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Application of Flood Hazard Potential Zoning by using AHP Algorithm

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Abstract

Flood is one of the most complex and destructive natural disasters that caused tremendous damages during decades. Because of some local factors such as latitude, topography as well as external factors such as Influential atmospheric fronts, the Golestan Province confronted with climate variability and extreme events such as catastrophic floods. In this research, some descriptive, field data such as topographical, land use, geological and hydro-meteorological data were used in order to determine effects and weighing the variables and sub-class of each variable in relation to the flood hazard mapping. In addition, the AHP algorithm was applied in order to determine flood risk maps. The results showed in 0.95% of drainage basins in Golestan Province located in very high flood hazard, 22.75% in high flood hazard, 11.1% in middle flood hazard, 22.37% in low flood hazard and 42.81% very low hazard. The study showed that eastern parts have higher flood risk than central and west regions meanwhile, the area has a lower annual rainfall. Obviously, the flood control program should be based on a comprehensive plan and prioritized regard to the degree of flood risk.

Keywords: Flood Hazard Zoning; AHP-Fuzzy; Multi-criteria decision making

Introduction

Flood in simply is the water flow which is higher than the average volume of a river [1]. Flood was the most common, deadliest and most costly natural disasters during decades. Flood risk has increased over time, especially since many of the construction license issued in floodplains and even commercial and residential growth [2]. In Iran, along with other parts of the world, the occurrence of floods has been increased significantly in recent decades. Therefore, the upward trend of flood in five recent decades show that the number of flood occurrences in the 2000s are ten times more than 1960s and in other words the amount has been increased by 900%. Drainage basin physical characteristics such as shape, drainage slope and topography of the land, together with hydrological characteristics such as precipitation, storage and losses and surface retention, evapotranspiration and infiltration and phenomena resulting from human activities, are involved in the intensity and duration of floods [3]. The understanding these factors and classifying in different zones are the basics of flood management and risks reduction [4]. Therefore, identifying these factors is very important. In other words, before any planning for flood control, we should understand the behavior of their processes [5]. Flood hazard zone maps are a valuable tool to identify the nature of floods and their effects on human life. Flood hazard zoning map can be effective tool in the planning the future development of the city, as well as identify areas that needed development of infrastructure, drainage and flood drainage [6]. Multi-criteria decision analysis (MCDA) methods are required to analyze complex decision problems, which often includes data and incomparable criteria. The success of Geographic Information System (GIS) and MCDA in the analysis of natural risks [7,8] and other environmental studies have already been proven [9,10]. Each of the factors affecting the occurrence of floods has a different role in the risk of its occurrence in the basin, as it can be prioritized due to the impact of each of these factors.

In this research, in order to assess the impact of each of these factors, the Analytic Hierarchy Process (AHP) model is used. One of the methods which can used in decisions multi-criteria analysis is AHP lattice [11]. Generally, the AHP framework is combination of four major steps: (1) establishment of the model and structure; (2) paired comparison matrices and vectors of priority; (3) the formation of super matrix; and (4) choosing the best option [12]. The AHP method is one of the most comprehensive processes designed for decision making with multiple criteria, because this method provides the possibility of formulating the problem in a hierarchy [12]. For decision making model, at the highest level is the objective, criteria is in the middle level and in bottom are the options [13]. AHP method is made up of comparing pairs of indicators to judge the approach in the situations where the incompatibilities arise between the approaches of multi-criteria decision-making models [14]. In the field of flood zoning, many wide-range methods have done by many researchers that we follow some of them. Chen et al. [15] prepared a model based on GIS for urban flooding and runoff cumulative rainfall using surface runoff. Fernandez, Lutz [16] zoned Bwana Argentina Yerba city in terms of flood risk using GIS and multi-criteria decision-making system (AHP). Asgharpour & Ajdari [17] studied the seasonal floods in the basin of Qatoor Chai and concluded that the methods and innovative strategies at the regional level are needed. Morelli [18] studied Arno river flood potential in Italy through navigation using GPS and GIS model in different regions and concluded that the development of more urban areas is more at risk. Maantay & Moroko [19] zoned New York, time Back floods in a timescale. AL-Ghamdi [20] zoned Mecca using spatial analysis in GIS in terms of flooding based on the two major floods of 1990 and 2012 and obtained urban flood potential maps in different regions. Multi-criteria spatial analysis information systems (SMCA) as a useful tool in identifying the risk of major flooding in watersheds by Prawiranegara [21] were presented. In this study, a framework for the broadcast range to evaluate the risk of floods and mudslides was presented. In this study, by the preparation of a Geodatabase, defined variables, the objective function, weight indicators were a high-sensitivity analysis and identify areas at risk of flooding. In a study conducted by Supriya et al. [22] in Volar River Basin, they obtained Regression analysis between precipitation and maximum flow rate exceeding floods occurred in this area and prioritized the flooding obtained for each of the areas in the basin. A velar downstream area has the highest rate and upstream areas were ranked lower. In another study, the flood risk maps for river basin Zi Apo was prepared by Zhang et al [23]. This map is effective as biological actions in the flood mitigation. After calibration and validation of the study, it was found that the map can be a useful tool in calculating flood flow depth. In this map of the three levels of flood risks for digital elevation data are available that can be used for management planning.

