FLOOD RISK MAPPING: USING REMOTE SENSING TECHNIQUE TO IDENTIFY THE INFLUENCE OF FLOODS ON TERRITORIAL PLANNING (A CASE STUDY OF SHAKI DISTRICT, AZERBAIJAN)

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Abstract:

The primary objective of the study is to assess the impact of flood events on spatial planning, to identify their magnitude, and to develop a flood risk map for the Shaki area. Within this framework, theoretical and methodological approaches related to the reduction of damage caused by floods to the population and land use and disaster management were considered. Based on the available literature review, the sequence of five types of measures to combat flood risk in planning was compiled. The study analyzed previous studies and examined the extent of flood-prone areas and the chronological impact of flooding on the economy. For this purpose, two research questions were formulated for the region and the research was carried out within the framework of these questions. Several research methods were considered to produce the risk map, and the Multi-Criteria Decision Analysis method was used to determine the residential areas at risk and the level of risk. The Copernicus LULC map, the annual precipitation, and the DEM file were used as the database for the study.

To determine the risk zones, a model of the region has been created, the proportion of the region within the risk zone has been determined, satellite images have been processed using the method of remote sensing, a model of the region has been created and the settlements have been classified into 3 categories according to the location of the settlements and their distance from the rivers. The number of people living in each of the risk categories, their main occupation, and the areas in which they earn their income were determined and analyzed.

The study shows that the vast majority of the population of Shaki District, 96.1%, live in areas directly or indirectly exposed to flooding, or at least in an area at risk of flooding, including famous tourist sites such as Shaki Khan Palace, Upper and Lower Karvansaray, Kish Alban Church and the city center. Furthermore, 87% of the total land area and 29% of the region's tourism and other hospitality industries are classified as flood-prone or at high risk of flooding.

Key words: risk map, spatial planning, remote sensing, Shaki region, multi-criteria decision analysis, land use.

КАРТУВАННЯ РИЗИКІВ ПОВЕНЕЙ: ВИКОРИСТАННЯ МЕТОДУ ДИСТАНЦІЙНОГО ЗОНДУВАННЯ ДЛЯ ВИЗНАЧЕННЯ ВПЛИВУ ПОВЕНЕЙ НА ТЕРИТОРІАЛЬНЕ ПЛАНУВАННЯ (ПРИКЛАД ШЕКІНСЬКОГО РАЙОНУ, АЗЕРБАЙДЖАН)

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Анотація:

Метою дослідження є оцінка впливу паводкових явищ на територіальне планування, визначення їх масштабів та розробка карти паводкового ризику для Шекінського району, Азербайджан. В рамках цієї роботи були розглянуті теоретичні та методологічні підходи до зменшення збитків, завданих повенями населенню і землекористуванню, а також управління стихійними лихами. На основі наявного літературного огляду було розроблено послідовність п'яти видів заходів щодо боротьби з ризиком повеней при плануванні. Було проаналізовано попередні дослідження та вивчено масштаби затоплюваних територій і хронологічний вплив повеней на економіку досліджуваного району. Для цього було сформульовано два дослідницькі питання для району, і дослідження проведено в рамках цих питань. Для створення карти ризиків було розглянуто кілька методів дослідження, а для визначення житлових районів, що перебувають у зоні ризику, та рівня ризику було використано метод багатокритеріального аналізу рішень. Як база даних для дослідження було використано карту "Copernicus LULC", річну кількість опадів та файл цифрової моделі рельєфу.

Для визначення зон ризику було створено модель району, визначено площі частку району в зоні ризику, оброблено супутникові знімки методами дистанційного зондування та класифіковано населені пункти на 3 категорії відповідно до їх розташування та віддаленості від річок. Було визначено та проаналізовано кількість людей, які проживають у кожній з категорій ризику, їх основний рід занять та сфери економічної діяльності.

Дослідження показало, що переважна більшість населення Шекінського району, 96,1%, проживає на територіях, які прямо чи опосередковано піддаються підтопленням, або, принаймні, перебувають в зоні ризику підтоплення, включаючи відомі туристичні об'єкти, такі як палац Шекі-Хана, Верхній і Нижній Карвансарай, церква Кіш-Албан і центр міста Шекі. Крім того, 87% загальної земельної площі і 29% об'єктів туристичної та інших галузей індустрії гостинності району класифікуються як схильні до затоплення або з високим ризиком затоплення.

