J. Environ. Treat. Tech.
SSN: 2309-1185

Journal weblink: http://www.jett.dormaj.com

Evaluation of a GIS-Based Floodplain Height Difference Model for Flood Inundation Mapping, Case Study: Rudbar, Iran

Mohammad Ali Nezammahalleh, Mojtaba Yamani, Abolghassem Goorabi*, Mehran Maghsoudi, Shirin Mohamadkhan

Physical Geography Department, Faculty of Geography, University of Tehran, P.O.Box: 1417853933, Enqlab Ave., Tehran, Iran

Received: 20/06/2017 Accepted: 12/09/2017 Published: 30/09/2017

Abstract

Most of the human societies are experiencing increasing losses of flood hazard each year. Flood inundation mapping is useful for flood mitigation and risk reduction. To detect flood inundation areas, a novel GIS-based model has been developed in the present work. This model makes it possible to calculate the height difference of floodplain surfaces from riverbed by the use of terrain data and hydrometric statistics. The output of the model disregards the mountain topography and represents the local terrain of the floodplain. The output along with the peak discharge by Creager model has been applied for the inundation mapping. The estimated values of the model and observed values have a RMSE of 2.58. The results showed a significant difference, at 95% confidence interval, between the flooded and non-flooded villages in the height differences. It can be concluded that the rural settlements lower in height are more at risk of flooding.

Keywords: Floodplain Height Difference, flood inundation, GIS-based model, Rudbar

1 Introduction

Flooding is one of the environmental hazards to human society [1, 2]. In the recent years, the frequency and intensity of flood events are increasing as a result of climate changes [3] and expansion of human settlements towards unsuitable areas [2, 4]. Population increase results in the expansion of the settlements towards hazardous areas and more exploitation of the nature. These uncontrolled increasing processes of climate change and population increase cause catastrophes that require more expenses in the future for remediation and mitigation policies [5, 6].

According to the Centre for Research on the Epidemiology of Disasters, Emergency Events Database (CRED EMDAT), the natural hazards left 35,561,592 people killed and $ 2.7 billion of financial losses from 1900 to 2015 [7]. The flooding event in 2015 in Rudbar region made serious damage to the local societies [8]. The flooding killed and injured many people and devastated many human settlements and also caused enormous financial losses in the past years [4]. These kinds of losses can be repeated again in the future in many susceptible areas mainly in vulnerable parts of settlements [9]. Therefore, it is necessary to investigate the flooding and make flood inundation mapping in such flood prone areas for risk reduction.

The flooding in mountain streams with multiple process patterns have been modeled through process routing, a formative scenario analysis and hazard assessment using expert elicitation and scenario trajectories [10]. Some flood inundation researches used regional flood frequency analysis using hydro-geomorphic characteristics and flood quantiles for multivariate regional regression models [11]. Some studies assessed building vulnerability using building evacuations, inundation and access properties to apply the evacuation model and define vulnerability patterns of settlements [12]. Flooding resilience and vulnerability of settlements was also discussed to show the importance of resilience in flood damage and risk reduction [13]. The effects of flood runoff in a variety of human activities were examined by GIS techniques [14].

The flood inundation mapping was examined in some studies using HEC-GeoRas in ArcGIS and GeoHMS [11, 15] to make a zonation of flood prone areas in different regions. Many researches used some criteria for flood zoning using hydraulics techniques [16]. The previous flood inundation models [16] did not calculate the height of floodplain from the riverbed for each pixel.

The purpose of this research is to introduce a novel flood inundation method as a GIS tool based on terrain and peak discharge data for application in any region of interest. The study has also evaluated the results of the model by field data and flood event in July 19, 2015.

