

Flood hazard zoning using HEC-RAS in GIS environment and impact of manning roughness coefficient changes on flood zones in Semi-arid climate

M. Golshan^a, A. Jahanshahi^a, A. Afzali^{b*}

^a *Department of watershed Management, Faculty of Natural Resources, Natural Resources and Agricultural Science University, Sari, Iran*

^b *Desert Management Dept., International Desert Research Center (IDRC), University of Tehran, Tehran, Iran*

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Abstract

Development of rural areas in rivers margins and flood plains, without understanding and attention to the dynamical and hydrological conditions and upstream areas of the rivers will cause to increase flood risk and loss of life and financial. Flood zoning has many applications, in floodplain management. For management of the three major branches of the Halilrood River, Rabor, Roodar and Javaran in Safarood watershed in Kerman Province, flood hazard zonation was considered in this research. For this purpose, Flood levels in 2 to 200 return periods in three mentioned reaches (72.13 km) using HEC-RAS and HEC-GeoRAS extension were determined in GIS environment. Initially, Rivers Plan was divided to 163 cross sections and in 75 of them, hydrological data were collected and roughness coefficient was determined by Manning method. Results showed that 90.26 percent of the total area affected by the 200-year flood, Susceptible to flooding by the flood under 25 years as well as study on flood depth in the floodplain showed that 68.26 percent of the average depth of floods with 200 years return period is belonged to floods with under 25 year return period. Survey on roughness coefficient in the return period of 200 years, revealed that with a doubling of the roughness coefficient, area under flood 7.15 percent increase which proves direct relationship between the return period and flood area. The result confirms accuracy of combination geographic information system and HEC-RAS software in flood zoning and river modeling.

Keywords: Zoning; Flood; Manning coefficient; Halilrood

1. Introduction

In international culture, flood is defined as a water flow with high discharge, which water rises and drowning out its land around that are not usually under water (Ghodsian, 1998). Flood plains are often fertile lands, which are under flood risk (Ahmadi, 2007). In recent years the development of the cities that are on the rivers margins, the growing population, lack of attention to the environment capacity and inappropriate use of resources has led to damage to the mentioned communities that indicates the necessity of applying flood plains management

(Rezaei Moghaddam and Esmaili, 2005). Due to the recognition of flood zones and management to reduce flood damage, preparation and study of flood zoning maps have been used extensively in flood plains management studies and it is considered in the agenda of the relevant agencies as one of the basic and important information in studies of development projects in the world, Before making any investment or conducting development projects in flood plains (Alizadeh, 2012). Determining the rivers' bed floor and verge, studying and justifying the economic feasibility of development projects, flood forecasting and warning, rescue operation and flood insurance are some applications of these maps. There are different ways to prepare these maps, which one of the newest methods is the

* Corresponding author. Tel.: +98 912 3317789,
Fax: +98 21 88971717.
E-mail address: aliafzali61@ut.ac.ir