Ключові слова: карта ризиків, просторове планування, дистанційне зондування, Шекінський район, багатокритеріальний аналіз рішень, землекористування.

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Introduction

Flood disasters and the resulting flood risks are among the most significant consequences of climate change, and they pose a significant challenge for many cities. Between 1980 and 2009, global flooding events caused over 500,000 deaths, injured over 300,000 people, and affected 2.8 million people (Doocy et al., 2013). Since the early 2000s, policy approaches have taken into account the need to prevent or minimize flood risk and adapt to climate change, which has shifted towards integrated flood risk management that includes a broader range of adaptation measures than hydrological engineering (Kaufmann & Wiering, 2021; Potter et al., 2020). One of the primary reasons for this shift is that traditional flood control infrastructure is considered insufficient, and the current action plan against increased risks is unsatisfactory (Takeuchi, 2001; Vis et al., 2003).

In this context, the importance of planning is increasingly recognized. For instance, building codes are being regulated, buffer zones are being designated, and the range of measures to increase flood resilience across areas and sectors is being expanded through the design of green-blue infrastructure (Sayers et al., 2013; Wingfield et al., 2019). However, this transition is often challenging to implement in practice, as shown by studies conducted in the Netherlands, Poland, Germany, and the UK (Hegger et al., 2013; Potter, 2013).

The research indicates that existing planning systems and rationalities prioritizing engineering-based methods can hinder flood-prone areas from implementing innovative adaptation measures. This resistance to policy changes and conventions can result in people not following approved plans during floods and inundations, as shown by Gersonius et al. (2016) and Parsons et al. (2019). In other words, engineering-focused planning can limit the ability of flood-prone areas to adapt and may cause them to resist changes (Mahmudov, 2006).

The Shaki-Zagatala economic district is one of the areas most affected by natural disasters in Azerbaijan (Pashayev, 2018). This region experiences various natural disasters, including floods, inundations, landslides, and earthquakes. Currently, 171 settlements with a population of 400,000 people in the region, including 55,000 or 55.8 percent of 98,000 families, are at risk of flooding (Pashayev, 2018, p. 58).

The scientific novelty of our research lies in the preparation of a flood risk map for the Shaki region for the first time, and the calculation of the total area of the flood-prone zones. The fact that the Shaki region is the political, economic, and tourism center of the region and that flood disasters cause significant damage to the population and farms every year, makes this problem urgent. Therefore, we formulated the following research questions:

1. What is the level of flood risk in the region, and how is it distributed across the territory?

2. To what extent are the population and settlements exposed to this risk?

Literature review

Two theories are central to understanding the regulation of human behavior and activity during natural disasters. The first theory, exogenous in nature, posits that these events have the potential to disrupt the reliability of daily activities and infrastructure. For instance, large-scale flood events are often seen as disruptive shock events (Wiering, 2008) that present an opportunity to effect political and power changes within coalitions (Penning-Rowsell et al., 2006). The second perspective emphasizes the significance of endogenous changes that may cause deviations from established policies. These changes could include shifts in societal values related to floods, rivers, and green infrastructure, the emergence of new governance structures, the rise of new political ambitions, or the acquisition of new knowledge (Garrelts & Lange, 2011).

The studies considered five types of action planning (Table 1) to respond to floods and implement appropriate measures as quickly as possible. However, before enacting any of these plans, it is necessary to prepare a risk map during the territory planning process, taking into account the level of exposure to floods. According to a report by the United Nations (UN), 43% of the world's natural disasters from 1995 to 2015 were caused by floods. Moreover, floods affected approximately 56% of all people impacted by natural disasters, and approximately 26% of those affected by flooding died (Bertilsson et al., 2019). Rapid urbanization, economic progress, and population growth have greatly expanded the areas at risk of natural disasters, particularly floods. Consequently, the environment, residential areas, and social infrastructure are constantly exposed to risks. Vulnerability is a crucial element in determining flood risk and is defined as the susceptibility of assets located in flood-prone areas. The other two components of flood risk are hazard and exposure. Without all three elements, the risk of flooding cannot be accurately assessed. Flood hazard pertains to the potential damage caused by the inherent natural phenomenon associated with the flood event itself.

