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REDUCING THE IMPACT OF CHECK DAMS ON THE HYDRODYNAMIC CHARACTERISTICS OF FLOOD

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ABSTRACT: *In this paper, the effects of the proposed and the built check dams, located in different streams of the study area, were studied in order to assess their impact on flood mitigation. For the purpose of assessment and comparison between the effect of check dams on flood reduction, in the proposed and the built works, the morphometric and edaphic characteristics of the study area should be primarily collected, including the slope, infiltration rate, land use, and flow accumulation map. These data will create the base map, which shows the flood potential. In the next step, by adding the impact of the proposed and the built check dams in the base map, a final map will be achieved, which reflect the impacts of check dams on the flood zoning of the study area (gonbadchi). The perceived findings were compared with the built works. Overall, it was comprehended that the impact of the proposed and the built dams is low, which has been caused by the low number and the distribution of check dams.*

KEYWORDS: Flood mitigation, Morphometric, Check dams**;**

INTRODUCTION

Flooding is the most influential natural disaster in Iran and many other countries, and is typically caused by climatic factors, such as rainfall. While flooding is often unavoidable and unexpected, it can be controlled through some appropriate measures that can minimize the losses and damages. One of the fundamental works for flood mitigation is flood zoning. In natural regions, similar to urban areas, researchers usually use the hydrostatic characteristics of flood for flood zoning. In this paper, it is claimed that since flood zoning is not enough for flood mitigation, it must be accompanied with some other reform works.

In a river basin, there are many water-related human interventions, such as water storage, diversion, small dams, and other related actions, which can change the natural water systems, affect the velocity of stream flows, reduce erosion, trap the channel sediment, and help to stabilize the channel side-slopes. These alterations, while have significant ecological effects on various temporal and spatial scales, also impact on the natural connectivity of lotic ecosystems. In fact, when a channel slope is modified by some alterations in a check dam, the water depth and the flow velocity will decrease below the check dam, or in the upstream, the slope will be lowered to the ultimate bed slope.

In general, a check dam (also known as gully plug) is a small and temporary (or permanent) dam, constructed across a drainage ditch, swale, or channel, and is used to lower the speed of concentrated flows for a certain design range of storm events. A check dam can be built from wooden logs, stone, pea gravel-filled sandbags or bricks, and cement. A reduced runoff speed reduces erosion and gully erosion in a channel and allows sediments and other pollutants to settle out. Liu (1992) demonstrated that the installation of check dams produces positive effects on controlling the upstream channel stability. In the upstream reaches of each check dam, the stream channel becomes wider and flatter. In addition, the depositional surface behind the check dam, when the storage capacity is filled, is relatively stable. Furthermore, Porto and Gessler (1999) predicted the ultimate equilibrium bed slope in the upstream of a check dam.

The results of the present study showed that the procedures suggested by Ferro et al. (1994) and Julien and Wargadalam (1995) do not lead to satisfactory results. Better predictions of the ultimate bed slope can be achieved using the criterion suggested by Gessler (1990), which is based on the stochastic analysis of the incipient motion in a non-uniform bed material. It should be mentioned that the improperly designed and installed check dams can cause negative changes in the hydrological and sedimentary characteristics of a stream and affect the ecological habitats. Thus, from a hydrological point of view, the existence of a large number of small reservoirs as well as their spatial distribution and storage capacities must be known. In fact, it is necessary to assess the effect of watershed management works (including check dams) on the basin behavior. In this study, more assessment of check dams with the aid of the quantitative and qualitative figures, gathered from field observations, will be employed for the proposed and the built works, until a fundamental pattern for the increase of the operating quality and also, the integrated programs for the objectives of watershed management, can be acquired.

In order to simulate the hydrodynamic characteristics of flood in the study area, where the check dams have been constructed and also, to understand the influence of the proposed and the built check dam structures on the flow control, the multi-criteria decision analysis (MCDA) was utilized. Multi-criteria decision analysis (MCDA) provides a methodology for analyzing complex decision problems, which often involve incommensurable data or criteria. The combination of GIS and MCDA has an excellent performance in the analysis of natural hazards (Rashed and Weeks, 2003; Gamper et al., 2006) and in other geo-environmental studies (Dai et al., 2001; Kolat et al., 2006), but this type of model must have a specific procedure for analyzing the uncertainty associated with the spatial outputs.

