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FLOOD RISK ZONING USING GEOGRAPHICAL INFORMATION SYSTEM CASE STUDY: KHORRAMABAD FLOOD IN APRIL 2019

DOLOČANJE OBMOČIJ POPLAVNE OGROŽENOSTI Z UPORABO GEOGRAFSKEGA INFORMACIJSKEGA SISTEMA, ŠTUDIJA PRIMERA: POPLAVA V KHORRAMABADU, IRAN, APRILA 2019

Parastoo Karimi[1], Payam Alemi Safaval[2,*], Saeed Behzadi[3], Zahra Azizi[4], Mir Masoud Kheirkhah Zarkash[5], Hamide Kavusi Kalashami[6]

[1] Department of Range and Watershed, Faculty of Natural Resources, Sari Agricultural Sciences University, Mazandaran, Iran
[2] Geological Survey & Mineral Exploration of Iran
[3] Faculty of Civil Engineering, Shahid Rajaee Teacher Training University, Lavizan, Tehran, Iran
[4] Department of Remote Sensing and GIS, Science and Research Branch, Islamic Azad University, Tehran, Iran
[5] Soil Conservation and Watershed Management Research Institute, Agriculture Research Education and Extention Organization AREEO
[6]Yazd Branch, Islamic Azad University, Yazd, Iran

Abstract

Today, there are varieties of methods for determining the risk of flooding in different areas of a catchment. However, the use of GIS-based weighting is receiving increasing attention among researchers. In early 2019, severe and continuous floods occurred in some provinces of Iran. Khorramabad was one of the cities most affected by the floods. Regrettably, during the construction development of Khorramabad city, the minimum distance from roads was violated. In this study, flood risks in the area were zoned using a GIS-weighted overlay algorithm. Flood zoning was done based on various maps indicating factors such as rainfall, distance from the waterway, soil composition, waterway density, slope, soil permeability, land use, and vegetation. The flooding area then was parceled into six categories with return periods of 10, 30, and 50 years. As a result, the city was divided into three critical areas in terms of flood risk. The results indicate that the confluence of the Karganeh and Khorram–Rud rivers lacks sufficient capacity to withstand and repel floods. As a result, the city will suffer severe damage in future floods.

Keywords: flood risk zoning, weighted overlay, GIS, Khorramrud River, Khorramabad city.

* Stik / *Correspondence*: payam.alemi@srbiau.ac.ir

Izvleček

Danes obstajajo različne metode za določanje poplavne ogroženosti na različnih območjih povodja. Uporaba orodij GIS je med raziskovalci deležna vse več pozornosti. V začetku leta 2019 so se v nekaterih provincah Irana pojavile hude in neprekinjene poplave. Khorramabad je bilo eno izmed mest, ki so jih poplave najbolj prizadele. Zaradi gradbenih posegov v mestu je prišlo do poslabšanja stanja cest. V tej študiji so bila za to območje določena poplavno ogrožena območja z GIS-algoritmom utežnega prekrivanja. Določitev poplavnih območij je temeljila na podlagi različnih kart, kot so karte padavin, oddaljenosti od plovnih poti, pedoloških kart, gostote rečne mreže, naklona, prepustnosti tal, rabe tal in vegetacije. Poplave so bile razvrščene v šest kategorij s povratnimi dobami 10, 30 in 50 let. Na podlagi tega je bilo mesto razdeljeno v tri kritična območja glede poplavne ogroženosti. Rezultati kažejo, da sotočje rek Karganeh in Khorram-Rud nima potrebne zmogljivosti za preprečevanje poplav; v prihodnjih poplavah bo mesto znova utrpelo resno škodo.

Ključne besede: določanje poplavnih območij, utežno prekrivanje, GIS, reka Khorramrud, mesto Khorramabad.

1. Introduction

Floods are a common natural phenomenon that pose temporary threats to both the earth and human habitation (Jalilzadeh and Behzadi, 2020). Devastating floods not only endanger lives but also cause great economic damage to residents and threaten their safety (Goodarzi et al., 2020; Huang et al., 2008; Parhi, 2018). Human intervention in catchments, particularly in settlements and industrial activities, has significantly increased flood risks. (Samela et al., 2018). Burton et al. (2003) utilized GIS to investigate land-use change's role in the hydrology of man-made areas. They showed that land-use changes can be a significant factor influencing a basin's hydrology. (Burton et al., 2003). Charlton et al. (2006) also stated that changing land-use patterns increase flows, leading to flooding. Also, factors such as slope, height, Normalized Difference Vegetation Index (NDVI), proximity to rivers, and so on affect how an area is affected by floods (Tehrany et al., 2013; Tehrany et al., 2015). Researchers claim that urban management plays an important role in managing risk and reducing long-term disasters (Basawaraja et al., 2011; Steinberg and Lindfield, 2012; Wapwera and Egbu, 2013). The heterogeneous expansion of cities without adhering to urban planning criteria and disregarding river boundaries has resulted in changes in the city's impermeability levels. (Zayyari et al., 2020). Research has shown that decreased soil permeability increases flooding even during short-term rainfall events. Man-made developments increase flood risks up to eightfold, increasing flood volumes by up to six times and shortening concentration times (Vij, 2007). Climate change is predicted to increase flood intensity and frequency in many parts of the world in the future (Khosravi et al., 2016; Scheuer et al., 2017). From 1900 to 2013, 87% of severe weather disasters were caused by heavy rainfall, while landslides, droughts, extreme temperatures, fires, and heat followed (Guha-Sapir et al., 2012).

