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# Mapping The Flood-Prone Areas for Developing a Flood Risk Management System in The Northeast of Iran

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## Abstract

Flood hazard and disaster in Iran is one of the most frequent and damaging types of natural disaster. The Gorganroud watershed in the Golestan province recently has incurred severe damages resulted from flood events. Thus, this work was aimed to assess and map the flood susceptibility areas in the Gorganroud watershed to propose a comprehensive layout for flood monitoring and alarming stations. The Analytic Hierarchy Process (AHP) integrated with Weighted Linear Combination (WLC) approach within the GIS environment was employed to extract flood hazard zones. Results revealed that the cities Maraveh Tape, Bandar Gaz, Gorgan, Galikesh, Kordkooy, Minoodasht, Azadshahr, Kalale, Ramian, Gonbadkavoos, Aghala, Bandar Torkaman, and Gomishan with the ranks of 1 to 10, respectively populated the highest proportion of the "High" hazard class. Additionally, two percentages of the cities Aliabad, Azadshahr, Galikesh, and Gorgan were exposed to the hazard class of "Very High". According to results, about 32% of the villages and 26% of their population in the study area are exposed to the high and very high flood hazard zones. Furthermore, around 50% of the populations within high and very high hazard zones are <14 yr and >65 yr who are vulnerable to natural hazards. Based on the results of the flood hazard zoning, a layout of the monitoring plan for the flood warning system in the Gorganroud basin was proposed. This plan comprised 74 repeater stations and 215 alarming stations and fourteen control and monitoring centers were considered to collect and display data from all stations, as well.

***Keywords:*** *AHP; flood risk management; flood warning and a monitoring station; hazard zoning; multi-criteria evaluation.*

## 1. Introduction

Globally, floods are generally considered to be the most common natural disaster (Stefanidis and Stathis, 2013). Over the past several decades, flooding has caused significant economic damage and loss of life in every corner of the globe (Gaume et al., 2009). Despite substantial measures that have been enacted to prevent floods, the resultant loss of human life and property persist at high levels (Alexander, 1993; Cui et al., 2002). Worse still, flooding events are expected to increase in frequency and intensity in coming years due to rising sea levels and more frequent extreme precipitation events (Ramin and McMichael, 2009; IPCC, 2007; Stijn et al., 2013; Jonathan et al., 2013). Within this context, defining optimum strategies for appropriate flood management is essential (Ballesteros-Cánovas et al., 2013). Flood hazard risk, naturally, is usually measured by the probability that a flood will occur. A flood event generally results from a specific situation, i.e. high-intensity rainfall plus degraded geographical environment; however adequate information regarding these effective factors, as well as the relationship between them, is yet lacking.

The risks associated with climate and weather can be understood as an interaction of hazard, exposure, and vulnerability, forming a 'risk triangle' (Crichton, 1999, 2007). Specifically, in relation to flood risk, a source – pathways – receptors model is being used (DEFRA & EA, 2006). These models are combined (Figure 1) in relation to the risk of surface water flooding to people in urban areas. Climate hazard, or 'source', in the risk triangle framework, relates to extreme weather events, such as intense rainfall causing surface water flooding. Vulnerability refers to the intrinsic characteristics of the hazards' receptors (which can be people, infrastructure, and/or economic activities), and defines the extent to which these receptors are susceptible to harm from, or unable to cope with hazards. The term 'exposure' can be defined as nature and degree to which a receptor (the urban communities in this study) is exposed to climate or weather hazards (Parry et al., 2007). Thus, exposure, closely related to the concept of a flooding 'pathway' (DEFRA & EA, 2006), refers to the geographical location of a receptor, as well as the characteristics of the specific location that can exacerbate or reduce the magnitude of a hazard impact. According to this framework, for risks to be realized, the receptors and hazard need to coincide spatially. Further, the magnitude of risk depends on the level of vulnerability of the receptors, the nature of the hazard, and the physical characteristics of the environment defining the exposure (Lindley et al., 2006).

