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Flash Flood Susceptibility Analysis At Sub-Watershed Level Using Morphometric Ranking Approach (Mra) In District Khyber, Pakistan

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Abstract:

Flash floods frequently occur in District Khyber which causes widespread losses of life and property. The current study analyzes flash floods at the sub-watershed level using the morphometric ranking approach (MRA). The ASTER GDEM acquired from the open source (https://search. Earthdata. Nasa. gov) has been processed using Arc Hydro Tool in ArcMap 10.8. Nineteen geo-morphometric parameters have been derived and were utilized in this research. The district has been delineated into 15 Sub-Watersheds (SW-1 to SW-15. Based on the Morphometric Ranking Score, the sub-watersheds are classified into three classes- highly susceptible, moderately susceptible, and low susceptible sub-watersheds. Based on the MRA, the SW-1, SW-2 SW-6, SW-7, SW-1, S[1]W-12, and SW-13 are included in the high flash flooding susceptible zone. These seven Sub-watersheds cover an area of 745.4 Km^2, which accounts for 46.66% of all the sub-watersheds. The moderate flash flood hazardous sub-watersheds include SW-3, SW-8, SW-10, and SW-14. The zone of moderate flash flood susceptibility covers an area of 334.44 km^2 which accounts for 26.67% of all the Sub-watersheds of the study area. This includes those sub-watersheds which have morphometric ranking scores between 49-54. The low flash flooding susceptible Sub-watersheds include SW-4, SW-5, SW-9, and SW-15 (26.67% of the total sub-watersheds) covering an area of 255.96 km^2. The cumulative MR score of these Sub-watersheds ranges between 41-48. It is anticipated that flash flood hazard modeling, analysis, and mapping will help the locals and the concerned departments to chalk out effective flood mitigation strategies for sustainable development.

Key Words: *Flash floods, Morphometric Ranking Approach, DEM, District Khyber*.

1. Introduction

Flash floods (FFs) are abrupt and quick flooding occurrences that usually occur within a few hours of heavy rainfall or the unexpected discharge of water from a natural or manmade source (Shah et al., 2024; Nasir et al., 2023). These floods can be extremely devastating due to their quick onset and the massive amounts of water involved. They frequently cause death, property

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damage, and environmental degradation. Flash floods can occur in a variety of locations, including cities, deserts, and mountains (Ahmad et al., 2021; Waqas et al., 2021). Flash floods can caused by intense and prolonged rainfall, especially in places with weak drainage systems (Majeed et al., 2023; Tariq & Giesen, 2012), rapid snowmelt in mountainous places, sudden dam or levee collapses which can unleash huge quantities of water downstream, (Roger et al., 2017; Ahmad et al., 2020; Ahemaitihali & Dong, 2020; Liu et al., 2020; Boutaghane et al., 2020; Huq et al., 2020; Waqas et al., 2021). Additionally, human actions such as deforestation and poor land use can increase the risk of flash floods by interrupting natural water flow patterns (Mahmood & Rahman,2019; Saeed et al., 2021).

Flash floods are among the most damaging hydro-meteorological disasters, resulting in widespread loss of life and property worldwide (Nasir et al., 2020; Ahmad et al., 2021; Waqas et al., 2021; Chaithong, 2022; Majeed et al., 2023). Floods kill people (Mahmood & Rahman, 2019; Manzoor et al., 2022), demolish homes and infrastructure (Bukhari & Rizvi, 2016), wash away standing crops and orchards (Saeed et al., 2021), pollute the environment, and transmit diseases (Farooq et al., 2019; Xiong et al., 2019). The severity, frequency, length, and amplitude vary by country and region due to variations in climate, geography, socioeconomic development, and demography (Tariq & Giesen, 2012; Bukhari & Rizvi, 2016; Liu et al., 2020).

Floods have a significant impact on both human lives and the economy. Floods have killed about 100,000 individuals and impacted more than 1.5 billion people worldwide during the previous three decades. Flooding causes economic damages ranging from 50 to 60 billion US dollars annually. Floods account for almost one-third (1/3) of all geo-hydro-meteorological disaster injuries, deaths, and property destruction (Bukhari & Rizvi, 2016; Mahmood & Rahman, 2019). Floods cannot be avoided (Saeed et al., 2021), but the negative effects can be mitigated through good management, weather forecasting, early warning, hazard mapping, and modeling (Rahman and Shaw, 2015).

Flash flood hazard mapping and modeling are regarded as one of the most essential nonstructural measures (Nasir et al., 2020; Islam et al., 2020; Majeed et al., 2023). Flood hazard mapping is done using several models and methodologies (Islam et al., 2020; Waqas et al., 2021). The Supervised Classifier and NDWI Thresholding (Sing and Kansal 2022), CART (classification and regression tree), XGBoost (Abedi et al., 2022), CubbeSata model (Wang and Vivoni 2022), Morphometric Ranking Approach (MRA) (Nasir et al., 2020), and El-Shamey's Approach (Ahmad et al., 2020) are important models used for flash flood hazard mapping and zonation. However, Morphometric Ranking Approach is one of the most commonly used models for mapping flash flood susceptibility at the sub-watershed level (Asfaw & Workineh, 2019). Many researchers have used the Morphometric Ranking Approach (MRA) to map and model flash flood hazards. Nasir et al. (2020) used MRA to assess FF susceptibility in the Swat River Basin. Waqas et al. (2021), employed MRA to assess flash flood hazards in the Dir Lower, Khyber Pakhtunkhwa province. Elassal (2022) used MRA to assess the risk of flash flooding in the Kingdom of Saudi Arabia. Mahmood and Rahman used MRA to anticipate and forecast the extent and limitations of flash flood hazards in the Ushairy River basin. Elsadek et al. (2018) conducted a flash flood study using El-Shamy's technique in Wadi Qena (Egypt).

Globally, floods are increasing in frequency, intensity, and magnitude. Pakistan is one of the most flood-prone and devastated countries in the world. (Tariq & Giesen, 2012; Nasir et al., 2020; Ahmad et al., 2020; Huq et al., 2020; Bukhari & Rizvi, 2016; Iqbal et al., 2018; Mahmood & Rahman, 2019; Saeed et al., 2021; Majeed et al, 2023). Monsoon winds, western disturbances, and tropical cyclones along the coast are the primary causes of severe precipitation and flash floods in Pakistan (Yaqoob et al., 2015; Majeed et al., 2023). FFs are prevalent in the hilly slopes and foothills of Baluchistan and Khyber Pakhtunkhwa, particularly in the districts of Chitral, Swat, and Dir (Shah et al., 2024). District Khyber, located in the northwest of Khyber Pakhtunkhwa, is drained by the rivers Kabul, Bara, Chaura, and Khyber. The district is one of Khyber Pakhtunkhwa's flash flood-affected districts (Khan & Ali, 2019; Saeed et al., 2021). As a result, the current study aims to assess flash flood hazard susceptibility at the sub-watershed level of district Khyber using the Morphometric Ranking Approach. It is predicted that flash flood hazard modeling, analysis, and mapping will assist locals and relevant departments in developing effective flood mitigation policies for sustainable development.

2. Materials and Methods

The Study Area

District Khyber once known as Khyber Agency, is located in Khyber Pakhtunkhwa's province of Pakistan. Khyber Agency's administrative status was converted to district upon the merging of the FATA with Khyber Pakhtunkhwa (Shah et al., 2024). District Khyber encompasses an area of 2576 km^2 and extends from 33°45'N to 34°20'N, 70°30'E to 71°27' East (GoP, 2000). The district shares borders with Afghanistan in the northwest, Mohmand in the north, and Peshawar in the east. Kurram district is in the southwest, while Orakzai district is in the south (GoP, 1983; Shah, 2014; Khan et al., 2019; Shah et al., 2024) (Figure 1 depicts the location of the study area, district Khyber).

Topographically, the district is divided into two distinct regions: hilly terrain (Tirah and Landikotal) and plain lands (Bara and Jamrud). Tirah is mountainous and humid, whereas Landikotal, Bara, and Jamrud have arid to semi-arid climates (Khan, 2008). The Tirah region enjoys a good summer, whereas the plains face high temperatures. Summer temperatures range from 26°C to 40°C in the plains of Bara and Jamrud, and from 15°C to 30°C in the hilly terrain of Tirrah (GoP, 1972; Docherty, 2007). Tirah experiences cold winters, whereas the Bara and Jamrud plains enjoy pleasant weather. Western disturbances and monsoons are the primary precipitation sources in the district (Warburton, 2007; Khan, 2008; Shah, 2014). The district's mean annual rainfall is 400mm. The district is drained by the rivers Kabul, Bara, Chaura, and the Khyber Stream.

2.1 Data Collection

Table 1 depicts the selected 19 morphometric parameters, their symbols, and formulas that were used to determine the flash flood susceptibility at the sub-watershed level in district Khyber. The data regarding these morphometric parameters was acquired through the analysis of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER GDEM-2), acquired from the NASA EARTHDATA Open Access for Open Science website (https://www.earthdata.nasa.gov/sensors/aster). The ASTER GDEM has been utilized and favored by several researchers for morphometric analysis (Beg et al., 2023; Jamal & Ali 2023; El Mhamdi et al., 2024). The GDEM was processed in ArcMap 10.8 using the Arc Hydro tool to delineate the drainage network and boundaries of watersheds and sub-watersheds. ASTER GDEM-2 is used for drainage network extraction and sub-watershed delineation using the standard methodology described by various researchers (Banerjee et al., 2017; Sajadi et al., 2022; Dimpel et al., 2022).

