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Morphometric and Hypsometric Assessment of the Spna Watershed

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Abstract

The study presents a comprehensive morphometric and hypsometric (HI) analysis and correlation of the Spna watershed, located about 50 km northwest of Duhok City. The watershed has an overall area of 317.65km2. Using a 12.5 m resolution Digital Elevation Model (DEM) and ArcGIS Pro, the basin was delineated and divided into 15 sub-watersheds. Three different morphometric parameters- relief, areal, and linear were quantitatively analyzed. Results show the watershed has a coarse drainage density (3.12 km/km²), a moderate bifurcation ratio (average 4.3), and an elongated shape, suggesting moderate surface runoff and susceptibility to erosion. The hypsometric curve analysis shows that the main watershed has an HI value of 0.28, which means it is in an older stage of landform development, while the result of HI in sub-watersheds varies from 0.24 to 0.47, showing they are at different stages from youthful to mature. There were high negative correlations between HI and watershed parameters, such as elevation, area, and ruggedness index. These indicate the effect of terrain morphology on erosion potential and stability.

Keywords:

Morphometric, Hypsometric, Correlation, Spna.

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1. Introduction

The term "watersheds" indicates the essential unit of Earth's ecosystems on Earth, natural drainage system, urban, agricultural, woodland, wetland, lake, and river ecosystems, which play a crucial role in surface activities within the watersheds (Cao et al., 2022). A watershed is defined as a region of land that contributes to runoff that travels down a watercourse to a shared point. For this reason, it is regarded as a suitable unit for containing flood hazards and conserving water resources (Bhardwaj, 2019).

The morphology involves studying the shapes and structures of landforms, focusing on quantitative assessments. Morphometric analysis, as defined by many scholars like Mokarram and Sathyamoorthy (2018) entails measuring and mathematically evaluating the Earth's surface, including its shape and dimensions. This analysis proves invaluable in various aspects such as drainage basin assessment, erosion control, flood frequency analysis, watershed prioritization, and natural resource management and conservation. Geomorphological parameters dictate hydrological behavior by revealing changes in the Earth's surface over time. Given that many basins are either ungauged or inaccessible, research on basin geomorphology becomes increasingly significant (Nageswara Rao, 2020). Geomorphological analysis provides a quantitative understanding of basin geometry, shedding light on factors like rock hardness, structural control, and the geological history of drainage basins (Gajbhiye, 2015). Drainage basins are pivotal hydrological and geomorphic units, and studying their drainage lines helps discern the three-dimensional geometry and evolutionary processes of a region (Franke et al., 2015).

The hypsometric curve is indicative of the general slope of a basin and incorporates important geomorphic data of a catchment in terms of the area of the basin lying at a specific level or above that level (Strahler, 1952). Hypsometric curves allow us to study the stages of erosion in a basin while also providing an important understanding of basin slope and geomorphology because they control erosion relative to rock characteristics and are thus beneficial for catchment management, basin planning, and rainwater collection system development (Sarp et al., 2011). Catchments are categorized as young (exhibiting a convex upward curve), mature (characterized by an S-shaped hypsometric curve that is concave downward at lower elevations and convex upward at higher elevations), and peneplain or deformed, solely based on the defined hypsometric curves (the deformed type is concave upward). Their collective findings highlight RS and GIS as highly effective tools for integrating land use analysis, morphometric analysis, and soil erosion control, thereby safeguarding land from further degradation.

The objective of the article is to conduct a comprehensive morphometric and hypsometric (HI) analysis of the Spna watershed to determine the developmental stage of the watershed and its sub-watersheds using hypsometric curves and HI values. And to analyze correlations between HI and watershed morphometric parameters to assess terrain influence on erosion potential.

2. Methodology

A. Study Area

The Spna watershed is located about 50 km northwest of Duhok City center, Kurdistan Region, Iraq, and is geographically located between the Matin and Gara mountains at latitudes (37°9'48.809"-36°59'40.629”) North and longitudes (43°4'16.541"-43°21'25.095") East, as shown in Figure (1). The total area of the basin is 317.65 km². Topographically, the basin is a mountainous area, mostly consisting of mountains, hills, gullies, and valleys. The altitude of the study area ranges from 647 m to 2088 m at the highest point above sea level.

The Spna watershed is a tributary of the Khabour River. It flows from the eastern part of the watershed, reaching the Khabour River at Dukare village, the watershed's outlet. The Spna watershed encompasses about 36 villages, such as Dukare, Tahlava, Banka, Arze, Dihe, Shrte, Zivnge, Zewe, Ghalbishe, Aradna, Ashawa, Skrine, Kovile, Koreme, Garbaraske, etc., along with the Bamarne and Sarsank sub-districts.

The climate in the Spna watershed is semi-arid, which is almost the same as the Mediterranean climate (Köppen climate classification, 1884). It has dry summers and cold, rainy winters and exhibits notable seasonal fluctuations in temperature, precipitation, and potential evaporation (Ali et al., 2022). The mean annual precipitation recorded at the Bamarne station is 804.8 mm. The minimum mean monthly temperature (4.7 °C) occurs in January, while the maximum mean monthly temperature (32.4 °C) is recorded in July (Ismail et al., 2016).

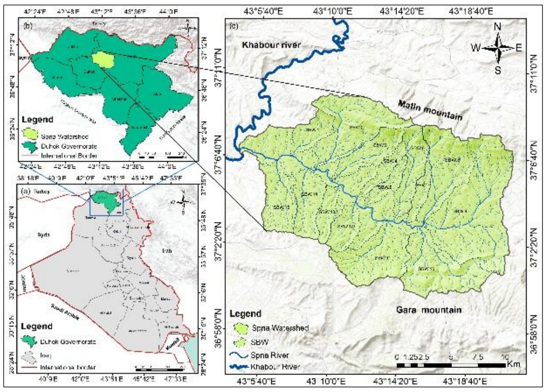

Fig. 1: Study area of the Spna watershed.

B. Data sources and programs

The study utilized a high-resolution Digital Elevation Model (DEM) downloaded from https://search.asf.alaska.edu/#/ with 12.5 m resolution. The study area has been delineated and analyzed using ArcGIS Pro.

C. Morphometric parameters

The Spna watershed is morphometrically analyzed to enable more focused evaluations incorporating hydrological and geomorphological components. This study employs quantitative methods (linear, aerial, and relief) parameters, in addition to other ones used for calculation, then analyzed (Table 1).

Table 1: Formulas and references for calculating the morphometric parameters of the Spna watershed.