Susceptibility refers to the likelihood or probability of experiencing negative impacts from an event. This definition encompasses the characteristics of individuals or groups, as well as their circumstances, which can influence their ability to anticipate, manage, withstand, and recover from the adverse consequences of physical events. To effectively and sustainably reduce flood risk, decision-makers must be provided with adequate support to implement appropriate measures, as emphasized by Fernandez et al. (2016).

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Previous studies on Shaki district

Several studies have been conducted to study the impact of natural disasters and floods on the economy and territorial organization in the research region. Shaki region is one of the regions that suffered the most from natural disasters and recorded the highest level of destruction (Babakhanov and Pashayev, 2004). The Kish and Shin Rivers, which are destructive and flooded rivers of the Greater Caucasus, pass through the territory of the region, and the population living in their basins is regularly affected by floods in various ways (Artunov, 2022).

Floods that occurred especially in Shinchay and its tributaries (which include: Kara, Chakhyl, and Gozludara) hit Bash Goynuk, Shin, Bash Layyski, Ashagi Shabalid, and other villages; floods occurring in Kishchay and its tributaries (Damarchin, Donuzca, Gaynar, Sariguney, Chukhadurmaz, etc.) damage the city of Shaki, Kish, Okhud, Baltali, Gokhmug, Inja, and other villages (Alizade et. al, 2005). Alakbarova et al. (2017) conducted an economic-geographical assessment of flood risk based on the principle of basin analysis and determined that the basins of the Kish and Shin Rivers in the Shaki region harmed 51.6 thousand people in one way or another in 2009. In Shaki district,

Table 1

The sequence of development of five types of measures to combat flood risk during planning

Proceedings	Functions	Statements in planning policies/regulations	(Non) structural interventions affected in practice
Avoiding or leaving the area	Controlling the development of the territory in flood-prone areas and preventing the consequences that may occur during the event	Plans for the zoning of flooded areas; zoning and relocation plans of enterprises	Organization of functions (economic enterprises, residences, and recreational areas) (Kang et al., 2009; Sayers et al., 2013) Population relocation and resettlement (Thampapillai & Musgrave, 1985)
Security measures	Prevention of ingress of flood waters	Multi-purpose/multi-functional engineering measures for leisure, tourism, and commercial facilities	Construction of flood walls or levees (with setbacks, residential and commercial development, and greening) (Voorendt, 2017) Construction of reservoirs (for water storage, supply, natural landscape, and tourism areas) (Wingfield et al., 2019)
Damage reduction	Minimization of damage	Building natural-based infrastructure for watershed maintenance, protection, and flood crossings	Creation of green buffers and flood prevention areas (Kang et al., 2009; Sayers et al., 2013; Wingfield et al., 2019) Creation and protection of wetlands, lakes, and green-blue corridors (Kang et al., 2009; Sayers et al., 2013) Water reduction and improvement of waterways and canals (Kang et al., 2009; Wingfield et al., 2019) -Low-impact development measures (rain gardens, permeable pavement, green roofs) (Wingfield et al., 2019)
Preparation	Organization of effective responses in case of floods	Evacuation plans; organization of safe havens; building control	Optimization of road networks (Elsergany et al., 2015) Creating safe havens (Coutinho-Rodrigues, Sousa, and Natividade-Jesus, 2016) Construction of waterproof buildings (removable parking lots, retaining walls) (Voorendt, 2017)
Restoration	Facilitating better and faster recovery after a flood event	Post-recovery plan; critical infrastructure protection	Building reconstruction, Power generation, and relocation of supporting buildings such as health centers and police stations) and strengthening (Sayers et al., 2013)

including Shaki city, a total of 29 villages, or 41.2 percent of rural areas, were affected by flooding. These floods caused significant damage to the region's economy and social infrastructure at various times. The most severe incidents occurred in the city, where sewage systems overflowed and leaked, flooding streets, residential areas, and catering facilities. The floods also damaged agriculture, crops, and livestock in flood-prone areas in riverside settlements in rural areas (Artunov, 2022, p. 53).

Material and method

Study area. The total area of Shaki district, located in the northwest of Azerbaijan, is 2488 km^2 and it is the second largest district of Azerbaijan after Guba district. The Shaki district is surrounded by the Dagestan Republic of the Russian Federation from the north, Oghuz from the east, Yevlakh from the south, and Gakh from the west (Fig. 1).