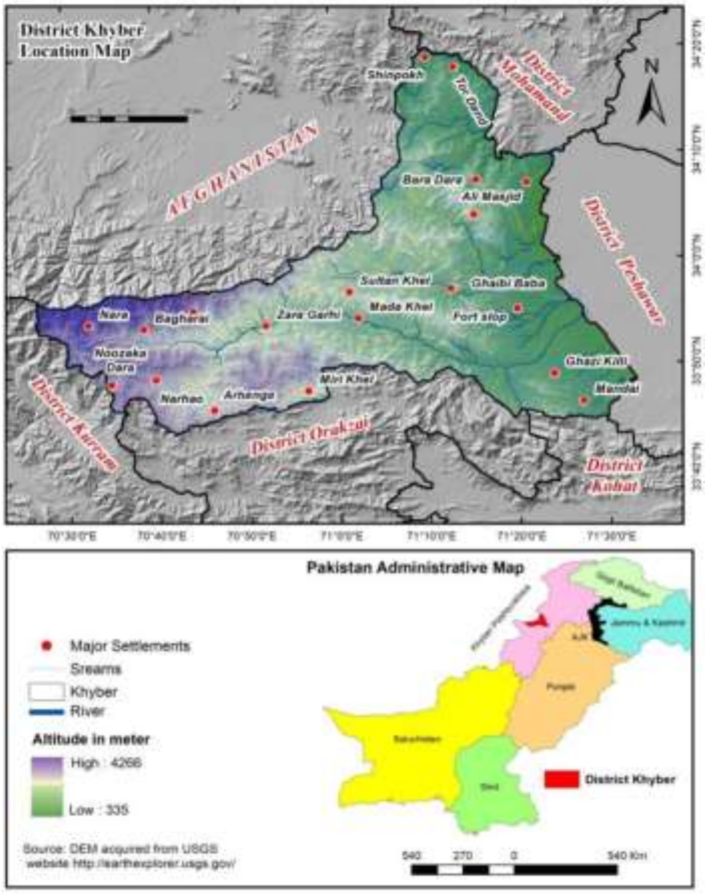

Figure:1 Location Map of District Khyber Source: Dem acquired from USGS website http:earthxplorer.usgs.gov/ www.grove.com.pk

2.2 Data Analysis

The following steps were involved in the data analysis

Fills and Sink

Fills and Sink is a process used to remove small depressions and elevation in a DEM dataset. These depressions and elevations can occur due to errors in data collection, or they may represent real features like small ponds or holes or peaks and ridges in the terrain. This aims to smooth out the terrain by filling these depressions and lowering the elevation with interpolated elevation values derived from the surrounding terrain.

Creation of Flow Direction Grid

A Flow Direction Grid, also known as a flow direction raster, is a fundamental component in hydrological modeling within GIS. It represents the direction of water flow at each cell in a Digital Elevation Model (DEM) grid. Each cell in the flow direction grid contains a code or value indicating the direction in which water would flow from that cell. Each cell in the spatial analyst toolbox had its flow direction identified using the "Flow Direction" tool.

Flow Accumulation
Flow Accumulation is a raster dataset commonly used in hydrological modeling and terrain analysis within GIS. It represents the cumulative flow of water through each cell in a Digital Elevation Model (DEM) grid. In simpler terms, it shows the total upstream area that contributes flow to each cell in the DEM. The number of cells that flow into each cell was determined by calculating the accumulated flow for each cell using the "Flow Accumulation" tool.

Stream Definition
A stream is typically defined as a continuous flow path of water that is represented by a sequence of connected cells with high flow accumulation values. Streams are usually delineated based on a threshold applied to the flow accumulation grid derived from the DEM. Cells with flow accumulation values above a certain threshold are considered part of the stream network. This threshold can be chosen based on factors such as the desired stream density or the size of the streams one wants to identify.

Stream Segmentation
Stream segmentation refers to the process of dividing a stream network into individual segments or reaches based on certain criteria. This segmentation is essential for further analysis and characterization of the stream network in hydrological studies and watershed management.

Stream Network Extraction

A stream link refers to a representation of a continuous flow path within a stream network. It's essentially a digital representation of a segment or reach of a stream. A stream link is a linear feature that represents a portion of a stream or river. It is typically defined by a sequence of connected cells in a raster grid or by line segments in a vector dataset. Using the "Stream Link" tool, a raster with stream cells with a value of 1 was created. Next, a vector representation of the stream connection raster was created by utilizing the "Raster to Polyline" tool. Next, the polyline was transformed into a feature class using the "Stream to Feature" tool.

Streams Ordering

Stream order, also known as Strahler stream order, is a method used to classify and organize the branches of a stream network based on their hierarchical structure. Developed by Arthur Newell Strahler in 1952, this system assigns a numerical order to each stream segment within a watershed based on the characteristics of its contributing tributaries. The "Stream Order" tool in Hydrology was used to classify the newly formed streams as first-order, second-order, third-order, and fourth-order streams. The methodology is explained in the flow chart depicted in figure 2.

Sub-watershed delineation
Watershed delineation is the process of identifying the boundaries of a drainage basin or watershed, which is an area of land where all surface water drains to a common outlet, typically a pour point. This process is fundamental in hydrology and GIS for understanding the flow of water across landscapes and for various water resource management applications. In watershed delineation, pour points serve as starting points for tracing the boundaries of individual drainage basins. Watershed boundaries are delineated based on the principle that all runoff within a basin ultimately converges at the pour point. Using the "Watershed" tool in the Spatial Analyst toolbox, the pour points were specified. In light of the flow accumulation raster, this defines the watershed.

2.3 Morphometric Ranking Approach (MRA)

The morphometric ranking approach is a method used in geomorphological analysis to classify and rank drainage basins based on their morphometric characteristics. These characteristics include various parameters derived from the geometry and topography of the drainage basin, such as shape, relief, and drainage pattern. The approach aims to quantitatively assess the relative importance and behavior of different basins within a region. In the context of flash flood risk assessment, the morphometric ranking approach plays a crucial role in identifying and prioritizing areas that are more susceptible to flash flooding based on their geomorphological characteristics. The morphometric ranking Approach (MRA) is one of the most extensively applied models used for flash flood risk analysis (Mahmood & Rahman, 2019; Nasir et al., 2020; Singh & Kansal 2023; Dutal, 2024). The following steps are involved in the analysis:

Computing of Morphometric Parameters

For the present study, a total of nineteen (19) morphometric parameters were derived using the above-mentioned methodology and were subsequently utilized to assess the flash flood susceptibility at the sub-watershed level.

Grouping of Morphometric Parameters

Based on the available literature, the morphometric parameters are classified into two groups. The Group1 parameters have a direct relationship with the flash flood genesis. It means that the higher the numerical value of the parameter higher the peak flow. These include Stream density (D_d), drainage frequency (Fs), Sub-watershed Area(A), Total streams of sub-watershed (N_u), Total stream length (L_u), Stream order (S_o), Basin relief (Bh), Relief ratio (Rr), Circularity ratio (C_r), Gradient (G) and Bifurcation ratio (R_b).

Group 2 includes those parameters which have an inverse relation with peak flow. It means that the greater the value of the parameter lower the peak flow and vice versa. These include the Elongation ratio (Er), Shape or form factor (Bs), Overland flow length (L_o), Compactness coefficient (C_c), Geometry number (G_n), and Ruggedness number (R_n).

Standardization of Parameters

The computed geo-morphometric parameters will be expressed in different units. These will be standardized using the following two equations. Equation 1 will be used for group 1 parameters while equation 2 will be used for group 2 parameters. The standardized values of the morphometric parameters range from 1 to 5. Where 1 means low hazard degree and 5 means highest degree of hazard for group 1 parameters while for group 2 morphometric parameters the higher the numerical value of the parameter, the lower the peak flow. These values are summed up to get the cumulative ranking score of the watershed.

$$Risk\ Score = 4 \times \left(\frac{X - Xmin}{Xmax - Xmin}\right) + 1 \dots\dots\dots\dots\dots\dots\dots..Eq.1$$

$$Risk\ Score = 4 \times \left(\frac{X - Xmax}{Xmin - Xmax}\right) + 1 \dots\dots\dots\dots\dots\dots.Eq.2$$

$Where\ X = the\ parameter\ value\ under\ consideration; Xmin\ is\ the\ minimum\ parameter\ value\ and\ Xmax = maximum\ parameter\ value\ in\ the\ parameter\ class$

Ranking of Morphometric Parameters

As an outcome, every morphometric parameter (MP) becomes more consistently expressed in comparison to the same value in other sub-watersheds, indicating its level of vulnerability. Five grade classes are assigned to every MP. Rankings of 5 and 1 correspond to high risk and low risk, respectively, for the following variables: (A), (N_u), (U), (L_u), (L), (W), (R_{lw}), (D_d), (F_s), (R_b), (C_r), and (D_t). While rank 5 signifies minimum risk and rank 1 signifies maximum risk for (Rn), (Er), (Lo), (Gn), and (Bs), respectively.

Flash Flood Susceptibility Ranking

Each ranking of the morphometric parameter in each sub-watershed (the result of the previous step) is totaled and divided and subsequently classified into three classes: Low flash flood susceptible zone, Moderate flash flood susceptible zone, and High Flash flood susceptible zone.

Flash Flood Susceptibility Map

Creation of a flash flood susceptibly map of the study area at the sub-watershed level has been carried out. Figure 2 depicts the flow chart of data analysis which will be adopted to analyze the flash flood Risk at the sub-watershed level of the study area through the MR approach. The methodology is explained in the flow chart depicted in Figure 2.

