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The Prioritization of Isochrones Affecting Peak Flood Discharge in Neishabour Bar Watershed, Iran

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Abstract

Iran has geographically located in an arid and semi-arid climate in most regions. Precipitation and its distribution in such regions cause irreparable damage by creating seasonal floods. This study presents a suitable model for optimizing watershed management and flood control in order to reduce flood risks. To reach to this purpose, the concept of time-area diagram in HEC-HMS hydrological model as well Single Successive Sub-watershed Elimination (SSSE) is employed to simulate the flood hydrograph corresponding to the design precipitation for each sub-watershed. According to SCS model for estimating flood discharge and kinematic wave for flood routing, the curve number and Manning's roughness coefficient were calibrated and identified as the most effective parameters. After evaluating the different search methods and objective functions, the univariate gradient as best search method and the Nash-Sutcliffe as the best objective function was selected due to the highest consistency of the simulated discharge in the three events. Finally, the model was validated for 2 storms and the Nash-Sutcliffe values were calculated as 0.948 and 0.892, respectively. After calculating the peak discharge of each sub-watershed, the effect of each on the output flood production was determined using F and f flood indices. Then, isochronic surfaces of the watershed were extracted using three methods and the spatial distribution of the sub-watersheds in the area was investigated. The results revealed that the level of 0.75-1 located in the middle part of the watershed is posed as the first priority. Also, it is colcluded that the surfaces near the outlet have played a much smaller role in peak discharge. In general, from the outlet to the upstream and middle parts of the watershed, as travel time level increases, the effect of sub-watersheds on peak flow discharge increases.

Keywords: Flood potential, Flood routing, HEC-HMS, Isochrone, Kinematic wave, Prioritization, Single Successive Sub-watershed Elimination (SSSE).

1. Introduction

Due to large size of watersheds and economic and operational constraints, watershed rehabitation from a flood control perspective is not practical in a single project and may even have opposite effects. Flood control projects are managerial decisions that should be confirmed by studying the physical, social, and economic conditions and estimating the effects of implementing the plans (Djordjevic and Bruck, 1998). Given that floods and damages caused by floods are increasing in most watersheds, it is necessary to determine flood-prone regions and prioritize sub-watersheds in terms of flood control projects and comprehensive watershed management. Experience has shown that the relationship between the flood and the watershed is the outcome of the interaction between a large number of physical processes that control the generation and transmission of flood (Menabde et al., 2001).

In order to prevent flood hazards in downstream, it is necessary to identify flood-prone area in upstream of watersheds (Smith and Ward, 1998). In recent years, various models have been used to simulate streamflow, which, if used properly, they will be useful for flood routing (Chieyen, 1995). Location and distance or proximity to the watershed outlet affect the flood of the watershed and determine the flood-producing regions.

Today, the use of experimental and mathematical models for flood simulation to access flood properties is on the agenda of watershed managers. The properties such as peak discharge, flood volume and time to peak discharge are parameters that can be studied to better manage a watershed. Modeling is an imitation of the actual performance of a process or system over time which whether done by hand or by computer involves the artificial system and its investigation in order to draw conclusions about the performance of the actual system. Providing a simulation model is used as an analysis tool to predict the effects of existing systems. To model a system, it is necessary to understand the concept and boundaries of system. A system is defined as a group of objects that are interconnected in order to achieve a certain objective within the framework of a relationship or interdependence. For example, rainfall -runoff system starts from precipitation in the watershed and after applying loss (evaporation, infiltration, and etc.) turns it into runoff (Tajbakhsh et al., 2018).

HEC-HMS computer mathematical model is one of the hydrological models designed to simulate the surface runoff response of the watershed to certain precipitations. This program can analyze the hydrological properties of large watersheds, water reserves and flood and runoff hydrology of natural and urban watersheds. In this model, different components are combined to simulate the physical system of the watershed, and each component is part of the factors that convert precipitation into runoff in the watershed, which by combining the effects of these factors, the final flood hydrograph will be obtained (Khosroshahi, 2016).

Saghafian and Khosroshahi (2005) used HEC-HMS model to determine the sensitivity of the effect of some factors affecting the flooding of sub-watersheds using the analysis of output hydrographs in Damavand Watershed around Tehran. The results showed that the hydrological behavior of the sub-watersheds with respect to the output is nonlinear and the factors affecting the flooding of the sub-watersheds can be identified from the perspective of the effect on the output flood of the watershed and this method can determine most important sub-watershed. In another study, Ghaemi (1994) while introducing six factors affecting the occurrence of floods including depth and time of precipitation, snow depth, soil type, vegetation, slope and shape of the watershed and quantitative evaluation according to expert opinion, determined flood intensity of Karkheh sub-watersheds. Comparison of flood magnitudes of these sub-watersheds disregarding the effect of rive route on reducing the peak discharge of flood, would affect the accuracy of the of sub-watersheds impacts with the specified weights and the watershed output. For this purpose, flood hydrograph analysis provides very valuable data about the interaction between existing components and how the watershed responds to precipitation. Studies by Clark (1945), Maidment (1993a), Laurenson (1964) and Donker (1992) on the use of the time- area method showed the importance of the effect of spatial distribution of sub-watersheds located at different levels of the watershed on flood hydrograph formation. One of the main topics of the surface runoff process is the variable areas of runoff origin, investigating the areas with the highest runoff production. The knowledge of the source areas is related to the mechanisms of runoff generation from specific levels of watersheds and the effect of each level on the output and peak flood discharge. For determining the levels involved in runoff production, Gorokhovich (2000) investigated these levels at each time step by GIS. This study has investigated the levels of involved in the flow without prioritizing the areas affecting the peak flood discharge. Following the studies conducted in this issue, Saghafian and Farazjoo (2007) investigated the effect of flooding of sub-watersheds on the formation of flood hydrographs through HEC-HMS model. In this study, the interaction between effective factors, including the location of sub-watersheds at the peak flood discharge, was evaluated. Furthermore, Roghani et al (2004) by studying Rudak watershed showed that the area located near the watershed outlet played a much lesser role in peak discharge and generally the effect of sub-watersheds on peak flood discharge increases from the outlet to the upstream and middle parts of the watershed, along with increasing the area of isochrone.

