GEOSPATIAL ASSESSMENT OF FLASH FLOOD SUSCEPTIBILITY IN CHAJ DOAB PUNJAB PAKISTAN

S. Akram[1]*, S. Siddiqui[2] , G. Abbas[3]

[1]Institute of Geography, University of the Punjab, Lahore Pakistan
[2]Centre for Integrated Mountain Research, University of the Punjab, Lahore Pakistan
[3]Riphah International University, Riphah College of Veterinary Sciences, Lahore, Pakistan.
*Corresponding Author: E-mail: sabageographer@gmail.com

ABSTRACT: The study area is positioned between the Jhelum and Chenab rivers. Such areas are flooded almost annually and with varying intensities. This research aims at using the Analytical Hierarchy Process (AHP) and Frequency Ratio (FR) models to formulate flash flood risk maps, applied within a Geographic Information System (GIS) framework. Eight physical parameters that may influence flash floods were incorporated together using a weighted overlay, where drainage density received the highest influence. The outcome categorizes the area into five flood risk zones, which are "very low risk," "low risk," "moderate risk," "high risk," and "very high risk." About 1,268 km² or 9% of the total area is included in the "very high risk" category. Mangla, Marala, and Trimmu valleys proved to be the most vulnerable zones, having been devastated by flash floods in the past. This study provides critical insights and policy recommendations for risk managers, emergency response teams, hydrologists, and climate scientists to enhance disaster preparedness and mitigation efforts.

Key Words: Analytical Hierarchy Process, Geographical Information System, Weighted overlay analysis, Drainage density, Frequency Ratio Model.

(Received 01.07.2024 Accepted 05.09.2024)

INTRODUCTION

Pakistan confronts numerous risks, including cyclones, waterlogging, riverbank erosion, droughts, floods, landslides, earthquakes, desertification, heat waves, and water salinity. Pakistan has experienced 25 catastrophes, predominantly floods, earthquakes, and landslides, though these are not the sole occurrences (Ahmed et al., 2013; Zope et al., 2017; Kheramand et al., 2018). Flood modeling studies, in conjunction with Geographic Information Systems (GIS), are employed in the analysis of floods across various return periods. Floods can inflict damage owing to inadequate mapping or preventive efforts, as well as several factors such as drainage density and slope.

Flood modeling studies, in conjunction with Geographic Information Systems (GIS), are employed in the analysis of floods across various return periods. Floods can inflict damage owing to inadequate mapping or preventive efforts, as well as several factors such as drainage density and slope (Liu et al., 2020). Flood disasters have become the most prevalent natural phenomenon today due to climate change and other environmental issues (Hussain et al., 2011). The integration of remote sensing satellite data with GIS is both useful and efficient for estimating flood risk, charting inundations, and determining evacuation locations and routes (Kwang et al., 2017; Ali et al., 2019).

Flood risk modeling forms an important part of basin management, using both hydrologic and hydraulic models.

Hydrologicmodels account for factors, including precipi tation, runoff, flood frequency, temperature, and rainfall interpolation whereas hydraulic models apply drainage density, slope, land use, elevation, water percolation, and flow accumulation. The analytical integration for these physical parameters can be ascertained by combining Multi-Criteria Analysis and Analytical Hierarchy Process (AHP), which produces flood risk zones ranging from highly vulnerable to less susceptible areas (Scoriano et al., 2000). This study focuses on modeling risk vulnerability and zonation in the Chaj Doab floodplain, utilizing GIS and hydraulic models for flood hazard assessment and geo-visualization (Guerriero et al., 2020; Pimentel & Flowers, 2011). Another essential component is the incorporation of the Digital Elevation Model (DEM), which contains elevation data, in the analysis (Ishaq & Leghari, 2020; Muthusamy et al., 2021). Susceptibility assessments of floods evaluate possible damages, including monetary loss. The digital elevation models that include SRTM DEM and ASTER DEM/ALOSPALSAR are common research tools for zonation, management, and flood risk modeling (Ali et al., 2019).

The facility is unable to address the problem of substantial flooding due to inadequate maintenance and support. Insufficient data regarding disaster preparedness is present. Initiating comprehension of flood programs is essential, particularly for communities residing in proximity to flood plains (Guerriero et al., 2020; Samanta et al., 2018). Data from the past thirty years indicates that flooding occurs nearly annually. The factors contributing to the country's designation as dangerous include its vast latitudinal span, geographical position, the presence of three mountain ranges, significant climate variability, and the region's topographical features.

The floodplain of the Jhelum and Chenab rivers is particularly vulnerable to frequent floods in the summer season. Annually, significant damage occurs to standing crops, and infrastructure, and results in mortality among both animals and humans. In the research area, population settlements are pushing toward potentially dangerous zones. A significant number of communities are situated adjacent to the river basin. This results in insufficient information for the local department, leading to significant environmental, economic, and social harm. This study intends to conduct flood risk modeling (Pham et al., 2020; Ghezelsofloo & Hajibigloo 2020). In light of recent global climatic changes, the inhabitants of Chaj Doab have encountered tragedies and many natural calamities during the past few years (Khatoon et al., 2017). The tributaries of the Jhelum and Chenab rivers predominantly drain agricultural regions. This has heightened the risk of property destruction and loss of human life in Chaj Doab. Consequently, the nation has faced severe flooding annually, indicating that flooding has become a perennial phenomenon (Bui et al., 2019; Hoang et al., 2018).

The economy of Pakistan is greatly dependent on water provided by the upper Jhelum River, which is sourced from the southern slopes of the Himalayas and Pir Panjal. The Chenab River in Pakistan is among the significant tributaries of the Indus, one of the main rivers in the Indus basin (Ashraf et al., 2016). It lies between 73°30' and 74°28' E and 32°7' and 33°0' N (Figure 1). Situated on the southern periphery of the valley, it is a component of Kashmir (Figure 1). This region comprises the districts of Gujrat, Mandi Bahuddin, and Sargodha. River flooding poses a considerable challenge in Pakistan due to monsoon precipitation and snowmelt, which result in the overflow of the country's rivers. The whole study area encompasses 14158.00 km². Three major rivers contribute to flooding in Pakistan, with the River Jhelum and the River Chenab playing key roles (Mahmood et al., 2019). This project aims to assess flood susceptibility by location using GIS, coupled with FR and AHP analyses, to mitigate flood disasters in the Chaj Doab, encompassing the Jhelum and Chenab Basins. The results of the FR and AHP studies were utilized to identify and delineate flood risk zones, ranging from high to low flood risk, within the research area. The objective of this study was to evaluate the precision of flood maps and assess their utility in disaster management by examining the underlying terrain. It additionally provides advice to policymakers or local authorities regarding flood risk management policies. These findings will assist planners, researchers, and local government in impact assessment, enabling them to predict future flood zones and mitigate flooding risks through the development of various strategies. Chaj Doab refers to the area delineated by the Jhelum and Chenab Rivers.