Data gathering. Data obtained from open sources (Table 2) were used in the preparation of the flood risk map for the study region. For this purpose, land use covering the years 2018 and 2019 (Copernicus Platform), rainfall distribution in the region between 2010 and 2020 (World Climate Data), and digital elevation model (DEM) for the area were obtained and processed.

Remote sensing. Remote sensing and GIS technologies are widely utilized in many studies for flood risk mapping and natural disaster assessment. The use of risk maps enables precise identification of flood hazards and risk distribution areas, as well as future predictions. Consequently, the area's vulnerability to floods can be analyzed both quantitatively and qualitatively. Among the various methods employed for generating flood risk maps, the Geospatial method is one of the most commonly used, which can be classified into three main categories:

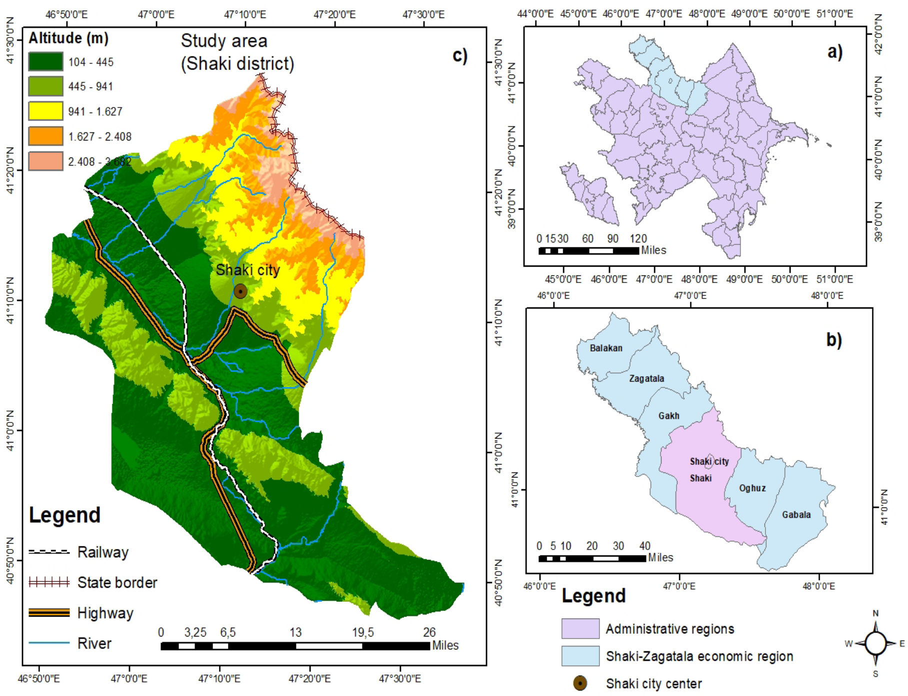

Fig. 1. Study area: a) Administrative regions of Azerbaijan Republic, b) Shaki-Zagatala economic region, c) Shaki district

Table 2

Data used and their source

NAME	SOURCE	TIME OF ACQUISITION	TYPE	FEATURES
LAND COVER	Copernicus[1] (LULC data)	01.01.2018-2019	Tif (metadata)	30 m
THE AMOUNT OF PRECIPITATION	World climate data[2,3]	2010-2020	Tif (metadata)	1 km^2
DEM (ELEVATION MODEL)	OSM[4]	01.01.2020	Tif (metadata)	30 m

[1] Buchhorn et al., 2019
[2] Fick & Hijmans, 2017;
[3] Harris et al. 2014
[4] https://www.openstreetmap.org/#map=6/39.232/40.430

a) Hydrological approach or method: includes SWAT analyzes and hydrodynamic approach based on shallow water equation for precipitation.

b) Machine learning (ML) and artificial intelligence (AI): Mainly use statistical data from the historical period and include fuzzy logic, artificial intelligence learning, decision engines, reduced error decision trees, etc.

c) Statistical and factorial method: Changes that may occur in the area are studied based on statistical data. At this time, some information is included in GIS technologies as variables or influencing factors. Logistic regression and analytical hierarchy process (AHP) methods are used in GIS systems and confusion matrices are constructed.

