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Calculation of the Spatial Flooding Intensity with Unit Flood Response Method in the Tangrah Watershed, Iran

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Abstract

Increased flooding in recent years indicates that most parts of the country are subjected to periodic and destructive flood attacks. Therefore, the identification of high-risk areas with potential runoff production within a watershed area is one of the most important measures in flood control and reduction of the damage caused by it. In this study, the quasi-distributional ModClark method was employed to simulate the hydrograph of flooding, and the unit flood response method was applied to determine the intensity of flooding of different areas of the Tangrah watershed, Iran. For this purpose, the ModClark model was first calibrated and verified. Thereafter, the design of rainfall with 50 and 100-year return periods (T_r) was extracted at the Tangrah station and the design flood was calculated with the above-mentioned return periods. By combining the curve number layers, slope, precipitation, and flow distance, homogeneous units were obtained in terms of the flood. The effect of each homogeneous unit on the total watershed output was obtained by the removal of each unit and implementation of the rainfall-runoff model. According to the 100-year return runoff production potential, homogeneous units of 116 with a *fi* (0.54 m^3/ s. km^2) were identified as the most effective cell in the Tangrah watershed area, which could be explained by the soil type, vegetation, and other physical factors of these units.

Keywords: ArcGIS; Distributed Model; Flooding Map; ModClark Model; Unit Flood Response.

1. Introduction

Flood management is carried out at four levels, these include prediction, preparation, prevention, and evaluation of damage [1]. One of the measures to reduce the risk of flood in the lower reaches is to resort to flood-control at its source. Therefore, it is important to identify flood-prone areas in watersheds for flood-control operations. In determining the flooding of large watersheds, it is essential to divide the watershed into hydrological units and investigate the potential of each unit in terms of flood participation at the outlet of the watershed. One of the methods for identifying flood-prone areas is the unit flood response method [2]. Generally, the flood-prone changes are controlled by three factors: soil, vegetation, and topography [3]. Several studies have been conducted on flooding. Juracek (2000) identified the priority of flood-prone sub-basins in large watershed areas of 150 to 6600 km^2 in the state of Kansas, USA. In this study, the effect of spatial distribution of rainfall intensity was studied. The results revealed that the differentiation of flood-prone sub-basins was very limited [4]. Saghafian et al. (2002) presented a novel method based on the development of the concept of time-area for distributed modeling. In this method, a digital elevation model, slope, flow direction, and flow

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density maps were used [5]. Foody et al. (2004) employed the HEC-HMS model to simulate the flood in order so as to identify flood-sensitive areas in an area in western Egypt which led to the identification of two sensitive areas [6]. Knebl et al. (2005) conducted a modeling of the flood streaming in the summer of 2002 using HEC-HMS and HEC-RAS software and radar data in the San Antonio Watershed in the United States. They used the ModClark method to convert rainfall into runoff and calibrated watershed parameters manually. The results showed that the model was a suitable tool for regional hydrological forecasting in the basin [7].

Khosroshahi and Saghafian (2005) investigated the response of Damavand watershed sub-basins using the HEC-HMS model. In this research, the contribution of each sub-basin was calculated in peak discharge of the output flood such that no single-variable relationship exists between the flood index and other characteristics of the sub-basins, including the curve number and ground gradient [2]. Studies by Linde et al. (2008) demonstrated that distributive models were better than Lumped reality models in terms of showing the reality [8]. Plate (2009), in his paper, divided the hydrological models for flood management according to scale into models based on rectangular grids, models based on sub-basins, and models based on response units, and in terms of determining the flood hydrograph on the basis of given frequencies referred to both in continuous and real-time modeling [9]. Paudel et al. (2009) compared the distributed and Lumped models using radar data and HEC-HMS hydrologic software. The results of this study showed that by using the same CN values, the ModClark method offered better results than Clark's [10]. Chidaz et al. (2009) evaluated the HEC-HMS model in the Kasilian watershed. In this research, by using the sequential elimination method of sub-basins, the role of all sub-basins in the outlet flood hydrograph was determined. The results showed that the study of participation of sub-basins in the outlet flood was not directly related to their area [11]. Saghafian et al. (2010) studied the flooding of the Rudzard watershed area by using the unit flood response method in sub-basins and cellular units. The results indicated that the largest and closest sub-basins to the outlet or the furthest and smallest basins did not necessarily have the highest and lowest impacts on the maximum flood discharge [12].

Golian et al. (2010) simulated the spatial distribution of rainfall with the Monte Carlo (MC) method and the mean Huff pattern for all rainfall durations was imposed for the temporal distribution. For each of the MC run, the random weight assigned to every sub-watershed follows the Probability distribution Function (pdf) of weights in historical rainfall events. The HEC–HMS model with two different infiltration methods namely SCS–CN and Green–Ampt and Muskingum river routing were adopted as the hydrologic model. After the calibration and validation of the model for Madarsoo watershed in Golestan province in Northeastern Iran, the MC simulations were performed for 1,2, 6 and 12 h durations. The outputs from the SCS–CN method exhibit only a slight increase in threshold values with respect to duration and was not in the range of our expectations from watershed response, i.e. the rainfalls with greater durations should be greater in depth to produce a specific peak discharge. For the Green–Ampt infiltration method, the rainfall thresholds with 50% probability associated with the critical discharge under dry soil moisture condition were 44.5, 49.0, 64.2 and 94.6 mm for 1, 2, 6 and 12 h durations, respectively. Results for July 2001 flooding revealed that the cumulative rainfall intersected all 10%, 50% and 90% rainfall threshold curves but for July 2005 flooding the 10% curve was only intersected by the cumulative rainfall curve. The advantage of MC-derived rainfall threshold curves in real-time operations is that decision-makers have the flexibility to adopt a curve more consistent with flood observations in the region [13].