Collection and Preparation of Data: For this research, analysis was carried out using an ArcGIS database that was constructed and applied to examine both primary and secondary data sources. The research had major problems in acquiring proper data. Geological and soil data were derived from the Pakistan Hydrology and Meteorological Department in Punjab, Pakistan, as well as the Geological and Soil Survey of Punjab (Gosh & Kar, 2018). The DEM derived from PALSAR Phased Array L-band data with a resolution of 12.5 meters was downloaded from the Alaska Satellite facility (https://vertex.daac.asf.alaska.edu/). The access to this DEM was done using a geographic search type and the dataset was ALOS PALSAR. The areas of interest were defined either by using a shapefile or by manually delineating a polygon. This paper describes the research methods and frames, specifying the tool and procedure applied for data collection. Flood risk mapping and assessment were conducted through different capabilities of ESRI ArcGIS. Tools provided by ArcGIS were then employed in the flood modeling process after performing the flood risk mapping. The geographical data produced from this model provides very useful insights for flood managers to develop recommendations that might help reduce the risk of future floods (Samanta et al., 2018).

Analytical Hierarchal Process (AHP) Modelling: The idea in this research is to create susceptibility maps, which entail an integration of several physical parameters. In developing the above kinds of maps, various analytical and decision-making approaches have been used. For instance, when evaluating and creating flood zonation maps, the AHP is used. In such calculations, summation and division are used to come up with the values for every factor, and the resultant values are assigned appropriate weightings. Specific parameters were chosen to apply within the AHP modeling framework. The AHP method played a significant role in the production of zonation maps, and this chapter stresses its application in producing susceptibility maps. The techniques that were applied in the AHP method were efficient and rational and combined with ArcGIS techniques to produce the required maps.

Digital Elevation Model: The DEM is extracted by ArcGIS 10.8, through the hydrology tool, to extract the parameters found in topography, namely stream order, flow accumulation, flow direction, fill, mainstream, stream density, slope, and elevation. Raster layers sometimes appear as vectors and lines, such as when using the "Raster to Polyline" tool when computing drainage density according to Pimentel & Flowers, 2011. Modeling is highly applied in different evaluations and decision-making processes. This process, in most cases, is implemented by professional experts out of the theoretical sphere. Risk assessment modeling is highly related to decision-making. It provides essential methods that help in determining the vulnerability of elements exposed to risk. It works as a pre-hazard assessment of the potential impacts and consequences related to specific risk elements (Tehrany et al., 2014; Thomas, 2017).

Fill Tools: The Fill tool is used for several purposes, including removing sudden elevati on changes. Specialized functions like Zonal Fill, Fill Sinks, Focal Flow, Flow Direction, Sink, and Watershed help to address such changes. After filling the sinks, the limits of the filled areas can be defined, and the remaining areas are processed in subsequent runs (Kheradmand et al., 2018; Zope et al., 2017).

Hydrology tool: All these were done within the ArcGIS environment to ensure the best outcome. The L-band data downloaded were imported into ArcGIS 10.8, and the shapefile of the study area was overlaid. The Mosaic and Extract tools were then used to extract the Area of Interest (AOI) to ensure an accurate delineation of the study region.

Raster Data: This study used several sources for data collection, which are included in the methodology below for flood susceptibility modeling in the region. Acquisition of Satellite Images with 10 m Spatial Resolution The United States Geological Survey (USGS) provided satellite images with 10 m spatial resolution. Sourced from EarthExplorer, at https://earthexplorer.usgs.gov, is a Sentinel-2B image comprising 13 spectral bands. Altogether five Sentinel images were mosaic, and composite to cover the whole extent area. Seven specific bands, used for the objective study area, the shape of an overlay area, were put above it, and its portion to draw the extent of that selected area. Mask tools extract the area of that entire study region using the feature in ArcGIS and assemble spectral layers for preparing multispectral images. ArcMap 10.8 was used in the generation of the composite images (Idrees et al., 2021).

Supervised classification and Unsupervised: This study applied supervised classification, in which images are analyzed using a classifying method. In the supervised classification process, training samples must first be prepared for every type of land cover in the image. These samples then generate signature files for each class basis for the classification. Maximum Likelihood method Classification with classification toolbar in ArcMap 10.8 classification was done on Sentinel-IIA-B 2019 images into five major classes, namely agricultural land, barren land, built-up, water bodies, and snow cover. The land covers of the study area might be understood by classifying the images. Spa tial Analyst Extraction by Mask Tool is used to extract the area of interest Chaj Doab.

The following step was to create a geodatabase, which is a file used to organize GIS datasets for various types of land cover. A feature class was created to digitize the training samples of different visible land cover and land use classes. Five land cover classes were identified for this study: agriculture, vegetation, water, built-up areas, and glaciers (Ec.europa.eu, 2003; Vivekanandan, 2018).

The signature file, created by using statistical methods, evaluates the relationship between variables to generate a signature class that stores raw statistics about the training samples. This information incorporates data about the number of classes, samples from each class, and other relevant data (Braimah et al., 2014; Soriano et al., 2000; Ullah & Zhang, 2020). After gathering about 1,000 training samples from the composite images (Relief, 2013; Siddayao et al., 2014), the supervised classification was performed. After completing the classification, an accuracy assessment was performed to validate the correctness of the classification. The accuracy evaluation results were good for all images (Braimah et al., 2014; Soriano et al., 2000; Ullah & Zhang, 2020).

