Geospatial Assessment of Flash Floods Susceptibility Using El-Shamy's Approach: A Study of District Khyber, Pakistan

Farooq Shah*, Muhammad Jamal Nasir†, Said Alam‡

Abstract

The Study area District Khyber is situated in the Khyber Pakhtunkhwa, Pakistan. Flash flooding is a recurring phenomenon in District Khyber, Pakistan and cause widespread damages to life and property in the district. The remotely sensed open-source ASTER GDEM dataset is used for this purpose. The DEM was processed using the Arc Hydro Tool in ArcMap 10.8 environment and three morphometric parameters were derived. Subsequently, El-Shamy's approach was employed to analyze the flash flood susceptibility based on the derived parameters i.e. drainage density (D_d), stream frequency (F_s), and bifurcation ratio (R_b). The flash flood susceptibility was assessed for 15 Sub-Watersheds by Plotting of D_d vs R_b and F_s vs R_b. The D_d vs R_b analysis reveals SW-8 has the highest flash flood susceptibility (FFS). While the remaining fourteen SW-1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, and SW-15 has the moderate FFS. Plotting F_s vs R_b reveals that SW-6, 8 and SW-I2 are highly susceptible while SW-1, 2, 3, 4, 5, 7, 9, 10, 11, 13, 14, and SW-15 are moderately susceptible to flash flooding. The current study is expected to assist the relevant government agencies and the local communities in developing policies for environmental sustainability that effectively mitigate flash flooding.

Keywords: Flash Floods; El-Shamy's Model; Digital Elevation Model; District Khyber

Introduction

Flash floods are defined as a sudden surge of water in a river or stream channel that is unlikely to be predicted or detected in advance (Ahmad et al., 2020). Heavy, concentrated thunderstorms in the mountains are the main causes of these floods. Because of their great velocity and bed load, flash floods wreak extensive destruction. Even though these floods are brief—they typically last two to six hours—they significantly erode the soil beside the rivers, along with damage to infrastructure. Stream channel modifications caused by flash floods often result in the removal of engineering infrastructure such as spurs, dikes, bridges, and culverts (Nasir et al., 2020; Waqas et al., 2021; Majeed et al 2023). They are considered among the most destructive hydro-meteorological disasters

* Department of Geography & Geomatics University of Peshawar, Peshawar 25120, Pakistan, farooqshah227@gmail.com

†Corresponding Author: Department of Geography & Geomatics University of Peshawar, Peshawar 25120, Pakistan, drjamal@uop.edu.pk

‡ Qurtuba University of Science and Technology, Hayatabad, Peshawar, KP 25000, Pakistan, saidalamgeo@gmail.com

responsible for widespread losses of property and life (Mahmood and Rahman, 2019; Manzoor et al., 2022).

Due to variations in geographical location, social and economic progress, and demographics, the intensity, frequency, and duration of flash floods vary from region to region (Tariq & Giesen, 2012; Ali et al., 2017; Xiong et al., 2020). The most commonly noticed and researched reasons for floods include topography, floodplain habitation, and intense and extended rainfall (Ali et al., 2017; Xiong et al., 2020; Nasir et al., 2020; Hou et al., 2020; Dahri and Abida, 2020). Floods have a significant impact on economies and on the survival of people. An estimated 55 billion US dollars are lost economically each year as a result of floods. Approximately one third of all the hydro-meteorological disaster-related fatalities, injuries, and property damages are caused by floods (Bukhari & Rizvi, 2016; Mahmood & Rahman, 2019). Floods are unavoidable but their negative effects can be lessened with good management, weather forecasting, early warning, hazard mapping, and modeling (Rahman & Shaw, 2015; Saeed et al., 2021).

Identifying and defining areas that are vulnerable to flash floods is an essential component in flash flood susceptibility assessment and flood control. To mitigate flash flood losses, it is very helpful to identify locations that are susceptible to flooding (Nasir et al., 2020). Multiple methods have been developed for evaluating the likelihood of flooding. Some of the most widely used approaches are: Integrated Bivariate and Multivariate statistical model (Tehrany et al., 2014); Multi-Criteria Decision Analysis (MCDA) (Dash and Sar, 2020); Frequency Ratio Method (Tehrany et al., 2015); Rahmati et al., 2016); Support Vector Machine (SVM) (Tehrany et al., 2015); Analytical Hierarchy Process (AHP) (Rozos et al., 2011); Logistic Regression (Pradhan, 2010); Morphometric Ranking Approach (MRA) (Elmoustafa and Mohamed, 2013); and El-Shamy's approach (El-Shamy, 1992). According to Asfaw and Workineh (2019), El. Shamy's Approach is one of the most frequently employed to flash floods susceptibility assessment due to its easy and quick assessment.

El-Shamy's Approach used morphometric characteristics of sub-watersheds to assess the risk of flash flooding at watershed level. The geo-morphometric parameters are increasingly being derived using remotely sensed data, such as digital elevation models (DEM) (Ghany, 2015; Chaithong, 2022). El-Shamy's method has been widely used by researchers for flash flood susceptibility assessment. Nasir et al. (2020) assess the flash flood susceptibility in the Swat River basin using El-Shamy's approach. Using the El-Shamy's Approach, Waqas et al. (2021)

evaluated the risk of flash flooding in Panjkora River basin. Elassal (2022) assessed the risk of flash floods in the Saudi Arabia using El-Shamy's methodology. Mahmood and Rahman (2019) forecast and estimate the limits and extent of flash flood hazards in the Ushairy River basin using El-Shamy's approach. Elsadek et al. (2018) used El-Shamy's methodology to assess the flash flood in Wadi Qena (Egypt).

