

Supporting Information for

Flood Susceptibility and Potential Flood Risk Assessment in Afghanistan Using Morphometric and Socioeconomic Indicators

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S1. Flood Susceptibility Indicators (FSI)

Flood susceptibility in this study is assessed using a set of morphometric and climatic indicators derived for 49 sub-basins across Afghanistan. These indicators capture key controls on runoff generation, flow concentration, and inundation potential in a region marked by strong topographic variability and limited hydrometeorological data. The analysis integrates drainage network characteristics (stream order, stream frequency, drainage density, drainage texture), basin geometry (compactness coefficient, circularity ratio, elongation ratio, form factor), relief parameters (basin relief, ruggedness number), and hydrological response metrics (infiltration number, length of overland flow). Together, these variables describe basin-scale efficiency in generating and routing runoff during rainfall events.

S1.1. Watershed delineation process

The watershed delineation for Afghanistan was based on the hydrologically corrected MERIT Hydro DEM (90 m) [1] which was selected because it provides globally consistent, hydrologically conditioned elevation and river-network information suitable for national-scale analysis in a data-scarce and topographically complex region. The DEM was pre-processed to fill sinks and remove artefacts, after which flow direction and flow accumulation grids were derived in ArcHydro. Stream initiation was defined using a threshold of 1000 pixel units, and the resulting drainage network was used to delineate 49 sub-basins through a semi-automated workflow with manual refinement to ensure hydrological realism. The derived stream networks and basin boundaries were checked against OpenStreetMap river layers, HydroSHEDS products, and high-resolution Google Earth Pro imagery, particularly in low-relief or internally drained regions where DEM-based drainage representation may be uncertain. Although finer-resolution DEMs are available, their use at national scale requires greater computational effort and careful hydrological conditioning and may introduce spurious drainage features in low-relief terrain. For this reason, MERIT Hydro was considered the most appropriate dataset for consistent watershed delineation in the present study.

Similar semi-automated approaches combining DEM-based delineation and manual refinement have been widely used in data-scarce or topographically complex regions [2–4]. Based on the final sub-basin boundaries and derived drainage network, key morphometric indicators, including drainage density, basin relief, drainage texture, infiltration number, stream frequency, compactness coefficient, circularity ratio, elongation ratio, bifurcation ratio, length of overland flow, and form factor, were computed for each sub-basin. Additional parameters such as basin area, basin length, perimeter, stream order, stream number, and total stream length were also extracted and used as inputs to the flood susceptibility analysis (Table 2).

S1.2. 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 [5]. 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.

S1.3. Stream Frequency (F_s)

The number of stream segments of all orders per unit area of a basin is called stream frequency [6,7]. 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 [6,8] as shown in Figure. S1a.

S1.4. Drainage Density (D_d)

The total length of streams per unit area of a basin is known the drainage density [6]. It is one of the vital morphometric indicators, indicates the catchment geomorphological response for the generation of the runoff [9]. 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 [10,11]. According to [12], 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 [13,14]. Thus, the flood susceptibility increases dependent on drainage density. The morphometric analysis shows, the D_d values varies from 0.015 km / km² to 0.141 km / km² and catchment number of 5, 10, 19, 21, 25, 27, 30, 40, and 45 has the highest D_d values (Figure. S1b).

S1.5. Basin Relief (B_R)

The altitude difference between the basin's outlet and highest elevations is defined as the basin relief [15]. It is one of the significant morphometric indicators that directly influence landform evolution, sediment movement process and risk of flooding [8]. 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 [16–18]. 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 (Figure. S1c).

S1.6. Drainage Texture (D_t)

The D_t is a ratio of total stream numbers per basin perimeter [6]. 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 susceptibility [6,19]. The drainage texture values vary from 0.021 to 0.181 as shown in Figure. S1d.

S1.7. Infiltration Number (I_n)

The I_n , function of drainage density and stream frequency, is used to demonstrate catchment infiltration capacity [20]. Th higher runoff and lower infiltration rate in the catchment resulted by the higher infiltration number values and the computed values is illustrated in Figure. 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.

S1.8. 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 [6]. The C_c is inversely proportional to the runoff and influenced by the basin slope regardless of the watershed's size [21]. 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 Figure. S1f.

S1.9. 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 [22] and is defined as a ratio of basin area to the area of the circle that has an equivalent circumference as the basin perimeter [23]. 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 Figure. S2a.

S1.10. 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 [24]. 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 [15]. The E_r values changes from 0.03 to the 0.17 as shown in Figure. S2b

S1.11. Ruggedness number (R_n)

The R_n is the dimensionless morphometric parameter and is calculated by multiplying the relief by the drainage density [12,25]. The basin with high R_n is characterized by steep slopes and favouring erosion that respond to rapid flow and flash floods [7,8]. The basins in north-eastern of the study area has the highest R_n values as illustrated in Figure. S2c.

S1.12. Bifurcation ratio (B_r)

The B_r is defined as the ratio of the total number of stream order to the next higher order [6,15]. The B_r express the degree of ramification that represents the geological, lithological and tectonic characteristics of the basin [26,27]. According to [10,28], 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 [6]. The mean value of B_r usually considered as bifurcation ratio value of the basin and the result of the finding is shown in Figure. S2d.

S1.13. Length of Overland Flow (LO_f)

The LO_f is inversely proportional to flood susceptibility 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 [6]. The LO_f is an independent morphometric parameters affecting both physiographic and hydrologic drainage basin developments [29] and the finding of this study has shown in Figure. S2e.

S1.14. Form Factor (F_f)

The F_f is expressed as a ratio between the basin area and the square of the basin length [29]. 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 [30,31]. The computed results are shown in Figure. S2f.

S1.15. 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[32]. 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 susceptibility index. The mean monthly precipitation (Figure. 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.

S2. Flood Vulnerability Indicators (FVI)

Flood vulnerability refers to the degree or potential harm to which a socio-economic system and physical assets in a particular region, over a specific period, are susceptible or resilient to the impacts of

natural hazards [32–34]. It is influenced by multiple factors, including economic patterns, infrastructure, public policy, human settlements, social inequalities, and gender relations, and it varies across individuals, regions, and nations [35,36]. The socio-economic indicators included in this study were selected based on three criteria: (i) their established role in disaster risk and vulnerability assessment frameworks [37,38] (ii) their contextual relevance to Afghanistan, and (iii) their spatial availability, as detailed in the following subsections:

S2.1. 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 [39]. Therefore, population density is ranked as the highest weighted indicators for flood vulnerability index as shown in Figure. S5a.

S2.2. Rural Population Density (P_{rd})

Rural population is defined the number of people who lives in square kilometre of rural areas (Figure. S5b). 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.

S2.3. 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 [40,41]. The country profile of literacy rate has been shown in Figure. S5c, where the changes in value range are between 15% to 55%.

S2.4. Female Literacy Rate (FL_r)

FL_r represents the percentage of literate women in a province (Figure S5d). Women in developing countries are generally more vulnerable to flood disasters than men due to lower income, limited mobility, and higher birth rates [42–45]. Low female literacy further exacerbates this vulnerability by limiting access to hazard information, emergency response, and coping strategies. In contrast, female education can enhance disaster awareness, empower women, and improve household and community coping capacity [41,46]. Therefore, higher FL_r increases public resilience and reduces flood vulnerability. In the Afghanistan context, where female literacy is particularly low, this indicator is critical for capturing social vulnerability and assessing the capacity of communities to respond effectively to potential flood risk.

S2.5. 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 (Figure. S5e). Generally, public access to the lifeline reinforces coping capacity and reduces vulnerability [47]. 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.

