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Original Research

Flood Risk Assessment Using GIS (Case Study: Golestan Province, Iran)

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Abstract

In recent years humans have endured increasing numbers of natural disasters, of which flooding is the greatest and most common throughout the world. Iran is also exposed to floods, considering the severe damage recently incurred in Golestan province, particularly Gorganroud watershed. Due to the importance of the subject and lack of comprehensive studies on flood risk in the country's watersheds, it is crucial to perform flood risk assessment using appropriate tools, such as Landsat ETM+ imaging and digital elevation model data collections in geographic information system throughout the region. For this purpose, database maps of 6 sub-watersheds in Gorganroud watershed were prepared in 5 layers affecting flooding in the region. By overlaying and weighing three layers in GIS software, a layer of flood hazard intensity was obtained. Next, by means of obtained numbers and scoring, the overuse layer priorities were determined. Then, these two flooding layers were overlaid with the help of a two-dimensional matrix, and the final map of flood risk was obtained. Finally, it was found that Chelichay and Sarab Gorganroud, making up to 24.59% of the Gorganroud watershed, are the most risky sub-watersheds. In light of the fact that the data pertaining to Gorganroud watershed have never been entirely used to sort out the risk priorities in the region, the new method presented in this paper can lead to a more accurate and comprehensive understanding about what is really taking place in it.

Keywords: flood risk, two-dimensional matrix, Gorganroud Watershed, geographic information system

Introduction

During the past 20 years, worldwide natural disasters have resulted in the death of at least 3 million people, while also adversely affecting nearly 800 million people [1]. It has been determined that 30 out of 40 natural disasters occur in Iran, where flooding has been highlighted as the most damaging one [2]. Additionally, Iran, as a country with a high rate of natural disasters, has suffered from the loss of over $ 3.7 billion [3]. Flooding is dangerous, particularly along the southern shore of the Caspian Sea and in northern and northeastern Iran, which was afflicted by a powerful flood in August 2001 that killed 210 people and cost $31 million in damage. During 2002-11, there were also dangerous and smaller floods at the same places, which led to a loss of $65 million and the deaths of 28 people [4].

"Flood risk" can bear different definitions as it refers to natural disasters, depending on their adverse impacts on humans, lives, and the economy. However, flood risk can be discussed in terms of two elements: hazard and vulnerability [5]. From the flood risk management point of view, flood risk mapping is a crucial factor. Flood mapping is limited to flood-prone hazard mapping [6]. Previously, some

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flood-related studies for determining the hazard and risk of flood have investigated a history of flood frequencies. For instance, Lawrence [7] tested the ecological risk along with natural hazards, and studied 30 main specifications about risk to determine the one correlated with ecological risk. Jiqun [8], using geographic information system (GIS), global positioning system (GPS), and other technologies in China prepared a combined system for monitoring and evaluating a flood. Sinnakaude [9] discussed making a flood map in Pari River using Arcview software in the field of AVHEC-6 extension. Yalcin [10] provided multi criteria evaluation methods for analyzing the regions vulnerable to floods using ArcGIS software. Pistrika and Sakiris [11] introduced a three-stage method for determining and evaluating the flood risk and vulnerability of flood-prone regions. Hansson [12] provided multi-criteria analysis for designing the strategic assessment of flood damage using computerized models. In Iran, Rowshan [13] studied the climate and water analysis in endangered watersheds using runoff modeling. Khodaei [14] developed a model for flood warning systems and predicting flood occurrence in Golestan province. Saadat [15] also proposed a new classification in Golestan dam about changes in the geomorphology leading to flooding in Iran. However, no studies have yet investigated flood risk in the Gorganroud watershed using 5 significant factors: floodplain area, flood prone hazard, flood prone intensity, flood intensity and hazard, and overuse lands. Therefore, it is necessary to prioritize the potential vulnerability and hazard of regions to flooding [16]. Also, detailed flood risk mapping is necessary to reduce the hazards of flooding. Accordingly, GIS was applied as a tool for flood risk mapping. For this reason, the first step included collection of the geo data base, digitizing, and integration of collected data into the GIS based on previous studies and methodologies. Then, Landsat-7 ETM+satellite images and SRTM (2000) as an accessible database were applied [17]. The present study provides a new risk map model composed of five main factors affecting the flood in Golestan in the form of five layers in GIS environment.

