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Research Article

GIS-Based Identification and Analysis of Optimal Evacuation Areas and Routes in Flood-Prone Zones of Swabi District, Pakistan

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This study explores the main elements causing flooding in Pakistan's Swabi area and finds that elevation, slope, precipitation, and vicinity of rivers all play a major role in flooding occurrences. Low-lying areas, steeper slopes, intense monsoon rainfall, and proximity to rivers increase vulnerability to floods. Additional factors such as curvature, normalized difference vegetation index (NDVI), topographic wetness index (TWI), land use and land cover (LULC), and soil type exhibit comparatively less impact on flooding. The evaluation of flood risk incorporates nine factors through the AHP procedure, assigning weights that emphasize the importance of rainfall, slope, elevation, and distance to rivers using GIS software. The resulting flood hazard map categorizes the region into high-, moderate-, low-, and very low-risk zones, with approximately 49.42% identified as high flood risk areas. Evacuation planning designates secure zones, moderate-risk areas, and high-risk zones, emphasizing the need for flexible and adaptable routes in response to evolving flood scenarios. The study's comprehensive approach, integrating GIS and AHP, provides valuable insights for effective flood management in the Swabi district, despite limitations related to data quality. The findings contribute to resolving flooding issues and offer a foundation for coordinated actions by authorities and communities in flood-prone areas.

Keywords: analytic hierarchy process (AHP); flood risk mapping; GIS; multicriteria decision analysis; swabi district

1. Introduction

Over a billion people live in locations that are vulnerable to flooding, making floods one of the deadliest natural disasters on Earth. Extreme hydrological events and flood dangers are expected to be severe and to grow over time under forecasted climate change scenarios [1]. In contrast to other natural disasters, flooding poses a threat to 45% of the global population and is responsible for 5,424 recorded deaths between 2000 and 2017 [2]. The regions with the greatest increase in flood risk in the future are Asia, America, and Europe. The population of Asia's fastest-growing cities, including Mumbai, Dhaka, Jakarta, and Bangkok, will be particularly susceptible to coastal floods and flood hazards by the 2070s [3, 4]. Severe floods harm cultural artifacts and have a variety of severe consequences for people's health and the economy [5]. Thailand has seen some of the greatest flood catastrophes in recorded history since late November 2011. Ten million people are said to have been affected thus far, and 65 of Thailand's 77 provinces have been declared disaster areas. As per a World Bank study, Thailand's 2011 floods resulted in an approximate economic loss of $80 billion, making it the fourth most costly environmental catastrophe worldwide from 1995 to 2011 [6].

Due to global climate change, extreme weather events such as heat waves, typhoons, and floods are occurring more frequently and concentrated, endangering several countries. Climate change raises serious concerns regarding hydrological hazards and the management of water resources. Flash floods are among the most devastating natural catastrophes. It occurs on all continents in basins of varying sizes that enclose a small area of hundreds of square kilometers, severely impairing and disturbing human activities. These natural disasters are caused by intense, rapidly developing rainstorms. Researchers use a range of models to study flood susceptibility. Traditional flood risk mapping techniques often have a restricted reach because of insufficient data, according to Lin et al. [7]. Conventional methods need data gathering, which is sometimes expensive, time-consuming, and insufficient at the local or national level, particularly in developing countries. On the other hand, powerful dynamic technologies such as remote sensing and geographic information systems (GISs) may offer a plethora of data for floodplain zoning, catastrophe prediction, and disaster avoidance. For this kind of research, GIS is a particularly helpful tool since it can handle enormous amounts of geographic data that are required for flood modeling [8]. Swat, Pakistan's fast urbanization and shifting climatic patterns have made urban areas more susceptible to food-related disasters. Reliability in food risk assessment is essential for efficient urban development and disaster relief [9]. One of the districts in Pakistan that is frequently badly damaged by floods is the Swat Valley [10]. The floods that have occurred since 1973 have wreaked the most havoc on the regions located near the river banks [11].

Floods are among the most frequent natural disasters globally, causing extensive damage to ecosystems, human communities, and individual lives each year. The effectiveness of flooding is influenced by various factors such as flood intensity, amplitude, frequency, flow duration, and changes in river course and geometry [12]. Floods have been identified as one of the most severe and destructive disasters in recent years, amid various geoenvironmental risks and crises. To identify areas at risk of flooding, flood vulnerability mapping is crucial. This mapping is vital for flood-prone regions to ensure effective field management and preparedness [13]. Variables such as elevation, land use and land cover (LULC), rainfall, slope, proximity to rivers, topographic wetness index (TWI), and drainage density have significantly contributed to flooding in the study area [14]. To identify areas vulnerable to flooding in the Kulik river basin, researchers employed the frequency ratio (FR) model. This method analyzes factors that influence flooding, such as slope, elevation, rainfall patterns, drainage density, land cover types, TWI, population density, road network density, and household density. By analyzing these factors, the model can pinpoint areas with a higher likelihood of experiencing floods [15].

The variables that are most frequently used in environmental studies are hydrological variables (drainage density, river distance, TWI, and stream power index [SPI]), natural variables (elevation, slope, aspect, slope curvature, rainfall, lithology, and topographic position index), and factors related to human disturbance [16–18]. Planning and mitigation strategies for land use in floodplains must take into account flood risk accurately. This facilitates the availability of maps, allowing planners to emphasize the most risky regions geographically—a critical stage in the mitigation process [19, 20]. Many remote sensing and GIS techniques may be used to map and forecast the occurrence of flood frequency hazards (FFHs), despite the fact that predicting and preventing floods are challenging tasks [21–23]. Using GIS techniques to analyze remote sensing data, several datasets may be obtained to create maps of flash flood hazards and identify high-risk areas. AHP's knowledge-driven approach, which is based on GIS-weighted overlay analysis, has proven effective in forecasting various environmental conditions [24].

Based on the weights given to every aspect or indicator role in the flooding process, the AHP approach enhances understanding of each aspect or warning role in the flooding process [25]. The recommended plan examines the flood-prone area thoroughly using established approaches [26, 27]. The results provide useful figures that may be used in a variety of situations. As a result, the concept complements probability attribution methodologies nicely. When attempting to utilize this strategy, there are certain difficulties. We performed a flooding simulation using a similar drainage method to generalize the network due to a shortage of knowledge on the subterranean drainage system in the study area; while there were certain mistakes in the flooding simulation findings, they had little bearing on the assessment of the flood risk level [28].

Flood catastrophes are one of the most prevalent natural dangers as a result of changes in the climate and additional environmental issues. This is because the regularity with which climate change causes floods is a truth that the world has only recently become aware of. There isn't much time for warnings since local fast reaction teams find it difficult to estimate when the water level will reach its peak. Therefore, it is still difficult to forecast and regulate flash floods [29]. Having access to current, accurate information is crucial to preventing floods or at least lessening their effects. One type of important data is a hazard map that shows the probability of floods. Numerous studies have used soil parameters, imagery from satellites, data-estimated LULC, climatic variables, and geomorphic and physical watershed features to evaluate and predict flood risk. This is done to support flood catastrophe mitigation that is both effective and sustainable [8]. The GIS approach combines and analyzes enormous amounts of geographical data to anticipate and locate additional water supplies [24]. The criteria are merged into numerous subcriteria and a multilevel hierarchical structure using this technique. Using this multicriteria decision-making approach, several prediction tests resulted in a hierarchical ordering criteria-based solution to tough choice analysis issues [30–32]. The input dataset for the model includes information on elevation, slope, SPI, TWI, shape, density of drainage depressive disorders, runoff, distance to river, and precipitation. Pakistan and other arid to semiarid areas receive varying quantities of rainfall throughout varying time periods. Furthermore, their summers are scorching to extremely hot, while their winters are mild to moderate [33]. As a result, there are rare flash floods that can inflict damage to roadways, dams, lives of individuals, and properties [34]. The damage from the catastrophic floods that hit the Swat area in 2010 and 2022 has been projected to reach RS.68 billion [35].

At a 2.8% annual growth rate, Pakistan's population, which now stands at about 220 million, is predicted to increase to 250 million by 2025. Nearly 19 major floods have occurred in Pakistan during the past 60 years, flooding a range of 594,700 km^2, impacting 166,075 villages, and initiating cumulative immediate damages of nearly $30 billion. 10,668 persons lost their lives as a result of these floods [36]. Floods are an inevitable part of nature, but with careful planning and risk-reduction techniques, the likelihood may be decreased. Identifying flood risk areas and implementing critical risk reduction measures, both structural and nonstructural, have been shown in several studies to be beneficial in reducing flood damage to a level that is acceptable [37, 38]. Many models are used by researchers to study flood susceptibility. Wang et al. claim that insufficient data usually cause standard flood risk mapping approaches to have a restricted reach [39]. Data collection is necessary for conventional operations, but it can be costly, time-consuming, and inadequate at the individual or regional level, especially in developing countries. However, highly developed dynamic techniques such as remote sensing and GIS may offer a range of data for forecasting, flood zoning, and risk management. Given that natural disasters are spatially based, multidimensional events, GISs are particularly valuable tools for this kind of research since they can handle large amounts of spatial data, which are necessary for flood modeling [38].