use of geographic information systems (GIS) and its combination with the hydraulic and hydrological models (Rezaei Moghaddam and Esmaili, 2005). Results of flood plain zone are compared with the two hydraulic models, MIKE11 and HEC-RAS. Initially The Analysis of hydraulic flood is performed with entry data geometric cross sections, boundary conditions and initial data after calibration then the results of the model that consists of flood zones as layers of data transfer to ARCVIEW software and overlay with topographic maps 1/2500 national mapping agency. Finally, results are shown in flood zone maps for the HEC-RAS and MIKE11 models. When we compared the results of the two models, we found little difference between the models (Montazami *et al.*, 2014). In these models, Manning roughness coefficient can be noted among several factors which are effective on velocity, depth and water stress during the floods. Several studies have been conducted on flood hazard zonation and flood areas in Iran and the world. Rezaei Moghaddam and Ismaili (Mousavi Baygi *et al.*, 2012) studied the geomorphologic effects of floods in Raeskola Watershed, after preparing some cross sections using HEC-RAS software, shear stress, river power and other needed parameters were determined and it was clear that the size of floods could be more accurately predicted for small steep mountain rivers by ancient water table and stream power indices. Ismaili et al (Esmaili and Hasouni Zadeh, 2009) studied the hydraulic behavior of Konchancham River in Ilam Province against possible floods damage in order to reduce the damage. They used HEC-RAS software and HEC-GeoRAS extension to display the study area and extract the needed data. The results showed that the combination of hydraulic models is not only feasible but also facilitates the hydraulic modeling. Examined the flood zoning in Gorganroud watershed by the combination of HEC-HMS and HEC-RAS models. By determining the area of flood zones in GIS environment, they concluded that the Dogh River watershed had greatest amount of flooding. Finally, the number of damaged villages and towns and the amount of flooding in rural, urban and agricultural lands were predicted (Shaebanlou *et al.*, 2009). Study in part of Zamostea village (Romania) was used as a pilot drainage basin for the flash-flood simulation using the Hec-Ras program and the ArcGIS extension, HecGeo-Ras. The programs are capable to simulate the water flow and to investigate the floodway encroachments in the study area. The damages evaluated in the field

along with the program's results reveal the fact that more than half of the built-up areas of Zamostea village are established along brooks, within the floodplain area (Haliuc and Frantiuc, 2013) assessed the agricultural losses caused by floods using HEC-RAS and GIS in a reach of 29.5 km long of Garehsou River in Kermanshah Watershed and concluded that the presented suggestions for the combined plan of reform and dredging had no huge differences with the reform plan and dredging plan in terms of reducing the damage (Hekmati Far *et al.*, 2009). assessment of flood hazard by developing a flood hazard map for mid-eastern Dhaka (37.16 km²) was carried out by 1D hydrodynamic simulation on the basis of digital elevation model (DEM) data from Shuttle Radar Topography Mission and the hydrologic field-observed data for 32 years (1972–2004). The inundation simulation was conducted using hydrodynamic program HEC-RAS for flood of 100-year return period. The simulation has revealed that the maximum depth is 7.55 m at the southeastern part of that area and affected area is more than 50% (Masood and Takeuchi, 2011). Studied the zoning of Karoon River between Babdgir to Ahvaz using the HEC-RAS model. They calculated the output flooding using the hydraulic method and hydrograph index and drew 44 sections along 43 km of river and achieved the maximum water surface elevation at certain levels for return periods of 5 to 100 years and calculated the area of flood hazard (Qomi Oili *et al.*, 2010). The vulnerability assessment from the 1979 flood event simulated by HEC-RAS model presents the intensity of risk to which the City of Jackson is exposed with its major transportation corridors (I-55, Highway 80) and numerous critical facilities getting affected by flood waters. Flood risk assessed by simulating higher magnitude flood Events using such hybrid approach magnifies the vulnerability of the region and reinforces that any land Use planning decisions in floodplains should make informed choices by incorporating scientifically derived information in their decision making process (Yerramilli, 2012). Examined the flood hazard zonation using HEC-RAS model and ArcGIS software and HEC-GeoRAS extension in a reach of 4.5 km long of Gezilouzan River. They prepared zoning maps for periods of 2, 5, 10, 25, 50, 100 and 200 years and found that 86.14% of the total flood zone with 200 years return period was belonged to floods with under 25 year return period (Ghaffari and Amini, 2010). Studied the Manning roughness coefficient changes in flood zones of Atrak