Study Area

Golestan province in the north of Iran has a long history of severe damage from and many people dying in floods [16]. Gorganroud watershed of Golestan province is considered one of the largest watersheds located in northeastern Iran and southeastern of the Caspian Sea. This region, with an area of 14,049 km^2, is surrounded by many rivers, including the Gorganroud, Gharesou, Zav, Gharechay, and Mohammadabad. This watershed is located in southeastern of the Caspian Sea between longitudes 54º 2' and 56º 16' E and latitudes 36º 34' and 37º 47' N [18].

Methodology

According to the previous findings and field studies, five layers have been made (as explained in details through the following context). After collecting the data, the floodplain layer was created using satellite images and a pseudo 3D radar model in the area. Then, through positioning, the situation of vulnerable villages and cities to flooding including 14 towns and 1,000 villages, was determined. In preparing the flood-prone hazard layer, many factors can be employed to determine the rate of flood hazards that are individually or collectively influential. However, in general this paper deals with five factors, including the number of flood occurrences, life losses, financial losses, the populations vulnerable to flooding and density of residential centers for determining the flood hazard. Flood damages are the best indicators for flood hazard [19]. Due to their different effects on all of the mentioned factors, the proper scores were obtained based on the experts' views and conditions of the watershed. Afterward, the rate of flood hazard was determined according to the sum of scores. Similarly, considering the score of each factor and the quantitative values of flood hazard, classification indices were determined and flood classification was performed. According to the range of the total scores of above indices, the flood-prone hazard layers were grouped in 7 categories. Upon such criteria, the quantitative values for flood hazards were obtained, where extreme flood conditions indicated the flood hazard, and in normal conditions it was not necessary to conduct a flood control plan. Specific peak discharge intensity of hydrometric stations was used to determine flood intensity, so that first of all the stations were prepared for maximum specific discharge for a return period of 50 years as a flood-prone index. For comparing the sub-watersheds, the specific discharge values of hydrometric stations throughout the country, extracted from reasonable statistics, were studied and grouped into 9 classes based on data quantal method.

As for making a layer for flood hazard and intensity of the watershed, the sub-watersheds were studied based on basic information, flood hazard and flood intensity, and by studying the number and frequency of flood events in Gorganroud watershed. Flood events during 1951-2008 [20] were recorded based to the collected data, and a map of flood prone intensity was prepared. Overuse layer was obtained using slope information, land use and susceptibility to erosion in the GIS environment. This layer is of high importance since people, by overusing the land capacities, can result in flood occurrence, erosion, sedimentation, and landslides. Therefore, after overlapping 3 effective layers, including floodplain area, flood prone hazard, and flood prone intensity, 1 layer of prioritization in the layer of flood hazard and intensity in sub-watersheds was obtained. Then, by providing an overuse layer and overlapping the layer of flood hazard and intensity with overuse layer and combining these 2 layers using a 2D matrix, the final layer of flood risk was obtained in 6 sub-watersheds of Gorganroud, with 3 final priority setting for flood control as the first priority indicated by W_1, the second priority by W_2, and the third priority by W_3, so that one can easily attain the flood risk map in the sub-watersheds (Fig. 1).

Results

Floodplain

Identification of the floodplain reveals that middle Gorganroud sub-watershed with an area of 107.76 km^2 makes up most of the floodplain area and Chelichay, including an area of 19.5 km^2 covering the smallest portions of the floodplain area (Table 1, Fig. 2) [20].

Flood Prone Hazard

The majority of villages fall in the territory of middle Gorganroud (23 villages and 1 town), while the minority of them fall in the territory of Gharesou (4 villages). Moreover, a maximum population of about 420,525 has been reported in Gharesou sub-watershed, while Sarab Gorganroud includes a minimum population of about 62,498. However, a minimum population of 3,532 vulnerable to floods resides in Doogh sub-watershed, while the maximum population vulnerable to floods is residing in Middle Gorganroud about 34,597. Maximum damage has been inflicted on middle Gorganroud, Chelichay, Doogh, and Sarab sub-watersheds, while minimum damage has been recorded in Payab Gorganroud. The minimum number of flood occurrences belongs to Gharesou and Middle Gorganroud sub-watersheds. As shown in the flood-prone hazard map, extreme class, being 13,362 ha, can be found in Middle Gorganroud and Chelichay, hard class being 9,700 ha, can be witnessed in Doogh, moderate class, being 14,856 ha, can be seen in Sarab, and low class, being 11,971 ha, can be spotted in Gharesou and Payab sub-watersheds within the Gorganroud watershed (Tables 2, 3, and 4, Fig. 3).