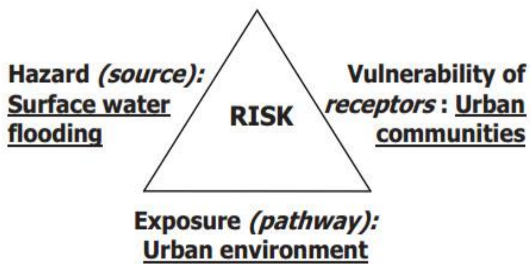


**Fig. 1.** Flood risk triangle (adopted from Crichton (1999) and DEFRA and EA (2006)).

Basin physical characteristics such as shape, slope drainage and topography of the land, together with hydrological characteristics such as precipitation, storage, and losses, evapotranspiration and actions resulting from human activities, are involved in the occurrence and intensity of floods and increase or decrease that. Understanding these factors and classify them in every area are the basics of flood control and risk reduction (Razavi, 2008). Therefore, in order to mitigate flood damages, identifying the driving factors is very important. In other words, before any planning for flood control, we should understand the behavior of its process (Ghanavati, 2003). Flood zoning maps present valuable information about the nature of floods and their effects on land (Valizadeh Kamran, 2007).

Multi-criteria decision analysis (MCDA) is required to analyze complex decision problems, which often includes conflicting criteria and objectives. The success of Geographic Information System (GIS) and MCDA in the analysis of natural risks (Gamper and Thoni, 2006; Rashed, 2003) and other environmental studies have already been proven (Dai et al., 2001; Kolat, 2006). Each of the factors affecting the occurrence of floods has a different role in the basin, as it can be prioritized due to the impact of each of these factors. In this study, the Analytic Hierarchy Process (AHP) is used to prioritize the impact of each of these factors. Generally, AHP arises from the combination of four major steps: (1) The establishment of the model and structure; (2) The establishment of the paired comparison matrices and vectors of priority; (3) the formation of supermatrix; and (4) choosing the best option (Najafi, 2010).

In Iran during recent decades, as with other flood-prone areas of the world, the incidence of the flood has been increased significantly (Management and Planning Organization of Iran Country, 2001). The upward trend of the flood in 5 recent decades show that the number of flood occurrences in the 2000s are ten times more than that in 1960s. Therefore, in this work, Gorganroud basin as a vulnerable watershed to flood events in the northeast of Iran was selected to be assessed in terms of flood occurrence and flood zoning utilizing a GIS-based analytic hierarchy process. Furthermore, a plan for flood warning stations was proposed based on the details of the flood zoning map.

## 2. Materials and Methods

### *Study watershed*

The study watershed is located within Golestan province in the north-east of Iran. Golestan Province has 14 cities, 27 districts and 927 villages (Figure 2).

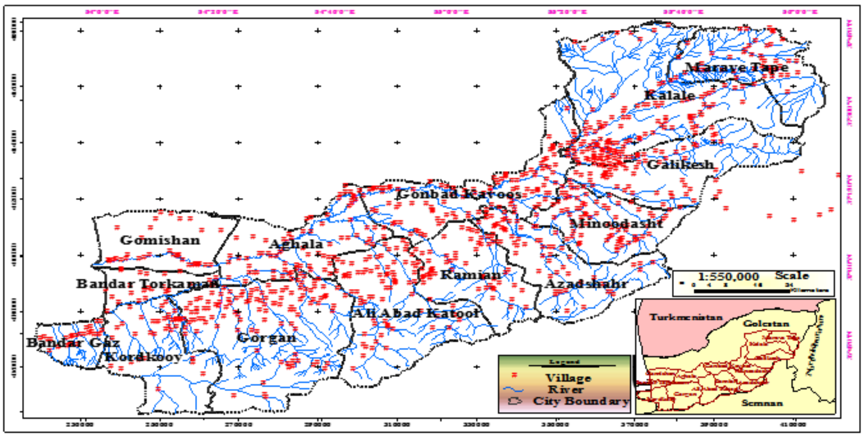


**Fig. 2.** The geographic location of study area

In this watershed, the most of the damaging floods occur in the summer and spring; such as the flood events during 2000-2005 in Atrak and Gorganroud basins. High floods occur mainly in the eastern region; such as the flood event dated 11 August 2011 at an area of 100,000 hectares in the municipalities of Minoodasht, Galikesh, Kalaleh, and Gonbad that caused a great deal of damages to the urban facilities, rural infrastructure, agricultural, residential, commercial, forest and rangelands. During the period 1991-2013, with 106 of rainfall events, 548 flood points were recorded in the watershed. Figure (3) depicts the number of flood events during the period 1991-2013 in the study area. Figure (4) also illustrates the number of financial losses resulted from flood events amid the period 1991-2013. This figure shows that the cities Galikesh, Maravetappe, and Azadshahr involve the most of damages, respectively (Figure 4).

