Flood hazard in Afghanistan is intensified both by natural and socioeconomic factors

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1. Flood Hazard Indicators (FHI)

1.1. Watershed delineation process

The watershed delineation process in the Afghanistan region involves using digital elevation models (DEMs) such as the MERIT Hydro DEM to identify and define the boundaries of individual catchment areas. This process begins by processing a DEM to fill any sinks and remove errors, ensuring a continuous flow path for water across the terrain. Once the DEM is prepared, flow direction and flow accumulation grids are created to determine the direction of water movement and the accumulated flow at each point. Threshold values are then set in ArcHydro to define the criteria for stream initiation. These thresholds typically represent a minimum number of cells or drainage area required to consider a cell as part of a stream. For instance, a threshold of **xxx** cells might mean that a stream will only be formed if the accumulated flow reaches 1,000 cells. Adjusting these thresholds allows for finer or coarser basin delineation, depending on the level of detail required. Once the threshold is applied, ArcHydro generates a stream network and identifies watershed boundaries, enabling detailed hydrological analysis and flood risk assessment in the region. The basic essential morphometry indicators, namely drainage density, basin relief, drainage texture, infiltration number, stream frequency, compactness, circulation ratio, elongation ratio, bifurcation number, overland flow length, and form factor were identified. The morphometric indicators derived from the DEM analysis were including the basin area, length, perimeter, and stream order, number and stream length are used for flood hazard analysis as shown in Table 3.

1.1.1. Stream order (N_o)

The stream order, defined as a measure of the relative size of streams, has been ranked based on the Strahler method (Strahler, 1957) . The smallest tributaries are referred to as 1st order, where two 1st order tributaries join, a channel segment of 2nd order is formed and so on. After acquiring the flow direction and flow accumulation through watershed delineation techniques in Arc-GIS, the six order stream networks within forty-nine water catchments were extracted.

1.1.2. Stream Frequency (F_s)

The number of stream segments of all orders per unit area of a basin is called stream frequency (Alam et al., 2021; Horton, 1945). High F_s indicates rapid runoff and has a direct relation to basin lithology, impermeable surface material, sparse vegetation cover and structural hill , in contrast, the alluvial deposits and flat terrain basin have low F_s (Horton, 1945; Patton, 1988) as shown in Fig. S1a.

1.1.3. Drainage Density (D_d)

The total length of streams per unit area of a basin is known the drainage density (Horton, 1945). It, one of the vital morphometric indicators, indicates the catchment geomorphological response for the generation of the runoff (Melton, 1957). The soil and rock formation and its infiltration capacity, underlying lithology, vegetation cover and relief aspects of the basin are the dominant controlling factor of the D_d (Haggett and Chorley, 1969; Nasir et al., 2020). According to (Strahler, 1964), the regions with arid and semi-arid climate has higher D_d compare to humid regions with the same geology because of flash floods and scarce vegetation. The higher D_d values suggests the high runoff and low D_d shows the existence of erosion resistant factors that rainfall percolate into the soil to recharge groundwater storage (Bassey Eze and Efiong, 2010; Sahu et al., 2017). Thus, the flood hazard increases dependent on drainage density. The morphometric analysis shows, the D_d values varies from 0.015 km / km^2 to 0.141 km / km^2 and catchment number of 5, 10, 19, 21, 25, 27, 30, 40, and 45 has the highest D_d values (Fig. S1b).

1.1.4. Basin Relief (B_R)

The altitude difference between the basin’s outlet and highest elevations is defined as the basin relief (Schumm, 1956). It is a significant morphometric indicators that directly influence landform evolution, sediment movement process and risk of flooding (Patton, 1988). Basin Relief is crucial indicator to characterize the nature of flow and inundation of the area. The steep topography with huge slope variation accelerates runoff, and the low relief and flat area slow down flood flows and helps infiltration process. However, in some certain condition the slight slope area might affected more and inundated first as compared to the high slope area (Kirby et al., 2002; Radwan et al., 2019; Yalcin and Akyurek, 2004). As a result of varying topographic of study area, the B_R values widely range from 7.14 km to 0.43 km from north-eastern mountainous basins to southwestern plateaus respectively (Fig. S1c).

1.1.5. Drainage Texture (D_t)

The D_t is a ratio of total stream numbers per basin perimeter (Horton, 1945). In other word, the D_t indicates relative drainage lines spacing within a basin that is determined by infiltration rate, soil and rock types, vegetation, rainfall and climate which is directly proportional to flood hazard (Choudhari et al., 2018; Horton, 1945). The drainage texture values vary from 0.021 to 0.181 as shown in Fig. S1d.

1.1.6. Infiltration Number (I_n)

The I_n, function of drainage density and stream frequency, is used to demonstrate catchment infiltration capacity (Faniran, 1968). Th higher runoff and lower infiltration rate in the catchment resulted by the higher infiltration number values and the computed values is illustrated in Fig. S1e. The plain sandy barren regions in the southwestern part of the study area within lowest values of I_n indicates high infiltration capacity of corresponding catchments and less flooded area.

1.1.7. Compactness coefficient (C_c)

The compactness coefficient is defined as the watershed perimeter divided by the circumference of an equivalent circular area of the watershed (Horton, 1945). The C_c is inversely proportional to the runoff and influenced by the basin slope regardless of the watershed's size (Bhat and Romshoo, 2009). The C_c with the value of 1 indicates a circular basin where the time of concentration to peak flow is less than elongated basins and such areas are prone to flooding. In this study, C_c values vary from 2.2 to 4.1 as shown in Fig. S1f.

1.1.8. Circulatory ratio (C_r)

The C_r is one of the areal aspects of morphometry parameters that influenced by the length and frequency of the basin stream (Chandniha and Kansal, 2017) and is defined as a ratio of basin area to the area of the circle that has an equivalent circumference as the basin perimeter (Miller, 1953). The basins within high C_r value indicates a low concentration time for runoff to reach peak flow and, in consequence, experience more flooding. The basins numbered 4, 8, 10, 27, 30, and 38 are classified as circular basins compared to others, as shown in Fig. S2a.