Table 1 Morphometric parameters

S.No	*Parameters*	*Symbols/Unit*	*Formula*	*Reference*
1	*Area*	A (Km^2)	$A = Area\ of\ the\ Basin$	*Horton*, 1945,
2	*Length*	$Lb(Km)$	$L = length\ of\ basin$	*Horton*; 1945
3	*Perimeter*	$P(Km)$	$P = Basin\ Perimeter$	*Horton*, 1945
4	*Stream Order*	Lo	$Hierarchical\ Rank$	*Srahler*, 1957
5	*Streams Number*	Nu	$Nu = N1 + N2 \ldots Nu$	*Horton*, 1945
6	*Streams length*	$Lu(Km)$	$Lu = L1 + L2 \ldots Lu$	*Strahler*, 1957
7	*Stream frequency*	Fs	$Fs = Nu/A$	*Horton*, 1945
8	*Drainage Density*	$Dd(^{Km}/_{Km^2}$	$\mathrm{Dd = Lu/A}$	Horton, 1945
9	Bifurcation Ratio	Rb	$\mathrm{Rb} = \frac{\mathrm{Nu}}{\mathrm{Nu+1}}$	Horton, 1945
10	Relief	Bh(m)	$\mathrm{Bh = Hmax - Hmin}$	Schuman, 1956
11	Relief Ratio	Rr	$\mathrm{Rr = Bh/Lb}$	Schuman, 1956
12	Gradient	G(Degree)	$\mathrm{G} = \frac{\mathrm{Bh}}{\mathrm{Lb} \times 60}$	Mahmood, 2018
13	Circularity Ratio	Cr	$\mathrm{Cr} = 4 \times 3.14\mathrm{A/P^2}$	Miller, 1953
14	Elongation Ratio	Er	$\mathrm{Er} = 1.128(\mathrm{A})^{1/4}\mathrm{L^b}$	Schuman, 1956
15	Basin Shape Factor	Bs	$\mathrm{Bs = Lb^2/A}$	Horton, 1945
16	Overland flow length	Lo	$\mathrm{Lo} = 0.5 \times 1/\mathrm{Dd}$	Horton, 1945
17	Ruggedness Number	Rn	$\mathrm{Rn = Dd} \times (\frac{\mathrm{Bh}}{1000})$	Strahler, 1964
18	Geometry Number	Gn	$\mathrm{Gn = Bh \times Dd/G}$	Strahler, 1964
19	Compactness coefficient	Cc	$\mathrm{Cc} = 0.2812 \times \mathrm{P}/\sqrt{\mathrm{A}}$	Horton, 1945

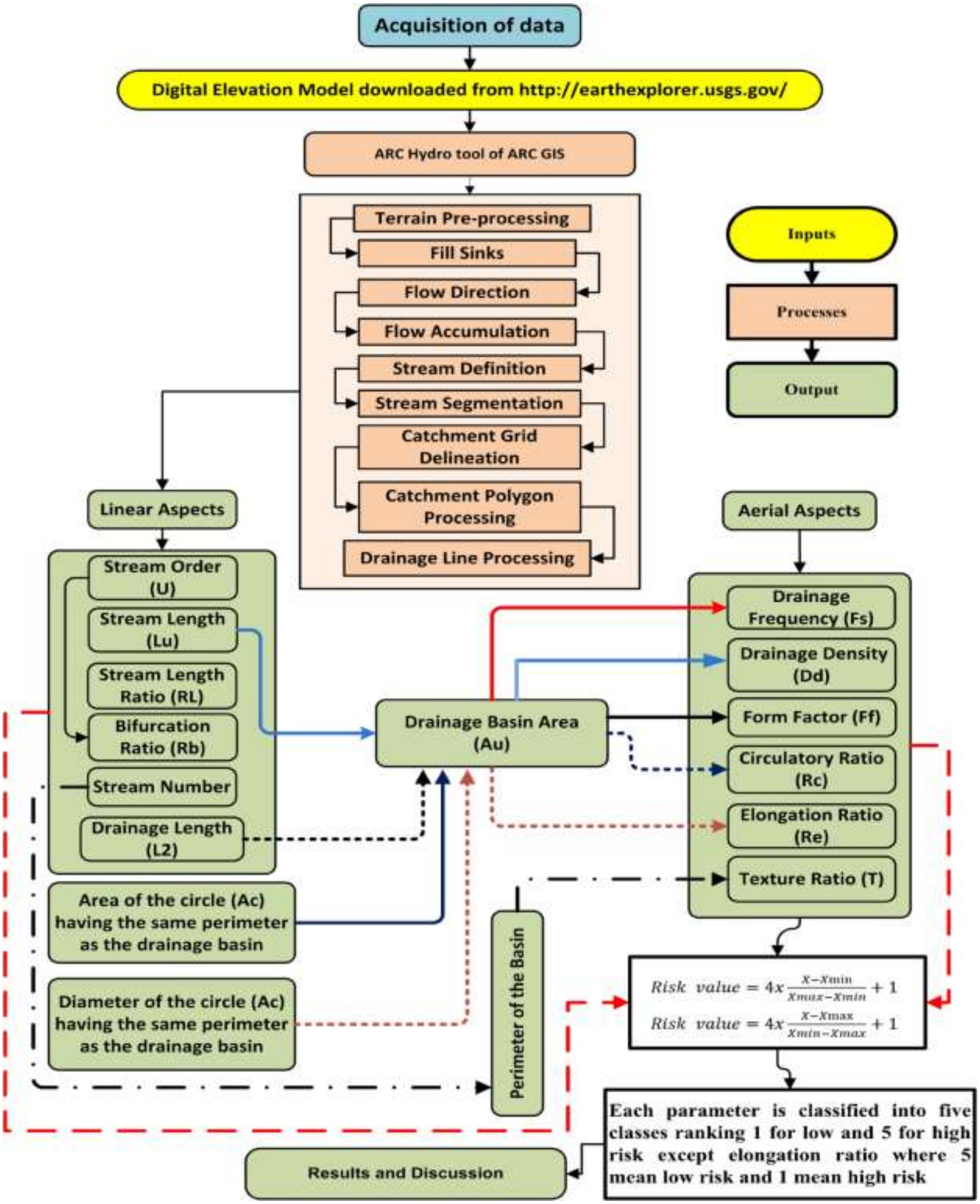
Acquisition of data
Digital Elevation Model downloaded from http://earthexplorer.usgs.gov/
ARC Hydro tool of ARC GIS
Terrain Pre-processing
Fill Sinks
Flow Direction
Flow Accumulation
Stream Definition
Stream Segmentation
Catchment Grid Delineation
Catchment Polygon Processing
Drainage Line Processing
Inputs
Processes
Output
Linear Aspects
Stream Order (U)
Stream Length (Lu)
Stream Length Ratio (RL)
Bifurcation Ratio (Rb)
Stream Number
Drainage Length (L2)
Area of the circle (Ac) having the same perimeter as the drainage basin
Diameter of the circle (Ac) having the same perimeter as the drainage basin
Drainage Basin Area (Au)
Perimeter of the Basin
Aerial Aspects
Drainage Frequency (Fs)
Drainage Density (Dd)
Form Factor (Ff)
Circulatory Ratio (Rc)
Elongation Ratio (Re)
Texture Ratio (T)
$Risk\ value = 4x\frac{X-Xmin}{Xmax-Xmin}+1$
$Risk\ value = 4x\frac{X-Xmax}{Xmin-Xmax}+1$
Each parameter is classified into five classes ranking 1 for low and 5 for high risk except elongation ratio where 5 mean low risk and 1 mean high risk
Results and Discussion

Figure 2 Methodology flowchart for Flash Flood susceptibility analysis through Morphometric Ranking Approach.

3. Results and Discussion

Impact of Morphometric Parameters on Flash Flood Genesis

Table 2 depicts the group one morphometric parameter value at the sub-watershed level. Table 3 depicts the group two morphometric parameter value at the sub-watershed level.

Table 2 Sub-watershed Group one Morphometric Parameters value

Sub-Watersheds	Basic Morphometric Parameters							Derived Morphometric Parameters						
	Group One Morphometric Parameters													
	SW Area (Sq. Km)	SW Perimeter (Km)	Stream Order	Stream Number	Stream Length (Km)	SW Length	SW Relief	Drainage Density	Stream Frequency	Relief Ratio	Gradient	Circularity Ratio	Bifurcation Ratio	Elongation Ratio
SW-1	216.57	71.21	4	85	152.73	24	2432	0.705	0.392	0.10	6.08	0.54	4.02	0.68
SW-2	221.60	72.30	4	98	189.57	16	1341	0.855	0.442	0.08	5.02	0.53	4.45	1.05
SW-3	52.48	37.00	3	18	45.36	13	984	0.864	0.342	0.08	4.54	0.48	3.625	0.63
SW-4	41.15	35.71	3	15	27.05	12	1874	0.657	0.364	0.15	9.37	0.41	4.00	0.60
SW-5	50.25	37.00	3	18	34.41	12	1213	0.684	0.358	0.10	6.07	0.46	3.625	0.67
SW-6	48.40	35.44	4	20	39.74	7	733	0.82	0.413	0.10	6.29	0.48	2.416	1.13
SW-7	83.00	57.00	4	36	91.76	12	1478	1.105	0.433	0.12	7.39	0.32	3.11	0.86
SW-8	55.00	41.00	3	25	73.45	16	1249	1.335	0.454	0.08	4.68	0.41	2.916	0.52
SW-9	108.00	60.21	3	42	98.04	20	1217	0.907	0.388	0.06	3.65	0.37	6.062	0.59
SW-10	72.39	43.00	3	29	58.7	11	1132	0.810	0.400	0.10	6.17	0.49	3.25	0.87
SW-11	175.00	79.32	4	71	140.00	24	1472	0.80	0.405	0.06	3.68	0.35	3.86	0.62
SW-12	25.51	26.23	3	12	23.55	8	1117	0.923	0.470	0.14	8.37	0.47	2.833	0.71
SW-13	57.39	39.00	3	29	46.1	11	1422	0.803	0.505	0.13	7.74	0.47	4.8	0.78