	Linear aspects parameters	Code	Unit	Formula	Reference
1	Stream Order	*Nu*	*Km*	Hierarchical order	(Horton, 1945)
2	Stream Length	*Lu*	*Km*	Total length of the stream (*km*)	(Horton, 1945)
3	Mean Stream Length	*Lsm*	*Km*	$Lsm = Lu / Nu$	(Horton, 1945)
4	Bifurcation Ratio	R_b	*No*	$R_b = Nu / (Nu_{+}1)$	(Horton, 1945)
5	Watershed Length	*L*	*Km*	Longest watershed dimension paralleling the principal drainage	(Gray, 1961)
2.	Relief aspect parameters	Code	Unit	Formula	Reference
1	Basin Relief	*Hr*	*M*	$Hr = H\,(maxi) – h\,(mini)$	(Schumm, 1956)
2	Relief Ratio	R_h	*No*	$R_h = Hr / L_b$ Where *Lb* = Watershed length (m)	(Schumm, 1956)
3	Relative Relief	R_{hp}	*No*	$R_{hp} = (R_h * 100) / P$ Where R_h = relief ratio (m), *P* = watershed perimeter (km)	(Melton, 1957)
4	Ruggedness Number	*RN*	*No*	$RN = D_d * Hr$ Where, *Hr* =Basin Relief D_d = Drainage Density km/km^2	(Patton and Baker, 1976)
3.	Areal aspect parameters	Code	Unit	Formula	Reference
1	Watershed Area	*A*	km^2	The location where rain and snow fall to supply water to a stream.	(Strahler, 1957)
2	Watershed Perimeter	*P*	*Km*	Outer boundary of a watershed.	(Pike and Wilson, 1971)
3	Form Factor	R_f	*No*	$R_f = A / (L_b)^2$	(Pike and Wilson, 1971)
4	Elongation Ratio	*Re*	*No*	$Re = 2 * \sqrt{(A/\pi)}$	(Schumm, 1956)
5	Drainage Density	D_d	km/km^2	$Dd = Lu / A$	(Horton, 1945)
6	Stream Frequency	*Fs*	*Per sq km*	$Fs = \sum Nu / A$	(Horton, 1945)
7	Length of Overland Flow	*Lo*	*Km*	$Lo = ½\, D_d$	(Horton, 1945)
8	Lemniscate Ratio	R_L	Km^2	$R_L = (L^2) / 4*A$	(Chorley, 1957)
9	Circularity Ratio	*Rc*	*No*	$Rc = 2\pi\,(A/P^2)$	(Singh and Singh, 2011)
10	Texture Ratio	*T*	Km^{-1}	$T = N_1/P$	(Horton, 1945)
11	Compactness Constant	*Cc*	*No*	$Cc = P / pc$ Where *pc* =Equivalent Circle Perimeter (*pc*)	(Horton, 1945)
12	Infiltration Number	I_f	*mm/hour*	$I_f = D_d/Fs$	(Dubey et al., 2015)
13	Drainage Texture	*Dt*	Km/ km^2	$D_t = Nu/P$	(Horton, 1945)
14	Constant of channel maintenance	*C*	*Km*	$C = A/ Lu$	(Schumm, 1956)

D. Hypsometric parameter

The hypsometric integral (HI) parameter is estimated to determine the geomorphological evolution of the Spna watershed and its sub-watersheds. Hypsometric curves for each watershed are produced by extracting elevation ranges from DEM data at a 12.5m resolution using ArcGIS Pro 3.02 software. The HI values are calculated using the following equation (Farhan et al., 2016):

$$HI = \frac{E_{mean} - E_{min}}{E_{max} - E_{min}}$$

Where: E_{mean} is the mean elevation.

E_{max} is the maximum elevation

E_{min} is the minimum elevation.

Correlation coefficients between hypsometric integral (HI) and morphometric parameters in the Spna watershed are calculated using Minitab 18 software.

3. Results and Discussion

A. Morphometric Parameters

The linear aspect

There are 2164 streams found in the Spna watershed, which are divided into six orders. The 1st order includes 1626 streams, the 2nd order includes 425 streams, the 3rd order includes 83 streams, the 4th order includes 24 streams, the 5th order includes five streams, and one stream is in the 6th order (Fig. 2, Table 2). The maximum stream number is found in SBW9, while the minimum number is present in SBW4. Low current is associated with SBW9, which corresponds to an increase in surface runoff, while SBW4 exhibits reduced current but possesses high permeability, facilitating greater infiltration into surface runoff. According to Horton (1945), stream length (Lu) is a key factor in determining geometric similarity among basins. Generally, stream orders are shorter for greater orders and longer for lesser orders. The correlation between stream lengths and order of streams is inverse (Konwea and Ajayi, 2022).

The total stream lengths in the Spna watershed are calculated to be 991.65 km, with contributions from streams ranging from 1st order to 6th order as shown in Table (2).

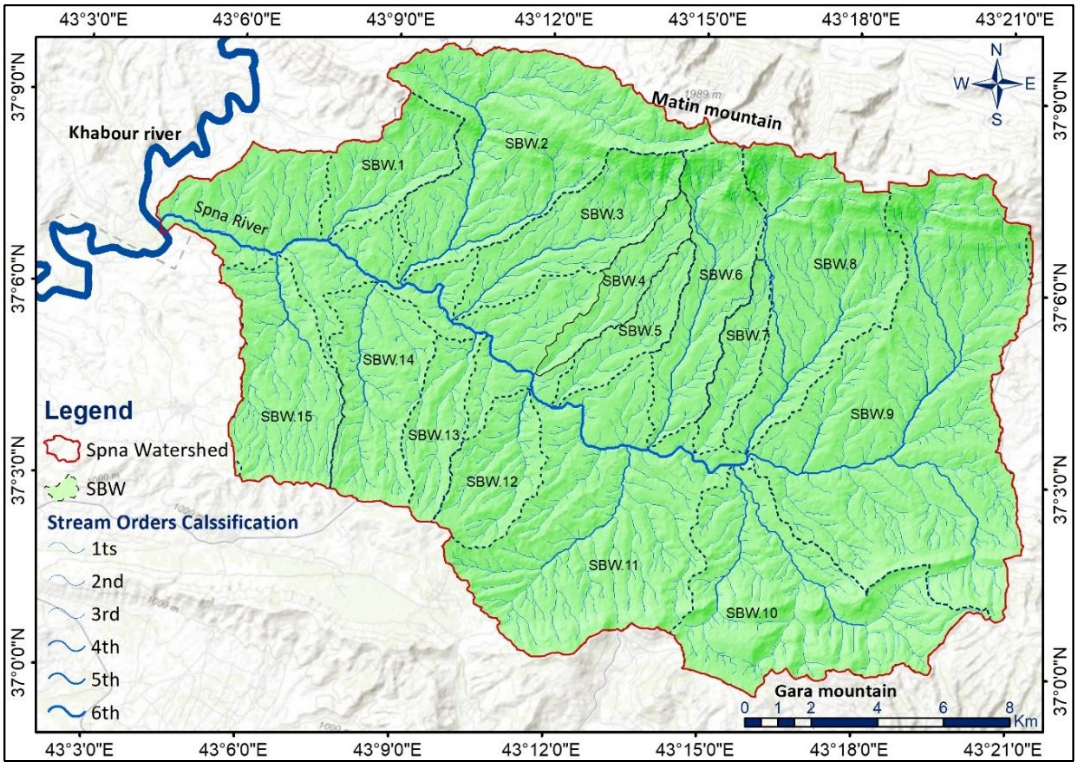

Fig. 2: Spna watershed stream orders.