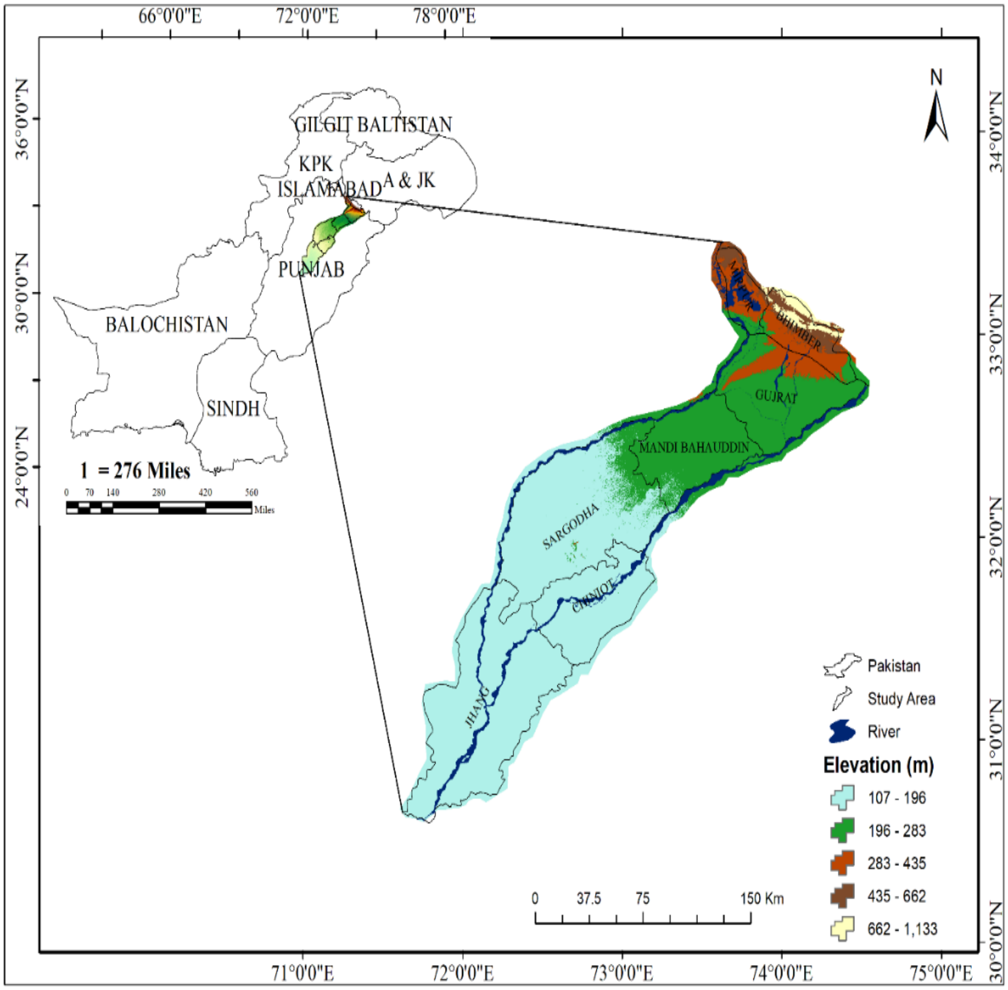

Figure 1: Location-based map of Chaj doab that shows major cities along the Jhelum and Chenab rivers.

Table 1: The sources of data collection and their purpose of application.

S.No	Primary Data	Spatial Resolution	Data Availability	Research variables
1	ALOS-PALSAR (DEM) (Raster)	12.5	https://search.asf.alaska.edu/	Slope, Drainage density, Elevation, Flow accumulation, and Distance from water
2	Sentinel-2 (Raster)	10m	(https://earthexplorer.usgs.gov)	Land Use land cover Map, delineation of drainage basin
4	Soil Data (Vector)	1:100,000	Soil Survey of Pakistan	Soil Map
5	Geological Data (Vector)	1:10000	Geological Survey of Pakistan	Geological Map
6	Rainfall Data (Digits)	Charts/tables	Pakistan Meteorological Department	Rainfall data sets

Research Variables: Flood risk mapping and evaluation were conducted utilizing several functionalities of the ESRI ArcGIS software. After flood risk mapping, ArcGIS tools and methodology were employed to conduct spatial data flood modeling. The spatial data from this model assisted flood managers in formulating effective recommendations for mitigating future flood risk `; Malik et al., 2021; Samanta et al., 2018). DEM was used to obtain topographic parameters like stream order, fill, flow accumulation, flow direction, main streams, stream density, slope, and elevation through the use of ArcGIS 10.8 hydrology tools. For the computation of drainage density, some raster layers were converted into vector and line features. For instance, the raster data were transformed into polylines (Pimentel & Flowers, 2011).

Various parameters are examined and deliberated upon during the conversation. FR is a frequently employed bivariate analytical method in flood risk assessments (Stedinger 1993; Ullah & Zhang 2020; Jung et al., 2013).

Elevation Data Set: Elevation data indicates the variation in ground height over a region. This information is essential for the creation of flood maps, as these factors are recognized to directly influence flood mapping. They provide us the opportunity to model, explore, and exhibit awe. The ALOSPALSAR DEM has been utilized to derive many interims (Figure: 2). delineates the elevation within the study area over five distinct classes, ranging from 0 to 150 meters that have lower elevation, 151 to 300 color assigned on the map then 301 to 450 meters and the last one is the highest elevation point that exceeds from above 600 meter.

Drainage density Data Set: It is defined as the entire length of the stream network per unit area. The analysis showed that the three major rivers in the study area had a greater risk since they had huge flow accumulation. Figure 3 indicates the classification of areas by drainage density with very low drainage density areas being shown in green and the areas having very high drainage density shown in purple and ranked as the most critical Rank 1.

Employing AHP, we determined density as the second most critical measure, utilizing kernel density to ascertain river density within a 500-meter radius. It was found that river concentrations are greatest along the Jhelum and Chenab Rivers, as well as at their confluence with the Trimmu River. The capacity for water absorption varies with increasing density in the study area, which is particularly susceptible to flash flooding. As density increases, the capacity of the land to absorb water decreases, making it more prone to flash floods when water encounters vulnerable land cover (Ali et al., 2022; Iqbal et al., 2022) .

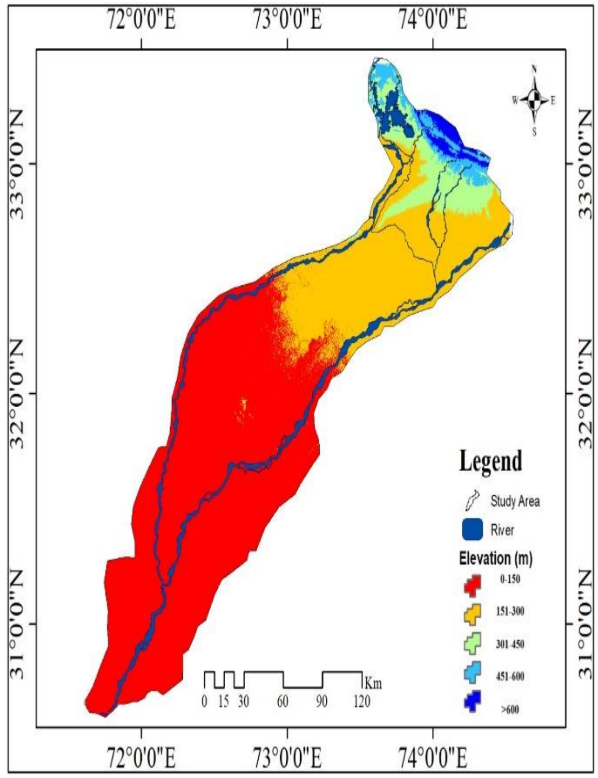

Figure 2: Elevation map of Chaj Doab.