1.1.9. Elongation ratio (E_r)

The E_r is inversely proportional to the flooding, that means the basin has lower runoff and higher infiltration capacity whereas the E_r values high (Erena and Worku, 2018). It is defined as the ratio of the diameter of a circle of the same size as the catchment to the maximum length of the catchment (Schumm, 1956). The E_r values changes from 0.03 to the 0.17 as shown in Fig. S2b

1.1.10. Ruggedness number (R_n)

The R_n is the dimensionless morphometric parameter and is calculated by multiplying the relief by the drainage density (Costa, 1987; Strahler, 1964). The basin with high R_n is characterized by steep slopes and favouring erosion that respond to rapid flow and flash floods (Alam et al., 2021; Patton, 1988). The basins in north-eastern of the study area has the highest R_n values as illustrated in Fig. S2c.

1.1.11. Bifurcation ratio (B_r)

The B_r is defined as the ratio of the total number of stream order to the next higher order (Horton, 1945; Schumm, 1956). The B_r express the degree of ramification that represents the geological, lithological and techonomic characteristics of the basin (Mesa, 2006; Prabhakar et al., 2019). According to (Haggett and Chorley, 1969; Howard, 1990) the high B_r suggests a high runoff potential generation with relatively minimum concentration time for the flash flood during torrential rains. The B_r is usually high at mountainous or dissected drainage and minimum in flat terrain basins (Horton, 1945). The mean value of B_r usually considered as bifurcation ratio value of the basin and the result of the finding is shown in Fig. S2d.

1.1.12. Length of Overland Flow (LO_f)

The LO_f is inversely proportional to flood hazard and which is defined the length of initial water flowing over the land surface before it reaches in stream channels or on the other hand it is the half of reciprocal of drainage density (Horton, 1945). The LO_f is an independent morphometric parameters affecting both physiographic and hydrologic drainage basin developments (Horton, 1932) and the finding of this study has shown in Fig. S2e.

1.1.13. Form Factor (F_f)

The F_f is expressed as a ratio between the basin area and the square of the basin length (Horton, 1932). The higher value of F_f interpreted as a more circulated shaped basin that indicates shorter duration of peak flows and high discharge in the catchment (Alqahtani and Qaddah, 2019; Gregory and Walling, 1973). The computed results are shown in Fig. S2f.

1.2. Precipitation (P)

Precipitation is the main indicator that characterize hydrological response of the area to the natural hazard. It, coupled with terrain characteristics, determines total surface runoff and significantly contributes flooding in the basin. The high surface runoff is generated as a result of high rainfall that leads to high sediment transportation in the catchment(Mishra and Sinha, 2020). In consequence, there would be more flooding due to limited space in the channel. Therefore, the rainfall was given the highest weightage in the level 2 decision indicators for computing the flood hazard index. The mean monthly precipitation (Fig. S3) shows the north-eastern regions receives the highest precipitation of 1100 mm, where the Indian monsoon flow in during summer and autumn season, and the lowest mean monthly precipitation occurs in the bare and sandy cover southwestern regions.