Material and methods

Study area

The study area is the Golestan Province located in northeastern of Iran. The population of Golestan is 2 million with the area of 20,000 km^2, the portion of the rural population is about 47 % and this area is well known for deadly flash floods. The climate is warm and semi-humid and annual precipitation is varying between 350 to 1000 mm with an average of 550 mm. Figure (1) shows the location of cities and villages distribution over the province. (Golestan Province Regional Water Organization, 2015) The province could be dividing into two different parts, flood-prone (mountainous regions) with area of 950,000 ha and flood plain, adjacent areas on mountain slopes, valleys and streams within area of 680,000 ha. Table 1 describes flooding situation of sub-basins in the province. The number of flood events in the province occurred in terms of time during the years 1991 to 2013 was about 106 heavy rainfalls in 548 points of the drainage basin that caused remarkable flood events over the province, which their trend is clear in Figure 2 in the period 1991 to 2013 (Watershed Deputy of Golestan Province, 2015). The greatest floods occurred mainly in the east of the province is the flood in 21 March 2001 which damaged the urban and rural facilities, infrastructure, agricultural, residential, commercial with 100,000 ha area in the cities of Minoodasht, Galikesh, Kalaleh and Gonbad, particularly forest and rangeland of the Golestan National Park (Figure 3).

Table 1. Flooding basins of Golestan Province.

Description	Flood Capacity	Basin
Mountainous and forested, great plain, high width, high population density, crop density, importance of transportation	Very High	Gorganroud
Mountainous and forested, moderate plain, moderate width, high population density, crop density, importance of transportation	High	Gharesoo
Mountainous and forested, small plain, small width, high population density, crop density, importance of transportation	High	Gorgan

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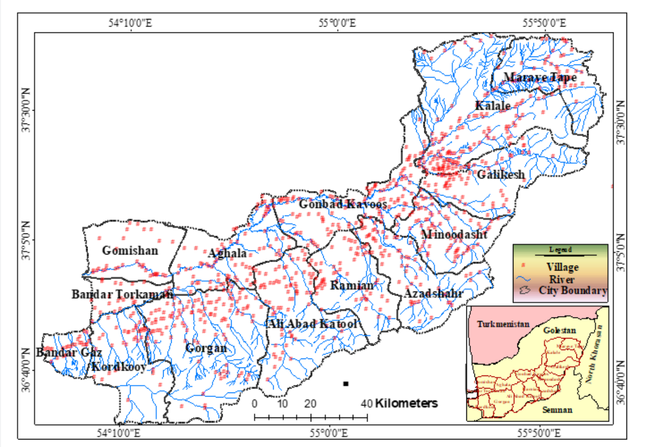

Figure 1: Distribution of villages in the Golestan province.