Creating maps that highlight flood hazards is crucial for devising evacuation plans in areas prone to flooding. GIS and remote sensing techniques are used in extensive research to identify, evaluate, and map communities that are vulnerable to floods and places that are in danger of flooding [40, 41]. This is primarily accomplished by overlaying the identified factors that trigger floods onto topographic and hydrological data, enabling the visualization of potential flood zones [42, 43]. Data analysis aids in locating low-risk flood-prone locations for evacuation centers. Accessibility, amenities, and population density are among the factors taken into account. The research found the best centers based on capacity, accessibility to hospitals, and highways using GIS-based assessment. By weighing the requirements of impacted people and reducing flood risks, this method helps decision-makers select appropriate evacuation centers [44]. The flood-triggering components and their spatial distribution serve as the basis for making such judgments once again [45]. Finding safe pathways is essential to flood evacuation strategy that works. As seen by actual events such as Hurricane Katrina in 2005 in New Orleans, Louisiana, GIS-based network analysis is useful in identifying the best evacuation routes [46]. In order to create routes that minimize trip time, this method involves looking at transportation networks, maps showing flood hazards, and relevant data. In this paradigm, mapping the possible dangers connected with each route depends heavily on the elements that cause floods [47].

The Swabi district in Pakistan has experienced several significant flood events in recent history. Notably, the floods in 2010 and 2013 stand out due to their severe impact on the local population and infrastructure. The 2010 floods in Pakistan were among the worst in the country's history, affecting the Swabi district severely. Heavy monsoon rains led to widespread flooding, resulting in the displacement of thousands of people, destruction of homes, and significant agricultural losses. In 2013, heavy monsoon rains again caused severe flooding in Swabi. The floods led to significant damage to infrastructure, homes, and agricultural land. Efforts to mitigate the effects included emergency responses from local and international aid organizations [48–50].

In many nations, flooding continues to be an annual unwelcome guest. It frequently manifests as a disaster that has a severe impact on both the lives of those impacted and the local economy. When making judgments on essential emergency measures, even seasoned administrators and engineers are sometimes taken by surprise by the rapidly changing circumstances. Floods directly and negatively impact the systems that support agricultural and industrial output, services, and marketing. Floods impede the movement of goods and services into the communities they touch by destroying or seriously damaging the physical infrastructure [51]. The main method used by flash flood management strategies to lower the danger of flooding is to simulate the topography, hydrology, and climate of a basin. It is preferable to complete risk analysis and these mapping methods as quickly as is practical. The aim of this project is to create a framework based on remote sensing to detect areas that are vulnerable to flooding and to mitigate the effects of floods by reducing or controlling them within the study area. The current study uses geoinformation techniques and a multicriteria decision analysis AHP model to analyze the risk of flooding and sensitivity mapping in the Swabi region for environmentally friendly agricultural and urban areas and development of infrastructure. The following research questions are the focus of the study that is being offered to provide better flood risk analysis solutions by creating a categorized framework.

- Utilizing AHP and ArcGIS to create an urban flood risk indicator (UFRI).
- In Pakistan's Swabi district, identify possible flood zones using thematic maps.
- Mapping the hazard of flooding to enhance flood control methods and lessen socioeconomic losses.
- To assess the road network's performance during flood situations and employ network analysis methodologies to establish evacuation routes that are both efficient and safe.
- To promote the creation of successful evacuation plans and disaster preparedness measures in the area, we will

offer practical advice to legislators, urban planners, and emergency responders.

2. Materials and Methods

2.1. Study Area. Swabi district, as shown in Figure 1 situated in the Khyber Pakhtunkhwa province of Pakistan, covers an area of approximately 1543 square kilometers and is positioned between approximately 34.12° north latitude and 72.47° east longitude. As of September 2021, it had an estimated population of around 1.55 million. There are four different seasons in the district's global climate: spring, summer, autumn, and winter. Summers (May to September) are hot and dry, with regular highs of over 30°C (86°F) and rare highs of over 40°C (104°F). Winters (November to February) are cold, with temperatures dropping to near freezing, especially in December and January. Spring and autumn offer milder and more pleasant conditions, making them optimal for outdoor activities and fieldwork. Swabi district presents a diverse range of resources and features, including its role as an agricultural region, the presence of educational institutions like the Ghulam Ishaq Khan Institute, cultural heritage sites such as the Kalu Khan Fort and the Takht-i-Bahi Buddhist Monastery, and the influence of the Indus and Kabul Rivers on water resources and agriculture. The district's soil types—alluvial, loamy, clay, and sandy—further contribute to its research potential in agriculture and land use. Overall, Swabi district provides a rich and varied landscape for multidisciplinary studies in agriculture, climate, culture, and rural development.

2.2. Collecting Data and Model Construction. The factors of variable analysis, topography, and morphometric analysis that went into producing the AHP-GIS-based maps are covered in this section. We have to remember that the kind of flood has a big impact on the factors that are part of the multiparametric AHP model. The variables utilized in the vulnerability analysis are listed in Table 1, along with the appropriate risk categories and relative significance levels. One of the most important steps in multicriteria decision analysis is selecting the criteria using a geographical reference. The AHP uses real facts and objective evaluations to select projects, plans, strategies, or alternatives according to numerical standards. According to Saaty [30], there are two types of decisions: analytical and intuitive. Making analytical judgments requires forming an opinion, contrasting options, or assessing each option in the context of an ideal. On the other hand, choices made intuitively are entirely subjective and cannot be supported by reason. The AHP demonstrates the superiority of the latter option. Consequently, the factors assessed in this research were selected according to their significance in causing floods within the study region. The TWI, soil types, yearly rainfall distribution, elevation and inclination, and land-use statistics are entirely taken into explanation [52]. After data from the NASA Satellite Data and Environmental Systems Research Institute's (Esri) land use cover are added as shown in Table 2, ArcGIS is used for analysis. The hazard was then evaluated and classified using the USGS's techniques to develop the Swabi district risk of flooding map. The final flood risk map is produced by utilizing AHP to locate the weighted overlay—which is depicted in Figure 2.

2.3. Elevation and Slope. The drainage via a certain outlet or location, whether surface or subsurface, is determined by the slope. The interaction of geology, framework, soil type, and drainage is characterized by the combination of slope angles, which are determined by the form of the slope. While water buildup is a concern on flatter surfaces, surface runoff is a major problem on steeper slopes. Conversely, pluvial floods would be more likely to occur in small depressions or digital elevation model (DEM) cells that are lower than the surrounding ones. This emphasizes how important it is to comprehend how ground elevation and flood danger may be related [24] Using slope-generating tools and the ArcGIS DEM, this study created a slope map. A DEM for the research region was made available via the Earth Data Search website (https://search.earthdata.nasa.gov/search). Slope influences the likelihood of catastrophic floods and is correlated with runoff velocity. Consequently, on slopes with high slopes, the rate of water penetration will be substantially slower. Water flow and velocity will be maximized as a result. Because water builds up gradually as it runs down a slope from high to low and because floods typically only occur in the lower region, the length of the slope has an impact on both the likelihood of flooding and the actual occurrence of flooding. Elevation and the risk of flooding are related. It appears that cells are more vulnerable to floods in lower elevation areas [17]. With a range of 254–2231 m, the elevation was further divided into five groups. The natural break technique was used to split the research region into five groups, with a slope range of 0–205.3. "0–11.27," "11.28–28.18," "28.19–47.5," "47.51–70.84," and "> 70.85" are the percentages. Figures 3(a), 3(b), 3(c), and 3(d) display the Swabi district's elevation and slope maps, both original and revised.

2.4. Types of Land Usage. The amount of rainfall and runoff generated is affected by the various land-use groupings. Land cover influences how frequently floods occur due to vegetation's ability to absorb rainwater. The ESRI land cover dataset https://www.esri.com was used to determine the land cover because high-resolution land use data for the study's area were unavailable. Considering the plant cover, the land uses were classified into seven distinct categories. Figure 4 depicts seven different types of land uses as follows: (i) water bodies, (ii) trees, (iii) snow/ice, (iv) crops, (v) barren ground, (vi) built area, and (vii) rang land.