Multi-Criteria Decision Analysis (MCDA). Multi-Criteria Decision Analysis (MCDA) methods can be used by combining socioeconomic, environmental, and technical objectives to make an optimal decision (Ghanbarpour et al., 2013). Therefore, MCDA has been widely accepted as an important method for the analysis of complex decision problems that often involve irreconcilable incommensurable criteria. Although the settlement of the population, the development of agricultural areas, and the application of modern technology in territorial planning reduce natural disasters, at the same time they also affect their increase (Chaudhary & Piracha, 2021). As a result, the areas affected by natural disasters are expanding, and the number, scale, type, strength, and intensity of recurrence of risky areas are increasing as well. (Linnerooth-Bayer & Amendola, 2000).

Model building. Multi-criteria analysis was employed to create a flood risk map for the region. This involved incorporating various factors, as well as obtaining additional parameters through the processing of a DEM file (Table 2). Numerous sources were utilized to prepare the flood and flood risk map for the study area, and these sources are publicly available and widely used for analysis and investigations (Table 2). The model's construction considered the area's elevation model (DEM), slope, land use, precipitation distribution (Prc), and distance to the river network, with particular attention given to the month of April (Mahmudov, 2016), as it experiences increased flood occurrences and transportation disruption (Fig. 2).

After the processing of satellite images, a model for preparing a flood risk map for the area was established. The principle of building the model is carried out according to the input of the data provided successively, and the Weighted Overlay (WO) method is developed (Fig 2). Overlap procedures play an important role in many GIS applications (O'Sullivan & Unwin, 2003), including techniques at the forefront of advances in land useability analysis, such as multi-criteria decision analysis, artificial intelligence (AI) (computing) techniques, visualization techniques (Jankowski et al., 2001) and Web-GIS (Rinner & Malczewski, 2002). ArcGIS 10.3 and ArcGIS 2.8.4 versions and the model boulder function were used as software. Application of the model is possible for any district and region

Results and discussion

Factors affecting and formulating flood risk. The resulting flood inundation area and risk map for the region can be used to determine the level of danger and potential damage resulting from flood exposure. Additionally, the map can identify the number of settlements and areas located within the risk region, as well as potential climate change effects on precipitation and river water levels. These are just a few examples of the many factors that can influence flood risk mapping.

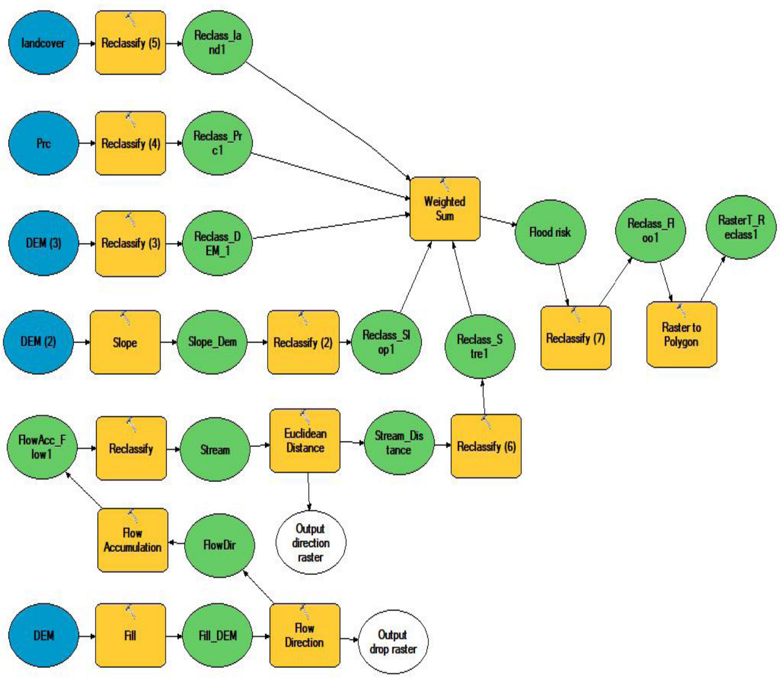

Fig. 2. The working principle and sequence of the flood risk mapping methodology

It's important to consider all relevant factors and to use advanced tools and techniques, such as computer modeling and remote sensing, to accurately assess flood risk and develop effective flood management strategies:

a) Topography: The elevation and slope of the land can play a significant role in determining flood risk. Low-lying areas are more prone to flooding, and areas with steep slopes can contribute to increased runoff and erosion. (Ward et al., 2013)

b) Hydrology: How water moves through the landscape is also important for flood risk mapping. Factors such as precipitation, soil moisture, and groundwater levels can all contribute to flooding (Shah & Lone, 2022).