The available data on floods in recent years indicate an increasing trend in the frequency of this phenomenon. The existing problems related to floods and the importance of controling it require the application of practical methods. Determining floody regions and prioritizing isochronic surfaces in terms of flooding plays an important role in watershed management. Thus this syudy aims to investigate the involvement of upstream levels of watershed (here Neishabour Bar watershed) and identify and prioritize isochrones is of special interest. In order to provide a model for controlling and reducing flood hazards, this study while investigating the runoff production capacity of the watersheds and the hydrological isochrones of the study area, evaluated their role in the peak discharge of flood hydrograph.

2. Material and Methods

2.1. Study area

The study area is located in Neishabour Bar watershed with an area of 113.88 km² in the southwest of Binalood Mountain. This area is located 100 km northwest of Mashhad. It is bounded on the north by the open watershed of Sar-e-Hesar and the Haftchah, on the south by the Taghan watershed, on the east by the Frizi watershed, and on the west by the Baqamj watershed. The average height of the watershed is 2226 m and its average slope is 32.66% geologically from the northern part of the watershed to the middle part. The average precipitation in the region is 330.4 mm. The average slope of the river is 4.2% and the average annual flood volume at the Ariyeh station is about 28 million cubic meters yearly. The table 1 shows hydrometric stations used in this research and their locations is shown in Figure 1.

Table 1. Rain gauge and hydrometric stations used in this study

Station	Type	Altitude (m)	Longitude	Latitude
Bar-Ariyeh	Meteorological	1520	58° 42′	36° 29′
Bar-Ariyeh	Hydromettic	1520	58° 42′	36° 29′
Karkhane Ghand	Rain Gauge	1074	58° 66′	36° 17′
Marousk	Rain Gauge	1900	58° 22′	36° 8′

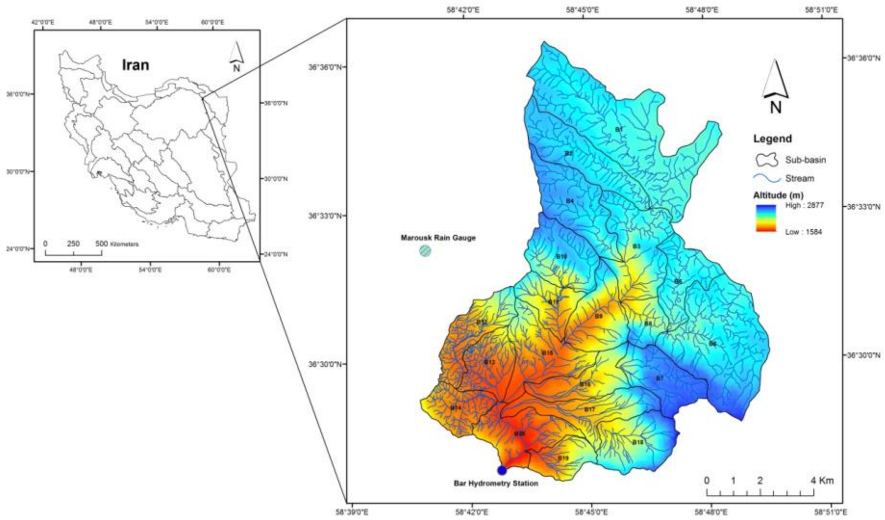


Fig. 1. Geographic location of study area

2.2. Data set

In order to study the hydrological behavior of the watershed and flood control, it is necessary to provide the forcing data, geographical maps and isochronal mapping. The hydrological data set of streamflow as well precipitation in 5 different events including May 11, 1991; March 16, 1992; March 31, 1992; May 30, 1993 and March 5, 1996 collected from Marousk rain gauge and Bar hydrometric stations. In order to extract the digital elevation model (DEM) the Aster sensor data set was used with a resolution of 30 m. ArcGis 10.3 was employed to provide the necessary data for conducting this study. All the required specifications and maps were extracted including slope map, flow direction and cumulative flow for isochronal mapping. The soil hydrological groups and land use map for producing the curve number (Figure 2) is used according to detailed-executive studies of watershed management.