Flood risk assessment is highly dependent on local conditions due to spatial and temporal variability. Identifying the factors affecting the zoning of basins in terms of runoff production capacity is necessary and inevitable. Flood zoning is the identification of areas with potential for surface runoff (Minea, 2013). This procedure is based on the similarity of hydrological and hydrogeological characteristics of the study area. Since the identification of possible flood locations leads to better management, the overall assessment of flood risks is essential.

A flood risk map is one of the most important components of flood risk management. Flood susceptibility modeling maps also help reduce flood damage (Choubin et al., 2019). Geographical Information Systems (GIS) is a computer system for capturing, storing, and displaying data related to positions on Earth’s surface that plays a crucial role in creating these maps (Abdollahi and Behzadi, 2022; Behzadi, 2020). GIS is a powerful tool for collecting, managing, and manipulating spatial data. Moreover, models in GIS are used for spatial data management and decision-making (Behzadi and Memarimoghadan, 2019; Wondrade et al., 2014).

Numerous studies have been conducted worldwide to identify the primary factors affecting flood severity. (Alaghmand et al., 2010; Udin et al., 2018; Woldesenbet et al., 2018; Xiao et al., 2017; Zhao et al., 2018). Siddayao et al. (2014) used the Analytic Hierarchy Process (AHP) to model Risk Assessment in the northern Philippines. In their study, they integrated the AHP method with a weighted overlay and obtained highly accurate results (Siddayao et al., 2014). Jabbar et al. (2019) used a new weighting approach to assess the sensitivity of the Eagle Creek watershed in the United States. Also in Bangladesh, the flood risk was evaluated based on 16 criteria using a weighted overlay method and a multi-criteria spatial approach. This study showed that this method is effective in determining an area’s vulnerability to flood effects (Jabbar et al., 2019). Since the cost of setting up ground stations is high in traditional flood monitoring methods, the use of remote sensing data has received more attention. The time series of remote sensing data and the widespread use of mathematical models for flood prediction have made remote sensing a very effective method in managing flood risk areas (Rana and Suryanarayana, 2021).

The flood of April 2019 in Iran caused huge human and financial losses, especially in Khorramabad in the Lorestan province. Considering the extent of the flood and the lack of reliable spatial data to identify critical and risky areas during the flood, the present study aims to zone the flood risk in Khorramabad city. In this study, flood risk zoning was done based on maps such as rainfall, distance from the waterway, soil types, waterway density, slope, soil permeability, land use, and vegetation. This process was performed using the weighted overlay algorithm.

2. Study Area

The Khorramabad catchment area is located in Lorestan province, part of the Karkheh basin. The Khorramabad catchment area is situated at $47^{O}\ 45^{/}$ to $48^{O}\ 36^{/}$ East and $33^{O}\ 10^{/}$ to $33^{O}\ 50^{/}$ North, at an altitude of approximately 1200 meters above sea level. The catchment area is 2481 square km and its perimeter is 702 km. Khorramabad has a relatively large canal that drains flood waters caused by rainfall and eventually leads to the Karkheh Dam (Khaledi and Behzadi, 2020; Shiravand et al., 2019). This canal, which passes through the center of Khorramabad, has a sub-branch called the Karganeh Canal. The Karganeh Canal extends east-west and joins the central canal of Khorramabad from the left bank (Figure 1). The Khorramrud River is one of the tributaries of the Kashkan River. The Khorramabad River's length is 80 km, the height of the source is 1600 m, and its average slope is 1%. The Khorramrud River originates from the peaks around the city of Khorramabad. After crossing the eastern valley of Sefidkuh, it enters the city of Khorramabad. The river finally flows out of the southern part of Khorramabad.

3. Research Methods

In this study, the required data were first identified. Then the impact of each layer was determined. According to the weighted overlay model, the layers were overlapped together and the flood-zoning map was obtained for the region. Figure 2 shows the flowchart of the work steps. In this study, ten different factors were used to determine the flood risk potential of Khorramabad. These factors include Digital Elevation Model (DEM), slope, rainfall (three return periods), vegetation, land use, soil, land permeability, waterway density, and waterway distance. Among these factors, slope, waterway density, waterway distance, rainfall, soil permeability, DEM, and vegetation have numerical values, while land use and soil are qualitative. The layers required for flood risk zoning are then produced as follows.