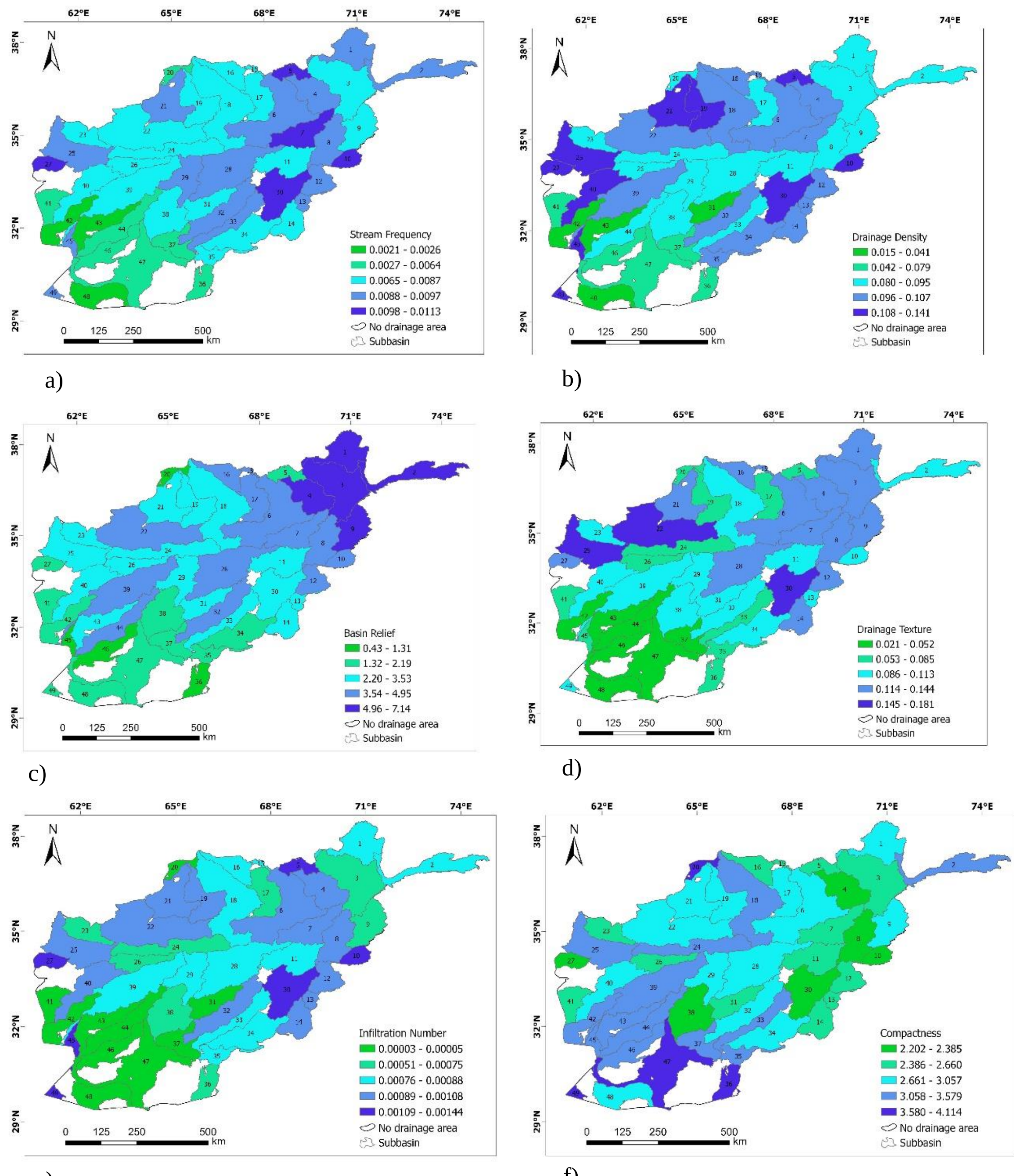


Figure S1. Thematic layers used for the assessment of flood hazard Afghanistan region a) Stream frequency, b) Drainage density, c) Basin relief, d) Drainage texture, e) Infiltration number, f) Compactness coefficient

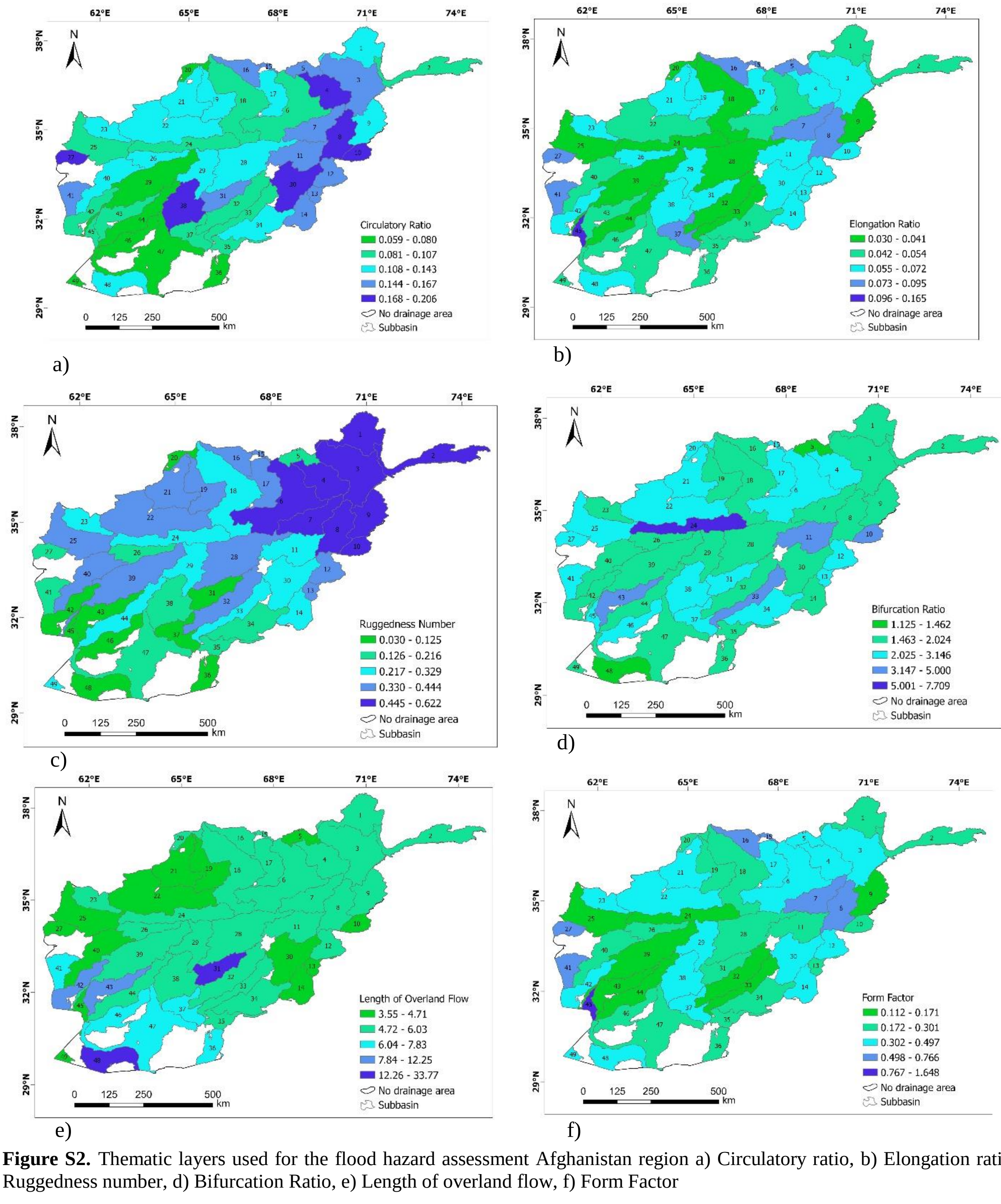


Figure S2. Thematic layers used for the flood hazard assessment Afghanistan region a) Circulatory ratio, b) Elongation ratio, c) Ruggedness number, d) Bifurcation Ratio, e) Length of overland flow, f) Form Factor