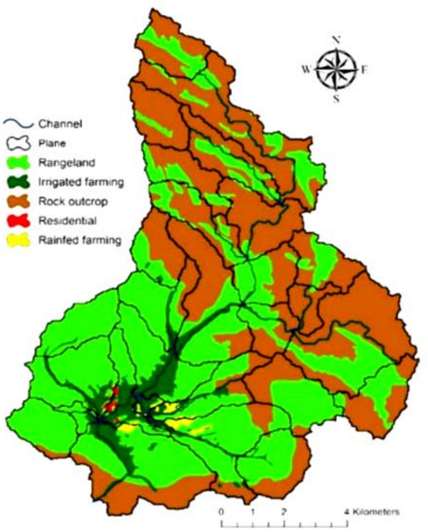


Fig. 2. Spatial distribution of sub watersheds and land use map in Bar watershed

2.3. Rainfall-runoff simulation using HEC-HMS model

HEC-HMS model is an extended version of HEC-1 under Windows designed by hydrological engineers at the US Army Center for Engineering to simulate the surface runoff of a watershed. This model shows the watershed as an interconnected system with hydrological components. Each component of the model simulates one part of the precipitation-runoff process within a watershed that is commonly referred to as a sub-watershed. In this model, different components are combined to simulate the physical watershed system, and each component performs some of the necessary calculations for a complete hydrograph. The structure of the model consists of three main parts of watershed model, precipitation model and control specifications (Scharffenberg and Fleming, 2006). In this study, the initial precipitation and infiltration loss was set using SCS-CN and then SCS unit hydrograph was used to determine the direct runoff hydrograph of the watershed (McCuen, 1989). Flood routing was performed using kinematic wave (Chow et al., 1988). Figure 3 shows a schematic model of the watershed.

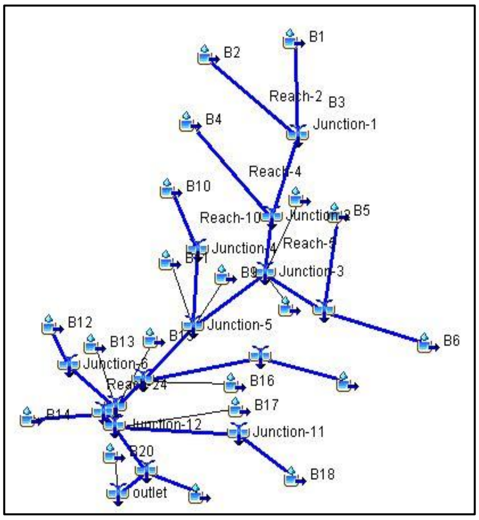


Fig. 3. Schematic diagram of hydrological modeling by HEC-HMS

2.4. Calibration and validation of HEC-HMS model

In this study, Simple-Split Sample Test has been used to calibrate and validate HEC-HMS model (Ewen and Parkin, 1996). In this method, observational floods are divided into two groups. The model parameters are calibrated using a set of data and objective functions. Then, the model was validated by implementing the model using optimized parameters for the second group of data, and finally the observational hydrograph and the simulated hydrograph were compared with each other.

The model was calibrated according to sensitivity analysis, Manning's roughness coefficient, curve number (CN) parameters and three recorded events. In model calibration, several existing objective functions were used and in each function, the difference in peak flow, total flood volume and time to peak was investigated between the simulated and observational hydrographs and the function that showed the least difference in the mentioned indicators was selected as the best objective function. In general, the Nash-Sutcliffe objective function evalutes efficiency in model calibration (Nash and Sutcliffe, 1970; Memarian et al., 2013). The model efficiency is measured by this function using the following formula:

$$\mathrm{NSE} = 1 - \left[\frac{\sum_{i=1}^{n}(Q_{s_i} - Q_{o_i})^2}{\sum_{i=1}^{n}(Q_{o_i} - \bar{Q}_o)^2}\right] \quad (1)$$

Where Qsi and Qoi are the simulated and observed flow discharges in time step i, respectively, and $\overline{Q_o}$ is the average observed discharge during the simulation period. If the value of NSE is 1, there is perfect match between the observational and simulated data. If the value of is zero, the model does not predict observational data better or worse than the average values. If the value of NSE is greater than 0.75, the simulation results are well described, but when the values of NSE are between 0.36 and 0.75, the model results are satisfactory (Motovilov et al., 1999).

Univariate Gradient and Nelder-Mead search methods were used for optimization. Nelder-Mead method, or the downhill simplex method, is a common numerical method for finding the minimum or maximum of an objective function in a multidimensional optimization space. This method is zero-order and can therefore be implemented in nonlinear optimization problems where it is impossible or difficult to obtain a function derivative. Nevertheless, the Nelder-Mead method is an innovative method that can converge to non-stationary points (Nelder and Mead, 1965). In general, according to the obtained results, the univariate gradient search algorithm showed higher efficiency in the calibration process than the Nelder-Mead algorithm.

According to the selected storm events, the hydrological component is defined based on the date of event occurrence in the model. For calibration and validation steps, three events of May 11, 1991; March 16, 1992 and March 31, 1992 were selected for calibration and two events of May 30, 1993 and March 5, 1996 were selected for validation.

In the present study, the baseflow discharge was separated from the total discharge by determining the slope of the hydrograph curve before the start of runoff from the respective storm (Mahdavi, 2005). For this purpose, based on the slope of the hydrograph curve before the start of runoff and using the relevant basic flow equation (Tallaksen, 1995), the baseflow values were eliminated by HEC-HMS software.