Floods are becoming more frequent, intense, and massive globally. Pakistan is among the world's most flood-prone and devastated countries (Bukhari & Rizvi, 2016; Iqbal et al., 2018; Saeed et al., 2021; Majeed et al, 2023). The excessive rainfall and subsequent flash flooding in Pakistan are primarily caused by monsoons, and western depressions (Yaqoob et al., 2015; Majeed et al., 2023). Within Pakistan, the FFS are more frequent in the hilly regions and foothills of Khyber Pakhtunkhwa and Baluchistan, particularly in the districts of Dir, Swat, and Chitral (Tariq & Giesen, 2012).

The study area district Khyber is one of those in the province of Khyber Pakhtunkhwa that is affected by flash floods (Saeed et al., 2021). Therefore, using El-Shamy's approach, the present research attempts to evaluate the flash floods susceptibility in district Khyber at the sub-watershed level. It is anticipated that the current research will be useful in developing effective strategies for flood mitigation to promote sustainable development.

Methodology

The Study Area

District Khyber is situated in the Northwest of Khyber Pakhtunkhwa's province of Pakistan. Covering an area of 2576 km^2, District Khyber is extended between 33°45'N to 34°20'N latitude and 70°30'E to 71°27'E longitude (GoP, 2000). The district shares boundaries to the north and west with Afghanistan, to the north and east with the district of Mohmand and Peshawar. Districts of Kurram and Orakzai are situated to the South-West, and South respectively (GoP, 1983; Shah, 2014; Khan et al., 2019). Geographically speaking, the district is comprised of two separate regions: the plains of Bara and Jamrud and the hilly territory covered by Tirah and Landikotal areas. Figure 1 depicts the location of the study area.

The climate of the hilly Tirah is humid, whereas the Landikotal, Bara, and Jamrud are arid to semi-arid (Khan, 2008). Although it's sweltering in the plain areas, summer is nice in the Tirah region. In the plains of Bara and Jamrud, summer temperatures range from 26°C to 40°C, whereas in the mountainous region of Tirrah, it varies form 15°C to

30°C. The district's primary rainfall sources are monsoons in summer and western depressions in winter. The research area receives 400 mm of rainfall on average annually. The drainage systems of the district comprise the Khyber Stream, River Bara, River Chaura, and River Kabul (GoP, 1972; Bangash, 2016).

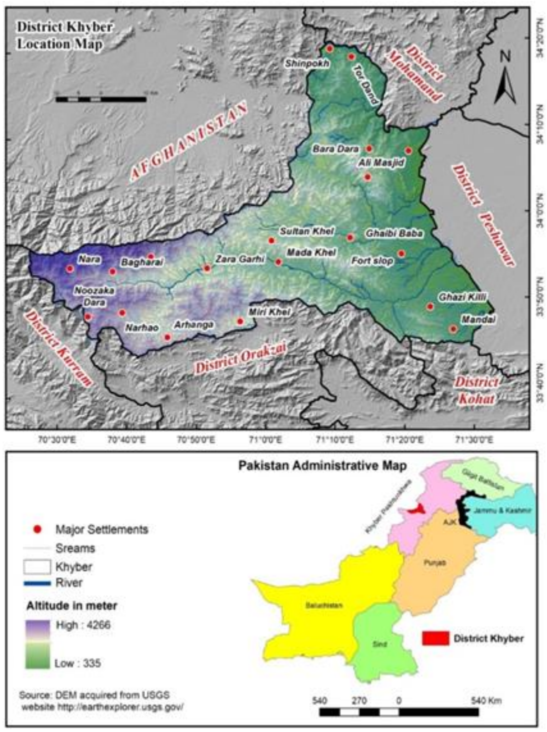


Figure:1 Location Map of District Khyber Source: Dem acquired from USGS website http:earthxplorer.usgs.gov/ www.grove.com.pk.

Data Collection

Secondary source of information was used to accomplish the study's objectives. The Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTERGDEM-2) was acquired from https://asterweb.jpl.nasa.gov/GDEM.asp. The GDEM was analyzed using ArcHydro tool in ArcMap 10.8 environment to derive the morphometric parameters used in the current study for flash flood susceptibility assessment.

Computing of Morphometric Parameters

For the present study 3 parameters were derived from GDEM-2 i.e. sub-watershed boundary, sub-watershed area (A) and drainage network. The sub-watershed area and drainage network was subsequently used to compute the drainage density (D_d), stream frequency (F_s) and bifurcation ratio (R_b), using the formulas stated in Table 1. Figure 2 illustrates the research methodology adopted to achieve the study objectives.

Table 1: Morphometric parameters

S.No.	Parameters	Symbols/Units	Formula	Reference
1	Area	A (Km^2)	A=Area of the Basin	Horton, 1945
2	Stream Number	Nu	N_u=N1+N2..N_u	Horton, 1945
3	Stream Length	Lu (Km)	L_u=L1+L2…L_u	Strahler, 1957
4	Stream Frequency	F_s	$F_s=N_u/A$	Horton, 1945
5	Drainage Density	D_d (Km/Km^2)	$D_d=L_u/A$	Horton, 1945
6	Bifurcation Ratio	Rb	$R_b=N_u/N_u+1$	Horton, 1945