Ghavidelfar et al. (2011) compared Clark lump and ModClark distributed models in the Randan watershed in Tehran province. The results revealed that both models accurately simulate flood hydrograph. They argued that ModClark distributed model in the estimation of time to peak and runoff volume showed better results compared to peak discharge [14]. Bakhtyari-kia et.al. (2012) utilized an artificial neural network to identify areas with a potential of runoff production in the Johor River watershed in Malaysia [15]. Shafapour Tehrani et al. (2013) identified areas with a potential of runoff production using RS and GIS Remote-Sensing techniques and two different approaches of Decision Tree and composition of abundance and logistic regression in the Malaysian Kelantan basin. Maps of the altitude digital model, slope form, geology, river network, power of flow index, rainfall, land use, moisture index and slope were used as spatial data. Finally, a potential runoff production map was prepared [16]. Halwatura et al. (2013) simulated runoff in the tropical region of Attanagalu Oya from the HEC-HMS model. Their research results demonstrated that the Snyder's unit hydrograph method is more accurate in comparison with the Clarke unit hydrograph method in flow simulation [17]. Shabanlou (2014) in a study titled "Flood Hydrograph Calculation Using Different Methods in the Karun River" simulated flood hydrograph in Karun watershed using the SCS Model with HEC-HMS Software, and compared this model with the ModClark model using GIS with the use of both distributed and lump mathematical models. From the field data, the results of the distributed model are closer to the recorded hydrograph of the basin [18]. Studies by Jiang et al. (2015) in relation to rainfall-runoff modeling, parameter estimation and sensitivity analysis in Luanhe Province, China, showed that the distributed model has a better performance than the Lumped model [19]. Thomas and Roy (2016) investigated the comparison of hydrograph extraction in the Bharathapuzha River Basin. According to this study, because in most areas without statistics, the preparation and development of unit hydrograph is difficult, therefore, the incompatibility of observation simulator hydrograph can be attributed to the large area of the watershed [20].

Saghafian et al. (2016) investigated a coupled ModClark-curve number rainfall-runon-runoff model. In this Research, a novel rainfall-runon-runoff mathematical model is developed via Soil Conservation Service (SCS) infiltration and ModClark rainfall-runoff coupled models. After deriving model formulation, three different spatial patterns of curve number (uniform, downstream increasing, and decreasing) in conjunction with various rainfall durations and intensities were investigated under with and without runon scenarios over a V-shaped watershed. The results indicated that there was lower surface runoff volume and peak discharge in all cases when runon was accounted for. In Particular, in regions with low curve number, there were major differences between the hydrographs simulated by the commonly practiced no-runon model and the presented runon model. Moreover, the runon effect in case of decreasing curve number in downstream direction was more pronounced than that of the increasing case. However, this effect decreased with depth, intensity, and duration of rainfall [21]. Rezaei et al. (2016) in their study "Spatial variability of flooding using unit flood response in the Khanmirza watershed," showed that flooding potential increased from the downstream to the upstream watershed, showing the importance of management and flood prevention and watershed management plans at the source. In this research, the objective is to determine flooding in distributional and sub-basin forms and to compare them with the Tangrah watershed [22].

2. Materials and Methods

2.1. Study Area

Tangrah watershed with an approximate area of 186,000 hectares is part of the Madarsoo watershed in Golestan province in Northeastern Iran. The runoff from this watershed zone enters the Golestan dam through the Dough River (Figure 1).

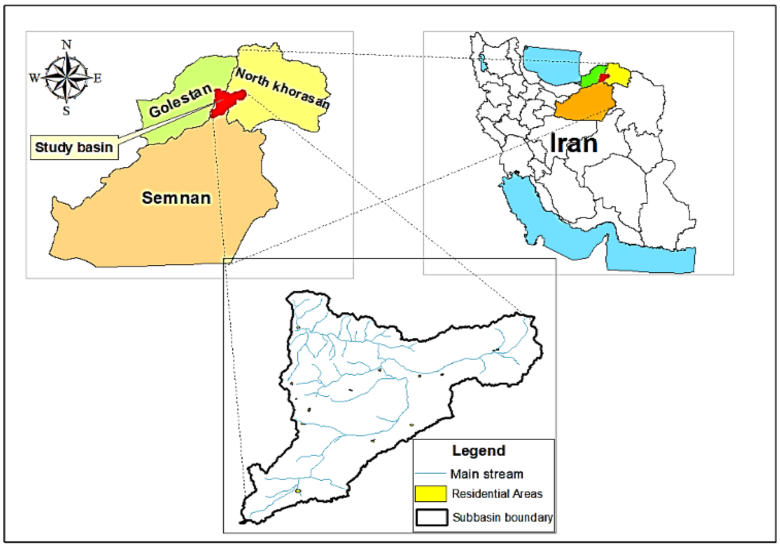

Figure 1. Position of study area (Madarsoo, Tangrah watershed and Dough river)

The average annual rainfall of this basin is 425 mm and the average annual temperature is 14.3 ºC. There are many differences between Tangrah subbasin and other subbasins located in upstream from the viewpoints of climatic condition, plant cover, geology, physiography and geomorphology. In study area, maximum Drainage density exist in tow sub-basins Dasht and Dasht -e- Sheikh and maximum main stream slope in Tangrah and ghizghaleh subbasins, respectively.