Single Successive Sub-watershed Elimination (SSSE) (Khosroshahi, 2016) was used to identify flood prone regions within the watershed. For this purpose, by successively eliminating the sub-watersheds each time HEC_HMS model was implemented, the discharge of the watershed without the given sub-watershed was calculated. Thus, after completing the routing of each hydrological unit, the effect of each sub-watershed in the production of flood was obtained. Using the obtained values, the effect of each of the hydrological units on the flood of the watershed was calculated quantitatively and prioritized from this perspective.

2.5.Flood index

In this study, the hydrological units of the region have been prioritized based on F and f flood indices (Zehtabiyan et al., 2010), which can be calculated based on the following equations:

$$F = \left(\frac{\Delta Q}{Q}\right) \times 100 \quad (2)$$

Where F is the contribution of sub-watersheds to the total discharge of the watershed in %, ΔQ is the reduction in discharge due to eliminating the given sub-watershed (m^3.s-1) and Q is the total discharge of the watershed ($m^3.s^{-1}$).

$$f = \frac{\boldsymbol{F}}{\boldsymbol{A}} \quad (3)$$

Where f is the contribution of sub-watershed to the flood of the watershed per unit area and A is the sub-watershed area (km²). According to the flood index, the sub-watershed that had the largest contribution to the flood of the watershed was identified as the highest flood prone sub-watershed, then the other sub-watersheds are prioritized in order of involvement in the flood. In this study, the involvement of all upstream sub-watersheds of Bar- Ariyeh hydrometric station was determined during 100-year return period.

2.6. Extraction of the watershed's isochrones

Isochronic surfaces show the spatial distribution of travel time. Isochronic maps have been developed to determine the best runoff time distribution in the hydrological design of the watershed (Nema and Lohani, 2012). In this study, the three methods described below were used to extract isochrones of the watershed, and finally a method was selected and used as a reliable method for further analysis.

2.6.1. Method 1

By GIS, isochrones can be easily extracted. In this way, in the digital elevation map of the watershed, the distance from the upstream point to the outlet that is along the main stream is measured. It is assumed that the concentration time is proportional to the flow distance and is inversely related to the second root of the slope between the two points. Thus:

$$t = \frac{CL}{\sqrt{S}} \tag{4}$$

Where t is the travel time in hr, L is the length of the canal in km, S is the slope between two points in the canal in percent and C is the factor of proportion. Then, the initial estimation of the concentration time is done using Kirpich equation (Maidment, 1993b), as follows:

$$T_C = 0.06628 L^{0.77} H^{-0.385} \tag{5}$$

Where Tc is the time of concentration in hr, L is the length of the canal in km and H is the average slope of the canal in %. By substituting the values of L and H in Equation (5), Tc is calculated. The following equation is used to calculate C:

$$C = t_C \sqrt{\frac{S_A}{L}} \tag{6}$$

which S_A is the slope of the main canal in percent. The calculated values of C are now used in Equation (4), and the travel between two points in the watershed is obtained using Equation (4). Then, the travel time between different points in the watershed is calculated, which the starting point of this operation is from the watershed outlet. Finally, all values of travel time for each canal will be extracted and shown on the map. Then, using Inverse Distance Weighted (IDW) (Childs, 2004), the isochron map of the watershed was prepared at regular intervals (Nema and Lohani, 2012).

2.6.2. Method 2

In order to extract isochrones in method 2, soil conservation service method was used (DHI, 2009):

$$T_{lag} = \frac{\left(L * 3.28 * 10^3\right)^{0.8} * \left(\frac{1000}{CN} - 9\right)^{0.7}}{1900 * Y^{\;0.5}} \tag{7}$$

Where T_{lag} is the lag time in hr, L is the hydraulic length of the watershed in km, CN is the curve number and Y is the average slope of the watershed in percent. All components of Equation (7) were prepared by GIS, the lag time was calculated and finally the travel time was calculated according to the following formula (Bilaşco, 2008):

$$Tc = \frac{Tlag}{0.6} \tag{8}$$

Flow Length function by Arc GIS was used to calculate the hydraulic length.

2.6.3. Method 3

In this method, the following formulas were used to prepare isochronic map:

$$vel = \frac{1.49 * \mathrm{H}_R^{\;0.667} * S^{\;0.5}}{N} \tag{9}$$

where *vel* is the flow velocity in feet per second, H_R is the hydraulic coefficient, S is the slope in percent, and N is the Manning's roughness coefficient. It should be noted that in this method, three flow regimes were used to apply the values of hydraulic coefficient and Manning's roughness coefficient, so that different hydraulic coefficient and Manning's roughness coefficient were applied for each flow regime. Therefore, the regions related to each flow regime were extracted from the cumulative flow map. For this purpose, first the cumulative flow map was prepared using the Flow Accumulation function by GIS and classified according to Table 2.

Finally, in order to apply the hydraulic coefficient and Manning's roughness coefficient for regimes 1 and 2, a descriptive data table was used, and to apply Manning's roughness coefficient for regime 3, Manning's roughness coefficients produced at the calibration stage of the hydrological model is employed. Also, Equation (10) was used to apply the hydraulic coefficient for regime 3.

$$H_R=0.32(a) + 1.7255 \quad (10)$$

where, a is the contributing area of the upstream watershed in square miles.

After calculating the flow velocity in m / s using the following equation, the travel time is calculated:

$$TC= \text{flow length}_{(\text{downstream})} / vel \quad (11)$$

Where flow length is the length of the flow in m.