2.5. Distance to River. By measuring the distance between a place and adjacent rivers, one may determine the level of risk that the location presents. The D8 technique was utilized to extract the streams, and the STRAHLER methodology—which gives an order of one to any links lacking tributaries in the STRAHLER technique—was used to

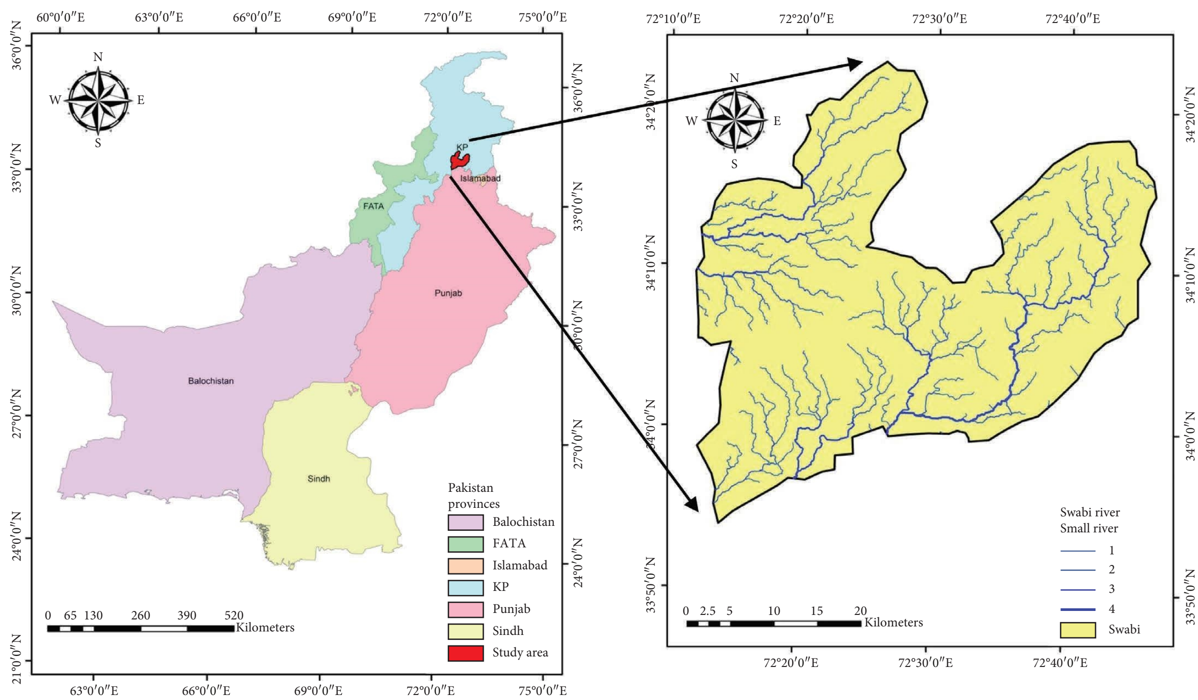


Figure 1: Map showing the research area’s location.

recognize the various levels within the recovered rivers [30]. Flooding was less likely in distant cells along some streams than in neighboring ones. Figure 5 depicts the classification of distances from streams into five risk zones.

2.6. TWI. The TWI measures the ability of the water to collect; a high value indicates greater water because of a minimal slope, as seen in Figure 6. The infiltration brought about by rainfall-runoff generation is influenced by the hydrolithological formations.

2.7. Types of Soil and Precipitation. Poor drainage and rapid water absorption characterize soils that are sandy. Flooding is greatly impacted by this kind of soil. Clayey soils retain water for a longer period and are less permeable than sandy soils. This indicates that places with clayey soil are more likely to flood [27]. When measurements are unavailable, the soil’s appearance and texture might be used to estimate its moisture content. As a point of contact between the land cover and the atmosphere of the earth, it divides precipitation into two categories: runoff and groundwater storage. Reduced soil erosion, slope stabilization, and crop and plant development all depend on the rise in soil moisture levels that results from enough precipitation falling to make up for losses to streams and groundwater. The soil types in an area are generally important because they control the quantity of water that may percolate into the earth and, therefore, the amount of water that flows. Soils’ ability to act as sponges and absorb water is greatly influenced by their structure and infiltration capability. The capacities of different kinds of soil differ. Greater surface runoff from less soil infiltration capacity raises the risk of floods. Floods are caused by runoff from sloping terrain that travels downslope at a pace greater than the soil that can absorb it. Figure 7 shows the classified cover of soil and rainfall map for the research region.

2.8. The NDVI and Curvature. The contour and curvature of the slope, or its profile, are shown by the curvature attribute. A surface’s concavity or convexity is determined by its curvature. Its second derivative gives the curvature of the surface. The output of the curvature function is shown in Figure 8. The categories were created by combining first-hand information from earlier flood study with scholarly literature [27]. To standardize the classes, a three-grade system was employed. Positive, entire numbers were allocated to each class.

The density and health of vegetation are assessed using the normalized difference vegetation index (NDVI). It computes photosynthetic activity using data from satellites and displays the amount of photosynthetic activity in a specific region. The NDVI is calculated using the visible and near-infrared light reflectance that satellite sensors have collected.

A number closer to +1 indicates high vegetation density and health, while a value closer to −1 indicates low vegetation density and health. NDVI values range from −1 to +1. NDVI readings are frequently used to track drought, vegetation growth, and other environmental conditions that may have an impact on the health of plants. Figure 8 shows the outcomes of the curvature function. Academic literature and first-hand experience from past flood studies were used to construct the categories.

Table 1: Flood susceptibility evaluation ranges for both main and secondary factors.

Flood criteria's	Unit	Class	Class ranges/flood probability	Class ratings	Percentage weight
TWI	Level	2.6–3.3	Very low	1	5
		3.3–8.8	Low	2	
		8.8–14.7	Moderate	3	
		14.7–20.4	High	4	
		20.4–26	Very high	5	
Slope	%	0–13.80	Very high	5	16
		13.80–27.45	High	4	
		26.45–41.15	Moderate	3	
		41.15–61.30	Low	2	
		> 61.30	Very low	1	
Elevation	Meter	710–1595	Very low	1	13
		1595–2445	Low	2	
		2445–3316	Moderate	3	
		3316–4118	High	4	
		4118–5853	Very low	5	
Distance from rivers	Meter	0–142	Very high	5	23
		142–291	High	4	
		291–432	Moderate	3	
		432–572	Low	2	
		572–725	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	−0.166–0.03	Very high	5	3
		0.03–0.047	High	4	
		0.047–0.129	Moderate	3	
		0.129–0.219	Low	2	
		0.219–0.540	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	

2.9. Data Acquisition. Source of the data acquired is shown in Table 2.

2.10. Analytical Hierarchical Process (AHP). AHP is a crucial decision-making method used in a wide range of fields, including banking, business, politics, education, and engineering. As the most popular multicriteria decision-making technique (MCDM), Saaty (1980) created the AHP, which takes its cues from Myers and Alpert (1968). Because of the AHP's many advantages when making important judgments, several scholars have reproduced it [20]. The AHP is a mathematical model that can be easily modified to balance both qualitative and quantitative aspects while taking the priorities of the user or group into account. An arbitrary index value is chosen in order to compute the compliance rate once the comparison matrix has been converted into a priority vector. The ultimate state of the choice is represented by the greatest level, followed by its criteria and the level with the least desirable possibilities. Decisions can be taken at the local level. For pairwise comparisons to be consistent, precise definitions of each discrete criterion and the overall number of criteria are essential. They have to be

Table 2: Source of the data acquired.

S. no.	Data class	Explanation	Basis
1	DEM	30-meter-sized cells in the ASTER global digital elevation model	NASA's Earth Data Search [53]
2	Soil data	An electronic version of the world's digital soil map in 5 × 5 ESRI shapefile format	United Nations Food and Agriculture Organization, FAO Map Catalogu [54]
3	LULC data	10-m LULC Sentinel-2	ArcGIS Living Atlas Utilisation, Esri Land Cover [55]
4	NDVI data	Landsat 8–9 OLI/TIRS C2 L1; Landsat Collection 2 Level-1	USGS Earth Explorer. American Geological Survey [56]
5	Rainfall data	High-resolution monthly precipitation datasets from CRU TS with a resolution of $0.5 \times 0.5°$	UAE Data from CRU's Climate Research Unit [57]

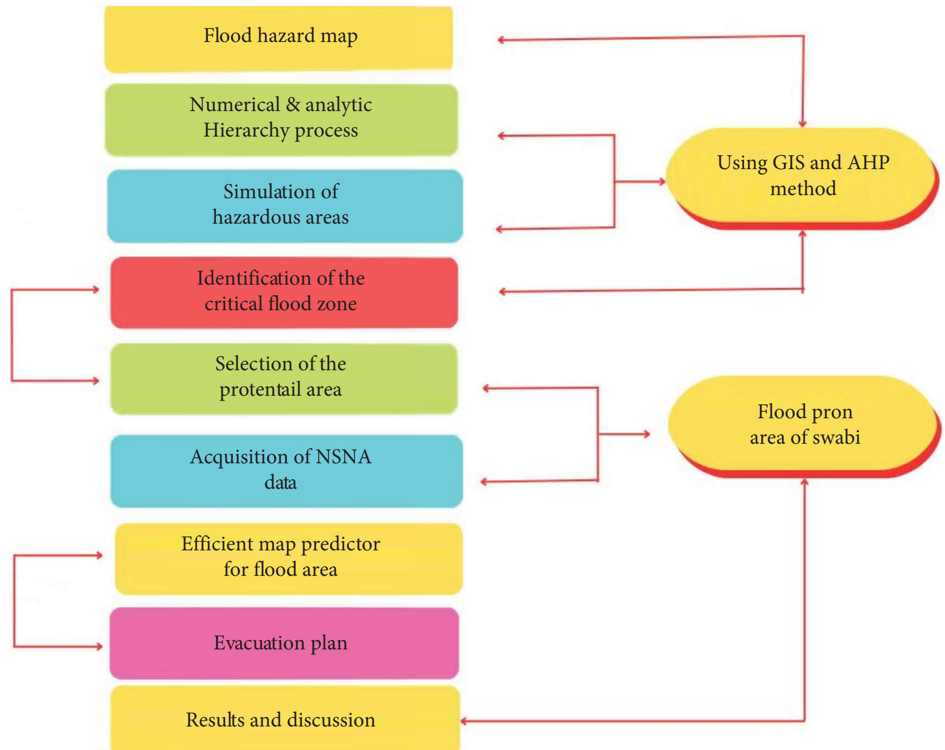


Figure 2: The current study's methodological structure.

grouped according to commonalities in order to make sense of the criteria. AHP may be used to a range of criteria.