MATERIALS AND METHODS

The study area

The study area is located in the North Slope of Alvand, which is the central part of Hamadan Province (Figure 1) in the central Zagros, Iran (48˚ 46' 45" to 48˚ 51' 29" N; 34˚ 49' 20" to 39˚ 53' 34"), with ca. 2745 km2. The rocks of the region are influx granite, shiel, eslite and schist of the Jurassic era (Figure 1). Based on the data from Asad Abad climatology station (1997-2007), the average annual temperature of this region is +10.75 ˚C, varying from -15 ˚C to +34 ˚C from winter to summer. The coldest and hottest months are February and August, respectively. In addition, the average annual precipitation of this region is 443.11 mm. According to the Ombrothermic curve, the driest months are from May to September. The regional climate, according to Ambreget method, is semi-arid cold and semi-humid.

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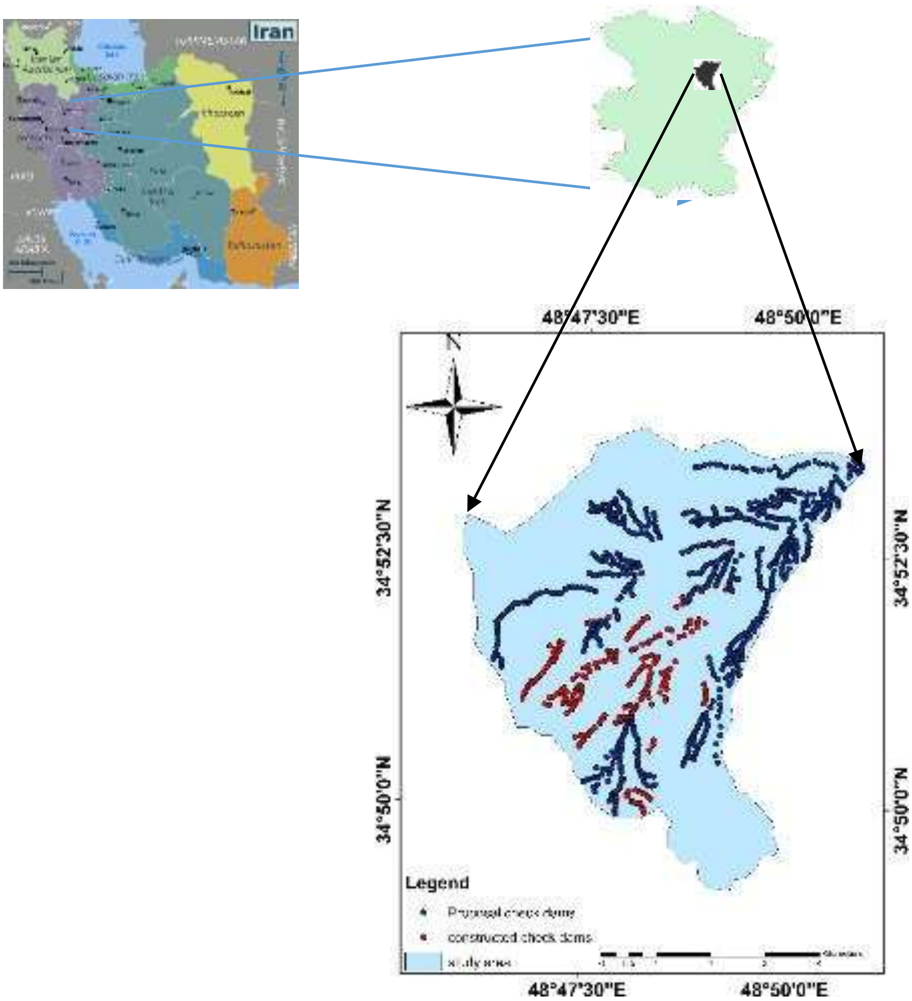


Figure (1): location of the study area

A flood hazard depends on the flood magnitude (i.e., the flood depth, velocity, and duration). In natural areas, many researchers have recently paid attention to the hydrodynamic characteristics of flood, or the flood velocity (kelman et al., 2004). In this research, a combination of catchment characteristics (including terrain slope, flow accumulation, infiltration data, and land use) has been taken into account in order to evaluate the flood hazard. The flood hazard component is calculated based on the assumption that the flood velocity normally occurs in the areas with high terrain slope, low infiltration rate, high flow accumulation, and land use with the lowest plant cover.

