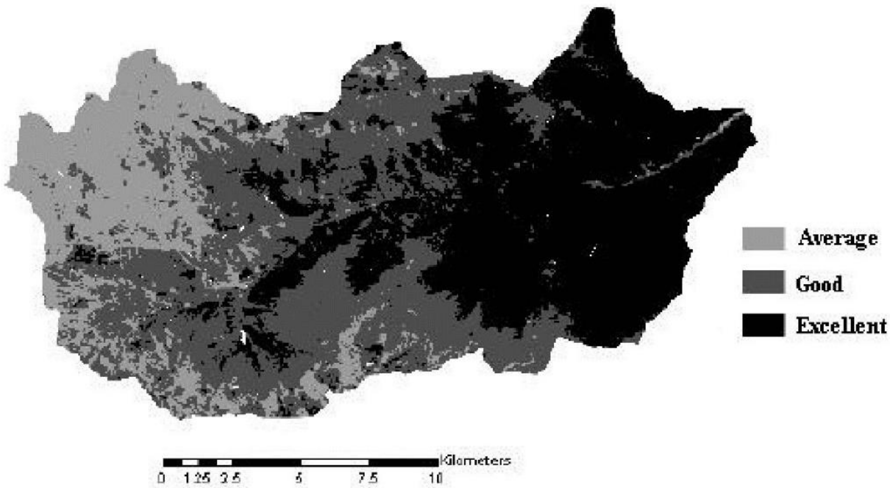

Fig.3. Land cover situation map

Soil hydrological group

Soil hydrological group affect a significant impact on estimating of runoff height and different soils have a different potential of runoff producing. Based on SCS method, soil hydrological groups include four ones (A, B, C and D). Groups have a weak ability to produce runoff and D group have a high potential to produce runoff. Map of soil hydrological group of these three watersheds are determined using slope maps, topography, geology and land use. Table 4 summarized the covered area of soil hydrological groups and Fig. 4 showed the soil hydrological groups map of studied watershed.

Table 4. Soil hydrological groups covered the studied watershed

Hydrological group	A	B	C	D	Water
Value	-	32	49	17	2

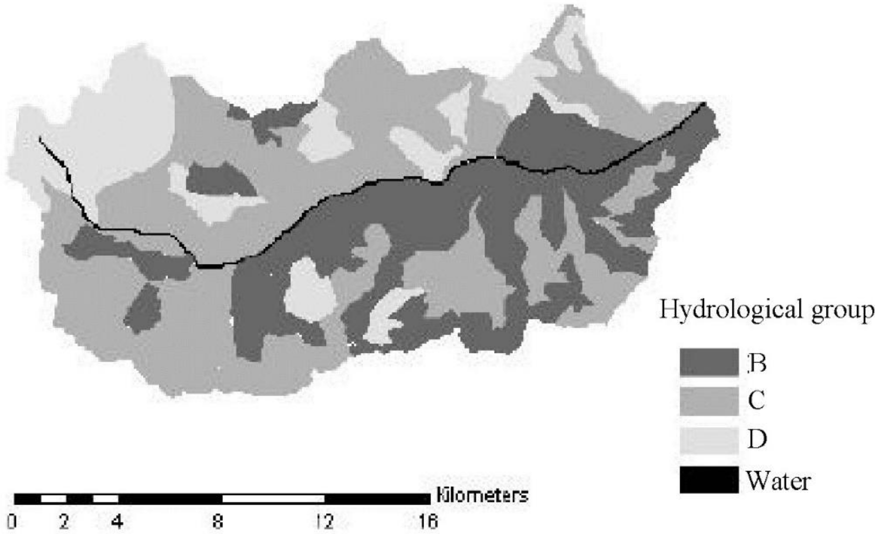

Fig.4. soil hydrological group of studied watershed

As shown in Fig. 4 and Table 4, more than 30% of Navrud watershed has B hydrological groups that have average potential of a runoff production. About 2% of watershed area is covered with water and permanent river cover.

Climate change

In this study, the climate change trend was evaluated by XLSTAT software using effective climatic parameters obtained from Navrud station. Then, the flood risk was predicted using probabilistic distribution function. The atmospheric general circulation models (NCCCSM), was applied to provide the synthetic weather series for three A1B, A2 and B1 scenarios. Based on the outputs of NCCCSM, daily rainfall values of the base period 2012-2020 and the LARS-WG model, daily rainfall pattern were simulated for two 20-year periods of 2021-2040 and 2041-2060.