SW-14	83.00	49.00	3	35	76.8	13	1061	0.925	0.421	0.08	4.90	0.43	5.33	0.79
SW-15	45.23	40.30	3	15	45.88	14	918	1.014	0.330	0.07	3.93	0.35	3.33	0.54

Table 3.
Sub-watershed Group Two Morphometric Parameters value

Sub-Watersheds	Group Two Morphometric Parameters				
	Basin Shape Factor	Ruggedness Number	Geometry Number	Compactness Coefficient	Length of Overland Flow
SW-1	2.66	1.71	0.28	1.36	0.70
SW-2	1.16	1.14	0.22	1.37	0.58
SW-3	3.22	0.85	0.18	1.44	0.57
SW-4	3.50	1.23	0.13	1.57	0.76
SW-5	2.87	0.82	0.13	1.47	0.73
SW-6	1.01	0.60	0.09	1.42	0.60
SW-7	1.73	1.63	0.22	1.76	0.45
SW-8	4.65	1.66	0.35	1.56	0.37
SW-9	3.70	1.10	0.30	1.63	0.55
SW-10	1.67	0.91	0.14	1.42	0.61
SW-11	3.29	1.17	0.32	1.69	0.62
SW-12	2.51	1.03	0.12	1.46	0.54
SW-13	2.11	1.14	0.14	1.45	0.62
SW-14	2.04	0.98	0.20	1.51	0.54
SW-15	4.33	0.93	0.23	1.69	0.49

Sub-watershed Area (A)

The sub-watershed area is the most important watershed feature that influences runoff. The larger the watershed, the more water may be harvested and the greater the possibility of flooding. All other morphometric parameters are more or less proportional to the watershed area. Larger watersheds have larger streams and a higher drainage density (Horton, 1945). In terms of area, sub-watershed no.2 (221.60 km^2) is the largest, and sub-watershed no.12 (25.51 km^2) is the smallest in district Khyber. The size and characteristics of a watershed can influence the frequency and severity of floods in a variety of ways. The amount of rainfall that a watershed receives is an important consideration (Nasir et al., 2020; Ahmad et al., 2021).

Sub-watershed Perimeter (P)

Perimeter (P) is the outside limit of a watershed and is measured in kilometers (Km). The watershed perimeter, also known as the watershed boundary or catchment area boundary, has the potential to substantially affect flooding (Horton, 1945). The form and size of the watershed's perimeter influence the drainage characteristics of the area. Larger watersheds with longer perimeters may retain more water, boosting the risk of flooding, especially following severe or prolonged rainfall events. A watershed's perimeter also determines the capacity of the rivers and streams that flow through it, wider perimeters encompass larger territories, where water discharge into the canals may exceed their capacity, resulting in flooding. (Mokarram & Sathyamoorthy, 2016; Mahmood & Rahman, 2019). In the study area, sub-watersheds 11,2,1 have the longest perimeters of 79.32 km, 72.30 km, and 71.21 km, respectively indicating a significant susceptibility to flash floods.

Sub-watershed Length (Lb)

Watershed length (Lb) is the length of a line drawn parallel to the main stream channel, measured in kilometers. The size or length of a watershed is a key factor in determining flooding risk. Longer watersheds have a larger area, which enables them to accumulate more rainfall (Horton). If there is a lengthy period of heavy rainfall, a larger watershed has more surface area to collect and channel water into rivers and streams. Longer watersheds often have a longer concentration time since water takes longer to flow through the system. This longer period of concentration might lead to delayed peak flows and prolonged flood events (Horton, 1945; Ghany, 2015, Chaithong, 2022). SW-11 (24 kilometers), SW-1 (24 kilometers), and SW-9 (20 kilometers) are the longest Sub-Watersheds in district Khyber, while SW-6 (7 Km) is the shortest.

Sub-watersheds Relief and Gradient

Relief (Bh) and gradient (G) are key watershed morphometric factors. The greater the relief and gradient, the faster the velocity of running water, and thus the rate of soil erosion. Watersheds with high relief and gradient are prone to flash flooding. Relief refers to elevation variations in the landscape, whereas gradient refers to the slope or steepness of the ground. The gradient of the landscape influences the pace with which water flows. Steeper slopes lead to faster runoff because water moves downward more quickly. Water can accumulate quickly in regions with steep gradients and abrupt elevation changes, resulting in a rapid and powerful flow downstream (Hadley & Schuman, 1961; Ahmad et al., 2021; Nasir et al., 2020). In the study area, the sub-watersheds (SW-1) have the highest value of watershed relief (2432 m) and hence high potential for flash flooding. The slope is the most important geo-morphometric parameter which affects the time to peak discharge of a watershed after rainfall.

Sub-watersheds Stream Number (Nu)

The total number of drains and channel lines within a watershed is known as the stream number or number of streams (Nu). A higher concentration of streams is indicative of a drier environment, minimal vegetation cover, a deep water table, and barren, hard, impermeable rocks. Flooding is more likely to occur in areas with more streams than in regions with fewer streams. However, the width, depth, and slope of individual streams might affect the genesis of flash floods. When it rains heavily, a network of tiny streams may be more vulnerable to sudden increases in water levels than a network of wider, more stable streams (Horton,1945; Strahler, 1957; Farhan & Anaba, 2016; Mahmood & Rahman, 2019). With 98 streams, the sub-watershed-2(SW-2) in district Khyber has the most. A high Nu value denotes a significant risk of flash floods.

Sub-watersheds Stream Order (U)

Stream order describes how rivers or streams are arranged in a hierarchy according to where they are in a drainage network. The Strahler stream order system, which classifies streams according to the tributary hierarchy, is frequently linked to the idea of stream order. First-order stream segments are the smallest, unbranched drains within a watershed. When two or more first-order streams are joined, they create second-order streams, which are joined to create third-order streams, and so on. Greater watershed sizes and drainage areas are frequently correlated with higher stream orders. The stream order in the studied area varies from third to fourth order (Strahler, 1957; Farhan et al., 2016; Farhan & Anaba, 2016). While the SWs 3, 4, 5, 8, 9, 10, 12, 13, 14, and 15 are drained by third-order streams, the sub-watersheds 2, 6, 7, and 11 have fourth order streams.

Sub-watersheds Length of Overland flow (L_o)

The length of overland flow is denoted by L_o. This crucial morphometric parameter depicts the physiography of a watershed. Overland flow length is the distance traveled by flowing water before it concentrates into specific stream channels. L_o is determined by the slope, relief, and lithology of the watershed. High L_o values indicate plain topography, hard impermeable rocks, and low drainage density, and vice versa. The length of the overland flow has a considerable impact on flash flooding since it determines the speed and volume of water that reaches a certain region. It determines the amount of water that can be conveyed. Shorter overland flow pathways typically result in faster reactions to rainfall events. Longer overland flow pathways, on the other hand, may take some time for water to accumulate downstream. This lag time can be critical in flash flooding scenarios because it influences the rate at which floodwaters rise (Horton, 1945; Ahmad et al., 2021; Nasir et al., 2020). In the current study, SW-8 has the lowest Lo value of 0.37, while SW-4 has the highest value (0.76) of overland flow length (Table 4.1).

Sub-watersheds Circularity Ratio (C_r)

In hydrology and geomorphology, the circularity ratio is used to assess the shape of a watershed. It is defined as the ratio of a watershed's size to the square of its perimeter. The circularity ratio is a dimensionless quantity that spans between 0 and 1. A fully circular watershed has a circularity ratio of one, but irregularly shaped watersheds have smaller circularity ratios. Watersheds with higher circularity ratios typically have a more efficient runoff system. This is because a circular structure reduces the distance from any point in the watershed to the outflow, resulting in a faster runoff response. Circular watersheds often disperse rainfall more evenly throughout their area, preventing concentrated flow routes. Irregularly formed watersheds with lower circularity ratios may have regions where runoff concentrates more, resulting in localized flash flooding. Circular watersheds frequently have higher drainage density, implying a denser network of streams and channels. This can speed up the conveyance of water, increasing the risk of flash floods (Miller, 1953; Ghany, 2015; Mokarram & Sathyamoorthy, 2016). In district Khyber, SW-1 has the highest circularity ratio (0.54) and SW-7 has the lowest (0.32).

Sub-watersheds Drainage Density (Dd)

Drainage density is defined as the total length of stream segments per km^2 of watershed. It is represented as Km/Km^2. Drainage density is the concentration of streams and channels in a particular area. The relationship between drainage density and flash flooding is complex and influenced by a variety of factors. Watersheds with a large number of streams have high Dd. Watersheds with high drainage density feature steep slopes, high relief, impermeable soil and rocks, and little vegetation cover. Watersheds with low Dd, on the other hand, are usually found in flat areas with low relief and moderate slopes, significant plant cover, and highly permeable soil and lithology. The bigger the Dd number, the more susceptible to discharge and flash flooding (Horton, 1945; Asfaw & Workineh, 2019; Chaithong, 2022). In the present study, sub-watershed-8 has the highest Dd value (1.335 km^2), whereas SW-4 has the lowest Dd value (0.657 km^2).

