

Hydromorphometric Analysis of the Koya Basin in the Kurdistan Region of Iraq.

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Received: 23 May 2025

Received in revised form: 29 July 2025

Accepted: 15 October 2025

Available online: 01 October 2026

Abstract

This study conducts a comprehensive hydromorphometric analysis of the Koya basin in the Kurdistan Region of Iraq, using ALOS PALSAR DEM data and GIS-based techniques to evaluate relief, linear, and areal parameters. The elongated basin (form factor = 0.21) features a sixth-order drainage network dominated by first-order streams, with high mean bifurcation ratios ($R_b = 5.13$) indicating structural control over drainage patterns. Moderate drainage density (1.95 km^{-1}) and infiltration number (4.31) reflect balanced dissection but elevated runoff potential, while rugged terrain (ruggedness number = 2.31) and significant relief (1,185 m) underscore topographic complexity. Comparative analysis reveals similarities to tectonically influenced basins in Erbil and Kirkuk, though Koya's hypsometric integral (0.47) and dissection index (0.81) suggest a mature yet dynamically evolving landscape. Slope and aspect analyses identify southwest-facing slopes as hotspots for erosion and reduced soil moisture retention. The findings highlight the interplay between geomorphology and hydrology, emphasizing that elongated basin geometry mitigates flood intensity, while high-drainage-density zones necessitate targeted management. This study provides the first district-scale hydromorphometric assessment of the Koya basin, offering critical insights for policymakers to optimize watershed management, prioritize flood mitigation in structurally active regions, and enhance groundwater recharge strategies in semi-arid environments.

Keywords:

Hydromorphometry, Semi-Arid Region, Groundwater Recharge Management.

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1. Introduction

Hydro-morphometric studies are a significant aspect of hydrological and geomorphological investigations, providing insights into watershed characteristics, drainage systems, and their influence on water resource management (Horton, 1945). The integration of Remote Sensing and Geographic Information System (GIS) techniques has significantly enhanced the accuracy and effectiveness of hydro-morphometric analysis, making it feasible to analyze important morphometric parameters such as relief, linear, and areal parameters, which play an important role in watershed behavior, surface runoff potential, and erosion (Patel et al., 2013; Mohammed et al., 2026). The Koya basin, located in the Kurdistan

Region of Iraq, is characterized as being topographically complex and having a plurality of drainage systems. Although various hydro-morphometric measurements have been conducted in Kurdistan provinces like Erbil and Kirkuk, very few scientific studies examine the entire Koya basin (Al-Saady et al., 2016). Earlier studies focus primarily on sub-watersheds or specific places in Koya rather than on a district-level study.

Most available studies are conducted on sub-watersheds or specific sites in Koya, not at the district level. Existing research has compared hydromorphometric parameters across different areas inside and outside Koya. For example, Ahmed et al. (2023) conducted research in the Erbil area using principal component analysis (PCA) to evaluate drainage density, basin shape,

and elevation trends. Likewise, Goran and Khattab (2023) analyzed the Hesh Karo River catchment using GIS, demonstrating strong hydrological relationships among stream length, stream order, and runoff potential. Al-Tamimi et al. (2022) investigated the Laylan sub-basin in Kirkuk Governorate and identified significant morphometric parameters, such as drainage density and stream frequency, to evaluate erosion processes.

Additionally, Ahmed and Jirjees (2022) carried out a flood hazard evaluation and research on water management practices in the Taqtaq watershed (Taqtaq sub-district, Koysinjaq district), which was beneficial. Fatah et al. (2020) conducted a comprehensive morphometric study of northeastern Erbil watersheds, highlighting the application of GIS-based methods in watershed management. Regardless of these beneficial attempts, no one has yet conducted a comprehensive hydro-morphometric study of the entire Koya basin. This research gap highlights the need for a district-scale morphometric study to provide a more detailed insight into Koya's hydrological and geomorphological characteristics.

Although there have been studies on some of the watersheds and sub-basins of Koya, no study has yet presented a full morphometric analysis at the district level. Either they concentrate on some limited sections of Koya, or they investigate watersheds in other regions of Kurdistan. This calls for a general review of the Koya basin's hydromorphometric parameters, including its relief, linear, and areal characteristics. By bridging this gap, the present study aims to provide fresh insight into the Koya basin's hydrological behavior and geomorphic dynamics.

The primary objective of this study is to conduct a hydromorphometric analysis of the Koya basin using ALOS PALSAR Digital Elevation Model (DEM) data and GIS-based techniques. The study is especially concerned with the analysis of relief, linear, and areal morphometric parameters; stream order extraction and classification to interpret drainage patterns; the establishment of the hydrological significance of the basin's topographic features; and the identification of possible applications to water resource management and flood hazard mitigation.

To attain these goals, the research aims to address the following research questions:

1. What are the dominant morphometric characteristics of the Koya basin in relation to relief, linear, and areal factors?

2. What is the resemblance of the hydromorphometric structure of the Koya basin to other studied watersheds in Kurdistan?

3. What are the morphometric implications for flood control and water resource management in the Koya basin?

This study aims to perform a comprehensive hydromorphometric analysis of the Koya Basin in the Kurdistan Region of Iraq, using ALOS PALSAR DEM data and GIS-based techniques, to assess its relief, linear, and areal parameters, interpret drainage patterns, and evaluate the basin's hydrological and geomorphological characteristics at the district level

GIS-based software is used to map the drainage network, delineate watersheds, and calculate key morphometric parameters. The methodology follows a systematic process that includes stream-order classification and calculation of hydromorphometric indices. The derived data are analyzed to prepare topographic and hydrological maps, facilitating an integrated interpretation of the drainage system of the Koya basin.