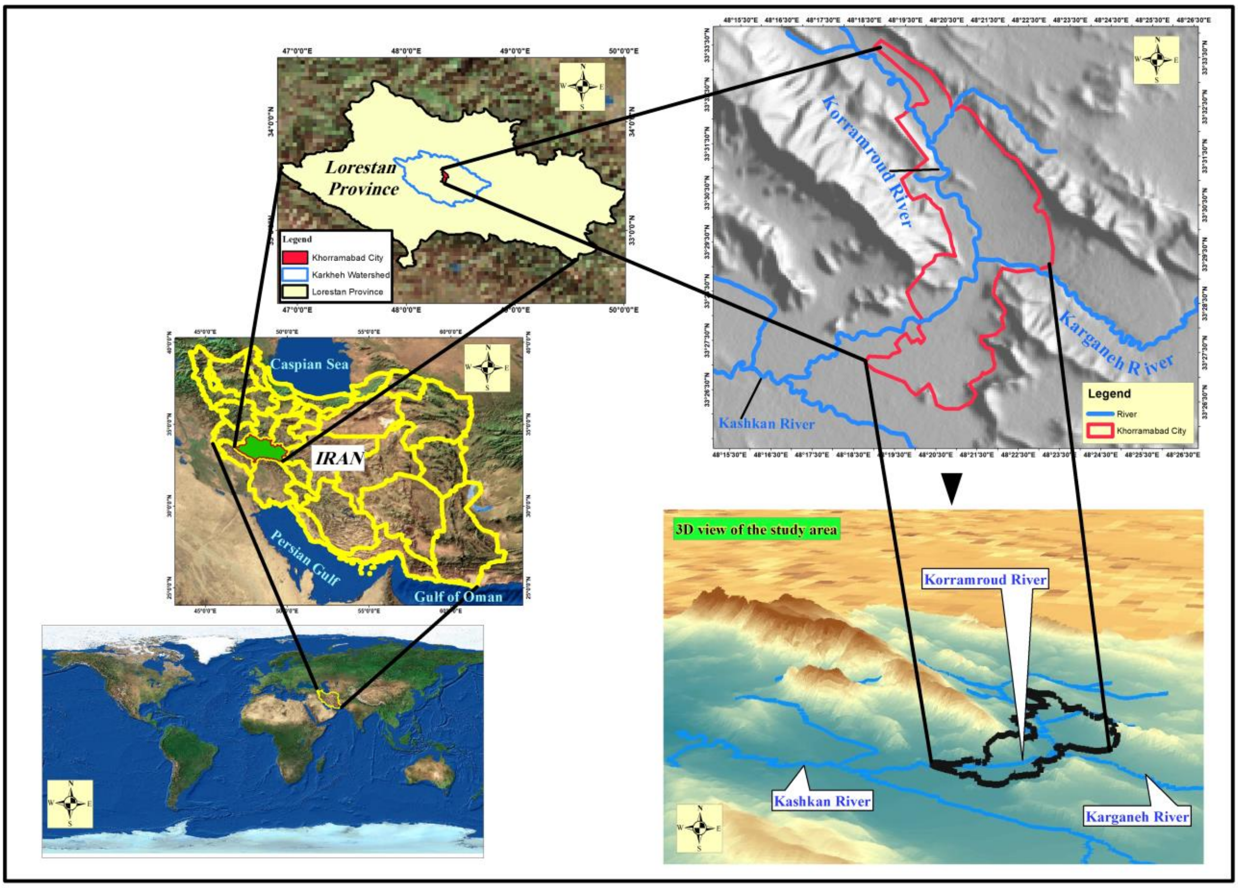

Figure 1: *Location of Khorramabad city in the Khorramabad catchment area.*

Slika 1: *Lokacija Khorramabada in njegovo prispevno območje.*

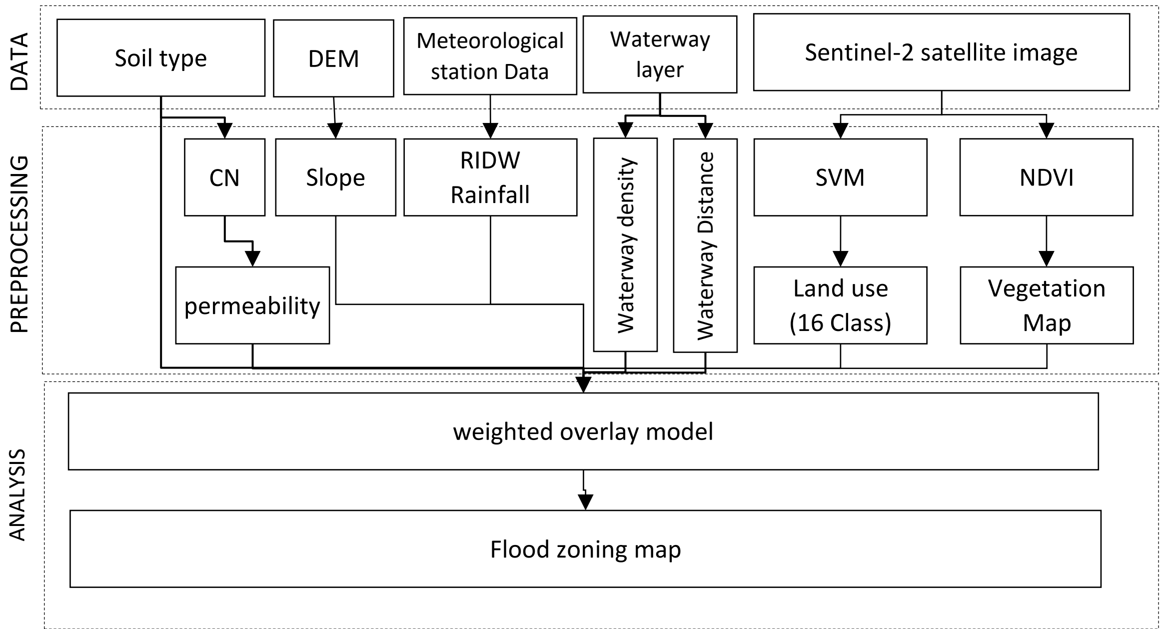

Figure 2: *Flowchart of the work steps.*

Slika 2: *Diagram delovnih korakov.*

A slope map is generated using DEM 30m. A rainfall map is also produced using meteorological station data and the Inverse Distance Weighting (IDW) interpolation algorithm. A soil permeability map is produced using layers such as soil, land use, vegetation density, rainfall and land capability, and SCS equation (Equation 1). The waterway density is obtained from the digital layers of rivers. Land use is extracted in 16 classes using a Sentinel-2 satellite image and the Support Vector Machine (SVM) supervised classification method. The area's vegetation is also obtained by applying the NDVI index to the Sentinel-2 satellite images.

$$S = \frac{\sum S_{ij} W_i}{\sum W_i} \qquad (1),$$

where S_{ij} is the *ith* layer and W_i is the weight of the *ith* layer.

Since not all factors have the same degree of impact, a weighting factor is assigned for each factor based on the weighted overlay model (Table 1).

Table 1. *The weight of the layers used in this study.*

Preglednica 1. *Uteži slojev, uporabljenih v študiji.*

Layers	Weight
Rainfall	0.24
Waterway Distance	0.18
Waterway Density	0.14
Soil permeability	0.13
Soil Type	0.09
Land Use	0.08
Vegetation	0.07
Slope	0.07

These weights are used to apply the importance rating in flood risk analysis. After map normalization, criteria are determined. The criteria targeted in this study include rainfall, waterway distance, waterway density, soil permeability, soil type, land use, vegetation, and