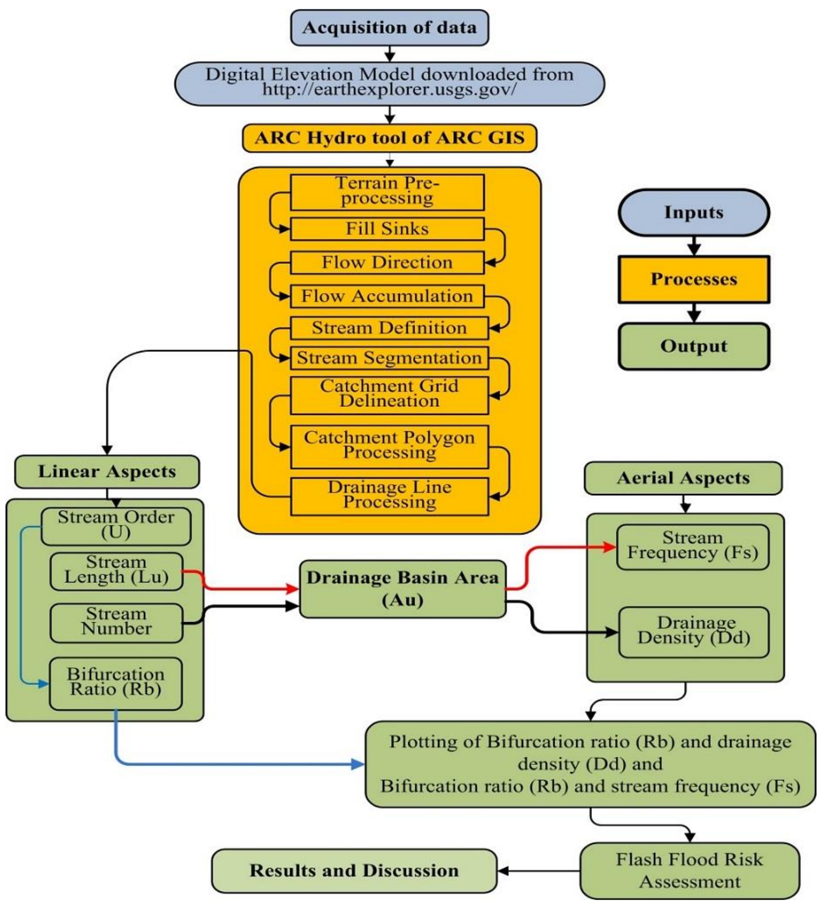


Figure: 2 Illustrating Methodology Flow Chart (Nasir et al., 2020).

Results and Discussion

A total of 15 sub-watersheds were delineated in district Khyber. A total of 06 morphometric parameters have been computed and were subsequently used for flash flood modeling. Table 2 depicts the sub-watershed parameter values for all the 06 basic and derived morphometric parameters. Figure 3 illustrates the 15 sub-watersheds across the district Khyber.

Table 2 Morphometric parameters values.

SW' s	Basic Morphometric Parameters			Derived Morphometric Parameters		
	SW Area (Km^2)	Stream Number (No)	Stream Length (Km)	Drainage Density (Km/Km^2)	Drainage Frequency (No/Km^2)	Bifurcation Ratio
1	216.57	85	152.73	0.705	0.392	4.02
2	221.60	98	189.57	0.855	0.442	4.45
3	52.48	18	45.36	0.864	0.342	3.625
4	41.15	15	27.05	0.657	0.364	4.00
5	50.25	18	34.41	0.684	0.358	3.625
6	48.40	20	39.74	0.82	0.413	2.416
7	83.00	36	91.76	1.105	0.433	3.11
8	55.00	25	73.45	1.335	0.454	2.916
9	108.00	42	98.04	0.907	0.388	6.062
10	72.39	29	58.70	0.810	0.400	3.25
11	175.00	71	140.00	0.80	0.405	3.86
12	25.51	12	23.55	0.923	0.470	2.833
13	57.39	29	46.10	0.803	0.505	4.80
14	83.00	35	76.80	0.925	0.421	5.33
15	45.23	15	45.88	1.014	0.330	3.33

Drainage density

Drainage density (D_d) can be computed by dividing the entire length of all the streams in a watershed by the watershed area (Schumm, 1956). Equation 1 can be used to compute the drainage density:

$$Dd = Lu/A \tag{1}$$

where *Lu* is the length of stream of the watershed and *A* is the area of basin.

According to Horton (1945), drainage density measures the stream proximity or separation. It also reveals the terrain, soil properties, vegetative cover, absorption capability, and stream segmentation and distributions. The drainage density affects how long it takes for rainwater to proceed across spaces (Schumm 1956). D_d value is also an empirical measure of runoff potential, relief dissection, and ultimately the drainage effectiveness of watersheds. A high D_d value indicates a low infiltration rate and heavy runoff because of scant plant cover, impervious subsurface soils, and mountainous relief. On the other hand, lower runoff, and strong infiltration, is implied by low drainage density (Strahler, 1964).

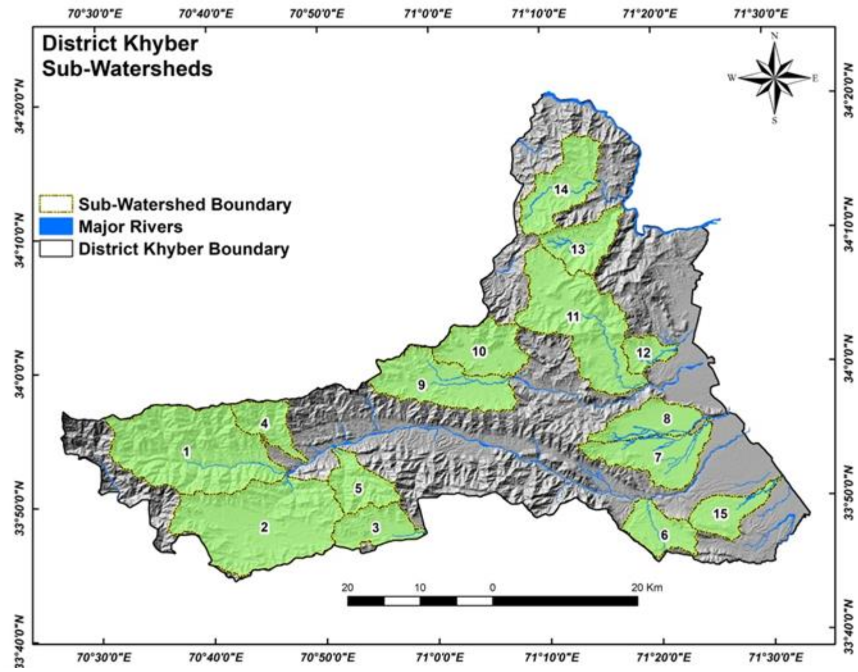


Figure 3 Sub-Watersheds of District Khyber

Table 2 depicts the computed drainage density values for all the 15 sub-watersheds. The analysis suggests that the SW-8 has the highest D_d value (1.335/Km^2), whereas SW-4 has the lowest D_d value (0.657/Km^2). Figure 4 shows the spatial distribution of drainage density across the study area.