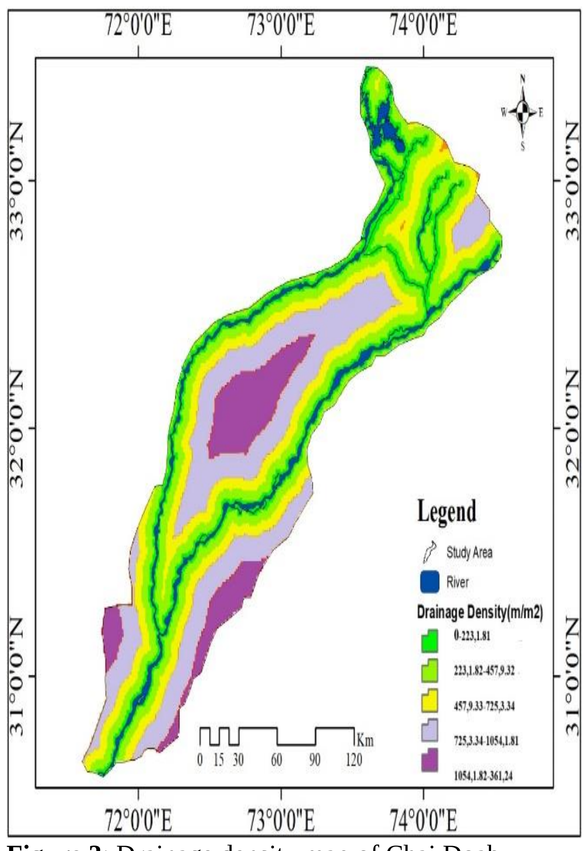

Figure 3: Drainage density map of Chaj Doab

Slope Data Set: The DEM and slope generation capabilities in ArcGIS 10.8 were utilized to produce the slope map for this study. In an area characterized by a gentle slope, precipitation or excess water from the river consistently accumulates. River-induced floods are mostly attributed to variations in DEM cell elevations, whereas pluvial floods are predominantly generated by local depressions. This indicates that the relationship between elevation and risk is crucial. It regulates terrestrial movement, infiltration, and subsurface flow distance. The gradient of the slope affects the volume and direction of surface runoff and subsurface drainage that arrive at a spot. The slope significantly affects the contribution of precipitation to streamflow by regulating the duration of overland, subsurface, and infiltration flow. A rougher surface is better as it impedes flood response, unlike a smooth or flat surface that facilitates faster water flow. Surface runoff is more probable on steeper inclines, whereas waterlogging is more prevalent on level terrain (Figure 4). Gentle slopes are more prone to floods than steep slopes

Landuse land cover

Rainfall runoff is far more prevalent on bare ground compared to regions with dense vegetation. Lush vegetation prolongs the descent of water from the atmosphere to the soil and reduces runoff. Conversely, concrete exhibits a markedly low water absorption rate due to its impermeable nature.

The satellite images in this study were categorized utilizing a supervised classification methodology. The greatest likelihood technique is employed for this procedure. The categorization toolbar of ArcMap 10.8 was utilized to categorize Sentinel-II satellite images of 2021 into four classes such as land cover classes, Agricultural land, Barren land, Built-up areas, and Water bodies (Figure 5). Flood hazard mapping incorporates land-use and land-cover management, as these factors reflect the existing utilization of the land, its patterns and types, and its significance regarding soil stability and infiltration. Consequently, land use and land cover are critical factors influencing flood probability.