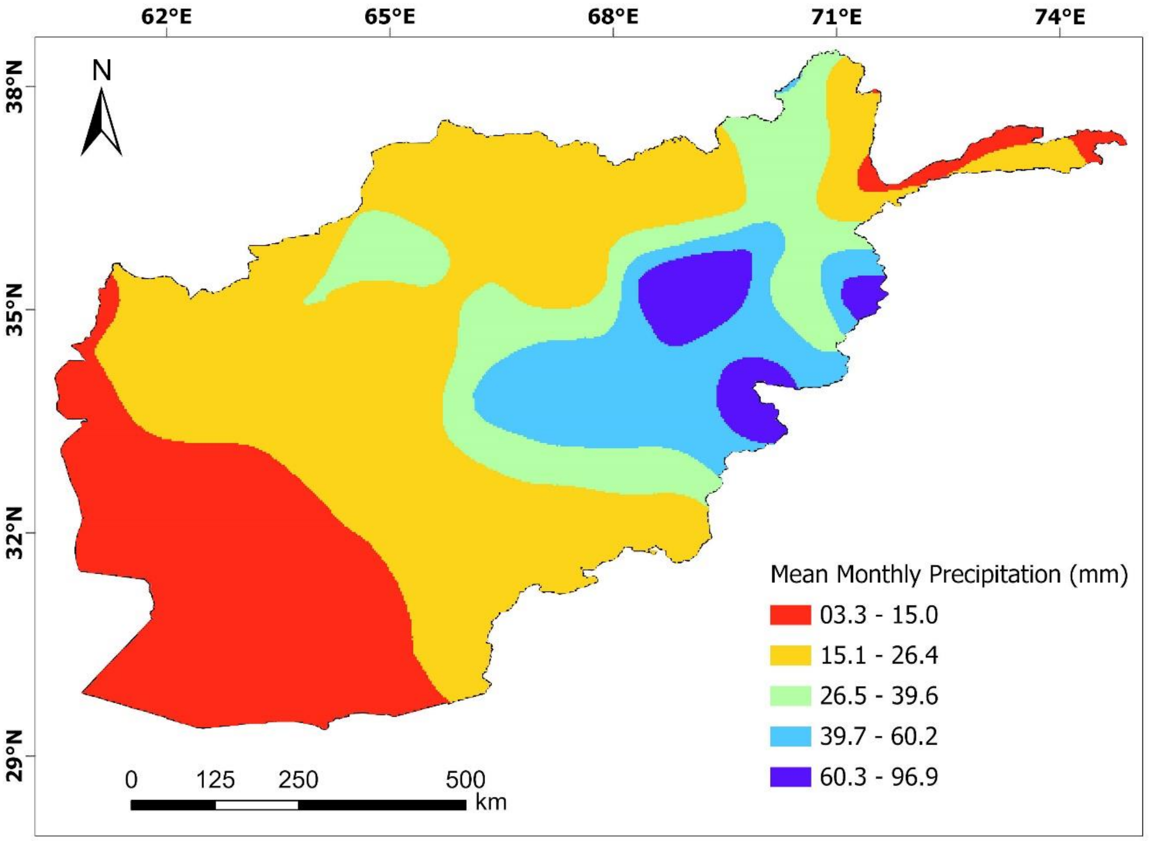


Figure S3. Average precipitation map used for the assessment of flood hazard Afghanistan region.

2. Flood Vulnerability Indicators

Flood vulnerability describes the degree or potential harm to which a socio-economic system and physical assets in a particular region over a specific time are either susceptible or resilient to the impact of natural hazards (Mishra and Sinha, 2020; Shahid and Behrawan, 2008). Flood vulnerability depends on several factors including condition of economic patterns, infrastructure, public policy, human settlements, social inequalities, gender relation, etc and it is different for each individual in different region and nations (Shahid and Behrawan, 2008; Van et al., 2022).

2.1. Population Density (P_d)

Population density is a measure of the number of persons per square kilometre. From the perspectives of human life, health, and the economy, the degree of flood vulnerability is closely tied to the population density of the affected area. Higher population density increases the potential impact on people and infrastructure, leading to greater risks for both human safety and economic losses in the event of a flood. Flood events with similar severity has higher impact-higher probability of loss of life and property in densely populated area rather than sparsely populated ones (Kandilioti and Makropoulos, 2012). Therefore, population density is ranked as the highest weighted indicators for flood vulnerability index as shown in Fig. S4a.

2.2. Rural Population Density (P_{rd})

Rural population is defined the number of people who lives in square kilometre of rural areas (Fig. S4b). In fact, Afghanistan is non-industrialized country where more than 85 percent population lives in remote areas. Rural population indicator, due to low public services, access to the health centres and infrastructure in rural areas, has been weighted as the third most vulnerable indicators in level 2 decision indicators in flood vulnerable computation.

2.3. Literacy rate (L_r)

Percentage of literate person in a province is defined as a L_r. It's one of the several contributing factors of vulnerability that rely on population response on the hazardous events. Naturally, educated population easily understand or predict the nature and severity of a disaster through awareness networks and prepare for possible worse condition (Müller et al., 2011; Pandey et al., 2010) . The country profile of literacy rate has been shown in Fig. S4c, where the changes in value range are between 15% to 55%.

2.1. Female Literacy Rate (FL_r)

The FL_r represents the percentage of literate women in a province (Fig. S4d). Literature has shown that in general women in undeveloped country are highly vulnerable to flood disaster compared to the men as a result of low income, less mobility and high birth rate (Ali et al., 2021; Cutter, 1996; Dwyer et al., 2004; Kablan et al., 2017; Nazeer and Bork, 2019), in contrast, women education can improve awareness, women's empowerment and coping capacity against disaster (Kuhlicke et al., 2011; Müller et al., 2011). Hence, FL_r increases public resilience and in turn reduces flood vulnerability

2.2. Basic, comprehensive and sub health centre (H_c)

The basic, comprehensive and sub health centre is defined as a total number of health centres per province (Fig. S4e). Generally, public access to the lifeline reinforces coping capacity and reduces vulnerability (Jonkman and Kelman, 2005). The health centre facility plays a crucial role in managing potential losses and facilitating recovery during and after flooding. Therefore, it is considered as proxy indicator for flood vulnerability computations.