Sub-watersheds Stream Frequency (F_s)

Stream frequency, denoted by Fs, is the number of streams per Km^2 of watershed/sub-watershed. Stream frequency is directly proportional to drainage density. The greater the Fs, the higher the drainage density, and vice versa. Watersheds with impermeable lithology, steep slopes, and low vegetation cover have high stream frequencies. Stream frequency is proportional to the time it takes for water to flow from the farthest point in a watershed to the outflow. A greater stream frequency may reduce the time it takes for rainfall-runoff to reach the main channel, thus leading to faster response times and a higher danger of flash floods (Horton, 1945; Singh et al., 2014; Farhan et al., 2016). SW-13 has the highest Fs value in Khyber district, at 0.505. The SW-15 has the lowest stream frequency value (0.330) (Table 4.1).

Sub-watersheds Ruggedness Number (R_n)

R_n denotes the surface roughness of a watershed. Rough surfaces reduce the speed of flowing water. The ruggedness Number (Rn) is a geomorphological quantity used to gauge the roughness or harshness of the terrain. It is frequently used in hydrology and hydraulic studies to better understand the effects of terrain characteristics on various processes, such as flash floods. A greater Ruggedness Number corresponds to more difficult or steep terrain. Steeper slopes can accelerate surface runoff, potentially resulting in faster and more violent flash floods. Watersheds with high R_n values are less susceptible to flash flooding. Table 4 illustrates the Rn values in the district Khyber. (Strahler, 1964; Farhan & Anaba, 2016, Mahmood & Rahman, 2019). SW-1 is the sub-watershed with the most difficult topography in the research area with an Rn score of 1.71. The sub-watershed-6 has the lowest value, 0.60. Watersheds in the higher reaches have high values of R_n.

Sub-watersheds Shape Factor (B_s)

Symbolically, the basin shape factor is represented by B_s and is defined as the ratio of the basin length squared to the basin/watershed area. The basin shape, a measure of a watershed's elongation or compactness, influences how rapidly precipitation accumulates and drains in a given area. Longer basins take longer to peak, which reduces the likelihood of flooding. The basin shape has an inverse relationship with flash flood susceptibility. The higher the B_s, the lower the sensitivity to flash floods, and vice versa. In the current study, the SW-8 has the highest value (Table 4.1) of Bs which is 4.65 while the lowest value of 1.01 has been recorded by the SW-6. Understanding the basin shape factor is critical for hydrologists and urban planners when determining the flash flood risk in a certain area. It aids in the development of effective stormwater management systems as well as the implementation of mitigation measures to reduce the impact of flash floods (Horton, 1945; Ahmad et al., 2021; Nasir et al., 2020).

Sub-watersheds Compactness Coefficient (C_c)

The compactness coefficient (C_c) assesses the form or shape of a watershed or drainage basin. It is defined as the watershed's area divided by its perimeter squared. The compactness coefficient influences runoff characteristics and the possibility of sudden and strong flooding. Compact watersheds have higher flow concentration, which means that a greater amount of rainfall quickly accumulates and flows into river systems. This concentration of flow can contribute to rapid rises in river levels and an increased likelihood of flash flooding (Horton, 1945, Mahmood & Rahman, 2019; Ghany, 2015). In district Khyber, the SW-1 has the lowest (1.36) Cc while the SW-7 has recorded the highest value of 1.76. Table 4.1 depicts the Cc values in the study area. The greater the value of the compactness coefficient lower the surface run-off and vice-versa.

Sub-watersheds Geometry Number (G_n)

The geometry number (G_n) is a dimensionless parameter that measures the impact of channel shape on flow characteristics. In the context of flash flood genesis, it can have serious consequences. The value of G_n is determined by the density of streams and the relief of the basin. Drainage basins with high relief typically have high drainage density, and thus high G_n. The geometry number has an inverse relationship with the threat of flash floods. High Gn values reduce flash flood vulnerability, while low Gn values increase flash flood susceptibility (Strahler, 1964; Farhan & Anaba, 2016; Asfaw & Workineh, 2019). In the current investigation, SW-8 has the highest Gn value and SW-12 has the lowest geometry number (Table 4.1, Figures 4.30, 4.31).

Sub-watersheds Bifurcation Ratio (R_b)

In the context of river or stream networks, the bifurcation ratio is a geometric quantity that defines the network's branching pattern. It is defined as the number of low-order stream channels divided by the number of higher-order stream channels in a watershed. The R_b can affect a variety of hydrological processes, including flash flooding. A network with a larger R_b ratio may disperse water more evenly among the downstream channels, potentially lowering the risk of flash flooding in any particular channel. The higher the bifurcation (Rb), the lesser the flash flood susceptibility. Lowering the value of Rb increases the susceptibility to flash flooding (Horton, 1945; Mokarram & Sathyamoothy, 2016). In the research region, sub-watershed 9 has the greatest Rb value of 6.062, while sub-watershed 12 has the lowest bifurcation value of 2.833.

4. Flash Flood Hazard (FFH) Zonation

The overall morphometric ranking score of sub-watersheds varies between 42 to 68. Based on the ArcMap natural breaks (Jenks) classification method the overall ranking score is classified into 3 classes. Sub-watersheds with the overall morphometric ranking score greater than 55 were classified as highly susceptible to flash flooding, those having 48-54 were grouped as highly susceptible, sub-watersheds having a morphometric ranking score < 48 were considered moderately susceptible and sub-watersheds with the morphometric ranking score below 45 are grouped as low susceptible to flash flooding. Tables 3 depict the calculated group 1 & 2 morphometric parameters value and their flash flood susceptibility ranking based on the procedure described in section 2.3.

High Susceptible Sub-watersheds

Based on the MRA, the SW-1, SW-2 SW-6, SW-7, SW-1, SW-12, and SW-13 are included in the high flash flooding susceptible zone. These seven Sub-watersheds cover an area of 745.4 Km^2, which accounts for 46.66% of all the sub-watersheds. These sub-watersheds are the largest in terms of area and perimeter. The high flash flood hazard Sub-watersheds are located in the upper reaches characterized by mountainous topography, high relief, steep slopes, and humid climate.

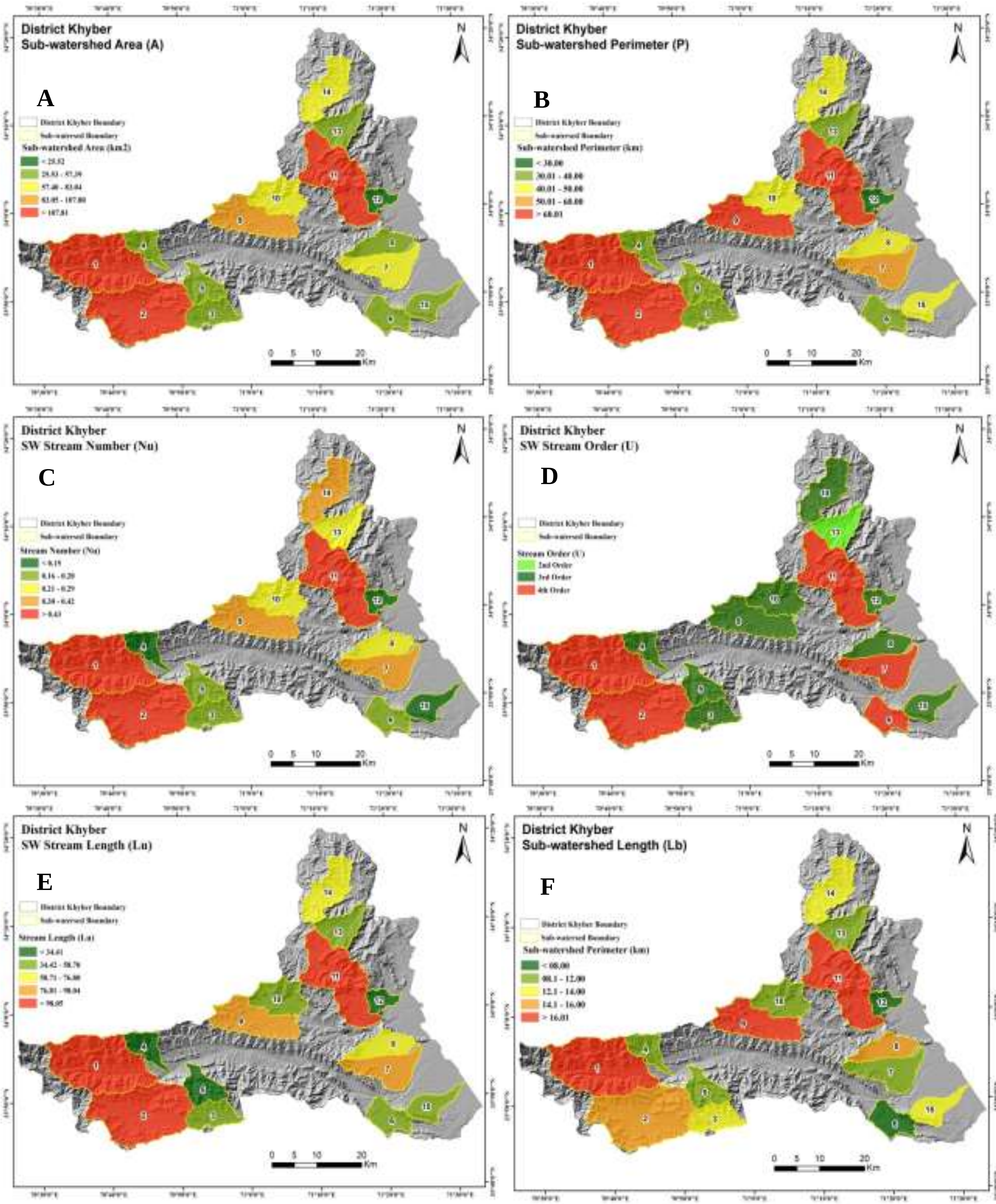

Figure 3. ***(A)*** Sub-watershed Area, (A); ***(B)*** Sub-watershed Perimeter (P); ***(C)*** Sub-watershed Stream Number (N_u); ***(D),*** Sub-watershed Stream Order (U); ***(E)*** Sub-watershed Stream Length (L_u); ***(F)*** Sub-watershed Length (L_b).