An illustration of flood damage in Golestan National Park was show in figure (5).

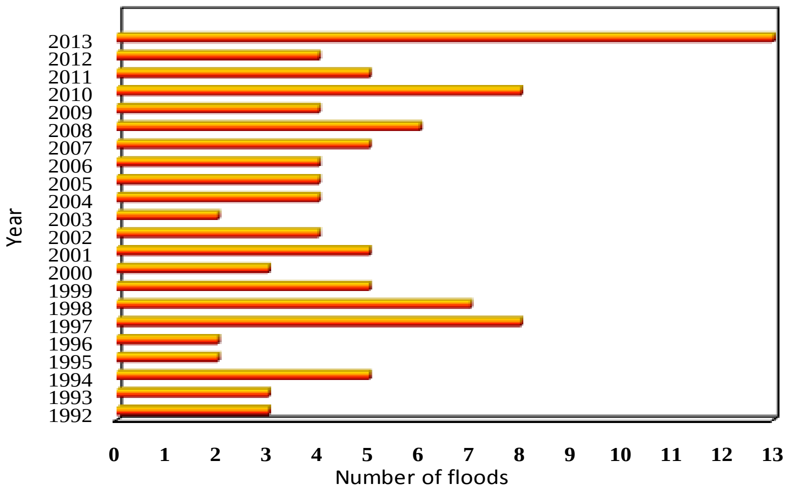


**Fig. 3.** Number of flood events during the period 1991-2013 in Golestan Province

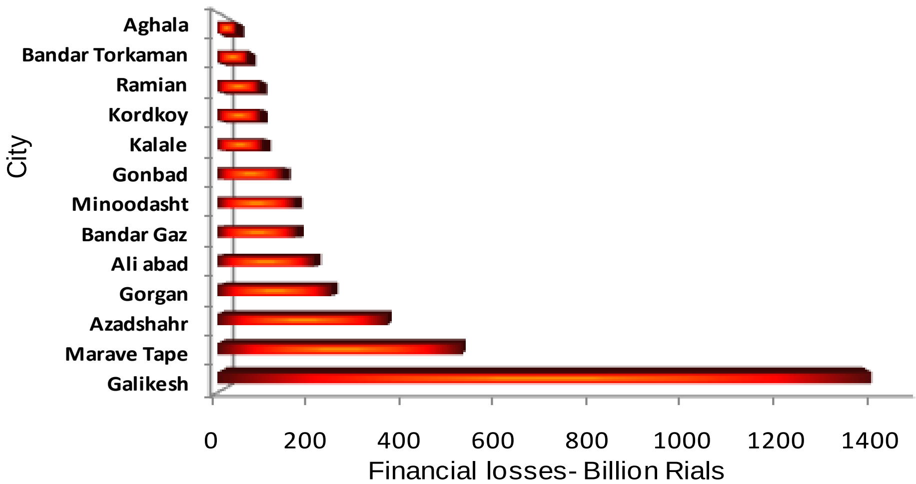


**Fig. 4.** Financial losses of flood events during the period 1991-2012 in Golestan Province

**Fig. 5.** An illustration of flood damages in the year 2013 (Golestan National Park)

In this study, Model Builder tool in Arc GIS software was employed to integrate different functions for flood zoning based on a GIS-based multi-criteria evaluation. Figure (6) shows the computational steps of this work.