To determine the relative weights of the relevant components, an AHP pairwise comparison matrix was employed. Relative weights are assigned to the criterion based on their priority. There is a relative significance scale with a range of 1–9, with 9 being the most significant component.

Equation (1) was utilized to generate the final flood risk zone map, which was obtained by multiplying the weights by the individual element's rate.

$$H = \sum_{1}^{n} w_i x_i, \tag{1}$$

where n is the number of items, $w(i)$ is the amount of weight of each component, and $x(i)$ is each element's rating for every factor. H represents the flood hazard level. The weighting factors of the selected flood risk components in the AHP approach were theoretically revealed by the matrix of pairwise comparisons displayed in the subsequent equation.

$$A = [a_{ij}] = \begin{pmatrix} 1 & a_{ij} \ldots & a_{1n} \\ \frac{1}{a_{ij}} & 1 & a_{2n} \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & 1 \end{pmatrix}. \tag{2}$$

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 pairwise assessment matrix is shown in Table 5 using a 9×9 matrix with diagonal elements equal to 1. The ratings are calculated by summing the values of each column and each row. For example, rainfall intensity is ranked one in the category because it is far more significant than land use. Row discusses how important land usage is. The ArcGIS-weighted overlay function may be utilized to determine priorities and assign values based on a decision matrix. The resulting map can be seen as illustrated in Figure 9.

Equation (3) is used to determine the consistency index (CI).

$$CI = \frac{\lambda_{\max} - n}{n - 1}, \tag{3}$$

where the number of classes is indicated by n.

A pairwise comparison matrix, called the consistency ratio (CR), is computed using the following equation:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}, \tag{4}$$

where RI provides a random CI.

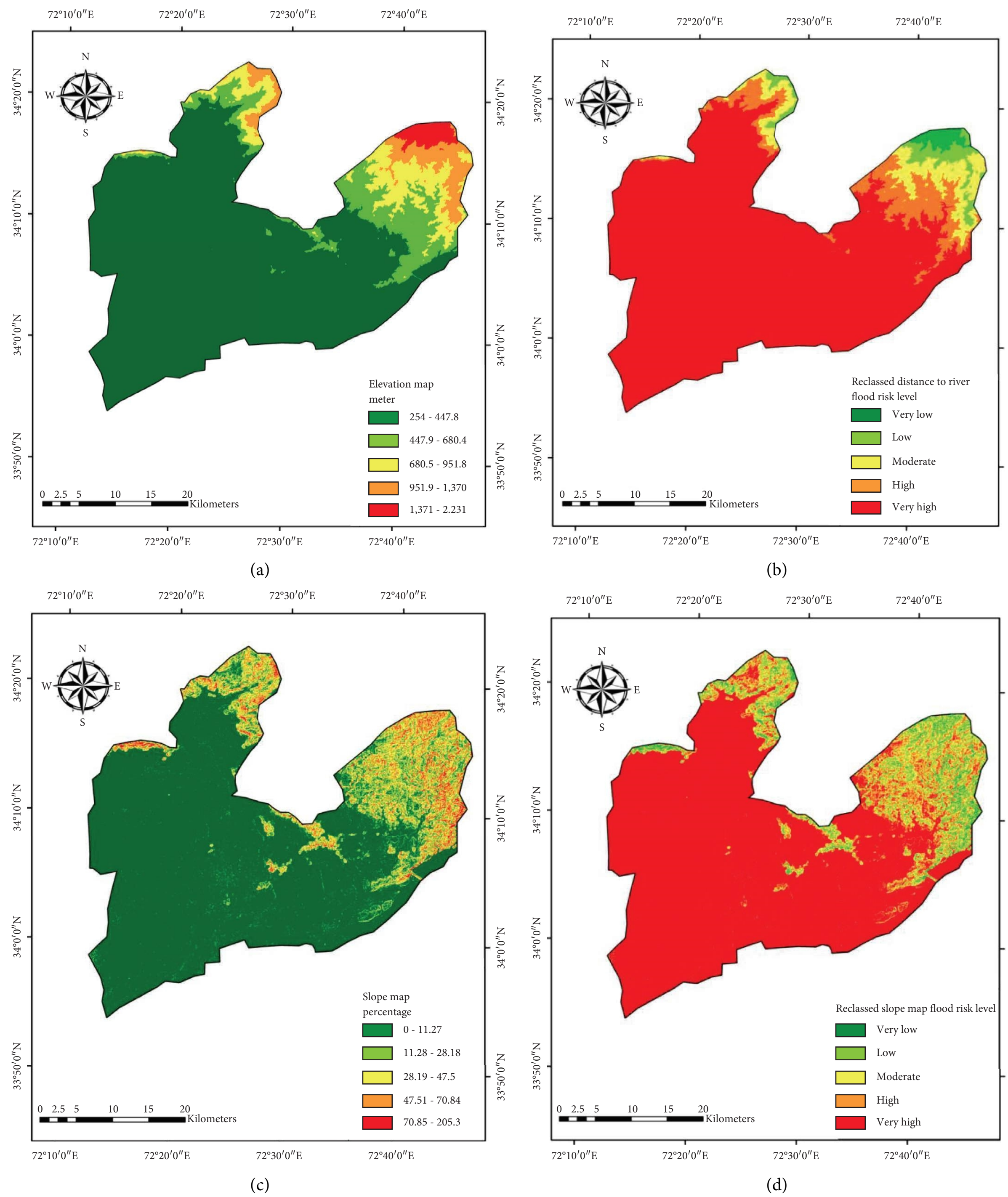
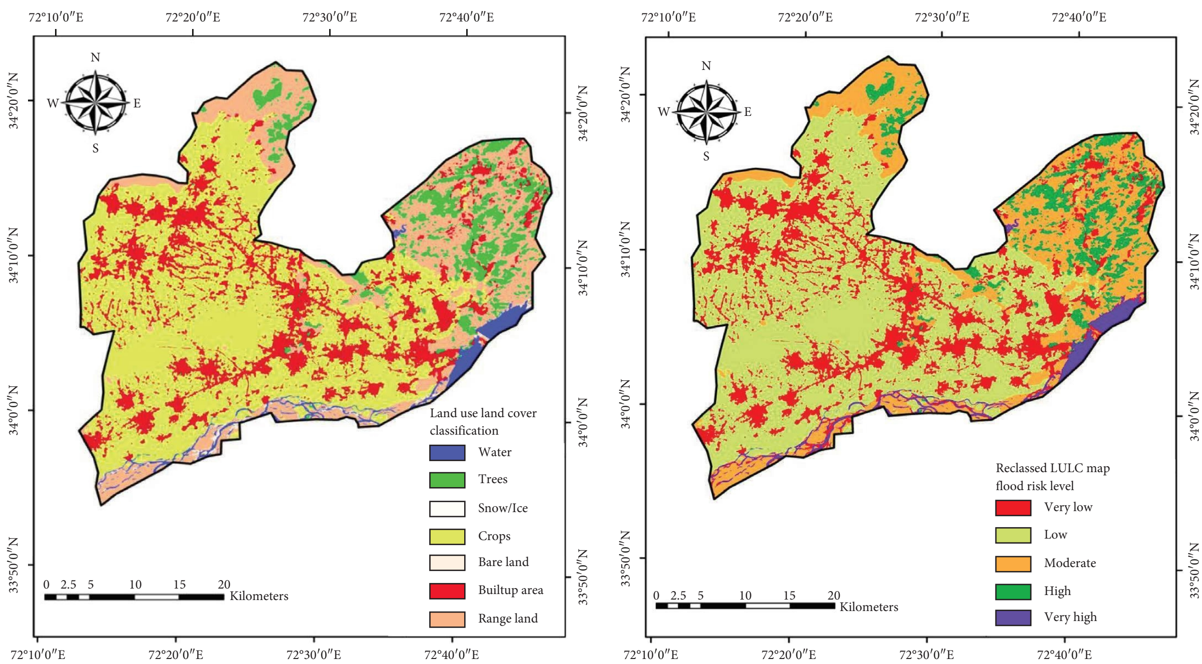


Figure 3: (a) Elevation map. (b) Reclass of elevation map. (c) Slope map. (d) Reclass of slope map.

A coefficient of determination (CR) of less than 0.10 indicates that a comparison matrix has satisfactory consistency. The decision-making process is repeated until consistency is attained if this is not the case. CR = 0.00 is the ideal number for consistency. With a CR of 5%, the AHP calculation in this study is deemed genuine because it is within the permissible range (CR < 10%). Although AHP is frequently used to create trustworthy hazard maps, mistakes may occur since it depends on expert judgment to determine the criteria weight. In order to address this, sensitivity analysis was conducted to assess the impacts of a 5% change in criteria weights using the one-at-a-time (OAT) approach. Table 1 displays the results.