Analytic Hierarchy Process (AHP)

Multi-criteria decision analysis (MCDA) provides the methodology and techniques, required for analyzing complex decision problems, which mostly include incommensurable data or criteria (Fernandez and Lutz, 2010). Geographical Information Systems (GIS) are powerful tools that can manage a large amount of data, involved in multi-criteria decision analysis (Fernandez and Lutz, 2010). Analytic Hierarchy Process (AHP) is one of the multi-criteria decision making methods, which was originally developed by Prof. Thomas L. Saaty. In short, it is a method to derive the ratio scales from the paired comparisons. The input can be obtained from the actual measurements (such as price, weight, etc.), or from the subjective opinions (such as satisfaction feelings and preference). The AHP allows some small inconsistencies in judgment, based on the fact that human is not always consistent. The ratio scales are obtained from the principal Eigenvectors, and the consistency index is attained from the principal Eigenvalue. Consequently, according to the properties of the reciprocal matrices, the consistency ratio (CR) can be calculated. In a reciprocal matrix, the largest eigenvalue (ymax) is always greater than or equal to the number of rows or columns (n). If a pairwise comparison does not contain any inconsistency, ymax will be equal to n. The more consistent the comparisons are, the closer the value of the computed ymax will be to n. A consistency index (CI) that measures the inconsistencies of pairwise comparisons can be written as follows:

$$CI = (Ymax - n)\ n-1$$

and the coherence measure of the pairwise comparisons can be calculated in the form of the consistency ratio (CR):

$$CR = 100\ (CI * ACI)$$

where the ACI is the average CI of the randomly generated comparisons. A consistency ratio, of the order of 0.10 or lesser, would be a reasonable level of consistency (Saaty, 1980). In fact, any consistency ratio, above 0.1, requires revising the judgments in the matrix, because of the inconsistent ranking of a particular factor. The consistency ratios for all the pairwise comparisons, which were used to obtain the urban flood hazard map, were calculated and found to be consistent (CI < 0.1) (Fernandez and Lutz, 2010). Moreover, the use of GIS and MCDA has proven successful in natural hazard analysis (Rashed and Weeks, 2003; Gamper et al., 2006) and also, in other geo-environmental studies (Dai et al., 2001; Kolat et al., 2006).

Membership function (mathematics)

The membership function of a fuzzy set is the generalization of the indicator function in classical sets. In fuzzy logic, it represents the degree of truth as an extension of valuation. The degrees of truth, even though they are conceptually distinct, are often confused with probabilities; that is because fuzzy truth represents the membership in vaguely defined sets, and not the likelihood of an event or a condition. Membership functions were introduced by Zadeh in his first paper on fuzzy sets (1965). Zadeh, in his theory of fuzzy sets, proposed a membership function (within the interval (0, 1)), which operates on the domain of all possible values. In this study, in order to assign values to the parameters, the sigmoidal function is used. In general, the sigmoidal MF can be open to the right or to the left. The general expression of the sigmoidal MF is given in below:

$$f(x; a, b, c) = \frac{1}{1 + \left| \frac{x - c}{a} \right|^{2b}}$$

where “c” locates the distance from the origin and “a” determines the steepness of the function. If a is positive, the Mf will open to the right; otherwise, if it is negative, it will open to the left. In linguistic terms, the former represents the concept of “a very large positive”, where the later represents “a very large negative”. Symmetrical or asymmetrical, but closed (not open to the right or the left) MFs can be constructed by using either the difference or the product of the two sigmoidal MFs, as described above. The MF formed by the difference between the two sigmoidal MFs is defined as the difference-sigmoidal MFs, and the MF formed by their product is defined as the product-sigmoid MF. They are shown in Fig. 11(h) and i(i), respectively. All the MFs in this family are smooth and non-zero at all points.

ANALYSIS AND RESULTS

The base map

In order to assess the impact of check dams on the hydrodynamic characteristics of flood (i.e., the mechanical works of watershed management), in the first step, a map representing the physiographic and edaphic characteristics of the study area, is required. In fact, this map will show the potential occurrence of flood. In this paper, in order to prepare the mentioned map, the below maps were used:

The slope map

The slope of the land in the watershed is a major factor in determining the water velocity. The request function for assigning a score to this map, is the sigmoid function, in which the large inputs have large membership values.