2.3. Safe Drinking Water (DW_p)

The percentage of household who has access to improved drinking water in a province is defined as safe drinking water (Fig. S5a). The flood vulnerability in water scarce region would be coupled by the lack of human basic needs like sanitation and safe drinking water (McCluskey, 2001; See et al., 2017). In the context of the study area, the lack of vegetation and forestry areas - that functions as a barrier to reduce flood velocity, sediment transpiration and erosion process would increase the probability of water source contamination and spreading of epidemics in the areas (Zanetti et al., 2016). Therefore, safe drinking water indicator plays a key role for FVI.

2.4. Distance to nearest drivable road (DD_r)

The DD_r is defined as the average shortest route in kilometre from an individual living house to the drivable road in the province (Fig. S5b). This parameter identifies the degree of household vulnerability and their coping resilience for flood hazard during flooding. Whatever the DD_r is high, the individual access to the welfare centre or the rescue team traveling time would be more, thus, the DD_r is considered one of the indicators for flood vulnerability assessment.

2.5. Cultivated Land (C_L)

Cultivated land is determined by the percentage of area in each province that are used for food and agricultural production (Fig. S5c). Afghanistan's population entirely depends on agricultural products for their livelihood; thus, crops cultivation, gardening and pasture is the household primary income source. Therefore, flooding has higher impact on the provinces with higher percentage of cultivated lands.

2.6. Poverty Rate (P_r)

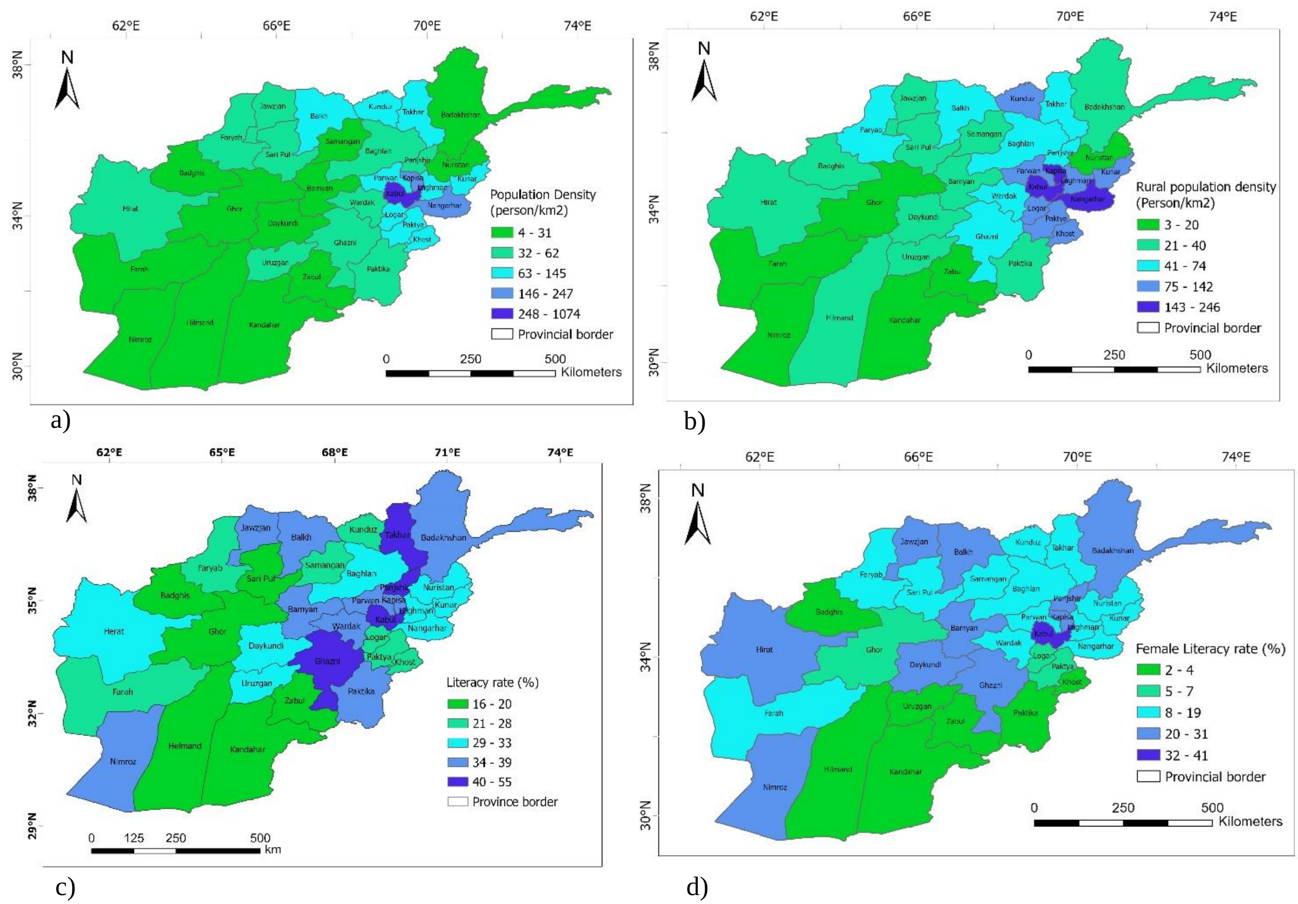
Poverty rate is defined as a percentage of people whose income falls below the poverty line in a province. According to United Nation agencies reports in 2023, Afghanistan remains within the top 3 countries most at risk of worsening humanitarian crises by more than 85 percent of people in poverty (Fig. S5d). Poverty rate is an important indicator for FVI assessment which represents socio-economically poor regions where greater portion of people uses mud or low-quality material for their housing constructions, in turn, that increase vulnerability and reduce resilience capacity for flooding (Nazeer and Bork, 2019; Rafiq and Blaschke, 2012; Shah et al., 2013).