The outcome of this study will add to the body of knowledge in hydromorphometry by presenting the first-ever basin-level analysis of Koya. Unlike earlier studies that have addressed small watersheds, this study presents an integrated assessment of the entire basin, offering insightful information on drainage patterns, surface flow, and likely flood-prone zones.

The applications of this study include helping policymakers and conservation organizations with proper watershed management, delineating areas prone to flooding and suggesting mitigation measures, and aiding water conservation efforts by improving understanding of drainage patterns and their origin.

2. Study Area

Koya District is in the Kurdistan Region of Iraq, about 75 kilometers southeast of Erbil city. This area is located between the latitudes of 35° 49' 35" N and 36° 16' 44" N, and longitudes of 44° 15' 18" E and 44° 57' 27" E. The total study area is about 1911 square kilometers. The altitude over the study area ranges between 271 m and 1,455 m above sea level, which indicates a heterogeneous



In the present



Fig. 3: The flow diagram shows the steps of the methods and data investigation.

The morphometric parameters have been divided into three types, including linear, areal, and relief aspects.

Linear Aspects of Morphometry

Linear aspects of morphometry help to evaluate the surface structure and drainage characteristics of a basin. These parameters are crucial for understanding the hydrologic behaviour and geomorphological development of a watershed (Strahler, 1957).

A. Basin Perimeter (P)

Basin perimeter is the total length of the outer boundary that encloses the drainage area. It is extracted using GIS tools during watershed delineation (Schumm, 1956).

B. Main Channel Length (Cl)

Main channel length is the distance measured along the longest stream from its source to the outlet. It is measured directly using the GIS line tool (Gregory and Wallingford, 1973)

C. Basin Width (Bw)

Basin width indicates the overall shape of the basin and is calculated by dividing the area by the basin length. It helps assess surface runoff and flood potential (Schumm, 1956).

Formula: $Bw = A / Lb$ (Schumm, 1956)

A = Basin area, Lb = Basin length

D. Lemniscate Factor (K)

The Lemniscate factor describes the shape of the basin, particularly its elongation. Lower values indicate an elongated basin shape (Chorley, 1957)

Formula: $K = (3.14 \times Lb^2) / (4 \times A)$ (Chorley, 1957)

K = Lemniscate factor Lb = Basin length
A = Basin area

E. Basin Length (Lb)

Basin length is the longest dimension of a basin from the outlet to the farthest point. It can also be estimated using an empirical equation based on the basin area (Schumm, 1956).

Formula: $Lb = 1.312 \times A^{0.568}$ (Schumm, 1956)

Lb = Basin length; A = Basin area

F. Stream Order (Nu)

Stream order classifies stream segments based on a hierarchical system developed by Strahler. It reflects the complexity of the drainage network (Strahler, 1952).

Formula: Nu = Number of streams of a particular order u (Strahler, 1952)

G. Stream Length (Lu)

Stream length refers to the total length of all stream segments of a given order. It is extracted from GIS using the line features of stream orders (Horton, 1945).

Formula: Lu = Total length of streams of order u (km) (Horton, 1945)

H. Mean Stream Length (MLu)

Mean stream length is the average length of streams of a specific order and indicates the stages of basin development (Strahler, 1964). It is derived by dividing the total stream length (Lu) by the number of stream segments (Nu).

Formula: $MLu = Lu / Nu$ (Strahler, 1964).

MLu = Mean stream length, Lu = Total stream length of order, Nu = Number of streams of order

I. Stream Length Ratio (RLu)

The stream length ratio compares the length of streams in one order to the next lower order and helps in understanding the geomorphic

development of the basin (Horton, 1945). It is influenced by variations in slope and lithology.

Formula: $RLu = Lu / Lu+1$ (Horton, 1945)

RLu = Stream length ratio Lu = Stream length of order
 $Lu+1$ = Stream length of next higher order

J. Bifurcation Ratio (Rb)

Bifurcation ratio is the ratio of the number of streams in a given order to those in the next higher order (Strahler, 1957). It reflects the degree of branching and can indicate structural controls such as faults or joints.

Formula: $Rb = Nu / Nu+1$ (Strahler, 1957)

Rb = Bifurcation ratio; Nu = Number of streams of order; $Nu+1$ = Number of streams of next higher order

K. Mean Bifurcation Ratio

The mean bifurcation ratio is the average of all bifurcation ratios calculated between successive stream orders (Strahler, 1964). It helps assess the overall structural influence and the uniformity of the drainage pattern.

Formula: Mean of all Rb values (Strahler, 1964)

L. Rho Coefficient (ρ)

The rho coefficient is used to evaluate the relationship between stream length and bifurcation, and is useful in interpreting geological and drainage density characteristics (Strahler, 1964). It is calculated as the ratio of the stream length ratio to the bifurcation ratio.

Formula: $\rho = RLu / Rb$ (Strahler, 1964)

ρ = Rho coefficient
 RLu = Stream length ratio
 Rb = Bifurcation ratio

Areal Aspect

Areal aspects refer to the parameters that describe the size, shape, and spatial distribution of a drainage basin, which directly influence surface runoff, infiltration, and hydrological response. These aspects help quantify how the basin area is utilized by drainage features and how efficiently it drains precipitation. Morphometric parameters under this category offer crucial insights into the basin's hydrological behavior and geomorphological development (Strahler, 1957).