S2.6. Safe Drinking Water (DWp)

The percentage of household who has access to improved drinking water in a province is defined as safe drinking water (Figure. S6a). The flood vulnerability in water scarce region would be coupled by the lack of human basic needs like sanitation and safe drinking water [48,49]. 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 [50]. Therefore, safe drinking water indicator plays a key role for FVI.

S2.7. 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 (Figure. S6b). This parameter identifies the degree of household vulnerability and their coping resilience for flood susceptibility 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.

S2.8. Cultivated Land (CL)

Cultivated land is determined by the percentage of area in each province that are used for food and agricultural production (Figure. S6c). 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.

S2.9. Poverty Rate (Pr)

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 (Figure. S6d). 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 [45,51,52].

S2.10. Unemployment Rate (Ur)

The unemployment rate represents the percentage of unemployed people in a province (Figure S6e). It reflects the population's capacity to cope with and recover from flood events, both during and after such occurrences [33,43]. High unemployment reduces economic resilience, limiting households' ability to invest in protective measures, secure safe housing, or recover from flood damages. In Afghanistan, widespread unemployment further exacerbates vulnerability, particularly in rural and peri-urban areas where alternative livelihood opportunities are scarce. Therefore, the unemployment rate is a critical socio-economic indicator for assessing flood vulnerability and represents a direct measure of the population's adaptive capacity.

S2.11. Land Use and Land Cover (LULC)

The catchment runoff and its hydrological properties have 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 roots and pores, whereas the built up or urbanization areas increases the probability of flood occurrence [17,53–56]. The land use and land cover (LULC) data for Afghanistan were obtained from the National Land Cover Monitoring System (NLCMS, 2000–2018) (<https://rds.icimod.org/Home/DataDetail?metadataId=1973187>). The original raster dataset was imported into ArcGIS and reprojected to the study area coordinate system (WGS 1984 / UTM Zone 42N). Using GIS raster calculation and reclassification tools, the dataset was reclassified into six major classes: (a) urban or built-up areas, (b) cultivated land, (c) water bodies and marshlands, (d) barren and sand-covered land, (e) forests and shrubland, and (f) snow-covered areas. The percentage area of each class within the study area was calculated using zonal statistics tools to support the flood vulnerability index (Table S1). The LULC data were validated using high-resolution satellite imagery and ground reference points available from ICIMOD reports, resulting in an overall classification accuracy of ~88%, which is consistent with similar regional datasets [57]. According to the classified LULC map in Figure.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-3 decision indicator in Table S8. 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.

The catchment runoff response and hydrological behaviour of Afghanistan are strongly influenced by land use and land cover (LULC). Vegetated surfaces can slow runoff and enhance infiltration through root systems and soil macropores, whereas built-up areas and compacted surfaces increase runoff generation and flood susceptibility [17,53-56]. The LULC data were obtained from the National Land Cover Monitoring System (NLCMS, 2000-2018; <https://rds.icimod.org/Home/DataDetail?metadataId=1973187>). The original raster dataset was imported into ArcGIS and reprojected to WGS 1984 / UTM Zone 42N. It was reclassified into six major classes: urban or built-up areas, cultivated land, water bodies and marshlands, barren and sand-covered land, forests and shrubland, and permanent snow cover. Percentage area for each class was calculated using zonal statistics to support the vulnerability index (Table S1). Urban or built-up areas and cultivated land were assigned higher vulnerability weights because they represent concentrated exposure of people, infrastructure, and livelihoods, whereas barren/sand-covered land and permanent snow cover were assigned lower vulnerability weights.

S3. Sensitivity analysis of PCA-AHP weights for FSI and FVI indicators

To evaluate the robustness of the flood susceptibility, flood vulnerability, to uncertainty in indicator weighting, we performed a sensitivity analysis of the PCA-AHP weights used in the study. Although the AHP procedure provided a consistent expert-based weighting structure, the resulting weights are not free from subjectivity. Therefore, a sensitivity analysis was carried out to test whether the spatial pattern of the derived indices remained stable under plausible variations in indicator weights.

The baseline analysis used the final PCA-AHP weights assigned to all indicators for the Flood Susceptibility Index (FSI) and Flood Vulnerability Index (FVI), as defined in Equations (7) and (8). These baseline weights were treated as the reference case against which all alternative +weighting scenarios were compared. A one-at-a-time weight perturbation approach was applied with some of the parameters. In this procedure, one indicator weight was modified by $\pm 10\%$, while all remaining indicator weights were proportionally adjusted so that the total sum of weights remained equal to 1.

For a given indicator i , the perturbed weight w_i^* was calculated as:

$$w_i^* = w_i(1 + \delta)$$

where w_i is the original weight and δ is the perturbation factor. In this study, δ was set to ± 0.10 and ± 0.20 , representing $\pm 10\%$ and $\pm 20\%$ changes, respectively.

After perturbing one weight, the remaining weights were rescaled as:

$$w_j^* = w_j \times \frac{1 - w_i^*}{1 - w_i}, j \neq i$$

so that:

$$\sum_{k=1}^n w_k^* = 1$$

This procedure was repeated separately for each indicator used in the FSI and FVI models.

For each perturbed weighting scenario, the susceptibility and vulnerability indices were recalculated using the same standardized input layers and the same overlay framework as in the baseline model.

The recalculated susceptibility index was obtained as:

$$FSI^* = \sum_{i=1}^n w_i^* x_i$$

and the recalculated vulnerability index as:

$$FVI^* = \sum_{i=1}^m w_i^* y_i$$

where x_i and y_i represent the standardized susceptibility and vulnerability indicator values, respectively, and w_i^* are the perturbed weights.

S4. Sensitivity analysis of selected PCA-AHP weights

The sensitivity analysis of selected PCA-AHP weights showed that the Flood Susceptibility Index (FSI) was generally stable under the tested $\pm 10\%$ perturbation scenarios, whereas the Flood Vulnerability Index (FVI) showed a comparatively stronger response to changes in selected socio-economic weights (Table S10). Here, changes are described as percentage-point differences relative to the baseline class proportions.

For the FSI, the baseline class distribution was 20.45% (Low), 30.59% (Moderate), 29.01% (High), and 19.95% (Very High). Increasing the weight of precipitation (P) by 10% caused only limited redistribution among adjacent classes. The Low class showed no change, the Moderate class decreased by 0.43 %, the High class increased by 1.61 %, and the Very High class decreased by 1.18 %. Under P -10%, the Low class again remained unchanged, the Moderate class decreased by 1.01 %, the High class increased by 1.01 %, and the Very High class showed no change. Perturbation of basin relief (BR) produced even smaller changes. Under BR +10%, the Moderate class increased by 0.19 % and the High class decreased by 0.19 %, while the Low and Very High classes remained unchanged. No change was observed under BR -10%. Overall, these results indicate that the FSI classification is relatively robust to moderate perturbation of the selected susceptibility weights.

For the FVI, the baseline class distribution was 17.29% (Low), 30.91% (Moderate), 20.48% (High), and 31.32% (Very High). In contrast to the FSI, the FVI responded more strongly to perturbation of selected indicator weights. Under population density (Pd) +10%, the Low class decreased by 1.69 %, the Moderate class decreased by 1.64 %, the High class changed only marginally by -0.09 %, and the Very High class increased by 4.42 %. Under Pd -10%, the Low and Moderate classes decreased by 2.02 and 2.38 %, respectively, the High class remained nearly unchanged at -0.01 %, and the Very High class increased by 4.41 %. A comparable pattern was observed for land use/land cover (LULC). Under LULC +10%, the Low, Moderate, and High classes decreased by 2.66, 1.27, and 0.49 %, respectively, while the Very High class increased by 4.42 %. Under LULC -10%, the Low and Moderate classes decreased by 2.02 and 2.30 %, respectively, the High class increased slightly by 0.38 %, and the Very High class remained elevated with an increase of 3.94 %. Overall, the results suggest that the susceptibility model is comparatively robust, whereas the vulnerability model is more responsive to changes in the selected weighting structure.