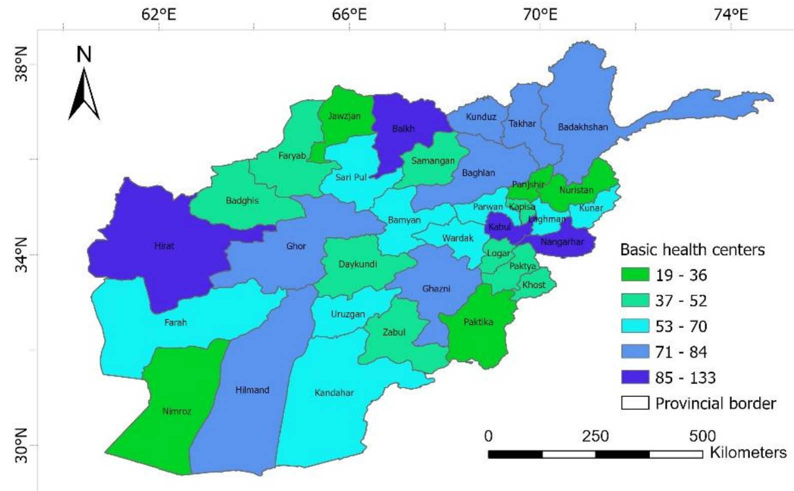
2.7. Unemployment Rate (U_r)

The unemployment rate, determined by the percentage of unemployed people in a province (Fig. S5e). It reflects the population's ability to cope with and recover from flood events, both during and after such occurrence (Dwyer et al., 2004; Holand et al., 2011).

2.8. Land Use and Land Cover (LULC)

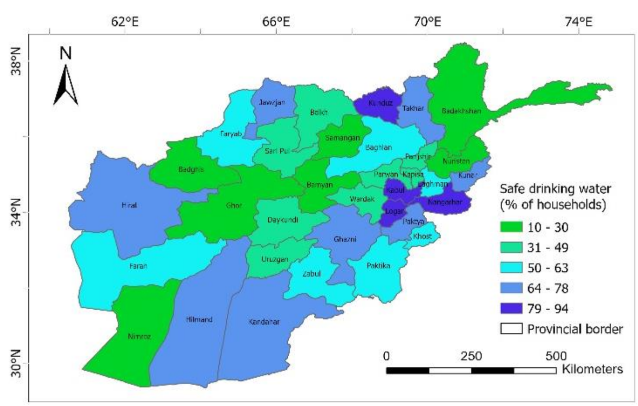
The catchment runoff and its hydrological properties has strongly been controlled by the LULC characteristics of the study area. The vegetated land covers slow down runoff in return recharge groundwater by influencing infiltration rate and hydraulic conductivity via rots and pores, whereas the built up or urbanization areas increases the probability of flood occurrence (Butler et al., 2006; Kazakis et al., 2015; Schmitt et al., 2004; Yalcin and Akyurek, 2004). According to the classified LULC map in Fig.1b, the majority of the study area is dominated by barren or sand-covered land, where economic activities are minimal. Consequently, the lowest vulnerability weight has been assigned to these areas, along with permanent snow cover, as indicated in the level-2 decision indicator in Table S6. The water body or marshland and forest or shrub is categorized as moderate importance. In contrast, urban or built-up areas and cultivated land hold the highest first and second importance weightage ranks, respectively, due to their significance in economic production and infrastructure.



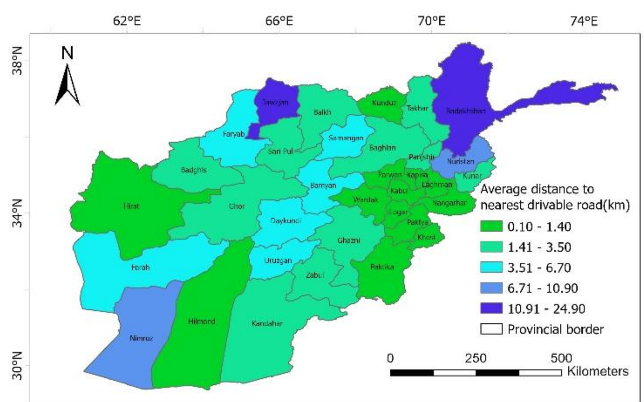


e)

Figure S4. Thematic layers used for the assessment of flood vulnerability of the Afghanistan region: a) Population density, b) Rural population density, c) Literacy rate, d) Female literacy, e) Basic health centres.



a)



