



Research

Urban flood risk assessment using AHP and geospatial techniques in swat Pakistan



Muhammad Waseem¹ · Sareer Ahmad¹ · Izhar Ahmad¹ · Hira Wahab¹ · Megersa Kebede Leta²

Received: 15 May 2023 / Accepted: 13 July 2023

Published online: 22 July 2023

© The Author(s) 2023 [OPEN](#)

Abstract

The rapid urbanization and changing climate patterns in Swat, Pakistan have increased the vulnerability of urban areas to flood events. Accurate assessment of flood risk is crucial for effective urban planning and disaster management. In current research study flood hazard index was developed using analytic hierarchy process (AHP) technique in combination with the geographical information system (GIS) environment in Swat, Pakistan. The study integrates various data sources, including topographic maps, land use/land cover information, rainfall data, and infrastructure data, to develop a comprehensive flood risk assessment model. The weights obtained from the AHP analysis are combined with geospatial data using a geographic information system (GIS) to generate flood risk maps. The flood hazard levels were categorized into five distinct classes: very low, low, moderate, high, and very high. Using the GIS-AHP approach, higher weights were assigned to rainfall, distance to river, elevation, and slope in comparison to NDVI, TWI, LULC, curvature, and soil type. The flood hazard map was then reclassified for each parameter. By overlaying these maps, it was determined that 5.6% of the total area is classified as very high flood risk, 52% as high risk, 39.3% as moderate risk, and 3.1% as low risk. The developed comprehensive flood risk assessment model in current study can identify high-risk areas, prioritize mitigation measures, and aid in effective urban planning and disaster management.

Article Highlights

- Flood risk assessment model using GIS and AHP identifies high-risk areas for effective urban planning and disaster management.
- Elevation, slope, rainfall, and proximity to the river are significant factors influencing flood vulnerability in Swat, Pakistan.
- GIS-generated flood hazard maps aid in prioritizing mitigation measures and increasing public awareness for flood risk reduction.

Keywords Flood risks management · Sensitivity assessment · Swat watershed flood hazard index (FHI) · Environmental factors · Spatial analysis · Geographic information systems

✉ Megersa Kebede Leta, megersa.kebede@uni-rostock.de; Muhammad Waseem, muhammad.waseem@giki.edu.pk; Sareer Ahmad, gcv2341@giki.edu.pk; Izhar Ahmad, gcv2339@giki.edu.pk; Hira Wahab, gcv2340@giki.edu.pk | ¹Department of Civil Engineering, Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Topi 23640, Pakistan. ²Faculty of Agriculture and Environmental Sciences, University of Rostock, 18059 Rostock, Germany.



SN Applied Sciences

(2023) 5:215

| <https://doi.org/10.1007/s42452-023-05445-1>

SN Applied Sciences
A **SPRINGER NATURE** journal

1 Introduction

Floods are one of the world's most deadly risks, and more than 1 billion people live in flood-prone areas [1]. Under projected climate change scenarios, extreme hydrological events and flood hazards are especially anticipated to be significant and to increase over time [2]. According to the HadCM3 climate model, the probability of floods worldwide will rise by roughly 187% in 2050, contrasting with a condition devoid of universal climate change [3]. Flood dangers, compared to other natural catastrophes, affected 45% of the world's population and resulted in 5424 documented fatalities between 2000 and 2017 [4]. Geographically, Asia, America, and Europe will experience the greatest increase in flood danger in the future. By the 2070s, populations residing in Asia's fastest-urbanizing cities, such as Bangkok, Jakarta, Dhaka, and Mumbai, among others, will be particularly vulnerable to coastal floods and flood hazards [5, 6]. Severe floods pose a threat to cultural treasures and have numerous detrimental effects on people's well-being and the economy [7]. Since late November 2011, Thailand has been struck by some of the largest flood catastrophes in history, impacting around 10 million people, with 65 out of Thailand's 77 provinces being designated disaster zones. According to a World Bank report, the 2011 flooding in Thailand caused an estimated \$80 billion in economic damage, ranking it as the fourth most expensive environmental disaster worldwide from 1995 to 2011 [8].

Floods, typhoons, heatwaves, and other extreme weather phenomena are occurring more frequently and with greater intensity as a result of climate change, placing many nations at risk. Concerns regarding hydrological risks and water resource management are profound due to climate change. Among the most hazardous natural disasters are flash floods, which occur in basins of various sizes encompassing a confined region of hundreds of square kilometers on all continents, causing severe damage and disruption to human activity [9]. These natural calamities are caused by the rapid onset and high-intensity rainstorms, particularly in areas with uneven terrain, leading to sudden and swift flooding [10].

Flood catastrophes are among the most frequent natural hazard due to climate change and other environmental problems. It is only recently that the world has recognized the frequency with which flooding is caused by climate change. Local rapid response teams face challenges in predicting the timing of peak water levels, leaving little time for warnings. Consequently, the understanding of flash flood prediction and control remains limited [11, 12]. To avert floods or at least decrease their

impacts, access to reliable and up-to-date information is essential. A hazard map that depicts the likelihood of flooding is one of these essential sorts of information. To evaluate and forecast flood risk, numerous investigations have used climatic variables, geomorphic and physical watershed parameters, soil characteristics, and land use/cover determined from remote sensing data [13]. This is carried out to promote sustainable development and management and effective flood disaster mitigation [12, 14].

The most commonly used variables in environmental studies are natural variables (such as elevation, slope, aspect, slope curvature, lithology, topographic position index, and rainfall), hydrological variables (such as drainage density, river distance, topographic wetness index, and stream power index), and human disturbance factors [15–17]. Accurate modeling of flood risk threats is crucial for successful floodplain land use planning and mitigation methods. Availability of easily accessible maps enables planners to identify the most hazardous locations geographically, which is a vital step in the mitigation process [18, 19]. Despite the challenges involved in flood prediction and prevention, a variety of remote sensing and GIS techniques can be employed to map areas susceptible to flash floods and anticipate their occurrence [20–22]. Multiple datasets can be obtained through the analysis of remote sensing data using GIS techniques to pinpoint high-risk areas and produce flash flood danger maps. The GIS-weighted overlay analysis-based knowledge-driven AHP approach has proven effective in modeling various environmental scenarios [23].

The GIS method can forecast and find more water resources by combining and analyzing vast quantities of spatial data [23]. This method incorporates criteria into multiple sub-criteria and a hierarchical tree with multiple levels. Several prediction experiments have applied this multicriteria decision-making approach to generate a solution based on hierarchical ordering criteria for challenging decision analysis [24–26]. The input data set for the model includes information such as elevation, slope, topographic witness index (TWI), stream power index (SPI), curvature, drainage density, depressions, runoff, distance to rivers, and rainfall. In arid to semiarid regions like Pakistan, rainfall varies in both time and location. These regions also experience mild to warm winters and scorching to extremely hot summers [27]. Consequently, irregular flash floods occur, causing damage to dams, roads, people's lives, and property [28]. The devastating flash floods that impacted the Swat region in 2010 and 2022 are estimated to have resulted in damage costs of RS.68 billion [29].

Pakistan, with its fifth-largest population of approximately 220 million people, is projected to reach 250 million by 2025 with an annual growth rate of 2.8%. Over the past 60 years, the country has experienced nearly 19 significant floods, resulting in the inundation of an area of 594,700 km², affecting 166,075 communities, and causing total direct cumulative losses of around \$30 billion. Tragically, these floods also claimed the lives of 10,668 individuals [30]. While floods are a natural phenomenon that cannot be entirely prevented, the risk can be mitigated through effective planning and mitigation strategies. Numerous studies have shown that the identification of flood-prone areas and the implementation of critical risk reduction measures, both structural and non-structural, can successfully reduce flood losses to an acceptable level [12, 31].

Researchers utilize various models to assess flood susceptibility. According to Guo et al., traditional methodologies for mapping flood risk often have limited effectiveness due to insufficient data [32]. Conventional procedures necessitate data collection, which, especially in poor nations, is frequently expensive, time-consuming, and unavailable at the local or regional level. On the other hand, geographic information systems (GIS) and remote sensing are advanced dynamic tools that can provide a variety of data for risk management, flood zoning, and forecasting. Because natural disasters are multidimensional phenomena with a spatial component, GIS is an especially useful tool for this type of investigation because it can manage massive volumes of spatial data used in flood modeling [12]. Flash flood management strategies heavily depend on modeling the hydrological, meteorological, and topographic factors of a catchment region to mitigate the risk of flooding. Conducting risk analyses and employing these mapping methods should be prioritized for timely completion. The study motivation for selecting Swat Valley is that it has been prone to devastating floods in the past, leading to substantial economic and human losses. However, the existing literature lacks comprehensive hazard maps and flood risk assessment studies specific to this region, which are essential for effective disaster management and urban planning. To fill this critical gap, our study sought to employ Analytical Hierarchy Process (AHP) and geospatial techniques to develop a systematic and data-driven approach for evaluating flood risks in urban areas of Swat.

The current study uses AHP a multi-criteria decision analysis model and geo-information tools to assess flood risk and susceptibility mapping in Swat District for sustainable agriculture, urban, and infrastructure development. The Main objective of the presented study is to develop a comprehensive flood risk map for Swat District in Pakistan.

2 Materials and methods

2.1 Study area

Swat is a valley and administrative district located in the Khyber Pakhtunkhwa province of Pakistan. It is situated in the country's northwestern region, surrounded by the Hindu Kush Mountain range to the north and west, and the Swat River flows through the valley. The geographic coordinates of Swat are approximately 35.3859° N and 72.4486° E, as shown in Fig. 1 below.

The climate of Swat is moderate, with pleasant summers and freezing winters. Summer runs from May through September, with temperatures ranging from 20 to 30 °C. Temperatures range from – 2 to 12 °C during the winter season, which lasts from November to March. Swat receives about 800 mm of rain every year, and the monsoon season lasts from July to September. The Swat River is the major river that flows through the valley. It originates from the Hindu Kush Mountain range and passes through the city of Mingora before joining the Kabul River. The Swat River is fed by several tributaries, including the Panjkora, Daral, and Bara rivers. The river is an essential source of irrigation for agriculture and a significant source of hydroelectric power generation in the region. The topography of Swat is dominated by mountain ranges, with the highest peaks being Falak Sher (6000 m), Mankial (5726 m), and Flir (5396 m). The valley is surrounded by several passes, including the Lowari Pass (3118 m) to the west, the Malakand Pass (1207 m) to the east, and the Shangla Pass (2143 m) to the south. Overall, Swat's geographical location, climate, and orography make it a unique and beautiful region in Pakistan, attracting tourists from all over the world. Swat valley is situated in the northern part of Pakistan, which is a part of the Himalayan orogenic belt. Swat's geology comprises sedimentary, metamorphic, and igneous rocks that formed during the Paleozoic to the Cenozoic era.