A. Basin Area (A) (Km²)

The basin area (A) is the total land-surface area that contributes water to a drainage system, measured using GIS tools. It is fundamental for calculating most morphometric parameters and reflects the scale of hydrological processes within the watershed (Strahler, 1964).

B. Drainage Density (Dd)

Drainage density represents the total length of streams per unit area of the basin, indicating the closeness of channel spacing. High values suggest impermeable subsurface material or high relief (Horton, 1945).

Formula: $Dd = \text{Total } Lu / A$

Dd = Drainage density (km/km²)

Lu = Total length of streams (km)

A = Basin area (km²)

C. Stream Frequency (Fs)

Stream frequency refers to the number of streams per unit area. It reflects the texture of the drainage network and is influenced by lithology and slope (Horton, 1945).

Formula: $Fs = \text{Total } Nu / A$

Fs = Stream frequency (no./km²)

Nu = Total number of streams

A = Basin area (km²)

D. Drainage Texture (Dt)

Drainage texture is the relative spacing of drainage lines in a basin, calculated as the total number of streams per unit perimeter. A coarse texture suggests gentle terrain, while a fine texture suggests steep slopes (Smith, 1950)

Formula: $Dt = \text{Total } Nu / P$

Where:

Dt = Drainage texture

Nu = Total number of streams

P = Basin perimeter (km)

E. Drainage Intensity (Di)

Drainage intensity combines stream frequency and drainage density to reflect the potential for surface runoff. A high value indicates a well-developed drainage system (Faniran, 1968).

Formula: $Di = Fs / Dd$

Where:

Di = Drainage intensity

Fs = Stream frequency

Dd = Drainage density

F. Elongation Ratio (Re)

The elongation ratio is a shape parameter indicating how close the basin's shape is to a circle. Values near 1 suggest a circular basin, while lower values indicate elongation (Schumm, 1956)

$$\text{Formula: } RE = 1.128\sqrt{A} / Lb$$

Where:

Re = Elongation ratio

A = Basin area (km²)

Lb = Basin length (km)

G. Circularity Ratio (Rc)

Circularity ratio expresses how circular the basin is and is useful in assessing erosion and maturity stage (Miller, 1953).

$$\text{Formula: } RC = 4\pi A / P^2$$

Where:

Rc = Circularity ratio

A = Basin area (km²)

P = Basin perimeter (km)

H. Form Factor (Rf)

Form factor describes the shape of the basin and its effect on flood peaks. Low values indicate elongated basins with lower peak flows (Horton, 1945).

$$\text{Formula: } Ff = A / Lb^2$$

Where:

Ff = Form factor

A = Basin area (km²)

Lb = Basin length (km)

I. Infiltration Number (If)

The infiltration number represents the combined effect of drainage density and stream frequency on infiltration. Lower values indicate greater infiltration capacity (Faniran, 1968).

$$\text{Formula: } If = Fs * Dd$$

Where:

If = Infiltration number

Fs = Stream frequency

Dd = Drainage density

J. Length of Overland Flow (Lg)

This is the average length of water flow over the ground before entering a channel. It is inversely related to drainage density (Horton, 1945).

$$\text{Formula: } Lg = 1/2Dd$$

Where:

Lg = Length of overland flow (km)

Dd = Drainage density

K. Constant of Channel Maintenance (C)

This constant represents the required area to sustain one unit length of stream channel, inversely related to drainage density (Schumm, 1956).

$$\text{Formula: } C = 1/Dd$$

Where:

C = Channel maintenance constant

Dd = Drainage density

Relief Aspect

Relief aspects represent the vertical dimension of a drainage basin, which influences runoff velocity, erosion potential, and sediment transport. These parameters offer insight into the topographic variation, landscape maturity, and tectonic activity within the basin. Understanding relief aspects is essential in geomorphological and hydrological investigations (Strahler, 1957).

A. Maximum Height (H) (m)

This is the highest elevation point within the basin and serves as a reference for calculating relief.

Measured using: DEM analysis in GIS software.

B. Minimum Height (h) (m)

This is the lowest elevation point in the basin, typically located at the basin outlet.

Measured using: DEM and outlet point analysis.

C. Total Basin Relief (Rb)

It is the difference between the highest and lowest elevations within the basin, indicating the total vertical extent.

$$\text{Formula: } Rb = H - h$$

Where:

Rb = Total basin relief

H = Maximum elevation (m)

h = Minimum elevation (m)

D. Relief Ratio (Rh)

The relief ratio expresses the steepness or gradient of a basin by relating total relief to basin length. Higher values indicate steeper slopes (Schumm, 1956).

$$\text{Formula: } Rh = Rb/Lb$$

Where:

Rh = Relief ratio

Rb = Basin relief (m)

Lb = Basin length (km)

E. Relative Relief Ratio (Rr)

This parameter relates the maximum basin elevation to its perimeter, providing insight into terrain roughness (Melton, 1957)

Formula: $Rr = H / P$

Where:

Rr = Relative relief ratio

H = Maximum height (m)

P = Basin perimeter (km)

F. Absolute Relief (Ra)

Absolute relief refers to the maximum elevation from mean sea level in the basin and helps assess terrain roughness.