Table 2: Linear aspects results in the Spna watershed and sub-watersheds.

Parameters	Stream Order	Sub-watershed															Main Watershed
		SBW.1	SBW.2	SBW.3	SBW.4	SBW.5	SBW.6	SBW.7	SBW.8	SBW.9	SBW.10	SBW.11	SBW.12	SBW.13	SBW.14	SBW.15	
Stream Number (Nu)	1st	50	173	74	25	26	77	27	134	332	165	112	40	26	77	68	1626
	2nd	12	49	21	6	8	19	7	36	89	38	33	10	6	27	19	425
	3rd	3	11	3	1	1	3	1	7	20	7	7	2	2	3	4	83
	4th	1	3	1			1		2	5	2	1	1	1	1	2	24
	5th		1						1	1	1					1	5
	6th																1
	Σ	66	237	99	32	35	100	35	180	447	213	153	53	35	108	94	2164
Stream Length (Lu)	1st	12.07	45.48	18.19	7.1	10.3	25.66	9.57	40.03	97.93	43.8	32.3	15.84	8.77	21.39	31.28	495.82
	2nd	7.48	25.37	16.67	5.24	5.39	14.28	3.45	24.21	44.4	21.44	28.38	5.39	5.73	10.24	13.41	260.08
	3rd	5.82	11.16	5.8	6.07	4	3.04	3.63	9.2	28.77	7.61	9.99	3.8	4.21	6.99	6.4	123.37
	4th	2.69	5.74	5.54			8.46		9.73	12.9	10.69	5.1	1.59	0.76	3.97	1.69	68.86
	5th		6.62						2.61	8.08	0.58					2.11	20
	6th																23.52
	Σ	28.05	94.37	46.19	18.41	19.69	51.44	16.64	85.78	192.09	84.13	75.77	26.62	19.46	42.6	54.89	991.65
Mean Stream Length (Lsm)	1st	0.24	0.26	0.25	0.28	0.4	0.33	0.35	0.3	0.29	0.27	0.29	0.4	0.34	0.28	0.46	0.3
	2nd	0.62	0.52	0.79	0.87	0.67	0.75	0.49	0.67	0.5	0.56	0.86	0.54	0.95	0.38	0.71	0.61
	3rd	1.94	1.01	1.93	6.07	4	1.01	3.63	1.31	1.44	1.09	1.43	1.9	2.1	2.33	1.6	1.49
	4th	2.69	1.91	5.54			8.46		4.87	2.58	5.35	5.1	1.59	0.76	3.97	0.85	2.87
	5th		6.62						2.61	8.08	0.58					2.11	4
	6th																23.52
Bifurcation ratio (Rb)	1st/2nd	4.17	3.53	3.52	4.17	3.25	4.05	3.86	3.72	3.73	4.34	3.39	4	4.33	2.85	3.58	3.83
	2nd/3rd	4	4.45	7	6	8	6.33	7	5.14	4.45	5.43	4.71	5	3	9	4.75	5.12
	3rd/4th	3	3.67	3			3		3.5	4	3.5	7	2	2	3	2	3.46
	4th/5th		3						2	5	2					2	4.8
	5th/6th																5

Watershed Perimeter (P)	14.91	33	19.96	16.3	14.9	23.34	14.46	28.01	42.75	31.61	24.93	13.58	14.66	19.24	20.32	90.57
Watershed Length (L)	5.13	9.38	7.6	6.78	6.44	9.34	6.12	9.59	12.82	7.21	7.73	4.96	5.85	6.51	6.84	26.66

Mean stream length (L_{sm}) explains the distinctive sizes of the contributing surfaces and stream network components (Ganie et al., 2022). The values of the mean stream lengths of the Spna watershed and its sub-watersheds are recorded in Table (2). In the main watershed, the mean stream length value ranges from 0.3 to 23.53 km, denoting that as stream order rises, the value of the mean stream length rises (Strahler, 1957). It is evident that when the order increases, the mean stream length of fifteen sub-watersheds increases as well. The mean stream length has a maximum value for all sub-watersheds of the Spna watersheds in the 6th-order streams, in which SBW.9 shows maximum stream length, while SBW.4 shows minimum stream length in the 5th order streams, as shown in Table (2).

The bifurcation ratio in the Spna watershed varies between 3.83 and 5. This ratio indicates a moderate to high bifurcation ratio; this result indicates that the watershed is classified within the typical category.

The relief aspects

The results of essential relief parameters of the main watershed and its sub-watersheds are listed in Table (3).

Relief is the most important factor in determining the watersheds' weathering, erosion, and landform characteristics, as well as the effectiveness of floods, water flow, drainage development, and slope steepness (Sreelakshmy et al., 2023). The minimum elevation of the Spna watershed is 647 m, and the maximum elevation is 2088 m. Consequently, the relief of the main watershed is estimated as 1441 m; this value is a moderate to high elevation difference, indicating a high slope, high flood effectiveness, high sediment transport, and erosion.

Table 3: Relief aspects result in the Spna watershed and sub-watersheds.

Relief aspect	Sub-watershed															Main Watershed
	SBW.1	SBW.2	SBW.3	SBW.4	SBW.5	SBW.6	SBW.7	SBW.8	SBW.9	SBW.10	SBW.11	SBW.12	SBW.13	SBW.14	SBW.15	
Minimum elevation (*h*)	681	709	729	748	759	791	801	820	820	816	783	752	728	707	674	647
Maximum elevation (*h*)	1423	2063	1942	1473	1182	2088	1187	2058	1944	1833	1514	1259	1271	1184	1187	2088
Watershed Relief (H_r) km	0.74	1.35	1.21	0.73	0.42	1.3	0.39	1.24	1.12	1.02	0.73	0.51	0.54	0.48	0.51	1.44
Relief ratio (R_h)	0.14	0.14	0.16	0.11	0.07	0.14	0.06	0.13	0.09	0.14	0.09	0.1	0.09	0.07	0.08	0.05
Relative Relief (R_{hp})	0.97	0.44	0.8	0.66	0.44	0.6	0.44	0.46	0.21	0.45	0.38	0.75	0.63	0.38	0.37	0.06
Ruggedness number (*RN*)	2.27	4.14	4.14	2.23	1.42	4.49	1.21	4.26	3.56	2.89	2.16	1.49	1.51	1.41	1.75	4.5

The relief ratio (R_h) of the main watershed is 0.05, and for sub-watersheds are variant from 0.06 km in SBW.7 to 0.16 km in SBW.3. These results indicate that the Spna watershed has a low to moderate slope for all sub-watershed values and a low intensity of runoff. When the drainage area and watershed size decrease, the relief ratio R_h usually increases (Lama and Maiti, 2019). Furthermore, a high relief ratio indicates quick incoming water into the mouth of the stream, affecting the flood risk and transfer of significant amounts of silt (Majeed and Amin, 2021).