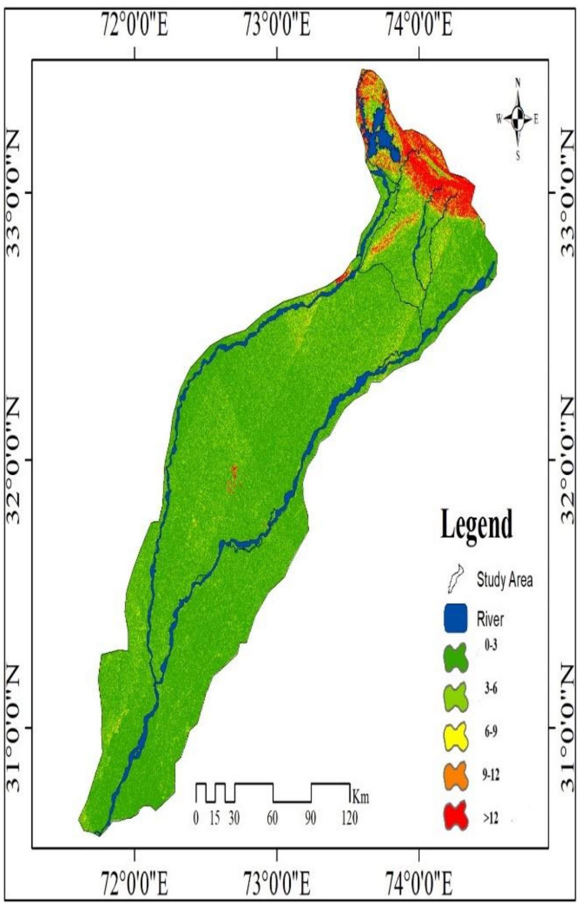

Figure 4: Slope Map for investigation of research

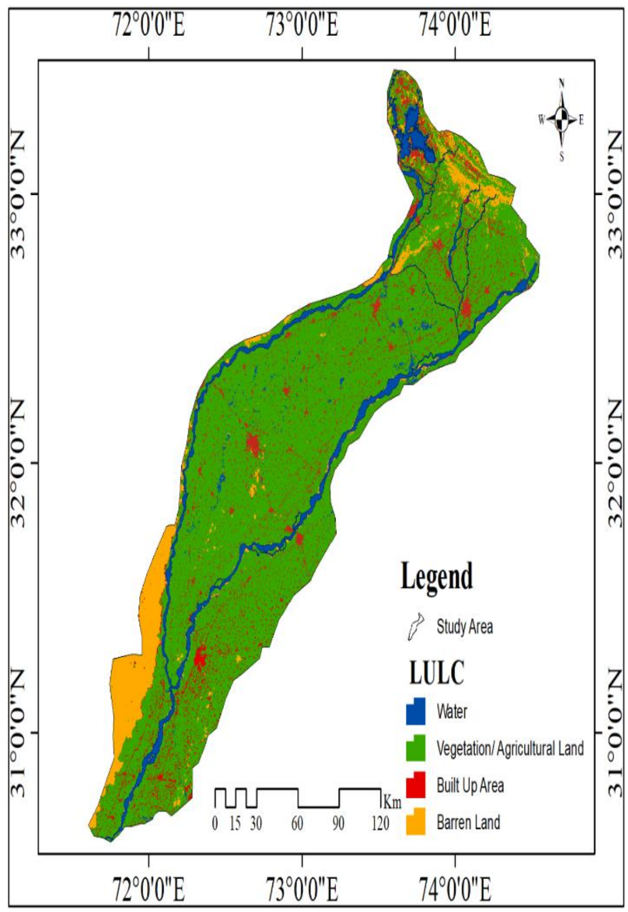

Figure 5: Supervised classification for Land Use Land Cover Data set

Geology and soil: Geology influences hydrological response, with soil permeability being the most critical geological attribute for surface runoff. These rock types have low infiltration rates and a heightened likelihood of floods. The geology and soil map of the research region were obtained from the Geological and Soil Department Survey of Pakistan.

Soil textures substantially influence flooding, as sandy soil rapidly absorbs water and generates less runoff. Soil types exhibit significant variability in their water retention capacity. Reductions in soil infiltration capacity result in heightened surface runoff, hence elevating the danger of flooding. Figure 7 illustrates the categorization of the soil map according to the soil's water absorption capacity for this case study.

The municipality contains three primary categories of soil: highly contaminated, moderately contaminated, and minimally contaminated soil. The most essential attributes of soil are its texture and moisture content. Soil textures significantly influence flooding, as sandy soil rapidly absorbs water and generates minimal runoff. Conversely, clay soils exhibit lower permeability compared to sandy soils, hence retaining greater amounts of water. Consequently, flooding is more probable in areas with clay soils.

Distance from the main water: Euclidean distance is a significant feature in flood analysis. Increased exposure correlates with heightened risk. In the study area, a distance of 5000 meters was designated as the most susceptible zone, whereas distances above 28000 meters were classified as low-risk or negligible-risk areas (Figure 6).

The flow direction of each cell determines the direction of water movement within that cell. The flow direction is dictated by the orientation of the cells of the steepest descent. Water can transfer from a grid cell to one or several of its eight adjacent cells.

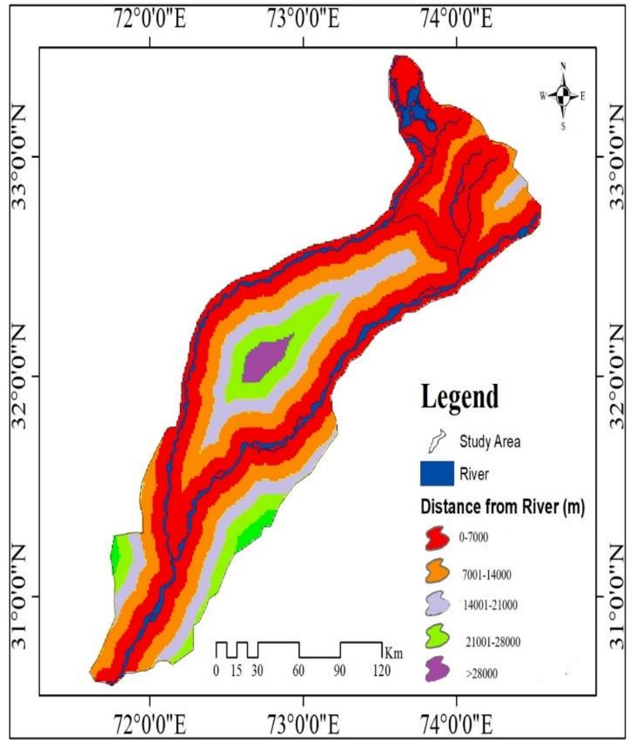

Figure 6: Distance from the river describes the chance of Flooding in the study area

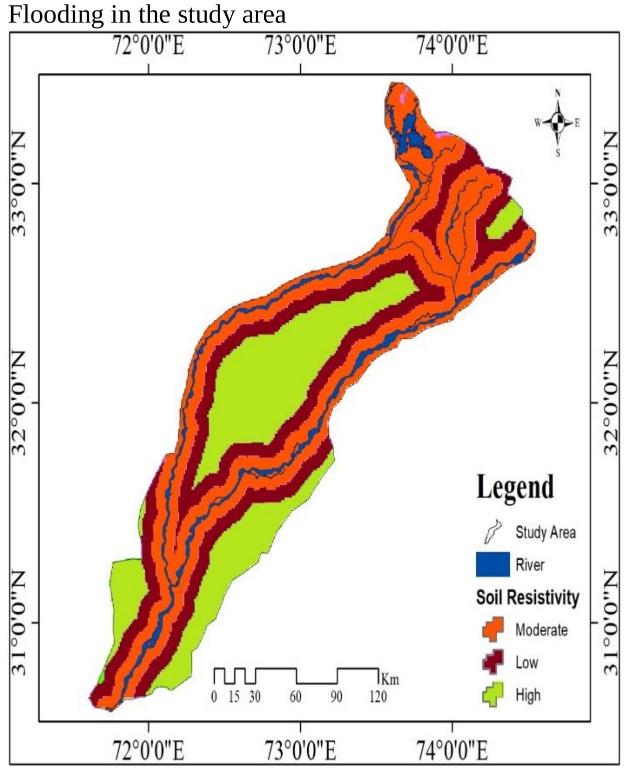

Figure 7: Soil Classification map based on the Geological Survey of Pakistan Soil Map

Precipitation Data Set: The monsoon season from July to September increases the rainfall rate in the study region, hence elevating the risk of flooding. In assessing forms of floods that are sudden, swift, and brief, the volume of surface runoff is paramount due to intense precipitation. The precipitation data was derived from five rain gauge stations: Wazirabad, Jhelum, Mandi Bahuddin, and Gujrat. Equation (1) was employed to ascertain the deviation of rainfall from the average for each rain gauge station. L denotes the reported precipitation, Z signifies the mean precipitation, and Q represents the precipitation deviation (Giordan et al. 2018). The inverse distance weighting (IDW) interpolation method was employed in ArcGIS to delineate rainfall anomalies for Chaj Doab. The yearly average precipitation data for the Chitral region from 2016 to 2019 was utilized to estimate variance and spatial mapping. This equation (1) was employed to ascertain the deviation of rainfall from the average for each rain gauge station.