The study area has 7 stations, contain: climatologic, Normal rain gauge and Rain recorder. the Tangrah watershed has two hydrometric stations at Dasht and Tangrah, the only active hydrometric station being the Tangrah station. The rain-gauge station of the Golestan National Park is the only station with adequate statistics on the basin [23]. The study area is one of the most vulnerable flooding areas in Iran. In the past two decades, the region encountered devastating floods, e.g. in summer of 2001, 2002 and 2005 and spring of 1992 [13]. Among the factors influencing the determination of the Tangrah watershed, Iran, for studying this Research are: the area,the morphometric and morphological diversity of the region, the existence of an active hydrometric station in the catchment outlet, the existence of the active rexording rain gauge station inside the basin, the flooding potential and the high runoff production potential, the existence of a sufficient number of rainfall events with the presence of rainfall-runoff data in the area. Table 1 shows some of the physiographic characteristics of the sub-basins of the Tangrah watershed, and Figure 2 depicts digital elevation model of the study area.

Table 1. Area and perimeter of sub-basins of Tangrah watershed

Mean slope (percent)	perimeter (km)	area (percent)	Area (km^2)	Subbasin
18	242	40	752	Nardin
17	54	8	146	Dasht-e-Sheikh
19	143	24	453	Cheshmehkhan
24	63	7	125	Ghizghaleh
15	15	1	12	Dasht
50	147	20	372	Tangrah
	664	100	1860	Total

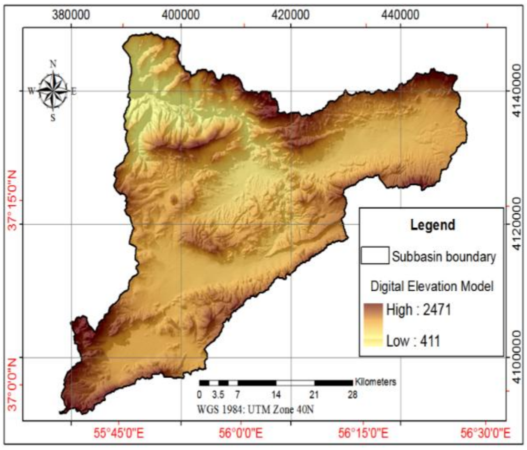

Figure 2. Elevation Digital Model Map of Tangrah Watershed

2.2. Research Method

The required information for this study is a topographic map of 1: 25000, a CN map (Figure 3), hyetograph and hydrographs related to each rainfall event during a long-term period. The hyetograph and hydrograph of the 38-year statistical period were prepared from the Golestan Regional Water Authority and the Water Research Institute. After preparing the DEM (Digital Elevation Model) map, all the stages of the watershed model were prepared, including the flow direction, flow accumulation, and the river and the sub-basin boundary map, using the GIS.

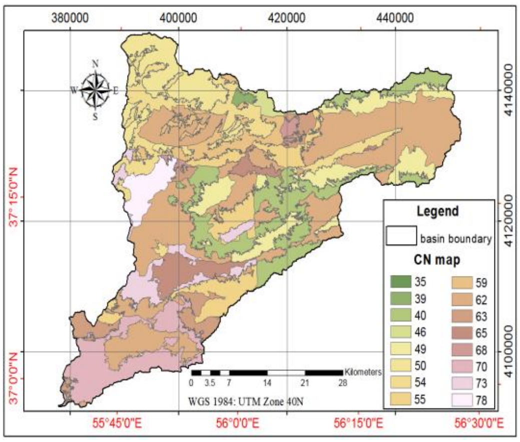

Figure 3. Map of curve number of Tangrah Watershed in moderate humidity

In this research, the inputs of the rainfall-runoff model were extracted and then calibrated and validated. In the next step, in order to determine the flooding of homogeneous units and sub-basins with unit flood response method, sequential removal and replacement of these units and simulation of flood hydrographs for designed rainfall were carried out. Then the effect of each homogeneous unit and sub-basin on the total output hydrograph in the watershed was calculated. The total number of simulations by the model is equal to the total homogeneous units.

In this method, the effective precipitation in each cell with a delay time is proportional to the length of the movement of that cell to the watershed outlet. The time of travel of each cell to the outlet of the watershed is proposed by relation (1) [24].

$$T_{cell} = \frac{T_c * L_{cell}}{L_{max}} \tag{1}$$

Where T_{cell} is the travel time from each cell to the watershed outlet, T_c is the watershed time of concentration, L_{cell} the distance between each cell to the watershed outlet, and L_{max} the maximum length of the water flow in the watershed. At the end, the obtained hydrograph is processed according to the relationship in the linear reservoir.

$$S_t = K * O_{(t)} \tag{2}$$

In which, $S_{(t)}$ is the reservoir at time *t*, O_t the output of the reservoir at time *t*, and *K* is the Clark reserve coefficient. In this study, software based on the ModClark method and developed by Alvankar et al. (2006) in the Visual Basic environment has been used [25]. By examining the available data, seven rainfall events with accessible rainfall-runoff information were selected. For calibration and validation of the incident model, the events were classified into two categories and five events were selected for calibration and two events for validation. At the time of the occurrence of each flood, by using the daily precipitation recorded at the rain gauge stations inside and around the Tangrah watershed, the spatial distribution of the storms was extracted using an Inverse Distance Weighted (IDW) method in the GIS environment. The time distribution of the storms was also determined using the rain gauge data recorded at the Golestan National Park's rain gauge station. The time of concentration of the Tangrah watershed was calculated using the Bransby Williams method (recommended for basins larger than 50 square miles). The reserve coefficient was used by a graphical method [26] and as a preliminary estimation in the calibration step. The watershed curve number was also calibrated using a coefficient. The steps in implementing the Clark model are presented in Figure 4.