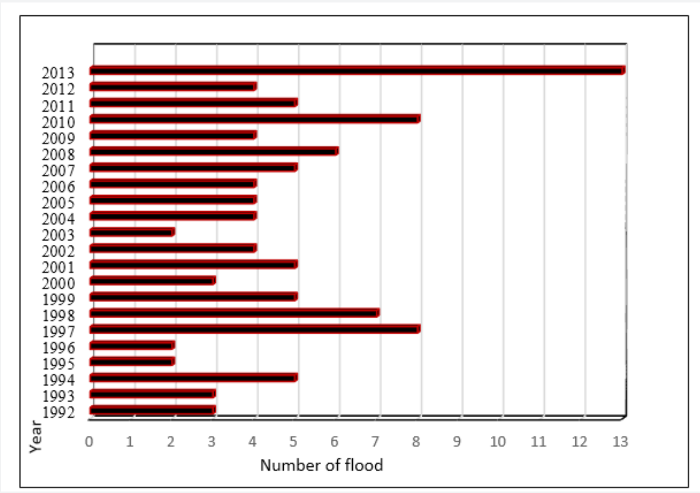

Figure 2: Number of flood events in the time period 1991-2013 in the Golestan Province.

Figure 3: Damages of flood event in year 2012 (Golestan National Park).

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In the current study, zonation of flood events in the Golestan province the ArcGIS software with Model Builder tool has been used. This modeling is generally an interface between input and output parameters and processing functions produce in the Process Modeler. In this interface, the user can apply several functions successively and processes performed one after the other. The flowchart of this process is presented in Figure (4), which include the provision of primary data, preparing them in GIS, multi-criteria decision analysis and mapping the flood hazard zone [24]. In order to obtain the importance degree of each factor or criteria on the occurrence of floods, the AHP algorithm has been applied. In order to solve a problem with this method, at first one should initiate basis network between purposes, sub-criteria, options and their relations. The next step is the comparison between all paired criteria. Weighting criteria and options will be achieved in a supermatrix while the rows should have a constant value [11].

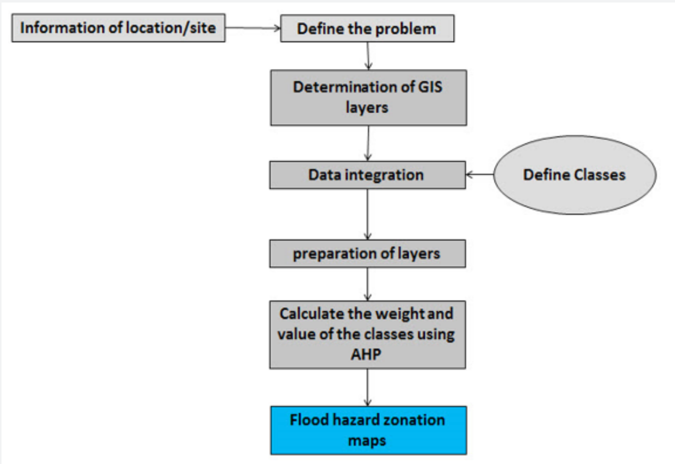

Figure 4: Flood hazard mapping flowchart.

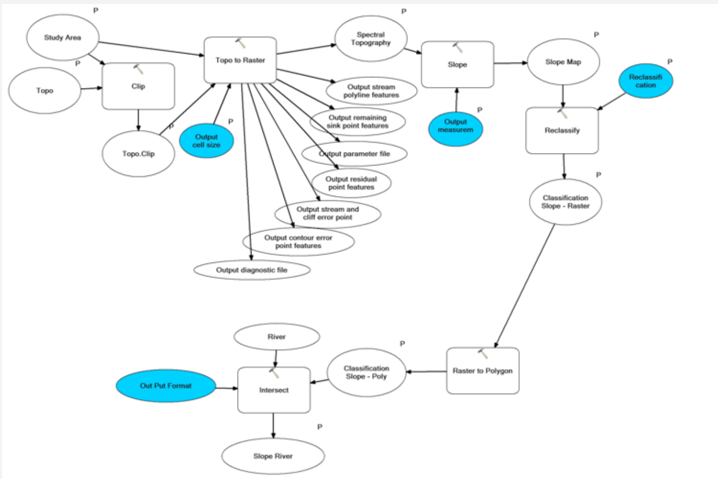

Figure 5: Algorithm of Steep River layers.