Measured using: GIS-derived DEM analysis.

G. Dissection Index (Di)

The dissection index estimates the degree of vertical dissection of the basin. Values close to 1 indicate deep dissection, while lower values reflect gentle terrain (Singh and Dubey, 1994).

Formula: $Di = Rb/Ra$

Where:

Di = Dissection index

Rb = Basin relief (m)

Ra = Absolute relief (m)

H. Ruggedness Number (Rn)

Ruggedness number combines basin relief and drainage density to express terrain ruggedness. It is a key indicator of erosion potential and surface roughness (Strahler, 1964)

Formula: $Rn = Dd * (Rb/1000)$

Where:

Rn = Ruggedness number

Dd = Drainage density (km/km²)

Rb = Basin relief (m)

I. Slope

It is a primary morphometric parameter that regulates the response of the land surface to runoff, erosion, and landform evolution. Commonly computed using Geographical Information Systems (GIS) tools with Digital Elevation Models (DEMs), it enables comprehensive analysis of

slope gradients for watershed management and land use planning (Moore et al., 1991).

J. Hypsometric Integral (HI)

Is the ratio of watershed area to elevation, indicating the degree of basin development. A high HI denotes a young, dissected terrain, whereas a low HI implies an older, eroded basin. This parameter is useful for further exploring erosion rates, geomorphological evolution, and hydrological processes (Moore et al., 1991).

K. Aspect Analysis

Aspect analysis determines the direction a slope faces, which significantly influences hydrological processes by directing surface water flow, runoff, and erosion patterns (Moore et al., 1991). The orientation of slopes affects solar radiation exposure, impacting soil moisture, vegetation, and microclimates; for example, south-facing slopes in the northern hemisphere typically experience higher evaporation rates, while north-facing slopes retain more moisture (Wilson and Gallant, 2000). Categorizing aspects helps identify zones of water accumulation or efficient drainage, which is crucial for flood and erosion risk assessment and land-use planning (Moore et al., 1991). Incorporating aspect analysis into hydrological modeling improves prediction accuracy and supports sustainable watershed management by enhancing understanding of terrain-driven water dynamics (Wilson and Gallant, 2000).

4. Results

4.1. Linear

The Koya basin exhibits a sixth-order drainage basin, comprising 4,232 streams totaling 3,731 km, overwhelmingly dominated by first-order streams (Table 1). The stream order map visually represents this (Figure 4). The mean bifurcation ratio (Rb) is calculated at 5.13, stream length ratios range between 0.27 and 0.53, and the Rho coefficient (ρ) is measured at 0.44 (Table 1). According to Strahler (1964). A high bifurcation ratio implies that geological factors, such as rock structure and tectonic activity, play a dominant role in shaping drainage configuration. The stream length ratio demonstrates a systematic reduction in slope and flow energy with increasing stream order. As noted by Horton (1945), Rho indicates a

moderate level of drainage integration, supporting more sustainable water resource management.

Table 1: Summary of drainage basin linear aspect parameters in the study area.

Stream Orders (u)	Stream Numbers (Nu)	Stream Length (Lu) in (Km)	Mean Stream Length (MLu) in (Km)	Stream Length Ratio (RLu)	Bifurcation Ratio (Rb)	Mean Bifurcation Ratio	RHO Coefficient (p)
1st	3276	1948.24	0.59	0.50	4.37	5.13	0.11
2nd	750	974.85	1.30	0.53	4.49		0.12
3rd	167	516.47	3.09	0.36	5.39		0.07
4th	31	187.03	6.03	0.44	4.43		0.10
5th	7	82.09	11.73	0.27	7.00		0.04
6th	1	21.87	21.87				
Total	4232	3731			7.00		0.44

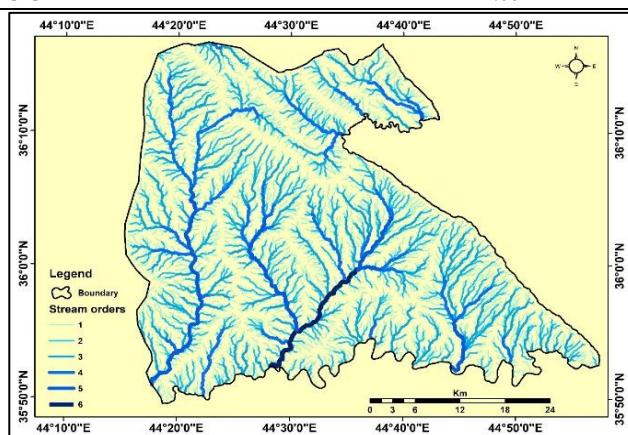


Fig. 4: Stream order distribution map of the study area.

The hierarchy of stream order reveals an inverse relationship, where both the number and total length of streams decrease with increasing stream order, as shown in (Figure.5) This pattern reflects a highly dissected terrain and indicates an early stage of geomorphic development, consistent with Horton's law of stream numbers.