River. They found that for return periods of 5-100 years with the roughness coefficient of 0-100%, by increasing in roughness coefficient the level and depth of water would significantly increase. One-dimensional model HEC-RAS was used to simulate the flood zoning in the Kota Tinggi district in Johor state. Implementation processes of the zoning on catchment for return periods of 2, 25, 50 and 100 years were applied with different roughness coefficients. In order to improve the results of flood zoning from the obtained results, it is better to include the items for changing hydraulic platform as a different scenario's problem. The sensitivity of HEC-RAS model to the roughness coefficient, the coefficient of narrowing and opening, and energy slope were examined and observed. The most sensitive on water surface profile is created by the changes in the roughness coefficient. The volume and upstream surface runoff area and stream or flood conditions and physical characteristics of the area (surface morphology, etc.) can be named as the most significant factors that can affect the severity and recurrence of floods in every region (Mousavi Baygi et al. 2012). In a study in a range of 6.5 km from the bed floor river of Taleghan, determined the flood zones with return periods of 25-200 in HEC-RAS software. The results showed that 88.16% of the 200-year total area was susceptible to flooding by floods with a return period of 25 years and less than that. After reviewing all of zones it was obtained that the high altitude of the area had a direct impact on the zones area (Yamani et al., 2010). Compared the vegetation impact on regimes and physical behavior of flow by comparing regimes of forest and outside Forest Rivers using HEC-RAS model and concluded that the HEC-RAS model could provide appropriate numerical values for studying this regime and other hydraulic characteristics of river's flow (Andam, 2003). Used the combination of HEC-HMS and HEC-RAS hydraulic models in order to provide a regional flood model for San Antonio watershed, Texas, America and compared the obtained model with flood model of summer 2002. The results demonstrated the effectiveness of the model in flood forecasting in regional scale (Knebl et al., 2005). Provided the map of flood hazard zoning for small watersheds near Baya Sea in Astoro valley. To this end, a combination of two Wetspa and HEC-RAS programs was used in ArcView software. The results showed a high

accuracy of these models in estimating the water surface in these zones. Considering that the first step in flood management plans is preparation of flood hazard zoning maps; as well as the results of studies conducted by researchers in Iran and other countries show that the combination of HEC-RAS hydraulic model and GIS has an acceptable accuracy for determining flood zones, which is used in the present study (Napradean and Chira, 2006).

Given that the river floodplains of the facilities and different user is located, to manage these areas in case of flooding and keep them, so when it comes zoning is flooding with different return periods.

This research aims the following goals:

1. Determining the flood zones with the return periods of 2, 5, 10, 25, 50, 100 and 200 years;
2. Evaluating the changes in roughness coefficient on flood zones area for the mentioned return periods;
3. Suggesting appropriate solutions to reduce flood damage in the area.

2. Materials and Methods

2.1. The study area

The Safarood Watershed with an area of 366.21 km² is the main watershed upstream the Safa Earth dam under construction, which is located in 170 km south west of Kerman and between geographical location of 56° to 57° E longitude and 29° 15' to 29° 28' N latitude. The northern part of the study area is mountainous and steep and the slope is reduced to the south. The maximum and minimum heights of the watershed are 4267 m in north west and 2086 m in south at the outlet. The average slope is 20.51%, this watershed is consist of two sub-watersheds and three main rivers including Rabor, Roodar and Javaran with a length of 29.1, 28.5 and 14.53 km, respectively. The main source of rainfall is mountainous and the main precipitation is occurred in the second half of the year Rezaei Moghaddam, M. H., R. Esmaili. 2005. The height of annual rainfall was 258.5 and 261 mm for Hanjan and Cheshmeh Aroes stations, respectively in 2009-2010, Yekom Consulting Eng. 2011. The regional climate is semi-arid with Domartan. About 78.87% (288.8 km²) of the total area is pasture land use type. Figure 1 shows the location of these areas in Kerman Province.