Table 1. Flood Plain area in Gorganroud sub-watersheds [20].

Sub-Watershed	Flood Plain Area (Hectare)
Gharesou	39.49
Payab Gorganroud	85.22
Middle Gorganroud	107.76
Chelli Chay	19.5
Doogh	25.86
Sarab Gorganroud	56.36

Flood Prone Intensity

According to the obtained results in the GIS environment and the following Tables (Tables 5 and 6) (Fig. 4), it can be concluded that the flood prone intensity is related to Chelichay sub-watershed with an area of 97,809 ha in the low class and also to the remaining sub-watersheds in very low class with an area of 1,210,675 ha.

Flood Hazard and Intensity

According to the statistics obtained for Gorganroud watershed and regarding the classification of flood intensi-

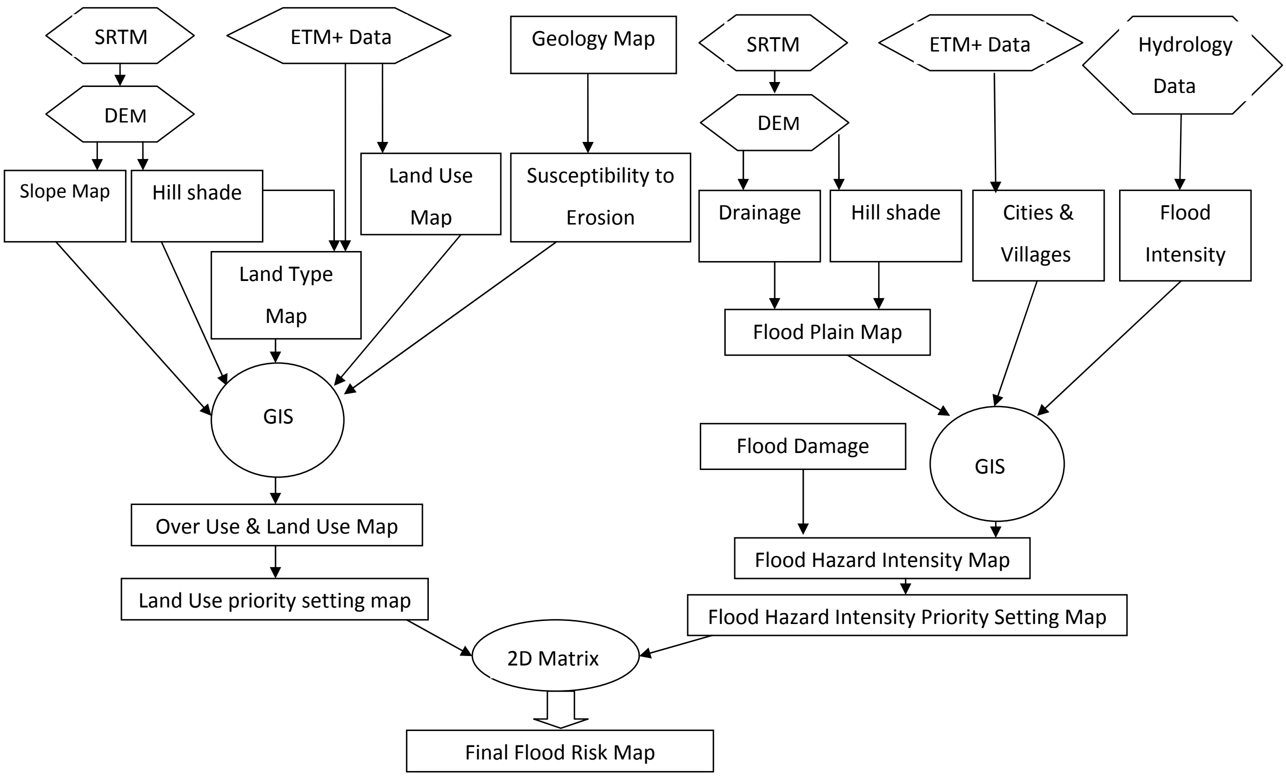

Fig. 1. Flow diagram of the methodology.