$$\boldsymbol{Q} = \left(\frac{(\boldsymbol{L} - \boldsymbol{Z}) \times \mathbf{100}}{\boldsymbol{z}}\right) \quad \textbf{Equation 1}$$

METHODOLOGY

Flood danger is a hydrological event capable of inflicting damage on individuals and their assets. Flooding poses a possible risk, although its magnitude and intensity can be elucidated by three variables. The factors include the probability of the threat manifesting, its intensity, and the rapidity of its onset. The factor map and pairwise comparison matrix are utilized in the weighting and ranking calculation processes. A comparison matrix based on pairwise assessments has been established to demonstrate optimal results for weighted sets. The results indicate the absolute values between zero and one, prioritized according to their weight values. The weighted linear combination has been defined such that the weighted total equals one. The effect factor in this research will be elevated if the weight assigned to some elements surpasses that of others. (Lee et al., 2012; 2015; Sajjad et al,. 2019; Idress et al., 2021;).

AHP Modeling and the SFWV: The Analytical Hierarchy Process is used in this analysis to support the decision-making. Flood-causing variables were compared, and their respective Selected Factor Weight Values were computed.

Five classes were established for flood zonation, used in various rankings, with the author making decisions on their geographical expertise. According to the factors that are more casual compared to all others. The inverse factor was used for all of these. Which one holds much less importance (Idress et al., 2021; Samboko et al. 2020) compared to the top five? (Table 2). In analysis, the relevance of variables causing floods has been weighed and a comparison matrix on pairwise basis is developed. Values have been assigned on a scale of 1-9 for each rank developed based on the seven chosen flood-causing factors. Each weight is determined by how much it contributes to the flood event. The reciprocal values (from 1/2 to 1/9) were also given to the other option to keep the comparisons consistent.

To ensure precision while considering the importance of each factor, weight values of categorized sub-factors have been calculated after determining the relative ranking of each factor. These calculations were done as per Eq. (2) as shown in the methodology (Markantonis et al., 2013).

$$Ax = \lambda max^X \quad \text{Equation 2}$$

where λ denotes the given eigenvalue of the criterion, x is the corresponding criteria, and A is the comparison matrix of the n criteria. Computing the Consistency Ratio (CR) is important for assessing each situation. For example, a CR of "0" means perfectly consistent, and values between 0 and 0.1 are mostly acceptable (Saaty, 1997). The Consistency Ratio can be computed using the following equation (Eq. 3):

$$CR = \left(\frac{CI}{RI}\right) \quad \text{Equation 3}$$

Using CR as the basis, we can get a consistency index of CI and a random index of RI from that value. RI was taken from (Markantonis etal,. 2013).. However, CI was calculated using eq. (4):

$$CI = \left(\frac{\lambda max - N}{N - I}\right) \quad \text{Equation 4}$$

Where the total of sub-factors number is λmax which will be the average value for the x criterion and the total of all the sub-factors, and N will be representing a number. AHP is versatile enough to be applied to diverse fields; one among them is the selection and appraisal of land use and land cover (Alexakis & Sarris 2014). By considering the next eq. 5 for this work, the frequency ratio, which is described by the stated parameters, for all classes used, to obtain their respective frequency ratios, such that:

$$FR = \frac{\left({}^{PpixE}/_{PpixT}\right)}{\left({}^{\Sigma pixE}/_{\Sigma pixT}\right)} \quad \text{Equation 5}$$

When a flood class is of concern, the number of pixels p in the concerned areas is represented by PpixE, while PpixT represents the total number of pixels in the research area. When a flood class is of concern, the number of pixels is represented by ΣpixE, and the total number of pixels is represented by ΣpixT (Bui et al., 2019). The value for the class weight specified in the current study for every class was considered as FR value for every class. Here, another flood vulnerability index, FVI, has also been developed which demonstrates the heightened significance of flood susceptibility in the present AHP and FR model analysis that varies from very high to shallow locations having a flood risk. In calculating the FVI with the help of the following equation 6, the SCWV of each class for all the variables given along with the SFWV for flood event conditions was considered:

$$FSI = \sum_{n=1}^{n} (w_i \times FR) \qquad \text{Equation 6}$$

SFWV is the variables' weight, i.e. the total number of variables, and FR represents the frequency ratio value of the respective class in this formula: the total number of variables = 7. Hence the SCWV equals:.

Table 2. Comparison of two factors that cause flooding in the form of a numerical scale.

S. No	Explanation	Importance Intensity
01	Extremely Important	8 and 9
02	Strongly more important	6 and 7
03	More important	4 and 5
04	Moderate more important	3 and 2
05	Important	1

Table 3. The flood-enhancing variables and their chosen factor weight values (SFWVs)

S. No	Data Sets/Variables	SFWV	Soil	Geology	Distance from water	Land use/land cover	Rainfall	Slope	Drainage density	Elevation
1	Elevation	0.0254	0.3	2	4	1	5	1	1	0.21
2	Drainage Density	0.2579	1	4	5	2	0.2	1	3	5
3	Slope	0.0142	0.3	4	2	1	5	1	4	0.3
4	Rainfall	0.0432	0.2	1	1	1	0.24	0.23	1	0.12
5	Land use/cover	0.14	1	0.3	0.12	0.5	0.5	0.1	0.2	0.11
6	Distance from water	0.2562	1	3	5	3	4	2	3	1
7	Geology	0.119	0.4	2	0.2	0.26	1	0.35	0.24	0.23
8	Soil	0.18	1	4	3	2	1	0.23	0.21	4

RESULTS

This paper introduces an experimental methodology to map flood susceptibility in study areas integrating the Analytic Hierarchy Process with GIS techniques and MCA. In this work, the method applied presents an innovative way of using GIS-based spatial modeling coupled with AHP to realize flood susceptibility mapping. It is with the above motive that this paper is attempting to identify the flood risk zones in the study area. Eight parameters were chosen for pairwise matrix correlation to assess the relative importance of each of these. A multi-parametric approach was adopted in preparing a flood risk map. The susceptible zones under morphometric and topographic conditions were identified. It yielded a Consistency Ratio of 0.04.