Lists of Tables

Table S1: Landuse and landcover areal statistics of Afghanistan

Landuse and land cover class name	Area (sq.km)	Percentage of area covered (%)
Urban or built-up area	26421	0.47
Agricultural land	69914	11.80
Waterbody and marshland	15815	2.85
Forest or shrub	16605	2.78
Barren land and sand cover	534504	81.29
Permanent snow cover	4167	0.76
Total	643646	100

Table S2a: PCA based ranking of flood susceptibility indicators using Varimax with Kaiser Normalization methods.

Flood susceptibility indicators	Component loading (~85%)			
	1 (42 %)	2 (20 %)	3 (16 %)	4 (7 %)
Precipitation	0.823			
Basin Relief	0.782			
Circulation ratio	0.784			
compactness	-0.801			
Ruggedness number	0.747			
Drainage texture	0.697			
Drainage density		0.967		
Stream frequency		0.712		
Length of overland flow		-0.879		
Infiltration number		0.881		
Elongation ratio			0.951	
Form factor			0.872	
Bifurcation				0.971

Table S2b: PCA based ranking of flood vulnerability indicators using Varimax with Kaiser Normalization methods.

Flood vulnerability indicators		Component loading (~ 73%)			
		1 (33 %)	2 (17 %)	3 (13 %)	4 (10 %)
Population Density	Exposure	0.798			
Rural population Density		0.660			
Cultivated land				0.603	
LULC		0.692			
Poverty rate	Sensitivity			0.517	
Unemployment rate					-0.702
Distance to nearest drivable road			0.679		
Basic health center	Adaptive Capacity	0.626			
Safe drinking water		0.606			
Female literacy rate			0.732		
Literate rate		0.636			

Table S3: Saaty's scale of preference

Intensity importance	Definition
1	Equal importance

3	Moderate importance
5	Strong importance
7	Very strong or Demonstrated importance
9	Extreme importance
2,4,6,8	Intermediate values
Reciprocals	Inverse comparison

Table S4: Saaty's Random index values

Number of criteria	Random consistency index (RI)
1	0
2	0
3	0.58
4	0.89
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.54
13	1.56
14	1.57
15	1.59
16	1.60

Table S5a: Calculation of relative importance weightage (RIW) for level 2 decision indicators used for the FHI i) Stream frequency, ii) drainage density, iii) Basin relief, iv) Drainage texture, v) Infiltration number, vi) Compactness coefficient.

i)	Stream frequency						
Decision indicators	0.002 0.005	- 0.005 0.006	- 0.006 0.008	- 0.008 0.009	- 0.009- 0.01	EEV	RIW
0.002- 0.005	1	1/2	1/2	1/3	1/3	0.488	0.085
0.005- 0.006	2	1	1/2	1/2	1/3	0.699	0.121
0.006- 0.008	2	2	1	1/2	1/3	0.922	0.160
0.008 - 0.009	3	2	2	1	1/2	1.431	0.248

0.009 - 0.01	3	3	3	2	1	2.221	0.385
ii) Drainage Density							
Decision indicators	0.01 - 0.04	0.04 - 0.07	0.07 - 0.09	0.09 - 0.11	0.11 - 0.15	EEV	RIW
0.01 - 0.04	1	1/2	1/3	1/3	1/4	0.43	0.071
0.04- 0.07	2	1	1/2	1/3	1/3	0.64	0.108
0.07 - 0.09	3	2	1	1/2	1/3	1.00	0.167
0.09 - 0.11	3	3	2	1	1/2	1.55	0.260
0.11 - 0.15	4	3	3	2	1	2.35	0.394
iii) Basin Relief (in km)							
Decision indicators	0.4 - 1.3	1.3- 2.6	2.6 - 3.9	3.9 - 5.4	5.4 - 7.1	EEV	RIW
0.4 - 1.3	1	1/2	1/3	1/5	1/5	0.37	0.06
1.3- 2.6	2	1	1/2	1/3	1/3	0.64	0.10
2.6 - 3.9	3	2	1	1/2	1/3	1.00	0.16
3.9 - 5.4	5	3	2	1	1/2	1.72	0.28
5.4 - 7.1	5	3	3	2	1	2.46	0.40
iv) Drainage Texture							
Decision indicators	0.02 - 0.05	0.05 - 0.08	0.08 - 0.1	0.1 - 0.14	0.14 - 0.18	EEV	RIW
0.02 - 0.05	1	1/2	1/3	1/3	1/4	0.43	0.07
0.05 - 0.08	2	1	1/2	1/3	1/3	0.64	0.11
0.08 - 0.1	3	2	1	1/2	1/2	1.08	0.18
0.1 - 0.14	3	3	2	1	1/2	1.55	0.26
0.14 - 0.18	4	3	2	2	1	2.17	0.37
v) Infiltration Number							
Decision indicators	0.00003 – 0.0005	0.0005 – 0.0007	0.0007 – 0.0008	0.0008 – 0.0010	0.0010 – 0.0014	EEV	RIW
0.00003 - 0.0005	1	1/2	1/2	1/2	1/3	0.53	0.10
0.0005 - 0.0007	2	1	1/2	1/2	1/2	0.76	0.14
0.0007 - 0.0008	2	2	1	1/2	1/2	1.00	0.18
0.0008 - 0.0010	2	2	2	1	1/2	1.32	0.24
0.0010- 0.0014	3	2	2	2	1	1.89	0.34
vi) Compactness Coefficient							
Decision indicators	2.2 - 2.3	2.3 - 2.5	2.5 - 2.9	2.9 - 3.5	3.5 - 4.4	EEV	RIW

2.2 - 2.3	1	2	2	3	4	1.86	0.38
2.3 - 2.5	1/2	1	2	3	3	1.32	0.27
2.5 - 2.9	1/2	1/2	1	2	3	0.84	0.17
2.9 - 3.5	1/3	1/3	1/2	1	2	0.49	0.10
3.5 - 4.4	1/4	1/3	1/3	1/2	1	0.34	0.07

Table S5b: Calculation of relative importance weightage (RIW) for level 2 decision indicators for the FHI i) Circulatory ratio, ii) Elongation ratio, iii) Ruggedness number, iv) Bifurcation Ratio, v) Length of overland flow, vi) Form factor