c) Land use: The way that land is used can have a significant impact on flood risk. Areas with high population densities or that are heavily developed are more susceptible to flooding, as are areas with impermeable surfaces such as pavement or concrete (Elaji & Ji, 2020)

d) Climate change: The effects of climate change, such as rising sea levels and changes in precipitation patterns, can also increase flood risk.

e) Infrastructure: The presence of infrastructure such as levees, dams, and drainage systems

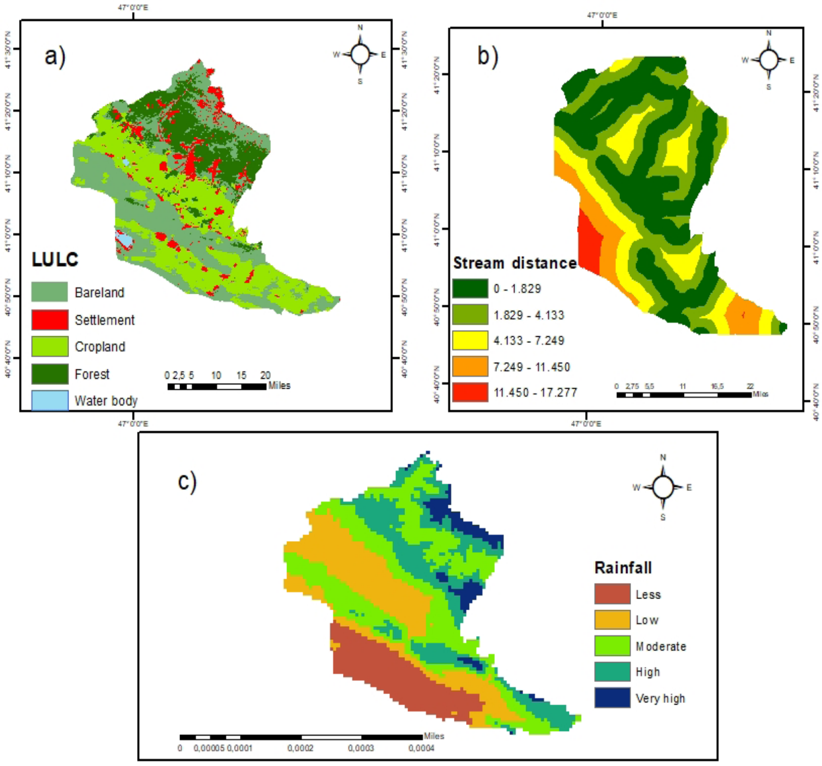

Fig. 3. Data obtained from the classification of satellite images:
a) Land Cover, b) distance to the river network, c) distribution area of annual precipitation

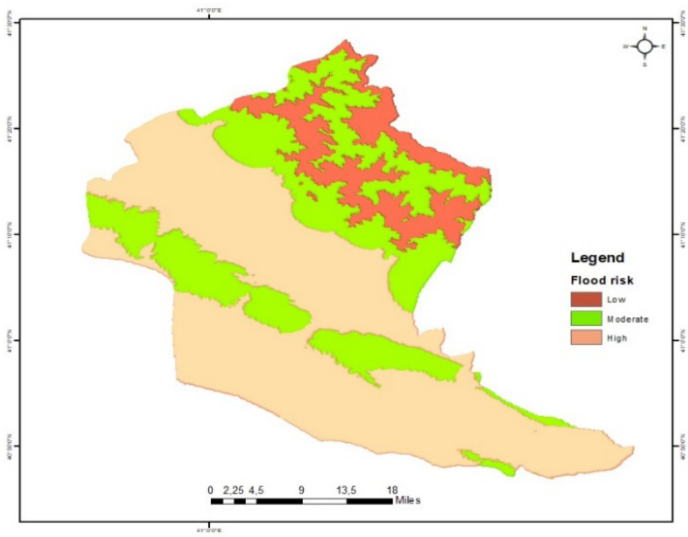

Fig. 4. Flood risk map: risk area and categories

can alter the flow of water and affect flood risk (Lin et al., 2019).

f) Historical flood events: Historical flood events can provide valuable information about the likelihood and severity of future floods, and can be used to inform flood risk mapping and management strategies (Park & Lee, 2019).