2 Materials and Methods

2.1 Study area

The study area of this research is Rudbar Basin with an area of 564 km^2 and mean water discharge of 2.15 cubic

Corresponding author: Abolghassem Goorabi, Physical Geography Department, Faculty of Geography, University of Tehran, P.O.Box: 1417853933, Enqlab Ave., Tehran, Iran, Tel.: +98 21 61113521; Fax: +98 21 66404366 email: goorabi@ut.ac.ir

meters per second. The watershed is located in northern slopes of Alborz Mountain Range (Figure 1). The area is located in the Central Alborz geologic zone mainly with sandstone, limestone, marl, and fan deposits and covered by dense forest and pasture [17, 18]. A catastrophic flooding event in the study area in July 19, 2015, devastated many settlements and transportation infrastructures and also killed some local people and passengers on the road [8].

2.2 Data

In this research, we have used digital topographic maps, at 1:25000 scale, derived from National Cartographic Center, SRTM elevation data, with 30 m resolution, from USGS, and discharge data of hydrometric stations from Regional Water Organization. Information about the flood events was gathered from the reports of Red Crescent and IRI Crisis Management Organization.

2.3 Floodplain height difference model

This present method is based on DEM pixel values and neighborhood functions. The pixels crossed by riverbed are initially considered zero (RO). Then, Using neighborhood relationships in ArcToolBox of ArcGIS, the elevation value of each pixel of river (RE) has been extended towards the both sides of river channel equal to the maximum width of floodplain.