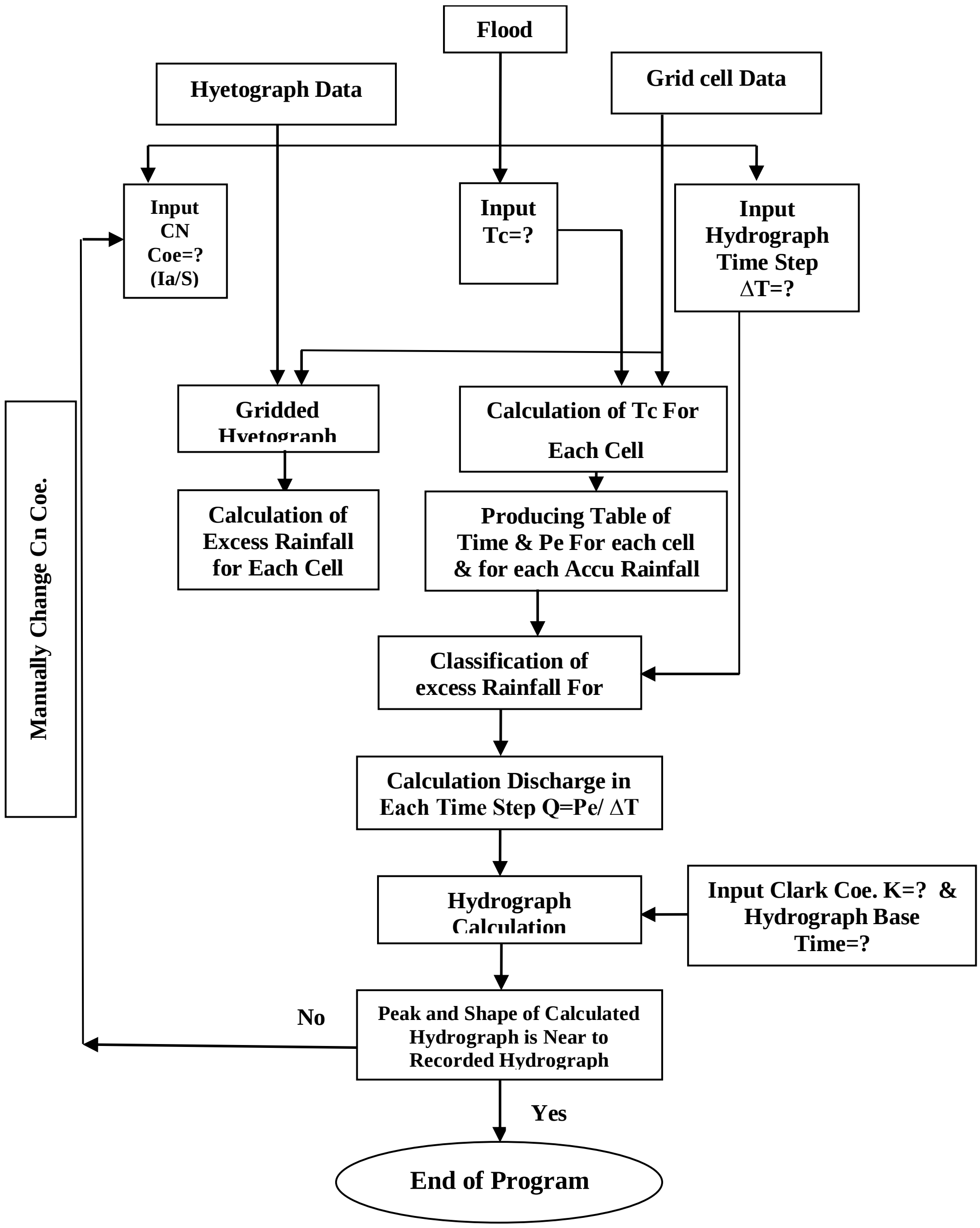

Figure 4. Flowchart of methods in the ModClark method

After calibration and validation of the model, design storm of the Golestan National Park station plan was first extracted to determine the flood-prone areas. Based on the intensity-duration-frequency curve (IDF) of the Golestan National Park station, the rainfall intensity for the return period of 50 to 100 years was estimated in terms of the time duration of concentration. The spatial distribution of design rainfall was done from the correlation between the height and depth of the annual rainfall. Then, in order to determine the flooding, each slope map, CN, flow length, and the average annual precipitation of the watershed were divided into four classes. After integrating the maps, the homogeneous units were coded in the GIS environment. In order to determine the effect of each homogeneous unit on the flood discharge, and to prioritize them in terms of flooding based on the unit flood response method, first, the output flood hydrograph for the rainfall was calculated at the return periods of 50 and 100 years with the participation of all watersheds. Then, the simulation was repeated with the successive deletion of each homogeneous unit and their effect on the water outlet of the entire watershed was determined at the simulation stage and the participation rate of each cell and sub-basin on the output peak discharge. In order to evaluate the effect of each cell on the output peak discharge, the flooding index (f_i) presented in Equation 3, was used [12].

$$f_i = \frac{\Delta Q_i}{A_i} \tag{3}$$

In which f_i is the flooding index of the sub-basin, im ($m^3.s^{-1}.km^{-2}$), ΔQ_i is the change of the output peak flow of the watershed zone determined by removing the sub-basin im ($m^2.s^{-1}$) and A_i is the area of the sub-basin im (km^2).