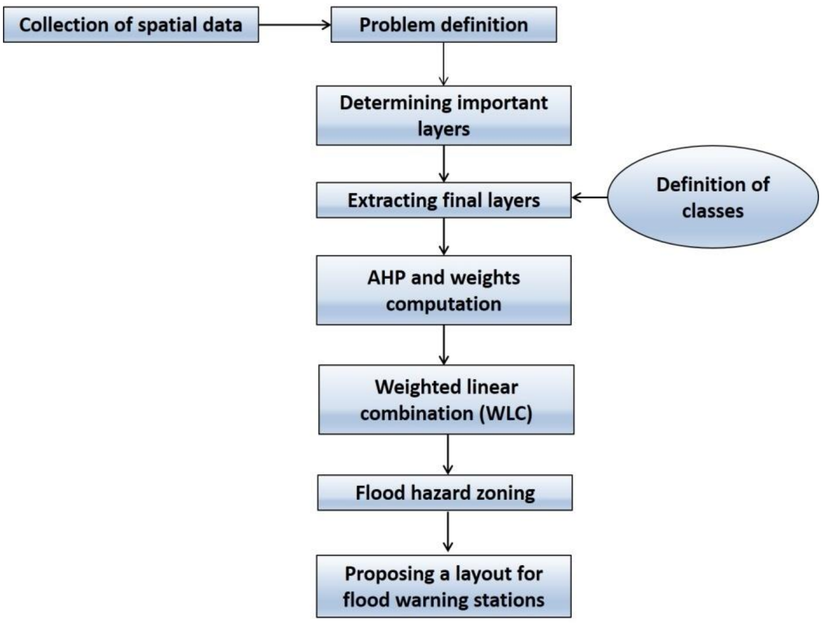


**Fig. 6.** The computational framework of this study

To obtain the degree of importance of each of the factors (criteria) and sub-criteria on the occurrence of floods, the AHP technique was used. To solve a problem with this approach, at first, a network of objectives, sub-criteria, options, and relationships between them should be plotted. The next step is pair-wise comparisons. The criteria related to paired comparisons are called control measures. Weights of criteria are extracted in a supermatrix (Momeni and Sharifi Salim, 2011). In AHP, a scale of 1-10 can be employed to determine the relative importance of a criterion than another criterion. The value of 1 represents the equal importance between two factors and the number 10 represents the extreme importance of a factor than another factor. After analyzing questionnaires, the Super Decisions software was used to calculate the weights of each criterion and sub-criteria (according to interconnections). This software package, along with the ability to build decision models can calculate dependencies and feedbacks in supermatrices. The final weights were inserted within attribute tables of data layers. Three teams of experts were employed to rate the parameters and then the average of scores was used in the AHP approach. Based on the results obtained from the questionnaire, the decision matrix was extracted. Finally, the final weights for all parameters were obtained utilizing the AHP technique.

The factors presented in Table 1 were pooled using Weighted Linear Combination (WLC) technique to extract flood hazard map. The WLC is the most common technique in MCE, which is based on the principle of weighted average:

$$A_i = \sum_{j=1}^{n} W_j * X_{ij} \tag{1}$$

Where, Wj is the j criterion weight; Xij is a value in the place i in relation to the criterion j, n is a total number of criteria and Ai is a suitability value which finally will attribute to the location i (Tajbakhsh et al. 2016).

## 3. Results and Discussion

After the factor "proximity to the river", which has been received the highest priority in flood zoning, the factor "slope" got the highest score by the expert's group. As established in the texts, with increasing the slope gradient, the time of concentration will be declined and the potential for flood events will be improved. High gradient causes the peaks in the hydrograph. The criteria "rainfall" and "gravilious coefficient" have near weights in flood zoning process. After them, the factors "vegetation" and "geology" rank in the next orders (tables 1-3).

**Table 1.** Average scores given by experts' 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 |
| **Rainfall** | 5 | 4 | 5 | 14 | 4.67 |
| **Slope** | 6 | 5 | 6 | 17 | 5.67 |
| **Gravilious coefficient** | 4 | 5 | 4 | 13 | 4.33 |
| **Proximity to river** | 10 | 10 | 9 | 29 | 9.66667 |

**Table 2.** The AHP decision matrix

| Parameters | Geology | Vegetation | Rainfall | Slope | Gravilious coefficient | Proximity to river |
|---|---|---|---|---|---|---|
| **Geology** | 1.00 | 0.70 | 0.50 | 0.41 | 0.54 | 0.24 |
| **Vegetation** | 1.43 | 1.00 | 0.71 | 0.59 | 0.77 | 0.34 |
| **Rainfall** | 2.00 | 1.40 | 1.00 | 0.82 | 1.08 | 0.48 |
| **Slope** | 2.43 | 1.70 | 1.21 | 1.00 | 1.31 | 0.59 |
| **Gravilious coefficient** | 1.86 | 1.30 | 0.93 | 0.76 | 1.00 | 0.45 |
| **Proximity to river** | 4.14 | 2.90 | 2.07 | 1.71 | 2.23 | 1.00 |
| **Total Sum** | 12.86 | 9.00 | 6.43 | 5.29 | 6.92 | 3.10 |