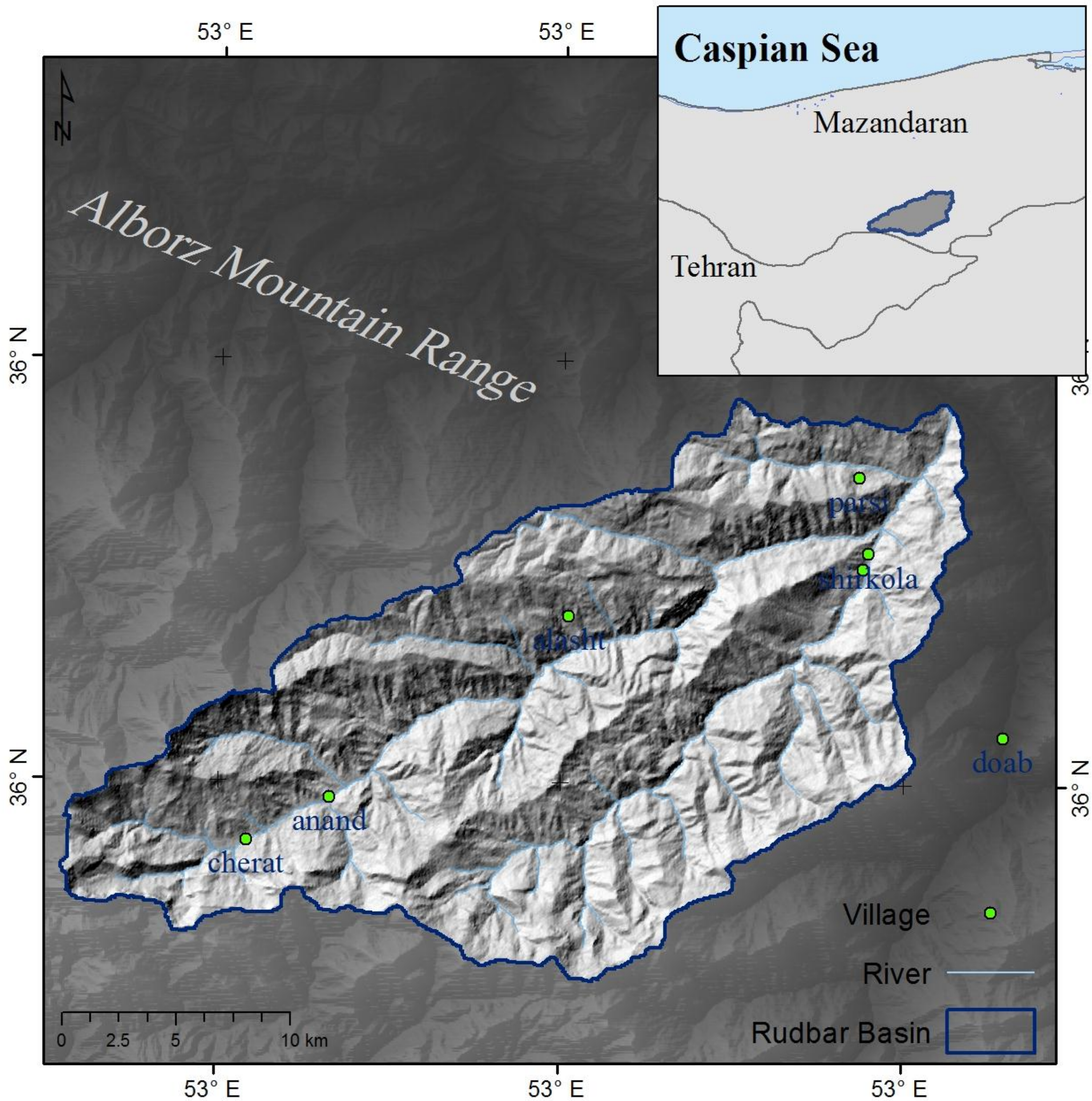

Figure 1: The position of the study area

Eventually, the riverbed elevation values (RE) have been subtracted from DEM values of the area. By this, there is a virtual cross profile for each pixel of the river path perpendicular to the path direction. The result is difference of each pixel of the area from the riverbed. This method is devised by python scripting and presented as a tool in GIS ArcToolBox for application in any region of interest (Figure 2, Figure 3).

The innovation of the method is that there is no method to obtain the height differences of the surrounding surfaces from the riverbed in mountainous areas. The tool devised by the authors take two inputs, the river path as a polyline feature and raster DEM. The output is a raster file indicating height differences around the river. The tool has been tried in different areas and returned the accurate results according to the field data. We have used DEM with a 10 m resolution as input raster and river feature after corrections by topology rules as input river feature.

2.4 Peak flow estimation

The peak flow is an important variable to show flood heights in certain return periods. In this research, the Creager peak discharge model has been used to calculate peak discharge in cubic foot per seconds (*Qp*).

$$Q_p = 46CA^{0.894A^{-0.048}}$$

where *A* is area in square miles and C is coefficient for different return periods in the region. The result can be used to obtain volume of possible flood water in the region.

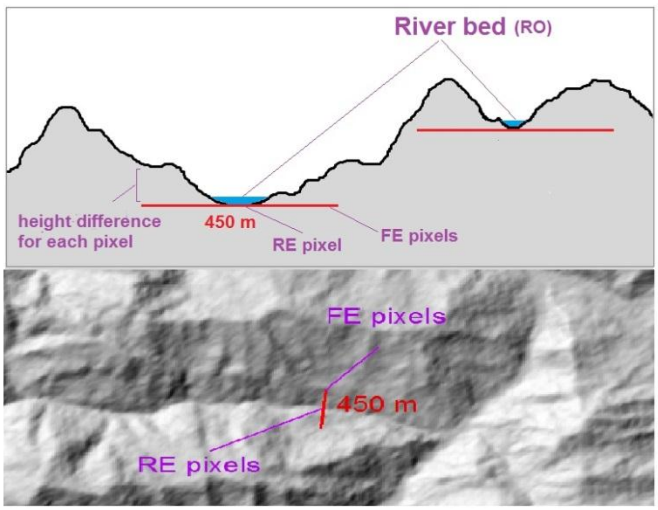

Figure 2: The schematic illustration of the FHD model; the upper is a schematic profile and the lower is a top view.