Stream Frequency (F_s)

F_s is the number of streams/km^2. It is represented empirically by Equation 2:

$$Fs = \frac{Nu}{A} \quad (2)$$

where *Nu* is the number of stream of all orders and *A* is the sub – watershed area.

According to Horton (1945), the watershed's morphological instabilities reflect how much runoff from the surface and stream flow will be generated. The drainage texture of watersheds is expressed via stream frequency, which is influenced by lithography and subsurface sediments.

There exists a positive correlation between the D_d and F_s values of a watershed. Higher F_s values signify reduced permeability and infiltration rate, resulting in higher runoff. The watersheds are particularly susceptible to flooding, soil erosion, and landslides under these hydrological circumstances (Farhan & Anaba, 2016).

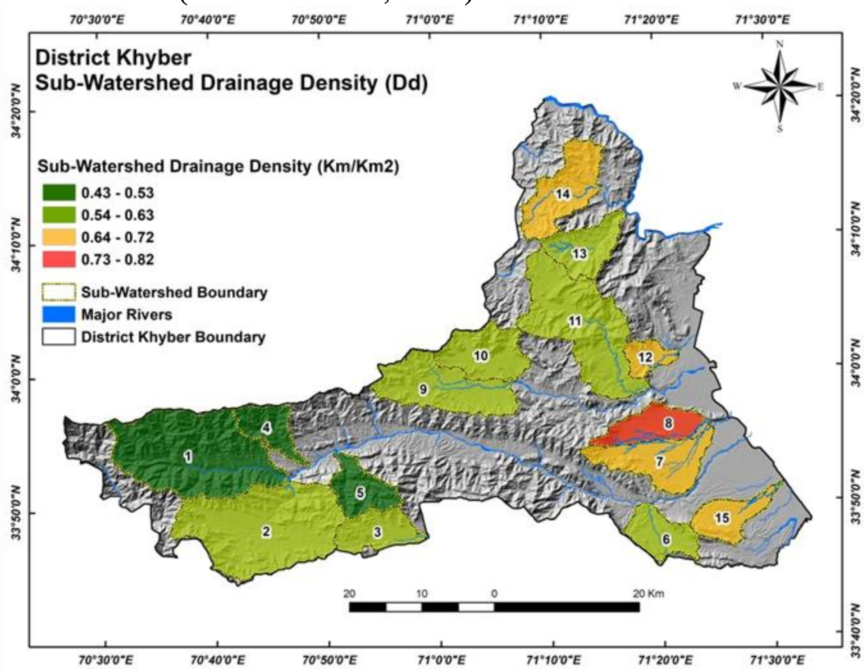


Figure 4: Drainage density (D_d) in District Khyber

Table 2 depicts the values of F_s across the study area, the analysis reveals that it varies between 0.505 streams/km^2 (SW-14) and 0.295 stream/km^2 (SW-13). The analysis suggests that SW-14 has been drained by maximum streams per km^2 and the SW-13 is drained by lowest number of streams per km^2. Figure 5 shows the spatial distribution of stream frequency values in the study area.

Bifurcation ratio (R_b)

The bifurcation ratio (R_b) is the proportion of streams in the preceding order (N_u) to the next higher order (Horton, 1945). It can be represented statistically as:

$$Rb = Nu/Nu + 1 \quad (3)$$

where Nu is the total number of stream segments of the order u, and $Nu + 1$ is the number of segments of the next higher order.

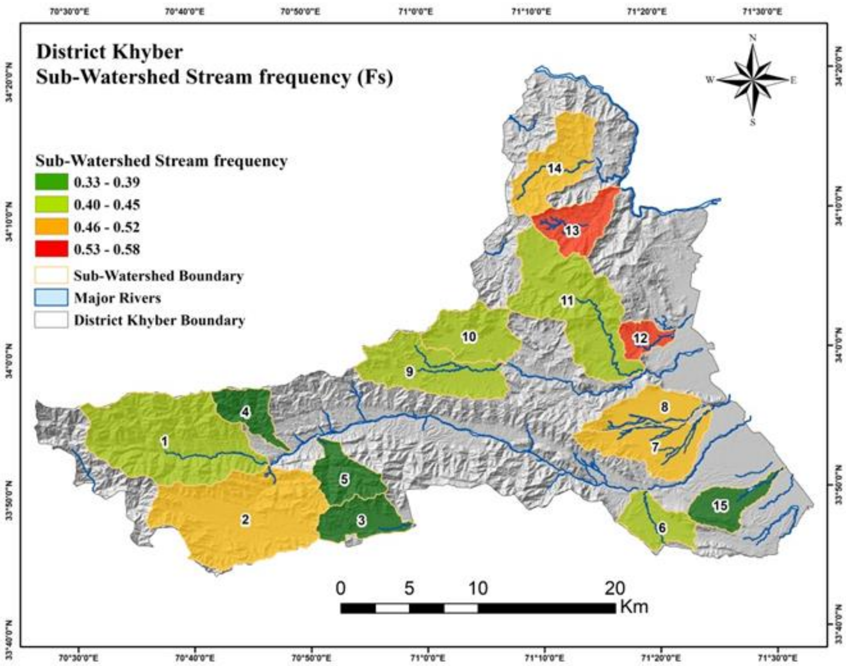


Figure 5: Stream frequency (Fs) in District Khyber.