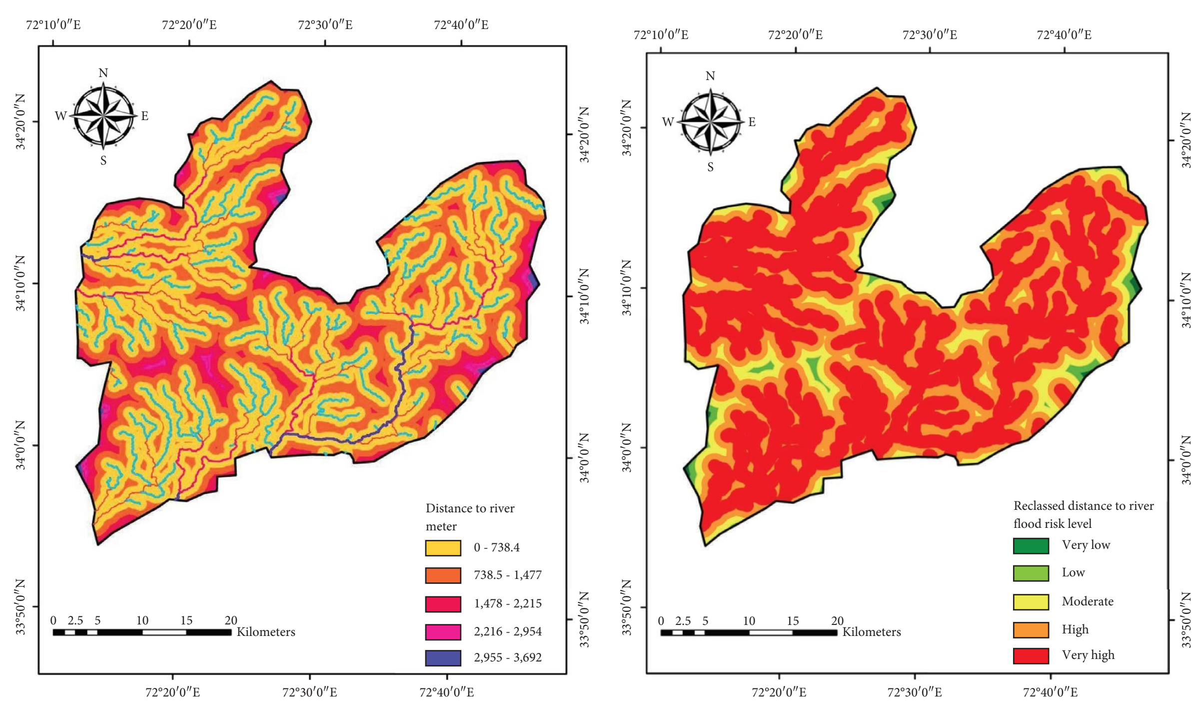
$$W(\mathrm{Cm}, \mathrm{pc}) = W(\mathrm{Cm}, 0) + W(\mathrm{Cm}, 0)\mathrm{xp}. \tag{5}$$

The major criteria's weight is denoted by $W(\mathrm{Cm}, 0)$, the degree of the percent change is indicated by pc, and Cm, in the event of a base run, denotes the threshold. Equations (6)



(a) (b)

Figure 4: (a) LULC map. (b) Reclass of LULC map.

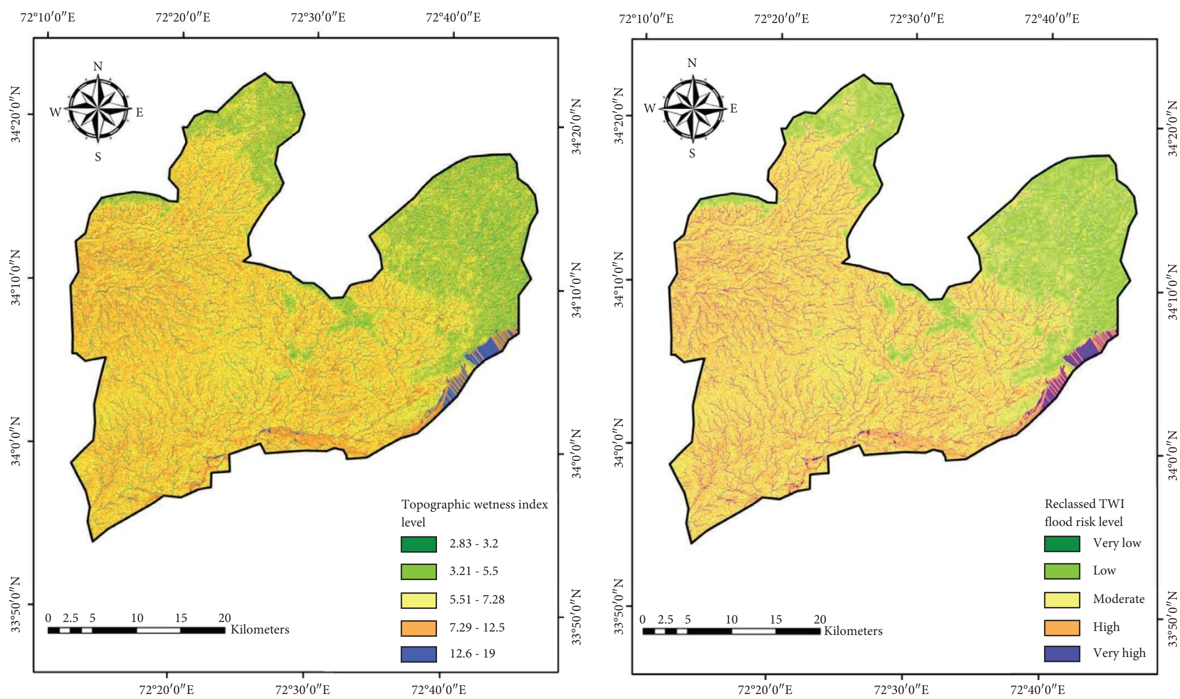


(a) (b)

Figure 5: (a) Distance to river map. (b) Reclass of distance to river map.

and (7) were utilized to modify the other criterion's weights proportionately at every percent change level; hence, the total of all the criteria weights must equal one.

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



(a) (b)

Figure 6: (a) TWI map. (b) Reclass of TWI map.

where $W(\text{Ci}, \text{pc})$ represents the ith criteria ci's weight at a certain percent change level.

$$W(\text{Ci}, \text{pc}) = (1 - W(\text{Cm}, \text{pc})x \frac{W(\text{Ci}, 0)}{(1 - \text{W}(\text{Cm}, 0))}. \quad (7)$$

There are n criteria in total, and RPC min and RPC max are the lowest and maximum values of the RCP, respectively.

The pairwise comparison matrix for each parameter is displayed in Table 5.

3. Results

According to the study's findings, the elevation, gradient, precipitation, and distance to a river had the most impact on the area's flooding phenomenon. Lower altitudes were more prone to floods, according to the elevation chart. The reason for this is that low-lying places are more prone to be submerged during periods of intense precipitation because water naturally flows to lower altitudes. According to the slope map, flash floods were more common in places with steeper slopes. According to the rainfall statistics, the research region saw heavy rainfall during the monsoon season, which is one of the main causes of the flooding problem. Figure 9 also makes it clear that places close to rivers are more likely to flood.

It was discovered that other factors including curvature, NDVI, TWI, LULC, and soil type had comparatively less of an effect on floods. The concave areas were more likely to flood since they had a tendency to retain water, according to the curvature map. According to the NDVI map, areas with negative NDVI values—that is, areas with little to no vegetation and nearly bare land—are more vulnerable to flooding since there are no obstacles in the path of the water. As a result, the flood will result in severe landslides and massive soil erosion. High TWI readings indicate that a region has the potential to retain water, which raises the danger of flooding. Similar to this, surfaces that are covered in plant and water bodies close to rivers are more likely to flood than other types of land cover. This is known as land use and land cover, or LULC. Because clayey soil drains more slowly than other soil types, it can retain water for longer periods of time, which raises the danger of flooding in locations with clayey soil.

3.1. Factors Influencing the Risk of Flooding Evaluation. The flood risks map was created using nine factors: the type of soil, NDVI, TWI, LULC, elevation, slope, rainfall, curvature, and distance to the river. The AHP treatment was performed for them. It was possible to acquire the CR ($\text{CR} = 5.4\% < 10\%$) within reasonable bounds. Table 1 presents the suggested ratings and weights for the nine aforementioned criteria. The five classifications of flood threat levels are very low, low, moderate, high, and very high, in ascending order. In contrast to NDVI, TWI, LULC, curvature, and soil type, GIS-AHP assigned large weights to rainfall, slope, elevation, and distance to rivers. For every parameter, a new flood danger map was created. Upon summing them up, it was discovered that 0.0071% of the entire region is subject to extremely low flood danger, 49.4127% to high flood risk, 46.7045% to moderate flood risk, and 3.8755% to low flood risk. Table 6 shows how the area is classified into several risk zones.