CR > 0.1 indicates borderline consistency of judgments. However, a slightly higher value is sometimes tolerable. In this case, the CR value is well within acceptable limits, ensuring reliability. A CR approaching 0.9, however, would indicate highly inconsistent and unreliable judgments. The flood risk map categorizes areas into five risk zones: 9% of the area falls under very high risk, 11% under high risk, 13% under moderate risk, 21% under low risk, and 46% under very low risk. The total study area spans 14,158 sq. km, where 9% falls under very high risk. Jhelum, Wazirabad, and Mandi Bahauddin cities have been mainly classified under the very high flood risk category, as the terrain in these areas is characterized as flat and low-lying according to the DEM.

The GIS-based flood hazard map shows that drainage density significantly influences flooding patterns, as reflected in the high weight assigned during the MCA overlay analysis phase of AHP. The selected eight parameters were weighted and categorized into five risk levels: very low, low, medium, high, and very high.

The analysis reiterates that Jhelum, Wazirabad, and Mandi Bahauddin are located in a very high flood-risk zone and susceptible to severe flooding due to flat terrain and proximity to the Jhelum and Chenab Rivers. The waters converging from these significant rivers add a lot of contribution to flood risks there.

Future studies may incorporate more physical elements and periodically update the weighting of factors to reflect changing conditions. This study provides a strong framework for flood susceptibility mapping, which can be useful in effective hazard management and planning.

Flood susceptibility mapping acts as an essential tool to plan and manage pre-hazard measures to minimize the risk factor. Chaj Doab has been identified with flood frequency due to its elevation factor. There have been successive catastrophic floods at different periodic return periods recorded from ancient times. The current analysis focuses on the vulnerability aspects of flood with the approach of decision-making with a combination of the Analytic Hierarchy Process and frequency ratio. Independent conditioning factors influencing flooding in the region play significant roles in the evaluation of floods. During the study, a statistical database was compiled for eight selected conditioning factors—river distance, drainage density, slope, elevation, rainfall, soil, geology, and land use/land cover (LULC)—with their corresponding subclasses.

With quantitative analysis of relationships between the occurrences of floods in historical periods and topographical as well as geo-environmental factors affecting flash floods, it is possible to determine impact weights for every factor. In this research, elevation class above 600 meters revealed the highest weight, reflecting a significant contribution to vulnerability to flood occurrences. Analogously, maximum weight to slope has been assigned for slopes > 12°. The northwest slope orientation had a greater weight than the other orientations. River distance analysis indicated that most of the flood-related weight was concentrated in areas less than 2800 meters from the river, and hence flash floods are more frequent in this proximity. There are areas identified which have more weighty factors such as higher factors on vegetation, residential land-use types, and land-use areas near rivers at moderate slopes.

The effort has been put to spatially associate the flood-prone areas with flood-inducing factors and their factor weight values have been calculated. Rainfall had a strong correlation with drought and flooding; the positive value meant above the rainfall and the negative value meant below the rainfall. The weight values of these factors, as determined by AHP, point out their relative significance in the generation of floods. Class weight values help show how each factor contributes to the flood process. Figure 8 shows all variables that affect and aggravate flooding.

The study also cited earlier literature, which stated that Chaj Doab was severely affected by a flash flood in 2016. The final flood susceptibility map, as concluded from the weightage overlay and AHP analysis, confirms that the same area affected by the 2016 Jhelum and Chenab flash floods is identified as highly susceptible. The drainage density was found to be the most critical factor responsible for flash floods in the study area, using the ALOS PALSAR DEM. Drainage density is the total length of the stream network per unit area. Using the flow accumulation data, three major rivers in the region, namely Wazirabad, Chinote, and Gujrat/Mandi Bahuddin, were identified as the riskiest areas in terms of flood susceptibility.

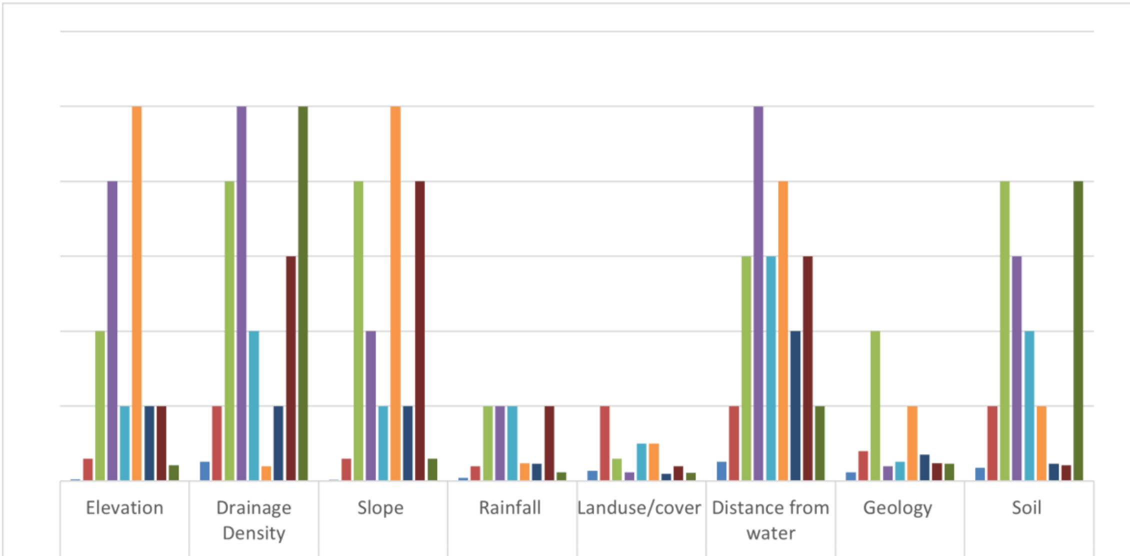

Figure 8: Relationship between flood susceptibility and flood-inducing factor**.**