The influencing factors for the risk map formation vary significantly, with elevation accounting for 10%, area slope for 15% (Ward et al., 2013), land use for 10% (Elaji & Ji, 2020), precipitation for 35% (Park & Lee, 2019), and river network density and distance for 30% (Shah & Lone, 2022).

Assessment of results. The study, which uses data processing and remote sensing technology (Fig. 3), classifies the Shaki disrict into three categories according to flood hazard (Fig. 4). The first category corresponds to 13% of the total area or 304.3 km^2 and includes highland and foothill areas where only 3.9% of the population (6,687 people) and three settlements are located, making it a low-risk area. All these settlements are mainly located in mountainous areas and in particular in mountain villages. In the event of a flood disaster, the supply of gas and electricity to the population in the villages is interrupted and cut off. Furthermore, mountain villages are popular tourist destinations and tourism and catering are essential sources of income for local people. These are mainly restaurants, cafés, and open public spaces where local people provide tourists with the products of their land, such as milk, cheese, meat, wine, and horse riding.

The second category, which includes agricultural and plantation areas, covers 29% of the area or 703 km^2. The moderate-risk area covers 62.8% of the population (107.21 thousand people) and 11 administrative-territorial units, including the city of Shaki. Although the problem is not as serious in the mountain villages, it is more pronounced in the lowlands. If we look at the figures, we can see that the most densely populated area, where tourism and industry are most concentrated, is the city center and its surroundings, where the risk level is category 2, and that the most dangerous rivers in the region, such as the Kish and the Shin, flow here, which is an indication of how dangerous this problem is. There are famous tourist sites that are on the UNESCO World Heritage List and play an important role in the development of the district, such as the Shaki Khan Palace, the Upper and Lower Karvansaray, the Kish Alban Church, and the city center.

The third category, consisting mainly of water basins and areas close to the river network, covers 58% of the total area, i.e. 1388.5 km^2. It includes 20 administrative-territorial units and 33.3% of the population (57.06 thousand inhabitants). In comparison with the other categories, it is distinguished by the size of the cultivated areas and the fertile land. It is no coincidence that the Shaki district is one of the first in the republic in terms of the area under grain cultivation. Most of the cultivated areas fall into this category. When floods occur, these villages suffer the most economic damage, and the population's main occupation is growing and selling agricultural products.

Conclusion

The research results show that the vast majority of Shaki District's population, 96.1%, live in areas that are at high risk of flooding disasters. In addition, 87% of the total land area of the region is classified as being vulnerable to flooding or at high risk of flooding. This is an indication that residential areas, industrial zones, and tourism facilities are likely to be vulnerable to flood disasters, with a high probability of significant damage in the event of such an event. With climate change, the impact of flood catastrophes and damage will continue to increase.

According to the research carried out, 96% of the population in the region is either directly or indirectly exposed to flooding or at least lives in an area at risk of flooding. This means that it is not only residential areas but also agricultural areas that are affected. In terms of the economy, 29% of the tourism and other hospitality industry is located in the affected areas. The areas that suffer the most damage during a flood event are agricultural areas, which are the main occupation of the population, including agriculture and animal husbandry. For example, in previous studies, the number of people living in the flood-affected Kish and Shin River basins was 51.9 thousand, and in this study, this number was determined to be 107.21 thousand people.

With population growth and settlement expansion, the scale and scope of flood damage to people and the economy increase every year. To prevent flood disasters and minimize the risk, a number of measures are being implemented in the district. Although the river basins are regularly cleaned every year, this is of little importance in the prevention of flood disasters. Most of the events are concentrated in the city center and surrounding areas. In rural areas, this is not enough to prevent flooding. Farming, especially crops, and livestock, is severely affected by natural disasters.

There is no compensation mechanism in place to prevent or minimize the damage to the population, and the insurance of agricultural fields and farms is only carried out on a voluntary basis. However, farmers are often reluctant to take this step and are unwilling to cover their properties. As a consequence, the extent and cost of damage in a flood catastrophe are increasing.

In addition to scale and number of days of rainfall, inappropriate use of land and lack of precautions can lead to higher levels of impact and losses. The implementation of educational activities among the population and the establishment of settlements in the areas around the river, and the expansion of tourist areas in this direction, can at least keep the damage to a minimum, even if it does not prevent the flood disaster. The use of agricultural land in the agricultural sector can also be adapted to the changing climate.

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