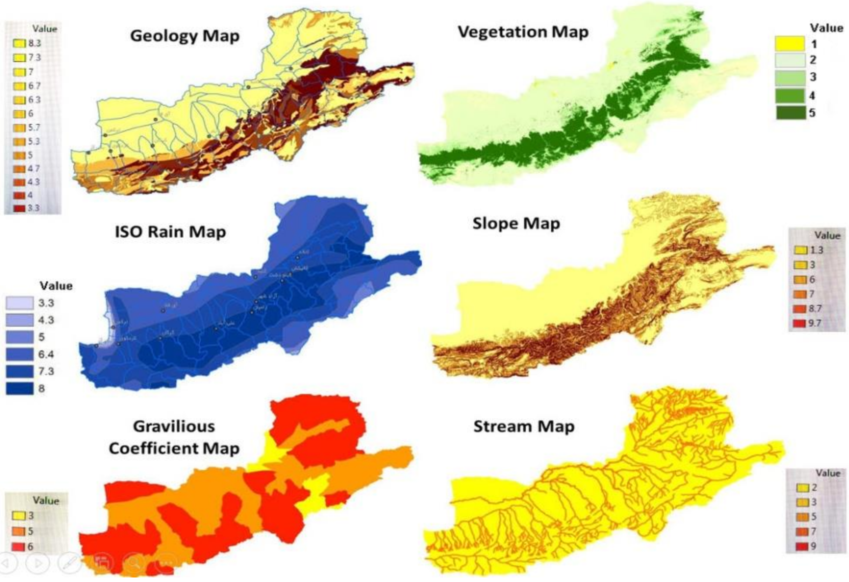


**Fig. 7.** The parameters' maps, classified based on the weights of different classes

**Table 3.** The final weight of parameters

| Parameter | Weight |
|---|---|
| **Geology** | 0.078 |
| **Vegetation** | 0.111 |
| **Rainfall** | 0.156 |
| **Slope** | 0.189 |
| **Gravilious coefficient** | 0.144 |
| **Proximity to river** | 0.322 |

The final hazard map was extracted using WLC technique in a range of values 2.39-8.29. This map then was classified into five hazard categories, i.e. very high, high, medium, low and very low (Figure 8). Mapping the potential flood risk can help decision makers, for evaluating the efficiency of drainage network infrastructure and development efforts needed to reduce flood risk. The final map shows that the areas surrounding waterways and areas in the east and center of the province have the highest rate of risk. Furthermore, this map shows the cities where are exposed to risk flood zones (figures 8-9).

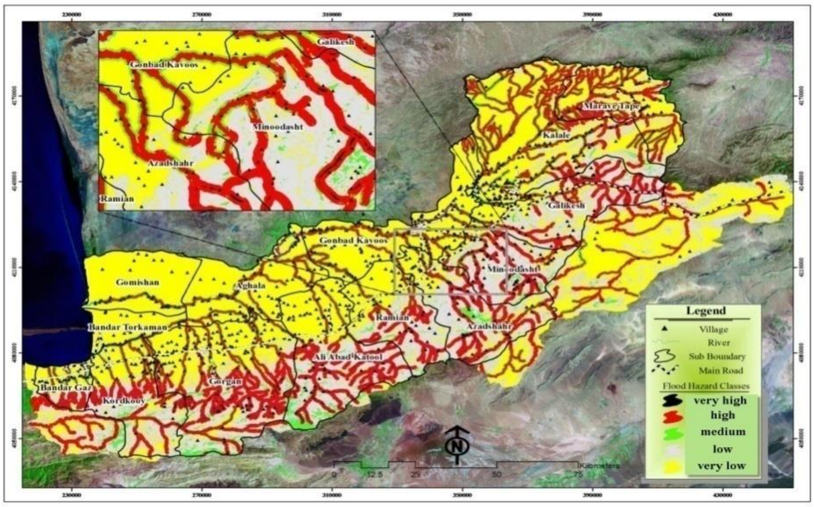


**Fig. 8.** Flood hazard zoning map in the study area

Results confirm that the cities Maraveh Tape, Bandar Gaz, Gorgan, Galikesh, Kordkooy, Minoodasht, Azadshahr, Kalale, Ramian,

Gonbad kavoos, Aghala, Bandar Torkaman, and Gomishan with the ranks of 1 to 10, respectively populate the highest proportion of the "High" hazard class. Moreover, two percentages of the cities Aliabad, Azadshahr, Galikesh, and Gorgan are exposed to the hazard class of "Very High" (Figure 9).