Schumm (1956) introduced the concept of bifurcation ratio, which can be described as the proportion of a particular order's stream segment count to the subsequent higher order segment count. It varies slightly between locations and settings, except those where strong geological control is predominant (Strahler, 1957). Its value varies according to the geology and lithological evolution of the watershed (Strahler, 1964). A higher value of R_b denotes strong structure control and the complexities in the stream pattern, while a lower value denotes less structure interruption impact on the watershed. Bifurcation ratios often range from 2 at the very least in "flat" watersheds to 4 in "rugged or highly dissected" watersheds Horton (1945).

In watersheds where its geological makeup does not alter the drainage pattern, the R_b values normally range from 3 to 5, (Strahler, 1964). There is a higher possibility of floods when the bifurcation ratio is higher since it will result in a faster flow to the exit and an elevated peak flow. It represents the basin's shape, with a circular basin probably having a low R_b value and an extended basin having a high value (Schumm, 1956). The calculated bifurcation ratio for each of the 15 sub-watersheds is shown in Table 2. The analysis indicates that the SW-9 has the highest R_b ratio (6.062) in the study area. The SW-12, however, has the lowest R_b (2.833). The research area's fifteen sub-watersheds spatial distribution of the bifurcation ratio is depicted in Figure 6.

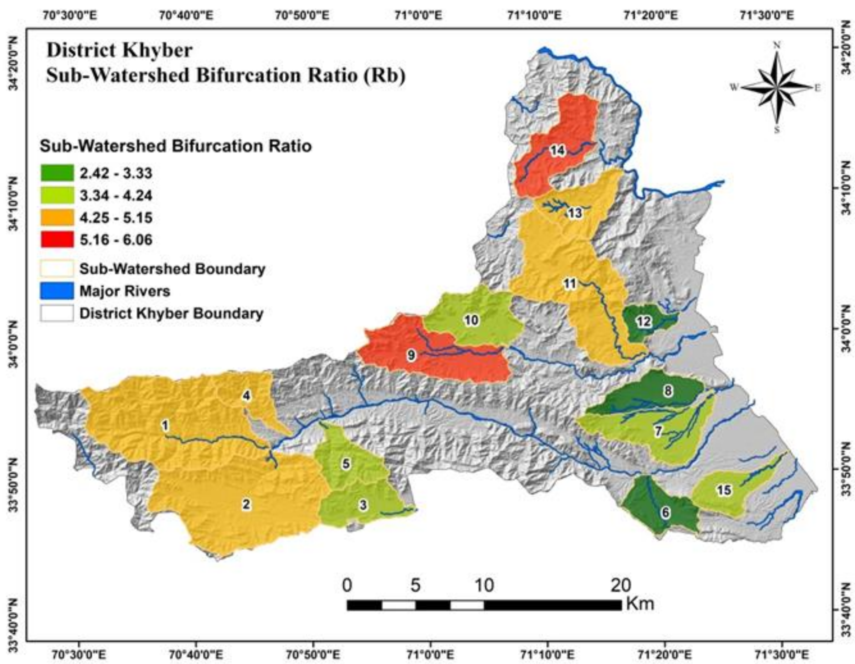
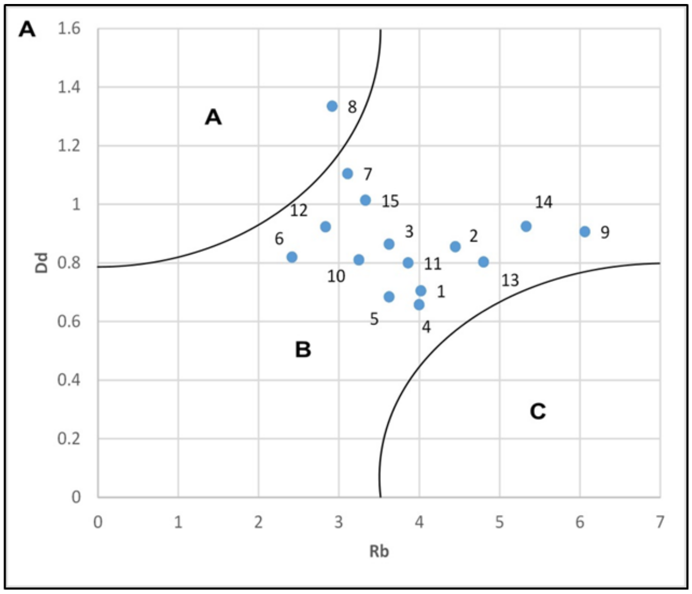


Figure 6 Bifurcation Ratio (Rb) in District Khyber

El-Shamy's Approach for Flash Flood Susceptibility Analysis

El-Shamy's approach is among the most widely applied methods for analyzing and assessing the flash floods susceptibility. According to El-Shamy (1992), in order to reduce the harmful effects of flash foods, it is important to examine the morphometric features of the sub-watershed to determine those that are more likely to produce flash floods. The drainage density of a watershed is determined by its relief, climate, land cover, runoff potential, and infiltration capability of surface materials. As a result, low D_d values suggest optimal permeable conditions, which reduce outflow; on the other hand, high stream frequency indicates impervious subterranean materials, lack of vegetation cover, substantial relief, and low permeation, which increase runoff potential (Elsadek et al., 2018).