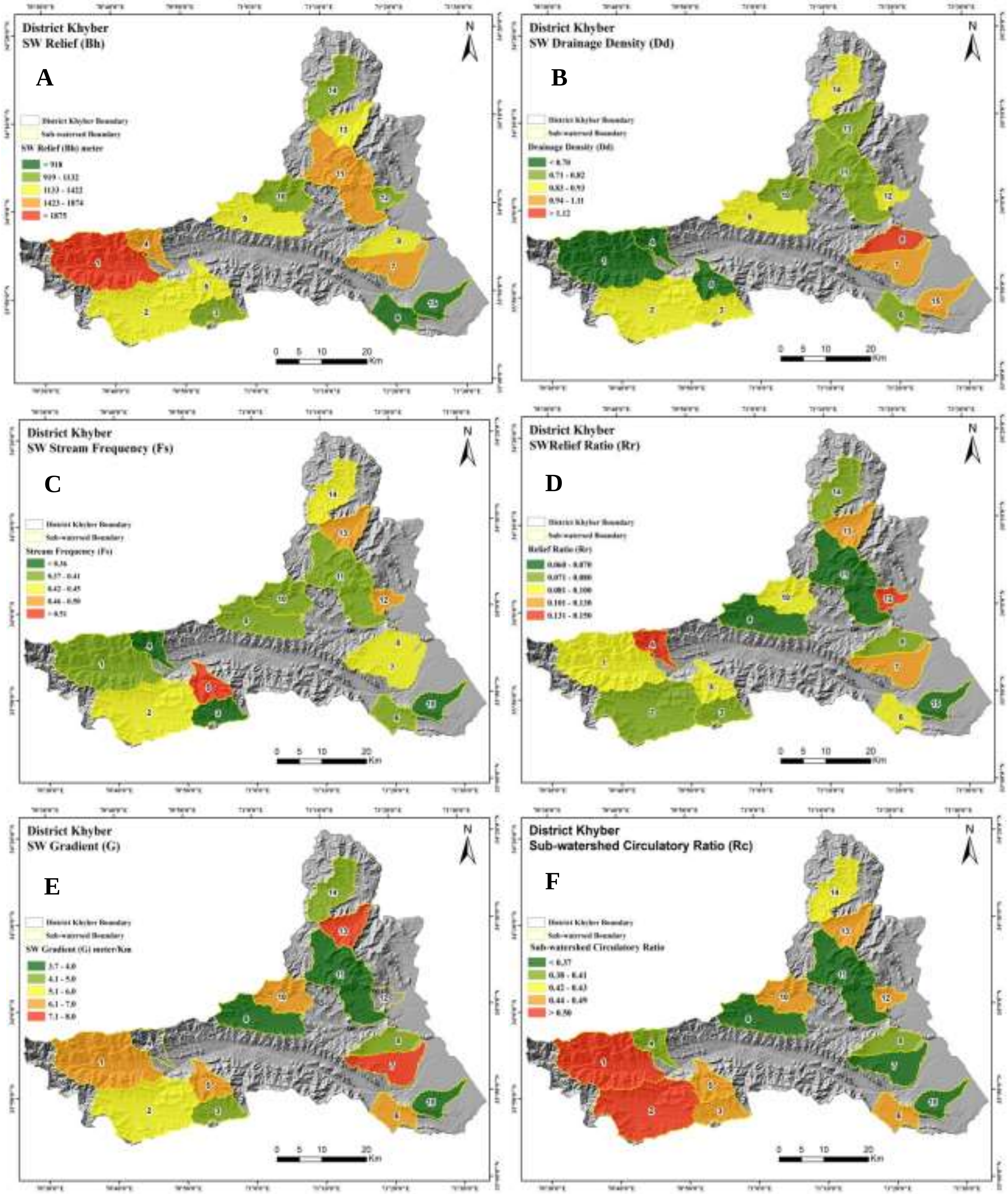

Figure 4. ***(A)*** Sub-watershed Relief, (Bh); ***(B)*** Sub-watershed Drainage Density (Dd); ***(C)*** Sub-watershed Stream Frequency (Fs); ***(D),*** Sub-watershed Relief Ratio (Rr); ***(E)*** Sub-watershed Gradient (G); ***(F)*** Sub-watershed Circulatory Ratio (Rc).

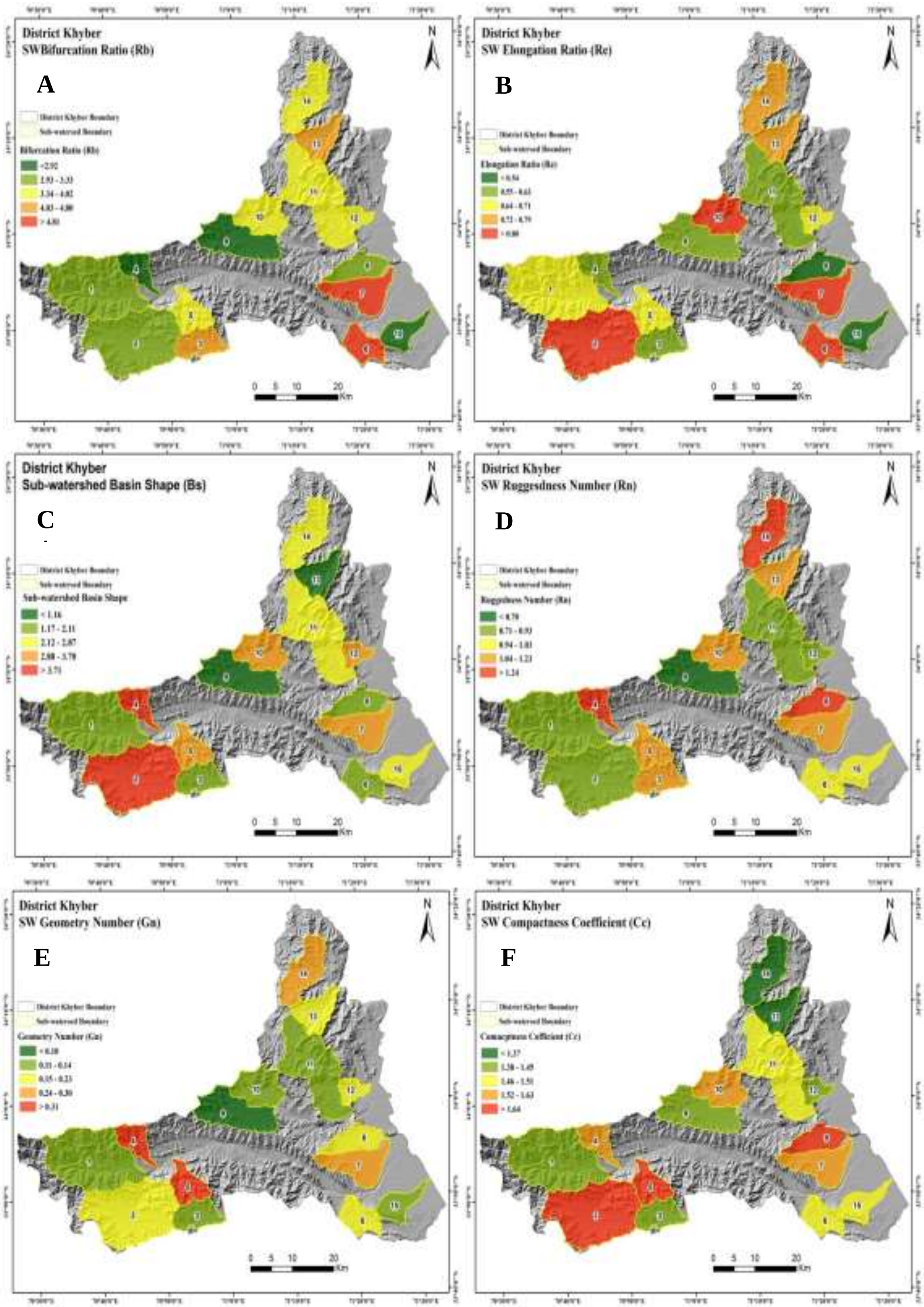

Figure 5. ***(A)*** Sub-watershed Bifurcation Ratio (R_b); ***(B)*** Sub-watershed Elongation Ratio (R_e); ***(C)*** Sub-watershed Basin Shape (B_s); ***(D),*** Sub-watershed Ruggedness Number (R_n); ***(E)*** Sub-watershed Geometry Number (G_n); ***(F)*** Sub-watershed Compactness Coefficient (C_c).

These Sub-watersheds also have high drainage density and stream frequency. The two Sub-watersheds have 4th-order streams with stream lengths of 152.73km and 189.57km respectively. In these sub-watersheds out of 19 selected morphometric parameters, 07 parameters i.e. SW Area, stream order, stream length, basin relief, basin length, circulatory ratio, and compactness coefficient have the highest MR score.

The Highly susceptible flash flood hazard zone (FFH) includes those Sub-watersheds that have a morphometric ranking score is > 55. Sub-watershed SW-11 drains parts of Landi Kotal which are located along the Pak-Afghan highway and sheds its water into the Khyber Stream. In the rainy season, flash flooding is a frequent phenomenon causing widespread losses. Sub-watershed 6 drains parts of district Orakzai and the South-eastern parts of district Khyber. This watershed collects its water from high mountainous areas. Sub-watershed 7 is located in the foothills of the Khajoori area in sheds its water in Hisara Khwar. construction of flash flood mitigation structures is highly recommended for the protection of life and property in these areas. Figure 4.44 shows the sub-watersheds flash flood susceptibility map of District Khyber, showing damage to the railway line by flash flooding in SW-12, which is highly susceptible to flash flooding.