i) Circulatory Ratio							
Decision indicators	0.05 - 0.08	0.08 - 0.10	0.10- 0.14	0.14- 0.16	0.16 - 0.20	EEV	RIW
0.05 - 0.08	1	1/2	1/3	1/4	1/5	0.38	0.06
0.08 - 0.10	2	1	1/2	1/3	1/4	0.61	0.10
0.10- 0.14	3	2	1	1/2	1/3	1.00	0.16
0.14- 0.16	4	3	2	1	1/2	1.64	0.26
0.16- 0.20	5	4	3	2	1	2.61	0.42
ii) Elongation Ratio							
Decision indicators	0.02 - 0.03	0.03 - 0.05	0.05- 0.06	0.06 - 0.07	0.07 - 0.16	EEV	RIW
0.02- 0.03	1	2	2	3	5	2.27	0.39
0.03- 0.05	1/2	1	2	2	3	1.43	0.24
0.05- 0.06	1/2	1/2	1	2	3	1.08	0.18
0.06- 0.07	1/3	1/2	1/2	1	2	0.70	0.12
0.07 - 0.16	1/5	1/3	1/3	1/2	1	0.41	0.07
iii) Ruggedness number							
Decision indicators	0.02 - 0.12	0.12 - 0.21	0.21 - 0.32	0.32 - 0.44	0.44 - 0.62	EEV	RIW
0.02 - 0.12	1	1/2	1/2	1/3	1/3	0.49	0.09
0.12 - 0.21	2	1	1/2	1/2	1/3	0.70	0.12
0.21 - 0.32	2	2	1	1/2	1/2	1.00	0.18
0.32 - 0.44	3	2	2	1	1/2	1.43	0.25
0.44 - 0.62	3	3	2	2	1	2.05	0.36
iv) Bifurcation Ratio							
Decision indicators	1.12- 1.59	1.59 - 2.06	2.06- 2.84	2.83 - 4.56	4.56 - 7.70	EEV	RIW
1.12 - 1.59	1	1/2	1/3	1/4	1/5	0.452	0.056
1.59 - 2.06	2	1	1/2	1/3	1/4	0.760	0.094

2.06- 2.84	3	2	1	1/2	1/3	1.316	0.163
2.84 - 4.56	4	3	2	1	1/2	2.213	0.275
4.56- 7.70	5	4	3	2	1	3.310	0.411
v) Length of overland flow							
Decision indicators	3.20 - 4.91	4.91 - 5.99	5.99- 7.83	7.83- 12.11	12.11 - 0.74	EEV	RIW
3.20 - 4.91	1	2	3	5	5	2.72	0.43
4.91 - 5.99	1/2	1	2	3	4	1.64	0.26
5.99 - 7.83	1/3	1/2	1	3	3	1.08	0.17
7.83- 12.11	1/5	1/3	1/3	1	3	0.58	0.09
12.11- 30.74	1/5	1/4	1/3	1/3	1	0.35	0.06
vi) Form factor							
Decision indicators	0.11 - 0.17	0.17 - 0.28	0.28 - 0.49	0.49 - 0.76	0.76 - 1.64	EEV	RIW
0.11 - 0.17	1	1/2	1/2	1/3	1/3	0.49	0.09
0.17 - 0.28	2	1	1/2	1/2	1/3	0.70	0.12
0.28 - 0.49	2	2	1	1/2	1/2	1.00	0.18
0.49 - 0.76	3	2	2	1	1/2	1.43	0.25
0.76 - 1.64	3	3	2	2	1	2.05	0.36

Table S6: Calculation of relative importance weightage (RIW) for level 2 decision indicators of Precipitation (mm) for the FHI.

Decision indicators	3-14	15-28	29-45	46-67	68-98	EEV	RIW
3-14	1	1/2	1/2	1/3	1/4	0.461	0.076
15-28	2	1	1/2	1/3	1/4	0.608	0.101
29-45	2	2	1	1/2	1/3	0.922	0.153
46-67	3	3	2	1	1/2	1.552	0.257
68-98	4	4	3	2	1	2.491	0.413

Table S7a: Calculation of relative importance weightage (RIW) for level 2 decision indicators for the FVI i) population density, ii) Rural population density, iii) Literacy rate, iv) Female literacy, v) Basic health centres

i) Population density							
Decision indicators	4-17	17-44	44-106	106-247	247-1074	EEV	RIW
4-17	1	1/2	1/3	1/5	1/7	0.34	0.05
17-44	2	1	1/2	1/3	1/4	0.61	0.09

44-106	3	2	1	1/2	1/3	1.00	0.15
106-247	5	3	2	1	1/2	1.72	0.27
247-1074	7	4	3	2	1	2.79	0.43
ii) Rural population density							
Decision indicators	3-17	18-34	35-62	63-119	120-246	EEV	RIW
3-17	1	1/2	1/2	1/3	1/3	0.49	0.09
18-34	2	1	1/2	1/2	1/3	0.70	0.12
35-62	2	2	1	1/2	1/2	1.00	0.18
63-119	3	2	2	1	1/2	1.43	0.25
120-246	3	3	2	2	1	2.05	0.36
iii) Literacy rate							
Decision indicators	15.8 - 19.9	20.0 - 28.1	28.2 - 33.4	33.5 - 39.3	39.4 - 55.3	EEV	RIW
15.8 - 19.9	1	2	4	5	7	3.09	0.45
20.0 - 28.1	1/2	1	2	4	6	1.89	0.28
28.2 - 33.4	1/4	1/2	1	2	4	1.00	0.15
33.5 - 39.3	1/5	1/4	1/2	1	3	0.60	0.09
39.4 - 55.3	1/7	1/6	1/4	1/3	1	0.29	0.04
iv) Female literacy							
Decision indicators	1.5 - 3.8	3.8 - 6.9	6.9 - 16.1	16.1 - 21.6	21.6 - 40.9	EEV	(RIW
1.5 - 3.8	1	2	3	3	5	2.46	0.40
3.8 - 6.9	1/2	1	2	3	4	1.64	0.27
6.9 - 16.1	1/3	1/2	1	2	3	1.00	0.16
16.1 - 21.6	1/3	1/3	1/2	1	2	0.64	0.11
21.6 - 40.9	1/5	1/4	1/3	1/2	1	0.38	0.06
v) Basic health centre facilities							
Decision indicators	19.0 - 36.0	36.1 - 52.0	52.1 - 70.0	70.1 - 84.0	84.1 - 133.0	EEV	RIW
19.0 - 36.0	1	3	3	5	5	2.95	0.46
36.1 - 52.0	1/3	1	2	3	3	1.43	0.22
52.1 - 70.0	1/3	1/2	1	2	3	1.00	0.16
70.1 - 84.0	1/5	1/3	1/2	1	2	0.58	0.09
84.1 - 133.0	1/5	1/3	1/3	1/2	1	0.41	0.06

Table S7b: Calculation of relative importance weightage (RIW) for level 2 decision indicators for the FVI i) Safe drinking water, ii) Distance to the nearest drivable road, iii) Cultivated Area, iv) Poverty rate, v) Unemployment rate

i) Safe drinking water							
Decision indicators	9.6 - 23.5	23.5 - 39.4	39.4 - 55.6	55.6 - 68.5	68.5 - 93.7	EEV	RIW
9.6 - 29.7	1	2	3	3	4	2.35	0.40
29.8 - 49.1	1/2	1	2	2	3	1.43	0.24
49.2 - 62.6	1/3	1/2	1	2	2	0.92	0.16
62.7 - 77.5	1/3	1/2	1/2	1	2	0.70	0.12
77.6 - 93.7	1/4	1/3	1/2	1/2	1	0.46	0.08
ii) Distance to the nearest drivable road							
Decision indicators	0.1 - 1.7	1.7 - 3.5	3.5 - 6.7	6.7 - 10.9	10.9 - 24.9	EEV	RIW
0.1 - 1.7	1	1/2	1/3	1/5	1/7	0.34	0.05
1.7 - 3.5	2	1	1/2	1/4	1/6	0.53	0.08
3.5 - 6.7	3	2	1	1/2	1/3	1.00	0.15
6.7 - 10.9	5	4	2	1	1/3	1.68	0.25
10.9 - 24.9	7	6	3	3	1	3.28	0.48
iii) Cultivated Area							
Decision indicators	0.8 - 4.2	4.2 - 8.2	8.2 - 18.9	18.9 - 33.4	33.4 - 51.6	EEV	RIW
0.8 - 4.2	1	1/2	1/3	1/5	1/7	0.34	0.05
4.2 - 8.2	2	1	1/2	1/3	1/5	0.58	0.09
8.2 - 18.9	3	2	1	1/3	1/3	0.92	0.14
18.9 - 33.4	5	3	3	1	1/3	1.72	0.26
33.4 - 51.6	7	5	3	3	1	3.16	0.47
iv) Poverty rate							
Decision indicators	12.8 - 34.3	34.4 - 50.7	50.8 - 61.8	61.9 - 76.5	76.6 - 90.2	EEV	RIW
12.8 - 34.3	1	1/3	1/5	1/7	1/7	0.27	0.04
34.4 - 50.7	3	1	1/3	1/4	1/5	0.55	0.08
50.8 - 61.8	5	3	1	1/3	1/4	1.05	0.15
61.9 - 76.5	7	4	3	1	1/2	2.11	0.30
76.6 - 90.2	7	5	4	2	1	3.09	0.44
v) Unemployment rate							
Decision indicators	10.6 - 13.8	13.8 - 18.3	18.3 - 25.3	25.3 - 33.3	33.3 - 46.4	EEV	RIW
10.6 - 13.8	1	1/2	1/2	1/3	1/3	0.49	0.09
13.8 - 18.3	2	1	1/2	1/2	1/3	0.70	0.12

