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FLOOD RISK ASSESSMENT IN KAND WATERSHED OF IRAN

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ABSTRACT

Flood risk is a function of three factors namely, flood hazard, exposed land uses, and their vulnerability that threatens various aspects of life is flood. Such factors and their role have been examined in Kand watershed, 14 km northeastern Tehran in Iran.

This study aims at preparing flood zoning maps in different return periods using HEC-RAS (Hydrologic Engineering Center -River Analysis System) and GIS (geographic information system); determining the vulnerability of buildings; providing the flood risk map regards to controlling land functions in the area of Kand Watershed.

The land use map demonstrates that the distance separating the Kand River and buildings is negligible. HEC-RAS software is used to calculate surface water profiles for 100-year return period. Flood discharges are calculated with the values of 451.86 m3/s. The mean depth of water is 1.4m. The vulnerability analysis of buildings shows that if the flood with the depth of less than 70 cm occurs, most equipment of the buildings will be damaged. As a result, the flood risk is high in the areas that have less distance with river. Therefore, flood risks maps are useful in making more precise decisions and actions relative to risk reduction management and mitigation.

INTRODUCTION

One of the natural hazards that threaten human lives and properties is flood. The flood occurs when the amount of river discharge exceeds the natural boundary and covers the surrounding area with different land uses. Flood risk is defined as the potential consequences of a flood [1, 2, 3, 4, 5, 6]. Flood risk assessment is a process for evaluating flood risk as defined by hazard and exposure of people and their properties to the event and impact [7]. In order to manage the flood risk, it is crucial to predict and deal with natural hazards before causing lives and financial damages. Perception of flood risk and estimation of damage to the properties has been recognized as a crucial element in flood risk management [8]. Therefore, flood risk assessment is a method for determination of areas prone to floods and evaluate the effects of developmental changes in the area [9]. One of the most recognized techniques of assessing flood risk is flood simulation, modeling and mapping [10, 11, 12, 13, 14, 15, 16, 17, 18,19]. Flood hazard simulation using HEC-RAS and hazard mapping using geographic information systems (GIS) models are widely applied as the primary steps in flood risk assessment [10, 20, 21].

Determining the scale of work is a core element in evaluation of flood hazards and flood risk which is chosen based on breadth of the area. Data collection can be conducted differently due to the type of the project and its breadth. The scale can be examined in following three levels [22]:

1. National and international level: the scale of work is macro and the areas such as international and cross-border rivers are analyzed in this level. Data are less precise and the details are not considered.
2. Region level: the scale of work is average and a part of long river or catchment area of moderate river is studied.
3. Local level: The scale of work is micro in this level, small flood plains are examined, and the damages to each building are calculated.

Flood risk assessment at the local scale is an important tool to assist the decision makers and mangers to identify and prioritize development [23]. In this level, the amount of effort and cost per unit area are greater since the more details are considered in such scale and the flood risk will be estimated according to each building.

Kand watershed locates in Lavasan city and is considered as one of the attractions of residents of Tehran due to its distance to Tehran and enjoying clean air. As a result, this city is one of the focal points of development. The Kand river is precisely passing through the densely populated part of the city and has a small distance to residential use. The study of the river discharge peak for this region in different years has shown a dramatic increase in the

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discharge. Therefore, this study aims at assessing the flood risk at the boundary of the Kand River in Lavasan city estimated in different return periods using HEC-RAS and ArcGIS. The flood hazard map has been created due to watershed characteristics using HEC-RAS. The vulnerability map was prepared from data of damage to residential buildings**.** Flood risk map has been generated as a spatial overlay operation between the hazard and vulnerability layer using ArcGIS.

