Coğrafiya elmləri / Geographical Sciences

MORPHOMETRIC INDICATORS OF RIVERS IN NORTHEASTERN AZERBAIJAN: COMPARATIVE ANALYSIS OF CLASSICAL AND MODERN METHODS

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Keywords: *Morphometric analysis; river basins; R.X. Piriyev school; GIS; DEM; drainage network; relief dissection*

Abstract. This study presents a comparative analysis of the morphometric characteristics of river basins in Northeastern Azerbaijan based on both classical approaches and modern digital methodologies. The theoretical foundation relies on the principles of the R.X.Piriyev morphometric school, which provides a systematic framework for assessing basin forms and drainage network structure. In the contemporary stage, Digital Elevation Models (DEM), satellite imagery, and Geographic Information Systems (GIS) were applied to determine basin shape indices, drainage density, and relief dissection parameters with higher precision. The comparative evaluation indicates that while classical methods effectively identify general morphodynamic tendencies, GIS/DEM-based analyses significantly enhance the quantitative accuracy of morphometric parameters, allowing for a more objective interpretation of geomorphological development stages.

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Introduction

The northeastern region of Azerbaijan is one of the areas characterized by a complex geomorphological structure, diverse surface processes, and an intensive hydrographic network. The formation of river systems in this territory is closely linked to the degree of relief dissection, lithological and geological conditions, climatic factors, and anthropogenic influences. The morphometric indicators of river basins serve as key parameters for determining the structure of the hydrographic network, the shape of the basin area, drainage intensity, and the dynamic stages of relief development. Analyzing these indicators holds significant scientific value in identifying the erosion potential of basins, distribution of water resources, landscape dynamics, and directions of geomorphological evolution (Eminov et al., 2022; Mardanov & Eldarov, 2018; Xəlilov, 2024; Əliyev et al., 2018).

Morphometric studies hold a special place in the development of the Azerbaijani scientific geography school, and R.X. Piriyev laid the methodological foundations for classical approaches in this field. The Piriyev school established a systematic scientific basis for classifying basin forms, determining the structural laws of drainage networks, assessing basin asymmetry, and studying the morphostructural characteristics of the relief. However, in recent decades, the extensive application of Digital Elevation Models (DEM), satellite imagery, and GIS-based spatial analyses has enabled a more precise, quantitatively refined, and dynamic assessment of morphometric indicators. In this context, the study of morphometric parameters in river basins of Northeastern Azerbaijan is of particular relevance, both for continuing the scientific legacy of the classical geographical school and for the comparative evaluation of results derived from modern digital methods. When the outcomes of classical approaches are compared with modern GIS- and DEM-based morphometric analyses, it becomes possible to identify not only methodological differences but also the morphodynamic development trends of basins more objectively. This not only aids in explaining the evolution of hydrographic systems but also has practical implications for water resource management, erosion risk modeling, and landscape ecological planning in the region.

Study area

The selected study area lies between 40°46′ and 41°51′ N latitude and 47°52′ and 49°24′ E longitude. Due to the complex orographic structure of Northeastern Azerbaijan, the river

network predominantly develops from the Main Watershed Range and the Fore-Caucasus Ridge in the direction of the Caspian Sea. The modern fluvial system of the region encompasses a series of river basins extending from the Samur River to the Tuğçay River. During the research, key rivers such as Qusarçay, Qudyalçay, Qaraçay, Ataçay, Şabrançay, Vəlvəlaçay, Dəvəçiçay, Gilgilçay, Tuğçay, Quruçay, and Çiğəcuqçay were selected for detailed investigation. The formation of these rivers and the characteristics of their drainage density are closely linked to active modern tectonic movements, climatic conditions, and the degree of relief dissection observed in the region (Quliyev, n.d.; Əliyev et al., 2018). Geomorphological studies conducted across the area indicate that the current river valleys have evolved along the traces of ancient fluvial systems, continuing their development upon older geomorphic frameworks.

Methodology

To align the study of the area with the article's aims and objectives, the research employed both classical and modern methodological approaches. It is essential to note that the views of N.V. Dumichenko and B.Ə significantly influenced the selection of methods, as Budagov identified ancient river valleys as critical indicators in understanding the region's hydromorphological evolution. Additionally, the presence of tectonic imprints preserved in the cross-sectional structures of contemporary valleys, the ongoing active development of relief, and the role of lithological composition, climatic conditions, vegetation cover, and geomorphological processes in shaping the hydrographic network were all pivotal factors guiding methodological choices (Mahmudov et al., n.d.; Schumm, 1956; İmanov & Məhərrəmova, n.d.).