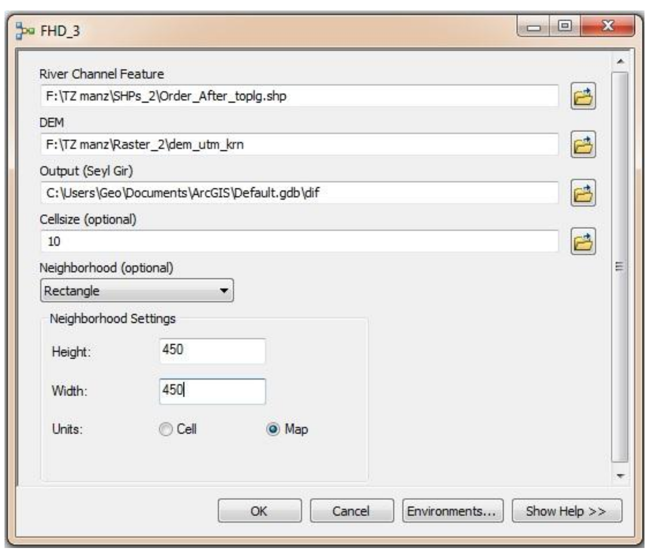

Figure 3: The devised tool to obtain height difference of the channel bed

Using the volume of peak flow discharge of a region and the surface area, the approximate height of flood water based on irregular conic shape can be obtained. According to volume equation, the height (h) can be found as the following:

$$h = \frac{V}{A} \times \frac{1}{3} \tag{2}$$

where, V is volume of water in cubic meters and A is the surface area of puddles and low areas in the channel. Therefore, the areas lower than the height can be extracted by an algebraic expression in ArcGIS.

2.5 Evaluation of the model

In order to evaluate the developed model, elevation values of 20 villages in the study area in the vicinity of the river have been collected by GPS. Accordingly, the corresponding elevation values of the riverbed points in the nearest distance from the villages have also been collected by GPS for each village. The difference of the village elevation from the riverbed elevation indicated the observed floodplain height difference.

The Root Mean Square Error (RMSE) has been used to measure the difference between the values predicted by FHD and the values observed in the field, Rudbar. There are individual differences for all the observed villages. The RMSE serves to aggregate the values into a single measure that indicate predictive power of the model. The RMSE of a model prediction with respect to the estimated variable X model is defined as the mean root square error:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (X_{o,i} - X_{ei})^2}{n}} \tag{3}$$

where X_o is observed values and X_e is the estimated ones by the model at place i. The RMSE values can show model performance.

3 Results and Discussion

3.1 Floodplain Height Difference

To make flood inundation mapping, it is required to have both the heights of floodplain surfaces from the riverbed as pixels and the height of flood water rise in the river channel. The developed FHD model has been used to calculate floodplain height. The flood rise has been calculated for the area through the volume of peak flow discharge. Eventually the heights of floodplain surfaces lower than the heights of flood water level represent the inundation areas for the watershed. The maximum floodplain width for Rudbar Watershed has been considered 450 m.

Figure 4 shows the output raster generated by FHD tool. In the raster file, each pixel value represents the height of each pixel from the riverbed. The FHD model has calculated the height differences in the areas near the river as a raster file for the entire study area. The raster file shows how much the surrounding areas near the river are higher than the riverbed. As an instance, the magnified image of a selected area was shown in Figure 4. The contours in 0.5 m and 3 m have been extracted from the height difference raster and shown in the magnified area as an example. Each contour line represents a specified height from floodplain. By this result, we can extract any number of cross profiles with the bed considered as zero.

With a given volume of water in the channel, we can obtain the height of flooding in the channel as a container. The puddles and holes inside the channel can be detected as contours. These are the areas can be submerged by a given volume of flood water.