In this study, probabilistic simulation has been incorporated to account the uncertainty of precipitation. Generalized extreme values (GEV) is a distribution function to predict the flood characteristic that is suggested based on the good-of-fitness tests.

$$F(x) = \exp\left(-\exp\left(k^{-1}\ln\left(-\frac{k(x-\gamma)}{a}\right)\right)\right) \quad (2)$$

where a, k, and γ are the calibrated parameters which is estimated using calibration between observed values of rainfall characteristics and random data generated by univariate distribution functions (Chen & Guo 2019).

Runoff

Runoff is one of the most important hydrological variables and used in most water resources applications. The SCS curve number method is a method of estimating runoff that prepared by soil conservation service of America. In SCS method, a determination of curve number is necessary that is a subordinate of soil characteristics, land use and hydrological properties such as antecedent moisture content. This method is used for watersheds with shortage data. In SCS method, runoff height obtained of rainfall data has calculated as following (Mishra et al. 2006).

$$Q = \frac{(p-0.2S)^2}{(p+0.8S)} \quad (3)$$

$$S = \frac{25400}{CN} - 254 \quad (4)$$

That, S is surface maintenance factor, Q is runoff height (mm), ρ is rainfall height (mm), CN is the curve number of runoff. If the watershed conditions is not uniform regarding factors affecting CN, CN weight average should be calculated (Melesse & Graham, 2003). Thus:

$$\overline{CN} = \left[\sum \left(\frac{A_i}{100} \right) (CN_i) \right] \tag{5}$$

where, $\overline{CN}$ is the curve number weight average in watershed's area and *Ai* is the percentage of watershed area that curve number as equal *CN*. Rainfall-runoff model, HEC-HMS, is one of the models that used from the calculated curve number for determination of flood hydrographs and or flood peak discharge. Several statistical criteria were used for evaluation of HEC- HMS model. Kitching, Hutcheon et al., (1986) proposed a criterion for model evaluation that maximum flow rates be evaluated by the percentage of error in the peak (Kitching et al., 1986).

$$PEP = \frac{Q_{PS} - Q_{PO}}{Q_{PO}} .100 \tag{6}$$

where, Q_{ps} is the maximum simulated discharge and Q_{po} is the maximum observed flow. To evaluate the maximum flood discharges were used from different runoff events by two criteria RMSE and MRE. Low values of these two criteria indicative are close values observed and calculated.

Results and Discussion

The probabilistic values of rainfall obtained for different scenarios of climate change are shown in Fig.5. These data were implemented as input information for the next steps.

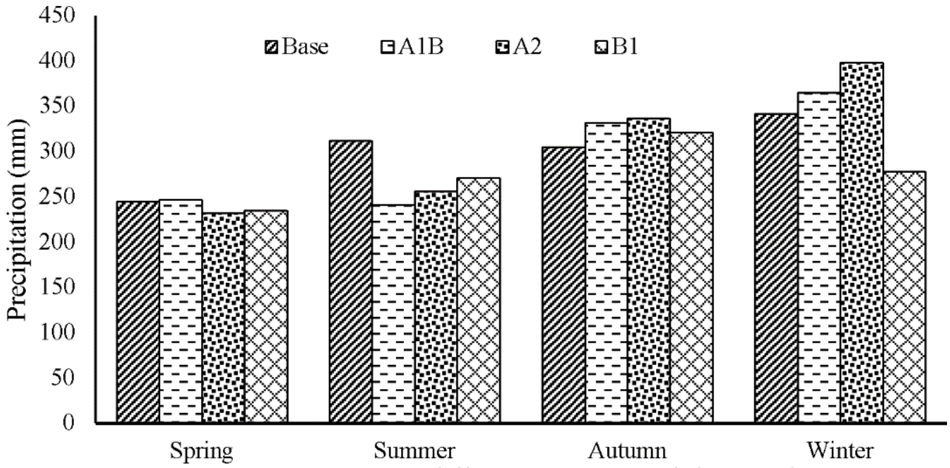

Fig.5. Mean precipitation in different scenarios of climate change

With preparation of land-use, land-cover and soil hydrological group maps, by SCS table that has written as Visual Basic program in Excel software, curve number can be determined for any number of the pixel of watershed. A weighted average curve number of watershed obtained using Eq.4. The weighted averages curve number (71.18) is less than average of curve number of it (73.23). In Navrud watershed about 30% has occupied with lower curve numbers such as 55 and 66. Fig.6 showed runoff curve number map in average moisture conditions.