Table 2. Flow regime classification (NRCS, 2009)

Flow type	Drainage area (acre)	Regime #
Low Retardance	0-2	1
Medium Retardance	2-40	2
High Retardance	>40	3

2.7. Prioritization of isochronic levels

In order to prioritize isochronic surfaces, we considered the contribution of sub-watersheds to the total discharge flow of the watershed (F) and the contribution of sub-watersheds in the flood of the watershed per unit area (f) as weighted coefficients. Then, by multiplying F or f by the contribution of each isochron to each sub-watershed and then the sum of these multiplications in the watershed, isochronic surfaces were prioritized.

3. Results and discussion

In this study, SCS-CN method is employed to estimate runoff and kinematic wave for routing. The parameters of curve number and Manning's roughness coefficient were calibrated as the most effective parameters on flow simulation. In order to determine the best search method and objective function, using different objective functions and two univariate gradient and Nelder-Mead search methods, values of peak flow and flood volume simulated by the model were compared with observed values.

In this comparison, the univariate gradient search method was selected as the best search method and the Nash-Sutcliffe objective function was selected as the best objective function due to the highest consistency of the simulated discharge in all three precipitation events with the observed discharge. Considering the NSE values of 0.885, 0.882 and 0.942 for the three events selected for calibration, it can be emphasized that the Nash-Sutcliffe objective function is suitable in this study. The simulated and observed peak flow and flow volume produced by HEC-HMS and best objective functions are shown in Table 3. It is indicating a very good agreement between the observed and simulated values and the reasonably proved proper selection of the objective function and search method.

According to consistency of the predicted hydrograph with the observed hydrograph in validation period (Table 4), it is possible to acknowledge the suitability of the calibrated model for predicting the floods of the studied watershed. Figures 4 and 5 show a comparison of the observed and simulated hydrographs of the precipitation event used to validate the model.

Table 3. Comparison of simulated and observed values of flood volume and peak flow during calibration process

Event date	Best objective function/Value	Flood volume (MCM)		Peak discharge ($m^3.s^{-1}$)	
		Simulated	Observed	Simulated	Observed
May 11, 1991	NSE/0.885	0.49	0.55	2.90	2.30
March 16, 1992	NSE/0.882	0.65	0.59	5.00	3.80
March 31, 1992	NSE/0.942	1.75	1.91	11.60	10.80

Table 3. Comparison of simulated and observed values of flood volume and peak discharge during validation period

Event date	Objective function value	Flood volume (MCM)		Peak discharge ($m^3.s^{-1}$)	
		Simulated	Observed	Simulated	Observed
May 30, 1993	NSE/0.948	0.67	0.73	5.1	6.5
March 5, 1996	NSE/0.892	2.24	2.08	15.7	15.2

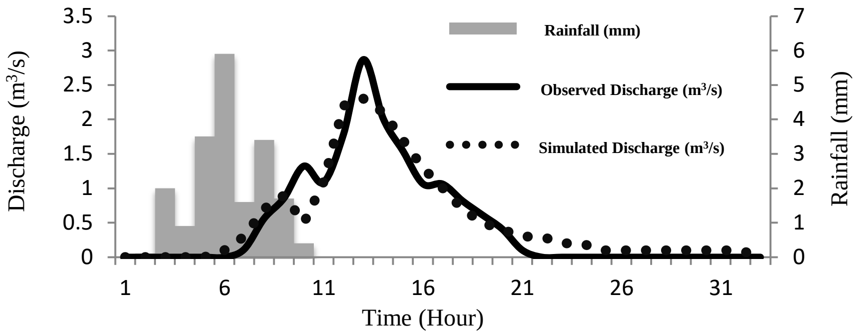


Fig. 4. Comparison of observed and simulated discharge (event May 30, 1993, used for calibrated model)

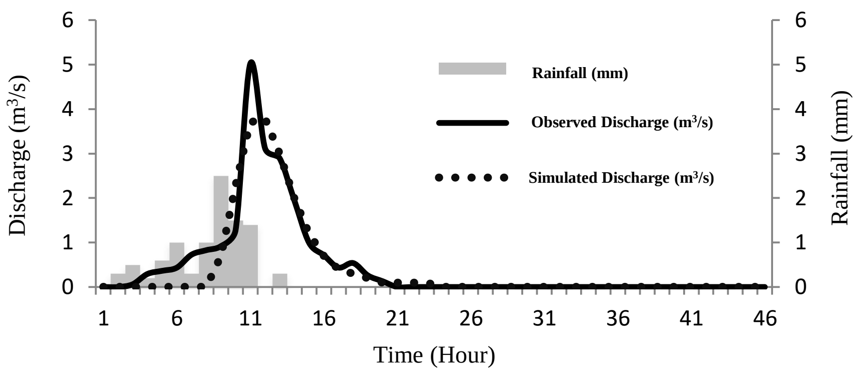


Fig. 5. Comparison of observed and simulated discharge (event March 5, 1996, used for calibrated model)

According to the result obtained from the calibration and validation of HEC-HMS model in the watershed, the suitability of this model can be used to predict possible floods. Studies in Golestan dam watershed, Khorasan Province (Saghafian and Farazjoo, 2007), MahRameh watershed, Fars Province (Zehtabiyan et al., 2010), Bustan dam watershed, Golestan Province (Bahrami et al., 2011), Gosh and Bahreh watershed, Khorasan Province (Nourali and Ghahraman, 2016) and Shamsabad watershed, Sistan and Baluchistan Province (Khosroshahi, 2016) also confirmed the efficiency of HEC-HMS model for flood prediction.