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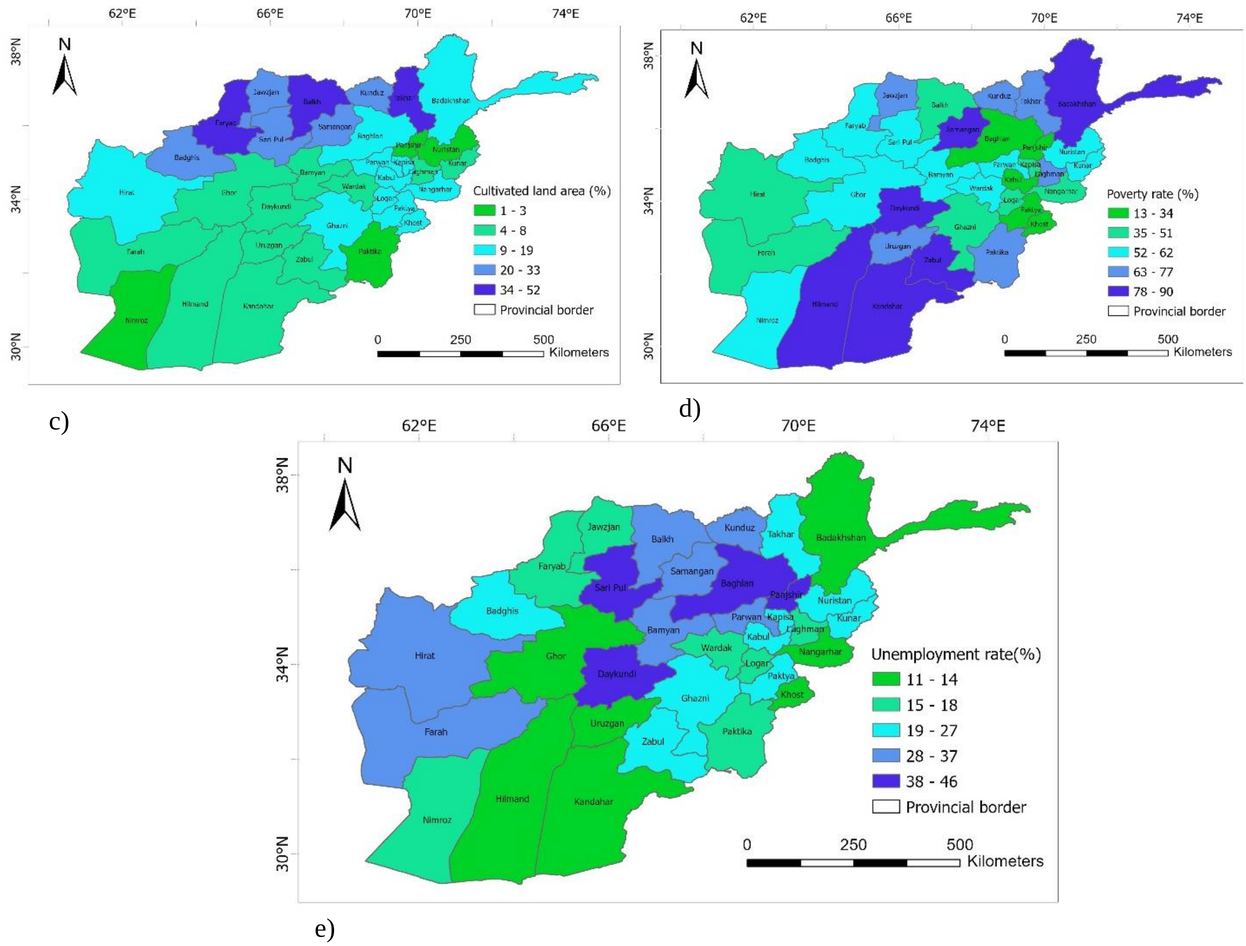

Figure S5. Thematic layers used for the assessment of flood vulnerability of the Afghanistan region: a) Safe drinking water, b) Distance to the nearest drivable road, c) Cultivated land area, d) Poverty rate, e) Unemployment rate

References

Alam, A., Ahmed, B., and Sammonds, P.: Flash flood susceptibility assessment using the parameters of drainage basin morphometry in SE Bangladesh, Quat. Int., 575–576, 295–307, https://doi.org/10.1016/j.quaint.2020.04.047, 2021.

Ali, M. G., Ali, S., Arshad, R. H., Nazeer, A., Waqas, M. M., Waseem, M., Aslam, R. A., Cheema, M. J. M., Leta, M. K., and Shauket, I.: Estimation of potential soil erosion and sediment yield: A case study of the transboundary chenab river catchment, Water (Switzerland), 13, 1–23, https://doi.org/10.3390/w13243647, 2021.

Alqahtani, F. and Qaddah, A. A.: GIS digital mapping of flood hazard in Jeddah–Makkah region from morphometric analysis, Arab. J. Geosci., 12, 1–20, 2019.

Bassey Eze, E. and Efiong, J.: Morphometric parameters of the Calabar River basin: implication for hydrologic processes, J. Geogr. Geol., 2, 18–26, 2010.

Bhat, S. and Romshoo, S.: Digital elevation model based watershed characteristics of upper watersheds of Jhelum basin, J. Appl. Hydrol., 21, 23–34, 2009.

Butler, D., Kokkalidou, A., and Makropoulos, C. K.: Supporting the siting of new urban developments for integrated urban water resource management, in: Integrated urban water resources management, 19–34, 2006.

Chandniha, S. K. and Kansal, M. L.: Prioritization of sub-watersheds based on morphometric analysis using geospatial technique in Piperiya watershed, India, Appl. Water Sci., 7, 329–338, https://doi.org/10.1007/s13201-014-0248-9, 2017.

Choudhari, P. P., Nigam, G. K., Singh, S. K., and Thakur, S.: Morphometric based prioritization of watershed for groundwater potential of Mula river basin, Maharashtra, India, Geol. Ecol. Landscapes, 2, 256–267, 2018.

Costa, J. E.: Hydraulics and basin morphometry of the largest flash floods in the conterminous United States, J. Hydrol., 93, 313–338, 1987.

Cutter, S. L.: Vulnerability to environmental hazards, Prog. Hum. Geogr., 20, 529–539, 1996.

Dwyer, A., Zoppou, C., Nielsen, O., Day, S., and Roberts, S.: Quantifying social vulnerability: a methodology for identifying those at risk to natural hazards, 2004.

Erena, S. H. and Worku, H.: Flood risk analysis: causes and landscape based mitigation strategies in Dire Dawa city, Ethiopia, Geoenvironmental Disasters, 5, https://doi.org/10.1186/s40677-018-0110-8, 2018.

Faniran, A.: The index of drainage intensity: a provisional new drainage factor, Aust J Sci, 31, 326–330, 1968.

Gregory, K. J. and Walling, D. E.: Drainage basin form and process: a geomorphological approach, (No Title), 1973.

Haggett, P. and Chorley, R. J.: Network analysis in geography, (No Title), 1969.

Holand, I. S., Lujala, P., and Rød, J. K.: Social vulnerability assessment for Norway: A quantitative approach, Nor. Geogr. Tidsskr. J. Geogr., 65, 1–17, 2011.

Horton, R. E.: Drainage-basin characteristics, Trans. Am. Geophys. union, 13, 350–361, 1932.

Horton, R. E.: Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology, Geol. Soc. Am. Bull., 56, 275–370, 1945.

Howard, A. D.: Role of hypsometry and planform in basin hydrologic response, Hydrol. Process., 4, 373–385, 1990.

Jonkman, S. N. and Kelman, I.: An analysis of the causes and circumstances of flood disaster deaths, Disasters, 29, 75–97, 2005.