slope. The weight overlay method is based on the AHP pairwise comparison matrix (Mousavi and Behzadi, 2019). In this method, each input layer is classified into High, Moderate, and Low classes. The layers' weight is given on a scale of 1 to 9. Thus, the relative preferences for both layers close to each other are determined (Saaty, 1980). Finally, the flood risk zoning map is classified into six classes (Table 2).

Table 2. *Flood risk classification.*

Preglednica 2. *Razvrščanje poplavne ogroženosti.*

No	Flood risk levels	Definition of risk
1	Safe	No disruption
2	Very low	Very Minimal disruption possible
3	Low	Minimal disruption possible
4	Moderate	minor disruption Possible
5	High	significant disruption Possible
6	Very high	severe disruption Possible

3.1. Data

3.1.1. Slope

The slope factor is directly related to runoff production. Increasing and decreasing the slope can respectively intensify and weaken the water flow. The slope layer of Khorramabad city is produced in 10 classes based on DEM. The generated slope map is between 0 and 74 degrees (Figure 3).

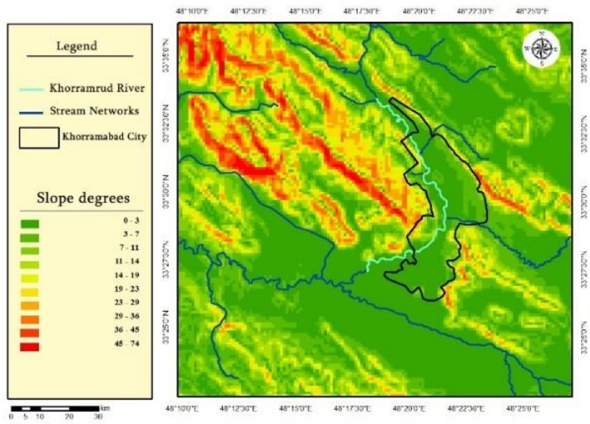

Figure 3: *Slope layer of the study area.*

Slika 3: *Sloj naklona na preučevanem območju.*

3.1.2. Waterway's density and distance from the waterway

The waterway density in a basin is obtained by dividing the total length of the waterway's network by the basin's area. Distance from waterways as a practical criterion in basin flooding is inversely related to flooding. In this study, the waterway density map and distance from waterways map for Khorramabad city are based on the region's waterway network map. The distance from the waterways is calculated between 0 and 6.70 km, and a density map is obtained between 0 and 1.53 (Figures 4 and 5).