The sedimentary rocks in Swat, including sandstone, shale, and limestone, were deposited during the Paleozoic era in a shallow marine environment. Swat also features metamorphic rocks such as schist, gneiss, and marble, formed as a result of tectonic activity during the Himalayan orogeny. Additionally, there are igneous rocks like granite and diorite that intruded into the metamorphic rocks during the Cenozoic era. The hydrogeology of Swat is complex due to its diverse geological formations. The primary aquifers, located in the sedimentary rocks, are predominantly unconsolidated and porous. These aquifers are replenished by rainfall and snowmelt, and

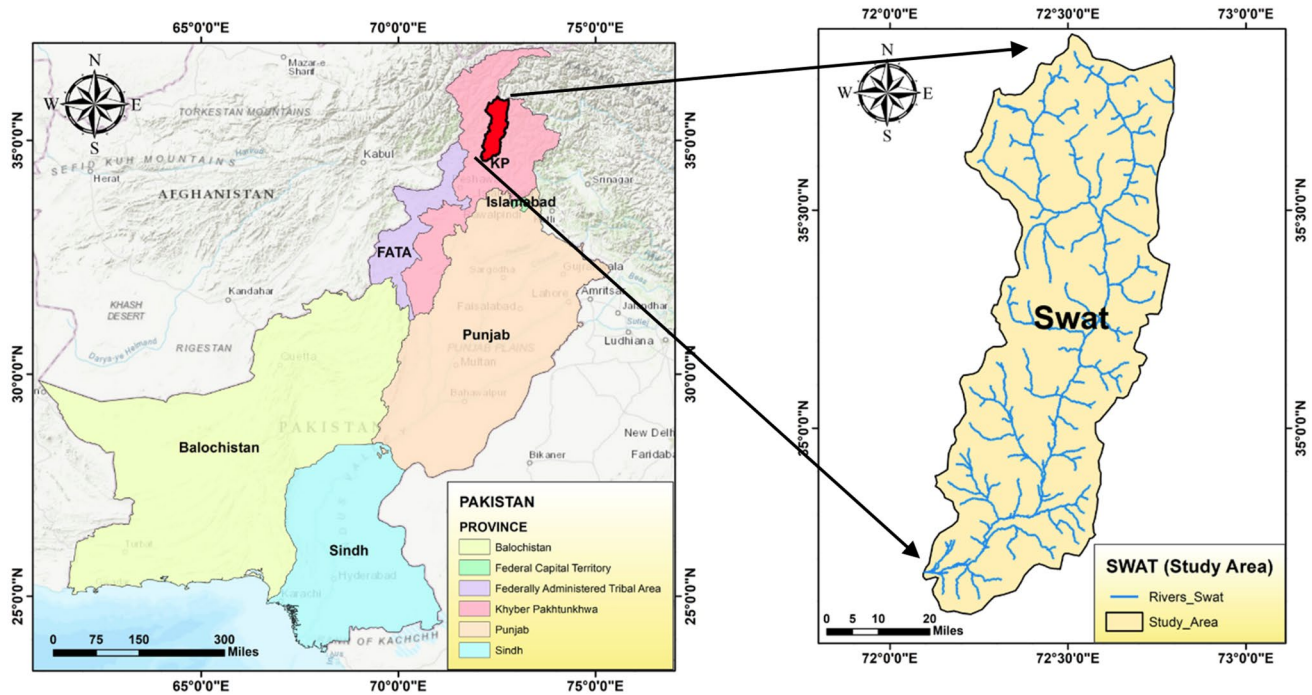


Fig. 1 Location map of the study area

groundwater flow is controlled by the region's topography and geological structure. Wells and springs are the primary sources of groundwater in Swat. Wells, usually shallow and hand-dug, serve domestic and agricultural needs. Springs, mainly situated in mountainous regions, provide water for drinking and irrigation. However, Swat's hydrogeology is under threat from increasing urbanization, deforestation, and pollution. These factors have caused a decline in water quality and quantity, necessitating the implementation of effective management strategies to protect Swat's groundwater resources.

2.2 Data collection and model setup

This section discusses the components of morphometric, topographic, and variable analysis involved in the creation of AHP-GIS-based maps. It is important to note that the type of flood significantly impacts the variables utilized in the multi-parametric AHP model. Table 1 presents the variables employed for vulnerability analysis, along with the corresponding risk categories and levels of relative importance. The selection of criteria using a spatial reference is a crucial step in multicriteria decision analysis. The AHP integrates objective assessments with actual data to determine initiatives, activities, schemes, or alternatives based on quantitative criteria [13, 33]. According to Saaty [10], decisions can be divided into two categories: intuitive and analytical. Analytical

decisions need the development of an opinion, the comparison of alternatives, or the evaluation of each choice considering an ideal. In contrast, intuitive decisions are totally subjective and cannot be justified by a logical argument. The latter choice is one that the AHP approves of. The assumptions for the study were derived from a thorough literature review and align with well-established factors influencing flood risk assessment. These assumptions include rainfall, distance to river, slope, elevation, land use/land cover (LULC), topographic wetness index (TWI), normalized difference vegetation index (NDVI), soil type, and curvature. Each assumption is supported by existing research and contributes to a comprehensive understanding of flood dynamics in the study area. These assumptions are grounded in established scientific knowledge and align with recognized factors contributing to flood risk. We have considered these assumptions to ensure a comprehensive assessment of flood hazards. As a result, the variables evaluated in this study were chosen based on how important they were for producing floods in the study area. Elevation and inclination, soil types, yearly rainfall distribution, the topographic wetness index, and land-use/cover data are all taken into account. Land Use Cover downloaded from NASA Earth Data and Environmental Systems Research Institute (Esri) [30]. The weighted overlay is then used to create the final flood risk map, as displayed in Fig. 2, is finally created.

Table 1 Flood susceptibility criteria and sub-criteria ranges for flood susceptibility assessment

Flood criteria's	Unit	Class	Class ranges/flood probability	Class Ratings	Percentage weight
Topographic Wetness Index	Level	2.5–3.2	Very low	1	5
		3.2–8.9	Low	2	
		8.9–14.6	Moderate	3	
		14.6–20.3	High	4	
		20.3–26	Very high	5	
Slope	%	0–13.70	Very high	5	16
		13.70–27.40	High	4	
		26.40–41.10	Moderate	3	
		41.10–61.25	Low	2	
		> 61.25	Very low	1	
Elevation	Meter	709–1596	Very low	1	13
		1596–2443	Low	2	
		2443–3310	Moderate	3	
		3310–4117	High	4	
		4117–5852	Very low	5	
Distance from Rivers	Meter	0–140	Very high	5	23
		140–290	High	4	
		290–430	Moderate	3	
		430–570	Low	2	
		570–720	Very low	1	
Soil Type	Clay percentage	5	Very high	5	3
		23	High	4	
		26	Moderate	3	
		30	Low	1	
LULC	Level	Waterbody	Very high	5	9
		Trees	High	4	
		Crops	High	4	
		Built Area	Moderate	3	
		Range Land	Moderate	3	
		Snow Ice	Low	2	
		Flooded Vegetation	Low	2	
		Bare Land	Very low	1	
NDVI	Level	– 0.167–0.02	Very high	5	3
		0.02–0.046	High	4	
		0.046–0.129	Moderate	3	
		0.129–0.218	Low	2	
		0.218–0.540	Very low	1	
Curvature	Level	Flat (– 0,9–0,54)	Very high	5	1
		Convex (0,55–11)	Moderate	3	
		Concave (– 10–1)	Very low	1	
Rainfall	mm/year	225–418	Low	1	27
		418–612	Moderate	3	
		612–805	High	4	
		805–1007	Very high	5	

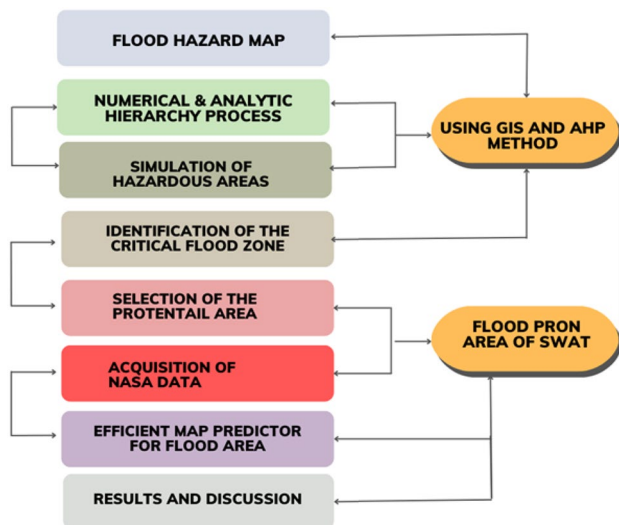


Fig. 2 Methodological framework of the current study

2.3 Elevation and slope

The slope plays a crucial role in determining surface or subsurface drainage in a specific area or outlet. The combination of slope angles, influenced by the slope's shape, determines the interplay between lithology, structure, soil type, and drainage. Higher slopes tend to experience surface runoff issues, while flatter surfaces are prone to water accumulation. In contrast, local depressions, which are cells in a digital elevation model with lower elevation than their surroundings, are more susceptible to pluvial floods. This highlights the importance of understanding the relationship between ground elevation and flood risk [23]. In this study, a slope map was created using slope-generating tools and the ArcGIS digital elevation model (DEM). The DEM for the study area was obtained from the Earth Data Search on the NASA website (<https://search.earthdata.nasa.gov/search>). The slope, which affects the speed of runoff, determines the probability of catastrophic floods. Higher slopes result in slower water penetration, optimizing water velocity and flow. The length of the slope is a factor that influences both floods and the likelihood of flooding since floods typically occur in lower areas where water gradually accumulates as it flows from higher to lower elevations. Elevation and flood risk are interconnected, with cells in lower-elevation regions being more prone to flooding [16]. To analyze elevation, it was classified into five categories ranging from 709 to 5852 feet. The slope range in the study area is 0 to 89, divided into five classes using the Natural Break technique. The percentage categories are "0," "0–13," "13–27," "27–41," "41–61," and "> 61". Figure 3a, b, c and d presents the original and reclassified elevation and slope maps for the Swat District.

2.4 Land use types

The various land-use groups influence the amount of rainfall and runoff generated. Land cover plays a role in the frequency of flood occurrences due to the ability of vegetation to absorb precipitation. High-resolution land use data for the research area weren't accessible, so the land cover was determined using the ESRI land cover dataset <https://www.esri.com> he land uses were divided into eight different groups based on the vegetation cover. These eight types of land uses include water bodies, trees, crops, built areas, range land, snow/ice, flooded vegetation, and barren land, as shown in Fig. 4.

2.5 Distance to river

The risk posed by an area can be estimated by considering the distance between the area and nearby rivers. The streams were extracted using the D8 approach, and the STRAHLER methodology was employed to identify different levels in the extracted streams. In the STRAHLER technique, links without tributaries are assigned an order of one and referred to as first order [24]. It was observed that cells located farther away from certain streams had a lower likelihood of flooding compared to those nearby. Distances from the streams were classified into five risk zones, as depicted in Fig. 5.