Finally, to determine the distribution of *fi* with rainfall height, slope percentage, curve number and distance of each unit from the output, each of the values of the following equations were standardized after extracting the values for each unit from the GIS software.

$$Z_{CN} = \frac{CN - \overline{CN}}{CN_{max} - CN_{min}} \tag{4}$$

$$Z_R = \frac{R - \overline{R}}{R_{max} - R_{min}} \tag{5}$$

$$Z_R = \frac{FD - \overline{FD}}{FD_{max} - FD_{min}} \tag{6}$$

$$Z_S = \frac{S - \overline{S}}{S_{max} - S_{min}} \tag{7}$$

In these relationships, Z_{CN} is the standardized value of *CN* (between -1 and +1); *CN*, is the curve number of each unit; ($\overline{CN}$), is the average curve number of all units; CN_{max} and CN_{min}, respectively are the maximum and minimum number of curves in units; Z_R, is the standard value of rainfall; *R*, is the rainfall of each unit; $\overline{R}$, is the average rainfall of all units; R_{max} and R_{min} are respectively the maximum and minimum rainfall of units; *FD*, is the distance from the output; $\overline{FD}$, is the average distance from the basin outlet; FD_{max} and FD_{min} are respectively the highest and the lowest distance of units from the basin outlet; S is the slope of each unit; $\overline{S}$, is the mean slope of all units; and S_{max} and S_{min} arethe maximum and minimum slope among units, respectively.

3. Results

Table 2 shows the parameters calibrated by the ModClark method. Thus, the ratio of initial losses decreased from 0.2 in the calibration phase to 0.15 and the coefficient of curve number increased by 10%. This indicates that the initial losses in the basin are low, but the calculated *CN* values are less than the values in reality. The time of concentration and the reserve coefficient parameters did not change much compared to the initial values. The results of the simulated hydrographs using the ModClark model in selected events and the results of the model evaluation in estimating the flood hydrograph characteristics are given in Figure 5 and Table 3, respectively. This model simulates the maximum discharge very well, and it was only just less than accurate on May 25, 2003 with an efficiency coefficient of 0.81. The model verification was done with the evaluation of two dates which shows that the modeling had good accuracy.

Table 2. Hydrological parameters of watershed before and after calibration

Calibration parameters	Calibrated value	Initial value
Curve Number Coefficient	1.1	1
Time of Concentration (hour)	25.93	25.93
Initial losses Ratio	0.15	0.2
Reserve Coefficient (hour)	23.2	25.93

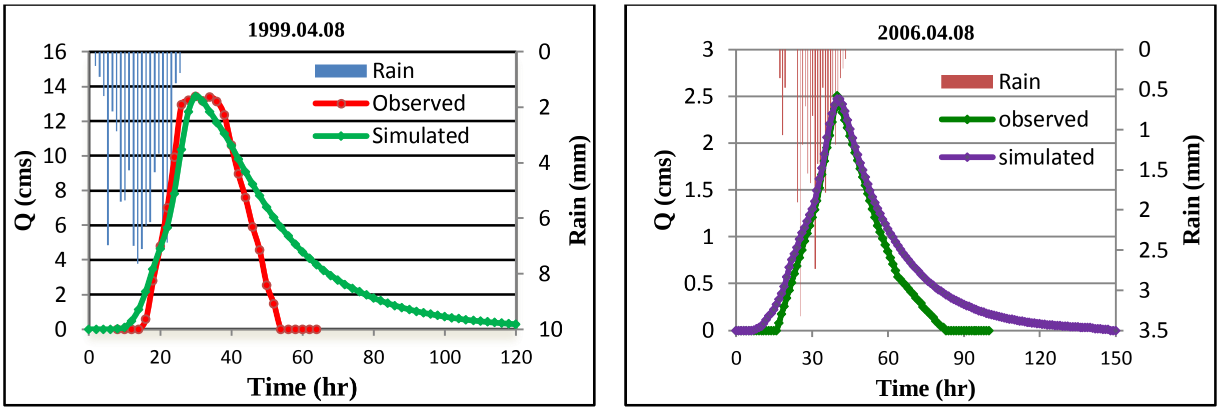

Figure 5. A sample observation hydrograph and simulation using the ModClark model in the validation step

In the validation step, the accuracy of the model was obtained with the Root Mean Square Error (RMSE), Efficiency Coefficient (EC) and coefficient of determination (R^2) which were equal to 1.55, 0.8 and 0.84, respectively. The accuracy criteria of the model represent the model's ability to simulate the hydrograph and are consistent with the results presented by Paudel et al. (2009), Saghafian et al. (2010), Ghavidelfar et al. (2011), Rajabi and Shabanlou (2012) [27], and Jiang (2015).