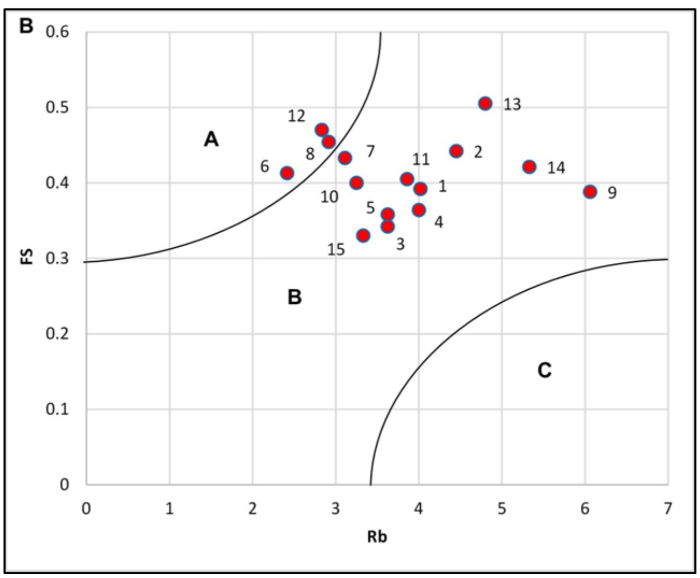


Figure: (7A) FFs assessment by Drainage density vs Bifurcation ratio and (7B) Stream frequency vs Bifurcation ratio.

The methodology relies on three different morphometric parameters: stream frequency, drainage density, and bifurcation ratio. El-Shamy used two distinct methods to calculate the susceptibility of a sub-watershed to flash floods. The bifurcation ratio and drainage density relationship forms the basis of the first technique, whereas the relationship between the bifurcation ratio and stream frequency is used in the second approach. The resultant graph can be divided into three zones by graphing stream frequency and drainage density against the bifurcation ratio and dividing the result at the midpoint. With a low bifurcation ratio and high drainage density, the initial zone (A) is particularly vulnerable to flash floods. Because of the low stream frequency, drainage density, and bifurcation ratio, the second zone (B) is relatively resistant to flash floods. The third zone (C) has a high bifurcation ratio, low stream frequency, and low drainage density, making it less vulnerable to flash floods.

Plotting of D_d vs R_b (Figure 7A) indicates that the SW-8 is highly susceptible to FFs in district Khyber while the sub-watersheds-SW-1, 2, 3, 4, 5, 6, 9, 10, 11, 12, 13, 14 and 15 are moderately susceptible. The graph of F_s against R_b is shown in Figure 7b. The analysis reveals that the sub-watersheds, SW-6, 8, and 12 show high susceptibility to FFs while the sub-watersheds- SW-1, 2, 3, 4, 5, 7, 9, 10, 13, 14 and 15 are moderately susceptibility to FFs.

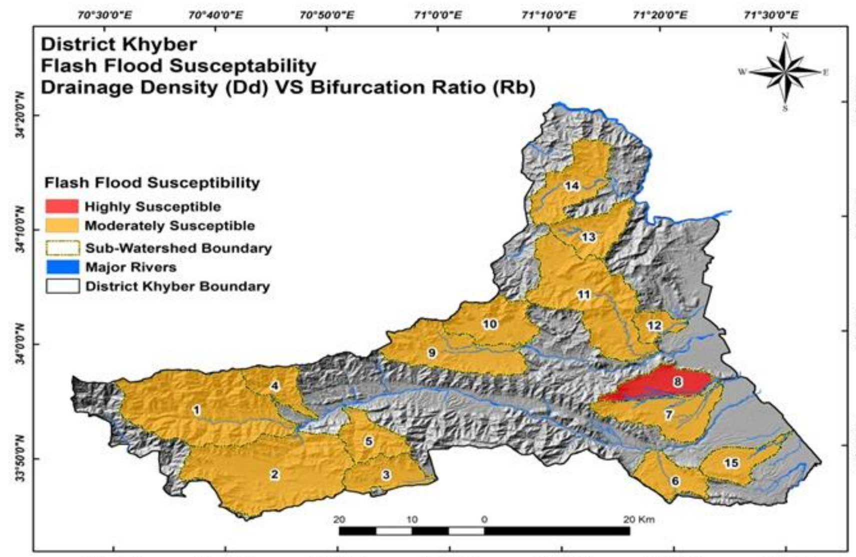


Figure 8: illustrates the sub-watershed susceptibility to flash flooding based on the relationship between drainage density and bifurcation ratio.

Sub-watersheds exhibiting high and moderate susceptibility have low bifurcation ratios, high drainage densities, and frequent streams. According to the link among drainage density and bifurcation ratio, Figure 8 depicts the sub-watershed susceptibility to flash flooding. Figure 9, on the other hand, shows how susceptible the sub-watershed is to flash flooding based on the connection between stream frequency and bifurcation ratio.

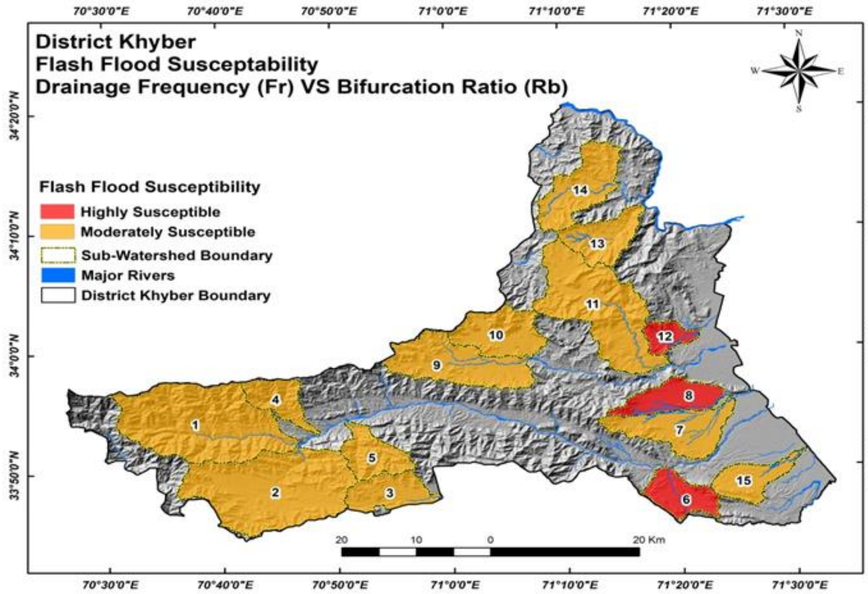


Figure 9 illustrating the sub-watershed susceptibility to flash flooding based on the relationship between stream frequency and bifurcation ratio.