In AHP algorithm, comparing the relative rank of values can be done in a range from 1 to 10. The number one represents the number of equal importance between the two factors and ten represents the extreme importance of a single factor than others. After analyzing questionnaire to calculate the weights of each criterion and sub-criteria (according to interconnections) Super Decisions software was used. This software package, along with the ability to build decision models can calculate dependencies and feedback in super matrixes. The final weights derived from this software inserted in descriptive tables of data layers in the application of ArcGIS and after preparation using mathematical models overlap, the risk of flooding in the basin zoning map was prepared. By using a topographic layer of the study area, slope map is created and after slope classification based on user-defined classes, stream layer will be determined based on the classification. Programming code for this tool was python

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language. Model Builder is an application you use to create, edit, and manage models. Models are workflows that string together sequences of geo-processing tools, feeding the output of one tool into another tool as input. Model Builder can also be thought of as a visual programming language for building workflows. The model starts with a feature class of multiple permit application point locations. This feature class is fed into an iterator that loops over each individual point and feeds the point into the Select Layer by Location tool, where all addresses (parcels) within 1 mile of the point are selected. These addresses are then passed to a custom script tool (one that you or your colleague created), Generate Mailing List, that executes Python code to output a mailing list in HTML format. Finally, the mailing list is fed to another custom script tool, Send Email Notifications, which runs a custom executable that sends e-mail notifications and produces a success code. As is clear from the algorithm of layers Steep River, in this algorithm have been used from tools "Topo to Raster, Intersect, Slope, Reclassify and Raster to polygon". In the section classification of the slope, the user can define manually classification or based on pre-designed table build slope classification layer. In Figure 5 is shown the algorithm creation layers of Steep River.

In the model, slope classification was prepared in separate layers. By increasing the slope in the drainage basin, with increasing basin slope it can be seen, the time of concentration decreases, therefore probability flood hazard will increase with causes of bigger peak flow in the flood hydrograph. The user can choose the number and classified intervals. Classified maps which are required for the modeling the flood risk include basin slope, rainfall, geology, vegetation, compactness coefficient and the drainage layer component (Table 2). In order to check the discordances between the pair-wise comparisons and the reliability of the obtained weights, the consistency ratio (CR) must be computed. In AHP, the consistency is used to build a matrix and is expressed by a consistency ratio, which must be less than 0.1 to be accepted. Otherwise, it is necessary to review the subjective judgments [25] and recalculate the weights. For computing the consistency ratio (CR), the following formula was applied:

$$CR = {}^{CI}\!/_{IR} \qquad (1)$$

Where CI represents the consistency index computing according:

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad (2)$$

Where, λ_{max} represents the sum of the products between the sum of each column of the comparison matrix and the relative weights and n represent the size of the matrix. RI is the random index representing the consistency of a randomly generated pairwise comparison matrix. It is derived as average random consistency index, computed by Saaty [26] from a sample of 500 matrixes randomly generated. Regarding the modeling benefits, it could be applied to determine flood risk zones in all the 51 sub-basins in the province. According to selected parameters, using AHP to rate the parameters by three separate group experts, eventually, average rates were determined (Table 3).

Table 2. Level of risk parameters.

	Class	Value	Level of Risk
Parameters	Gb	8.3	very high
	cl	7.3	high
	Dkh	7	high
	EI	6.7	high
	Jck	6.3	high
	Kab	6	high
	Mc	5.7	high
	Pd	5.3	high
	Pgf	5	high
	Ngm	4.7	moderate
	O	4.3	moderate
	Pn	4	low
	Qal	3.3	very low
Vegetation	Forest	5	very low
	Shrubs	4	low
	Agriculture	3	moderate
	Range land	2	high
	Waterbody	1	very high

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Iso-Rain (mm)	0-100	3.3	very low
	100-250	4.3	low
	250-300	5	moderate
	300-500	6.4	high
	500-700	7.3	very high
	700-1000	8	very high
Slope (%)	0-0.2	1.3	very low
	0.2-0.4	3	low
	0.4-0.6	6	moderate
	0.6-0.8	7	high
	0.8-1	8.7	very high
	1	9.7	very high
Gravilious coefficient	0-0.25	3	low
	0.25-0.5	5	moderate
	0.5-1.5	6	high
Stream Path (Rank of Stream)	1	2	very low
	2	3	low
	3	5	moderate
	4	7	high
	5	9	very high

Table 3. Average scores given by expert groups.