2.6 Topographic wetness index (TWI) and hydro-lithological formations

TWI is an index that measures the water's ability to accumulate, with a high value indicating deeper water caused by a low slope, as shown in Fig. 6. The hydrological and lithological formations influence the infiltration resulting from rainfall-runoff generation.

2.7 Soil types and precipitation

Sandy soil absorbs water rapidly and has less drainage, significantly impacting flooding. In contrast, clayey soils, which are less permeable and retain water for longer periods, make locations more susceptible to flooding. In the absence of measurements, the soil's texture and appearance can be used to estimate its moisture content. It plays a crucial role in dividing precipitation into runoff and groundwater storage, acting as a point of contact between the atmosphere and the land surface. Soil moisture levels rise when sufficient precipitation compensates for losses to streams and groundwater, leading to reduced soil erosion, slope stabilization, and plant growth. The soil types in a region are significant as they regulate water entry into the ground and, consequently, water flow. The structure

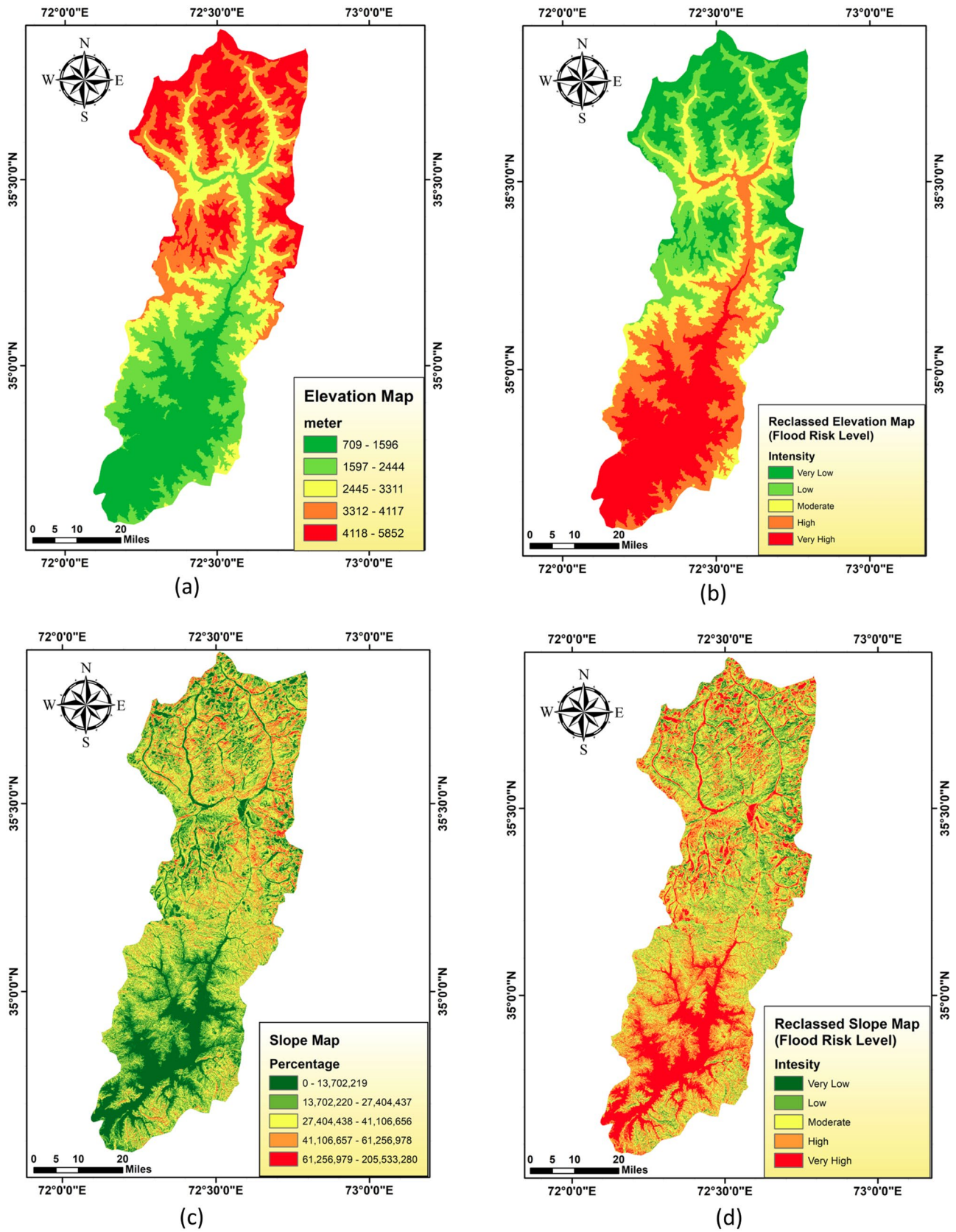


Fig. 3 **a** Digital elevation model; **b** Reclass of elevation map; **c** Slope map; **d** Reclass of slope map

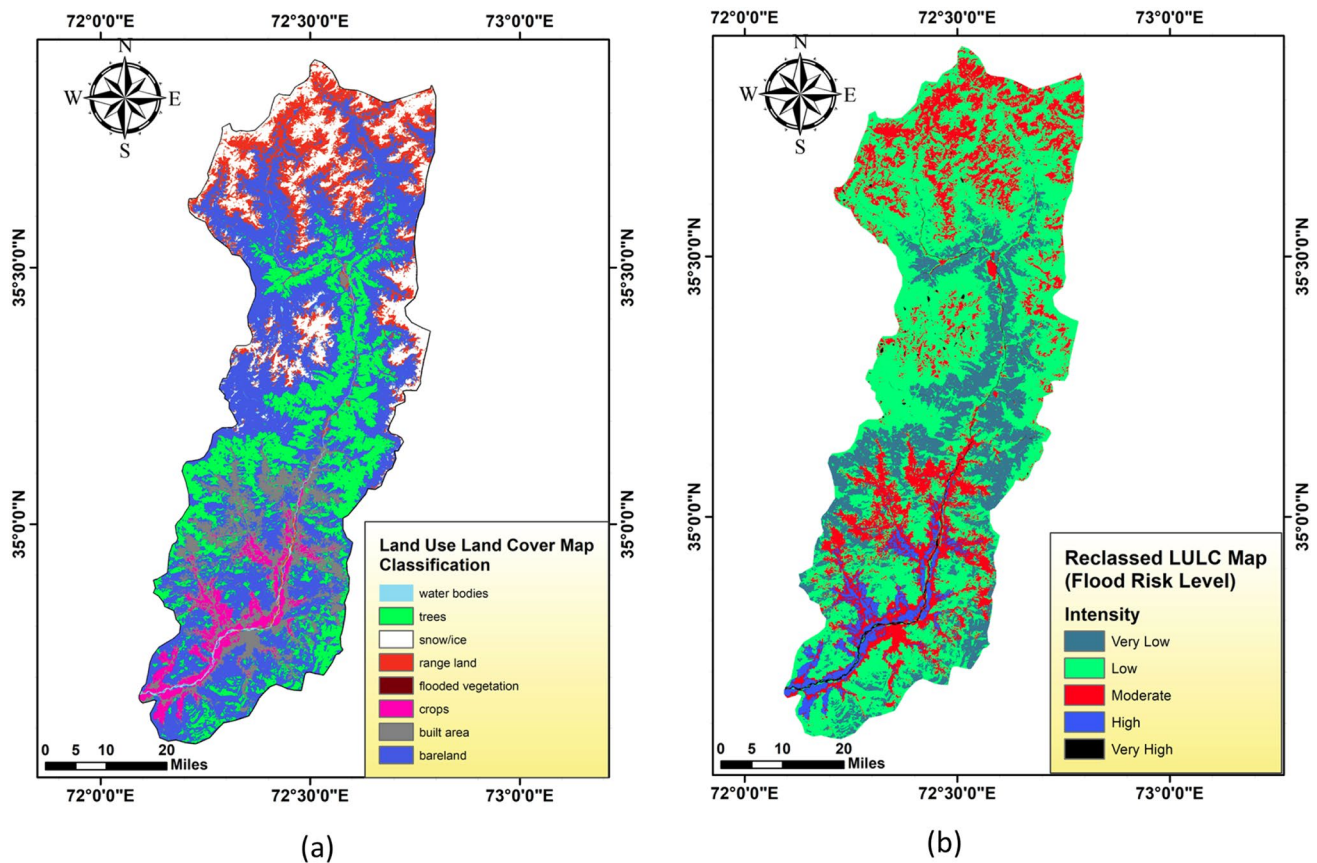


Fig. 4 **a** Land use land cover map; **b** Reclass of land use land cover map

and infiltration capacity of soils greatly influence their ability to absorb water and function as sponges. Different soil types have varying capabilities. Increased surface runoff due to decreased soil infiltration capacity enhances the likelihood of flooding. Flooding occurs when the rate of water supply exceeds the soil's infiltration capacity, causing runoff downslope on sloped ground. Figure 7 illustrates the categorized soil cover and precipitation map for the study area.

2.8 Curvature and NDVI

The Curvature feature represents the contour and curvature of the slope. It determines whether the surface is concave or convex based on its second derivative. The results of the Curvature function are displayed in Fig. 8. The classification of the curvature classes was established through a combination of academic literature and insights obtained from previous flood research [34]. A three-grade scale was employed to standardize the classes, with each class being assigned a positive whole number.

The normalized difference vegetation index (NDVI) evaluates the density and health of vegetation by utilizing

satellite data. It provides information about the level of photosynthetic activity occurring in a particular area. NDVI is determined by analyzing the reflectance of near-infrared and visible light detected by satellite sensors.

NDVI values range from -1 to +1, with higher values indicating greater vegetation density and health (+1) and lower values indicating lower vegetation density and health (-1). These values are commonly employed to monitor vegetation growth, drought conditions, and other environmental factors that can impact plant health. The results of the Curvature function are depicted in Fig. 8, with the classifications determined through a combination of academic literature and previous research on flood events [34].

2.9 Data acquisition

The maps in this research article were generated using geographic information system (GIS) software, specifically ArcGIS version 10.4 developed by Esri (). Table 2 below shows the source of the data acquired for the current research work.