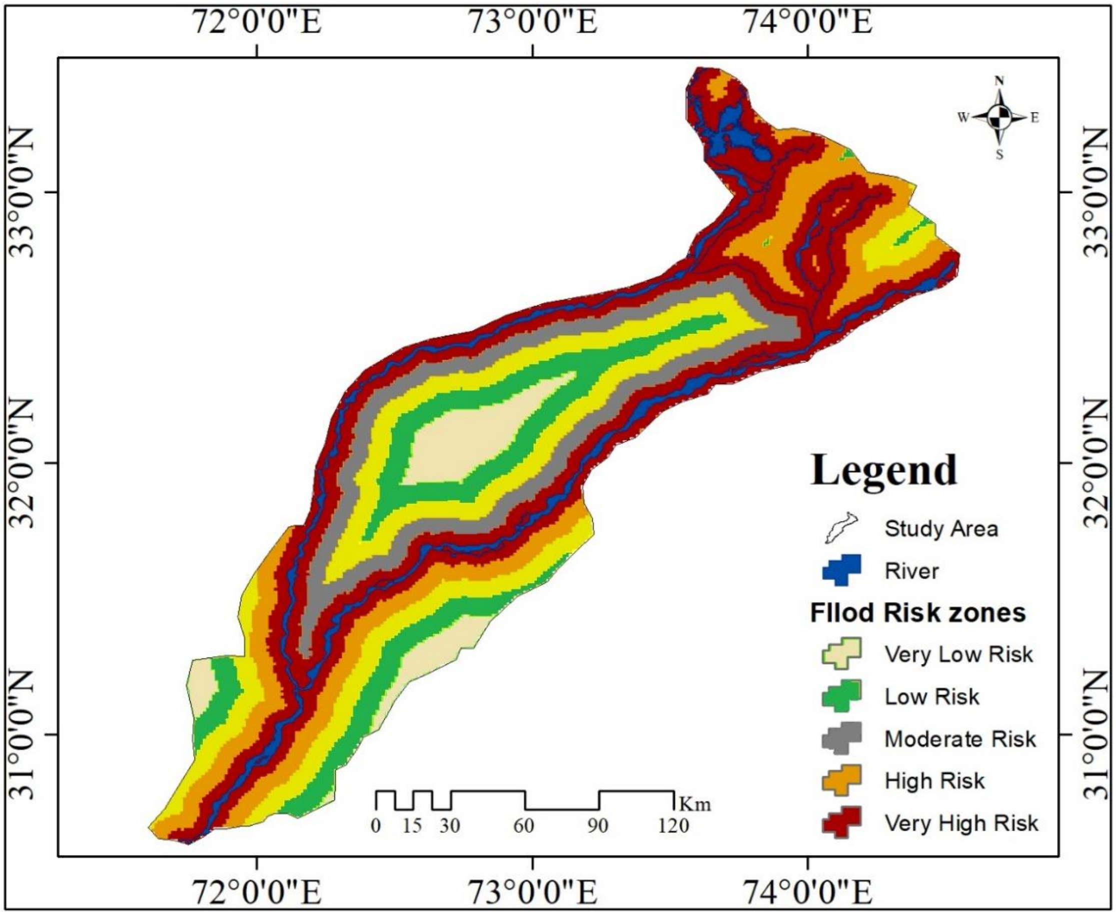

Figure 9: Flood risk zones very low to high-risk map of the study area using the AHP models

Table 2: Flood susceptibility risk classes and estimated area in square kilometers and percentages.

Value	Class	Estimated Risk Area (km^2)	Estimated Risk Area (%)
1	Very low Risk	6457	46
2	High Risk	1602	11
3	Low Risk	2933	21
4	Moderate Risk	1898	13
5	Very High Risk	1268	9
		14158.00	100

DISCUSSION

This paper presents an experimental methodology for flood susceptibility mapping in the study area by integrating the Analytic Hierarchy Process (AHP) and Geographic Information System (GIS) techniques, using a Multi-Criteria Analysis (MCA) approach.

The research demonstrates an innovative method for identifying flood-prone zones through spatial modeling within a GIS environment. The main objective of this study is to delineate flood risk zones in the region.

Eight parameters were identified and their relative importance was estimated by the pairwise comparison matrix. A multi-parameter approach, which used morphometric and topog raphic factors, was used to prepare a flood risk map that c lassified susceptibility zones.

The CR calculated for this exercise was 0.04, which was well within acceptable limits (CR ≤ 0.1).

Higher values of CR, such as 0.9, would point to randomness and lack of trustworthiness in the pairwise comparisons. The analysis revealed the following flood zone classifications: Very high flood risk zones: 9% of the area. High flood risk zones: 11% of the area. Moderate flood risk zones: 13% of the area. Low flood risk zones: 21% of the area.

Very low flood risk zones: 46% of the area. Altogether, these zones cover an area of 14,158 sq. km, where 9% of the area has a very high flood risk. The regions of Jhelum, Wazirabad, and Mandi Bahauddin have mostly been categorized into very high flood-risk areas.

DEM reflects that the terrain in this region is flat with a l ow elevation.From these findings, one realizes that using the integration of AHP and GIS is very practical in making flood risk assessments. Subsequent work should consider introducing additional factors representing physical factors in conjunction with their respective dynamically e volving weighing concerning shifting variable attributes to get higher reliability for the accuracy in mapping flooding susceptibility.

A flood hazard map was formulated by assigning specific values to each parameter, followed by a summation and normalization process to refine the assigned values. The final values and corresponding weights were made to evaluate the susceptibility of flood in the study area. Factors that include land use, slope, drainage density, geology, soil characteristics, and observed geographical conditions are analyzed to levels of susceptibility. The numerical values were assigned to these indicators, and the weightage values were incorporated into the analysis accordingly.

The flood hazard map was constructed and categorized into four zones, namely "very high," "medium," "low," and "flood-free," using ArcGIS techniques. This approach provided a detailed representation of the flood-prone areas within the research region.

Conclusion:

The FR and AHP techniques, with integration within Ar cMap 10.8, provided a basis for this research experimen t into flood susceptibility mapping in the study area. It h ad the objective of establishing risk flood zones in the northern region of Pakistan. That included Jhelum, Wazirabad, Gujrat, and Mandi Bahuddin. A relative significance weight was establishe d among eight parameters through pairwise matrix correlation. Spatial modeling was performed in a GIS environment. As per the opinion of experts and scores obtained through AHP, Jhelum, Wazirabad, Gujrat, and Mandi Bahuddin are highly susceptible to flash floods. The flood hazard map was prepared by assigning score values to each parameter, which were then added and normalized for f urther value refinement. Final values and weights were assigned, and a map was generated using ArcGIS algorithms to outline zones of very high, moderate, and low flood susceptibility. Factors controlling susceptibility were la nd use, slope, drainage density, geology, and soil characteristics. These numerical values and weightage are added to determine and define the susceptible flood zones, which leads to the production of flash flood maps categorized from very high to no susceptibility zones.

The findings are useful in giving insights and providing guidelines to decision-makers to reproduce similar methods in other parts of the country to save the lives and property of vulnerable populations. This methodology further provides a robust framework for policymakers and planners to evaluate and mitigate flood risks in the study area. Further research will include incorporating more physical factors and dynamically updating the weight of significance with changes in relevant variables.

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