Zone of moderate susceptibility

The zone of moderate flash flood susceptibility covers an area of 334.44 Km^2 which accounts for 26.67% of all the Sub-watersheds of the study area. This includes those sub-watersheds which have morphometric ranking scores between 49-54. There are 04 sub-watersheds that constitute the moderate FFH zone SW-3, SW-8, SW-10, and SW-14. The SW-4 drains areas of Rajgal and SW-10 draws its water from Bazar Zakha Khel. The SW-14 drains the upper parts of Landi Kotal and sheds its water into River Kabul.

Zone of low susceptibility

The low flash flooding susceptible zone includes 04 Sub-watersheds. These include SW-4, SW-5, SW-9 and SW-15 (26.67% of the total sub-watersheds). The Sub-watersheds of low susceptibility covers an area of 255.96 km^2. In this class, those Sub-watersheds are included which have morphometric ranking scores between 41-48. Figure 4.43 shows the percentage of sub-watersheds with different flash flood susceptibility classes.

Table 4. Morphometric Parameters Ranking Score

Sub-Watersheds	Group One Morphometric Parameters												Group Two Morphometric Parameters							
	SW Area	SW Perimeter	Stream Order	Stream Number	Stream length	SW length	SW Relief	Relief Ratio	Gradient	Drainage density	Drainage frequency	Circularity Ratio	Bifurcation Ratio	Elongation Ratio	Basin Shape factor	Length of Overland	Ruggedness Number	Geometry Number	Compactness	Rank Score
1	5	4	5	4	4	5	5	3	3	1	2	5	1	4	3	2	1	2	2	66
2	5	4	5	5	5	3	2	2	2	2	4	5	3	2	5	3	3	3	3	68

3	2	2	1	1	2	2	2	2	2	2	1	4	4	4	3	3	4	4	4	49
4	1	2	1	1	1	2	4	5	5	1	2	3	3	4	2	1	3	4	4	48
5	2	2	1	1	1	2	2	3	3	1	2	4	4	4	3	1	4	4	4	48
6	1	2	5	1	1	1	1	3	3	2	3	4	5	1	5	3	5	5	5	55
7	2	3	5	2	3	2	3	4	4	4	3	1	1	3	4	4	1	3	3	56
8	2	2	1	2	2	3	2	2	2	5	4	3	1	5	1	5	1	1	1	50
9	3	4	1	2	3	4	2	1	1	2	2	2	3	5	2	3	3	2	2	45
10	2	2	1	2	2	2	2	3	3	2	3	4	4	3	4	3	4	4	4	54
11	4	5	5	4	4	5	3	1	1	2	3	2	3	4	2	2	3	1	1	56
12	1	1	1	1	1	1	2	5	4	3	4	4	3	4	3	3	3	5	5	55
13	2	2	1	2	2	2	3	4	4	2	5	4	3	3	4	2	3	4	4	55
14	2	3	1	2	2	2	2	2	2	3	3	3	4	3	4	3	4	3	3	50
15	1	2	1	1	2	3	1	1	1	3	1	2	4	5	1	4	4	3	3	42

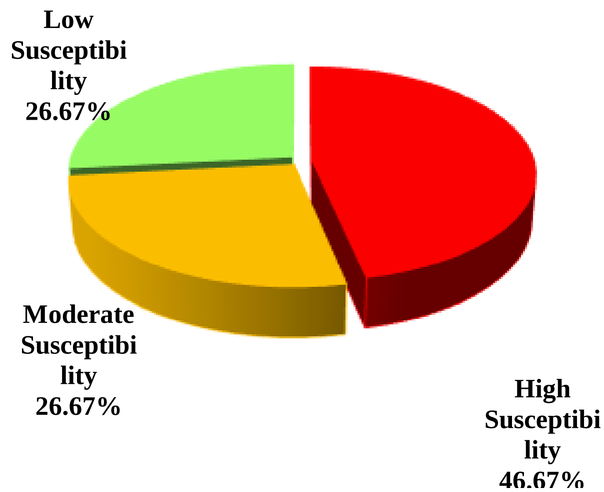

Figure 6. the percentage of sub-watersheds with different flash flood

River Bara, Chaura, and The Khyber Stream drain the district. The watersheds of these rivers have been delineated into fifteen sub-watersheds (SW-1 to SW-15). The majority of sub-watersheds with high and moderate susceptibility are located in the upper reaches of the study area. These sub-watersheds have larger areas, steep slopes, high relief, stream length, stream number, drainage density, drainage frequency, circularity ratio, and length of overland flow. Larger areas, high drainage density and frequency, steep slopes, and high relief make these sub-watersheds susceptible to flooding. In the past, all the losses of life and property have occurred in the high and moderately susceptible sub-watersheds. The very highly susceptible flash flood-prone sub-watersheds drain the areas of Tirah Maidan Valley and Rajgal Valley. The sub-watersheds have been drained into the Bara River. The sub-watersheds SW-6, SW-7, and SW-11 are highly prone to flooding. In 2001, 2005, 2007, 2008, and 2009 most of the casualties and property damages have occurred in the sub-watershed-11 which was drained by the Khyber Stream (Khan et al., 2019). The sub-watershed SW-6 is drained by the Bara River in the lower reaches. The sub-watershed SW-7 is drained by Hisara Khwar which is a hill torrent.

The SW-10 is drained by the Chaura River. River Bara drains the western and southern parts of the district. The relief decreases towards the east. The most susceptible sub-watersheds are located in the west on highlands. The losses of life and property which occur in the Bara River basin are mostly restricted to the lower reaches and take place when children and women collect firewood in the river channel or rear cattle. Passenger vehicles also face bad luck when they try to cross the road during flood times. Other damages include the washing away of agricultural land in the flood plain. The Khyber Stream is a hill torrent and drains the Northern parts of the Landikotal tehsil. The stream joins the Chaura River at Ali Masjid. Losses of life and property in the watershed of Khyber Stream are due to the construction of roads, houses, and other infrastructure along the stream channel.

The Pak-Afghan highway crosses the stream channel at several points and flash floods have frequently swept away vehicles while passing through the channel during flood times. The Chaura River drains the central and North-Western parts of the district Khyber. The river originates from the hills of Tehsil Zakha Khel and flows for some distance towards the South then turns eastward and receives the water of Khyber stream in addition to several hill torrents. People have developed agricultural land in the flood plain of the river channel. In the rainy season, the flash floods frequently wash away the agricultural land and standing crops.

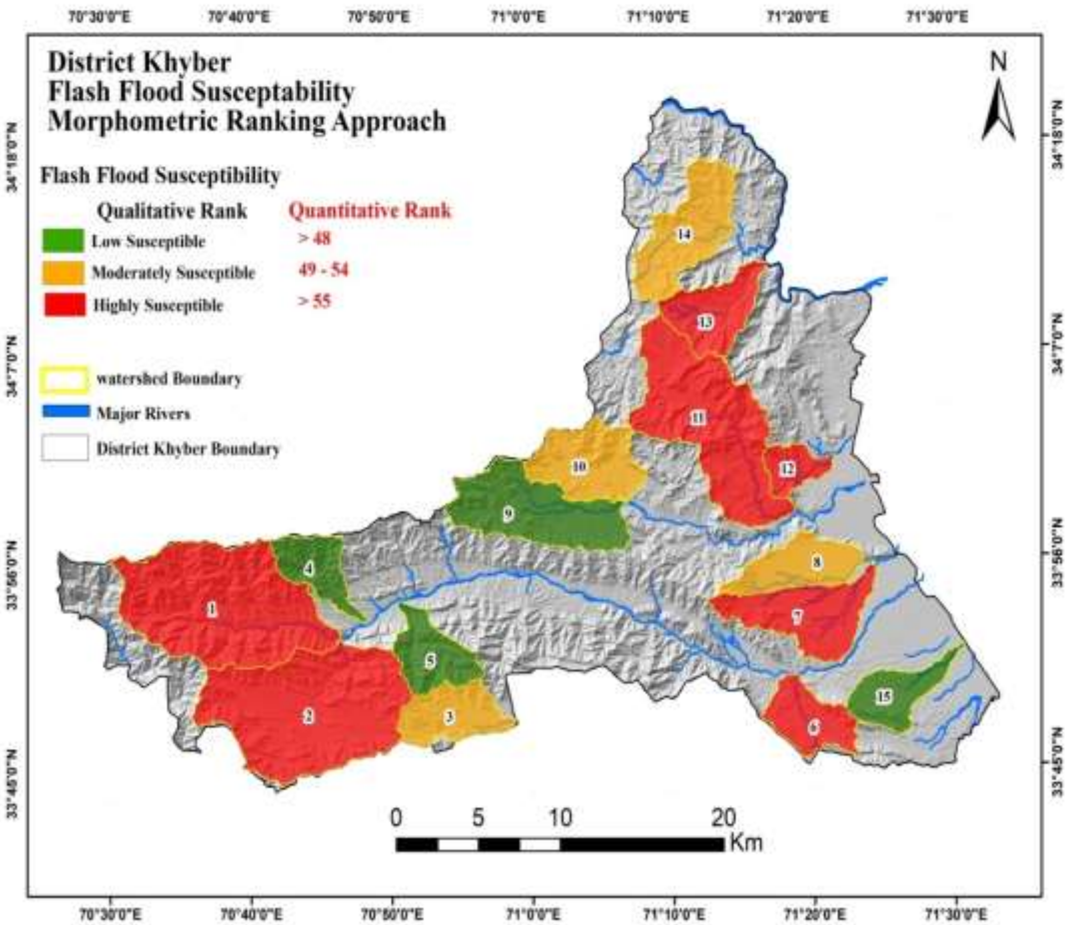

Figure 7. Flash Flood Hazard Zones computed through Morphometric Ranking Approach in District Khyber