18.3 - 25.3	2	2	1	1/2	1/2	1.00	0.18
25.3 - 33.3	3	2	2	1	1/2	1.43	0.25
33.3 - 46.4	3	3	2	2	1	2.05	0.36

Table S8: Calculation of relative importance weightage (RIW) for level 2 decision indicators of LULC for the FVI

Decision indicators	Urban /Built Up	Cultivated Land	Water Body / marshland	Forest / shrub	Barren Sand cover	Permanent Snow	EEV	RI W
Urban or Built Up	1	2	3	5	7	7	3.37	0.39
Cultivated Land	1/2	1	3	5	7	7	2.68	0.31
Water Body or Marshland	1/3	1/3	1	2	2	2	0.98	0.11
Forest or shrub	1/5	1/5	1/2	1	2	2	0.66	0.08
Barren or Sand cover	1/7	2/7	1/2	1/2	1	2	0.52	0.06
Permanent Snow	1/7	1/7	1/2	1/2	1/2	1	0.37	0.04

Table S9: Summary table of governing factors characterizing potential flood risks zones at subbasin/province level.

Potential Flood Risk Zones	Very High	High	Moderate	Low
Covered Area (%)	24	22	26	28
Corresponding subbasin	1, 2, 3, 4, 6, 7, 10, 15, 16, 18, 21	5, 8, 9, 11, 12, 23, 25, 27, 28, 30, 40	13, 14, 17, 19, 20, 22, 21, 32, 39, 44, 46, 48, 49	24, 26, 33, 34, 35, 36, 37, 38, 41, 42, 43, 47,
Provinces	e.g., Balkh, Panjshir, Parwan, Kapisa, Kabul	e.g., Bamyan, Wardak, Logar, Paktya, Khost, Herat	e.g., Badghis and Uruzgan	e.g., Ghor, Helmand and Kandahar
Corresponding River basins	Panj-Amu and Kabul River basin	Kabul, North and Harirud-Morghab	North and Helmand	Helmand and Harirud-Morghab
Hydro-morphometry governing indicators	high stream frequency, circular basins, higher precipitation, low	longer overland flow paths and significant relief within areas with lower	higher drainage density, shorter overland flow, and	higher drainage density, lower overland flow and higher

	compact basin and higher infiltration number	drainage density and infiltration numbers	higher infiltration numbers	infiltration number
Socio-economic governing indicators	high population density, significant land use changes, better access to safe drinking water and high poverty rates	Areas with higher population density, including rural populations, limited access to safe drinking water, and lower literacy rates	Higher rural and overall population density, closer proximity to drivable roads, significant land use changes, and lower female literacy rates	Literate rate, closer to an accessible road and lower population density

Table S10: Sensitivity analysis of PCA-AHP weights for selected FSI and FVI indicators

Flood susceptibility Index (FSI)	Low	Moderate	High	Very High
Baseline conditions	20.45	30.59	29.01	19.95
Precipitation(P)+10%	20.45	30.16	30.62 (0.43%)	18.77 (1.18%)
Precipitation(P)-10%	20.45	29.58	30.02 (1.01%)	19.95 (0.00%)
Basin Relief (B _R)+10%	20.45	30.78	28.82 (-0.19%)	19.95 (0.00%)
Basin Relief (B _R) -10%	20.45	30.59	29.01 (0.00%)	19.95 (0.00%)
Flood Vulnerability Index (FVI)	Low	Moderate	High	Very High
Baseline conditions	17.29	30.91	20.48	31.32
Population Density (P _d)+10%	15.60	29.27	20.39 (1.64%)	35.74 (-4.43%)
Population Density (P _d)-10%	15.27	28.53	20.47 (2.38%)	35.73 (-4.41%)
Landuse & Landcover (LULC) +10%	14.63	29.64	19.99 (1.27%)	35.74 (-4.42%)
Landuse & Landcover (LULC)-10%	15.27	28.61	20.86 (2.30%)	35.26 (-3.94%)

*Percentage change (%) in bold from baseline class proportions under each perturbation scenario.