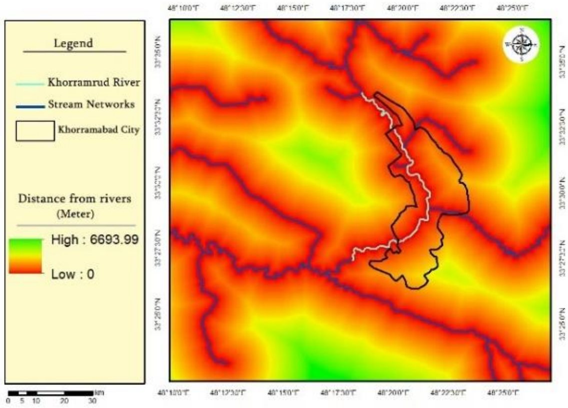

Figure 4: *Distance from the waterway.*

Slika 4: *Oddaljenost od plovne poti.*

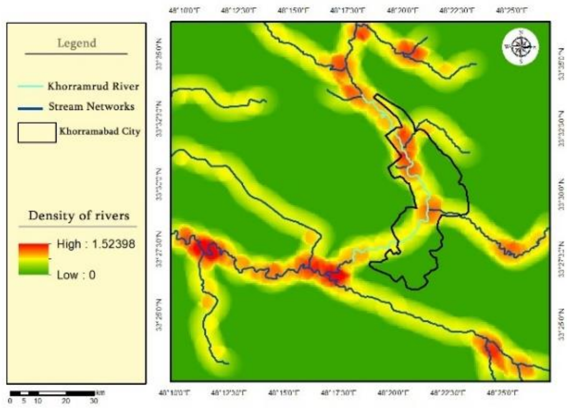

Figure 5: *Waterway density.*

Slika 5: *Gostota plovnih poti.*

3.1.3. CN curve number and permeability

The CN curve is one of the most important parameters for calculating runoff and flood. This curve is obtained for soil data, land use, vegetation density, rainfall, and soil capability using the SCS equation, which is defined by the United States Soil Protection Organization. In the studied area, the lowest CN curve number is 61 and the highest value is 97 (Figure 6). After that, the permeability map was produced from the CN curve number map (Equation 2). This layer shows the amount of rain that penetrates the ground. According to this map, the highest amount of permeability is related to irrigated agricultural lands with 163 mm, and the lowest amount of permeability is related to residential areas with 8 mm (Figure 7).

$$S = 25.4 \times \frac{1000}{CN - 10} \qquad (2),$$

where CN is the curve number of the area and S is the amount of permeability.

3.1.4. Vegetation

The portrayal of CN curvature relies heavily on vegetation, thus a vegetation map of the study area was created using a Sentinel-2 image and NDVI (Figure 8) (Norouzi and Behzadi, 2019). The map reveals low vegetation density around the Khorram River, which runs through the city of Khorramabad. It is observed that vegetation density is inversely proportional to the river path (Figure 8).

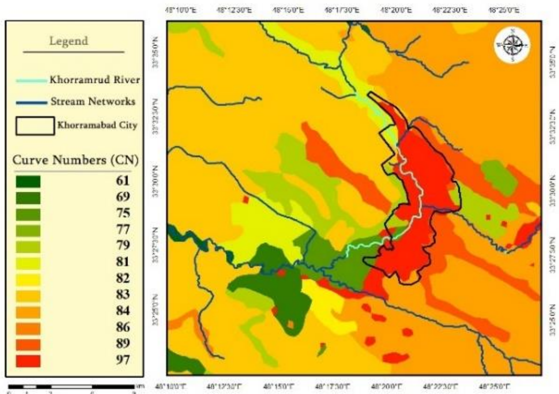

Figure 6: *The CN curve number of the study area.*

Slika 6: *Krivulje odtoka na preučevanem območju..*

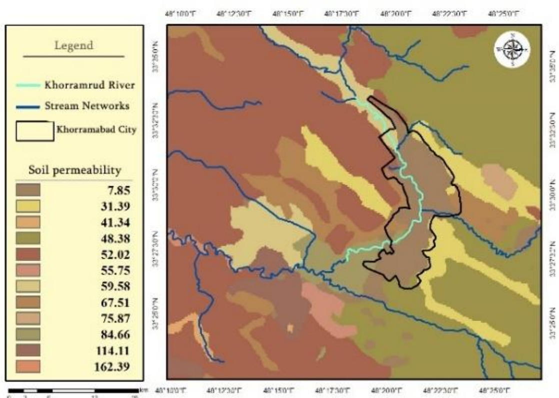

Figure 7: *The permeability map of the study area.*

Slika 7: *Karta prepustnosti tal na preučevanem območju.*

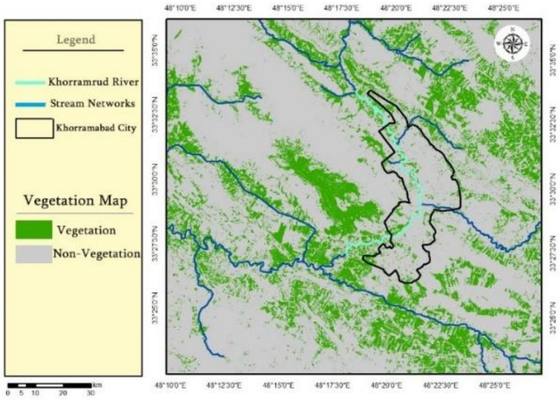

Figure 8: *Vegetation map of the study area using NDVI index.*

Slika 8: *Vegetacijska karta preučevanega območja z uporabo indeksa NDVI.*

3.1.5. Land use

A land use map (Figure 9) was created based on Sentinel-2 images in 16 classes using a supervised classification method and an SVM algorithm. The speed and power of water flow in each category were determined based on the land-use type of that class. For example, urban areas have low permeability and this is an important factor in intensifying the effects of floods. The weighting of each land use is determined by its impact on flooding. This weighting is directly related to the flood. For example, due to the low permeability in the urban class (man-made), the runoff rate will be higher.

