Determining the Participation of Sub-Basins in Peak Discharge and Runoff Volume with HEC-GeoHMS Model

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Abstract

One of the most important measures in flood management projects is to investigate the participation of different sub-basins of a watershed in determining the various components of flood discharge from the basin. Due to the lack of hydrometric stations at the outlet of all sub-basins, achieving this goal requires simulation of the rainfall-runoff process in the sub-basins through hydrological models. In this study, HEC-GeoHMS model was used in Aydooghmush watershed in East Azerbaijan province of Iran. Three corresponding storm events and floods were used to calibrate and validate the model. The CN map of the basin was extracted in the GIS. Rainfall histogram with different return periods years was entered into the model and by successively removing different sub-basins, its impact on peak discharge and outflow volume Was determined from the desired basin. The results showed that the priority of participation in the peak discharge and flood volume of the basin outlet belongs to sub-basin one (W90), which is due to the larger area of this sub-basin. To achieve unaffected area characteristics, the highest peak discharge is related to sub-basin four (W120) and in case of flood volume, priority is given to sub-basin two (W100). The results provide the possibility of explaining the correct flood management policies through the management of critical sub-basins in the study area.

Keywords: Aydooghmush Basin, Flood Management, HEC-GeoHMS Model, Sub Basin.

1. Introduction

In general, two categories of climatic and basin factors are involved in causing floods. The source of many floods, especially in arid and semi-arid regions, are storms with high intensity and relatively short duration. Therefore, in the study of storms, it is necessary to pay attention to their continuity, intensity and temporal and spatial distribution in the occurrence of floods. Outflow flooding is essential in order to prioritize flood control. Azami Babani et al. (2019) prioritized flooding of hydrological units in Pol-e-Shah catchment area. In this study, in order to simulate rainfall-runoff, SCS method was used and to determine the initial rainfall losses, the curved number method was used in HEC-HMS software. And upstream sub-basins have less flooding. Talebi et al. (2019) to compare the prioritization of sub-basins using HEC-HMS model and experimental methods in Eskandari watershed showed that the prioritization of sub-basins in different return periods follows a specific trend. HEC-HMS is more efficient in prioritizing sub-basins in terms of flooding than experimental methods. Knebl et al. (2005) used a combination of HEC-HMS hydrological model, HEC-RAS hydraulic model and radar precipitation model (NEXRAD) to present the regional flood model for the San Antonio Basin in Central Texas, USA, and compared the model results with summer floods. The results of the study indicate the efficiency of the model in predicting floods on a regional scale. In this study, the amount of flood in the sub-basins of Aydooghmush river was prioritized.

2. Materials and methods

2.1. Area of study

Aydooghmush watershed with an area of 157.9 square kilometers is located in East Azerbaijan province of Iran and in the geographical position of 53́, ˚46 to 44́, ˚47 east longitude and 14́, ˚36 to 33́, ˚37 is located north latitude. Its environment is 399 km, the average slope of the basin is 22.11%, the annual rainfall is 438 mm and its climate has mild and short summers and cold and long winters, which is a feature of mountainous areas. The length of the glacial period is 96 days and its average altitude is 1800-1,500 meters above sea level. The annual runoff of this basin is equal to 228 million cubic meters.

2.2. Research Methodology

HEC-GeoHMS uses ArcGIS to generate HEC-HMS hydrological modeling inputs. Arc Hydro Tools are also ArcGIS extended tools that are useful for processing spatial data and creating input files for the HEC-HMS model. In this study, the elevation map (DEM) of the basin was first loaded from the Earth Explorer system on the US Geological Survey (USGS) site with an ASTER sensor with a resolution of 50 meters (Fig.1). Land use map of the basin was created with four classes of garden, irrigated cultivation, rainy and rangeland cultivation and with supervised classification and maximum probability. The soil texture map of the basin was cut from the soil diversity layer of the country and finally, from the land use layers and soil hydrological groups, the infiltration curve number (CN) layer of the basin was created. To perform the above operations, HEC-GeoHMS and Arc

Hydro extensions in ArcMap 10.2.2 software package and SCS standard tables were used. The length of the main waterway, the maximum length of the stream and the slope for the sub-basins were determined. Hydrological nodes were identified in each sub-basin and an output was generated in HEC-GeoHMS. The HEC-HMS inputs of the study area are created with six sub-basins named W90, W100, W110, W120, W130, W140 and three nodes named J26, J31, J36 and waterways R10, R40 and R50. In this study, HEC-HMS 4.6 was used due to its compatibility with Arc-GIS 10.2. Figure (6) shows a schematic diagram of the basin model and sub-basins in the HEC-HMS environment.