Table 2. Range of scores to the different factors of flood hazard.

Flood Hazard Factors	Score
Flood occurency	10
Human Losses	40
Loss of Flood	25
Population	15
Residential Density	10
Total Scores	100

ty and flood hazard, it was determined that areas of about 342,000 and 447,000 ha are exposed to moderate hazard. According to the information collected over the past 56 years, Chelichay and Doogh sub-watersheds in this area are exposed to high flood hazard and can be classified in the first class, while Middle Gorganroud and Sarab Gorganroud sub-watersheds are in the second class, and Payab Gorganroud and Gharesou sub-watersheds fall in the third class of flood hazard and intensity (Table 7, Fig. 5).

Overuse Lands

Much of the overused lands belong to Sarab and Chelichay, having an area of 53,601 ha (class I); the average amount is possessed by Middle Gorganroud and Doogh, with an area of 22,318 ha (class II); and the least is located in Gharesou and Payab sub-watersheds, with an area of 25,629 ha (class III). The classification criterion has been indicated in Table 8. Moreover, Fig. 6 shows the priorities of overused lands layer obtained based in their area.

Discussion

Following this stage, the flood hazard and intensity layer was overlapped with the overuse layer using 2D matrix. Consequently, the final layer was obtained and the final flood risk map for 6 sub-watersheds was determined (Table 9). The results indicated that Chelichay and Sarab Gorganroud sub-watersheds are the most risky sub-watersheds in terms of floods, as in Chelichay sub-watershed both flood hazard and intensity and overuse necessitate assigning the first priority on flood control. Comparatively, Sarab Gorganroud sub-watershed is in the second class based on flood hazard and

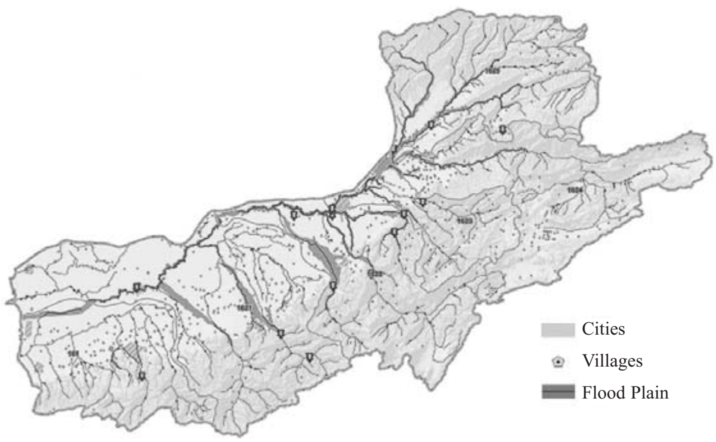

Fig. 2. Flood Plain map in Gorganroud sub-watersheds [20].

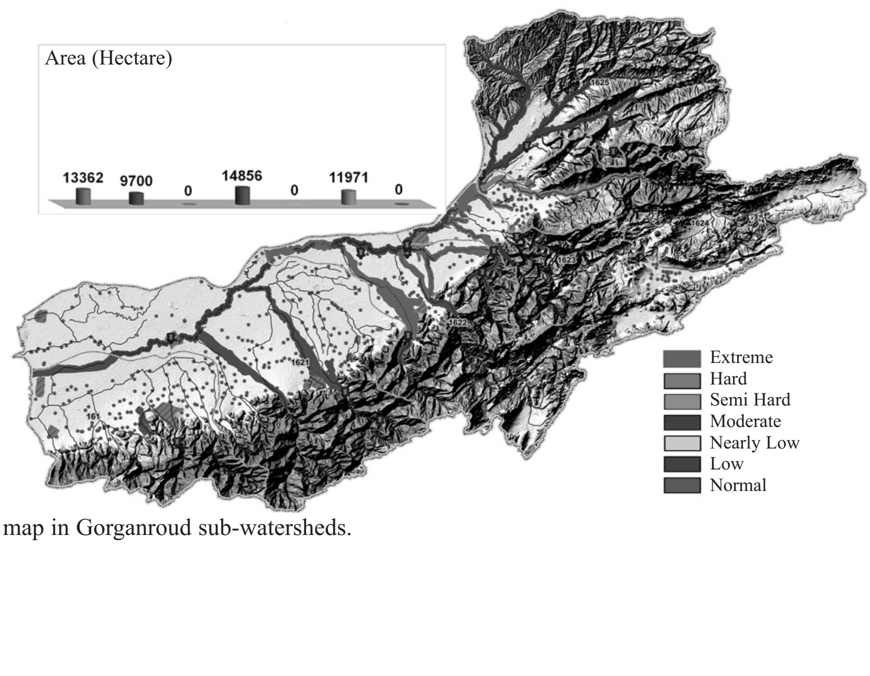

Fig. 3. Flood Hazard map in Gorganroud sub-watersheds.