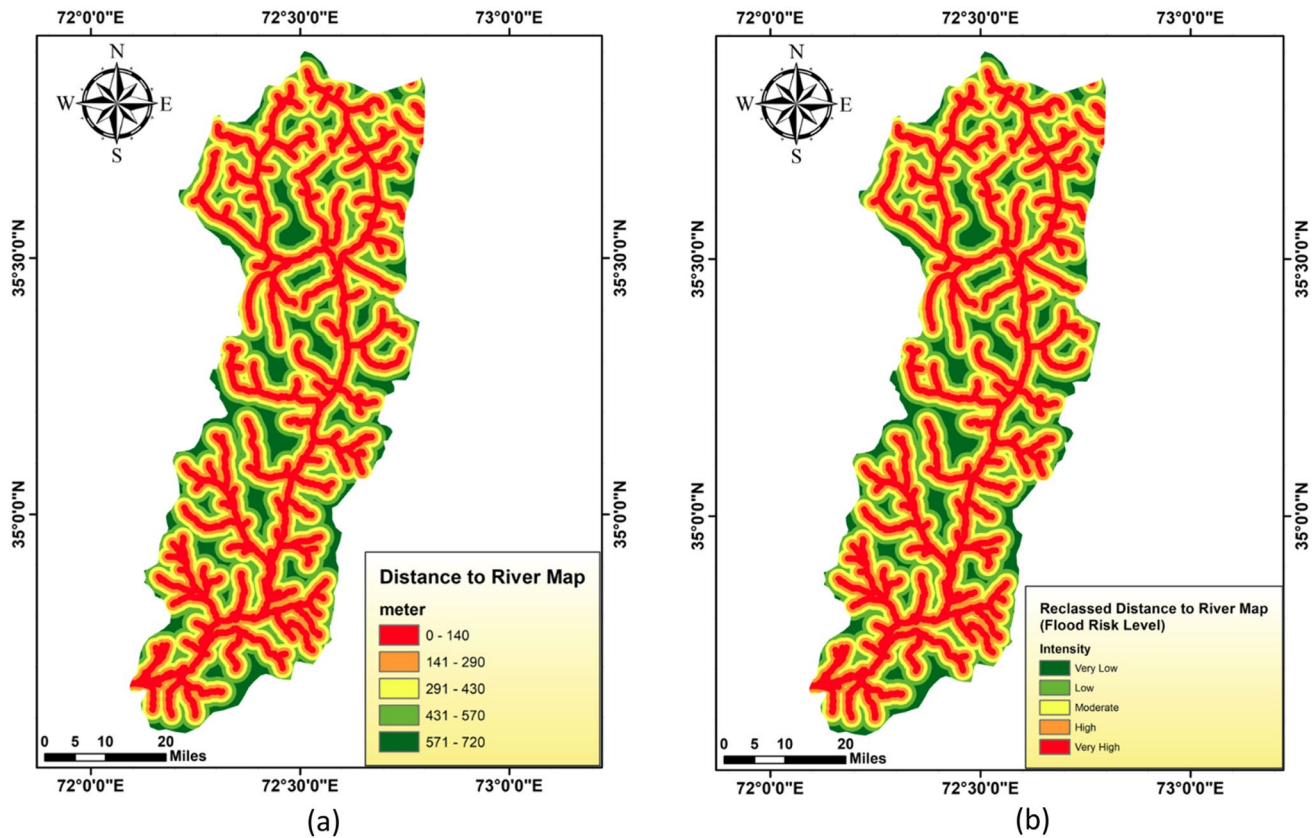


Fig. 5 **a** Distance to river map; **b** Reclass of distance to river map

2.10 Analytical hierarchical process (AHP)

AHP, which stands for Analytic Hierarchy Process, is a crucial decision-making approach that finds applications in various industries such as business, banking, education, politics, and engineering. It was initially developed by Saaty in 1980 as a multicriteria decision-making method, drawing inspiration from the work of Myers and Alpert in 1968, and has since become one of the most widely used approaches in this field [26]. The AHP is highly flexible and allows for the consideration of both quantitative and qualitative factors in decision-making, taking into account the priorities of the user or group implementing the model. In the AHP, the comparison matrix is transformed into a priority vector, and a consistency ratio is calculated by assigning an arbitrary index value. The highest level in the hierarchy represents the final state of the decision, followed by its criteria, and then the least preferred options at the lower level. Decisions can be made at the lowest level of the hierarchy. It is crucial to accurately define the total number of criteria and each discrete criterion to ensure consistent pairwise comparisons. Grouping similar criteria together is important for

a meaningful interpretation of the criteria. AHP can be applied with various criteria, and once the hierarchy is established, it compares the two criteria to determine their relative importance.

An AHP pair-wise comparison matrix was used to establish the relative weights of the pertinent components. As the criteria are prioritized, their relative weights are established. On a scale of 1 to 9, where 9 is the most significant component, there is a relative importance scale.

The final map of flood risk zones was created by combining the weights and multiplying them by the rate of each individual element, as given in Eq. (1).

$$H = \sum_{i=1}^n w_i x_i \quad (1)$$

where n is the number of components, $w(i)$ is each factor's weight, and $x(i)$ is each factor's individual rating, and H is the flood risk level.

The pair-wise comparison matrix indicated in the following equation (Eq. 2) theoretically revealed the weighting coefficients of the stated flood risk components in the AHP approach.

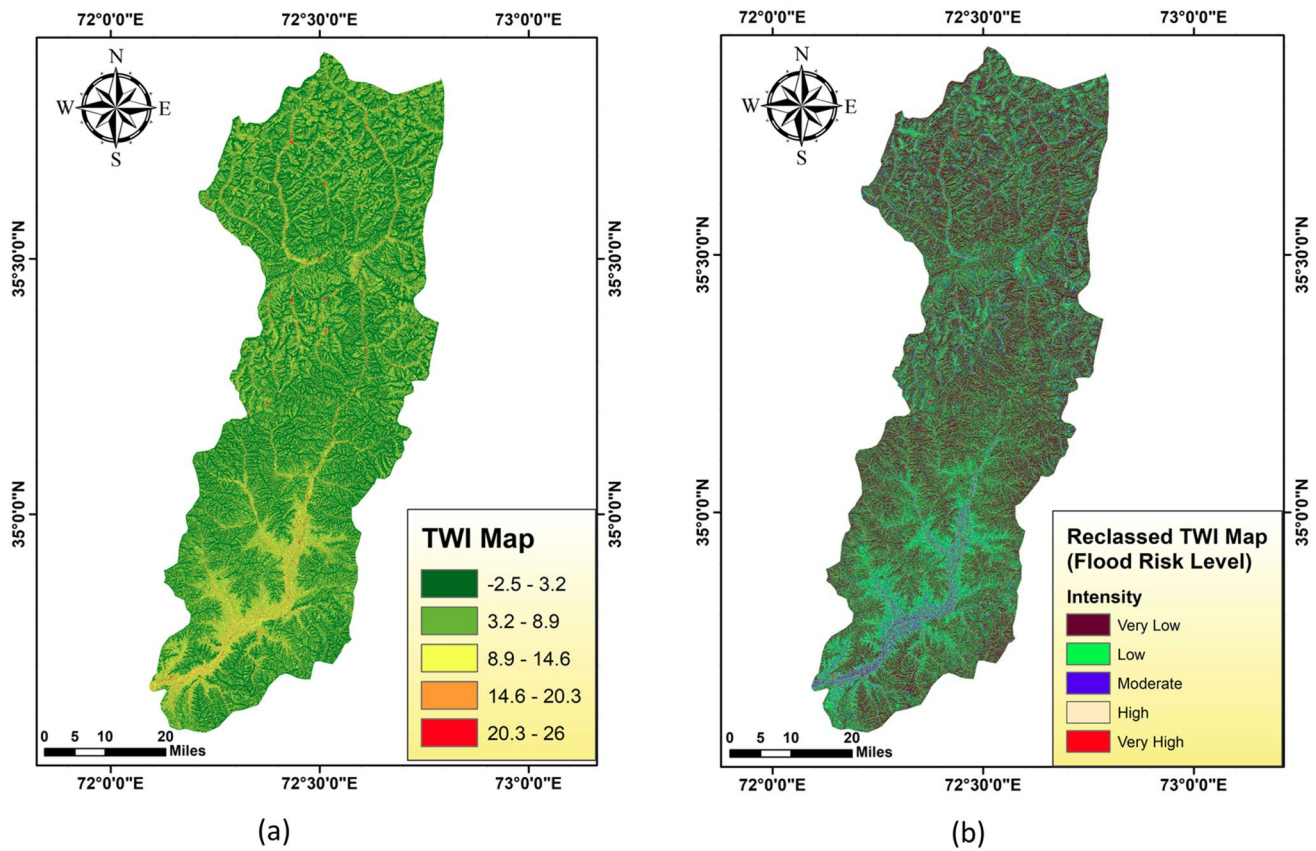


Fig. 6 **a** Topographic wetness index (TWI) map; **b** Reclass of TWI map

$$A = [a_{ij}] \begin{pmatrix} 1 & a_{1j} & \dots & a_{1n} \\ 1/a_{ij} & 1 & & a_{2n} \\ & & & 1/a_{2n} \\ & & & & 1 \end{pmatrix} \quad (2)$$

The scale of Relative Importance in the Analytic Hierarchy Process (AHP) is utilized to allocate weights or priorities to various criteria or factors, considering their respective significance or preference, to support decision-making processes. This scale is shown in Table 3 for the current study. The decision matrix in AHP is a tool to compare alternatives based on criteria and determine their relative importance as illustrated in Table 4. The pair-wise assessment matrix is shown in Table 5 using an 9 × 9 matrix with diagonal elements equal to 1. The ratings are computed by comparing each row’s values to each column’s values. Rainfall intensity, for example, is far more important than land use and thus has a value of one in category. Row talks about the importance of land use. Priorities can be calculated and placed in ArcGIS weighted overlay function after assigning values as in a decision matrix, with the results displayed on a map as shown in Fig. 9.

Consistency Index (CI), calculated using Eq. (3)

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (3)$$

where n represents the number of classes.

Consistency ratio, CR is a pair-wise comparison matrix, which is calculated with Eq. (4)

$$CR = \frac{CI}{RI} \quad (4)$$

RI donates random consistency index.

If the CR is less than 0.10, the comparison matrix is considered to have appropriate consistency; otherwise, the decision-making process is repeated until consistency is achieved. CR=0.00 is the best consistency value.

The consistency (CR) ratio of 5% indicates that the AHP calculation using the decision matrix is correct because it falls within the range. A CR value of less than 10% is considered acceptable.