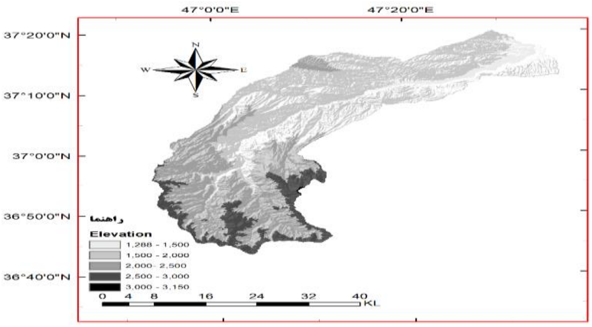

Figure 1. Elevation map of the Aydooghmush basin.

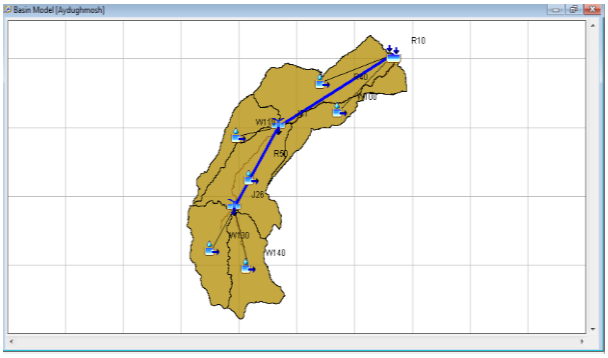

Figure 2. Diagram of the basin and sub-basins in the HEC-HMS model.

In this study, two flood events whose rainfall data were recorded from the rain gauge station at the basin outlet were selected as the events of the model calibration phase. The parameters of initial loss (Ia) and delay time (Tlag) were calibrated and the parameter of curve number (CN) was locked. To calibrate the difference values in flood peak discharge, flood volume and time to peak hydrographs were calculated and observed and the function that showed the least difference in the mentioned indices was selected as the best option. After calibration, a flood event with corresponding precipitation was used to validate the model.

After optimizing the parameters, the model was implemented using 24-hour design rainfall and flood hydrograph was obtained at the outlet of each sub-basin. Then, using the repeated method of individual removal, sub-basins were prioritized in terms of flooding. The flooding index used is defined as follows.

$$F = \frac{\Delta Qp}{QP} \quad \text{Eq. (1)}$$

$$f = \frac{\Delta Qp}{A} \quad \text{Eq. (2)}$$

Where, F is the share of the sub-basin in the total outlet discharge flow rate as a percentage, Qp is the amount of reduction in the total outlet discharge due to the removal of the desired sub-basin in cubic meters per second, QP is the total basin outlet discharge in cubic meters per second, f is the share of Sub-basin participation in discharge is the total output of the basin per unit area and A is the area of the sub-basin per square kilometer.