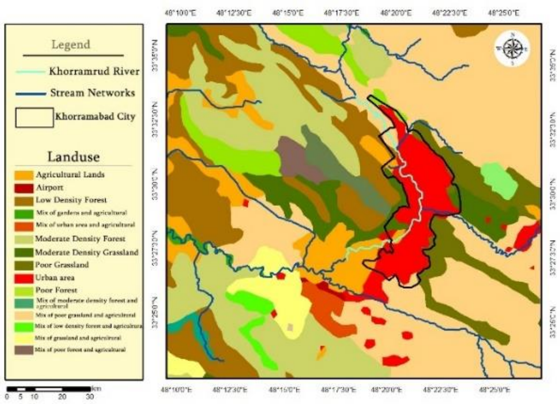

Figure 9: *Land use map of the study area.*

Slika 9: *Karta rabe tal preučevanega območja.*

3.1.6. Soil Type

Soil type is one of the determining factors in an area's flood potential. The higher the permeability and degree of soil saturation, the higher the absorption rate, and the less runoff is produced (Pasha et al., 2018). Based on the region's soil map, it is determined that most of the lands along the Khorramrud River are Inceptisol type with rock cover (Figure 10).

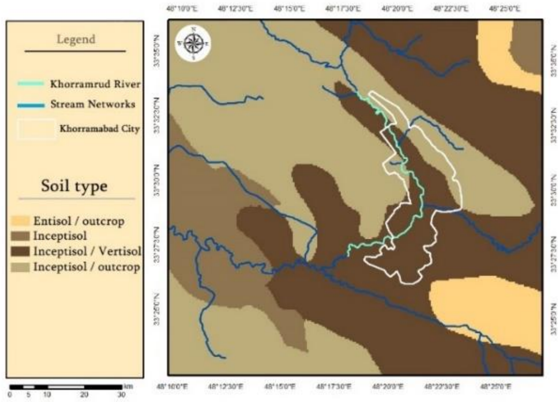

Figure 10: *Soil-type map of the study area.*

Slika 10: *Pedološka karta preučevanega območja.*

3.1.7. Rainfall

Rainfall is also another important factor in the rate of floods and river discharge in the basin. The rainfall map is estimated using daily rainfall data, which was obtained from the Iran Meteorological Organization (IMO) on the flood day and the day before the flood. Rainfall maps are generated using the IDW model on maximum precipitation data during 10-, 30-, and 50-year return periods (Figure 11-13). A rainfall map is also available at the time of the flood event in 2019 (Figure 14). The amount of rainfall is 600 to 1069 mm in 2019, while the average rainfall in the study area is between 300 to 630 mm. This indicates a significant increase in rainfall. This issue is almost true in all parts of the region and for other periods as well. The northern parts of the catchment also get more rain than the southern part.