The flow accumulation

Another important parameter in flood assessment is the flow accumulation. The accumulated flow is the sum of the water flowing down the slope, into the cells of the output raster. The high values of the accumulated flow indicate the areas of concentrated flow and consequently, a higher flood hazard (Kazakis et al., 2015). The score for this map is similar to the slope map, where the large inputs have large membership values.

The infiltration map

One of the parameters that effects on the response to the hydrological features is related to the infiltration characteristics. This parameter is mainly related to the soil properties, with an inverse impact on the water depth. In order to score this parameter, this study employed the sigmoid function, but the small inputs have large membership values.

The land use map

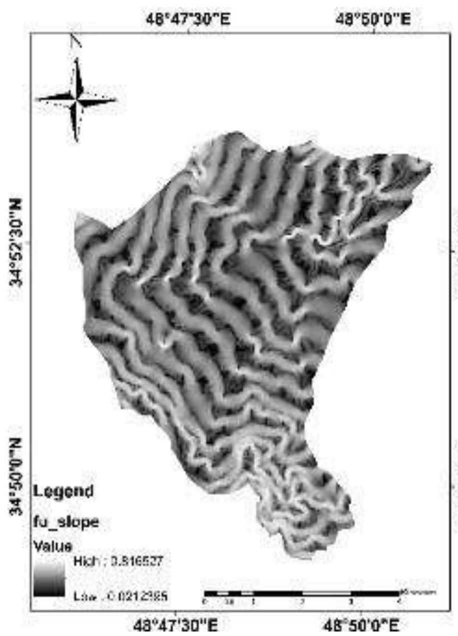
The final parameter in this study that can affect the velocity and the depth of water is land use mapping. For scoring of this map, similar to the other maps, in the first place, the AHP method was used to quantify the map. In this parameter, the related weights were assigned to the layers. These values were determined according to the importance level of the layers in the case studies of the floods in the area. The assigned weights for the layers of the study area were based on the local characteristics of each layer and the authors' judgment, which all are unveiled in Table 1. The most important layer, according to the weights, was defined as the dry lands; the rest of the lands, based on their impact on flood mitigation, were placed in the next orders of importance. After scoring the land uses with the AHP method, in the study area, based on the impact of every land use on the water depth and velocity, similar to the aforementioned maps, the sigmoid function was used, in which the dry lands have large membership values and high-density lands have small membership values.

Table (1) - The assigned weights with the AHP method, for the layers of land uses in the study area

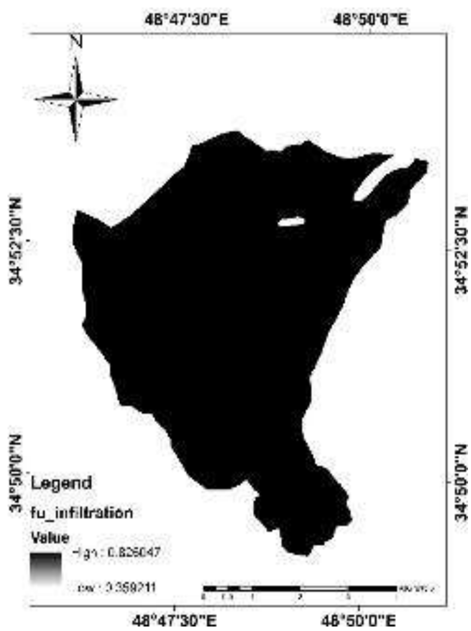
Layers	Weights
No check dam	0.69
Small check dams	0.25
Medium check dams	0.01
High check dams	0.044
Consistency rate	0.023

In the last step, in order to assign a score to the combination of the aforementioned maps, the arithmetic average was applied to prepare the base map for the study area:

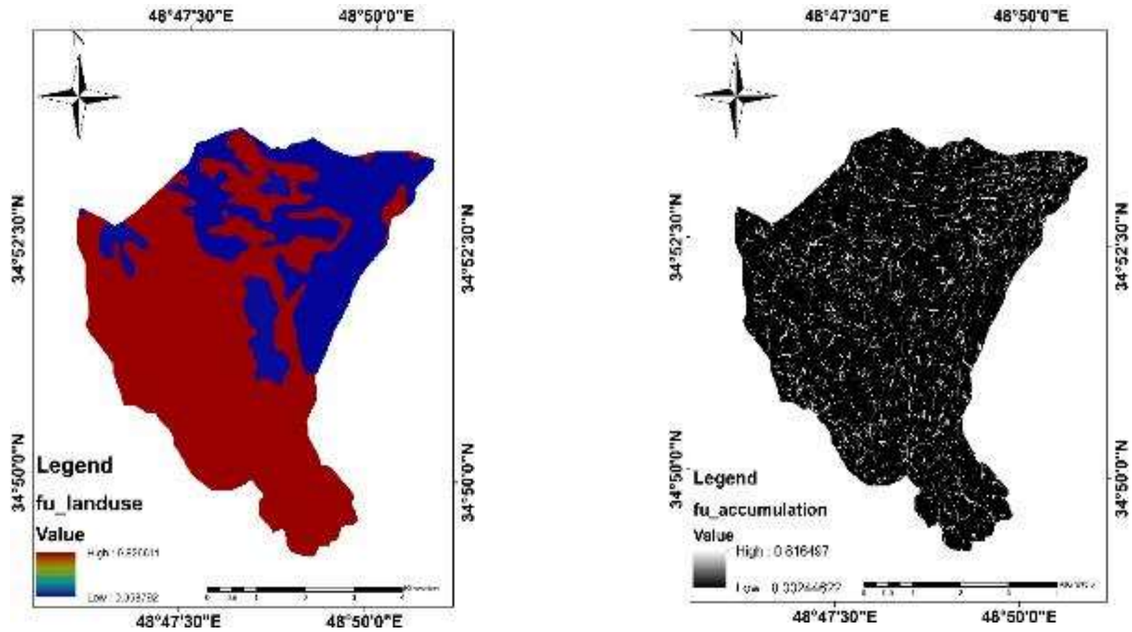
$$Base\ map = \frac{\sum scoring(slop\ , land\ use, infiltration\ and\ flow\ accumulatiom\ map)}{number\ of\ maps}$$



Slope mapping



Infiltration map:



Land use map flow accumulation map

Figure2. The fuzzy variables for base map

The impact range of check dams

In order to evaluate the impact of check dams on flood hazard zoning in the proposed and the built works, the impact of check dams must be added to the base map. The impact of check dams was induced based on the digital elevation model (DEM), with a spatial resolution of 10 mm. It is necessary that this topic would be related to the construction of the check dams. In total, in order to assign a score to the map that would show the impact range of check dams, some methods (such as the land use scoring) should be employed. In the beginning, in order to quantify the impact of check dams, the AHP method was applied and in the next step, the sigmoid function was utilized, in which no check dam has a large membership value and high check dams have small membership values.

Table (2) - The assigned weights for the layers of the study area

Layers	Weights
Dry lands	0.9
Low-density lands	0.25
Medium-density lands	0.01
High-density lands	0.044
Consistency rate	0.023