According to Kumar et al. (2022), the relative relief (R_{hr}) is one of the most reliable parameters for estimating the erosion rate within a drainage watershed. It is estimated by dividing the relief by the perimeter of the watershed, and it is an important measurement used to fully assess the shape and features of the land (Ibrahim, 2021). The main watershed's relative relief in the present study is 0.06, which indicates a very flat area with very little change in altitude. SBW.9 has the lowest value of 0.21 among the sub-watersheds indicating that it is a comparatively level area with a small elevation margin. In contrast, SBW.1 has the highest value of 0.97, which reflects steep and bumpy areas with vital altitude changes, possibly characterized by mountains or mountainous regions.

Roughness Number is an important variable that not only indicates how much resistance is given by the watershed to soil erosion, but also serves as an indicator of the slope of the watershed along with a high drainage gradient (Mohammed, 2023). The minimal ruggedness denotes that the watershed has been less affected by soil erosion; conversely, high ruggedness means that, due to increased relief and drainage density, the watershed is more vulnerable to soil erosion (Rawat et al., 2017). In the current study, the *RN* value of the main watershed is calculated as 4.5, indicating that the terrain is rugged, with high relief and dense with streams.

The areal aspects

The most important results of areal aspect parameters of the main watershed and sub-watersheds are shown in Table (4).

The watershed area is a crucial component of any watershed. The relationship between the total area and the length of the stream is stated by Schumm (1956). The Spna watershed covers a total area of 317.65 km^2, and 272.91 km^2 is covered by fifteen sub-watersheds. SBW.7 is the smallest of all sub-watersheds, covering 5.32 km^2, while SBW.9 is the largest one among the fifteen watersheds, covering 60.63 km^2 (Table 4). According to Sen (2008) classification, the Spna watershed is located within a big area, which classifies the watersheds according to their areas (under 5 km^2 = small, 5-99 km^2 = medium, 100-1000 km^2 = big, and more than 1000 km^2 = very big).

The Spna watershed's overall perimeter is 90.57 km, and Table (4) displays the statistics for its fifteen sub-watersheds. SBW.9 is the largest of all the sub-watersheds by perimeter, while SBW.12 has the smallest perimeter of 13.58 km. Since the perimeter of sub-watersheds increases with the area, they are extended to be semi-circular.

The R_f is a value that denotes the degree of erosion, the ability of a watershed's sediment loads to be transported, and the occurrence of floods. The R_f of the Spna watershed is 0.45. At the level of sub-watersheds, R_f values varied from 0.13 to 0.57 (Table 4). These results indicate that the main watershed, along with its sub-watersheds, has an elongated shape and a longer duration of low peak flow.

As stated by Schumm (1956), the elongation ratio (*Re*) is described as the maximum watershed length to the diameter of the circular watershed. An increasing elongation ratio indicates low water flow levels and a higher potential for infiltration, and vice versa (Haghnazari et al., 2015). The (*Re*) of the Spna watershed is 0.75, as shown in Table (4), which indicates the long shape and high runoff of the watershed.

Table 4: Areal aspect results in the Spna watershed and sub-watersheds.

Areal aspect	Sub-watershed															Main Watershed
	SBW.1	SBW.2	SBW.3	SBW.4	SBW.5	SBW.6	SBW.7	SBW.8	SBW.9	SBW.10	SBW.11	SBW.12	SBW.13	SBW.14	SBW.15	
Area km^2	9.16	30.89	13.53	5.99	5.88	14.85	5.32	24.90	60.63	29.65	25.61	9.06	6.99	14.36	16.07	272.91
%	2.88	9.7	4.26	1.89	1.85	4.67	1.68	7.84	19.09	9.33	8.06	2.85	2.20	4.52	5.06	85.92
Watershed Perimeter (*P*)	14.91	33.00	19.96	16.30	14.90	23.34	14.46	28.01	42.75	31.61	24.93	13.58	14.66	19.24	20.32	90.57
Form Factor (R_f)	0.35	0.35	0.23	0.13	0.14	0.17	0.14	0.27	0.37	0.57	0.43	0.37	0.20	0.34	0.34	0.45
Elongation Ratio (*Re*)	0.66	0.67	0.55	0.41	0.42	0.47	0.43	0.59	0.68	0.85	0.74	0.68	0.51	0.66	0.66	0.75
Drainage density (D_d)	3.06	3.05	3.41	3.07	3.35	3.46	3.13	3.44	3.17	2.84	2.96	2.94	2.78	2.97	3.42	3.12
Stream frequency (F)	7.21	7.67	7.31	5.34	5.95	6.73	6.57	7.23	7.37	7.18	5.97	5.85	5.00	7.52	5.85	6.81
Length of overland Flow (*Lo*)	0.16	0.16	0.15	0.16	0.15	0.14	0.16	0.15	0.16	0.18	0.17	0.17	0.18	0.17	0.15	0.16
Lemniscate Ratio (R_L)	0.72	0.71	1.07	1.92	1.76	1.47	1.76	0.92	0.68	0.44	0.58	0.68	1.22	0.74	0.73	0.56
Circularity ratio (*Rc*)	0.52	0.36	0.43	0.28	0.33	0.34	0.32	0.40	0.42	0.37	0.52	0.62	0.41	0.49	0.49	0.49
Texture Ratio(*T*)	4.43	7.18	4.96	1.96	2.35	4.28	2.42	6.43	10.46	6.74	6.14	3.90	2.39	5.61	4.63	23.89
Compactness Factor (Cc)	1.39	1.67	1.53	1.88	1.73	1.71	1.77	1.58	1.55	1.64	1.39	1.27	1.56	1.43	1.43	1.43
Infiltration number (I_f)	9.38	9.33	11.65	9.44	11.21	12.00	9.77	11.87	10.04	8.05	8.75	8.64	7.74	8.80	11.66	9.74
Drainage texture (D_t)	7.21	7.67	7.31	5.34	5.95	6.73	6.57	7.23	7.37	7.18	5.97	5.85	5.00	7.52	5.85	6.81
Constant of Channel maintenance (C)	0.33	0.33	0.29	0.33	0.30	0.29	0.32	0.29	0.32	0.35	0.34	0.34	0.36	0.34	0.29	0.32

The D_d value of the Spna watershed is 3.12, and the range for sub-watersheds is 2.78 to 3.46. According to Smith (1950), the D_d value of the Spna watershed and its sub-watersheds is designated as "coarse density," which suggests a comparatively higher density of streams or rivers per unit area of the watershed, as shown in Fig. 3.