Although AHP has been used extensively to create reliable hazard maps, the findings are mostly dependent on expert judgement, which could cause errors in the determination of the criteria weight. Sensitivity analysis was utilized in this study to look at the sensitivity requirements for mapping flood dangers. The weight of a single element is

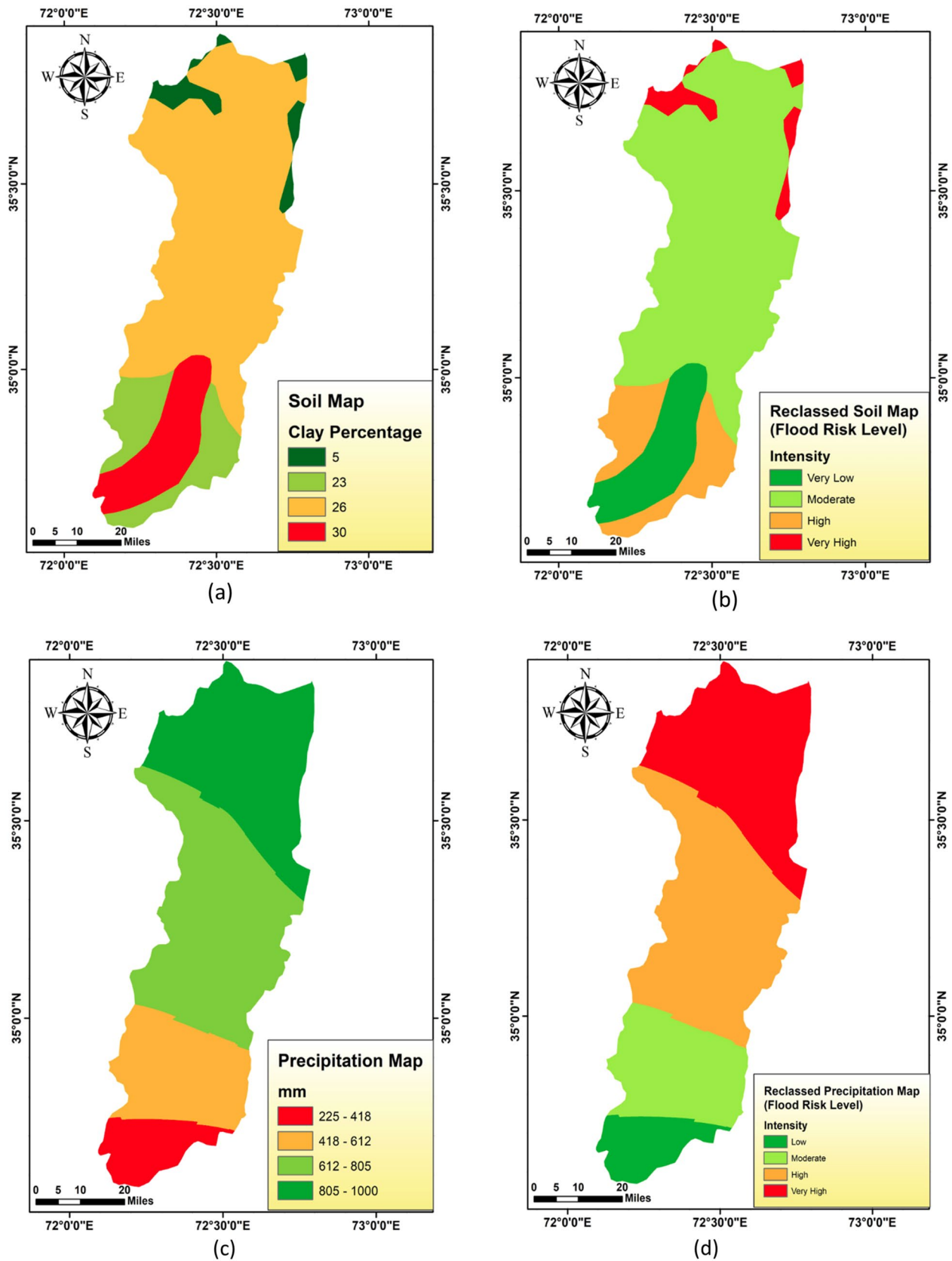


Fig. 7 **a** Soil map; **b** Reclass of soil map; **c** Precipitation map; **d** Reclass of precipitation map

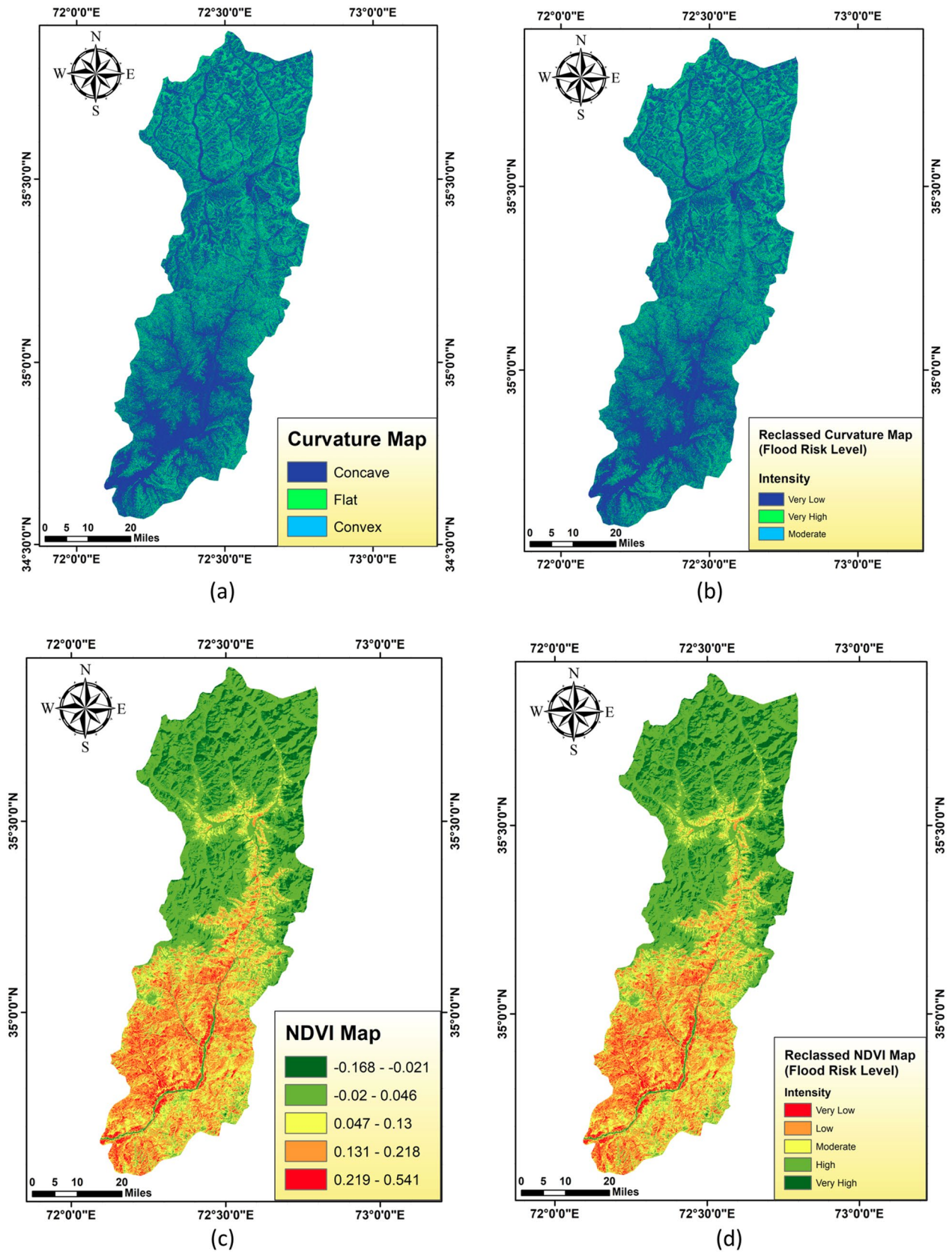


Fig. 8 **a** Curvature map; **b** Reclass of curvature map; **c** NDVI map; **d** Reclass of NDVI map

Table 2 Summary of the data used in this study and the sources from where the data is obtained

Sr. No	Data Type	Description	Source
1	DEM	ASTER global digital elevation model with 30 m cell size	Earth Data Search, NASA [35]
2	Soil Data	Digital Soil Map of the World- ESRI Shapefile format with resolution of 5'×5'	FAO Map Catalog, Food and Agricultural Organization of the United Nations [36]
3	LULC Data	Sentinel-2 10-Meter Land Use/Land Cover	Esri Land Cover—ArcGIS Living Atlas [37]
4	NDVI Data	Landsat Collection 2 Level-1 (Landsat 8–9 OLI/TIRS C2 L1)	USGS Earth Explorer. United States Geological Survey [38]
5	Rainfall Data	CRU TS Monthly precipitation high-resolution datasets with 0.5×0.5 degree resolution	CRU UAE Data, Climate Research Unit [39]

Table 3 The fundamental scale for pair-wise comparison

Intensity	Definition
1	Equal importance
2	Relative importance
3	Moderate importance
4	Relative importance
5	Strong importance
6	Relative importance
7	Very strong importance
8	Relative importance
9	Extreme importance

changed over a range of percentages when using the one-at-a-time (OAT) method, and the effects of the change are then evaluated as shown in Fig. 9. In this study, the range of percent change (RCP) was applied to all criteria weights with a 5% increase in the percent change (IPC) (i.e., plus or minus 5%) from a 20% beginning criterion weight. The weights of the primary criterion at various degrees of percent change were calculated using Eq. (5), which is displayed in Fig. 9. The interpolation table aids in assigning average values to criteria within a specified range, ensuring precise and standardized evaluations in the decision-making process as shown in Fig. 10.

Table 4 Decision matrix used in the current study

Category	Type	Priority	Rank	(+)	(-)
1	Rainfall	27.6%	1	12.4%	12.4%
2	Distance to river	23.9%	2	11.7%	11.7%
3	Slope	15.80%	3	5.3%	5.3%
4	Elevation	12.90%	4	3.8%	3.8%
5	LULC	8.90%	5	3.4%	3.4%
6	TWI	4.00%	6	1.7%	1.7%
7	NDVI	2.6%	7	1.0%	1.0%
8	Soil type	2.70%	8	0.7%	0.7%
9	Curvature	1.60%	9	0.7%	0.7%

The Rank column is color-coded is to indicate the priority order of the nine parameters

Table 5 Priority table for each parameter

Criteria	Rainfall	Distance to river	Slope	Elevation	LULC	TWI	NDVI	Soil type	Curvature
Rainfall	1	2	3	3	4	5	6	7	9
Distance to River	0.50	1	2	4	4	6	6	8	8
Slope	0.33	0.5	1	1	3	6	7	7	9
Elevation	0.33	0.25	1	1	2	4	7	6	8
LULC	0.25	0.25	0.33	0.50	1	3	6	5	7
TWI	0.20	0.17	0.17	0.25	0.33	1	2	1	5
NDVI	0.17	0.17	0.14	0.14	0.17	0.50	1	1	2
Soil type	0.14	0.12	0.14	0.17	0.20	1	1	1	2
Curvature	0.11	0.12	0.11	0.12	0.14	0.20	0.50	0.50	1

CFR: % 5.4

The diagonal values are highlighted with color to represent the relative importance of each parameter to itself. This convention simplifies the table's interpretation and aids in comprehension

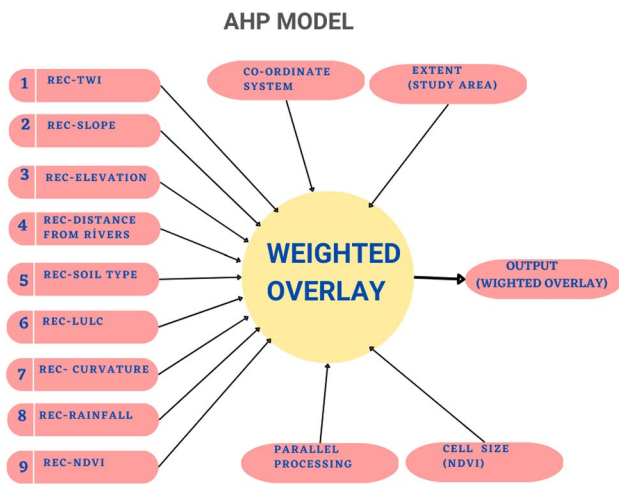


Fig. 9 AHP model for all parameter

$$W(Cm, pc) = W(Cm, 0) + W(Cm, 0) \times pc \tag{5}$$

$W(Cm,0)$ denotes the primary criterion's weight, Cm in the case of a base run, and pc denotes the percent change's level.