Since precipitation data may be distributed at the given interval, 6-hour precipitation calculated based on IDF curves was applied to the standard precipitation distribution of type Ia by SCS (McCuen, 1982) to distribute an event with 100-year return period. The peak flow in each sub-watershed was determined using the calibrated HEC-HMS model.

3.1. Effect of each sub-watershed on the flood

The results of the effect of sub-watersheds of the watershed using SSSE strategy through HEC-HMS hydrological model, for a storm of 100-year return period are presented in Table 5.

Table 5. The flood indices of F and f for different sub-watersheds for a 100-year return period

Sub-watershed	Area km^2	Peak discharge $\frac{m^3}{s}$	F (%)	f(%)
B1	16.94	44.10	0.09	0.01
B2	6.40	0.70	0.00	0.00
B3	7.20	21.80	19.44	2.70
B4	6.30	23.80	16.93	2.69
B5	4.22	16.60	9.72	2.30
B6	13.38	1.40	0.00	0.00
B7	4.76	15.20	10.24	2.15
B8	2.36	8.40	4.69	1.99
B9	5.06	11.50	3.39	0.67
B10	5.32	18.30	12.67	2.38
B11	3.27	0.30	0.00	0.00
B12	4.53	1.50	0.00	0.00
B13	3.92	0.00	0.00	0.00
B14	3.45	0.60	0.00	0.00
B15	6.05	6.30	16.32	2.70
B16	4.04	9.60	5.56	1.38
B17	5.19	6.10	4.51	0.87
B18	5.42	15.70	8.86	1.60
B19	2.82	0.30	0.00	0.00
B20	5.23	6.80	4.86	0.93

3.2. Isochronic surfaces

In order to conduct this study, it is necessary to select the most accurate and best map of isochrones. Since CN is one of the most effective factors on calculating the time of concentration and isochronic lines (Costache, 2014), methods 2 and 3 are much more accurate than method 1. In method 1, the maximum concentration time obtained is 3 h, which does not correspond to the observational statistics and the reality of the watershed.

On the other hand, between methods 2 and 3, method 2 has a more logical trend spatially than method 3, so that isochrones are somewhat different from each other. Also, temporally, the concentration time calculated by method 2 was more consistent with the concentration time in the observed hydrographs of the watershed (Figure 6), so method 2 was selected as the best method. It should be noted that several observational storms were used to calculate the concentration time. Thus, first Ø, which is an index of the loss in the watershed, was calculated according to the precipitation and runoff depth (McCuen, 1989).

Then, according to the definition of the concentration time, which is the interval between the end of excess precipitation and the turning point of the downward branch of the hydrograph (McCuen, 1989), the value of Ø of all total fractional and total precipitation hydrograph was obtained. Then, the interval between the turning point of the descending branch of the hydrograph and the end of the excess precipitation was measured.

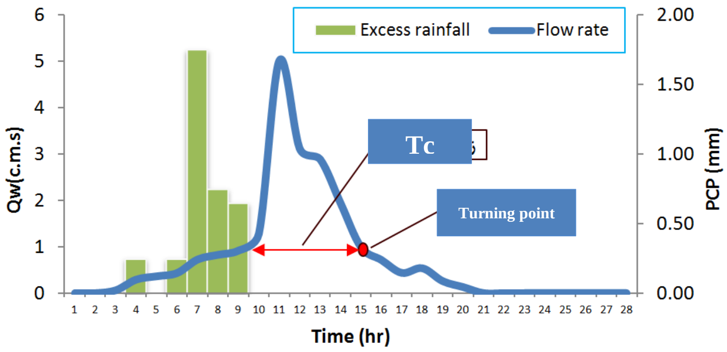
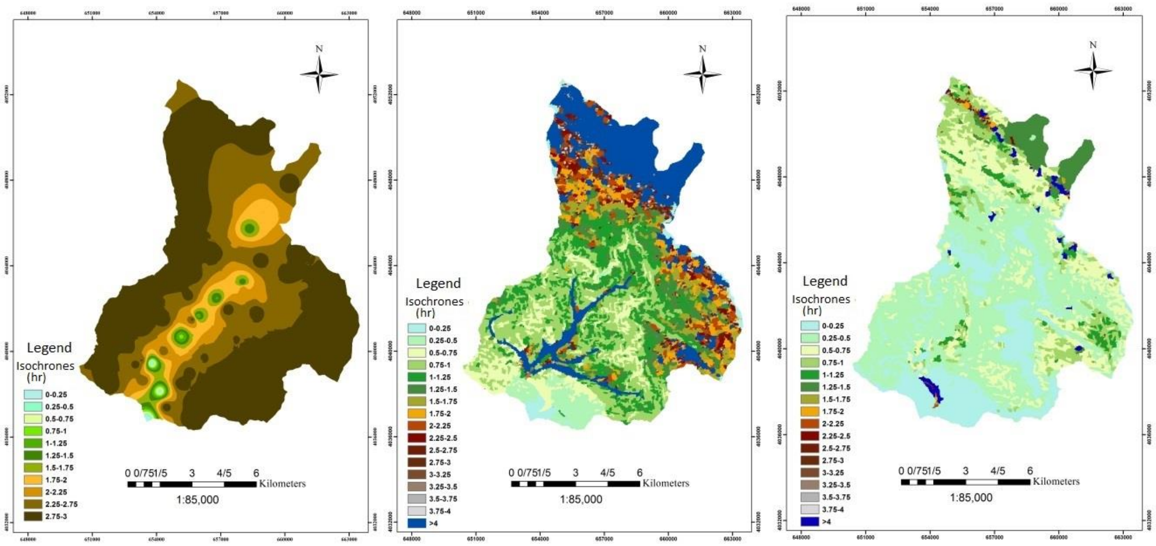