Table 3. Flood hazard scores classification.

Class of Flood Hazard	Range of Scores	Priority of Flood Hazard
Normal	10>	N
Nearly Low	10-25	VI
Low	25-40	V
Moderate	40-55	IV
Semi Hard	55-70	III
Hard	70-85	II
Extreme	85<	I

intensity and in the first class based on overused lands. Sub-watersheds of Middle Gorganroud and Doogh are in the second class and Gharesou and Payab is in the third class for flood control, and the highest vulnerability to these sub-watersheds is due to flood hazard and intensity.

The results also indicate that Chelichay and Sarab sub-watersheds are exposed to high levels of flood risk covering about 7.48% and 17.11% of the Gorganroud watershed area, respectively, and should be considered as top priorities in flood harnessing. Approximately 18.64% and 17.03% of the total watershed in Dough and Middle Gorganroud sub-watersheds have moderate flood risk. Finally, 26.35% and 13.36% of the watershed in Payab and Gharesou sub-watersheds have low flood risk (Fig. 7).

Conclusions

Having an overall look at Gorganroud watershed, one can mention the necessity for the protection of forests, conducting watershed projects and reviving the vegetation with respect to the density of vegetation and animals, preventing changes to land usage and sloppy lands from forest to the agricultural lands, preventing erection of roads and highways, strategic environmental assessments, and environmental impact assessment. The purpose of this

Table 4. Flood hazard classification based on scores range in Gorganroud watershed.

Sub-Watershed	Human Losses	Economic Losses	Population	Flood Density	Flood Occurrence	Total Scores	Class of Hazard
Gharesou	4	17.5	3.75	1	10	35.26	Low
Payab Gorganroud	4	13.75	6	5.5	8.5	37.75	Low
Middle Gorganroud	40	25	6	7	10	88	Extreme
Chelli Chay	40	25	12.75	2.5	5.5	85.75	Extreme
Doogh	40	25	3.75	2.5	5.5	76.75	Hard
Sarab Gorganroud	4	25	6	4	7	46	Moderate