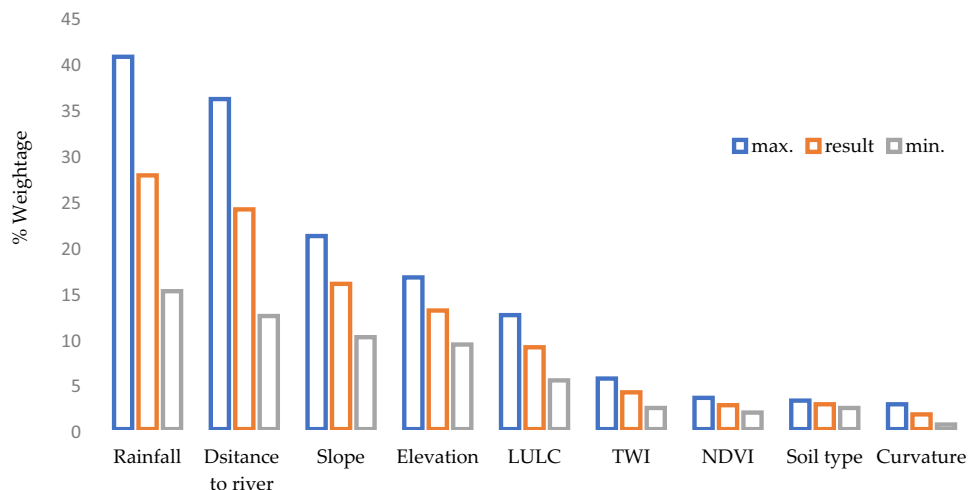
In order to alter the weights of the other criterion proportionally at any percent change level, Eqs. 6 and 7 were used; as a consequence, all criteria weights must add up to one.

$$W(pc) = \sum_{i=1}^n W(Ci, pc) = 1, RPCmin \leq pc \leq RPCmax \tag{6}$$

$W(Ci, pc)$ is the weight of the i th criterion ci at a certain percent change level,

$$W(Ci, pc) = (1 - W(Cm, pc) \times W(Ci, 0)) / (1 - W(Cm, 0)) \tag{7}$$

Fig. 10 Selected parameters and their impact comparison for study area



The total number of criteria is n , the RCP's minimum and maximum values are RPC_{min} and RPC_{max} , respectively (Fig. 11).

3 Results

The study's findings indicated that elevation, slope, rainfall, and distance to the river were the primary factors influencing the occurrence of flooding in the area. The elevation map revealed that regions with lower elevations were more susceptible to flooding. This is due to the natural flow of water towards lower areas, making them prone to inundation during intense rainfall events. The slope map demonstrated that areas with steeper slopes were at a higher risk of flash floods. Analysis of the rainfall data indicated that the study area experienced significant precipitation levels during the monsoon season, which played a crucial role in the occurrence of flooding. Figure 12 further illustrated that proximity to the river increased the vulnerability to flooding.

Less impact was observed on flooding from parameters such as curvature, NDVI, TWI, land use/land cover (LULC), and soil type. The curvature map indicated that concave areas were more susceptible to flooding as they tended to retain water. The NDVI map revealed that regions with negative NDVI values (indicating very poor or no vegetation, almost bare land) were at risk of flooding as there were no obstacles to impede the flow of water, potentially resulting in significant soil erosion and landslides. Areas with high TWI values indicated a higher water accumulation capacity, thereby increasing the risk of flooding. Concerning LULC, areas occupied by water bodies and vegetation near rivers were more prone to flooding compared to other land cover conditions. Clayey soil, due to its low drainage rate compared to other soil types, had an

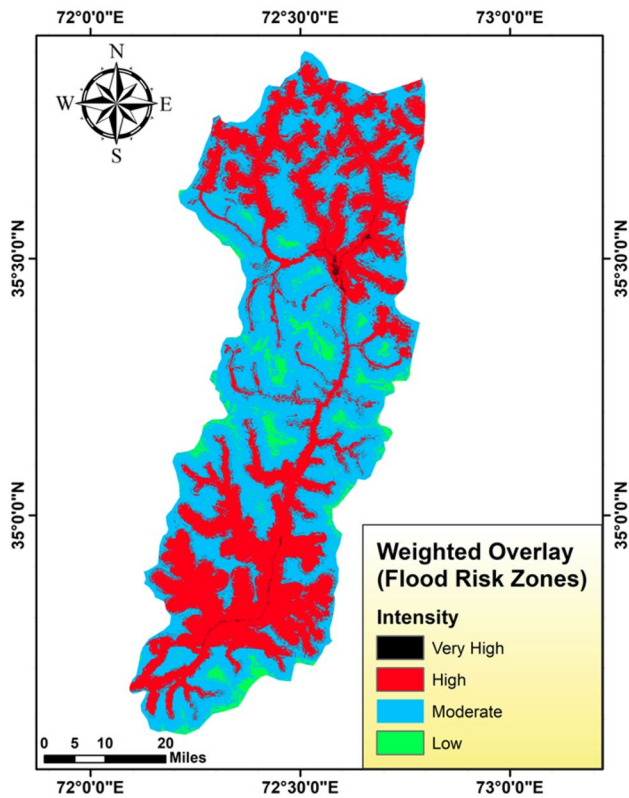


Fig. 11 Flood hazard map from AHP method for study area

The flood hazard map was generated by considering nine parameters: elevation, slope, rainfall, distance to river, curvature, NDVI, TWI, LULC, and soil type. The AHP process was employed to determine their relative weights, and it yielded a consistency ratio (CR) of 5.4%, which is below the acceptable threshold of 10%. This indicates the reliability of the results. Table 1 presents the recommended weights and ratings assigned to each of the nine criteria. The flood hazard levels were categorized into five distinct classes: very low, low, moderate, high, and very high. Using the GIS-AHP approach, higher weights were assigned to rainfall, distance to river, elevation, and slope in comparison to NDVI, TWI, LULC, curvature, and soil type. The flood hazard map was then reclassified for each parameter. Overlaying these maps determined that 5.6% of the total area is classified as very high flood risk, 52% as high risk, 39.3% as moderate risk, and 3.1% as low risk. Further details on the breakdown of the area categorized under different risk zones can be found in Table 7.

3.1 Flood hazard map

Flood hazard map was produced from the weighted overlay of nine parameters. The standard deviation approach was employed for the classification of the maps. The study region is divided into four groups for the flood hazard assessment: "Very high," "High," "Moderate," and "Low" flood risk zones, as illustrated in Fig. 11. The high flood risk zone covers the Southeast and Southwest parts of the study area, which is the most populated area in Swat district. The flood risk is either moderate or low in the middle

increased potential to retain water, thereby elevating the flood risk in clayey soil areas.

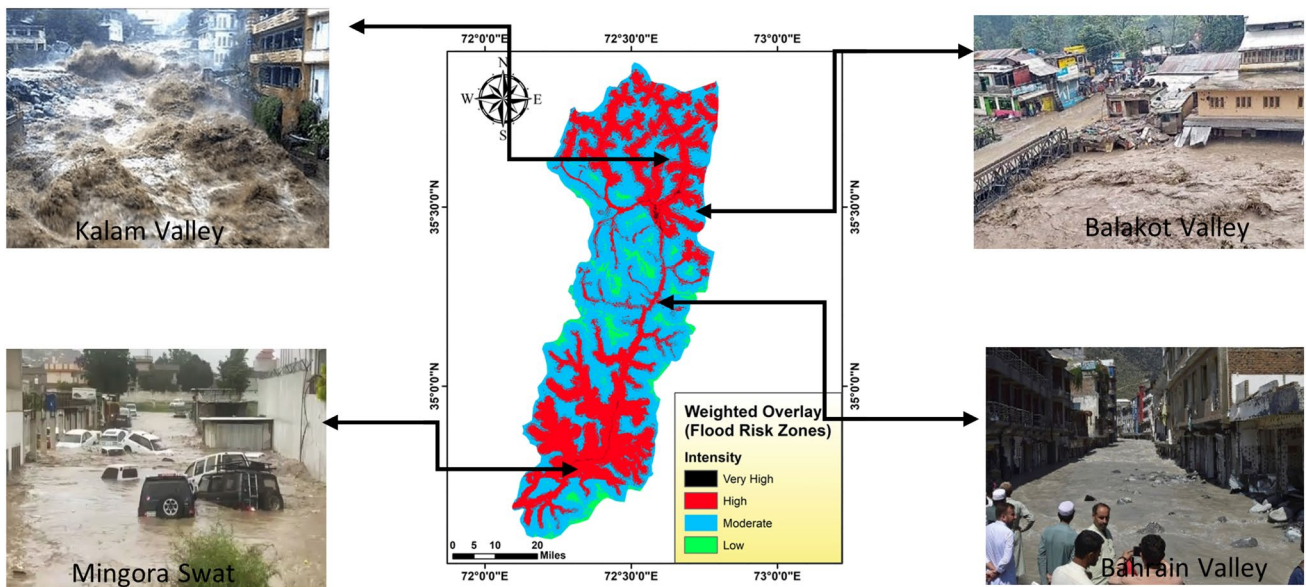


Fig. 12 Validated map of Study Area

Table 6 Estimated flood-prone area of Swat

Study area (District)	Total area (km ²)	Area under high risk (km ²)
Swat	5,337	3074.112

Table 7 Classification of flood prone areas in form of categories

Criteria (Flood risk)	Area(km ²)	Percentage
Very High	298.872	5.6%
High	2775.24	52%
Moderate	2092.104	39.3%
Low	165.447	3.1%
Total	5337	100%

of the map. The flood risk is high for the Northeast and Northwest sides as those areas are susceptible to flash floods.