3. Results and discussion

In this study, flooding prioritization was performed using two flooding indices f and F (Table 1). Sub-basins were also prioritized in terms of area and peak discharge to determine the relationship between sub-basin flooding and these two parameters. The results showed that W90 and W120 sub-basins, despite being in priority 1 and 2 in terms of area and peak discharge, but in sub-basins in terms of flooding index f in priority 6 and 5 respectively. Also, the W140 sub-basin, although it is in the third place in terms of area among the sub-basins and in the second place in terms of peak discharge, but has the lowest amount of flood index. While the W110 sub-basin with the smallest area has the highest flood index f. The first priority sub-basins are known to have the largest share of reduction in the total discharge of the entire basin by eliminating it. Table 2 shows the flood discharge in different return periods by sub-basins in cubic meters per second. The W120 sub-basin has the largest share of discharge in all return periods. Comparing the area and discharge of sub-basins (Table 2), it can be seen that sub-basins with the largest area do not necessarily have the highest peak discharge, such as sub-basin W90, which is ranked first in terms of area lower than other sub-basins. The reason for this is due to factors other than area. Prioritization based on the reduction of discharge per unit area also indicates that a factor other than the area factor, including the location of each sub-basin relative to the basin outlet, plays a role in the potential for runoff production and flooding of sub-basins. In cases where the area of sub-basins affects the prioritization of flood production potential, this prioritization can be done for each unit of sub-basin area. The index for determining the intensity of flood production per unit area of the basin is more efficient than the previous index in prioritizing the design of flood control operations for the existing costs and facilities. In the executive sectors, where the economic issues of the projects are decisive, the rate of reduction of outflow floods per unit area of the sub-basin is more important.

4. Conclusions

According to the model calibration, the initial hydrological loss coefficient (Ia) in SCS relation for W90, W100, W110, W120, W130 and W140 sub-basins was 0.74, 0.66, 0.63, 0.94, 0.85 and 0.90, respectively. The efficiency of HEC-GeoHMS model in the study basin was confirmed using the controls performed on peak flow, flood volume, peak time and general shape of the hydrograph and shows the high efficiency of the model in prioritizing sub-basins. In terms of flooding compared to other methods. Prioritization of sub-basins in the outflow flood of the basin varies greatly in the return periods, which can be attributed to these changes in rainfall and also the losses of each sub-basin for different return periods. The results of prioritization in terms of peak discharge, based on the share of each sub-basin in the basin outlet, show that sub-basins W120 and W110 had the highest and lowest share in peak discharge flood discharge, respectively, which shows the influence of factors such as area, location and physiographic characteristics of the basin. Spatial distribution of sub-basins shows that sub-basin W120, despite its long distance to the outlet of the basin, had the highest participation in the production of peak flood discharge and sub-basin W110 along with the said sub-basin had the least participation in floods. Considering that W110 and W90, which have the highest flood discharge, therefore, watershed management and flood control operations should be done with emphasis on these sub-basins. Sub-basin W140 that have a shorter latency than other, play the most important role in producing peak basin discharge, but this may not be true in all research. The results of the present study, while confirming the efficiency of the HEC-GeoHMS model in simulating the hydrological conditions of the basin, suggest its application to investigate the amount of flood production in different sub-basins and analyze their participation in order to manage and control floods in the sub-basins.

Table 1. Flooding indices f and F for Aydooghmush sub-basins.

Prioritization with f index	f index (percent)	Prioritization with F index	F index (percent)	Peak discharge Prioritization	Peak discharge (m^3/s)	Area Prioritization	Area (km^2)	Sub basin
6	1.22	4	14.69	4	69.8	1	388	W90
2	2.52	5	13.51	5	64.2	5	188	W100
1	2.94	6	13.15	6	62.5	6	162	W110
5	1.34	1	22.35	1	106.4	2	353	W120
3	1.98	3	15.68	3	74.8	4	240	W130
4	1.90	2	20.52	2	97.5	3	249	W140

Table 2. Flood discharge in different return periods by sub-basins in cubic meters per second.

Return period(year)									Sub basin
1000	500	200	100	50	25	10	5	2	
97.5	73.4	47.9	32.8	21.3	12.8	6.6	6.0	4.6	W140
74.8	55.3	35.6	24.3	15.7	9.4	5.9	5.3	4.2	W130
106.4	81.3	54.2	38.0	25.6	15.9	6.7	5.9	4.7	W120
62.5	50.4	36.8	28.2	21.1	15.1	7.4	5.3	2.2	W110
64.2	52.2	38.6	29.8	22.5	16.2	8.1	5.9	2.4	W100
69.8	54.4	37.7	27.5	19.4	13	5.8	4.6	3.5	W90
415.6	323.7	223.7	162.4	114.6	75.8	33.7	27.3	18.8	Outlet

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