Classical methods

The classical methods referenced in this study are drawn from the foundational work of R.X. Piriyev, whose methodological principles have been selectively applied in accordance with the research objectives. As part of the classical approach, various-scale topographic maps (particularly at 1:100,000) and geological maps (at a scale of 1:500,000) were employed. The classical analysis employed the measurement procedures and basin-shape formulas described by Piriyev (1958, 1986), including methods attributed to Volkov and Apollov. In H.M. Volkov's proposed method, two topographic maps with similar scales are selected. Using a compass with fixed needle points, measurements are taken along the designated river courses. Based on these measurements, the total river valley length is calculated using the following formula:

$$l_{np} = l_1 + (l_2 - l_1)k;\ \ k = \frac{\sqrt{d_1}}{\sqrt{d_2}-\sqrt{d_1}} \quad (1)$$

Where:

l_{np} – length of the curved line on the selected map,

l_1 – segment length d_1 measured from the smaller-scale map,

l_2 – segment length d_2 measured from the larger-scale map,

k – coefficient depending on the opening span of the compass.

In his research, R.X. Piriyev also employed A. Apollov's formula to calculate the basin form coefficient, also known as the compactness ratio (Piriyev, 1958). This coefficient is relatively simple and is determined by dividing the basin area (F) by the area of a square whose side is equal to the basin length (l^2), expressed as:

$$G = \frac{F}{l^2} \quad (2)$$

To determine the linear morphometric characteristics of river basins, parameters such as the circularity index, elongation ratio, curvature coefficient, and drainage density were also calculated. The Circularity Index (CI) is used to evaluate how closely the shape of a river basin approaches that of a circle. In hydrological studies, this index plays a significant role as a morphometric indicator of basin form and is crucial in analyzing watershed geometry.

$$CI = \frac{4\pi \times A}{P^2} \quad (3)$$

Where:

- A— basin area (km² or m²),
- P — basin perimeter (km or m),
- π— the mathematical constant 3.1416.

The stream length ratio is a key morphometric indicator that represents the total or individual lengths of streams of different orders (e.g., first-order, second-order, etc.) within the drainage network.

Drainage density (Dd) is one of the primary indicators used in hydrographic studies to characterize the hydromorphometric properties of a basin. This coefficient reflects the extent to which watercourses are concentrated within the basin area and is employed in analyzing erosion potential, water balance, and the degree of relief development.

$$Dd = \frac{L_{total}}{A} \quad (4)$$

Where:

- Dd— Drainage density (km/km²),
- L_{total}— total length of all rivers in the basin (km),
- A — basin area (km²).

Modern methods

In conducting the study using modern methodologies, the ArcGIS 10.4.1 software package was employed, along with the D8 method—an 8-step flow model based on GIS— and the Strahler stream order method. The data source was a Digital Elevation Model (DEM) with a spatial resolution of 20 × 20 meters, a linear unit of 1 meter, formatted as FGDBR, based on the WGS-84 coordinate system, and located within UTM Zone 39N. The D8 (Deterministic 8) method is a flow direction algorithm used in DEMs, where water from each pixel is assumed to flow in only one of eight possible directions. It is both deterministic (yielding consistent results for identical inputs) and convergent, meaning water from each pixel flows toward a single neighboring cell, merging with others but not diverging. The Strahler method (Horton–Strahler stream order system) is a hierarchical classification system that numerically defines the branching complexity of river networks. Initially proposed by R.E. Horton in 1945 and later refined by A.N. Strahler in 1952, this system has become a standard method in geomorphology for assessing the complexity of drainage networks. Despite being introduced in the 1950s, modern GIS-supported research methodologies and software applications still rely on this approach for processing and analyzing hydrological networks. In addition to parameters used in classical methods (3) and (4), the following morphometric indicators were also calculated during the application of modern methods.

Form factor (F)—a morphometric indicator expressing the elongation or circularity of the drainage basin. This factor is crucial in assessing hydrological properties, including flood potential, flow velocity, and the basin's response rate.

$$F = \frac{A}{L^2} \quad (5)$$

Where:

- F— Form factor,
- A— basin area (km²),
- L — maximum length of the basin (linear distance from source to mouth, km).

Stream Frequency (Fs) — refers to the ratio of the number of stream segments within a drainage basin to the basin area. This coefficient reflects the density and structural organization of the stream network, serving as a significant indicator of the degree of terrain dissection, hydrological flow velocity, and erosion tendencies.

$$Fs = \frac{N}{A} \quad (6)$$

Where:

- Fs— stream frequency, units/km²,
- N— total number of rivers (including all grades),
- A — basin area (km²).