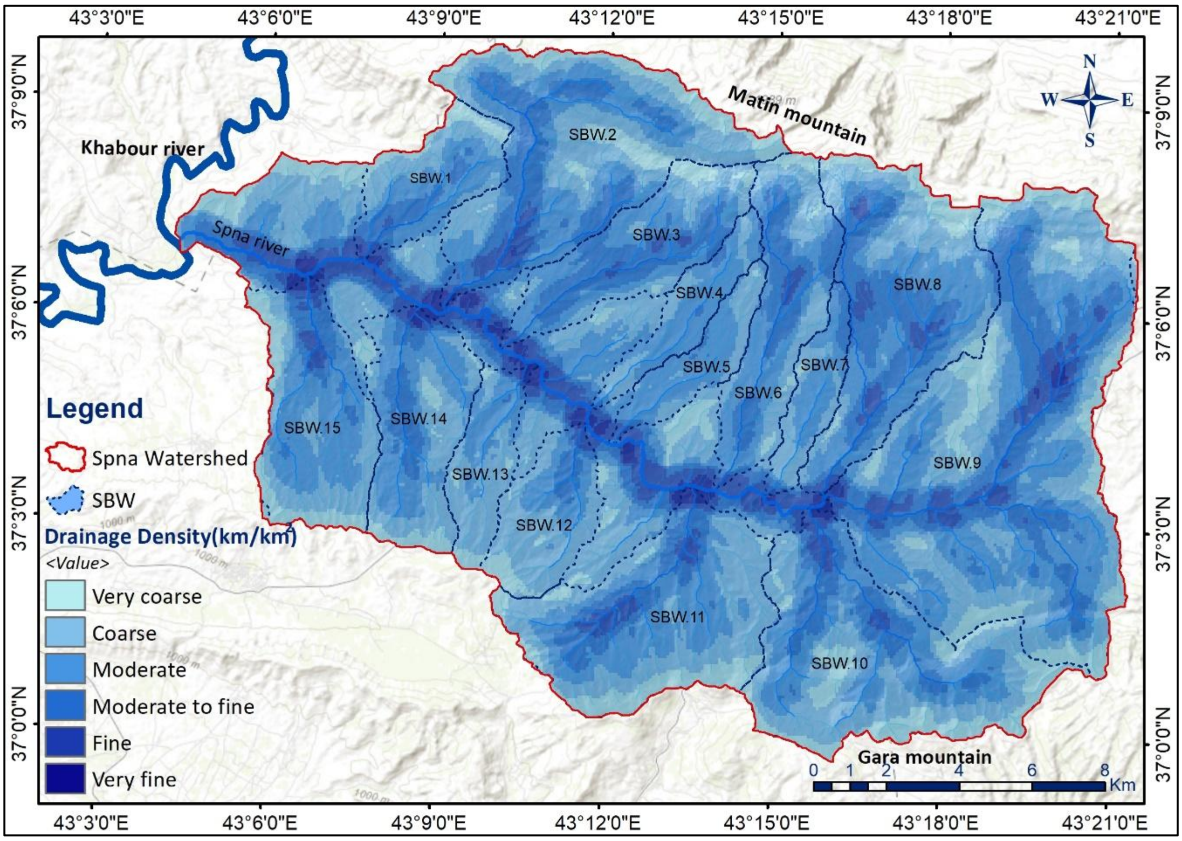

Fig. 3: Spna watershed drainage density.

The value F*s* of the Spna watershed area is calculated as 6.8 streams/km^2, which is a moderate density of streams (Table 4). Sub-watersheds such as SBW.2 (7.67 streams/km^2) and SBW.14 (streams/km^2) have the highest stream frequencies, indicating dense stream networks, while SBW.13 (5.0 streams/km^2) has the lowest value. Low F_s values are related to relief, low resistance, and low surface and subsurface material lithology (Revil et al., 2012). As stated by Sarkar et al. (2020), the classification of stream frequency of a significant number of streams, a low stream frequency value means more percolation and a high stream frequency value indicates a high surface runoff.

In this study, the value of the Spna watershed is calculated as 0.16 km. According to Sukristiyanti et al. (2018), the *Lo* has three classes: low (< 0.2 km), moderate (0.2-0.3 km), and high (> 0.3 km). Denoted good permeability and low to moderate slopes, with low surface drainage, infiltration rate, vegetation type, and precipitation amount all affecting the Lo value.

Chorley (1957) developed the lemniscate ratio (RL) as a method for estimating drainage shape. The lemniscates approximate the actual watershed shape better than the circularity ratio, and a lower lemniscate value means there are more and longer first-order streams. The RL value for the Spna watershed is 0.56 km, whereas the sub-watersheds' values range from 0.44 km to 1.92 km.

The circular ratio of the Spna watershed is 0.49, which indicates a long shape. The values between the sub-watersheds divided indicate the difference in shapes, where 0.28–0.62 means that the watershed is either elongated or relatively circular. A low circular ratio usually means that the watershed is more spread out and causes runoff that moves slowly, while a high number means that the size is more circular and the runoff is more rapid.

The texture ratio is a crucial element in drainage morphometric analysis, dependent upon the region's relief, infiltration capacity, and underlying lithology. The texture ratio of the main watershed is 23.89 km^{-1}, which indicates an excellent drainage texture with close currents. In sub-watersheds, the lowest value of SBW.4 is 1.96 km^{-1}, which suggests a coarse texture with widely dispersed currents, while SBW.9 has the highest at

10.46 km^{-1}, indicating a very fine drainage texture and high stream density.

As stated by Huggett and Shuttleworth (2022), the compactness coefficient (CC) is an index that expresses the relationship between a hydrological watershed and a circular watershed of the same region under only the effect of slopes of watersheds. A compactness coefficient in this study is calculated as 1.43 for the Spna watershed; this value indicates a moderately compact shape with some elongation. SBW.4 has the highest value at 1.88; it denotes a slightly elongated shape. While SBW.12 has the lowest value at 1.27, this indicates efficient drainage and a more circular shape, which may result in varied drainage response and slower runoff. The results are shown in Table (4).

The infiltration number (I_f) is defined as the product of drainage density and drainage frequency (Fs). The higher the infiltration number, the lower the infiltration and consequently the higher will be the runoff (Umrikar, 2017). A high infiltration number indicates low infiltration capability and high surface runoff. The infiltration number value of the Spna watershed is 9.74 mm/hour, and the value of its sub-watersheds ranges from 7.77 to 12 mm/hour, with higher infiltration capacity and reduced runoff in the Spna watershed due to a lower infiltration number.

Many facets of nature influence texture, including vegetation, lithology, soil composition, infiltration capacity, climate, topography, precipitation, and developmental stage. As stated by Ahmed et al. (2010), the D_t of the sub-watersheds ranges between 5 km^2 and 7.67 km^2, denoting that the Spna watershed has an intermediate texture; it indicates a medium drainage network with balanced runoff and infiltration according to Ahmed et al. (2010) classification.

The low score denotes moderate to high relief, moderate to dense forest cover, and a mild slope. The inverse of drainage density expressed in km2 means constant channel maintenance. The low value of the main watershed is 0.32 km^2/km, indicating a gentle slope, high relief, and dense forest cover.

The slope of a watershed is considered one of the most significant factors in geographic and hydrological analysis (Ghariba et al., 2025). In the present study area, the slope degree ranges from 0° to 70°. The southern and northern parts of the watershed exhibit steeper slopes compared to the central and western parts of the Spna watershed (Fig. 3.5). These steep slopes increase surface runoff velocity, which enhances soil erosion and leads to faster sediment deposition in lower areas (Kumari et al., 2021). According to Zinck (1980), the slope of the Spna watershed can be classified into five distinct categories.