Table 3. ModClark Model Assessment Results for Estimating Flood Hydrograph Specifications

Relative error (percent) of hydrograph factors			Accuracy criteria of peak discharge			Date of event	stage
Peak discharge	Time to peak	Base time	Determination Coefficient (R^2)	Efficiency Coefficients (CE)	Root Mean Square Error (RMSE)		
0.03	38.89	38.46	0.46	0.81	11.72	2003.05.25	Calibration
0.05	14.71	17.02	0.46	0.41	0.058	2003.11.03	
0.02	21.21	25.53	0.79	0.8	9.96	2004.05.05	
0.23	38.1	30.95	0.56	0.45	2.54	2004.09.18	
0.09	4.34	11.76	0.55	0.1	2.39	2005.10.08	
0.08	23.45	24.74	0.56	0.51	5.33	Average	
6.33	20	10.34	0.74	0.73	2.81	1999.04.08	Validation
4.06	7.5	30.95	0.93	0.87	0.28	2006.04.08	
5.2	13.75	20.65	0.84	0.8	1.55	Average	

Figures 6 and 7 show a map of the potential runoff production categories pertaining to the return periods of 50 and 100 years, respectively. According to the runoff potential mapping in both return periods, the homogeneous unit of 116 with a *fi* ($m^3/s.km^2$) was 0.43 (at the return period of 50 years) and 0.54 ($m^3/s.km^2$) (at the return period of 100 years) was identified as the most effective unit in runoff production in this basin. According to Table 4, in the 50-year return period, very low class flooding intensity area (51.81%), and in the 100-year return period, very low class flooding intensity area with the area of 47.24% have the highest area.

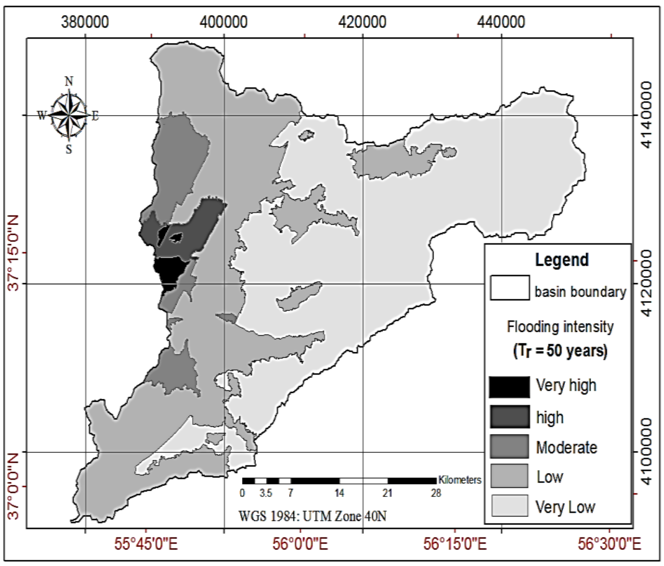

Figure 6. Map of the potential runoff production classes with the 50-year return period of Tangrah watershed

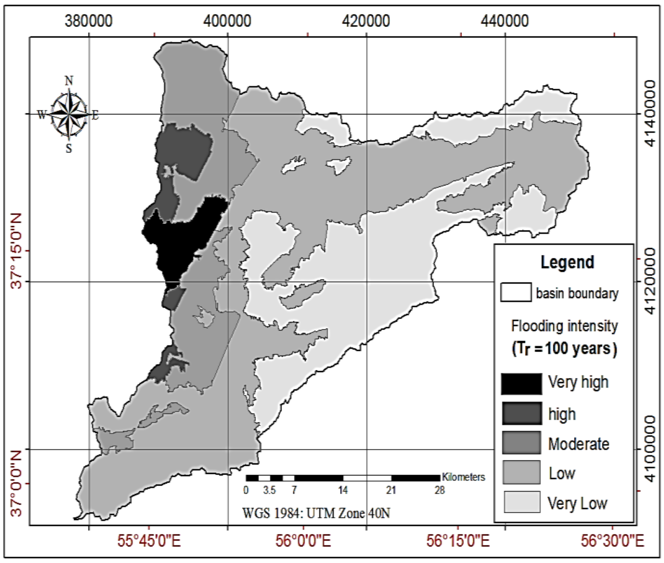

Figure 7. Map of the potential runoff production classes with the 100-year return period of Tangrah watershed

Table 4. Percentage of different areas of potential runoff production in Tangrah watershed

Return period of 100 years		Return period of 50 years	
Area (%)	Flooding Intensity Class	Area (%)	Flooding Intensity Class
3.34	Very high	0.93	Very high
3.84	High	2.41	High
15.48	Moderate	6.14	Moderate
47.24	Low	38.71	Low
30.1	Very low	51.81	Very low

4. Results for Sub-Basin Flooding Prioritization

The priority mapping of the sub-basins runoff potential based on the *fi* at the return period of 100 year is shown in Figure 8. The results of the prioritization of sub-basin flooding showed that the sub-basin of Ghizghaleh, with *fi* 0.2 ($m^3/s.km^2$) was in the class of very high in the map of runoff production and Cheshmehkhan and Dasht-e-Sheikh sub-basins with *fi* 0.04 ($m^3/s.km^2$) were on the class of very low potential for runoff production. According to Table 5, the results of peak flow values and the *fi* of each sub-basin showed that greater area and less distance from basin outlet did not necessarily have more effect on the outflow, but factors such as land use and hydrologic group of sub-basin soils affect peak output discharge and flooding which is consistent with the results of the research by Saghafian et al. (2006).