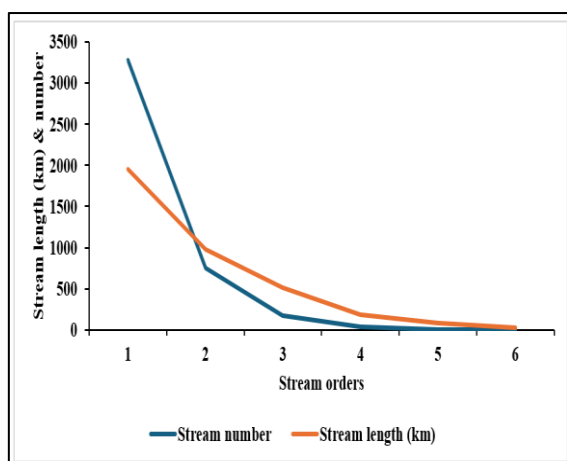


Fig. 5: Relationship between Stream length and Stream Number with Stream Order.

The linear morphometric measurements (Table 2) also substantiate these interpretations. The 277 km total basin perimeter reinforces an intricate and irregular drainage boundary, which

may influence runoff direction and collection patterns. The 95.87 km length of the basin is the cause of an extended basin configuration that has a tendency to slow down peak discharge and reduce flood hazard.

The 65 km length of the main channel indicates how long water would spend flowing within the basin, determining the size and timing of flood peaks. These models are highlighted by a 3.78 Lemniscate Factor and basin width of 19.93 km, both pointing to the basin's stretched character. Together, these parameters provide the basis for both geomorphic maturity and tectonic control of the drainage system and offer solid groundwork for comparative analysis with other basins within the Kurdistan Region.

Table 2: Summary of drainage basin linear aspect parameters in the study area

No.	Parameters	Results
1	Basin perimeter (P) (Km)	277 km
2	Main channel length (Cl) km	65km
3	Basin Width (Bw)	19.93 km
4	Lemniscate Factor (K)	3.78
5	Basin Length (Lb) (Km)	95.87 km
6	Stream Orders (Nu)	See Table 1
7	Stream Length (Lu) (km)	See Table 1
8	Mean Stream Length (MLu) (Km)	See Table 1

9	Stream Length Ratio (RLu)	See Table 1
10	Bifurcation Ratio (Rb)	See Table 1
11	Mean Bifurcation Ratio	See Table 1
12	RHO Coefficient (ρ)	See Table 1

4.2. Areal

The areal morphometric parameters of the Koya basin define the spatial arrangement and hydrological sensitivity of the 1.911 km² basin area, a large catchment that yields significant surface runoff—crucial in determining flood characteristics and water control. The drainage density of 1.95 km⁻¹ marks a moderately dissected terrain with evenly balanced infiltration and runoff, indicating neither highly permeable nor impermeable surface conditions. A stream frequency of 2.21 km⁻² lends credence to this assumption, reflecting a moderate level of drainage activity and basin physiographic maturity. The high drainage texture value of 15.28 km⁻³ reflects rugged terrain or robust subsurface materials, which could increase runoff and exacerbate surface erosion during periods of heavy rainfall. The drainage intensity of 1.13 represents a proportional relationship between stream number and drainage density, implying a stable and cohesively functioning fluvial system. Both elongation ratio (0.51) and form factor (0.21) suggest an elongated basin shape, which is typical of lagged peak runoff and reduced flood intensity—attributes directly imputable to the third research objective of flood mitigation. Similarly, the low circularity ratio of 0.31 indicates an irregular, non-circular basin shape, which tends to spread runoff over longer periods and minimize flood concentration. The infiltration value of 4.31 indicates low potential infiltration and high runoff risk, which is vital in identifying risk zones and improving water resource planning. Overland flow length of 0.26 km, in combination with the channel maintenance constant of 0.51 km², also illustrates moderate surface roughness and levels of channel development and therefore provides essential information on landform evolution and surface water flows. This is as indicated in (Table.3).

Table 3: Summary of drainage basin areal aspect parameters in the study area.

No.	Morphometric Parameters	Result
1	Basin Area (A) (Km2)	1911 km2
2	Drainage Density (Dd)	1.95 km -1
3	Stream Frequency (Fs)	2.21 km-2
4	Drainage Texture (Dt)	15.28 km-3
5	Drainage intensity (Di)	1.13

6	Elongation ratio (Re)	0.51
7	Circularity ratio (Rc)	0.31
8	Form Factor (Rf)	0.21
9	Infiltration Number (If)	4.31
10	Length of Overland Flow (Lg)	0.26
11	Constant of channel maintenance (C)	0.51 km2

Drainage Density Map (Figure 6) illustrates the pattern of drainage density of the Koya Basin, classified into five classes from "Very Poor" to "High." High drainage density (red colors) indicates greater surface runoff and lower infiltration, which are generally found on steeper slopes or in less permeable bedrock. Very poor drainage density areas (green areas) indicate flatness or very permeable soil, which favors water infiltration and minimizes runoff.

In the lineament density map (Figure 7) of the Koya Basin, regions of high lineament density (red) occur predominantly in the northern basin. This indicates that there is high tectonic activity or structural change in the area. High fracture density tends to enhance secondary porosity and permeability, facilitating groundwater infiltration and storage. It could also provide conduits allowing contaminant flow. The central and southern areas have very low to low lineament densities (light blue and blue). That means the geologic conditions are comparatively stable with fewer fractures. Fewer fractures typically mean that there is less groundwater storage capacity and flow because of lower permeability.