Parameters	Group 1	Group 2	Group 3	Total Sum	Average
Geology	3	2	2	7	2.33
Vegetation	4	3	3	10	3.33
Iso-Rain	5	4	5	14	4.67
Slope (%)	6	5	6	17	5.67
Gravilious coefficient	4	5	4	13	4.33
Stream Path	10	10	9	29	9.67

Geology map: Geology map was prepared by using a 1:100,000-scale geology map of Golestan, obtained from the Geological Department, Iran. Seven major rock types were found in the basin including gypsiferous marl, limestone, sand dunes, and sandstone, shale, swamp, and valley terrace deposits.

Slope map: The watershed slope map of the area was generated from ASTER DEM (Global Data Explorer, Powered by GeoBrain, USGS) image of the study area by using ArcGIS 10.2 software and spatial analysis techniques.

Gravilious coefficient: (C_c) is the most frequently used index of the shape of the watersheds. Therefore, in current research circularity ratio (C_c) was calculated for each sun-drainage basin by using the formula [27]:

$$C_c = 0.282\frac{P}{\sqrt{A}} \qquad (3)$$

Where P and A are the perimeter (Km) and area of the watershed (Km^2), respectively.

The vegetation map: The Vegetation map is generated from LANDSAT image of the study area by using NDVI Indicators. Then given a set of parameters to determine the value of each matrix were prepared. In this matrix, each parameter mutually with other parameters was evaluated and results obtained in the Table (4). According to the procedure of AHP algorithm, the index of each parameter with considering the error occurred spectrum must be set to 1.0, was derived as Table (5). Finally, for all parameters, the weighted index was identified, and it can be applied in the model. Based on the scores given to the each of the six investigated parameters, the layers were prepared which are shown in Figure (6).

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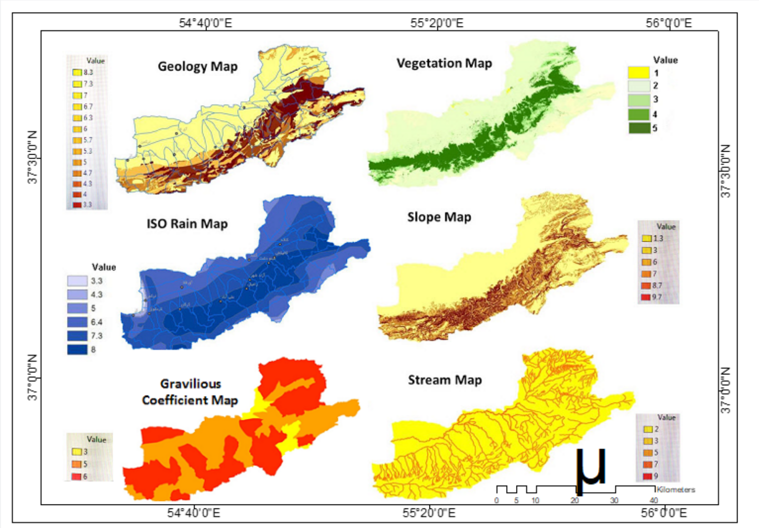

Figure 6: Map of the required parameters for modeling based on the average ratings by the expert teams.

Table 4. Matrix of parameters.

Parameters	Geology	Vegetation	Iso-Rain	Slope (%)	Gravilious coefficient	Stream Path
Geology	1	0.7	0.5	0.41	0.54	0.24
Vegetation	1.43	1	0.71	0.59	0.77	0.34
Iso-Rain	2	1.4	1	0.82	1.08	0.48
Slope (%)	2.43	1.7	1.21	1	1.31	0.59
Gravilious coefficient	1.86	1.3	0.93	0.76	1	0.45
Stream Path	4.14	2.9	2.07	1.71	2.23	1
Total Sum	12.86	9	6.43	5.29	6.92	3.1

Table 5. Classification of flood hazard zoning in the study area.