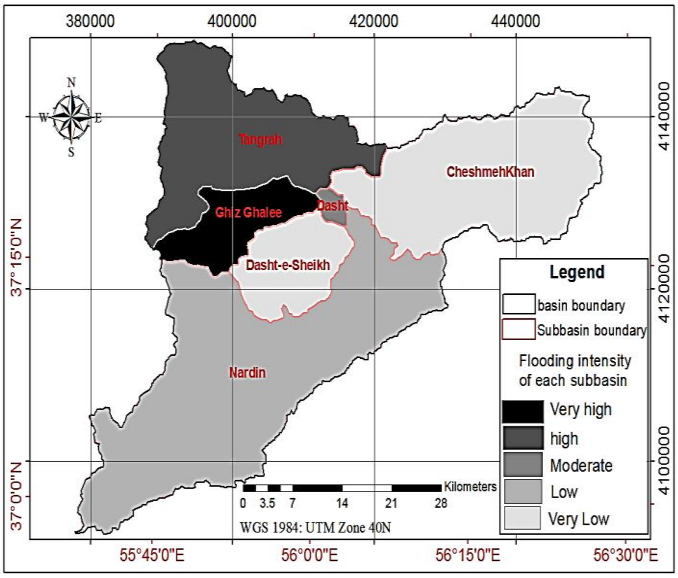

Figure 8. Flooding map of the sub-basins of Tangrah watershed with a Return Period of 100 years

Table 5. Peak flow and 100-year flooding classes of each sub-basin

Class	Flooding index of sub basin ($m^3/s.km^2$)	Average of flooding index homogeneous units	Peak discharge (m^3/s)	Area(%)	Sub basin
moderate	0.088	0.09	184.44	0.66	Dasht
Very low	0.045	0.04	179.31	7.82	Dasht-e-Sheikh
Very high	0.219	0.15	163.37	6.71	Ghizghaleh
low	0.062	0.08	144.01	40.43	Nardin
Very low	0.045	0.04	167.69	24.36	Cheshmehkhan
high	0.15	0.14	129.32	20.01	Tangrah

The results of sub-basins *fi* showed that the intensity of sub-basin flooding was not influenced by only one factor, and the combined effect of parameters especially *CN*, rainfall ratio of each sub-region, time of concentration, and distance to output were more effective. Figures 9 and 10 show the distribution of *fi* with the curve number, rainfall heights, distance from the outlet, and the slope percentage of all units in the basin.