Lists of Supplementary Figures

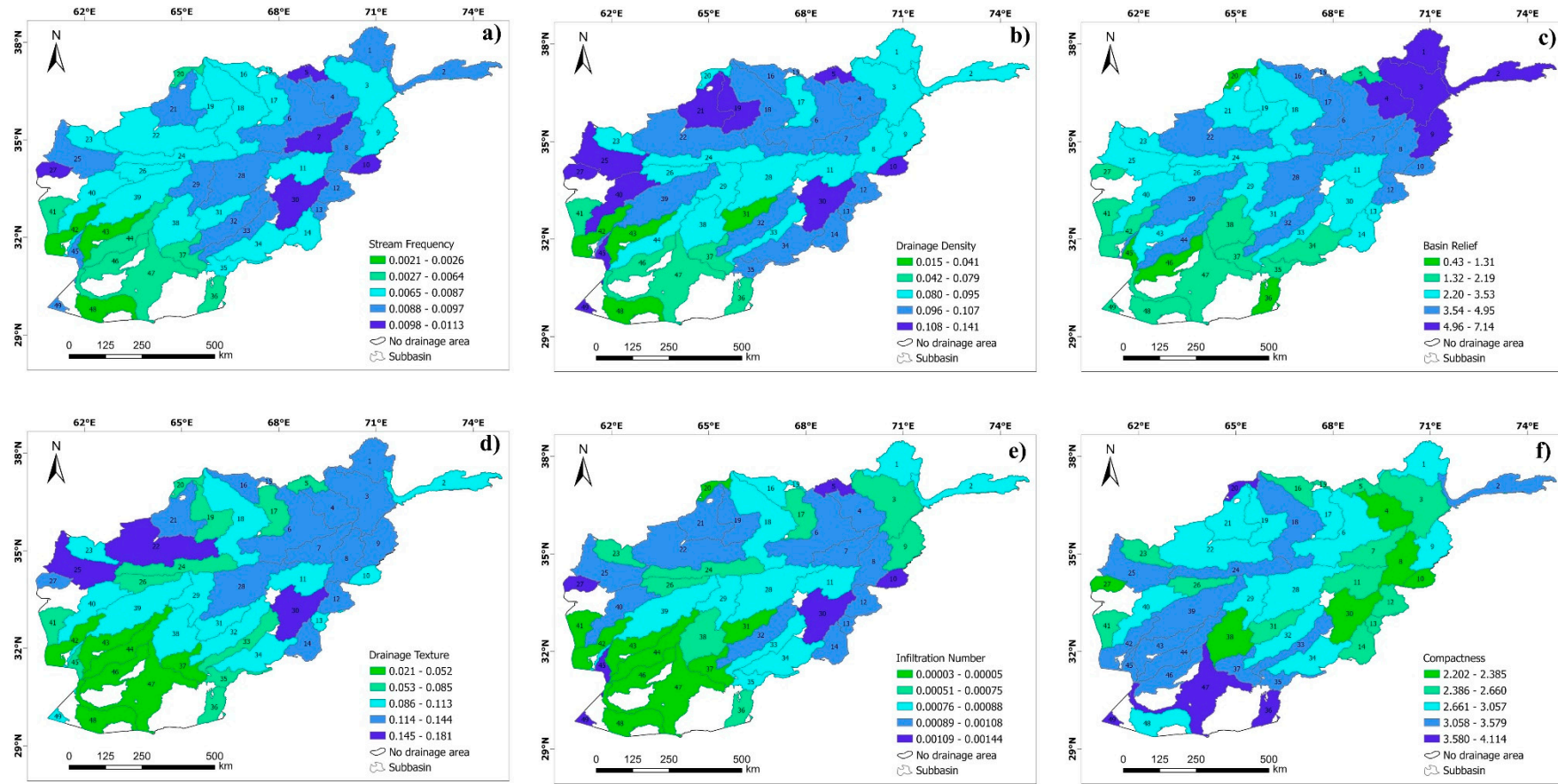


Figure S1: Thematic layers used for the assessment of flood susceptibility Afghanistan region a) Stream frequency, b) Drainage density, c) Basin relief, d) Drainage texture, e) Infiltration number, f) Compactness coefficient.

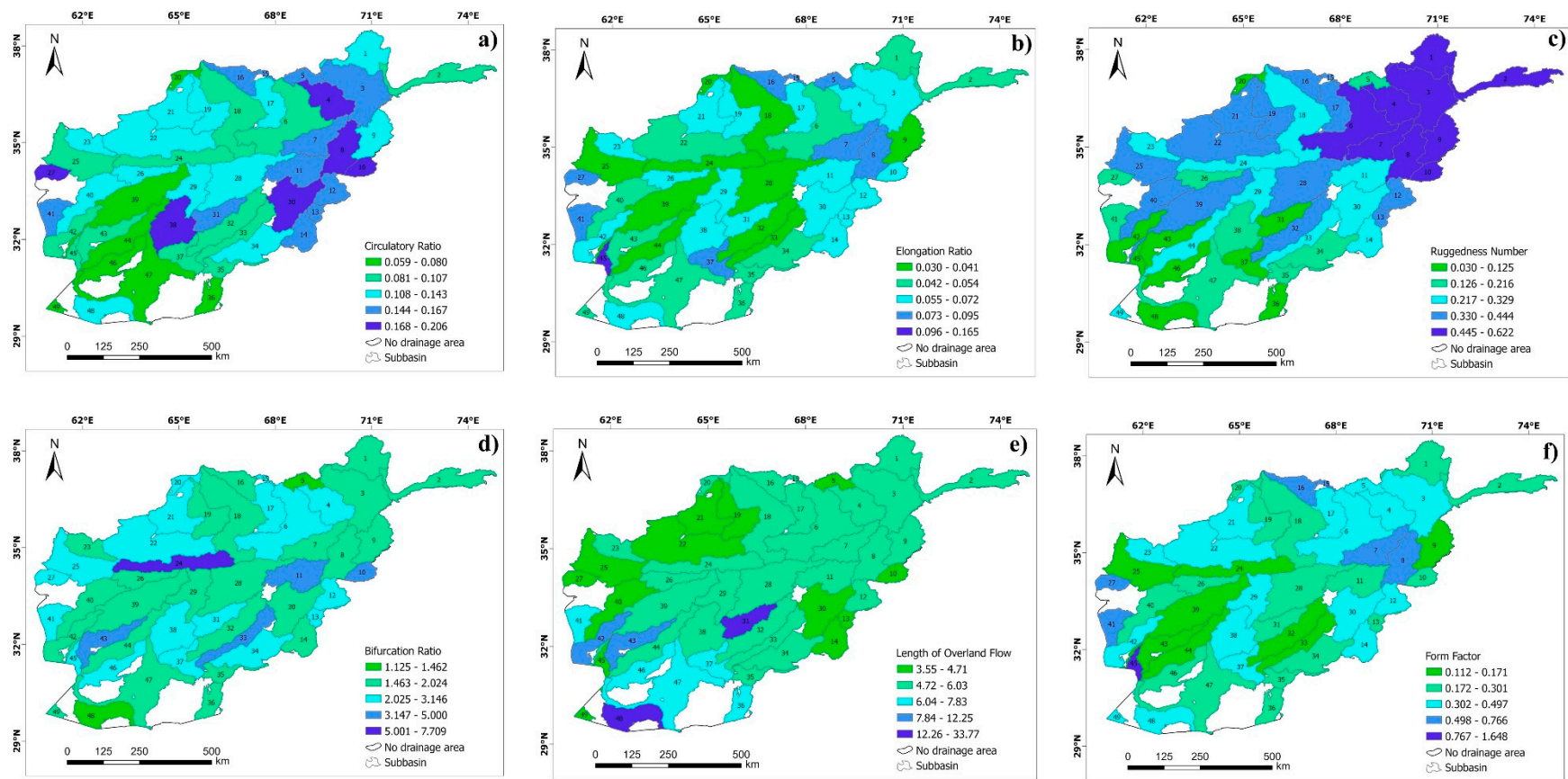


Figure S2: Thematic layers used for the flood susceptibility assessment Afghanistan region a) Circulatory ratio, b) Elongation ratio, c) Ruggedness number, d) Bifurcation Ratio, e) Length of overland flow, f) Form Factor.

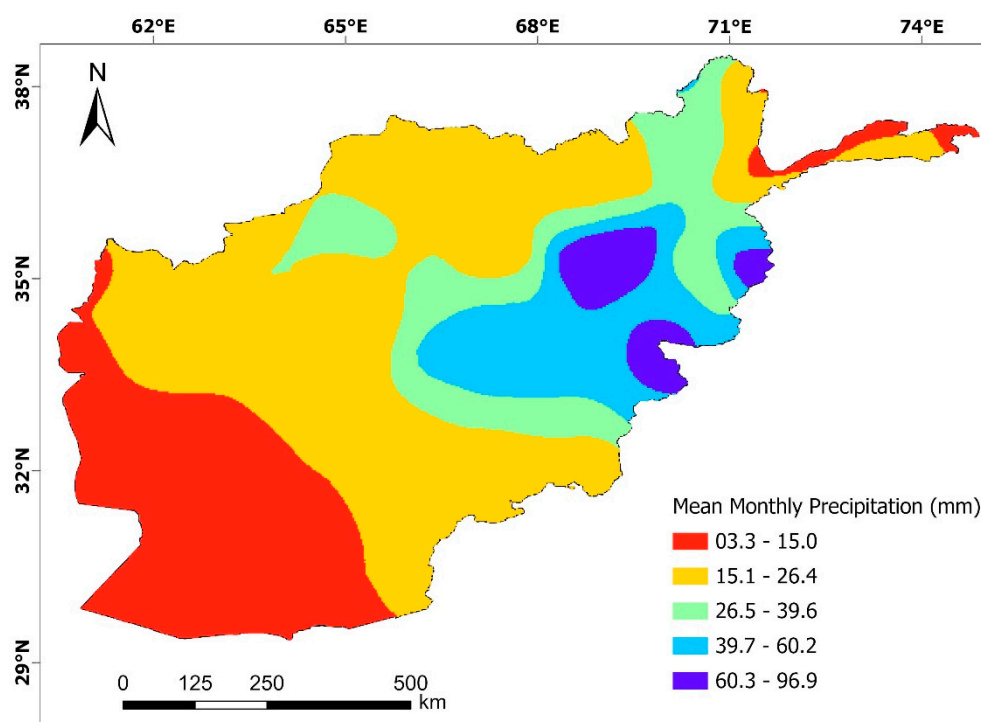


Figure S3: Spatial distribution of mean monthly precipitation across Afghanistan. The map classifies the country into six precipitation zones, ranging from very low (3.3–15.0 mm) to high (60.3–96.9 mm), highlighting regional variability in rainfall patterns.