5. Validation of the study

To validate the study's results, a questionnaire survey was carried out in all 15 sub-watersheds of district Khyber. The questionnaire included questions on the recurrence of the flash floods and the destruction inflicted by the flash floods in the area. The responses were based on the respondent's point of view, and a high level of impartiality was guaranteed as the talks were held in front of several people who would agree with the answers. The respondents were entirely male, and the majority of them were elderly individuals. The analysis indicated that flash floods occur in certain sub-watersheds almost every year. Table 5 depicts the survey results. Figures 8A, B, C, D E, F, G, and H show various types of damages caused by flash floods at the sub-watershed level in the last 20 years in district Khyber. The analysis reveals that in almost all sub-watersheds flash flooding is a recurrent phenomenon and some of the sub-watersheds experience flash floods almost every year. However, SW-1, SW-2, and SW-11 experienced 16 numbers of flash WS-13, and 14 floods in the last 20 years, which are among the most noticeable. These sub-watersheds were anticipated as highly susceptible to flash flooding by the MR approach.

Figure 8B shows the damages caused by FF to land. The analysis indicates that overall 34 acres of land have far washed away by flash flooding in the last 20 years. The majority of land is damaged in SW-1 and SW-2, 4 and 5 acre respectively. Figure 5.8C illustrates the no of animals that perished during flash floods. The analysis reveals that the majority of the animals have perished in SW-2. Figure 5.8D shows the number of fruit trees uprooted by flash floods. The analysis suggests that the majority of the fruit trees were destroyed in the upper reaches of river Bara. The majority of the fruit trees were washed away from Sw-1 and SW-2, identified as highly susceptible to flash flooding.

Figure 8H illustrates the overall cost of damages caused by flash floods in the last 20 years. The cost of damage to land, houses, animals, fruit treess etc. was provided by respondents and is based on the respondents' perception. The cost of Land used to calculate the overall cost of damages was PKRs 2 million /acre, fruit Tree cost PKRs 0.02 million/tree, wild Tree cost PKRs 0.02million/tree, house cost PKRs 2million/house, and animal cost PKRs .05 million/animal. Based on these estimates the overall cost of damages was computed at sub-watershed level. The analysis reveals that maximum damage is reported from SWS-11, estimated at 18.5 million PKRs, due to damage to the Khyber Safari railway line. This is followed by WS-2 15.2 million, WS-1, 10.85 Million. Figure 5.10 shows the cost of overall damages in PKRs at the sub-watershed level in district Khyber by flash floods in the last 20 years.

The analysis of the damages caused by flash floods during the last 20 years, suggests that the results of the Morphometric Ranking Approach are more consistent. The WS-1, WS-11, and WS-13 were anticipated as highly susceptible to flash flooding by the Morphometric Ranking Approach, were the ones where most of the damages occurred and which experienced the majority of the flash floods in the last 20 years.

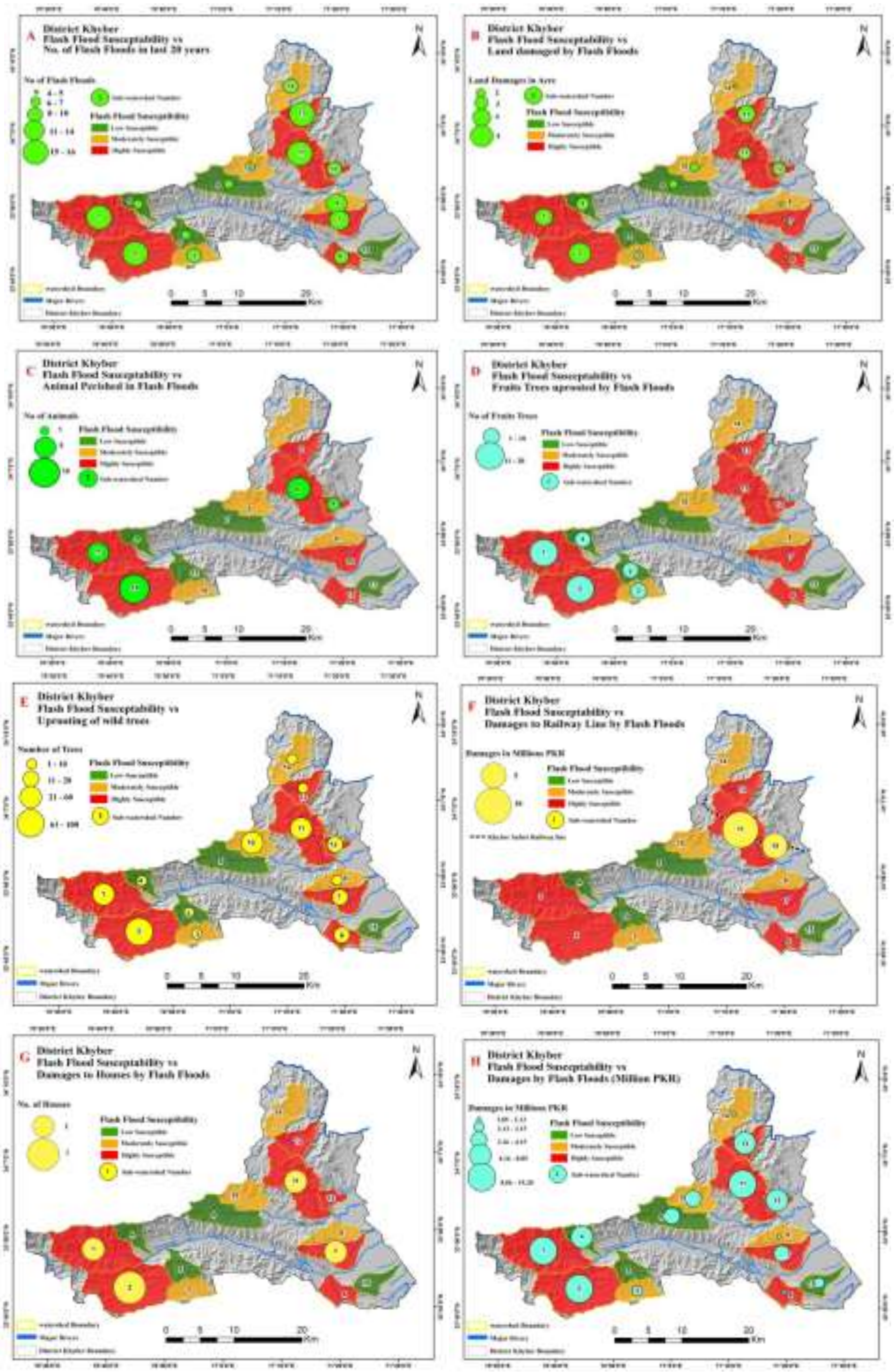

Figure 8. **(A)** No of Flash floods in last 20 years, **(B)** Land damaged by Flash floods in last 20 year **(C)** No of animal Perished in Flash flood in last 20 year and **(D)** No of fruits trees Uprooted by Flash floods in last 20 years, **(E)** No of wild trees Uprooted by Flash floods in last 20 years, **(F)** damage to Railway line by Flash floods in last 20 year **(G)** damage to Houses by Flash floods **(H)** Total damages in PKRS million occurred due to Flash floods in

6 Conclusion

Flash floods frequently occur in district Khyber in the rainy season causing life and property losses. ASTER GDEM has been processed in Arc GIS 10.8 to derive the watershed attributes. In the current study, nineteen (19) geo-morphometric parameters have been utilized to determine flash flood susceptibility at the sub-watershed level. The district has been delineated into fifteen sub-watersheds. The morphometric ranking approach has been utilized to determine the flash flood-prone sub-watersheds in the study area. The study reveals that flash flooding is a recurring phenomenon in district Khyber which causes widespread losses of life and property in the rainy season. The floods of 2007, 2008, and 2010 have caused extensive losses of property and life. The sub-watersheds of very high, high, and moderate susceptibility are located in the upper reaches of the district. These watersheds have high relief, slope, drainage density, stream frequency, and larger areas. Impermeable lithology and low vegetation cover. These are the major factors that affect the peak discharge.

The material losses that occur in the Bara River basin include the damage to agricultural land because the people have constructed their fields in the flood plain due to water availability for irrigation. Life losses in this basin occur when children and women collect firewood or rear livestock in the river channel and flash floods suddenly catch them unaware. Flash floods also swept away the vehicles which crossed the stream channel during flood times. Similar losses take place in the Chaura River basin. The Khyber Stream flows along the famous Pak-Afghan highway for several Kilometers and crosses the high at many points. The past floods have damaged the highway and railway track at several points. The houses have been constructed in the vicinity of the stream. In the basin of the Khyber Stream, flash floods frequently damage the infrastructure including settlements, shops, electric poles, the railway track, and other infrastructure. The Zigzag structure of the stream and the engineering structures like bridges and culverts also pierce the water and cause inundation. The major causes of flash floods in the District Khyber include heavy and torrential rainfall, thunderstorms, watershed attributes, encroachment of the stream channels, and engineering structures. Plantation, water storage structures, and protective walls are recommended as flood mitigation measures at the moderately susceptible, highly susceptible, and very highly susceptible sub-watersheds.

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