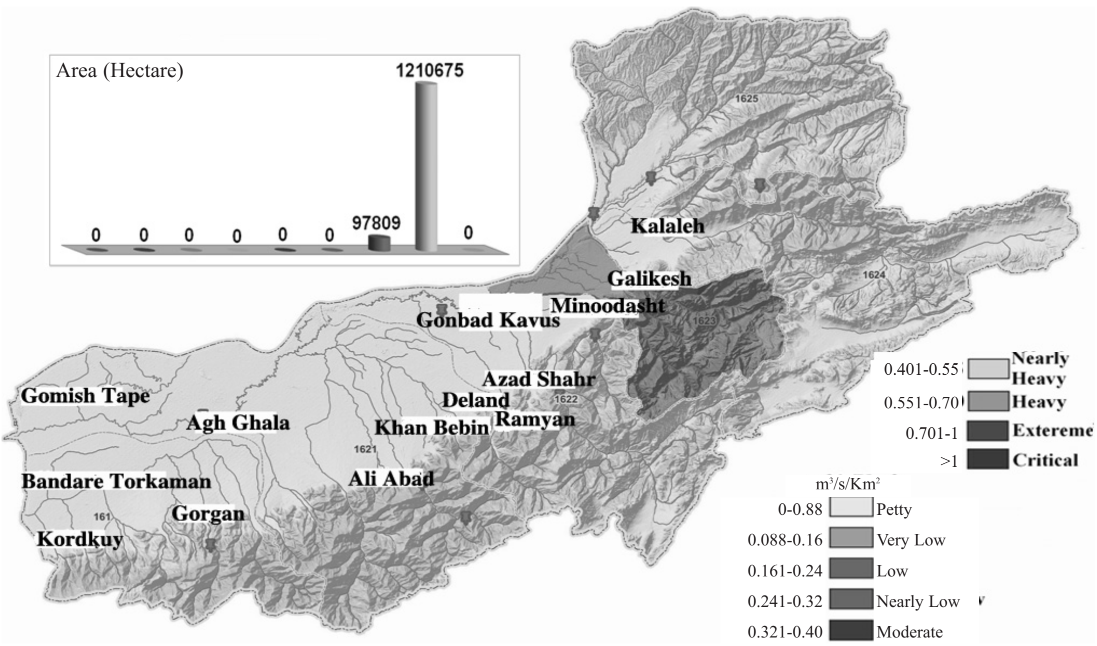

Fig. 4. Flood intensity map in Gorganroud sub-watersheds.

Table 5. Index classification of flood Intensity.

Flood Intensity Classification	Flood Control Priority	Variety Range of Flood Intensity ($m^3/s/km^2$)
Minimal	N	0-0.0880
Very Low	VIII	0.0880-0.16
Low	VII	0.161-0.24
Nearly Low	VI	0.241-0.32
Moderate	V	0.321-0.40
Nearly Heavy	IV	0.401-0.55
Heavy	III	0.551-0.70
Extreme	II	0.701-1
Critical	I	>1

study is to determine the sub-watersheds of Gorganroud watershed exposed to high flood risk using the ArcGIS software. As far as the literature search reveals, most of the flood risk studies are based on flood plain, flood prone hazard, and the probability of flood occurrence. In

Table 6. Flood intensity classification in Gorganroud sub-watersheds.

Sub-Watershed	Specific Peak Discharge	Flood Intensity
Gharesou	0.143	Very Low
Payab Gorganroud	0.113	Very Low
Middle Gorganroud	0.128	Very Low
Chelli Chay	0.236	Low
Doogh	0.118	Very Low
Sarab Gorganroud	0.105	Very Low

this research, however, six sub-watersheds of Gorganroud were more completely investigated by taking into account the overuse layer and flood hazard intensity as important factors in the flood risk of the region, which in turn can be an effective step toward determining the risk factors of the watershed as well as ascertaining the high risk sub-watersheds to help prevent and harness their destructive flooding and impede the annual problems of similar watersheds. In future studies, it would be

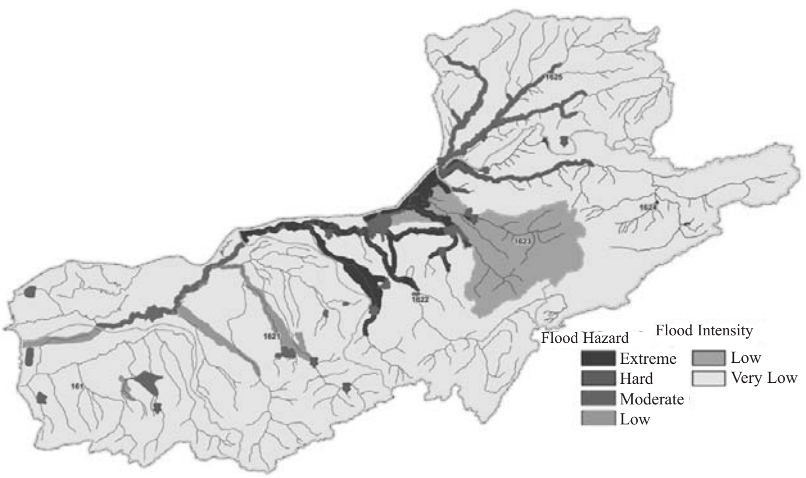

Fig. 5. Flood hazard and Intensity map in Gorganroud sub-watersheds.