Conclusion

District Khyber is mostly hilly. About 85% of the district is mountainous while only 15% is covered by valleys and plains. Flash flooding is a recurring phenomenon in district Khyber which causes widespread losses of life and property in rainy season. The floods of 2007, 2008 and 2010 have caused extensive losses of property and life.

Using El-Shamy's approach, the current study attempts to evaluate district Khyber's susceptibility to flash flooding at the sub-watershed level. According to the association between R_b and D_d, SW-8 is highly susceptible to flash flooding. Conversely, there is a moderate risk of flash flooding in the remaining 14 sub-watersheds, which are SW-1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, and SW-15. The relationship between R_b vs. F_s suggests that SW-6, SW-8, SW-12 has high flash flood susceptibility, while SW-1, 2, 3, 4, 5, 7, 9, 10, 11, 13, 14 and SW-15 are moderately susceptible to flash flooding.

The sub-watersheds having high flash flood susceptibility have high relief, slope, drainage density, stream frequency, larger SW areas, impermeable lithology and low vegetation cover. These are the major factors which cause high runoff after a rainstorm and can generate the peak discharge. The study concludes that morphometric analysis is one of the cost and time effective methods for flash flood susceptibility assessment at sub-watershed level. However, the low-resolution DEM can yield poor results. It is believed that modeling, analyzing, and mapping flash flood hazards are expected to assist the relevant government agencies and the local communities in developing policies for environmental sustainability that effectively mitigate flash flooding.

References

Ahmad, W., Nasir, M. J., & Iqbal, J. (2020). Flash flood susceptibility modeling for drainage basins of Dir Lower Khyber-Pakhtunkhwa: A comparative analysis of morphometric ranking and El-Shamy's approach. *In Remote sensing for agriculture, ecosystems, and hydrology XXII (Vol. 11528, pp. 99-110). SPIE*.

Ali, K., Bajracharyar, R. M., & Raut, N. (2017). Advances and challenges in flash flood risk assessment: A review. *Journal of Geography & Natural Disasters*, *7*(2), 1-6.

Asfaw, D. & Workineh, G. (2019), Quantitative analysis of morphometry on Ribb and Gumara watersheds: Implications for soil and water conservation. *International Soil and Water Conservation Research 7 (2019)* 150–157.

Banerjee, A., Singh, P., & Pratap, K. (2017). Morphometric evaluation of Swarnrekha watershed, Madhya Pradesh, India: an integrated GIS-based approach. Applied Water Science, 7, 1807-1815.

Bangash, S. (2016). The frontier tribal belt: Oxford University Press Karachi Pakistan.

Bukhari, S. I. A., & Rizvi, S. H. (2016). The Indus basin of Pakistan: a critical analysis of 2010 floods. Journal of ISOSS, 2(1), 71-77.

Bukhari, S. I. A., & Rizvi, S. H. (2015). Impact of floods on women: with special reference to flooding experience of 2010 flood in Pakistan. Journal of Geography & Natural Disasters, 5(2), 1-5.

Chaithong, T. (2022). Flash Flood Susceptibility Assessment Based on Morphometric Aspects and Hydrological Approaches in the Pai River Basin, Mae Hong Son, Thailand. Water 2022, 14, 3174.

Dahri, N., & Abida, H. (2020). Causes and impacts of flash floods: case of Gabes City, Southern Tunisia. Arabian Journal of Geosciences, 13, 1-15.

Dash, P., & Sar, J. (2020). Identification and validation of potential flood hazard area using GIS-based multi-criteria analysis and satellite data-derived water index. Journal of Flood Risk Management, 13(3), e12620.

Elassal, M. (2022). Morphometric Analysis and Flash Floods Assessment as a Tool for Rainwater Harvesting and Run off Hazard

Management in Asir Region, Saudi Arabia. Journal of Res Militaris 12(3).

Elmoustafa, A. M., & Mohamed, M. M. (2013). Flash flood risk assessment using morphological parameters in Sinai Peninsula. Open Journal of Modern Hydrology, 3:122–129.

Elsadek, W.M., Ibrahim, M.G. & Mahmod W.E. (2018). Flash Flood risk Estimation of Wadi Qena Watershed, Egypt Using GIS Based Morphometric Analysis. Journal of Applied Environmental Research 40(1) 36-45.

Farhan, Y., & Anaba, O. (2016). Flash flood risk estimation of Wadi Yutum (Southern Jordan) watershed using GIS based morphometric analysis and remote sensing techniques. Open Journal of Modern Hydrology, 6(02), 79.

GoP.(Government of Pakistan).1972.Census report of federally administered tribal areas(FATA): population census organisation statistics division govt.of Pakistan Islamabad.

GoP.(Governament of Pakistan). 1983. Census report of federally admnistered tribal areas(FATA): Population census organisation statistics division govt. of Pakistan Islamabad.

GoP. (Governament of Pakistan). 2000. Census report of federally admnistered tribal areas (FATA): Population census organisation statistics division govt. of Pakistan Islamabad.

Ghany, M.K.A. (2015). Quantitative morphometric analysis of drainage basins between Qusseir and Abu Dabbab area, Red sea coast, Egypt using GIS and remote sensing techniques. International Journal of Advanced Remote Sensing and GIS 2015, 4(1) pp. 1295-1322.

Horton, R. E. (1945). Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. Geological society of America bulletin, 56(3), 275-370.