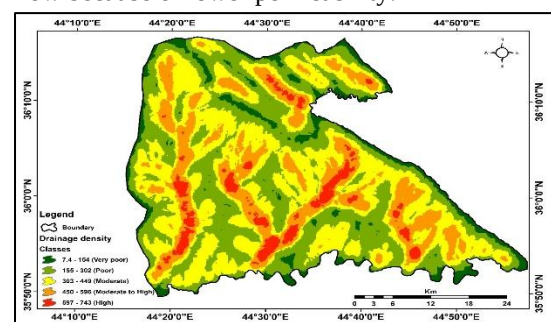


Fig. 6: Drainage density interpolation map for the study area.

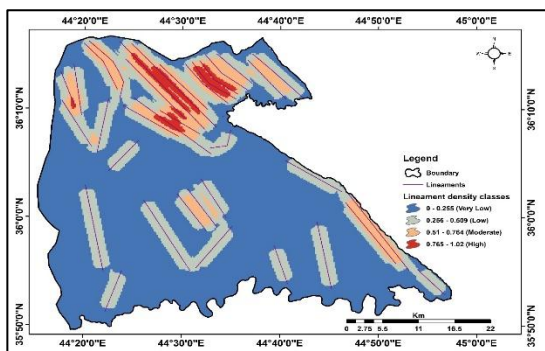


Fig. 7: Lineament density map for the study area.

The Drainage Density Map (Figure 6) spatially reinforces the numerical assessment, highlighting moderately dense drainage in elevated zones and validating the hydrological segmentation of the basin. In contrast, the Lineament Map (Figure 7) reveals the structural alignment of drainage channels, emphasizing tectonic influence and geological control, which directly aligns with the second research aim of comparing regional morphostructural characteristics. Together, these areal parameters and visual data synthesize a comprehensive understanding of the basin's form, function, and flood-related dynamics, addressing all three core research questions through both numerical and spatial perspectives.

4.3. Relief

The Koya basin exhibits a total basin relief of 1185 m, derived from a maximum elevation of 1455 m and a minimum of 270 m, as detailed in the (Table.4). This results in a relief ratio of 0.01 and a relative relief ratio of 0.01, indicating moderate overall steepness. The dissection index is 0.81, showing high levels of terrain dissection, while the ruggedness number is 2.31, reflecting moderately rugged terrain. These parameters collectively define the topographic framework for subsequent hydrologic and geomorphic processes, influencing drainage patterns and runoff dynamics.

Table 4: Summary of drainage basin relief aspect parameters in the study area.

No.	Morphometric Parameters	Result
1	Maximum height (H) (m)	1455 m
2	Minimum height (h) (m)	270 m
3	Total basin relief (Rb)	1185 m
4	Relief Ratio (Rh)	0.01
5	Relative Relief Ratio (Rr)	0.01
6	Absolute relief (Ra), m	1455 m
7	Dissection index (Di)	0.81
8	Ruggedness number (Rn)	2.31

The slope analysis, as illustrated in Fig. 8, reveals a dominance of gentle slopes (10–25°), with 1,123,765 count values, indicating that much of the district is characterized by moderately inclined terrain that promotes both runoff and infiltration. Steeper slopes (>40°) are less common, totaling 78,896 count values; these areas likely contribute to increased surface runoff and erosion potential. The distribution of slopes affects surface runoff and infiltration rates, thereby influencing streamflow dynamics and groundwater recharge.

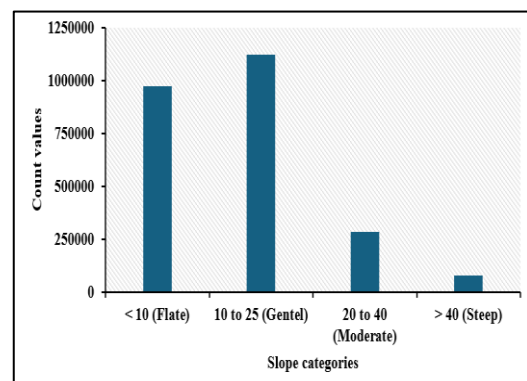


Fig. 8: Histogram showing the slope distribution for the study area.

Topographic slope distribution affects hydrological response, such as variability of streamflow and potential groundwater recharge, directly, as evidenced by work that links topography with the behavior of runoff and aquifer recharge. The distribution of topography can simply be observed on the map of slopes (Fig. 9), which classifies the slopes into five categories. On the map, the dominance of gentle slopes is indicated in green, dominating most of the study area. This prevalence of gentle slopes suggests a landscape of infiltration rather than rapid runoff, resulting in groundwater recharge and reduced flood risk in those green-dominated regions, whereas steeper slopes, colored orange and red, occur in the northern regions.

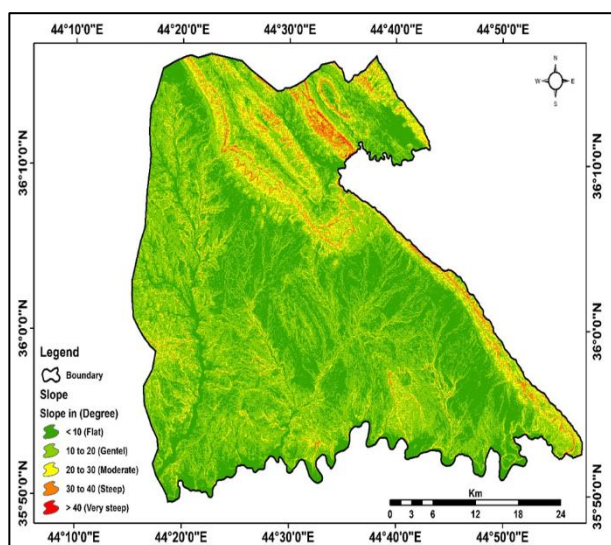


Fig. 9: Slope Map for the study area.