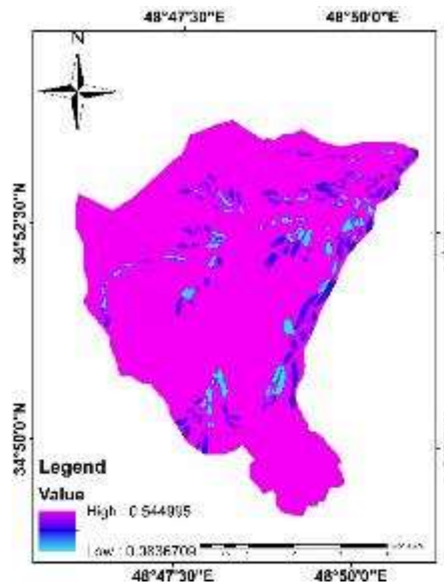


Figure3: the impacts of suggested check dams

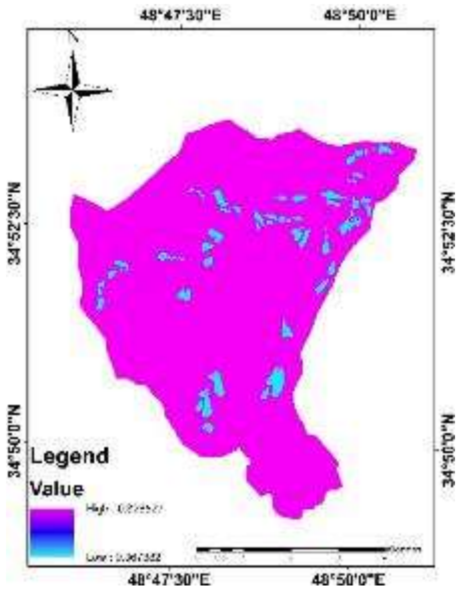


Figure 4: the impacts of built check dams

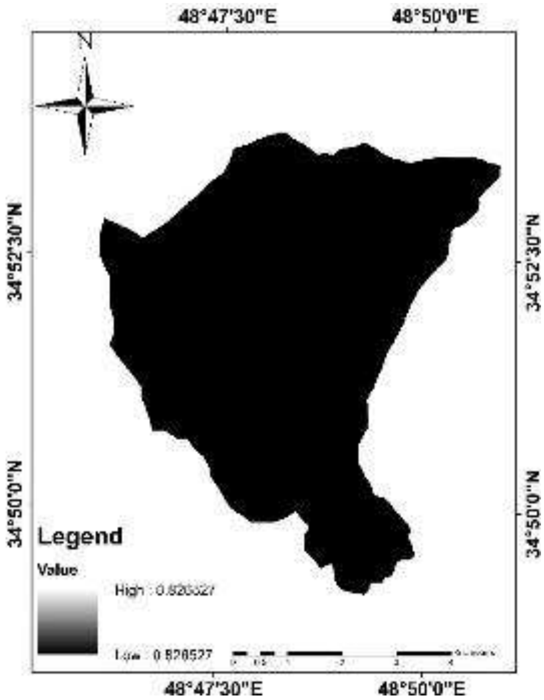


Figure 5: study area with no check dams

Flood hazard zoning

In the last step, after preparing the base map and the impact range of check dams, the below equation for flood zoning was used:

$$Flood\ haard\ zoning = Base\ map * Impacts\ of\ mechanical\ operations$$

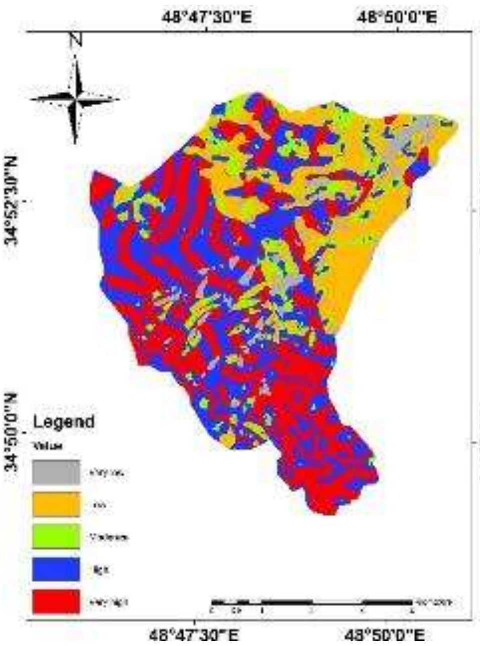


Figure 6: flood zoning with built check dams

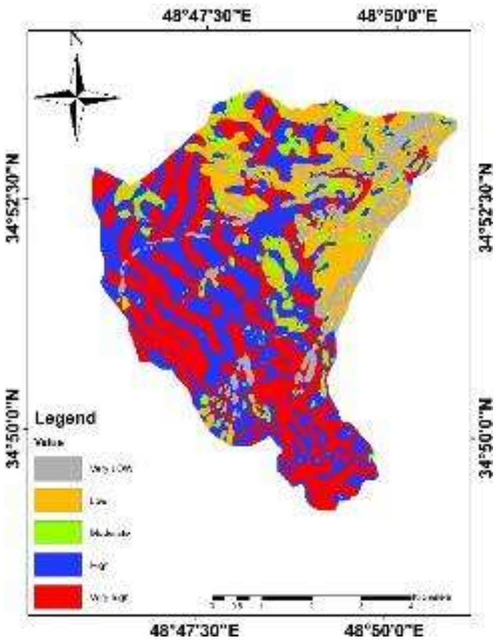


Figure 7: flood zoning with suggested check dams

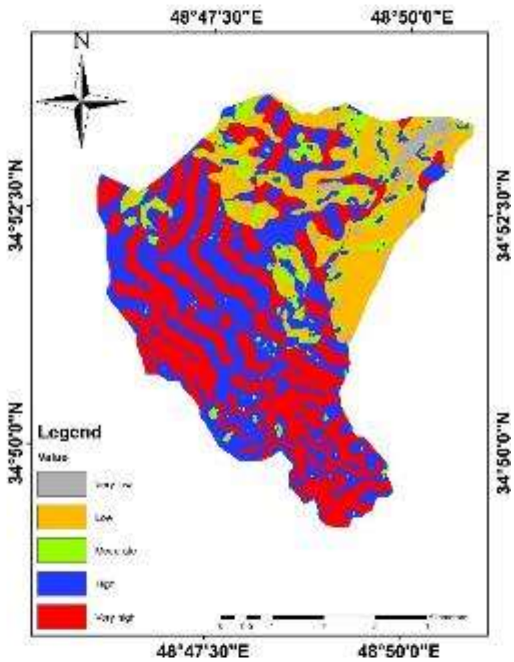


Figure 8: flood zoning before constructing check dams

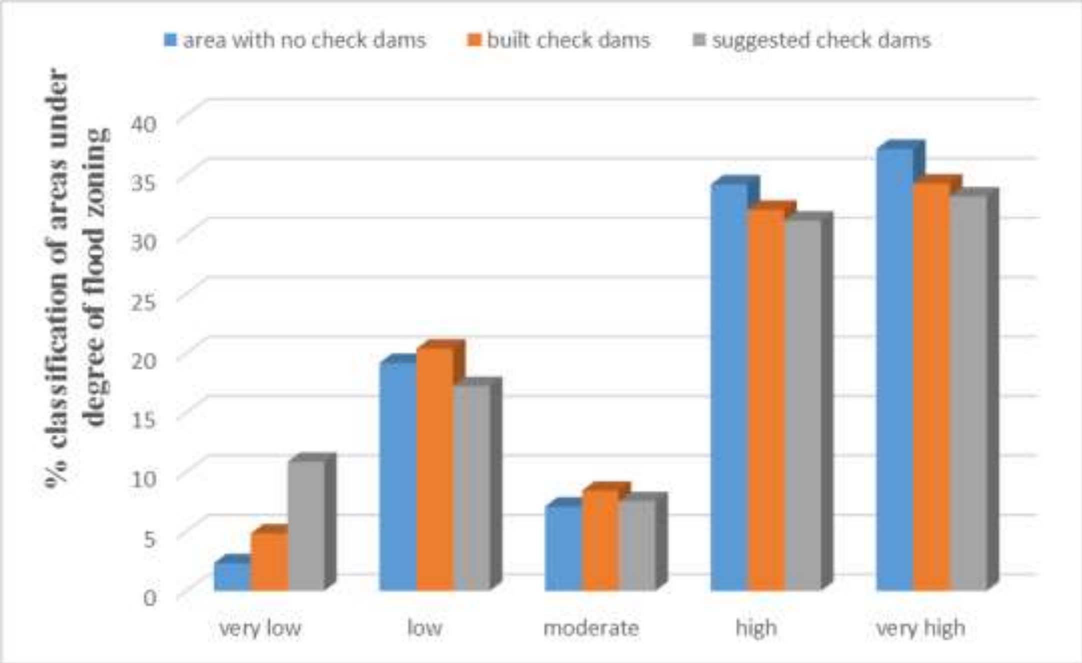


Figure (9): classification of areas under degree of flood zoning

CONCLUSION

An appropriate zoning of the flood hazard is one of the best practices, which can be effectively employed for flood mitigation and control management planning. In the present study, a preliminary assessment of flood zoning was carried out. The ArcGIS geographic information system, the multi-criteria decision analysis, and the fuzzy equations were used for the spatial modelling and visualization of the results. The obtained findings demonstrated that the built works, rather than the proposed check dams, have a very low impact on flood hazard zoning and this outcome has been resulted from the number, distribution, and size of check dams. According to the obtained values for the mentioned parameters and in total, in order to increase the impact of the watershed management works on flood hazard zoning, some methods are required, which can spread over the basins with the minimum costs for the processes such as the biological operations.

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