Row	Score Range	Flood hazard zoning
1	2.39-3.73	Very Low
2	3.73-4.56	Low
3	4.56-5.35	Moderate
4	5.35-7	High
5	07-Oct	Very High

Results and Discussion

The methodology used in this article focused on the analysis of those variables that control water flow at peak times. The systems MCDM criteria for prioritizing them from highest priority to lowest priority and classes were used. In this study, the range of these systems in order to provide the potential flood hazard study area due to good performance, the MCDM AHP-fuzzy system was used. This technique is the most widely used methods for solving the problem of multi-criteria decision systems [28]. This method is widely used in natural hazards and earned proportionality analysis [29]. With the development of new technologies, methods of preparing maps delineate flood and the environment and display these maps are required. New models, on the one hand, provide many possibilities for closer analysis and on the other hand, GIS provides users with a visual representation of flood maps. In the case of the good link between models and GIS, the option of applying the change, amend and update the maps easily and with minimal cost and time will be possible. The remarkable ability of this system is to manage flood plains before the flood and even crisis management and rescue during floods and reconstruction after the floods. The common method in preparing zoning maps after gathering data needed is calculation and plotting the maps of flood along the path of flow using model results. So finally, by applying weights and measures layers of geographic information system river flood risk zoning map of Golestan province were obtained (Figure 7). The model was developed using a flood hazard zoning map. The plan is to raster formats in the spectral range between 2.39 to 8.29. This map then is in five classes as very high-risk areas, areas with high risk, medium risk areas, areas with low risk and very low-risk areas (Table 5).

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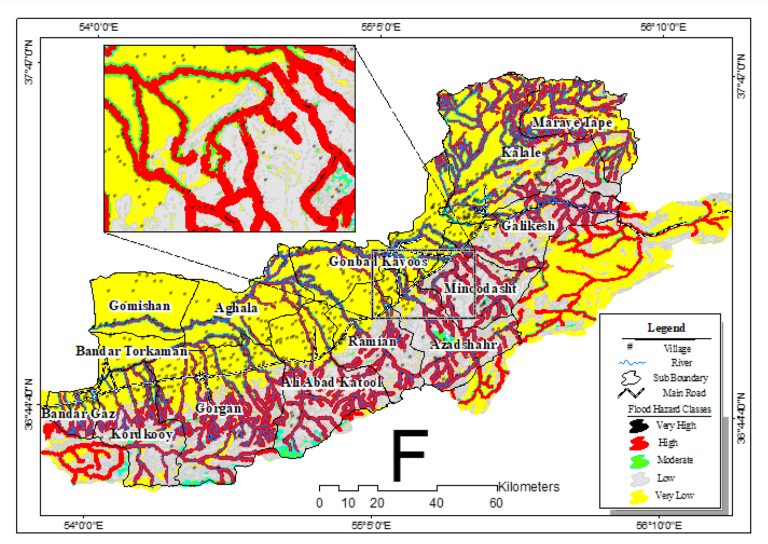

Figure 7: Flood hazard zoning map in the study area.

Proposed layout for flood warning stations

Flood Warning Decision Support System has a critical role to mitigate damages during flood events [30]. The flood warning system should have the following qualifications [31]. Always be active and provide updated information to the correct authorities and the users of the system, possibility for future system development, Flexibility in providing service to all applicants, maximum speed and accuracy in processing and Uses the top layer of security for the transmission of information access. It is not limited to a specific geographic location or region to increase awareness and limited to the physical presence of users to launch the system in processing information. In the case of flood risk, generates alarms and alerts [32] to users automatically in different forms, i.e. webpage, message, social media, etc. Thus, to survey floods, the stations and rain-gauge data alone or in combination should be used in suggested places. The location and number of such stations are intended to meet the objectives of the present study as follows:

a. The upstream catchment of sample stations should be a good index for the entire basin.