Aspect analysis, as in Fig. 10, indicates a prevalence of southwest-facing slopes (471,267 count values), potentially leading to increased evapotranspiration and reduced soil moisture on these slopes. This directional trend can influence microclimatic conditions, affecting vegetation patterns and, consequently, hydrological processes such as surface runoff and streamflow.

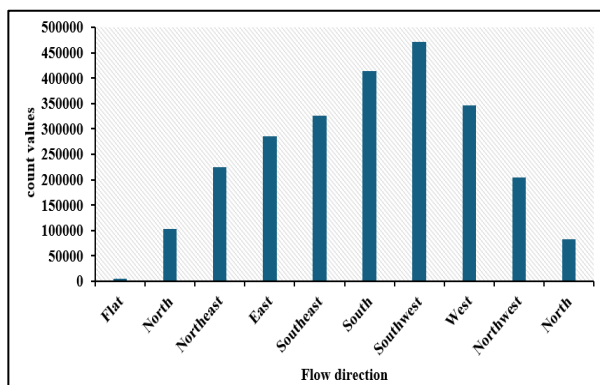


Fig. 10: Histogram showing the slope distribution (Aspect) for the study area.

This is visually supported by the flow direction (aspect) map (Fig.11), which clearly illustrates the spatial distribution and prevalence of southwest-facing slopes throughout the Koya basin. The map's color-coding, with a concentration of yellow indicating southwest-facing aspects, vividly highlights the area's most susceptible areas to direct sunlight. Furthermore, the flow-direction arrows converge along these southwest-facing slopes, suggesting a concentration of surface runoff and a potential for increased erosion in those specific locations.

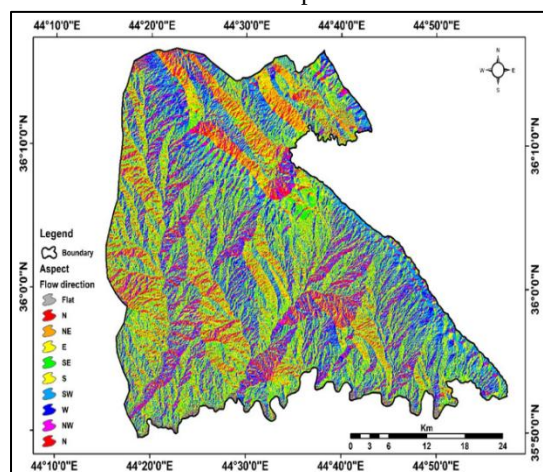


Fig. 11: Flow direction Map of the study area.

The hypsometric analysis shown in Table 5 provides an estimate of the hypsometric integral as 0.47 and hence shows the basin to be at a mature phase of development. The S-shaped hypsometric curve revealed in Fig. 12 represents an environment where the middle elevations have the largest contribution to the area of the basin. A shape of this type represents dynamic equilibrium between erosional and depositional activity, with moderate transport and sediment yield in the basin. This affects long-term water resources availability and control within the basin because a well-balanced sediment regime is vital to maintaining water quality and reservoir capacity.

Table 5: Summary of drainage basin areal aspects parameters in the study area

Value	Area (km ²)	Min	Max	Range	Mean	Mean-Min	H-integral	accumulation area (a)	a/A	h	h/H
1	172.58	270	388	118	349.48	79.48	0.67	1912.56	1.00	118.00	0.10
2	483.44	389	507	118	454.86	65.86	0.56	1739.98	0.91	236.00	0.20
3	570.42	508	625	117	563.83	55.83	0.48	1256.54	0.66	353.00	0.30
4	270.91	626	744	118	675.88	49.88	0.42	686.12	0.36	471.00	0.40
5	159.59	745	862	117	800.70	55.70	0.48	415.21	0.22	588.00	0.50
6	118.53	863	981	118	919.60	56.60	0.48	255.62	0.13	706.00	0.60
7	84.21	982	1099	117	1035.93	53.93	0.46	137.09	0.07	823.00	0.70
8	39.22	1100	1218	118	1147.02	47.02	0.40	52.88	0.03	941.00	0.80
9	10.92	1219	1336	117	1268.12	49.12	0.42	13.67	0.01	1058.0	0.90
10	2.75	1337	1455	118	1374.37	37.37	0.32	2.75	0.00	1176.0	1.00

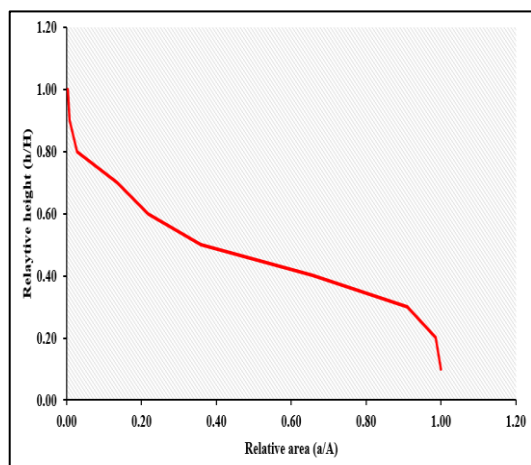


Fig. 12. Hypsometric Curve.