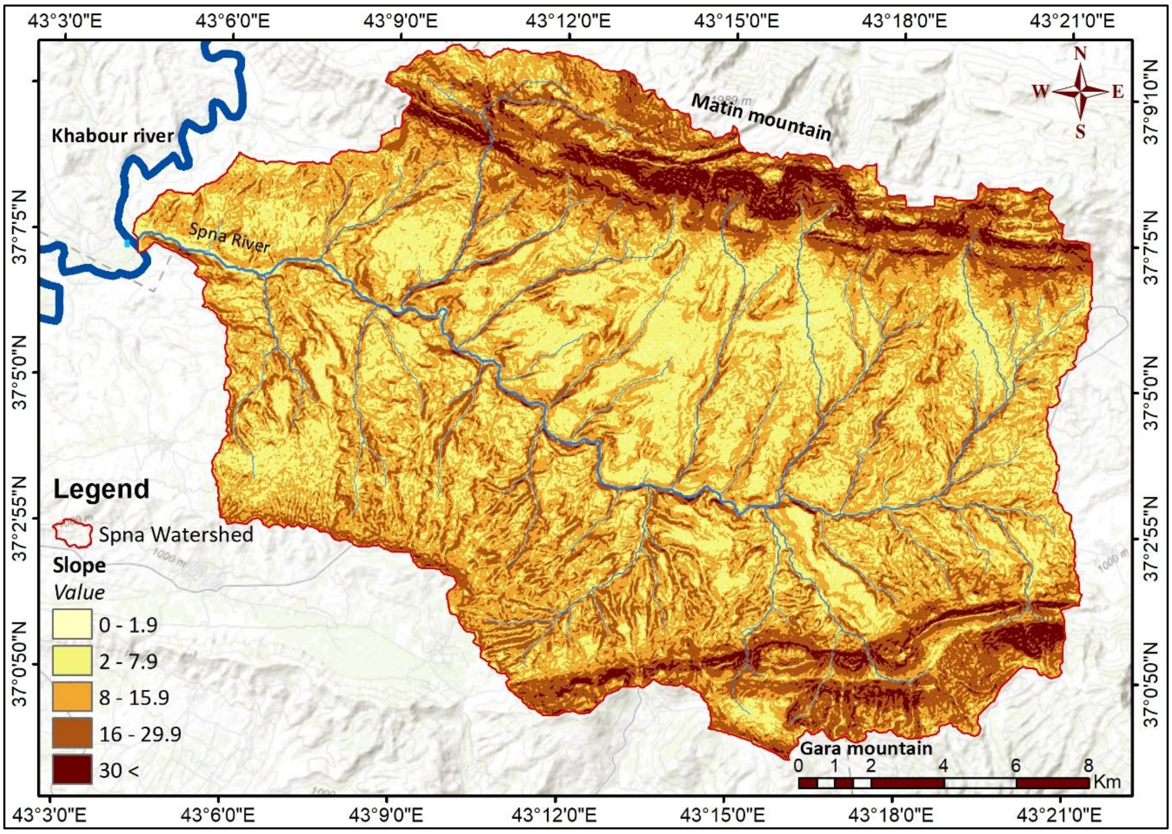

Fig. 4: Slope map of the Spna watershed.

The Spna watershed slope zones are undulating (5.736 km^2, 2%) and flat (98.538 km^2, 31%), which support moderate runoff and infiltration. Rolling areas (129.75 km^2, 41%) and mountainous regions (69.928 km^2, 22%) have steeper slopes, increasing runoff, while mountainous areas (13.701 km^2, 4%) contribute to rapid water flow and erosion, as shown in Table 3.5.

Table 5: Classification and slopes of the Spna watershed.

Colour code	No	Slope (Degree)	Area (km^2)	Area (%)	Classification
	1	0 - 1.9	5.74	2	Flat
	2	2 - 7.9	98.53	31	Undulating
	3	8 - 15.9	129.75	41	Rolling
	4	16 - 29.9	69.93	22	Hill
	5	30 - 73.4	13.70	4	Mountains
	Total		317.65	100	

B. Hypsometric parameter analysis

The hypsometric integral (HI) is defined by Strahler (1952) as the space located underneath the line that joins the cumulative percent area for the related percentage of total elevation. There is also a negative correlation between hypsometric integral and relief, drainage density and overall slope steepness. The study has applied the formula published by Pike and Wilson (1971) to calculate the hypsometric integrals. Strahler (1952) classified various influences on hypsometric curves while comparing multiple drainage watersheds and categorized them based on their geomorphic evolution stages as follows: (1) the youth stage (convex upward curves, where $HI \geq 0.60$), characterized by high susceptibility to erosion and landsliding; (2) the equilibrium or mature stage (S-shaped hypsometric curve, concave upward at higher elevations and convex downward at low elevations, where $0.30 \leq HI \leq 0.60$); and (3) the peneplain (old) or monadnock stage (concave upward curve, where $HI \leq 0.30$) as shown in Fig. (6) and Table (7).

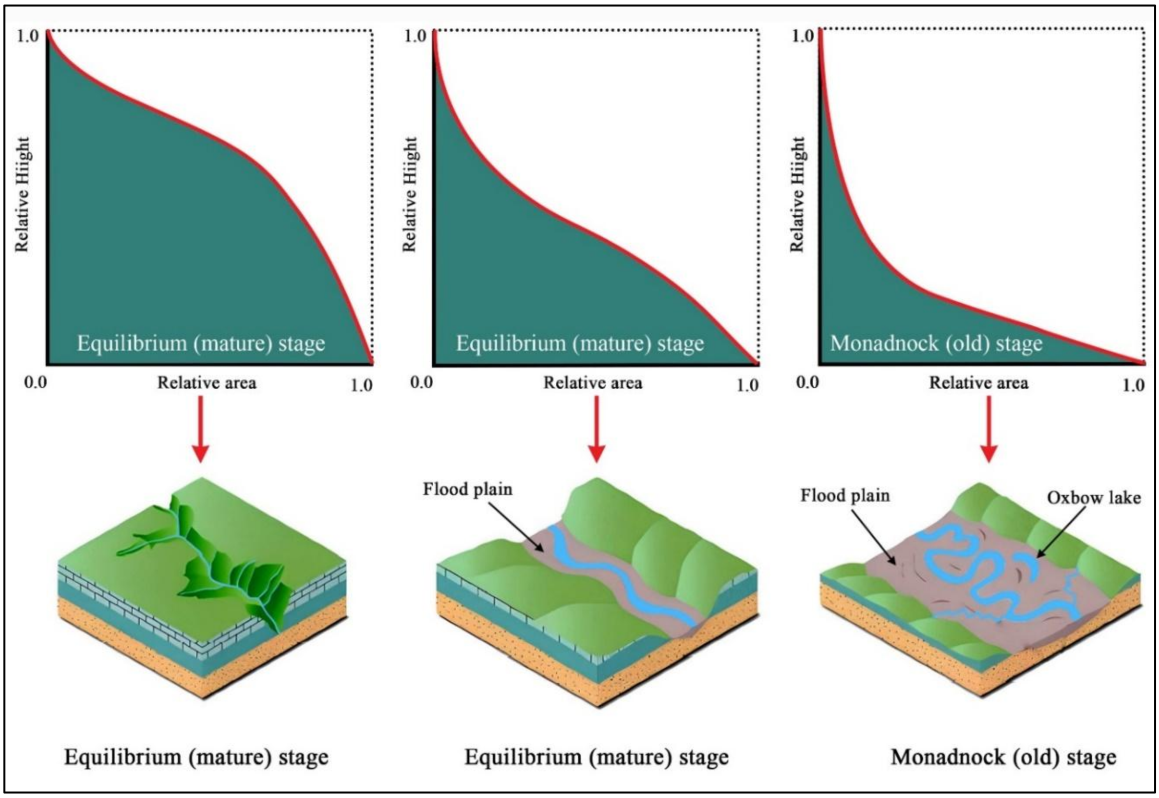

Fig. 6: Hypsometric curve types (youth, mature and old) stages that Strahler (1952) described.