MATERIALS AND METHODS

Study Site

Having an average elevation of 1700 meters above sea level, Kand Watershed is geographically located between 35°46' to 35°50' East longitudes and 51°35' to 51°50' North latitudes with a total land area of 69 km2. The location map of Kand River is presented in Figure 1. The only city of this watershed is Lavasan which is located in 14 km northeastern of Tehran, the capital of Iran. The population of the city is around 11,000 people [24]. The residential buildings and gardens are in both sides of the Kand river and in some parts of the study area, the distance between buildings and river is less than 10m. The floor data of the buildings shows that 70 percent of the buildings have 1 floor and 30 percent of them have more than 1 floor which should be considered in vulnerability map generation. Glenduk hydrometric station is the only station in this sub-area where atmospheric rainfall measurements take place. Figure 2 shows the peak discharge data of different years [25]. The study of peak discharge data shows that the edge of the Kand River has the potentiality for flooding. In addition, the amount of peak discharge has increased significantly in the years 1986 and 1994.

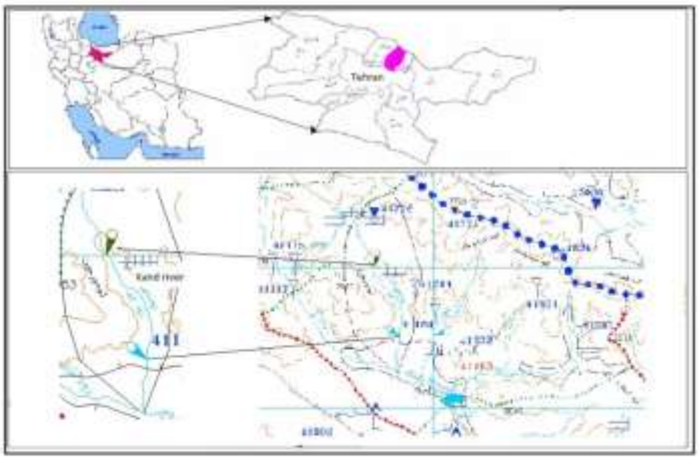

Fig.1 Location Map

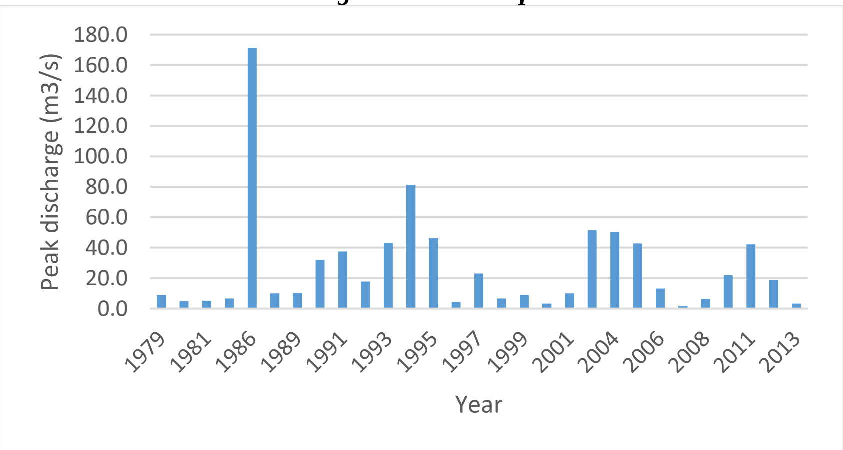

Fig.2 Peak Discharge of Water (1979-2013)

Data Collection

First, due to the peak discharges of the river in the past years, flood discharge was calculated by SMADA software for 100-year return period. Then, HEC-RAS software was used to calculate surface water profiles for different return periods. After entering the geometric data of the river into the mathematical model HEC-RAS, the flood flow rate was introduced into the model. The inputs to the model are actually the peak discharge calculated for the river. In this research, the roughness coefficient was calculated 0.06 using Manning's formula. Information about the boundary conditions of the river, including the riverbed slope in the upstream and downstream of the river, was given to the software. The slope of the riverbed upstream and downstream of the longitudinal profile of the river was determined using the slope calculation formula and its values were calculated 0.14 and 0.01, respectively. After entering all of the above information, HEC-RAS software has been used to calculate the level of water at each cross section of the software.