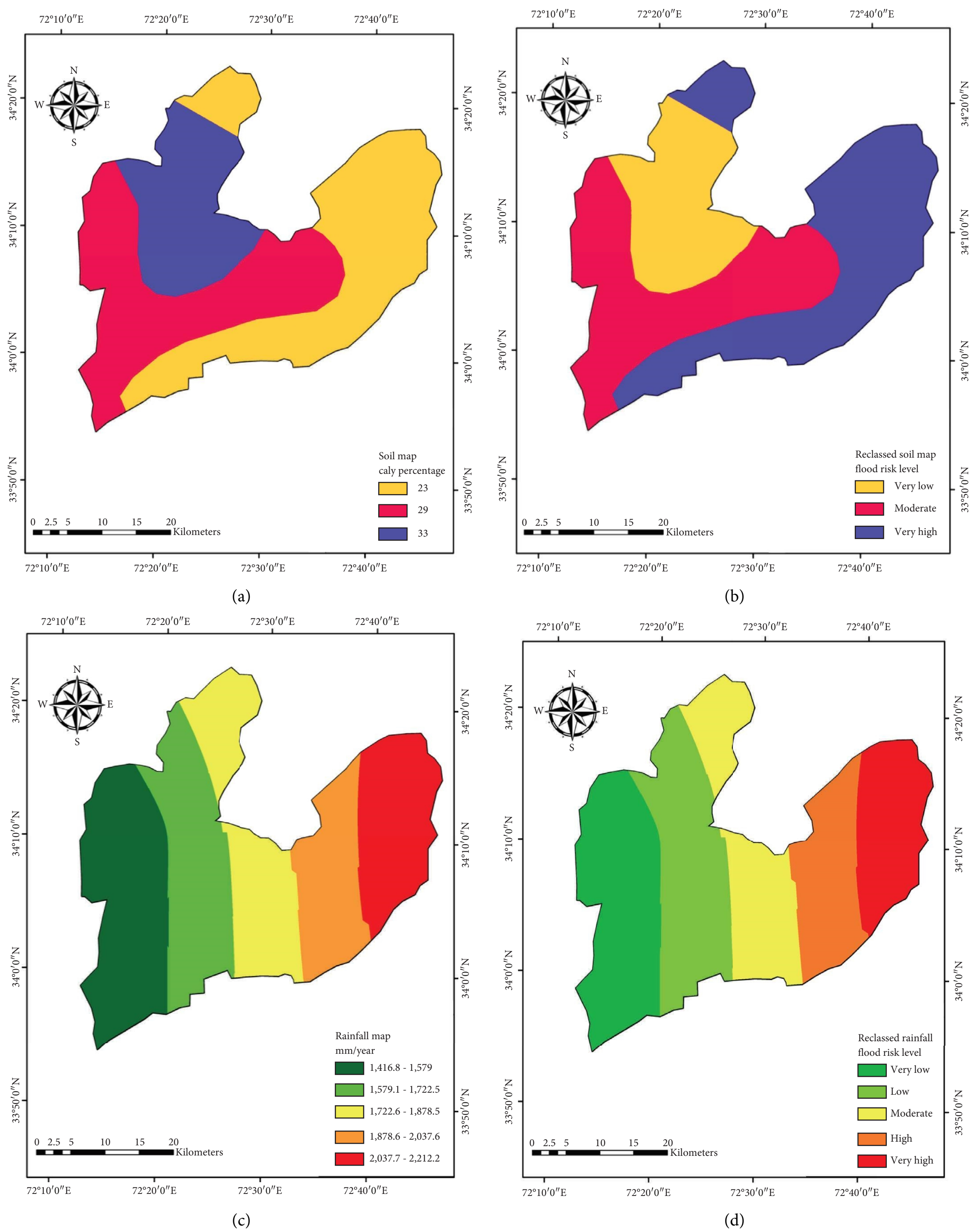


Figure 7: (a) Soil map. (b) Reclass of soil map. (c) Rainfall map. (d) Reclass of rainfall map.

3.2. Flood Hazard Map. The flood hazard assessment methods discussed in previous sections were used to create flood hazard maps. The method used to classify the maps was the standard deviation technique. For the purpose of the flood hazard assessment, the study region is split into four categories, as shown in Figure 10, which are "very low," "low," "moderate," and "high" flood risk zones. The study area's west and southwest are home to the Swabi district's most populated regions, which are inside the high flood risk zone. There is a high or moderate risk of flooding in the middle of the map. Flooding is either low or moderately likely to occur on the northeast and northwest sides.

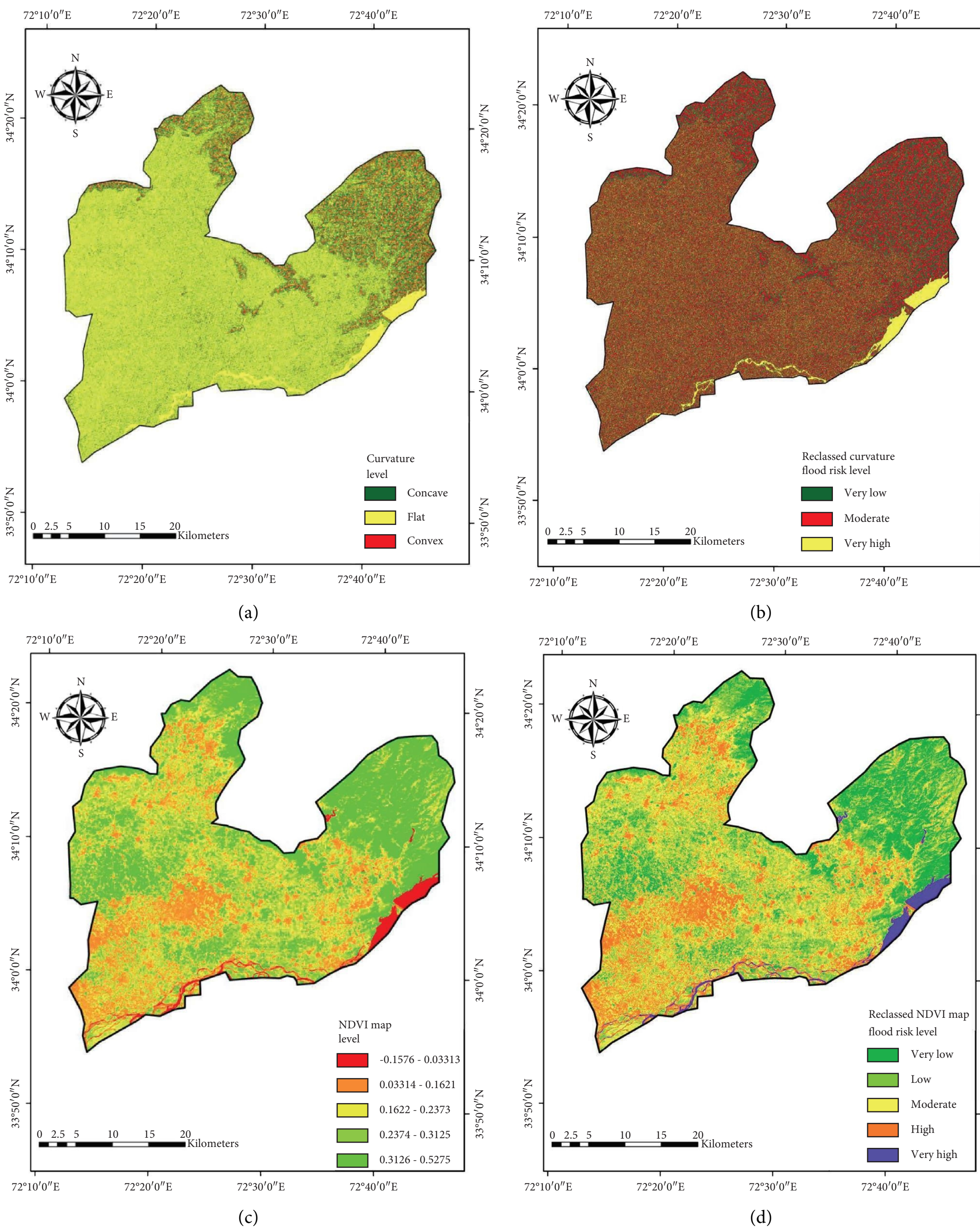


Figure 8: (a) Curvature map. (b) Reclass of curvature map. (c) NDVI map. (d) Reclass of NDVI map.

Rainfall is the primary element affecting the likelihood of floods. One important aspect of the damage caused by floods is the downstream water flow speed. Since most floods in the study area are caused by gravity, the slope and elevation of the land have a significant influence on the water's velocity and direction as it moves through the area. As rainstorms become more frequent and the stormwater gains velocity down the slope, the top speed increases. The advantage of the approaches and procedures used to create the danger map is that it is comprehensive. The generated hazard map is straightforward and simple to comprehend. It works best when applied in study area regions when primary data are not accessible. The computed area classification into flood risk zones, ranging from high to low, is displayed in Tables 6 and 7.

Table 6 indicates that high flood risk accounts for almost 49.4227% of the region. In some regions, deliberate development should be done to reduce the negative consequences of floods. All encroachments ought to be removed, particularly those that are close to the riverbank. Placement of

Table 3: The basic scale for comparing two things pairwise.