3.2 Evaluation of the model

The 20 villages in the region along the river are located in a variety of elevations. The vertical heights of the sample villages to the riverbed have been calculated and then compared with the estimated height difference by the FHD tool. The values are presented in Table 1. For example, the village number 6 was measured at a location 96.33 m higher than the riverbed and it is estimated 98.42 m higher than the riverbed. Accordingly, for the village number 10, the model exactly estimated its location on the floodplain 0.5 m higher than the river. The EMSE value is 2.58 for this region. Maximum error is for a location 15 m high from the riverbed.

Table 1: RMSE values for village points

No	Estimated by FHD	Observed height difference	Difference values
1	88.00	86.00	2.00
2	3.70	6.00	-2.30
3	7.58	7.66	-0.08
4	21.53	23.66	-2.13
5	42.42	42.50	-0.08
6	98.42	96.33	2.09
7	33.09	29.00	4.09
8	51.07	51.33	-0.26
9	53.73	54.06	-0.33
10	0.50	0.50	0.00
11	16.10	15.33	0.77
12	33.10	33.00	0.10
13	15.22	16.00	-0.78
14	15.98	14.00	1.98
15	23.65	24.00	-0.35
16	23.56	15.00	8.56
17	49.44	53.00	-3.56
18	0.50	0.50	0.00
19	88.00	87.66	0.34
20	0.19	0.50	-0.31

The output of FHD model has been used as height contours based on the return periods of 20 years, 50 years, and 100 years by the Creager method that were 211.79, 329.21, and 444.49 cubic meters per second, respectively. With the flood water height of 0.5 and 3 m, certain areas of channel and floodplain lower than a given contour would be submerged.

3.3 FHD Verification

The villages damaged by the flood catastrophe in 2015 are located in the heights less than 10 m to the riverbed. This has indicated the height difference can be used to predict the areas of future flooding. Some villages have been experienced the flooding. We selected 4 samples for flooded rural settlements and 16 sample villages for neighboring settlements without flood damage in the same rainfall and discharge.

To compare the mean values of FHD in two groups of villages afflicted in the flood event July 19, 2015 and those not damaged seriously in the event, two independent sample t-test can be applied. The 2-tailed significance values for RUNS test and one-sample Kolmogorov Smirnov test have been 0.818 and 0.390, respectively. With the normal distribution of the samples, the result of the independent samples t-test between 4 flooded and 16 none-flooded villages is significant at P-value=0.05, Table 2. Therefore, the mean values of height difference, extracted by the model, are different between the two groups of flooded and non-flooded villages.