Kablan, M. K. A., Dongo, K., and Coulibaly, M.: Assessment of social vulnerability to flood in urban Côte d'Ivoire using the MOVE framework, Water, 9, 292, 2017.

Kandilioti, G. and Makropoulos, C.: Preliminary flood risk assessment: the case of Athens, Nat. hazards, 61, 441–468, 2012.

Kazakis, N., Kougias, I., and Patsialis, T.: Assessment of flood hazard areas at a regional scale using an index-based approach and Analytical Hierarchy Process: Application in Rhodope–Evros region, Greece, Sci. Total Environ., 538, 555–563, 2015.

Kirby, W., Riggs, H., Sauer, V., and Thomas Jr, W.: The national flood frequency program, version 3: a computer program for estimating magnitude and frequency of floods for ungaged sites, Water-Resour Investig. Rep, 2, 4168, 2002.

Kuhlicke, C., Scolobig, A., Tapsell, S., Steinführer, A., and De Marchi, B.: Contextualizing social vulnerability: findings from case studies across Europe, Nat. hazards, 58, 789–810, 2011.

McCluskey, J.: Water supply, health and vulnerability in floods, Emerg. Med., 59, 66, 2001.

Melton, M. A.: An analysis of the relations among elements of climate, surface properties, and geomorphology, Department of Geology, Columbia University New York, 1957.

Mesa, L. M.: Morphometric analysis of a subtropical Andean basin (Tucuman, Argentina), Environ. Geol., 50, 1235–1242, 2006.

Miller, V. C.: A quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee, Columbia University New York, 1953.

Mishra, K. and Sinha, R.: Flood risk assessment in the Kosi megafan using multi-criteria decision analysis: A hydro-geomorphic approach, Geomorphology, 350, 106861, https://doi.org/10.1016/j.geomorph.2019.106861, 2020.

Müller, A., Reiter, J., and Weiland, U.: Assessment of urban vulnerability towards floods using an indicator-based approach–a case study for Santiago de Chile, Nat. Hazards Earth Syst. Sci., 11, 2107–2123, 2011.

Nasir, M. J., Iqbal, J., and Ahmad, W.: Flash flood risk modeling of swat river sub-watershed: a comparative analysis of morphometric ranking approach and El-Shamy approach, Arab. J. Geosci., 13, https://doi.org/10.1007/s12517-020-06064-5, 2020.

Nazeer, M. and Bork, H.-R.: Flood Vulnerability Assessment through Different Methodological Approaches in the Context of North West Khyber Pakhtunkhwa Pakistan, Sustain., 11, 18, 2019.

Pandey, A. C., Singh, S. K., and Nathawat, M. S.: Waterlogging and flood hazards vulnerability and risk assessment in Indo Gangetic plain, Nat. hazards, 55, 273–289, 2010.

Patton, P. C.: Drainage basin morphometry and floods, Flood Geomorphol. John Wiley Sons New York. 1988. p 51-64. 11 fig, 1 tab, 67 ref., 1988.

Prabhakar, A. K., Singh, K. K., Lohani, A. K., and Chandniha, S. K.: Study of Champua watershed for management of resources by using morphometric analysis and satellite imagery, Appl. Water Sci., 9, 1–16, 2019.

Radwan, F., Alazba, A. A., and Mossad, A.: Flood risk assessment and mapping using AHP in arid and semiarid regions, Acta Geophys., 67, 215–229, https://doi.org/10.1007/s11600-018-0233-z, 2019.

Rafiq, L. and Blaschke, T.: Disaster risk and vulnerability in Pakistan at a district level, Geomatics, Nat. Hazards Risk, 3, 324–

341, 2012.

Sahu, N., Obi Reddy, G. P., Kumar, N., Nagaraju, M. S. S., Srivastava, R., and Singh, S. K.: Morphometric analysis in basaltic Terrain of Central India using GIS techniques: a case study, Appl. Water Sci., 7, 2493–2499, 2017.

Schmitt, T. G., Thomas, M., and Ettrich, N.: Analysis and modeling of flooding in urban drainage systems, J. Hydrol., 299, 300–311, 2004.

Schumm, S. A.: Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey, Geol. Soc. Am. Bull., 67, 597–646, 1956.

See, K. L., Nayan, N., and Rahaman, Z. A.: Flood disaster water supply: a review of issues and challenges in Malaysia, Int. J. Acad. Res. Bus. Soc. Sci., 7, 525–532, 2017.

Shah, A., Khan, H., and Qazi, E.: Damage assessment of flood affected mud houses in Pakistan, J. Himal. Earth Sci., 46, 2013.

Shahid, S. and Behrawan, H.: Drought risk assessment in the western part of Bangladesh, Nat. Hazards, 46, 391–413, https://doi.org/10.1007/s11069-007-9191-5, 2008.

Strahler, A. N.: Quantitative analysis of watershed geomorphology, Eos, Trans. Am. Geophys. Union, 38, 913–920, 1957.

Strahler, A. N.: Quantitative geomorphology of drainage basin and channel networks, Handb. Appl. Hydrol., 1964.

Van, C. T., Tuan, N. C., Son, N. T., Tri, D. Q., Anh, L. N., and Tran, D. D.: Flood vulnerability assessment and mapping: A case of Ben Hai-Thach Han River basin in Vietnam, Int. J. Disaster Risk Reduct., 75, 102969, https://doi.org/10.1016/j.ijdrr.2022.102969, 2022.

Yalcin, G. and Akyurek, Z.: Multiple criteria analysis for flood vulnerable areas, in: XXth ISPRS congress ‘‘geo-imagery briding continents, 12–13, 2004.

Zanetti, C., Macia, J., Liency, N., Vennetier, M., Mériaux, P., and Provensal, M.: Roles of the riparian vegetation: the antagonism between flooding risk and the protection of environment, in: 3rd European Conference on Flood Risk Management FLOODrisk 2016, 13015, 2016.