Intensity	Definition
1	Equal significance
2	Comparative significance
3	Modest significance
4	Relative significance
5	Great significance
6	Comparative significance
7	Extremely important
8	Relative importance
9	Extraordinary significance

a flood protection wall where it will lessen the danger is appropriate.

3.3. Evacuation Areas and Routes. Figure 10 displays the identification of secure zones (dark green and light green), moderate-risk areas (yellow), and high-risk zones (blue) on the flood susceptibility map. The map with high flood vulnerability is divided into four zones according to this categorization. Evacuation centers have been selected in 130 communities (green pins in Figure 11) within secure regions to provide rapid shelter for villages in high-risk locations. The analysis of evacuation routes takes into account two scenarios: (1) Despite modest floods, the road network remains operational, with travel costs optimized based on available roadways. (2) Some road parts become waterlogged and useless and adapt the model for impacted routes by assigning submerged sections a speed of 0 km/h.

By rerouting evacuees onto flood-free pathways, this minimizes travel hazards and prioritizes their safety. Rather than utilizing a flood depth method to compute allowed driving speeds, this experiment takes a cautious approach, allocating 0 km/h for flooded roads in order to prioritize safety and avoid potentially problematic routes. When the research area is covered with a historical flood map (Figure 11), it becomes evident which road portions are prone to flooding, which leads to higher travel expenses and the need to choose other routes. Finding effective and safe evacuation routes for communities located in high-risk areas is the aim of our road network study, which is a crucial component of disaster response and evacuation planning.

The recommended evacuation routes may need to be further modified and verified based on real-time flood scenarios, taking into consideration the accuracy and caliber of available flood and road network data, given the dynamic nature of floods and the requirement for adaptable and flexible evacuation plans. A planned evacuation path for people living in a flooded region that leads to the closest evacuation site is shown in Figure 12. Evacuation route assessments in flood and normal conditions offer important information for creating adaptable and robust evacuation strategies. This emphasizes the transformational effect that floods may have on evacuation operations by taking into account the dynamic stages of flood disasters, each of which requires unique evacuation strategies.

In flood scenarios, larger standard deviations and maximum travel time values indicate more unpredictability and uncertainty. This underlines how crucial it is to establish evacuation routes taking into account both typical and flood circumstances. Teams in charge of emergency management should plan ahead for any delays, find detours, and distribute resources in a proactive manner. Campaigns for public awareness should inform locals about evacuation routes and readiness. Comprehending these fluctuations enables policymakers to devise enhanced approaches for overseeing and alleviating the consequences of flood incidents on evacuation endeavors.

3.4. Restrictions Associated With the Approach and Suggestion. Despite certain limitations related to the quality of the medium-resolution image (SRTM 30 m) used in this study and the subjectivity in defining the coastlines, the flood susceptibility map of the Swabi district, Khyber Pakhtunkhwa (KPK) watershed, continues to provide valuable support for planning, development, and decision-making by administrative authorities and decentralized territorial communities with jurisdiction. As a result of the operation, the quality of life for residents in this highly populated area—where environmental management and sanitation are real bottlenecks—will undoubtedly improve. The map was really created using field observations. Future research must take these discrepancies into account and, at the absolute least, test out more effective models that could lower error margins. In account of global change, this is the first attempt of its kind to evaluate the Swabi district KPK watershed's susceptibility to floods using a wide range of environmental data (SRTM, rainfall, geology, and so on). These findings provide a first step toward resolving the flooding issues in the Swabi region of Pakistan. They will also make it possible for all other development players, the government, and decentralized territorial communities to coordinate their activities before, during, and after the floods. From a scientific standpoint, this research will assist us in determining and evaluating the variables affecting the risk of flooding and improve our knowledge of the ecology of the KPK watershed in the Swabi district.

4. Discussion

The study's findings demonstrated how well the GIS and AHP tools worked to determine the likelihood of urban floods in Pakistan's Swabi district's KPK watershed. With the application of the AHP approach, it was determined that drainage and land use had the greatest effects on flood risk. GIS technologies were used to display the results, which included the creation of flood risk maps. The study also found that relatively few individuals in the KPK watershed had taken any safeguards, despite the fact that the majority of respondents thought there was a serious risk of flooding. The GIS maps showed that areas most vulnerable to flooding were those that were low-lying and had a lot of impermeable surfaces, such as roads and houses. Approximately 41% of

Table 4: The present study's decision matrix.

Class	Category	Importance	Rank	Positive	Negative
1)	Rainfall	27.7%	1	12.3%	12.3%
2)	Distance to river	23.8%	2	11.8%	11.8%
3)	Slope	15.7%	3	5.3%	5.3%
4)	Elevation	12.91%	4	3.7%	3.7%
5)	LULC	8.92%	5	3.5%	3.5%
6)	TWI	4.01%	6	1.8%	1.8%
7)	NDVI	2.60%	7	1.1%	1.1%
8)	Soil type	2.72%	8	0.8%	0.8%
9)	Curvature	1.62%	9	0.8%	0.8%

Table 5: Table of priorities for every 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 entire research area is made up of the urban area. Six physical and anthropogenic factors impacting the watercourse have been shown to be the most relevant when strong storm events create large runoff that exceeds the drainage system's capacity. Flood activity was influenced by the height, slope, distance from open channel streams, and hydrolithology. Human-caused causes associated with floods included proximity to totally covered streams, land cover-created urban areas, and extra land uses. A map of flood hazards was created using the AHP approach and GIS. The probability that a flood will occur within a certain time frame is known as the flood hazard. With the current study, flood hazards in connection to return periods could not be evaluated [32].

Consequently, the possibility of flooding in a particular location was depicted on a flood susceptibility map that was made. Using the standard deviation technique, this map of the research area's possible flood threats was categorized into five hazard level classes: very low, low, moderate, high, and very high. As seen in Table 7, two risk zones encircle around 49% of the continent. Fast-moving streams drain a large portion of the Swabi fluvial systems, causing catastrophic but uncommon flash floods. Consequently, the study area's tiny drainage basins and catastrophic stream behavior have an impact on how floods happen. In most cases, runoff rises in the higher reaches of watersheds, increasing the likelihood that urban areas below may flood. The AHP technique improved the understanding of every component or indicator function in the flood procedure based on the weights assigned to it [25]. However, there might be bias in the processing and analysis of data if it is cross-referenced in a GIS at the same resolution, interpolated, and originates from numerous sources. These parameters need to be weighted and normalized in order to reduce bias and uncertainty in the outcome. The subjectivity involved in selecting the indicator weighting value based on arbitrary expert opinions is another factor contributing to the AHP approach's failure. Results from an integrated AHP and GIS method can often be sufficient [58]. It is difficult to develop a consistent technique for assessing urban flood risk due to the dynamic nature of the elements that influence it, including population size, building layout, and volume and intensity of rainfall. Depending on the subject of the research, we look at and evaluate a subset of important indicators. Since the weighting has a major influence on the final flood risk estimate, it should be estimated exactly and exhaustively even if it has a high degree of uncertainty. The challenges of carrying out rescue operations after natural disasters have been researched. In the future, urban flooding has to be investigated in-depth in order to develop scientific standards for urban emergency rescue systems [59].

The discussion on evacuation areas and routes emphasizes the vital importance of strategic planning for emergency response and evacuation in flood-prone regions. The

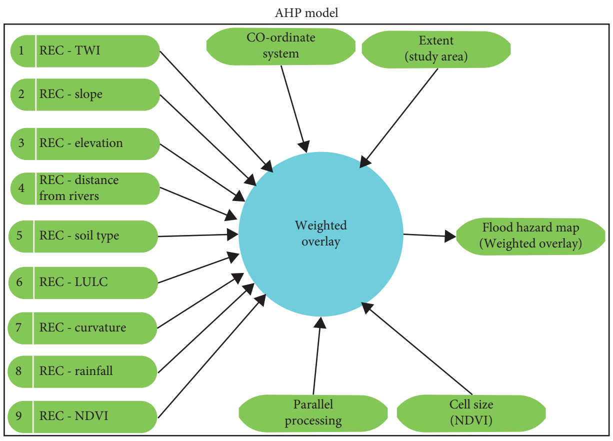


Figure 9: AHP model with every parameter set.

Table 6: Flood-prone locations are classified into groups.

Criteria (risk of flooding)	Area (ha)	Percentage (%)
High	72797.41	49.4127
Moderate	68807.54	46.7045
Low	5709.69	3.8755
Very low	10.41	0.0071
Total	148205.93	100

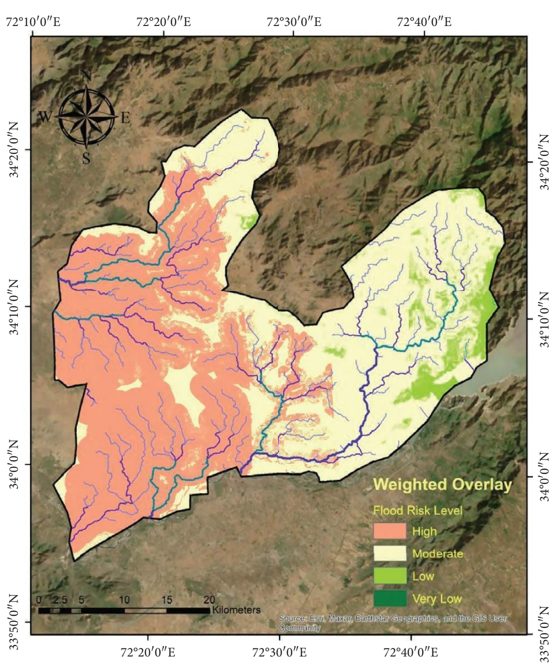


Figure 10: Map showing the research area's flood hazards derived using the AHP technique.