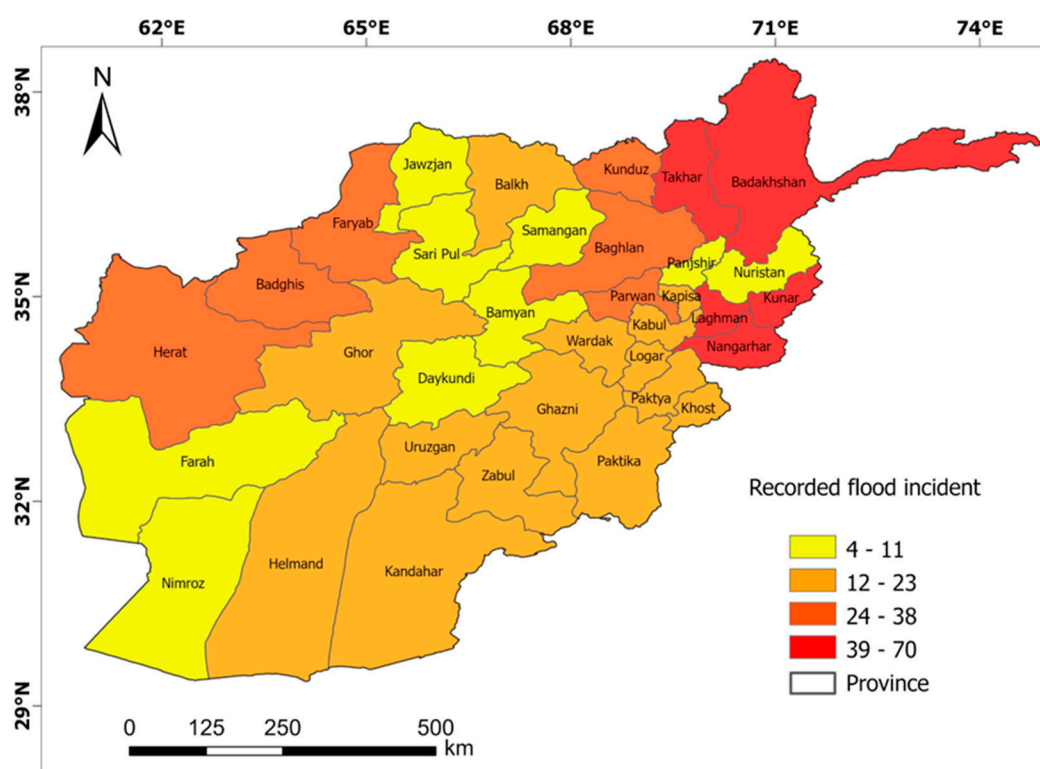


Figure S4: Spatial distribution of recorded flood incidents across Afghanistan region at province level. The map categorizes provinces into four classes based on the number of documented flood events: 4–11 (low), 12–23 (moderate), 24–38 (high), and 39–70 (very high).

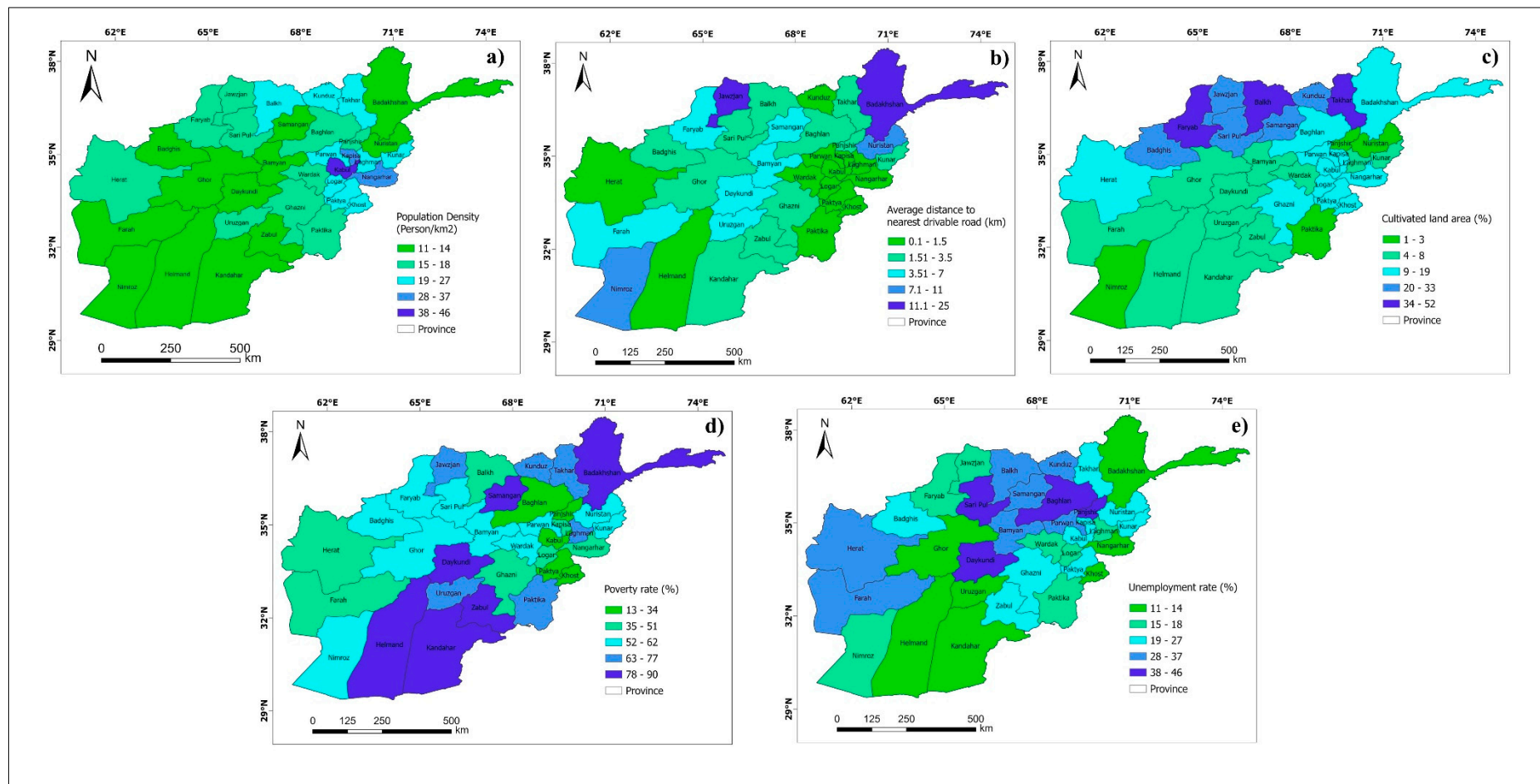


Figure S5: Thematic layers used for the assessment of flood vulnerability of the Afghanistan region: a) Population density, b) Rural population density, c) Literacy rate, d) Female literacy, e) Basic health centers.