5. Conclusion and Discussion

The hydromorphometric analysis of the Koya basin reveals a landscape shaped by structural controls and climatic dynamics. The basin's elongated geometry (form factor = 0.21) and sixth-order drainage network, dominated by first-order streams, reflect a balance between erosional processes and tectonic influences, as evidenced by high bifurcation ratios ($R_b = 5.13$) and lineament density in the northern regions. Moderate drainage density (1.95 km^{-1}) and elevated infiltration numbers ($I_f = 4.31$) indicate susceptibility to rapid runoff, particularly on steep, southwest-facing slopes where erosion and evaporation are pronounced. A comparative assessment aligns Koya's hydromorphometry with tectonically active basins in Erbil and Kirkuk, yet its unique relief (1,185 m) and dissection index (0.81) distinguish it as a mature but dissected terrain.

These findings underscore the need for integrated water management strategies. Prioritizing afforestation in high-density drainage zones, constructing erosion-control structures in rugged northern areas, and promoting infiltration practices in permeable southern regions can mitigate flood risks and enhance groundwater sustainability. The study establishes a foundational framework for basin-scale hydro-morphometric analysis in semi-arid regions, bridging critical gaps in the existing literature. Future work should integrate hydrological modelling and field validation to

refine flood hazard mapping and optimize resource allocation in Koya's complex terrain.

6. Acknowledgements

We would like to extend our heartfelt thanks to the Department of Earth Sciences and Petroleum at Salahaddin University, whose support and guidance were invaluable throughout the course of this research. This work would not have been possible without the valuable insights and encouragement provided by our colleagues and academic mentors

7. Conflict Of Interest

We declare that there is no conflict of interest regarding the conduct or publication of this research.

8. Funding Statement

This research received no external funding.

9. Author Contributions

Ala Qader: Conducted the research, processed and analyzed the ALOS PALSAR DEM data using GIS techniques, delineated the drainage basin and stream network, calculated the linear, areal, and relief morphometric parameters, prepared the maps, figures, and tables, interpreted the results, and prepared and wrote the manuscript.

Shwan Seeyan: Supervised the research, provided scientific guidance throughout the study, contributed to the interpretation and discussion of the results, and reviewed and revised the manuscript.

Both authors contributed to the final review and approval of the manuscript.

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التحليل الهيدرومورفومتري لحوض كويا في إقليم كردستان العراق

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تاريخ الاستلام: 23 أيار 2025 تاريخ المراجعة: 29 تموز 2025 تاريخ القبول: 15 تشرين الأول 2025

تاريخ النشر الإلكتروني: 01 تشرين الأول 2026

المخلص

تجري هذه الدراسة تحليلًا هيدرومورفومتريًا شاملاً لحوض كويه، إقليم كردستان العراق باستخدام بيانات ALOS PALSAR DEM والتقنيات القائمة على نظم المعلومات الجغرافية لتقييم معالم الارتفاع والخطية والمساحية. يتميز الحوض الممدود (عامل الشكل = 0.21) بشبكة تصريف من الدرجة السادسة تهيمن عليها جداول الرتبة الأولى، مع نسبة تشعب عالية (متوسط $R_b = 5.13$) تشير إلى تحكم التركيبية في أنماط الصرف. تعكس كثافة الصرف المعتدلة (1.95 كم⁻¹) ورقم التسلسل (4.31) معامل ارتشاح متوازناً ولكن إمكانات الجريان السطحي المرتفعة، بينما تؤكد التضاريس الوعرة (درجة الوعرة = 2.31) والتضاريس الكبيرة (1.85 متر) التعقيد الطبوغرافي. يكشف التحليل المقارن عن أوجه تشابه مع الأحواض المتأثرة تكتونيا في أربيل وكركوك، على الرغم من أن تكامل قياس الارتفاع في كويا (0.47) ومؤشر قياس درجة خشونة سطح الأرض (0.81) يشيران إلى مشهد ناضج ولكنه يتطور ديناميكياً. تحدد درجة ميل واتجاه الميل للاراضي والجوانب المنحدرات المواجهة للجنوب الغربي كنقاط ساخنة للتعرية وتقليل الاحتفاظ برطوبة التربة. تسلط النتائج الضوء على التفاعل بين الجيومورفولوجيا والهيدرولوجيا، مع التأكيد على أن هندسة الحوض الممدود تخفف من شدة الفيضانات، في حين أن المناطق ذات كثافة التصريف العالية تتطلب إدارة مستهدفة. تقدم هذه الدراسة أول تقييم هيدرومورفومتري على مستوى المنطقة لحوض كويه، وتقدم رؤية مهمة لصانعي السياسات لتحسين إدارة الأحواض المائية، وإعطاء الأولوية للتخفيف من حدة الفيضانات في المناطق النشطة تكتونيا، وتعزيز استراتيجيات إعادة تغذية المياه الجوفية في البيئات شبه القاحلة.

الكلمات المفتاحية:

قياس الهيدرومورفوميات، المنطقة شبه القاحلة، تغذية المياه الجوفية، إدارة موارد المياه الجوفية.

DOI: [10.33899/injes.v26i4.56166](https://doi.org/10.33899/injes.v26i4.56166), ©Authors, 2026, College of Science, University of Mosul.This is an open-access article under the CC BY 4.0 license (<http://creativecommons.org/licenses/by/4.0/>)