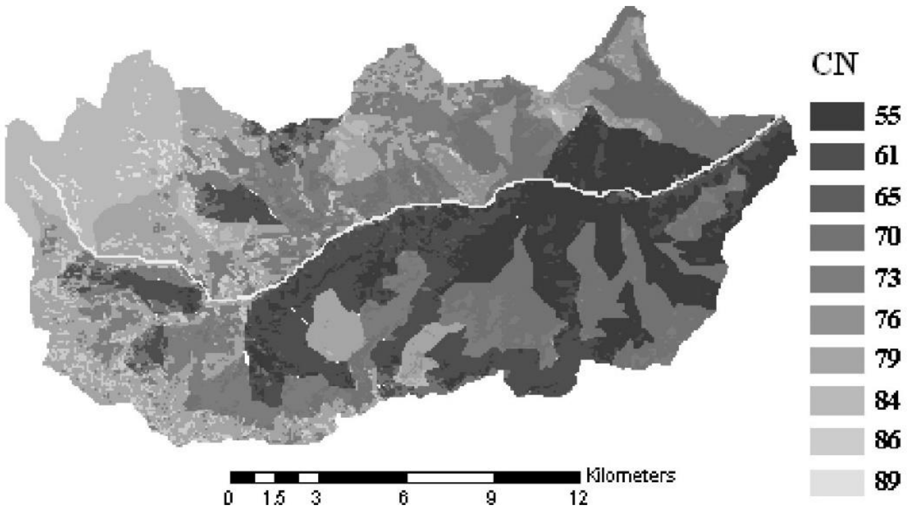

Fig.6. Runoff curve number map

In order to evaluate value of obtained curve number need to measure the values of flood discharge and storm of studied watersheds. Therefore, four flood events were used that had the accurate statistics of rainfall and runoff. The accuracy of the curve number was obtained by comparing the maximum observed flood discharge and maximum flood discharge that model determined by precipitation data and simulated curve number with RS and GIS. Thus, in this study rainfall-runoff HEC-HMS model was used.

Finally, error percentage between measured and observed discharges has calculated for evaluation of simulated discharges with RS and GIS and HEC-HMS model and also for comparison of observed discharges. Results obtained from the comparison of maximum observed flood discharge and calculated with HEC-HMS is shown in Table 5.

Table 5. Comparison of maximum simulated and observed discharge values

Parameter	10.11.2013	9.10.2015	4.12.2017	25.05.2019
Maximum observed flood (m^3/s)	47.76	114.64	43.5	10.11
Maximum calculated flood (m^3/s)	44.3	126.35	32.53	8.9
Error	7.3	25.2	10.2	12

MRE and RMSE criteria were used to evaluate obtained CN from the maps. Lower values of these criteria indicate a close observation and calculated results.

$$RMSE = \left[\frac{\sum_{i=1}^{N} \left(CN_i - \overline{CN_i} \right)}{N} \right]^{\frac{1}{2}} \quad (7)$$

$$MRE = \frac{\sum_{i=1}^{N} \left| \frac{\left(\overline{CN} - \mathrm{CN_i} \right)}{\overline{CN}} \right|}{N} \quad (8)$$

That, $\overline{CN}$ is the observed amount, CN_i is calculated value and N is the number of statistical years. Table 6 shows comparison results between the obtained CN from maps with CN result of observed discharge.

Table 6. Comparison of estimated CN and observed CN

Date of flood	4.2015	6.2017	5.2019
Calculated CN	68.99	68.99	68.99
Observed CN	71.5	72.55	73.37
RMSE		3.57	
MRE		0.05	

Conclusion

In this study, determination of vegetation condition, land-use, soil hydrological group and curve number of the watershed were done, and the level of cover vegetation was estimated. Navrud watershed by about 60% of high density forest and relatively high density forest and 32% of B hydrological groups and 80% of excellent and good vegetation coverage conditions led to lower curve number such as 55 and 61 allocated about 30% of watershed area and weight average curve numbers of the watershed is lower than the average watershed curve numbers. Acceptable results of observation discharge in comparison with calculated results showed that using GIS and RS techniques can be effective in determination of the watershed curve numbers. This research determined that by GIS and remote sensing without field survey could be informed from runoff, condition vegetation, land uses and the potential of flood seismicity of the region and the necessary strategies to prevent human and financial damage during floods occurrence must be taken. The results showed that the runoff volume in the future periods increases due to increasing rainfall intensity. Most area of the watershed has a low runoff risk and the southwest areas of the region and northern parts of the north are mainly at flood risk. Additionally, although rainfall severity is at its highest level at some parts, the amount of flood risk is not high, which can be due to the effect of vegetation. Increasing vegetation density, particularly forest type, can reduce the effect of runoff rate and thus reduce the risk of flood.

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