The Southern part of Swat valley, where the majority of the urban population resides and major road infrastructure is located, is identified as being at high risk of flooding according to the flood hazard map. This is a significant concern as it suggests that a significant loss of infrastructure may occur during flooding events, as observed in the 2010 flood incident [40]. Another crucial factor influencing the flood risk is rainfall. The speed of water flow downstream plays a vital role in determining the extent of flood damage. The slope and elevation of the terrain greatly influence the velocity and direction of water flow within the study area, as gravity plays a significant role in flood occurrences. As rainfall is relatively higher and more frequent in the Northern parts of Swat valley, the rainwater gains velocity as it flows down the slope, resulting in greater damage in the Southern areas of the valley. The methods and techniques used to develop the hazard map have the advantage of providing a comprehensive and easy-to-understand representation of the flood hazards. This hazard map can be particularly useful in areas where primary data is unavailable. Tables 6 and 7 present the calculated categorization of the area into flood risk zones, ranging from high to low.

Table 7 indicates that over 50% of the area is classified as having a high flood risk. To mitigate the negative impacts of flooding, it is crucial to implement strategic measures for planned construction in these areas. Encroachments, particularly those near the river banks, should be removed to prevent further vulnerability. Constructing a flood protection wall is recommended in regions where it will effectively mitigate the risk, with the southern site being the most feasible option. By implementing these measures, the potential damage from flooding can be significantly

reduced, ensuring the safety and protection of the population and infrastructure in the high-risk areas.

3.2 Model validation

Model validation is a critical process that involves systematically comparing the outputs of a model to independent observations in the real world. This comparison helps assess the accuracy and reliability of the model's predictions in terms of both quantity and quality. In the context of flood susceptibility assessment, researchers utilize various models to evaluate the vulnerability of different regions to flooding. However, it is essential to validate these models by comparing their outputs to actual observed data or ground truth information. By calibrating and validating the model using observable data, researchers can ensure that the model accurately reflects the real-world conditions and improves its reliability for future flood risk assessments.

In September 2011, a disaster risk mapping project was conducted in Swat District under the supervision of the National Rural Support Program (NRSP) and Diakonie, a German-based INGO. The objective was to assess the vulnerability of 11 selected villages in the district to flooding. These villages were chosen based on their extensive damages during the 2010 flood event [41]. The geographic locations of these villages were plotted on the current flood hazard map developed in this study. It was found that all of the selected villages fell within the moderate to high flood risk zones, thus validating the study's findings with field observation data. Another study titled "Flood Disasters and Land Use Planning in Swat Valley" was conducted by Atta-ur-Rehman et al. This study aimed to analyze flood disasters and the effectiveness of land use planning. They also developed a flood hazard zonation map using GIS tools [40]. A comparison was made between their flood hazard zonation map and the one developed in the current study. Although the emphasis of their study was more on land use analysis, the results were comparable. However, the current study incorporated nine different parameters into the development of the flood hazard map, making it more comprehensive and reliable. The comparison of both flood hazard maps validated the results of the current study and indicated their reasonableness. Swat Valley, like many other districts in Pakistan, experiences periodic severe flooding [42]. Areas located along the river banks have been particularly vulnerable to floods since 1973 [43]. Figure 12 shows illustrations of some flood events superimposed on the flood hazard map developed in the current study, highlighting the accuracy of the hazard map in depicting the flood-prone areas.

3.3 Limitations of the methodology and recommendation

While the current study has its limitations, such as the quality of the medium resolution image (SRTM 30 m) used and the subjectivity in assigning coastlines to certain parameters, the obtained flood susceptibility map of the Swat District KPK watershed remains a valuable tool for development, planning, and decision-making by administrative authorities and decentralized territorial communities. It will contribute to improving the quality of life for the densely populated area and addressing environmental management and sanitation issues. It is important to acknowledge the limitations and inconsistencies in future studies, incorporating them into the analysis and exploring more effective models to reduce error margins. This study marks the first attempt of its kind to assess the vulnerability of the Swat District KPK watershed to flooding in the context of global change, utilizing a wide range of environmental data including SRTM, rainfall, and geology. These findings serve as a starting point in addressing the flooding problems in the Swat area of Pakistan. Furthermore, the outcomes of this study will facilitate coordination among the government, decentralized territorial communities, and other development actors in their efforts to prevent, mitigate, and respond to floods. From a scientific perspective, this endeavor enhances our understanding of the ecology of the Swat District KPK watershed and enables the identification and evaluation of variables influencing flood risk.

4 Discussion

The study's findings demonstrated the efficiency of the Analytic Hierarchy Process (AHP) and Geographic Information System (GIS) tools in determining the danger of urban flooding in Pakistan's Swat District's KPK watershed. Elevation slope and rainfall were shown to be the most significant factors influencing flood risk using the AHP technique. In the meanwhile, flood risk maps were produced, and the findings were shown using GIS tools. The survey also discovered that although the majority of people in the KPK watershed believed that there was a significant danger of flooding, very few of them had taken any precautions. The GIS maps revealed that low-lying locations and those with a lot of impermeable surfaces, such as roads and buildings, were those most at danger of flooding. Extreme rainfall events have become more frequent and severe due to climate change and increased urbanization, resulting in regular urban flooding disasters. Swat District, being Pakistan's most populated district, is susceptible to urban floods and flash floods due to its

geographical location and topographic characteristics respectively. Hence, it was selected as the research area for the study. Based on the data, the extent of each danger zone varies as the rainfall factor increases. As rainfall increases, the intensity of floods also increases. However, the significance of the rainfall peak coefficient parameter in determining the position of the greatest danger zone decreases as the return period of precipitation increases [44]. The urban region constitutes approximately 33% of the entire study area. During intense storm events, when the runoff exceeds the capacity of the drainage system, six factors were identified as significant contributors to watercourse-related issues. These factors include slope, elevation, proximity to open channel streams, hydro-lithology, distance from fully covered streams, and human-induced factors such as urban areas and additional land uses. The AHP technique and GIS were employed to develop a flood hazard assessment map, which assesses the likelihood of a flood occurring within a specific timeframe. However, the current study did not consider the evaluation of flood hazards in relation to return times [26]. As a result, a flood susceptibility map was created to indicate the likelihood of flooding in specific areas. This map classified the potential flood hazards in the study region into five levels of susceptibility: very low, low, moderate, high, and very high. According to Table 7, approximately 40% of the region falls within two high-risk zones. In Swat, the fluvial systems are mainly composed of fast-flowing streams, which can lead to severe but infrequent flash floods. The presence of small drainage basins and the unpredictable behavior of streams in the area contribute to the occurrence of floods. Runoff tends to increase in the upper parts of watersheds, which raises the risk of flooding in urban areas downstream. By assigning weights to each element or indicator involved in the flood process, the AHP approach enhances our understanding of their individual roles [45].

However, the use of data from multiple sources, interpolation, and cross-referencing in a GIS at the same resolution can introduce bias when processing and analyzing the data. To mitigate bias and uncertainty in the final results, it is necessary to normalize and weight these parameters appropriately. The subjective nature of selecting indicator weights based on random expert judgments is another reason why the AHP approach may not be effective. In general, an integrated approach combining AHP and GIS techniques can yield satisfactory outcomes [46]. The proposed technique offers a comprehensive analysis of flood-prone areas using consistent methodologies [34, 47]. The findings provide valuable information that can be applied in different contexts. Therefore, this concept is beneficial when combined with probability attribution methodologies. However, there are challenges in implementing this technique. In our study, due to a lack of data

on the underground drainage system, we employed a simplified method of flooding simulation by generalizing the network. While there were some errors in the simulation results, they did not significantly impact the assessment of flood risk levels [48]. The specific objectives of the investigation determine the required level of resolution for considering physical, social, and environmental factors. To enhance the comprehensibility of the findings, data is presented in a raster format of the same size as the text. Future studies should aim to employ indicators with consistent spatial resolution.

Measuring urban flood risk consistently is difficult due to the dynamic nature of the factors involved, such as precipitation intensity and volume, population density, and building layout. In our research, we focused on examining and analyzing a subset of critical indicators relevant to the research topic. Despite the inherent uncertainty, it is crucial to precisely and thoroughly compute the weighting of these indicators as it significantly impacts the final estimation of flood risk. Researchers have extensively studied the challenges faced during rescue operations following natural disasters. In the future, a comprehensive investigation of urban flooding is necessary to establish scientific criteria for urban emergency rescue systems [49].

The findings of this study have several implications for flood risk management in the KPK watershed and neighboring areas. First and foremost, the research highlights the significance of land use planning and management in mitigating flood risk. The presence of numerous roads and impermeable surfaces in the study area leads to increased runoff during rainfall events, increasing the likelihood of floods. Therefore, it is crucial to make informed land use decisions to minimize the risk of flooding. The research highlights the need for improved drainage infrastructure and maintenance to mitigate the impacts of floods. It was observed that the drainage system in the study area was inadequate, which heightened the risk of flooding. Therefore, investing in drainage infrastructure and maintenance can help minimize the impacts of floods in the future. Furthermore, the study emphasizes the importance of educating and increasing public awareness regarding flood risk and preparedness. Although many people in the study region acknowledged the significant likelihood of flooding, only a few had taken any preparatory measures. To mitigate the impacts of floods, initiatives should be undertaken to enhance public awareness of flood risk and preparedness.

The significance of this research lies in its practical implications. The hazard maps produced by our study serve as valuable tools for urban planners, local authorities, and disaster management agencies. They enable

these stakeholders to make informed decisions about land use planning, emergency response strategies, and targeted mitigation measures. By utilizing our findings, they can proactively enhance the district's resilience and promote sustainable development, effectively minimizing the impact of flood hazards.

5 Conclusions

Due to the concentration of lowlands with moderate slopes, ephemeral streams with torrential behavior, completely covered streams, and urban areas, the eastern and southern parts of the research region exhibit a high concentration of very high and high flood danger zones. The locations of these flood-risk zones showed relatively little variation, as indicated by the uncertainty analysis. The flood danger map effectively illustrates the relationship between flood hazard zones and areas prone to flooding. The validation process demonstrated the reliability and precision of the hazard map. The current urban flood hazard map and spatial distribution were analyzed to identify potential sites for implementing flood protection measures. The proposed method, which provides a comprehensive analysis of the area, can be easily implemented in locations where primary data is limited and produces reasonable results. Therefore, scientists, stakeholders, engineers, and decision makers involved in future land use planning initiatives can adopt this method. It can also contribute to the development of flood mitigation techniques and be applied to disaster preparedness planning and post-fire management, enhancing their effectiveness.

Acknowledgements The ESRI and USGS are gratefully acknowledged by the study's authors for contributing the digital elevation model and land use and cover data, respectively.

Author Contributions Conceptualization, MW, SA, IA, and HW; methodology, SA, IA, HW, and MW; software, IA, SA, MW, and HW; validation, IA, MW, SA, and HW; formal analysis, SA, MW, IA, and HW; investigation, MW; data curation, SS, IA, HW, and MW; writing original draft, SA, IA; writing—review and editing, MW, and MKL; visualization, MW, and MKL. All authors have read and agreed to the submitted version of the manuscript.

Funding Open Access funding enabled and organized by Projekt DEAL. This study received no external funding. We are thankful to the University of Rostock, Open access program for their willingness to pay the article processing charges.

Data availability The datasets generated and/or analyzed during the current study are not publicly available due to privacy reasons but are available from the corresponding author on reasonable request.