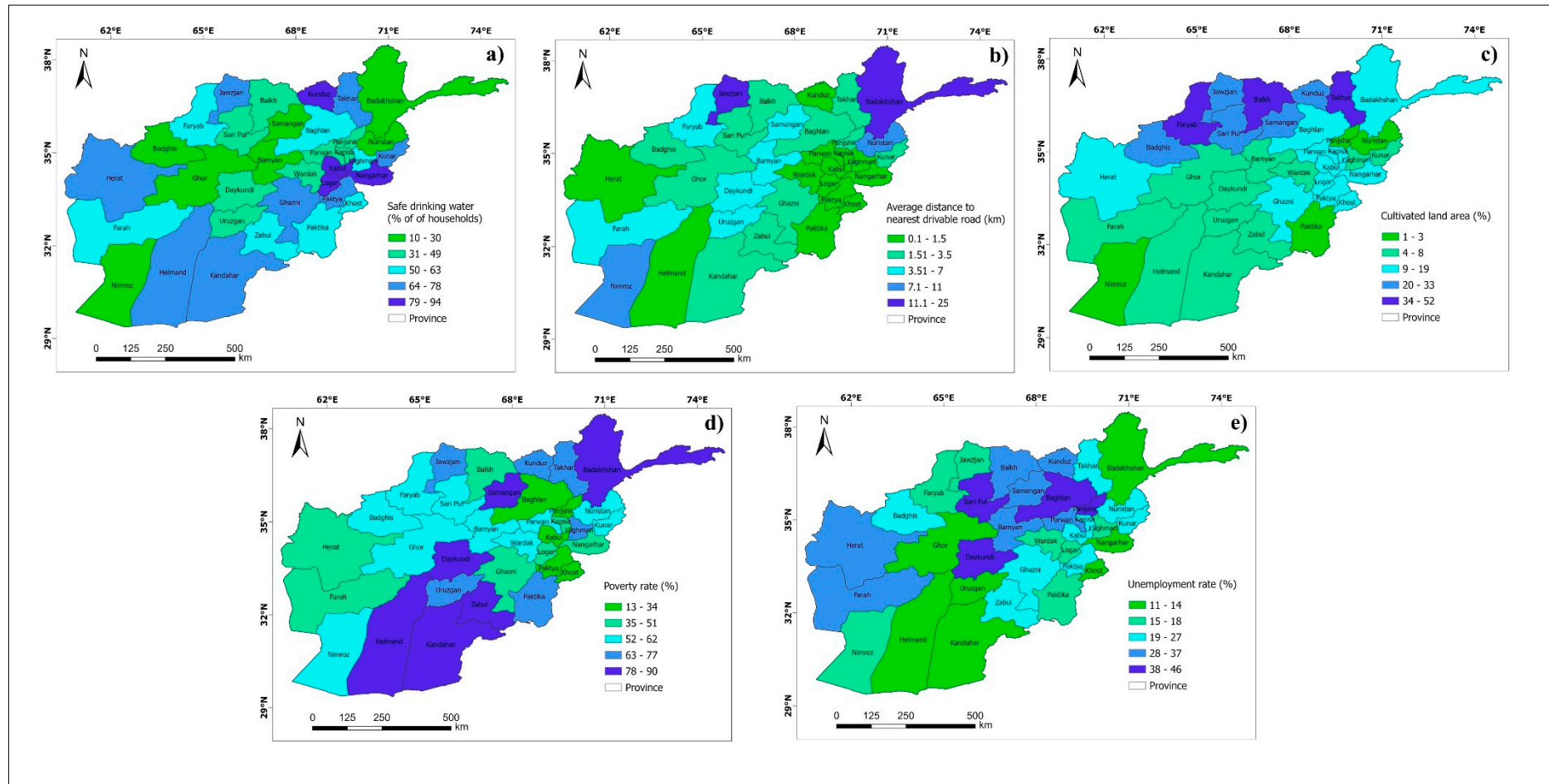


Figure S6: Thematic layers used for the assessment of flood vulnerability of the Afghanistan region: a) Safe drinking water, b) Distance to the nearest drivable road, c) Cultivated land area, d) Poverty rate, e) Unemployment rate.

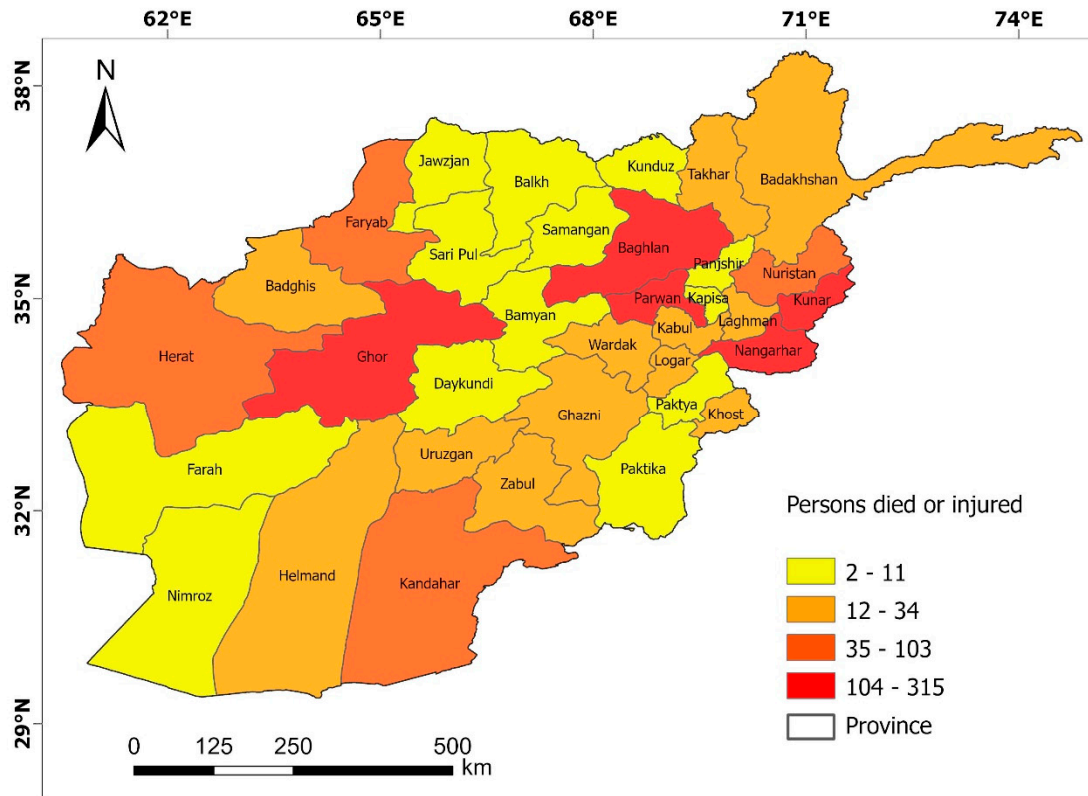


Figure S7: Spatial distribution of flood-related casualties across the Afghanistan region at the province level during various flooding events between 2019 and 2024. The map categorizes provinces into four classes based on the number of persons reported dead or injured: 2–11 (low), 12–34 (moderate), 35–103 (high), and 104–315 (very high).

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