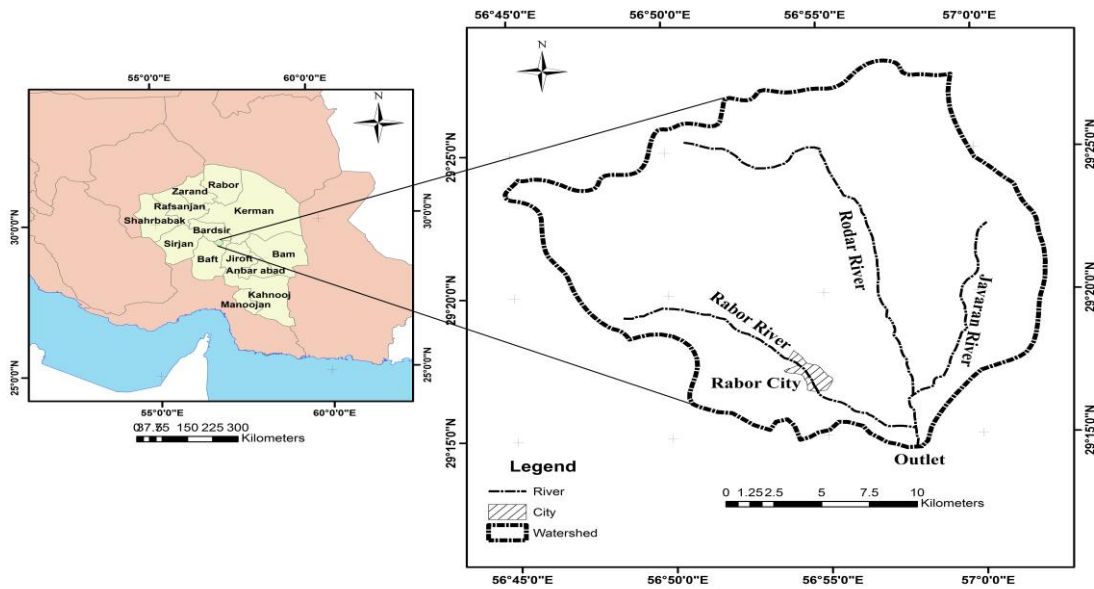


Fig. 1. The location of Seafood Watershed in Kerman Province

2.2. Method

After preparing 42-year discharge data (from 1968 to 2010), to avoid prolonging the number of reconstruction years of incomplete stations, the statistical year of 37 (1973 to 2010) was selected for both stations of Henjan and Meidan. Then the data had been controlled, corrected and revised. Next, the discharge was calculated by distribution of log Pearson Type III for eight return periods (2 to 200 years). Then, by closing the border areas in ArcGIS 10 and using HEC-GeoRAS extension, the layers of the central line (Rabor, Roodar and Javaran rivers), banks, boundaries determining the maximum flood zone, flow path, cross sections with TIN maps (Figure 1) were determined, and were entered into HEC-RAS software after combining together. At this stage, the hydraulic characteristics of river flow such as energy loss coefficients, river discharge with different return periods and roughness coefficients were entered into hydraulic model of HEC-RAS, and output results were returned to GIS by a file after running this model. At the end, the zoning was made in GIS environment using HEC-GeoRAS extension and the maps were produced, which the results are given below.

2.3. Determining Manning roughness coefficient

In hydraulics of rivers, many factors affect the velocity, depth and water stress during the flood, which Manning roughness coefficient can be pointed out Ahmadi, H, 2007. To model shear stress, the slope and velocity of the water we have to rely on empirical relationships. One of the empirical relationships to calculate the velocity of water and predict the hydraulic behavior of rivers is Manning's relationship.

$$V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \quad (1)$$

Where, n is Manning roughness coefficient; V is the flow velocity; R is hydraulic radius and S is the slope of the canal, Hekmati Far, H., et al. 2009.

3. Results and Discussion

After correction and preparation of the maximum instant annual rates of discharges at the considered station, to determine the discharge rate with different return periods, the distribution of Log Pearson Type III was chosen as the most appropriate distribution and the discharge rate with eight return periods was determined (Table 1).