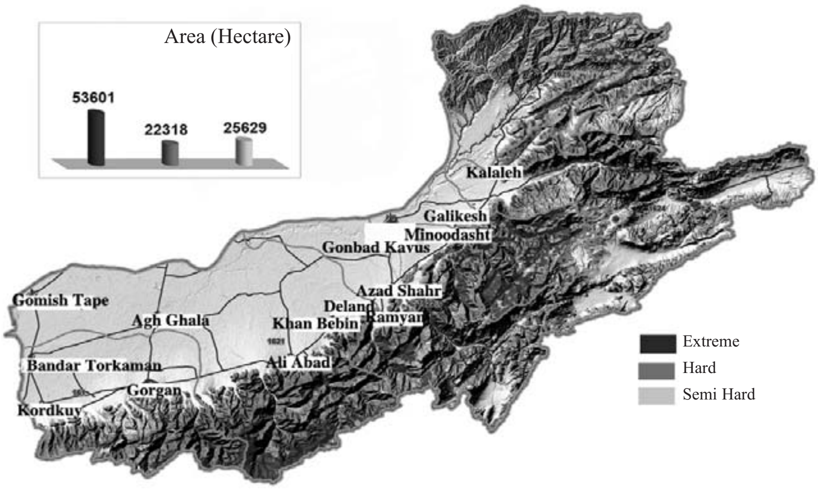

Fig. 6. Map of overuse Land in Gorganroud sub-watersheds.

Table 7. Priority setting of flood hazard and intensity in Gorganroud sub-watersheds (3 class).

Sub-Watershed	Flood Hazard	Flood Intensity	Priority of Flood Hazard	Priority of Flood Intensity	Priority of Flood Hazard Intensity
Gharesou	Low	Very Low	III	III	3
Payab Gorganroud	Low	Very Low	III	III	3
Middle Gorganroud	Extreme	Very Low	I	III	2
Chelli Chay	Extreme	Low	I	II	1
Doogh	Hard	Very Low	I	III	2
Sarab Gorganroud	Moderate	Very Low	II	III	2

Table 8. Overuse lands area in Gorganroud sub-watersheds.

Sub-Watershed	Area (Hectare)	Over Use Priority
Gharesou	6,496	3
Payab Gorganroud	19,133	3
Middle Gorganroud	11,588	2
Chelli Chay	28,089	1
Doogh	10,730	2
Sarab Gorganroud	25,512	1

Table 9. Flood risk priority setting in Gorganroud watersheds.

Sub-Watershed	Priority of Flood Hazard Intensity	Over Use Priority	Final Priority setting
Gharesou	3	3	3
Payab Gorganroud	3	3	3
Middle Gorganroud	2	2	2
Chelli Chay	1	1	1
Doogh	2	2	2
Sarab Gorganroud	2	1	1

better to take other flood-related factors (such as environmental ones) into account in order achieve a more comprehensive risk system. Furthermore, various organizations involved in flooding issues can be identified, and their roles in preventing flooding in the region can be determined.

References

1. HOSSEINI B., MEHDIYAR L. Applied strategic planning in crisis management, Aid and save learning and reduction of disaster impacts, international conference of crisis management, **2006**.

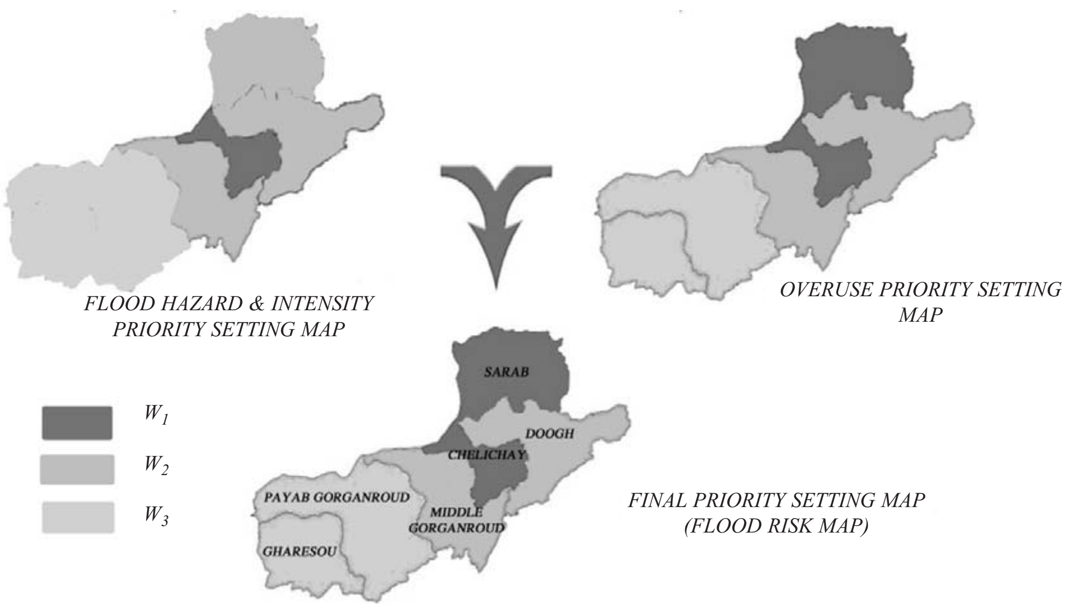

Fig. 7. Final Flood risk map of Gorganroud sub-watersheds.