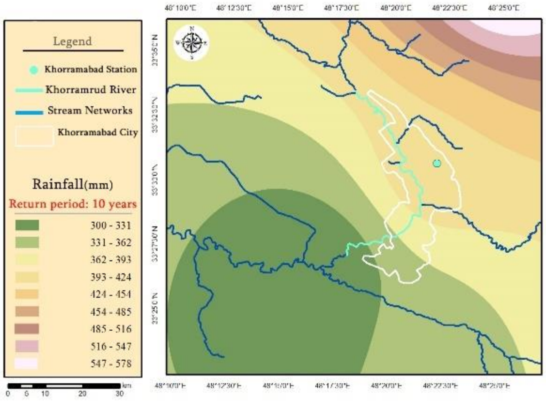

Figure 11: *Rainfall map with a return period of 10 years.*

Slika 11: *Karta padavin s povratno dobo 10 let.*

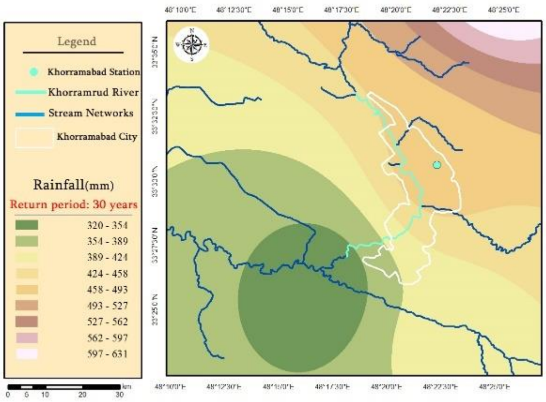

Figure 12: *Rainfall map with a return period of 30 years.*

Slika 12: *Karta padavin s povratno dobo 30 let.*

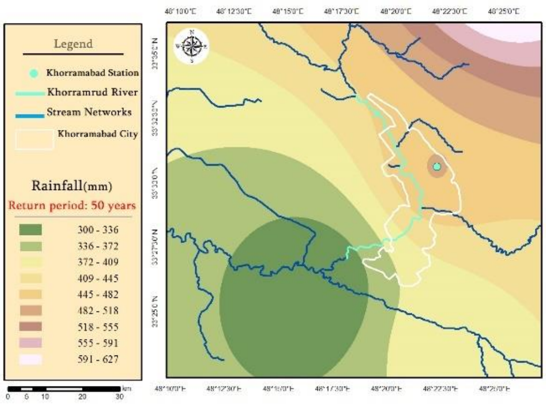

Figure 13: *Rainfall map with a return period of 50 years.*

Slika 13: *Karta padavin s povratno dobo 50 let.*

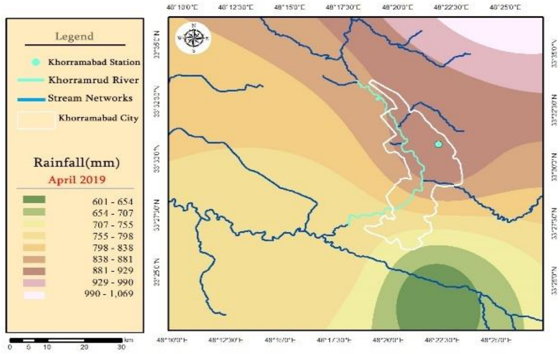

Figure 14: *Rainfall map of April 2019.*

Slika 14: *Karta padavin aprila 2019.*

3.2. Flood Risk Zoning Using Weighted Overlay Algorithm

The generated layers are considered the main criteria of the weighted overlay algorithm. Due to the direct impact of the rainfall layer among other layers, the most weight was allocated to the rainfall layer. All layers (waterway density, slope, etc.) were classified and, subsequently, the weight of sub-criteria was determined in the main layers based on Table 1. Finally, the layers are combined and the zoning map of flood potential is obtained for the return periods of 10, 30, and 50 years, as well as a map for April 2019 (Figure 15-18). The results show that the flood situation at the confluence of the Karganeh and Khorramrud Rivers in the southeast and the northern part of the Khorramrud River is at a very high risk, which is entirely consistent with the results of flood observations in April 2019 (Figure 18).

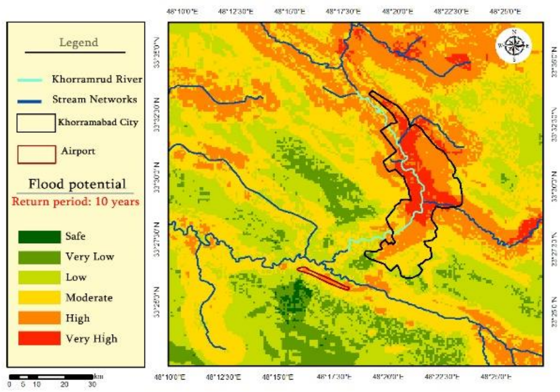

Figure 15: *Flood risk map with a return period of 10 years.*

Slika 15: *Karta poplavne ogroženosti s povratno dobo 10 let.*

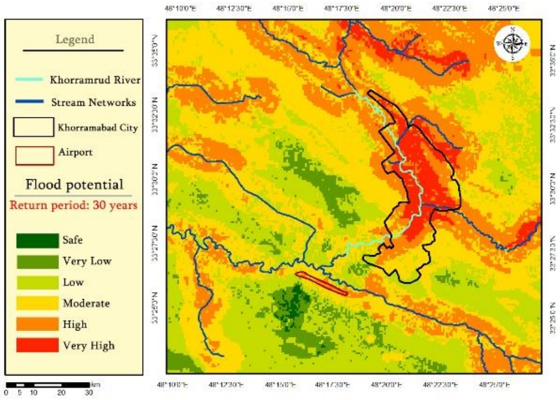

Figure 16: *Flood risk map with a return period of 30 years.*

Slika 16: *Karta poplavne ogroženosti s povratno dobo 30 let.*

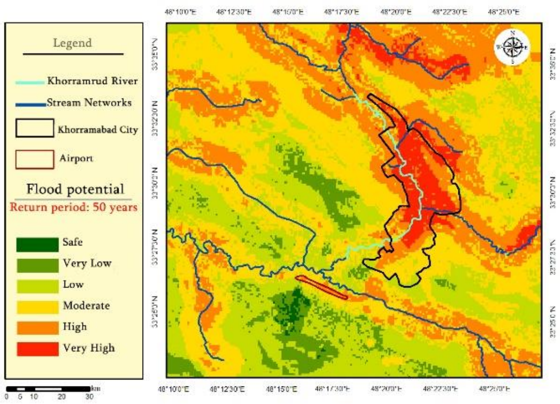

Figure 17: *Flood risk map with a return period of 50 years.*

Slika 17: *Karta poplavne ogroženosti s povratno dobo 50 let.*

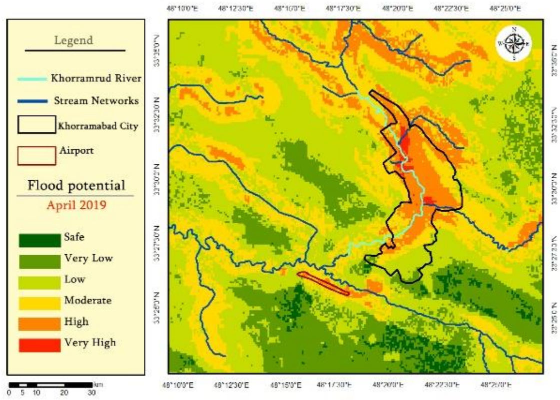

Figure 18: *Flood risk map of April 2019.*

Slika 18: *Karta poplavne ogroženosti iz aprila 2019.*

4. Results

The results of this research showed that he interaction of significant factors in Khorramabad's flood situation indicates a high risk of flooding in the city, which was objectively visible during the April 2019 floods. This map displays high-risk areas facing floods in 2019 based on spatial analysis in GIS. It predicts flood return periods and provides location-based information to city managers that did not exist until now: high-risk areas require more attention. In this study, first, the study area was categorized into various layers. Then, using a weighted overlay algorithm according to Table 2, these layers were classified into six classes. Flood risk zoning results indicate return period intensity in the study area. Figure 19 shows critical areas (in red color) of Khorramabad concerning its surrounding mountains during flood events.