Fig. 6. Calculating the watershed's time of concentration based on the event dated March 16, 1992



(a) (b) (c)

Fig. 7. Isochronic maps extracted via the Method 1 (a), Method 2 (b) and Method 3 (c)

After selecting method 2 as the best method, the involvement percentage of each of levels was determined, the area (percentage)-time diagram (Figure 8) was drawn and the involvement percentage of isochronic surfaces in the discharge of each sub-watershed and the watershed was determined.

According to the analysis (Figure 9), the effect of sub-watersheds located at each of isochronic surface increases from the watershed downstream to the upstream, especially to 0.75-1 (middle belt of the watershed) and then the area reduces by reducing the effect of the peak discharge level and then > 4 has the largest area compared to other levels of flood hydrograph. This is in good agreement with Clark's theory of flood hydrograph using the area-time diagram. This means that assuming the same runoff production potential of the watershed, the largest isochronic surface made the peak discharge of hydrograph.

3.3. Prioritization of the levels affecting watershed floods

At this stage, according to the spatial distribution of each of isochronic level in the sub-watersheds of the study area, the specific effect of the flood of isochronic surface on the outlet of the watershed was investigated. So that by applying the mathematical model and flood routing, the effect of isochronic surface has been evaluated by eliminating the effect of sub-watersheds located at isochronic surface. The study results of flood routing in sub-watersheds located at isochronic surface showed that a reduction in peak discharge was directly related to the arcreage increase in isochronic level of the watershed (Figure 9). Meanwhile, the regions located at > 4 and -1.75 with a reduction of 49.10 and 40.93 m^3 / s had the greatest effect on peak flood discharge, respectively.

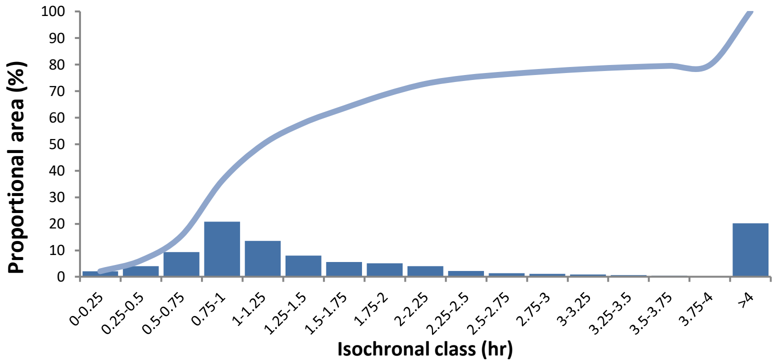


Fig. 8. Chart of area-time

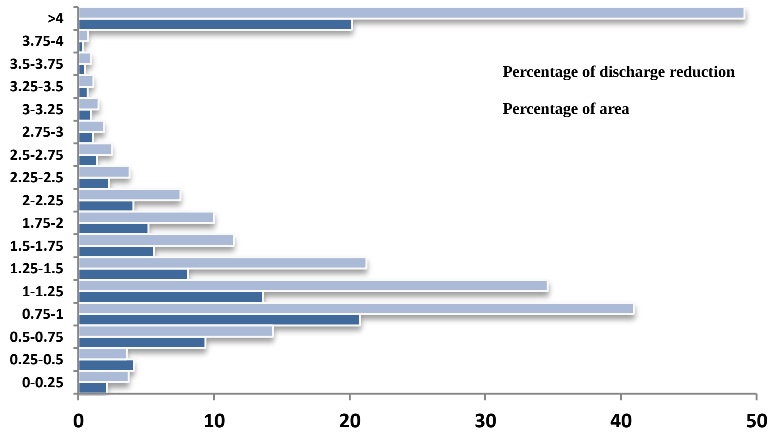


Fig. 9. The effect of isochronal area in peak discharge (in %)

Table 5. Prioritization of isochronic surfaces using the indices F and f

Isochronic surface	Percentage share of isochron surface * F	Percentage share of isochron surface * f	Prioritization based on F	Prioritization based on f
0-0.25	1.844	0.36	10	10
0.25-0.5	2.317	0.443	9	9
0.5-0.75	10.244	2.014	4	4
0.75-1	29.475	5.908	1	1
1-1.25	24.587	4.652	2	2
1.25-1.5	14.819	2.712	3	3
1.5-1.75	8.369	1.474	6	6
1.75-2	6.354	1.173	7	7
2-2.25	4.132	0.763	8	8
2.25-2.5	1.663	0.307	11	11
2.5-2.75	0.933	0.184	13	12
2.75-3	0.965	0.179	12	13
3-3.25	0.525	0.097	14	14
3.25-3.5	0.43	0.081	15	15
3.5-3.75	0.381	0.077	16	16
3.75-4	0.173	0.033	17	17
>4	9.755	1.887	5	5

In studies on prioritization based only on the peak discharge of the watershed without flood routing from the sub-watershed to the outlet of the watershed, the prioritization is considered over here and thus, the sub-watershed involvement in the flood of the watershed is not determined. Therefore, the watershed with higher peak discharge is the first priority. Table 6 shows the prioritization after flood routing of the sub-watersheds in the main watershed and based on the involvement of sub-watershed in the total discharge discharge (F) and the sub-watershed involvement in the total flood of the watershed per unit area (f).