Table 1. The peak discharge rate (cubic meters per second) with different return periods at studied stations

Return period	2 years	5 years	10 years	25 years	50 years	100 years	200 years
Henjan	53	162	259	397	504	610	713
Meidan	71	133	183	254	313	376	444

3.1. Determining the roughness coefficient

The roughness coefficient of bed floor and margins of the different studied reaches were determined using the geometric characteristics of the river, bed floor vegetation, and margins and size of the bed floor in Safarood watershed.

N coefficients for the main canal and the left and right banks of Rabor, Roodar and Javaran rivers were estimated for five reaches and 75 cross sections, which the results are presented in Table 2. Views of sediments carried by the flow in rivers' bed are shown in figures (2) to (5).

Table 2. Average values calculated by Manning roughness coefficient in the study area

Reach No.	cross sections No.	right bank	main canal	left bank
1	1-15	0.084	0.052	0.079
2	16-28	0.063	0.057	0.105
3	29-45	0.068	0.073	0.064
4	46-63	0.063	0.71	0.073
5	64-70	0.058	0.067	0.062



Fig. 2. Bed floor of Rabor River



Fig. 3. Bed floor of Roodar River



Fig. 5. Rabor Diversion Dam, upstream Diversion Dam was filled with coarse sediments



Fig. 4. Alluvial vertical wall of the left bank of the river in downstream of Marjan village

3.2. River simulation

In flood zoning studies, usually the determining of rivers' margins¹ and bed floor is considered with a 25-year return period (4), hence the flood

zone values for this period was examined with other seven periods.

3.3. Level, depth and velocity of flow

The results showed that according to the discharge rates entered separately for each river,

¹ Buffer

the drawn profile of water surface in HEC-RAS software at junctures was properly simulated. For example, a view of cross section of bed

floor and water surface height for two return periods of 2 and 200 ye ars at two selected section is shown in figures (6) and (7).

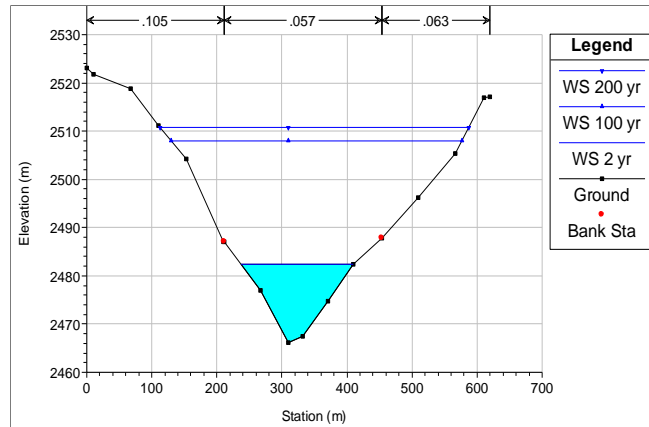


Fig. 6. Cross section and water surface height for Rabor River at a critical section

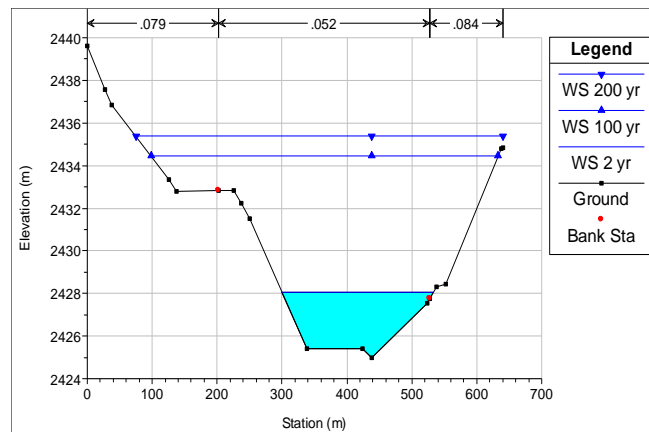


Fig. 7. Cross section and water surface height for Javaran River at a critical section

The results of the water surface calculation at different return periods in HEC-RAS software was transferred to GIS through HEC-GeoRAS extension and flood zones were determined for each period. It is obvious that by larger flood discharge, more areas go under water, but

certainly the extent of these changes is important, because this information could be very useful in planning land management of riverbank. The flood zones of 2- and 200-year floods are shown in figs 8-10 in figure.