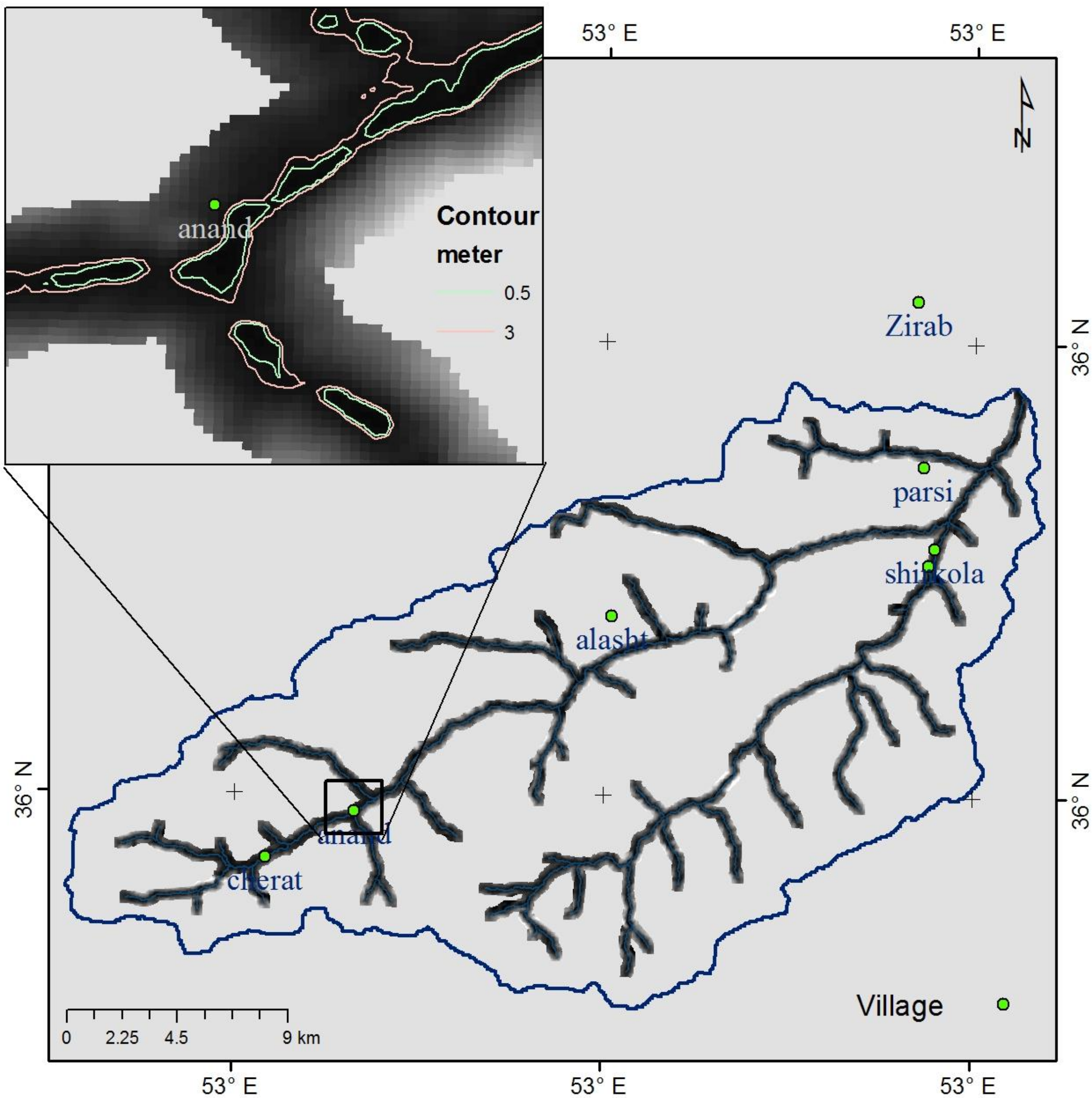

Figure 4: The output of the FHD model

Table 2: The result of the two independent samples T test for the two groups of flooded and non-flooded villages

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
FHD2	Equal variances assumed	4.620	.045	2.194	18	.042	32.43052	14.77880	1.38142	63.47962
	Equal variances not assumed			4.015	17.794	.001	32.43052	8.07648	15.44841	49.41263

4 Conclusions

An innovated GIS-based FHD model has been devised and applied for the first time in this research. The results of the method have successfully demonstrated the good performance of the method to estimate flood inundation zones in a case study, Rudbar. This method have calculated the height differences of the pixels of floodplain surfaces to the riverbed to obtain the terrain characteristics of the floodplain regardless of the floodplain slope along the channel on the relief mountainous areas. This tool can remove relief and slope and aspects of mountainous areas in order to get the topography on the floodplain. The output of the tool in a long profile no longer shows the mountain slope and flow direction but it just represents the local slopes of the floodplain. Using the neighborhood functions of Spatial Analyst, we have attempted to improve flood inundation mapping via the method. The RMSE has also confirmed the low error values of the model for the given area. The study has indicated that the lower areas relative to the riverbed are more at risk of flooding. It can be concluded that there is a significant difference between the two groups of the villages afflicted by flood and those not affected by the event. This method has detected the flood prone areas and the village might be submerged by any possible flood event.