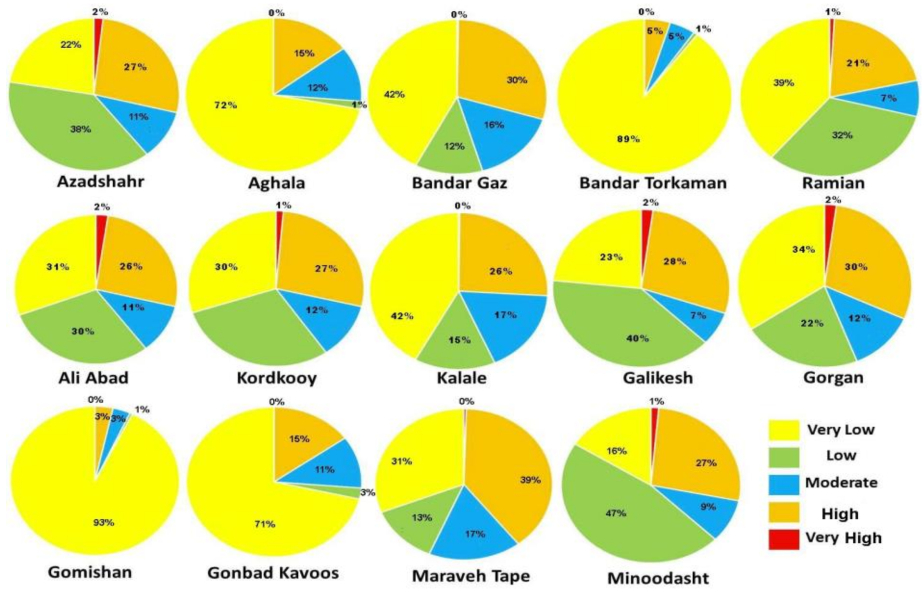


**Fig. 9.** The urban land proportions covered by flood hazard zones in the study area

Statistically, the number of villages located in flood hazard zones and populations were assessed, as presented in Table 4. As it can be seen, about 32% of the villages and 26% of their population are exposed to the high and very high flood hazard zones. Furthermore, Table (4) indicates that around 50% of the populations within high and very high hazard zones are <14 yr and >65 yr who are vulnerable to natural hazards.

With regard to the potential risk of flooding in the Gorganroud basin and the position of villages within the flood risk zones, we can implement the necessary actions in order to conduct training programs of coping with flood events and flood insurance for farming, horticulture and residential villagers and city dwellers in the study watershed and identify safe areas for the establishment of resettlement campsites.

**Table 4.**Population statistics of the villages covered by different flood hazard categories

| Flood hazard zone | Number of villages | Population | <14 yr | 15-64 yr | >65 yr |
|---|---|---|---|---|---|
| **Very High** | 12 | 5292 | 2456 | 2619 | 217 |
| **High** | 285 | 200087 | 86409 | 105839 | 7815 |
| **Medium** | 128 | 108345 | 48041 | 56287 | 4002 |
| **Low** | 83 | 33240 | 15224 | 16866 | 1148 |
| **Very Low** | 418 | 435268 | 190262 | 228419 | 16566 |

### *A proposed layout for flood warning stations*

Flood Warning Decision Support System has a critical role to mitigate damages during flood events (Winsemius et al. 2013). The flood warning system should have the following qualifications (Dale et al. 2013):

1-Always be active and provide updated information to the correct authorities and the users of the system.

2- The possibility for future system development

3- Flexibility in providing service to all applicants

4- The maximum speed and accuracy in processing

5-Uses the top layer of security for the transmission of information access

6- It is not limited to a specific geographic location or region to increase awareness

7- It is not limited to the physical presence of users to launch the system in processing information

8- In the case of flood risk, generates alarms and alerts 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:

- The upstream catchment of sample stations should be a good index for the entire basin.
- The time interval between notices of the threat of flooding for appropriate security should be measured accurately.
- The distance of flood warning stations from risk areas is sufficient 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.

Figure (10) 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 10).