Data Entry to ArcGIS

Using, the map of Digital Elevation Model (DEM) was estimated the elevation of the area around Lavasan. DEM is a digital map contains data of height, raster (pixel) or vector base with Triangulated Irregular Network (TIN). Data DEM is important to create flood hazard map. In this area DEM was generated from contour lines with the distance of 2 meters.

The file that created in the HEC-RAS software was converted to the exchange file and entered into the ArcGIS. In the RAS Mapping menu, there are options to enter the HEC-RAS exchange file and the corresponding TIN, read the exchange files, select the production of the TIN in the Flow Path range. Moreover, it is possible to generate and specify the flood area. By executing all the options in the aforementioned sequence, the operation has been performed. At this stage, the information in the exchange file is linked to the geometric data of the river displaying the spatial representation.

Finally, for 100-year return period flood simulation, a spatially-distributed grid of maximum flood depths was generated. The depth grid was converted into flood hazard map by categorizing depths to its corresponding flood hazard.

Vulnerability Analysis

Damage is divided into two categories, direct and indirect, and each of these is divided into tangible and intangible categories [26]. In this research, tangible direct damage is discussed. Therefore, the vulnerability rate of a residential building is calculated according to the following equation [27]:

Vulnerability rate = Price of damaged equipment at a specified depth / total cost of equipment in the residential building (1)

In order to determine the vulnerability rate, the water depth value is used for complete damage to each home appliances and the cost of these devices. The contents of the house are based on the pattern of urban houses and statistics published by the Iranian Statistics Center. The price of the equipment is estimated based on the market daily rate. If the flood with the depth of less than 70 cm occurs, most of the equipment will be damaged such as carpet, bed, TV, sofa, cleaning machine, etc. The vulnerability rate is a number between 0 and 1 and usually expressed as percentages.

Cost Estimation and Risk Assessment

A flood risk indicator for development planning is a measurable attribute of the existing flood risk or the impact of a development on flood risk. Flood risk indicators are used to inform the decision-making process, but they do not define what is or is not acceptable. These indicators are flood hazard, degree of expose of development to flooding, vulnerability of development to flooding, or the overall flood risk [9]. Therefore, the flood risk in each flood zone is obtained according to the following equation (2):

$$R = P(H) * (E * V * EX) \quad (2)$$

Where,

R is risk rate based on currency
P (H) is the probability of flood occurrence in each return period
E is the amount of exposure function for each element
V is the value of the vulnerability function for each element
EX is Valuation function of each element

Risk is thus a representation of the expected amount of damage for a given period of time [28]. The above equation could be simplified to the equation (3) [3, 29]:

$$R = H * V \quad (3)$$

Where,

R is Flood Risk
H is hazard
V is vulnerability

RESULTS AND DISCUSSION

Preparing the Hazard Map

First, flood discharges were calculated for 25-year and 100-year return periods with the values of 151.23 and 451.86 m^3/s, respectively. As shown in the figure 2, the rate of discharge in 1986 (171.3 m^3/s) is higher than the discharge with return period of 25 years. Therefore, flood with 100-year return period was used for the hazard map generation.

In the ARCMAP software, a map related to depth and width of flood was prepared which is in fact the same hazard map. As presented in table 1, there is a direct relation between depth of water and hazard level.

Vulnerability Rate	Water Depth (cm)
0.24	10
0.41	20
0.43	40
0.74	50
0.76	60
0.88	70
1	100

Table 1 Vulnerability Rate According to Water Depth

Figure 3 shows the depth of the flood and the return period of 100 years. As it is evident in the figure, the distance between the river's margins decreases, the depth of the flood is more and, as a result, the hazard will be more.
The flood hazard map can be used as basic information for identification of high risk areas. This map helps to use early warning system for the expected future flooding events so that the local government can make better decision for selection of future human settlements and urban infrastructure and manage the current areas with high-risk flood causing damage less damages.