Table 7: Convex, S-shaped and concave hypsometric curves with their descriptions by Strahler (1952).

Curve Shape	Visual shape	Landscape shape	Dominant elevation	Erosion rate	Slope characteristics	Interpretation
Convex	Upward bulge (∩ shape)	youthful	High	High	Steep, rugged slopes	The convex curve typically indicates mountainous or rugged terrain.
S-shaped	Combination of convex and concave	Mature/ transition	Mixed	Moderate	Mix of steep and gentle slopes	The S-shaped curve might reflect areas that transition from lower elevation e.g., foothills to higher altitudes (e.g., mountains or plateaus.
Concave	Downward curve U shape)	Old/mature	Low	Low	Gentle, smooth slopes	The concave curve is indicative of a region with a large amount of land at lower altitudes.

Hypsometric integrals and hypsometric curves help in analyzing ecological studies by assessing land use plans and assisting in flood prediction (Shekar et al., 2023). For the Spna watershed and all the sub-watersheds, hypsometric integrals and hypsometric curves are calculated, with geological stages and curve shapes determined, as shown in Table (8). In the present study, the main watershed HI value is 0.28 (Fig. 7). This value shows that the Spna watershed is in a mature to old stage of landscape evolution, which can be inferred and has an S-shaped curve. This characteristic indicates significant erosion, low relief, and an established drainage system without significant recent tectonic activity. As stated by Mohammed (2023), the hypsometric curve of a mature to old stage watershed is an S-shaped graph that increases at higher elevations and decreases at lower elevations, as shown in Table (8).

Table 8: Hypsometric integral value, geologic stages and curve shape of Spna watershed and their sub-watersheds.

Sub-watershed	Minimum elevation (h)	Maximum elevation (h)	mean	HI	Geologic stages	Curve shape
SBW.1	681	1423	897.325	0.29	Old Stage	Concave
SBW.2	709	2063	1292.6	0.43	Mature stage	Concave
SBW.3	729	1942	1105.7	0.31	Old Stage	S-shape
SBW.4	748	1473	1020.8	0.38	Old Stage	Concave
SBW.5	759	1182	957.7	0.47	Mature stage	S-shape
SBW.6	791	2088	1179.5	0.30	Old Stage	S-shape
SBW.7	801	1187	971.1	0.44	Mature stage	Concave
SBW.8	820	2058	1226.5	0.33	Old Stage	S-shape
SBW.9	820	1944	1093.9	0.24	Old Stage	Concave
SBW.10	816	1833	1182.6	0.36	Old Stage	Concave
SBW.11	783	1513	1013.8	0.32	Old Stage	Concave
SBW.12	752	1259	950.8	0.39	Old Stage	Concave
SBW.13	728	1271	941.6	0.39	Old Stage	S-shape
SBW.14	707	1184	890.2	0.38	Old Stage	S-shape
SBW.15	674	1187	898.4	0.44	Mature stage	S-shape
Main Watershed	647	2088	1052.57	0.28	Old Stage	S-shape

For all 15 sub-watersheds of the Spna watershed, HI values range from 0.24 to 0.47, which reflects diverse landscape development processes across the region.

SBW.5, SBW.7, SBW.15, and SBW.2 have high HI values (0.43-0.47), so they are categorized between youthful and mature stages. Such basins, therefore, possess convex or concave-convex hypsometric curves, alluding to limited erosion and relatively steep, elevated terrain characterized by rugged topography and high relief in these areas and implying a correspondingly high susceptibility to erosion under external influences, which include high-intensity rainfall incidences and changes in land use.

The intermediate landscapes, or landscapes that have modestly disappeared, are represented by the next five sub-watersheds: SBW.4, SBW.10, SBW.12, SBW.13 and SBW.14. Their HI values are medium (0.36-0.39). These areas have smooth reliefs with more balanced area profiles, with fluvial processes significantly shaping the landscape, yet some basic positional features persist.

On the other hand, SBW.1, SBW.3, SBW.6, SBW.8 and SBW.11 fall within the mature stage with HI values ranging from 0.29 to 0.33. Their concave hypsometric curves suggest that most parts have experienced advanced erosion, low relief, and well-established drainage networks. These sub-basins are, as a rule, more stable and stable against rapid geomorphic change, but they may still be able to contribute sediments downstream.

The minimum HI value is recorded in SBW.9 at 0.24, which makes it the most eroded sub-watershed in the area. Its deeply concave hypsometric curve is a result of long-term denudation and flattening of terrain, a characteristic of an old stage. This suggests a condition of minimal relief and subdued slopes, indicating an environment that is highly stable but possibly degraded.

These variations in hypsometric integral among the SBWs reflect some of the underlying variances in lithology, structural setting, erosional history, and tectonic activity. Understanding such trends is crucial for targeted management of watersheds, especially in terms of conserving areas that are prone to erosion and managing sustainable land use in the entire catchment area.