Table 7: Swabi's estimated flood-prone area.

Study area (district)	Total area (ha)	Region that has high danger (ha)
Swabi	148205.935389	72797.41

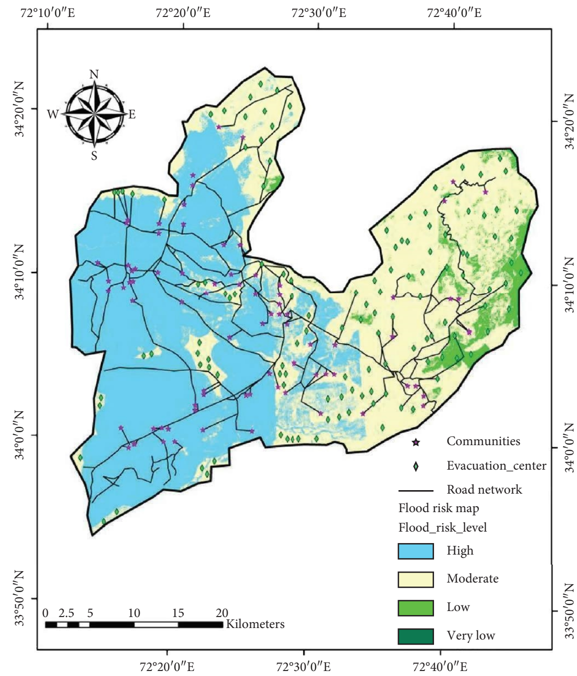
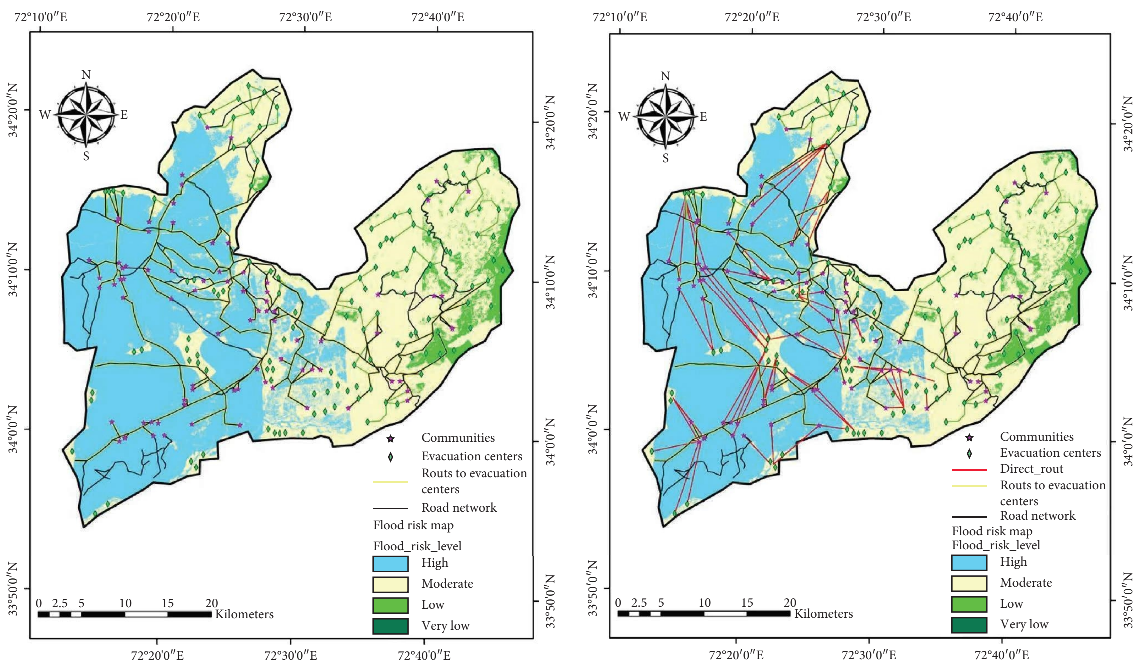


Figure 11: Areas classified as safe or at risk of flooding.

identification of secure, moderate-risk, and high-risk zones on the flood susceptibility map lays the groundwork for targeted evacuation efforts. By designating evacuation centers in secure areas, immediate refuge is provided for villages in high-risk zones, recognizing the vulnerability of these areas to potential flood disasters. The analysis of evacuation routes through the road network addresses varying flood scenarios, demonstrating a proactive approach to the dynamic nature of flooding events. A comprehensive overview of flood issues is demonstrated by the analysis of two scenarios: operational highways with minimal flooding and sunken road sections. Prioritizing safety, flooded roadways are marked with a speed limit of 0 km/h. A previous flooding map superimposed over the study region reveals higher travel costs and a preference for alternative routes. Safe and efficient evacuation routes are necessary in high-risk areas. Plans can be updated using real-time scenarios to take into consideration the unpredictable nature of floods. This highlights how important accurate data on floods and transportation networks are.

Building strong and flexible evacuation plans that take into consideration the particular measures required at different stages of a flood event is made easier with the help of evacuation route evaluations in both normal and flood situations. In flood situations, larger standard deviations and maximum travel time values indicate more unpredictability and uncertainty during such events. This highlights the significance of planning escape routes that account for both regular and flood conditions. Emergency management teams need to prepare for potential delays and longer travel times during floods. This means proactively identifying other routes and allocating sufficient resources. Public awareness campaigns are crucial in instilling in the local



(a) (b)

Figure 12: Evacuation route map. (a) Normal scenario. (b) Flood scenario.

population the need of being prepared and knowledgeable about the evacuation routes in their towns. Recognizing and understanding the differences in travel times during flood occurrences can help decision-makers create more efficient strategies for controlling and minimizing the effects of floods on evacuation operations, given the unpredictable nature of flooding and its direct implications on evacuation processes.

The study's conclusions have a number of implications for reducing the likelihood of flooding in the KPK watershed and other surrounding regions. The study's main finding is that managing and planning land use is essential to lowering the risk of floods. In the research region, there is a greater risk of flooding during rainy events because of the large number of roads and other impermeable surfaces, which enhance runoff. That being said, in order to reduce the likelihood of flooding, land use decisions must be carefully considered. The study underscores the necessity of enhanced drainage infrastructure and upkeep to lessen the effects of floods. Flooding was shown to be more likely in the research location due to an insufficient drainage system. Consequently, funding drainage infrastructure and upkeep can aid in lessening the effects of floods in the future. The necessity of educating and raising public knowledge about the risk of floods and flood measures to prepare is highlighted in the study's conclusion. To lessen the effects of floods, more should be done to educate the people about flood risk and preparedness.

5. Conclusions

This study identified key factors contributing to flood vulnerability in Swabi district, Pakistan. Elevation, slope, rainfall, and proximity to rivers emerged as primary determinants of flood risk. Through AHP-GIS integration, a flood hazard map was generated, classifying nearly 49.42% of the area as high risk. The resulting flood hazard map categorizes nearly half of the district as highly susceptible to flooding, emphasizing the critical need for comprehensive flood management strategies. Our research underscores the importance of strategic planning, including the establishment of evacuation routes and robust public awareness initiatives. While this study offers valuable insights, further research utilizing higher resolution data is essential to refine flood modeling and bolster preparedness efforts. The findings presented here provide a foundation for informed decision-making and effective flood mitigation in the region. The findings underscore the urgent need for strategic planning, including evacuation routes and public awareness campaigns, to mitigate flood impacts in the region. In conclusion, this study offers opinions and recommendations for reducing the danger of flooding in the KPK watershed, which is a crucial first step in resolving flooding issues in this region of Pakistan. To find possible places for flood protection measures, the urban flood threat map and geographical distribution were analyzed. The suggested technique, with its ability to offer a comprehensive study of the region and its ease of implementation in areas with limited primary data, holds promise for future use in land use planning projects. Scientists, stakeholders, engineers, and decision-makers are encouraged to employ this approach for more effective flood mitigation strategies, making it a valuable tool for postfire management and disaster preparation planning.

Data Availability Statement

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.

Ethics Statement

The authors have nothing to report.

Consent

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Conceptualization: S.A., M.W., S.H., and S.M.; methodology: S.A., S.M., F.P.M., M.M.S., and M.W.; software: I.A., S.A., M.W., and H.W.; validation: M.W., S.A., and M.M.S.; formal analysis: S.A., F.P.M., M.W., S.M., and S.H.; investigation: M.W.; data curation: S.A., S.M., S.H., and M.W.; writing–original draft: S.A. and S.H.; writing–review and editing: M.K.L., S.A., and M.M.S.; visualization: M.W. and M.M.S. All authors have read and agreed to the submitted version of the manuscript.

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