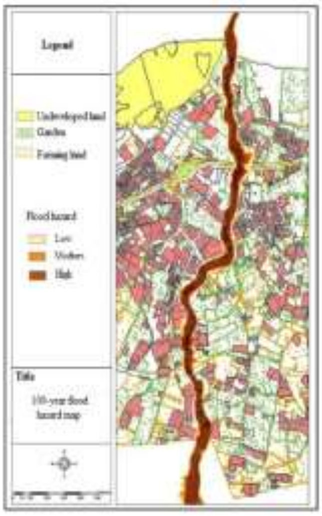

Fig.3 Flood Hazard Map for 100-Year Return Period

Preparing the Vulnerability Mam

To create the vulnerability map following aspects were considered: location characteristics, such as the nature of the building stock (e.g. low or high-rise buildings), the floor of the building and the land use. The floor data of the buildings shows that 70 percent of the buildings have 1 floor and 30 percent of them have more than 1 floor. The mean depth of flood with 100- year return period is 1.4 m. When the depth of water is 1 meter, the vulnerability rate is 100 percent and all the equipment will be damaged.

Figure 4 shows the degree of vulnerability of residential buildings to the 100-year return period. According to this map, if the flood with this return period occurs, 73 percent of the residential buildings will be damaged. As the distance increases, the depth of water is reduced, the degree of vulnerability becomes less, and the less damage is expected.

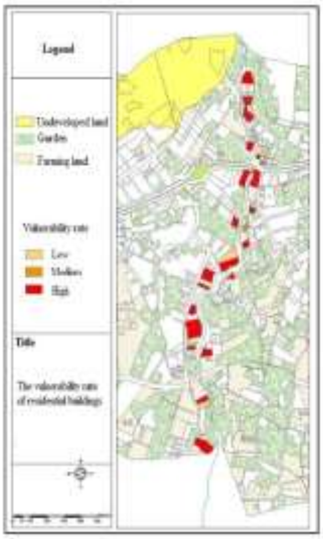

Fig.4 Vulnerability Rate of the Residential Building

Preparing the Flood Risk Map

Considering the value of the buildings contents, the risk, or, in other words, the estimated expected damage was estimated in the flood zone which it is provided in Figure 5. According to this map, the buildings that are nearer to the river have higher risk of flood.

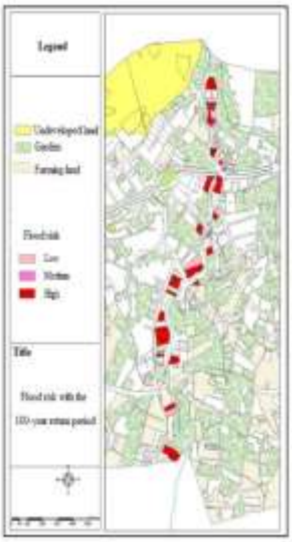

Fig.5 Flood risk map for the residential buildings

CONCLUSION

To best of our knowledge, this study is the first attempt in Iran that analyzes the vulnerability of residential buildings and generates flood risk map as a spatial overlay operation between the hazard and vulnerability layer using ArcGIS. Appropriate flood risk map can be used to select the best areas for development to reduce the damage to people lives and properties. In this study, a flood risk assessment has been carried out using hydrologic data, land use map and approximate price of people's properties. The 100-year return period was simulated using HEC-RAS and the flood hazard map was generated using GIS and DEM. Resulting hazard map revealed bank overflows at the most part of the study area and most of the buildings would be damaged by the flood. The vulnerability map was prepared based on approximate price of damaged equipment in each building. Using ArcGIS, the flood risk map was generated from overlay of vulnerability map and hazard map.

The proposed method can be used to prioritize spatial flood risk areas and can help to development of flood risk reduction strategies. The vulnerability map of the area shows the status of buildings against flood and flood warning systems should be considered in areas with high vulnerability. Flood risk map shows residential use of zones that suffer great damage during the flood, safe places for flood emergencies to shelter people, and secure roads. Risk maps determine the locations that are required to design a flood defensive system and flood risk reduction management programs can be cost-effective. Therefore, flood risk assessment helps planners to develop a proper decision on land use and consider appropriate solution to keep the current use safe from flood. These maps allow decision makers to adopt an appropriate management approach in order to control flood.

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