2. SHAKER M., HOSSEINI H. Aid and save learning and reduction of disaster impacts, international conference of crisis management, **2006**.
3. NAIENI K., ARDALAN A. Project final report early warning information management, Early warning system for flash floods in Golestan Province, Iran, **2006**.
4. AGRICULTURAL RESEARCH AND EDUCATION ORGANIZATION, Soil conservation & watershed management research institute, Gorganroud watershed floodplain, 245, **2004-2006**.
5. DANG N.M., BABEL M.S., LUONG H.T. Evaluation of flood risk parameters in the Day River flood Diversion area, Red River Delta, Vietnam, Nat Hazard, Springer, doi: 10.1007/s11069-010-9558-x, **2010**.
6. DE MOEL H., VAN ALPHEN J., AERTS J.C.J.H. Flood maps in Europe – methods, availability and use, doi:10.5194/nhess-9-289-2009. Nat Hazards Earth Syst Sci., 9, (2), 289, **2009**.
7. LAWRENCE J., XELROD A., TIMOTHY M. N. Perceptions of ecological risk from natural hazards, Decision Research, Journal of Risk Research, **2**, (1), 31, **1999**.
8. JIQUN Z., CHENGHU Z., KAIQIN X., MASATAKA W. Flood disaster monitoring and evaluation in China, Environmental Hazards, **4**, 33, **2002**.
9. SINNAKAUDAN S.K., GHANI A.A., AHMAD M.S.S., ZAKARIA N.A. Flood risk mapping for Pari River incorporating sediment transport, Environ. Model. Softw., **18**, 119, **2003**.
10. YALCIN G., AKYUREK Z. Analyzing flood vulnerable areas with multicriteria evaluation, XX^{th} International Society for Photogrammetry and Remote Sensing Congress, **2004**.
11. PISTRIKA A., TSAKIRIS G. Flood Risk Assessment: A Methodological Framework, Water Resources Management: New Approaches and Technologies, European Water Resources Association, Chania, Crete- Greece,14-16 June, **2007**.
12. HANSSON K., DANIELSON M., EKENBERG L. Assessment of a flood management framework, International Journal of Public Information Systems, **1**, (25-37), **2008**.
13. ROWSHAN G.R., MOHAMMADI H., NASRABADI T., HOVEIDI H., BAGHVAND A. The role of climate study in analyzing flood forming potential of water basins, Int J of Env Res., **1**, (3), 231, **2007**.
14. KHODAEI H. Optimizing flood warning system using value engineering, M.S. Thesis, University of Tehran, Natural Disaster Department, **2006** [In Persian].
15. SAADAT H., BONNEL R., SHARIFI F., MEHUYS G., NAMDAR M., ALE-EBRAHIM S. Landform classification from digital elevation model and satellite imagery, Geomorphology, **100**, 453, **2008**.
16. OMIDVAR B., KHODAEI H. Using value engineering to optimize flood forecasting and flood warning systems: Golestan and Golabdare watersheds in Iran as case studies, Nat Hazards., **47**, 281, **2008**.
17. SIDERIS M. observing and changing earth: proceeding of the 2007, international association of geodesy symposia, Perugia, Italy, Springer, 133, **2008**.
18. VARVANI J., FEIZNIA S., MAHDAVI M., ARAB KHEDRI M. Regional analysis of suspended sediment using Regression Equation in Gorganroud watershed, Journal of Iran natural resources, **55**, (1), **2002**.
19. CHANG H., FRANCZYK J., KIM C. what is responsible for increasing flood risks, Nat Hazards, **48**, 339, **2009**.
20. FOREST RANGE AND WATERSHED MANAGEMENT ORGANIZATION, Flood workgroup, Gorganroud watershed, national plan of natural resource and watershed management aspects in Iran, engineering & evaluation plan office, **1991-2008**.