References

1. Chen S. A.; Evans B.; Djordjevic S.; Savic, A. Dragan; (2012). Multi-layered coarse grid modeling in 2D urban flood simulations, Journal of Hydrology 470-471, 1-11.
2. De Risi, R., Jalayer, F., De Paola, F., (2015). Meso-scale hazard zoning of potentially flood prone areas. Journal of Hydrology 527, 315-325.
3. Krellenberg, K., Link, F., Welz, J., Harris, J., Barth, K., Irarrazaval, F., (2014). Supporting local adaptation: The contribution of socio-environmental fragmentation to urban vulnerability, Applied Geography 55, 61-70.
4. Ghahroudi, M.; Nezammahalleh, M. A.; (2013). Urban flooding management using the natural drainage system, case study: Tehran, capital of Iran, Floods: from risk to opportunity (IAHS Publ. 357) 174-180.
5. Alavipanah S.K., Nezammahalleh, M.A., (2013). The relationship of salt classification with distance to shoreline and elevation, case study Lake Urmia, Iran. Journal of Environmental Treatment Techniques 1, 35-37.
6. Muis, S.; Guneralp, B.; Jongman, B.; Aerts, J. C.J.H.; Ward, P.J.; (2015).flood risk and adaptation strategies under climate change and urban expansion: a probabilistic analysis using global data, Science of Total Environment 538, 445-457.
7. Centre for Research on the Epidemiology of Disasters, Emergency Events Database (CRED EMDAT), http://www.emdat.be/
8. Reports of Red Crescent and Crisis Management Organization, 2015.
9. Nezammahalleh, M.A.; Yamani, M.; Talebi, A.; Pourhosseini, Z.; Alavipanah, S.K.; (2013). a novel criterion for earthquake risk assessment, the case of Bushehr catastrophe in April 9, 2013; ISPRS conference, Tehran, 301-304.
10. Mazzorana B., Comiti F., Scherer C., Fuchs S., (2012), Developing consistent scenarios to assess flood hazards in mountain streams, Journal of Environmental Management 94, 112-124.
11. Sarhadi, A., Soltani, S., Modarres, R., (2012). Probabilistic flood inundation mapping of ungauged rivers: linking GIS techniques and frequency analysis, Journal of Hydrology 458, 68-86.
12. Hubbard, S.; Stewart, K.; Fan, J.; (2014). modeling spatiotemporal patterns of building vulnerability and content evacuations before a riverine flood disaster, applied geography 52, 172-181.
13. Matthews, E., Friedland, C.J., Orooji, F., (2016), optimization of sustainability and flood hazard resilience for home designs, Procedia Engineering 145, 525-531.
14. Iqbal S.M., Juel Rana Kutub Md., Debnath P., Falgunee N., Nawfee S.M., Sojib S.I., (2015), Determining the changeability of groundwater level in the southwestern part of Bangladesh using Geographic Information System (GIS): a spatio-temporal analysis, Journal of Environmental Treatment Techniques 3, 176-183.
15. Nistoran, D.G., Ionescu, C., Patru, G., Armas, I., Omrani, S.G., (2017), one dimensional sediment transport model to assess channel changes along Oltenita-Calarasi reach of Danube River, Romania, Energy Procedia 112, 67-74.
16. Teng J., Jakeman AJ, Vaze J., Croke BFW; Dutta D., Kim S., (2017)., Flood inundation modeling: A review of methods, recent advances and uncertainty analysis, Environmental Modeling & Software 90, 201-216.

17. Sadeghi-Pouya, A.R., Nouri, J., Mansouri, N., Kia-Lashkari, A., (2017), An indexing approach to assess flood vulnerability in the western coastal cities of Mazandaran, Iran, International Journal of Disaster Risk Reduction 22, 304-3016.
18. Ghahroudi, M., Sadough, S.H., Nezammahalleh, M.A., Nezammahalleh, S.K., (2012), Multi-criteria evaluation to select sites for ecotourism facilities: case study Miankaleh Peninsula, Anatolia 23, 373-394.