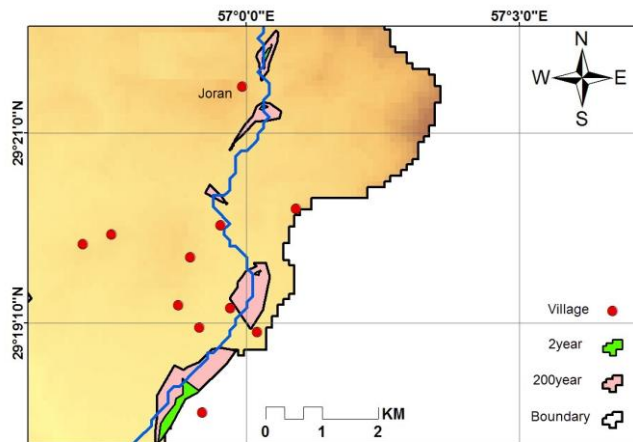


Fig. 8. Flood zones of Javaran River for return periods of 2 and 200 years

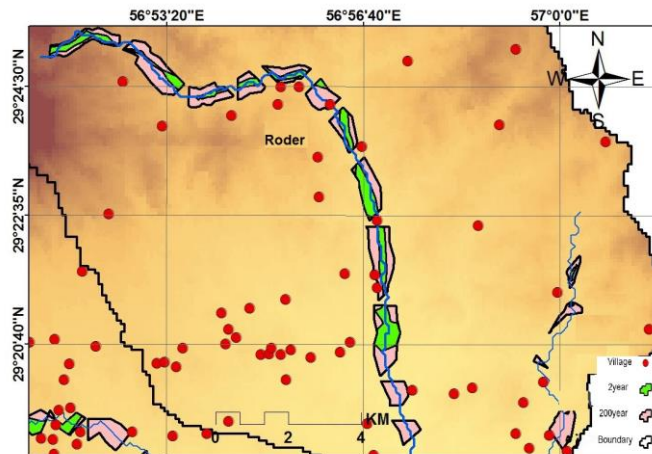


Fig. 9. Flood zones of Roder River for return periods of 2 and 200 years

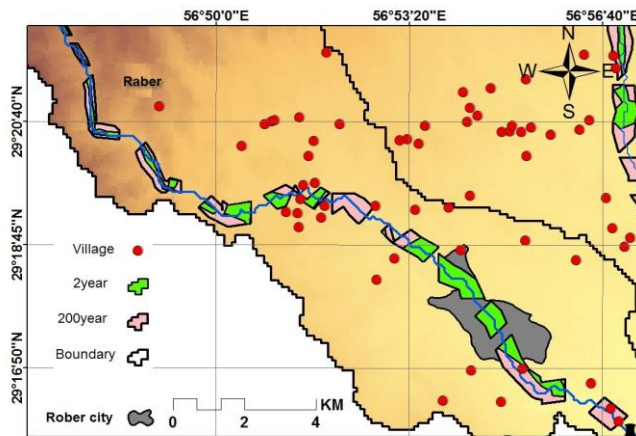


Fig. 10. Flood zones of Rabar River for return periods of 2 and 200 years

By determining the flood zones for each return period, the calculation of flood zone area would be possible. The land area affected by the flood at each return period is presented in table

(3). The other results achieved by this zoning method are information layers of depth and velocity for each cell of an area, which the values are presented in Table 3.