Hou, J., Li, B., Tong, Y., Ma, L., Ball, J., Luo, H., ... & Xia, J. (2020). Cause analysis for a new type of devastating flash flood. Hydrology Research, 51(1), 1-16.

Iqbal, M. S., Dahri, Z. H., Querner, E. P., Khan, A., & Hofstra, N. (2018). Impact of climate change on flood frequency and intensity in the Kabul River Basin. Geosciences, 8(4), 114.

Khan, B., Khan, A.N., Qasim, S., Rahman, A.U. (2019). Analysis of Human perceptions and adaptations to flash floods in Khyber Agency, FATA. Journal of engineering and applied sciences 38(1).

Khan, B. (2008). Causes, effects and remedies of flash floods: A case of Khyber Agency, FATA Pakistan. Doctoral Dissertation, University of Peshawar.

Mahmood, S., & Rahman, A. U. (2019). Flash flood susceptibility modeling using geo-morphometric and hydrological approaches in Panjkora Basin, Eastern Hindu Kush, Pakistan. Environmental earth sciences, 78, 1-16.

Majeed, M., Lu, L., Anwar, M.M., Tariq, A., Qin, S., El-Hefnawy, M.E., El-Sharnouby, M., Li, Q. and Alasmari, A. (2023), Prediction of flash flood susceptibility using integrating analytic hierarchy process (AHP) and frequency ratio (FR) algorithms. Frontier Environmental Science. 10:1037547

Manzoor Z., Ehsan M., Khan M.B., Manzoor A., Akhter, M.M., Sohail, M.T., Hussain, A., Shafi, A., Abu-Alam, T. and Abioui, M. (2022), Floods and flood management and its socio-economic impact on Pakistan: A review of the empirical literature. Frontier Environmental Science 10:1021862.

Nasir, M.J., Iqbal, J., Ahmad, W. (2020). Flash Flood Risk Modeling of Swat River Sub-Watershed: A Comparative Analysis of Morphometric Ranking Approach and El-Shamy Approach. Arabian Journal of Geosciences 1082(13), 1-19.

Nasir, M. J., Ahmad, W., Jun, C., Iqbal, J., & Bateni, S. M. (2023). Soil erosion susceptibility assessment of Swat River sub-watersheds using the morphometry-based compound factor approach and GIS. Environmental Earth Sciences, 82(12), 315.

Portuguez-Maurtua, M., Arumi, J. L., Stehr, A., Lagos, O., Chávarri-Velarde, E., & Rivera-Ruiz, D. (2023). Mapping of areas vulnerable to flash floods by means of morphometric analysis with weighting criteria applied. Water, 15(6), 1053.

Pradhan, B. (2010). Flood susceptible mapping and risk area delineation using logistic regression, GIS and remote sensing. Journal of Spatial Hydrology, 9(2).

Rahman, A. & Shaw, R. (2015). Flood risk and reduction approaches in

Pakistan. In A. Rahman, A. N Khan, & R. Shaw (Eds.), Disaster risk reduction approaches in Pakistan (pp 77-100). Koyto, Japan. Springer

Rahmati, O., Pourghasemi, H. R., & Zeinivand, H. (2016). Flood susceptibility mapping using frequency ratio and weights-of-evidence models in the Golastan Province, Iran. Geocarto International, 31(1), 42-70.

Rozos, D., Bathrellos, G. D., & Skillodimou, H. D. (2011). Comparison of the implementation of rock engineering system and analytic hierarchy process methods, upon landslide susceptibility mapping, using GIS: a case study from the Eastern Achaia County of Peloponnesus, Greece. Environmental earth sciences, 63, 49-63.

Saeed, M., Li, H., Ullah, S., Rahman, A. U., Ali, A., Khan, R. & Alam, S. (2021). Flood Hazard Zonation Using an Artificial Neural Network Model: A Case Study of Kabul River Basin, Pakistan. Sustainability, 13(24), 13953.

Schumm, S. A. (1956). Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geological society of America bulletin, 67(5), 597-646.

Shah, F. (2014). Impact of population growth and accessibility on land use and land cover change in Khyber Agency Pakistan. M.Phil thesis report.

Shamy, E. (1992). Recent recharge and flash flooding opportunities in the Eastern Desert, Egypt; Possibilités de recharge de nappes et de crues subites dans le Désert Oriental, Egypte. Annals of the Geological Survey of Egypt, 18, 323.

Strahler, A. N. (1957). Quantitative analysis of watershed geomorphology. Eos, transactions american geophysical union, 38(6), 913-920.

Strahler, A. N. (1964). Part II. Quantitative geomorphology of drainage basins and channel networks. Handbook of Applied Hydrology: McGraw-Hill, New York, 4-39.

Tariq, M. A. R., & Giesen, V. D. N. (2012). Floods and flood management in Pakistan. Physics and chemistry of the earth, 47, 11-20.

Tehrany, M. S., Pradhan, B., & Jebur, M. N. (2015). Flood susceptibility analysis and its verification using a novel ensemble support vector machine and frequency ratio method. Stochastic environmental research and risk assessment, 29, 1149-1165.

Waqas, H.; Lu, L.; Tariq, A.; Li, Q.; Baqa, M.F.; Xing, J.; Sajjad, A. (2021). Flash Flood Susceptibility Assessment and Zonation Using an Integrating Analytic Hierarchy Process and Frequency Ratio Model for the Chitral District, Khyber Pakhtunkhwa, Pakistan. Water,13, 165

Xiong, J., Pang, Q., Fan, C., Cheng, W., Ye, C., Zhao, Y., ... & Cao, Y. (2020). Spatiotemporal characteristics and driving force analysis of flash floods in Fujian Province. ISPRS International Journal of Geo-Information, 9(2), 133.

Yaqoob, M., Eren, B., & Doğan, E. (2015). Flood causes, consequences and protection measures in Pakistan. Disaster Science and Engineering, 1(1), 8-16.