Declarations

Competing interests The authors declare no competing interests.

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Wingfield T, Macdonald N, Peters K, Spees J, Potter K (2019) Natural Flood Management: Beyond the evidence debate. *Area*. <https://doi.org/10.1111/area.12535>
- Munawar S et al (2022) Future climate projections using SDSM and LARS-WG downscaling methods for CMIP5 GCMs over the transboundary Jhelum river basin of the Himalayas Region. *Atmosphere (Basel)*. <https://doi.org/10.3390/atmos13060898>
- Arnell NW, Gosling SN (2016) The impacts of climate change on river flood risk at the global scale. *Clim Change* 134(3):387–401. <https://doi.org/10.1007/s10584-014-1084-5>
- CRED, "2022 Disaster in Numbers," 2023, [Online]. Available: https://cred.be/sites/default/files/2022_EMDAT_report.pdf
- Hanson S et al (2011) A global ranking of port cities with high exposure to climate extremes. *Clim Change* 104(1):89–111. <https://doi.org/10.1007/s10584-010-9977-4>
- Adb, *Addressing Climate Change and Migration in Asia and the Pacific*. 2012. [Online]. Available: <http://www.adb.org/sites/default/files/publication/29662/addressing-climate-change-migration.pdf>
- M. Drdácý, L. Binda, I. Herle, and L. Lanza, 2007 Protecting the cultural heritage from natural disasters, *Adv. Res. Cent. Cult. Herit.* Feb, p. 100, , [Online]. Available: <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Protecting+the+cultural+heritage+from+natural+disasters#3%5Cnhttp://www.europarl.europa.eu/activities/committees>
- World Bank and R. T. Government, 2011 Rapid Assessment for Resilient Recovery and Reconstruction Planning, p.377, [Online]. Available: http://www.gfdr.org/sites/gfdr.org/files/publication/Thai_Flood_2011_2.pdf
- Ullah K, Wang Y, Fang Z, Wang L, Rahman M (2022) Multi-hazard susceptibility mapping based on convolutional neural networks. *Geosci Front*. <https://doi.org/10.1016/j.gsf.2022.101425>
- Saaty TL, Saaty TL (2013) The modern science of multicriteria decision making and its practical applications : The AHP / ANP approach the modern science of multicriteria decision making and its practical applications : The AHP/ANP approach. *Operations Res*. <https://doi.org/10.1287/opre.2013.1197>
- A. Lahrach, 2019 Water security and sustainable development * Zineb Moumen ¹, Najiba El Amrani El Idrissi ², Manuela Tvaronavičienė ³ Abderrahim Lahrach 4 14 1
- Tabari H (2020) Climate change impact on flood and extreme precipitation increases with water availability. *Sci Rep*. <https://doi.org/10.1038/s41598-020-70816-2>
- Al-Aizari AR et al (2022) "Assessment analysis of flood susceptibility in tropical desert area: a case study of Yemen. *Remote Sens*. <https://doi.org/10.3390/rs14164050>
- Allen MR, Ingram WJ (2002) Constraints on future changes in climate and the hydrologic cycle. *Nature*. <https://doi.org/10.1038/nature01092>
- Muzzamil S et al (2020) A review of the flood hazard and risk management in the South Asian Region, particularly Pakistan. *Sci. African* 10:e00651. <https://doi.org/10.1016/j.sciaf.2020.e00651>
- Chauhdry KT, Javed U (2019) Climate change and water security: focus on pakistan. *ISSRA Papers* 11(II):57–70
- Nsangu D et al (2022) Urban flood susceptibility modelling using AHP and GIS approach: case of the Mfoundi watershed at Yaoundé in the South-Cameroon plateau. *Sci African* 15:e01043. <https://doi.org/10.1016/j.sciaf.2021.e01043>
- Dottori F et al (2018) Increased human and economic losses from river flooding with anthropogenic warming. *Nat Clim Chang*. <https://doi.org/10.1038/s41558-018-0257-z>
- Nofal OM, Van De Lindt JW (2021) International Journal of Disaster Risk Reduction High-resolution flood risk approach to quantify the impact of policy change on flood losses at community-level. *Int J Disaster Risk Reduct* 62:102429. <https://doi.org/10.1016/j.ijdrr.2021.102429>
- Ullah K, Id JZ (2020) GIS-based flood hazard mapping using relative frequency ratio method : A case study of Panjkora River Basin eastern Hindu Kush Pakistan. *PLoS ONE*. <https://doi.org/10.1371/journal.pone.0229153>
- Sinha R (2005) GIS in flood hazard mapping : a case study of Kosi River Basin India. *GIS Develop Weekly*. <https://doi.org/10.13140/RG.2.1.1492.2720>
- Bhatt GD, Sinha K, Deka PK, Kumar A (2014) Flood Hazard and Risk Assessment in Chamoli District, Uttarakhand Using Satellite Remote Sensing and GIS Techniques. *Int J Innov Res Sci Eng Technol* 3(8):15348–15356. <https://doi.org/10.15680/IJIRSET.2014.0308039>
- Anthropiques P, Les SUR, La MDE (2012) Impacts conjugués des changements climatiques et des pressions anthropiques sur les modifications de la couverture végétale dans le bassin versant du n'zi -bandama (cô te d'ivoire). *Rev Ivoir Sci Technol* 20:124–146
- Rinc D, Khan UT, Armenakis C (2018) Flood risk mapping using gis and multi-criteria analysis : a greater toronto area case study. *Geosciences*. <https://doi.org/10.3390/geosciences8080275>
- Guo E, Zhang J, Ren X, Zhang Q (2014) Integrated risk assessment of flood disaster based on improved set pair analysis and the variable fuzzy set theory in central Liaoning Province China. *Nat Hazards*. <https://doi.org/10.1007/s11069-014-1238-9>
- Hussain M, Butt AR, Uzma F (2020) A comprehensive review of climate change impacts adaptation and mitigation on environmental and natural calamities in Pakistan. *Environ Monit Assess*. <https://doi.org/10.1007/s10661-019-7956-4>
- Ouma YO, Tateishi R (2014) Urban flood vulnerability and risk mapping using integrated multi-parametric ahp and gis: methodological overview and case study assessment. *Water*. <https://doi.org/10.3390/w6061515>
- Hagos YG, Andualem TG, Yibeltal M, Mengie MA (2022) Flood hazard assessment and mapping using GIS integrated with

- multi - criteria decision analysis in upper Awash River basin. *Appl Water Sci.* <https://doi.org/10.1007/s13201-022-01674-8>
29. Sweeney G, Hand M, Kaiser M, Clark JK, Rogers C, Spees C (2015) The state of food mapping : academic literature since 2008 and review of online gis-based food mapping resources. *J Plan Liter.* <https://doi.org/10.1177/0885412215599425>
30. Patrikaki O, Kazakis N, Kougiyas I, Theodosiou N, Voudouris K, Patsialis T (2018) Assessing flood hazard at river basin scale with an index-based approach : the case. *Geosciences.* <https://doi.org/10.3390/geosciences8020050>
31. Bengal W, Chakraborty S, Mukhopadhyay S (2019) Assessing flood risk using analytical hierarchy process (AHP) and geographical information system (GIS): application. *Nat Hazards.* <https://doi.org/10.1007/s11069-019-03737-7>
32. Region L, Wang Y, Li Z, Tang Z (2011) A GIS-based spatial multi-criteria approach for flood risk assessment in the dongting. *Water Res Manage.* <https://doi.org/10.1007/s11269-011-9866-2>
33. Tayyab M et al (2021) Gis-based urban flood resilience assessment using urban flood resilience model: A case study of peshawar city khyber pakhtunkhwa Pakistan. *Remote Sens.* <https://doi.org/10.3390/rs13101864>
34. Z. Khatoon, S. Gulzar, A. Shah, and T. Education, Manuscript Info. 1(2320): 329–344
35. "Earthdata Search | Earthdata Search." <https://search.earthdata.nasa.gov/search> Accessed Apr. 10, 2023
36. "FAOMapCatalog." <https://data.apps.fao.org/map/catalog/srv/eng/catalog.search;jsessionid=A9D9F0D0DE87CAE7106453B0B93D1C9D?node=srv#/search?facet.q=type%2Fdataset> Accessed Apr. 10, 2023
37. "Esri | Sentinel-2 Land Cover Explorer." <https://livingatlas.arcgis.com/landcoverexplorer/#mapCenter=-83.21%2C34.33%2C4&mode=step&timeExtent=2017%2C2021&year=2017&downloadMode=true> Accessed Apr. 10, 2023
38. "EarthExplorer." <https://earthexplorer.usgs.gov/> Accessed Apr. 10, 2023
39. "CRU TS Version 4.06." https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.06/ Accessed Apr. 10, 2023
40. Atta-ur-Rahman Farzana (2017) G. Rahman, and R. Shaw, 2017 Flood Disasters and Land Use Planning in Swat Valley Eastern Hindu Kush. Land use management in disaster risk reduction. Springer, Tokyo, pp 179–195
41. A. Mathematics, 2016 Disaster Risk Mapping District Swat 1–23
42. "FloodsIn Pakistan Maps, Graphs And Key Data | Critical Threats." <https://www.criticalthreats.org/analysis/floods-in-pakistan-maps-graphs-and-key-data> accessed May 11, 2023
43. "As Floodwaters Recede In Pakistan, Swat Valley Residents Come To Grips With Climate Change ." <https://www.rferl.org/a/pakistan-floods-swat-climate-change/32055964.html> Accessed May 11, 2023
44. Li G, Liu J (2022) Flood risk assessment using TELEMAC-2D models integrated with multi-index analysis in Shenzhen River Basin China. *Water* 14(16):2513
45. Schoenherr T, Tummala VMR, Harrison TP (2008) Assessing supply chain risks with the analytic hierarchy process : providing decision support for the offshoring decision by a US manufacturing company. *J Purch Supply Manage* 14:100–111. <https://doi.org/10.1016/j.pursup.2008.01.008>
46. Boroushaki S, Malczewski J (2010) Computers & geosciences using the fuzzy majority approach for GIS-based multicriteria group. *Comput Geosci* 36(3):302–312. <https://doi.org/10.1016/j.cageo.2009.05.011>
47. Sinha R, Singh GVBLK, Rath B (2008) Flood risk analysis in the Kosi river basin, north Bihar using multi- parametric approach of analytical hierarchy process (AHP). *J Indian Soci Remote Sens* 36:335–349
48. Lin K et al (2020) Assessment of flash flood risk based on improved analytic hierarchy process method and integrated maximum likelihood clustering algorithm. *J Hydrol* 584:1–57. <https://doi.org/10.1016/j.jhydrol.2020.124696>
49. Barroca B, Bernardara P, Mouchel JM, Hubert G (2006) Indicators for identification of urban flooding vulnerability. *Nat Hazards Earth Syst Sci.* <https://doi.org/10.5194/nhess-6-553-2006>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.