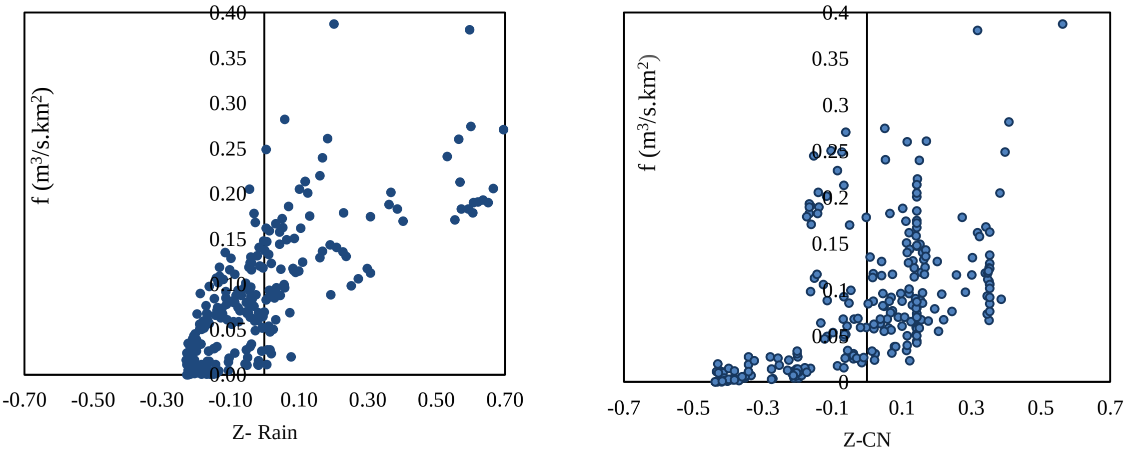

Figure 9. *fi* against rainfall height and standardized curve numbers

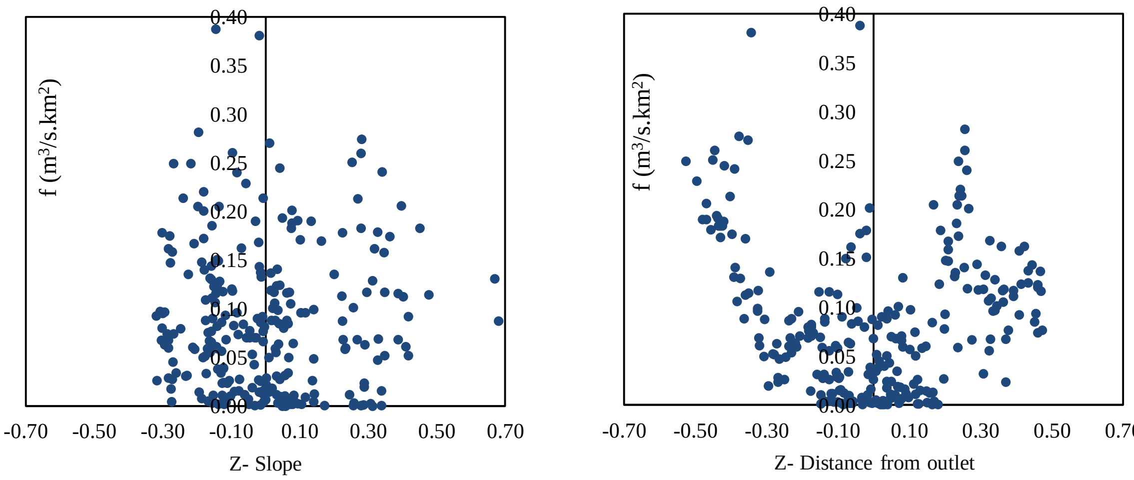

Figure 10. *fi* versus slope percentage and distance to standardized output

In this research, the distribution of the *fi* with the curve number, distance to output, and slope percentage and rainfall height of all cellular units found in the basin has been obtained (Figures 9 and 10), in which Figure 9 shows that with increasing rainfall, the index of flooding increases. Moreover, the *fi* increases with an increase in the curve number, but the distance to the outlet and the slope percentage did not follow a specific distribution (Figure 10). The results of the distribution of the flood index indicated that only one parameter of each homogeneous unit could not determine the *fi* of that unit, which is consistent with the results of Saghafian et al. (2010). The curve number and rainfall were directly related to the flood index, but the percentage of slope and distance to the outlet did not show a specific relationship with the *fi*, therefore, it can be concluded that it is more important to determine the index of flooding, rainfall, and *CN*.

5. Discussion

One of the proposed methods for identifying areas with a potential for runoff production is the unit flood response method. In this method, the processing of runoff from the design rainfall, and the determination of the effect of each of these units on the output flood from the total basin are done by successive removal of units within the basin. According to this method, it is possible to prioritize areas with a potential for runoff production.

The results revealed that by using the distributional characteristics of the ModClark model, we can study the potential of runoff production in cellular units of any small size requiring accurate inputs to the model. From the results of this study, it can be concluded that although a sub-basin may have low flooding in the scale of prioritization of the sub-basin, smaller units within it may have high flooding, indicating the importance of determining the flooding as a distribution in a flood-control project.

According to the runoff production potential in the return period of 50 and 100 years, it was found that the runoff production potential increased from the upstream to the downstream of the basin, and the homogeneous unit of 116 with a *fi* 0.54 ($m^3/s.km^2$) was identified as the most efficient cell in the flooding. It must be stated that in this basin that due to a higher rainfall, the steep slope, and a high CN, the flooding close to the outlet of the basin was higher than that of the upstream areas, a finding different from investigations by Saghafian et al. (2010) and Rezaei et al. (2016).

In Table 5, the *fi* of the sub-basins and in Figure 8, the potential runoff production map in the sub-basins indicate that the Ghizghaleh sub-basin with *fi* 0.21 ($m^3/s.km^2$) is the most flood-prone zone of the sub-basin and in studying the topographic specification of the area, Ghizghaleh was found to be the steepest sub-basin. Its *fi* indicated that it was located in a high-risk class and it was clear from this table that the largest and nearest sub-basin or the farthest and smallest sub-basins did not necessarily have the most and the least effect on the maximum flood discharge in the basin output. Factors such as land use and the hydrological group of the sub-basin soil could have a greater effect on the peak flow and the runoff production potential. The flooding intensity of sub-basins is not influenced by one agent alone, and the combined effect of the parameters, in particular the CN, the rainfall ratio of each sub-basin, time of concentration and the distance to the outlet have more effective roles.

The results of this research show that the participation rate of sub-basin in output discharge of the entire basin is not affected by area and peak flow of the sub-basin, but factors such as the spatial location of the sub-basins, distance to output, CN coefficient, and the role of the route of the main river have a significant impact on the flooding of the sub-basins. For example, the Nardin sub-basin which is ranked first in terms of area and account for about 40% of the total area is in the fourth place in terms of participation in the flood output of the entire basin. The results of the distribution of *fi* (Figuers 9 and 10) also indicated that the distance from the outlet and the slope percentage had no correlation with *fi*, and it can be concluded that only the distance from the output and the percentage of the slope of each cell cannot determine the *fi* of that cell, which is consistent with the results of Saghafian et al. (2010). The results of this research show that by integrating the Geographic Information System (GIS) and hydrological models, we can study the interactive effect of physiographic and climatic factors on the flooding potential of the watershed and with regard to a simultaneous peak flow and role of flood routing in rivers, we can prioritize sub-basins in the most desired way, a characteristic consistent with the results of Khosroshahi and Saghafian (2005).

6. Conclusion

Considering the high accuracy of ModClark’s distribution model, by using this hydrologic model, we can study the interaction of physiographic and climatic factors on the potential of watersheds' runoff production. Also, the results showed that because the use of the ModClark’s distributive model requires highly precise inputs, therefore; it is possible to use this method in very important tasks such as determining areas with high runoff potential in very small units. The results of this research can be used in flood-control planning for small structures and reinforcing them, land-use and vegetation management, conservation and control programs, and rainwater harvesting projects. The results of this study can also be used to determine the location of the installation of flood measurement and flood warning devices in flood prone sub-basins. Since prioritization in terms of sub-basin and cellular model has the same results, it is suggested that prioritization can be done in the case of a sub-basin unit if it is not necessary for smaller units than the sub-basin. Since the SCS-CN method is sensitive to the depth of precipitation, it is suggested that other methods of estimation of infiltration should also be used and their results should be investigated. It is recommended to use other distributive models for rainfall-runoff modeling and compare with the present study and the effectiveness of the Modclark model in more watersheds of the country should be investigated in order to determine its applicability according to different conditions in watersheds with different climatic and geomorphologic conditions.

7. References

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