b. The time interval between notices of the threat of flooding for appropriate security should be measured accurately.

c. The distance of flood warning stations from risk areas is enough to have enough time for leaving the risk area. Suggested rain-gauge stations should be equipped with data transmission instruments. The water level is measured frequently and if the rainfall degree controller measures the intensity more than the standard level, an alarm will be submitted to a downstream station by a modem and router in site and through telephone lines, so that the residents of the village will be notified of the possibility of flooding. The proposed survey stations should be equipped with sensors to measure the water level and rainfall. The water level should be measured periodically in short time steps. If the water level measured at these stations be exceeded the limit, the alarm panel will be activated. Moreover, a signal will be submitted to the downstream station through the frequency band and the corresponding antenna and the alarm system will be activated on this station.

The overall view shows that in the study area the villages and residential areas in riversides and floodplains are the most important community that should be aware via the flood warning system. In addition, joining multiple branches of the river increases the flood risk and damages. Therefore, the study and identification of vulnerable areas to establish flood warning system are essential. The instruments in monitoring stations should be used with the electrical output. The output signals of instruments are in the form of standard signals and they are analog or digital signals. The instruments in this work include the measurement of water level and rainfall measurements. After estimating the risk of flooding by controller software, the siren installed in place will be turned on. These actions are done in a short time, therefore; residents have enough time to save their lives from the natural disaster. The flood warning using a communication platform (UHF) will be sent to the control center. The Figure 8 gives an overview of the monitoring plan of flood warning system in Gorganroud basin. This plan includes 74 repeater stations and 215 alarming stations. The fourteen control and monitoring centers of Kalaleh, Marave Tapeh, Galikesh, Minoodasht, Azadshahr, Ramian, Aliabad, Kordkooy, Bandar Gaz, Bandar Torkaman, Gomishan, Aghala Gonbad Kaboos are considered to collect and display data from all stations (Figure 8).

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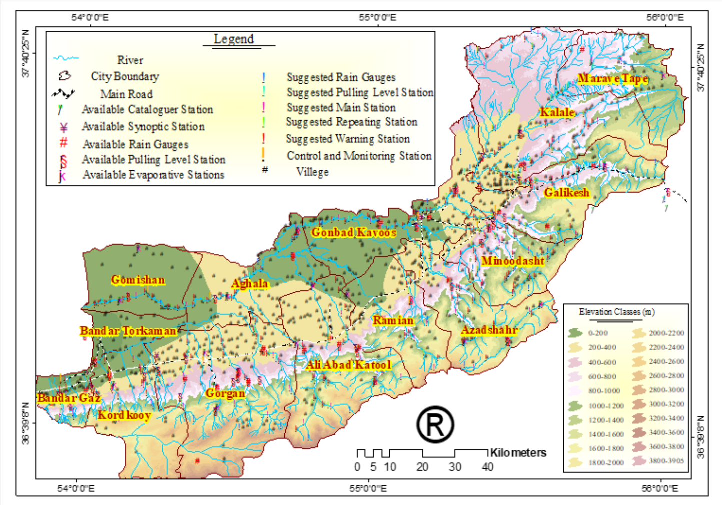

Figure 8: The proposed plan of monitoring flood warning stations in the study area.

Conclusion

Mapping potential flood risk is a new tool which can help decision makers of urban in, for example, evaluating the efficiency of drainage network infrastructure and development efforts needed to reduce flood risk. The final map shows that areas surrounding waterways and areas of eastern and central parts of the province have the highest rate risk. The number of villages located in various flood hazard zones and their populations was assessed over the study area. The results showed in 0.95% of drainage basins in Golestan were very high flood hazard, 22.75% high flood hazard, 11.1% middle flood hazard, 22.37% low flood hazard, 42.81% very low hazard. The study showed that eastern parts have higher flood risk than central and west regions. Meanwhile, the area (Gomishan, Gonbad Kavoos, and Bandar Torkaman) has a lower annual rainfall. Obviously, the flood control program should be based on a comprehensive plan and prioritized regarding the degree of flood risk.

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