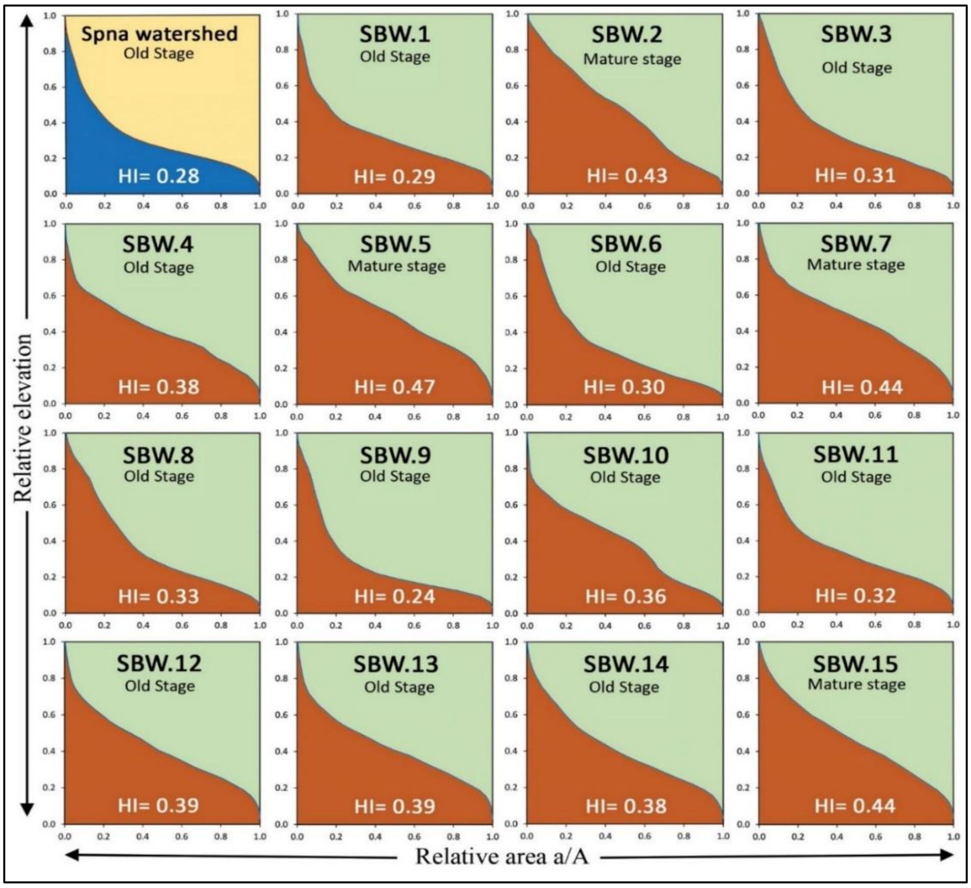

Fig. 7: Hypsometric curves of the Spna watershed and its sub-watersheds.

4. Correlation

The study analyzed the relationship between the hypsometric integral (HI) and various morphometric parameters for the Spna watershed and its sub-watersheds as shown in Table (9).

Table 9: Pearson's correlation matrix of hypsometric integral and morphometric parameters.

	HI	A	P	L	W	E	S	Rf	Dd	Tr	Rb	WR	Rr	RR
Hypsometric integral (Hi)	1													
Area (A)	-0.40	1												
Perimeter (P)	-0.47	0.96**	1											
Length (L)	-0.478	0.97**	0.98*	1										
Width (W)	-0.461	0.963**	0.985**	0.95**	1									
Elevation (E)	-0.624**	0.437	0.603*	0.588*	0.527*	1								
Slope (S)	-0.438	0.157	0.324	0.211	0.35	0.72**	1							
From factor (Rf)	-0.336	0.395	0.486*	0.323	0.588*	0.264	0.644**	1						
Drainage density (Dd)	-0.083	-0.017	0.013	0.124	-0.081	0.306	-0.178	-0.421	1					
Texture ratio (Tr)	-0.51*	0.965**	0.986**	0.963**	0.992**	0.551*	0.323	0.542*	-0.01	1				
Bifurcation ratio (Rb)	0.095	-0.024	-0.071	0.001	-0.117	-0.182	-0.469	-0.391	0.119	-0.094	1			
Watershed Relief (WR)	-0.61**	0.505*	0.652**	0.639**	0.585**	0.989**	0.705**	0.284	0.302	0.609*	-0.2	1		
Relief ratio (Rr)	-0.299	-0.365	-0.251	-0.3	-0.268	0.515*	0.641**	0.09	0.113	-0.26	-0.34	0.5*	1	
Relative Relief (RR)	0.039	-0.6**	-0.7**	-0.67**	-0.67**	-0.23	-0.04	-0.327	-0.037	-0.7**	-0.17	-0.23	0.62**	1
Ruggedness index (Ri)	-0.61	0.46	0.6**	0.66*	0.521*	0.981**	0.64**	0.185	0.434	0.557*	-0.2	0.988**	0.5*	-0.2

*** Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level.*

The data reveal a negative correlation between the hypsometric integral and several morphometric parameters, including area, perimeter, length, width, elevation, slope, form factor, drainage density, texture ratio, watershed relief, relief ratio, and ruggedness index. Notably, the hypsometric integral shows a negative correlation with watershed relief and elevation, while its relationship with texture ratio is also significant but negative. Moderate negative correlations are observed with area, perimeter, length, width, and slope.

5. Conclusion

Morphometric characteristics of the Spna watershed are calculated and analyzed using integrated remote sensing with GIS techniques to identify hydrological performance as well as to assist in the planning and execution of water and land management. The study region is classified as coarse texture, with a drainage density of 3.12 km/km2 indicating moderate surface runoff and infiltration capability. The stream frequency value of 6.81 reflects semi-parameter as well as distinct slope zones. A form factor value of 0.45 indicates a long-term, somewhat flat peak flow with a lengthy watershed shape. With an increase ratio of 0.75, the watershed is moderately prolonged, which makes it susceptible to erosion and sediment transport. The continuation of the channel maintenance of 0.32 indicates moderate sub-perpetuity and sloping gradients. A low hypsometric integral value of 0.28 suggests that the Spna watershed is in its old geomorphic stage with low relief and a well-developed and stable drainage system.

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الملخص

تقدم هذه الدراسة تحليلاً شاملاً للخصائص المورفومترية والتحليل الهيبسومتري (HI) والعلاقات الارتباطية بينهما لحوض سبنة الذي يقع على بُعد حوالي 50 كم شمال غرب مركز مدينة دهوك والتي تشغل مساحة مقدارها 317.65 كم2. تم استخدام نموذج الارتفاع الرقمي (DEM) بدقة 12.5 متراً في برنامج ArcGIS Pro لاستخراج حدود الحوض الرئيس وحدود الاحواض الثانوية. شملت الدراسة ثلاثة أنواع من الخصائص المورفومترية (التضاريسية والمساحية والخطية)، والتي تضمنت كلًا من معامل الشكل ونسبة التضرس وكثافة التصريف والرتب النهرية ونسبة التشعب ودرجة الخشونة. وقد تم تحليل هذه الخصائص كمّيًا، وأظهرت النتائج أن الحوض يتميز بكثافة تصريف خشنة (3.12 كم/كم²) ونسبة تشعب معتدلة (بمعدل 4.3) وشكل متطاول مما يشير إلى جريان سطحي معتدل وقابلية للتعرية. وأظهر تحليل المنحنى الهيبسومتري أن قيمة التكامل الهيبسومتري للحوض الرئيس بلغت 0.28 مما يشير على أنه في مرحلة متقدمة من تطور الأشكال الأرضية (مرحلة النضج)، بينما تراوحت قيم HI في الأحواض الثانوية مابين 0.24 و0.47 مما يشير إلى أنها في مراحل مختلفة من التطور تتراوح مابين مرحلة الشباب إلى مرحلة النضج. وبينت الدراسة وجود علاقات ارتباط سلبية معنوية بين قيمة HI وبعض خصائص الحوض مثل الارتفاع عن مستوى سطح البحر ومساحة الاحواض ودرجة الوعورة مما يوضح تأثير مورفولوجيا التضاريس على قابلية التعرية والاستقرار.

الكلمات المفتاحية:

مورفومترى، هيبسومتري، ارتباط، سبنة.

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