In investigation of flood potential using the index F, the parameter of area plays an important role and the hydrological unit with the highest area consequently has the highest peak discharge and the first rank of flood if the area of flood potential of a region has little effect. There may be regions that have many flood conditions, but in this method, their role in increasing flood discharge is ignored. As shown in Figure 9, the isochron 0.75-1 with 20.74% acreage covered the most of the watershed area, and the isochron 3.5-3.75 and 3.75-4 with 0.47 and 0.35% acreage covered the least of the watershed area. Moreover, for prioritizing the isochronic levels in the flooding of the watershed using F, as shown in Table 6, the level of 0.75-1 is the first priority and the levels of 3.75-4 and 3.5-3.75 hours are last priorities. Although the level of > 4 covered 49.11% of the total discharge of the watershed, for the prioritization of levels using F is in tha priority of rank 5. This is due to the fact that more than 80% of the level of > 4 is included in the farthest sub-watershed from the watershed outlet, which in prioritization calculation using F the contribution of the sub-watershed B1 to the total discharge of the watershed was 0.09. Using f for prioritization, the parameter of area is eliminated, the specific discharge is calculated in some way and the potential for flooding is investigated. The results of prioritization using f showed that although the isochron of 1-1.25 has a smaller area than the level of > 4, it is the second priority. According to the results obtained from the relevant indicators, the isochrones of 0.75-1 and 1-1.25 hours have the highest flood potential in the watershed and should be given priority in management plans and project implementation. Similar studies such as Ghazanfarpour et al, (2009) and Izanlu et al. (2009) showed that investigation of flood potential of the watershed by investigating the role of the isochrones in floods can have an effective application in the executive planning of the watershed. According to the results of the present study, it can be stated that in terms of much less effect of the sub-watersheds near the watershed outlet, these regions are suitable for the development of such regions (urban, industrial, and etc.). The flooding of each of the isochrones cannot explain the selection to perform any corrective operations. Rather, the contribution to output should be considered. In the watersheds with diverse geological formations and the risk of river bank erosion, the application of the present model, while reducing the level of floods in the river, plays an important role in preventing river bank erosion and conservation of coasts and agricultural lands along the river and its floodplain. The extent of sub-watersheds located at isochronic surface is not directly related to their effect on peak flood discharge i.e. two identical sub-watersheds in terms of physical and hydrological profile, in two separate locations, have different effects on peak flood discharge. Determining the spatial index of flood effectiveness is a good criterion for prioritizing flood control operations. Also, in order to make the best use of watershed management operations to control floods, erosion and sediment, it is suggested to use the proposed solution in this study to prioritize isochronic level.

4. Conclusion

In order to prioritize the isochrones affecting the peak flood discharge and routing the discharge of sub-watersheds in the main canals to the outlet of the entire watershed in Neishabour, HEC-HMS hydrological model and SSSE were used. In the present study, the curve number and Manning's roughness coefficient are the most effective factors on flood discharge and volume. By comparing the peak discharge and flood volume simulated by the model with observed values, among the studied objective functions, the Nash-Sutcliffe objective function (NSE) and the univariate gradient search method according to the Nash-Sutcliffe values of 0.885, 0.883 and 0.942 for the precipitation events of May 11, 1991; March 16, 1992 and March 31, 1992 in the calibration process were considered as the best objective function and search method. Comparison of observed and simulated hydrographs at the watershed outlet indicated the efficiency of the model in simulating runoff volume and peak discharge. After calculating the peak discharge of each sub-watershed, the effect of each sub-watershed on the output flood was determined using the flood indices F and f.

Then, using three methods, isochrones of the watershed are extracted and method 2 due to the effective intervention of CN, logical spatial distribution and consistency with the concentration time calculated from the watershed observation hydrograph was selected as the best method and the spatial distribution of the sub-watersheds was investigated in the region. Since the interaction between spatial distribution of sub-watersheds and their flood potential played an important role in the formation of floods from the watershed, their effect on the peak discharge of flood hydrograph was investigated. The study results showed that >4 with an area of 23.3 km² had the greatest effect on the peak discharge of the flood from the main watershed. However, for prioritizing isochronic surfaces using F and f indices, the level of 0.75-1 located in the middle part of the watershed with an area of 24 km² was the first priority.

Compared to these regions, the levels near the outlet have played a much smaller role in peak discharge. In general, from the outlet to the upstream and middle parts of the watershed, along with increasing isochronic time level, the effect of sub-watersheds on peak flood discharge increases. Therefore, by focusing on watershed management and flood control operations based on priorities and designated regions, while achieving the objectives of the research, a significant reduction in the executive costs of the project is predicted.

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6. Conflict of interest

No potential conflict of interest was reported by the authors.

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