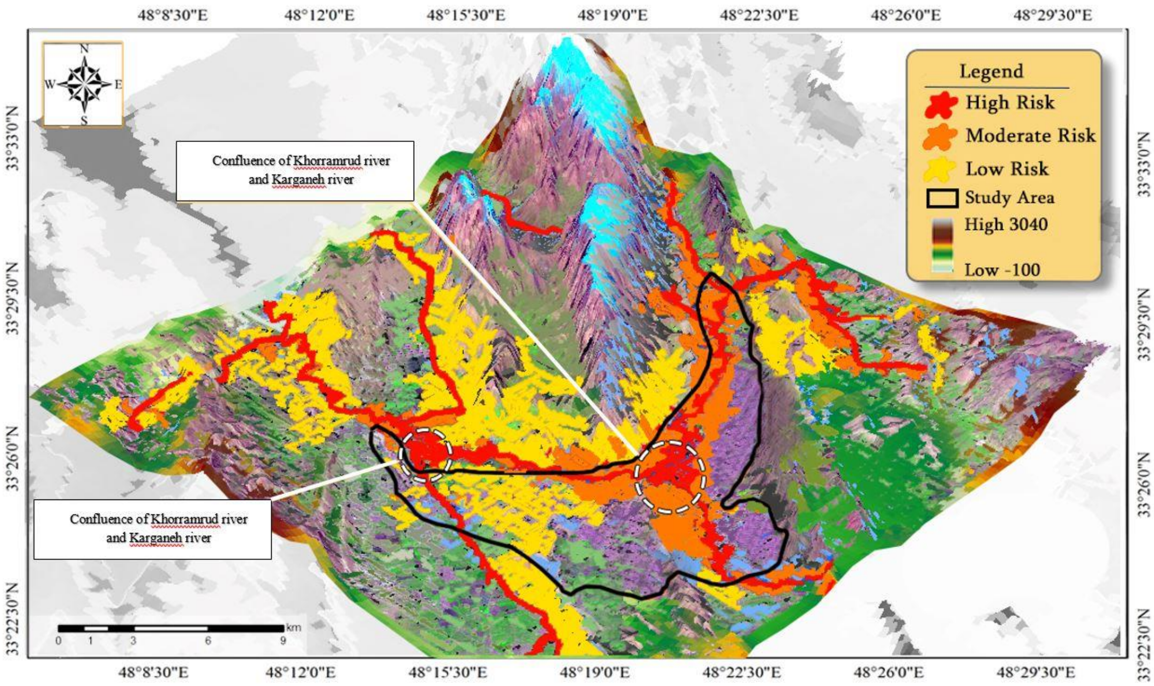

Figure 19: *Location of Khorramabad city concerning critical areas of flood risk.*

Slika 19: *Kritična območja glede poplavne ogroženosti v Khorramabadu.*

5. Discussion and conclusion

Various techniques exist for zoning flood risk in basins. This study utilized the weighted overlay algorithm, which involved identifying effective layers for flooding and assigning weights to each layer. Then, flood risk zoning maps were produced for return periods of 10, 30, and 50 years, as well as for the flood of 2019. Finally, the maps were classified into six different risk classes. The results indicate the optimum performance of this method in identifying areas with high and very high flooding potential. The maps show that large swaths of the city are at serious risk of flooding, and this has been confirmed by return maps. According to Figure 19, the most vulnerable area is the area of the Karganeh Bridge and the confluence of the Karganeh River in the southeast of Khorramabad and the Khorram River. The northern regions of the Khorramrud River are also at high risk of flooding. Based on the observations made by Heidari zadeh et al. (2019) in the study of floods in Khorramabad, the confluence of two rivers is considered one of the most critical areas affected by floods. The construction of a hospital near this point indicates the lack of a necessary study during site selection to create urban infrastructure.

Geomorphology is a crucial factor in flood assessment, as noted by Slater et al. (2015). Khorramabad is situated amidst mountains and highlands, while the river's path through the city has heightened flood risk. Urban development exacerbates this risk due to low permeability. The resulting maps indicate that the city's largest area faces the highest risk of flooding. Research worldwide has shown a recent uptick in urban flooding, particularly in metropolitan areas. Population concentration and land use changes increase soil impermeability and alter the hydrological cycle (Baqalani et al., 2019). As seen in the zoning maps, the higher risk zone increases in the return periods of 50, 30, and 10 years, respectively. This result is an important warning to help prevent the recurrence of the floods of 2019, which caused a lot of economic and human losses. Qanavati et al. (2011) obtained a similar result in their study; they declared that the percentage of flood potential areas with high potential increases with an increasing return period.

Finally, it can be said that the weighted overlay algorithm can help determine the areas with flood risk. The results of this algorithm can be used in urban flood management, flood risk prevention measures, and watershed management measures. The use of remote sensing techniques and GIS can help managers and decision-makers, especially city managers, in sustainable and environmentally friendly development in environmental management, event analysis, and future forecasting.

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