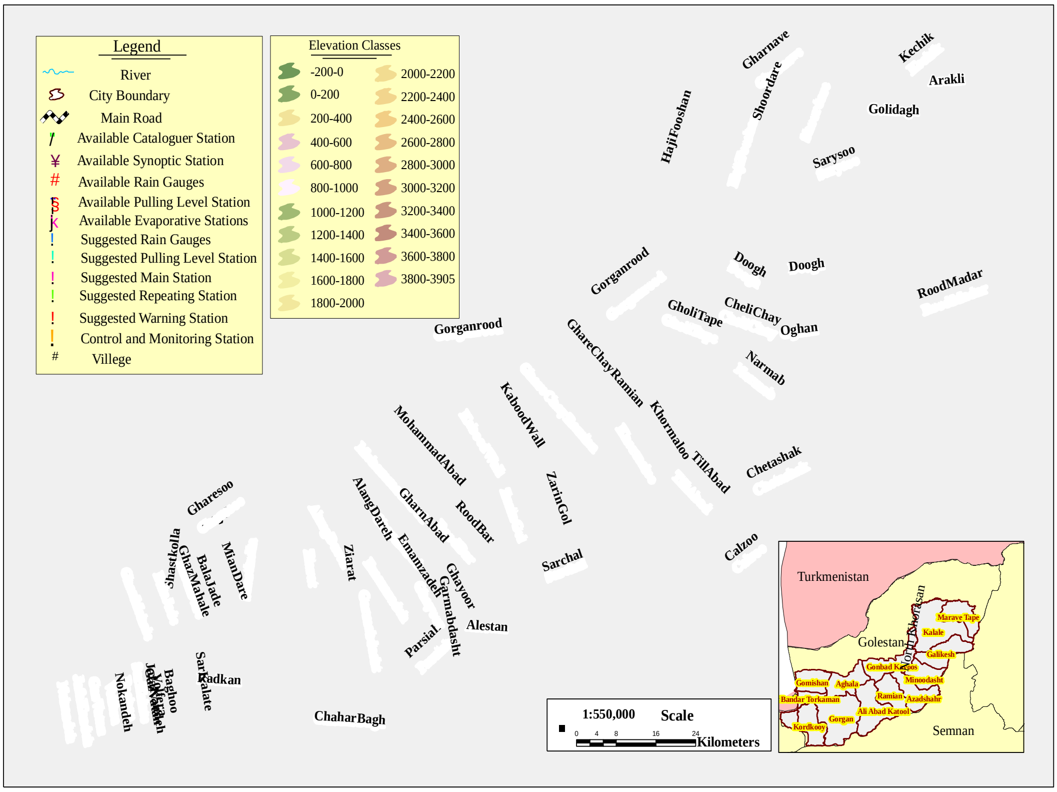


**Fig. 10.** The proposed plan of monitoring flood warning stations in the study watershed

## Conclusion

The flood hazard zoning map can be desired as an 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. To obtain the degree of importance of each of the factors (geology, vegetation, rainfall, slope, gravilious coefficient, proximity to the river) and sub-criteria on the occurrence of floods and mapping the zones, the AHP technique was used. The final hazard map was extracted using WLC technique in a range of values 2.39 (lowest hazard) to 8.29 (highest hazard). Results revealed that after the factor "proximity to the river", which received the highest priority in flood zoning, the factor "slope" got the highest score by the expert's group. The criteria "rainfall" and "gravilious coefficient" had near weights in flood zoning process. After them, the factors "vegetation" and "geology" ranked in the next orders. Results confirmed that the cities Maraveh Tape, Bandar Gaz, Gorgan, Galikesh, Kordkooy, Minoodasht, Azadshahr, Kalale, Ramian, Gonbad kavoos, Aghala, Bandar Torkaman, and Gomishan with the ranks of 1 to 10, respectively populated the highest proportion of the "High" hazard class. Moreover, two percentages of the cities Aliabad, Azadshahr, Galikesh, and Gorgan were exposed to the hazard class of "Very High". According to results, about 32% of the villages and 26% of their population in the study area are exposed to the high and very high flood hazard zones. Furthermore, around 50% of the populations within high and very high hazard zones are <14 yr and >65 yr who are vulnerable to natural hazards. Based on the results of the flood hazard zoning, a layout of the monitoring plan for the flood warning system in the Gorganroud basin was proposed. This plan includes 74 repeater stations and 215 alarming stations and fourteen control and monitoring centers were considered to collect and display data from all stations, a well.

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