Table 3. Area, mean depth and average velocity of flood at different return periods

return period	2 years	5 years	10 years	25 years	50 years	100 years	200 years
Area (ha)	498.3	517.1	532.2	549.1	574.3	599.6	608.3
average velocity (m/s)	2.11	3.02	3.13	3.46	3.72	3.93	4.04
mean depth (m)	0.48	0.86	0.89	1.14	1.3	1.5	1.67

3.4. Changes in roughness coefficient

The changes in flood zones area per changes in roughness coefficient values as well as the diagram of flood zone changes based on the increase in roughness coefficient are presented in Table (4) and Figure (11), respectively. Manning roughness coefficient change has a great impact on the results of expecting rivers hydraulic conditions and velocity, height and expanse of water during the flood. The results indicated that the flood depth would increase by

increasing in this coefficient, which are more obvious for upper return periods.

As it is shown in Figure 9, by doubling the value of roughness coefficient for return period of 2 years, the flood zone increased by 8.8%; while for return period of 200 years, it is 15.7%. It should be mentioned that the roughness coefficient increases in summer due to agricultural activities in agricultural land located on flood plains and relative increase in vegetation.

Table 4. Flood zone area (ha) for different return periods per increasing in roughness coefficient

Increasing rate n (%)	2 years	5 years	10 years	25 years	50 years	100 years	200 years
0	498.3	517.13	532.24	549.09	574.32	599.64	608.32
20	504.7	525.9	544.4	565	592.6	601	6381
40	506.7	526.9	546	562.8	594.9	629	642.3
50	516.3	537.2	555.6	577.1	607	637.4	658.8
60	520.7	541.9	559.9	580.3	607.6	639.2	663.6
80	529.1	548.6	565.7	585.8	617.9	653	684.3
100	542.1	565.7	584.3	605.1	636.3	673.3	703.8

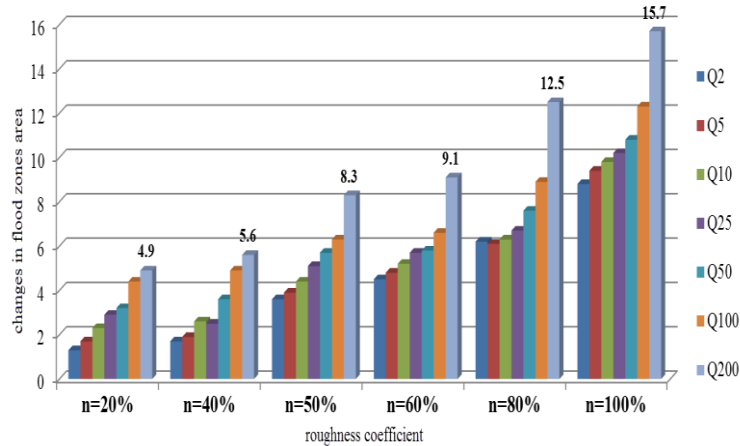


Fig. 11. Diagram of flood zone changes based on the increase in Manning roughness coefficient in different return periods

According to the tables of surface and depth of flooding, it can be seen that for return periods more than 25 years, the increasing in flood area had a slower trend. The focus of most investments including rural buildings, agricultural land and orchards are in floodplain under the 25 years, which is a legal part of the river. This issue represents a non-normative use of land in this area, so that farmers have been invaded near the typical riverbed because of the extent and fertility of the flood plain. This would increase the damage from flooding. By identifying the areas susceptible to flooding, the use of management practices to control land use through legal mechanisms would be facilitated, as knebl *et al.*, 2005; Rodriguez *et al.*, 2008; Timbadiya, P. V; *et al.*, 2011; also emphasized on the positive role of these researches in providing management practices to reduce flood damage. The results of this study about inappropriate land use associated with increased flood level and depth are consistent with Andam, 2003; Napradean, Chira, 2006 and Ghaffari, *et al.*; 2004, Haliuc and Frantiuc, 2013; Masood and. Takeuchi, 2011. The results of this study about the relationship between increasing in roughness coefficient with expanding of

flood zone, particularly for longer return periods are in accordance with Mousavi *et al.* 2012. Additionally, the obtained results of increasing in accuracy and velocity of search by using hydraulic model of HEC-RAS (in combination with GIS) are consistent with Esmaili, and Hasouni Zadeh, 2009; Ghaffari, and Amini. 2010; Yamani *et al.*, 2010; Yerramilli, S, 2012.

4. Conclusion

With respect to the floodplain zoning map, it was identified that the increasing trend of flood zone had a more rising trend for return periods of 2 to 25 years than 25 to 200 years. In general, from the area affected by the 200 year flood, 90.26% was susceptible to floods under 25 years and the major loss would be in floodplain zones under 25 years. The values of the flood zone area are presented in Table (5). Additionally, according to the flood depth map of the floodplain, the depth increasing trend for return periods of 2 to 200 years was relatively evenly, so that from the total flood depth for return period of 200 years, 68.26% was belonged to return periods under 25 years. Table 6 shows the average values of the flood depth.

Table 5. Percent of the flood zone area for different return periods to the 200-year flood

return period (year)	2	5	10	25	50	100	200
percent of area	81.91	3.1	2.48	2.77	4.15	4.16	1.43
cumulative Percent of area	81.91	85.01	87.49	90.26	94.41	98.57	100

Table 6. Percent of average depth of flooding to the average depth of 200-year flood

return period (year)	2	5	10	25	50	100	200
Percent of average depth	28.74	22.75	1.8	14.97	9.58	11.98	10.18
Cumulative Percent of average depth	2874	51.49	53.29	68.26	77.84	89.82	100

The results obtained from the flood velocity table also showed that 52.22% and 22.53% of the total average velocity of 200-year flood was related to the return period of 2 years and 5 years, respectively. After the return period of 5 years, the percent of flood velocity for each return period to return period of 200 years as

well as flooding area was greatly reduced, which was more obvious after the return period of 25 years. The main reasons could be the removal of sand from the mentioned zones around rivers and mountains region. The average flood velocity is shown in Table 7.

Table 7. Percent of average velocity to the average velocity of 200 -year flood

return period (year)	2	5	10	25	50	100	200
Percent of velocity	52.22	22.53	2.72	8.17	6.43	5.2	2.73
cumulative Percent of velocity	52.22	74.75	77.47	85.64	92.07	97.27	100

As it is shown in Table (3) and figures (8) to (10), for longer return period the discharge amount would be more and flood zone area would be wider. However, the difference in spreading flood zone area is primarily due to topographical features of the valley. Where ever the slope around the river is low, then the flood zone area increases and the water spread in wider area. Conversely, where the valley narrows, the width of the flood zone also reduced as well as the flood depth increased. Accordingly, with respect to the three rivers in the mountainous areas, and slopes across the river especially in the northern and north-

western areas with greater slope, the land area at risk of flooding in different return periods had no significant difference, however in floodplains (in the middle part of the watershed) due to gradual changes in slope across rivers with little change in elevation of the flood level, significant changes in the land area at risk of flooding is evident. The results of this study is consistent with Yamani et al (17). By examining the flood zone maps for return periods of 10 and 200 years, the area of horticultural and agricultural lands at risk of flooding is 121.3 and 132.6 ha, respectively (Table 8).

Table 8. Area of horticultural and agricultural lands at risk of flooding in the study area (ha)

return period (year)	2	10	200
Javaran	12.7	18.3	22.2
Roodar	32.8	56.4	60.1
Rabor	31.4	46.6	50.2

Considering the capabilities of GIS in providing and integration of data layers and conducting required changes, it is recommended to define basic information of the country's watersheds based on a single standard in this system. On the other hand, preparing flood hazard zonation maps, identifying rivers' margin and development of management standards required in all flood plains is essential. It is suggested that the development of residential areas in the vicinity of the mentioned rivers should be done with respect to margin and the proper distance. In addition, unethical harvesting of river materials for the construction of earth dams of Safarood downstream of this watershed should be organized and implemented in appropriate places.

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