Results and discussion

This subsection compares the results obtained through classical methods by R.X. Piriyev in 1958 with modern GIS- and DEM-based analyses. In the classical research conducted in 1958, the morphometric parameters of rivers in Northeastern Azerbaijan were determined based on analogous topographic maps and field observations (Piriyev, 1958). In the present study, these indicators were recalculated using modern GIS technologies and Digital Elevation Models (DEM). As a result of applying modern methods, additional morphometric parameters were calculated, yielding differing results in specific indicators. These differences are attributed to both the precision of the source data and the use of automated calculation methods.

Classical research results. The rivers of Northeastern Azerbaijan originate from the northern foothills of the Greater Caucasus mountain range and flow directly into the Caspian Sea. R.X. Piriyev established that the development level of the river network (across the entire massif) largely depends on its longitudinal gradient toward the Caspian. According to Piriyev (1958), approximately 1,246 rivers, including tributaries, were identified within the study area using a topographic map at a scale of 1:100,000. In the investigated part of Northeastern Azerbaijan, the average drainage density is 0.54 km/km² (determined based on measurements from a 1:100000 scale map). However, this density is not evenly distributed across the region. Compared to the southeastern, northwestern directions and the Caspian coastal lowlands, drainage density is significantly higher in mountainous areas. These features are explained by the influence of complex geomorphological factors shaped by the region's evolution of relief processes. In the river network of Northeastern Azerbaijan, especially in zones close to the Caspian coast, the rivers exhibit steep gradients and intense flow velocities. A key morphometric feature in this area is the development of deep erosion valleys within riverbeds. In the middle reaches, river valleys are represented by narrower morphological forms,

and in some areas, conical depressions and knolls are observed. These geomorphological elements can be interpreted as consequences of megarelief changes that occurred in the region's geological past. In such areas, climatic factors—especially high evaporation—necessitate the use of river water for irrigation purposes. In the lower course, the hydrographic and morphological characteristics of the rivers undergo significant changes. In this zone, rivers lose their stable channel forms and, flowing through alluvial depressions, break into multiple branches, moving in shallow, braided channels (Həsənov, 2015). In some cases, they undergo bifurcation and form branched systems. The low slope and weak energy potential of the terrain prevent the sediment transported from the upper reaches from settling along the channel, resulting in the dispersal of these materials across alluvial areas with minimal flow. This morphodynamic situation complicates the precise delineation of river basin boundaries. The shape of the river basin, being one of its geometric parameters, influences the seasonal distribution of runoff. For example, in elongated river basins, snow and rain floods persist for longer periods. Therefore, such basins tend to have higher relative flood volumes. In contrast, circular basins experience snow and rain floods over shorter durations. Thus, the shape of river basins is a morphometric parameter of hydrological significance. The rivers of Northeastern Azerbaijan are located around the Caspian Sea, between the main watershed and the lateral ridge. Due to the terrain slope in this region, a series of closely spaced parallel river systems has formed. These basins are predominantly elongated. However, elongation is not uniform across all rivers. The basins of rivers originating from the lateral ridge and flowing northeast of the Devechi River (e.g., Quruçay, Ataçay) are very narrow and elongated. The basins of rivers originating from the main watershed and intersecting the lateral ridge in their upper courses are also narrow and elongated. The basins of rivers flowing southeast of the Devechi River (e.g., Qudyalçay, Devechiçay, Tuğçay) display more complex configurations in their middle and lower reaches (Piriyev, 1958, 1986). According to Table 1, R.X. Piriyev determined that basins such as Qudyalçay, Qaraçay, and Vəlvələçay are morphometrically well-developed, expansive, and possess complex structures. At the same time, Ataçay, Türyançay, and Dəvəçiçay have simpler, elongated forms with lower compactness. He also highlighted the existence of a significant correlation between the compactness coefficient and the area and shape of the basin, noting that these parameters are of major importance for river flow, erosion power, channel formation, and water resource planning. The highest elongation ratio belongs to Qudyalçay (1.77), indicating a more elongated basin shape. In other rivers, this ratio ranges between 1.42 and 1.59, showing that they have relatively oval and compact basins. The lowest elongation ratios were observed in Qaraçay and Ataçay (1.42 and 1.49). Regarding the sinuosity coefficient, the highest values are recorded in Tuğçay (2.35) and Quruçay (2.00), indicating that these basins have a more dissected relief, i.e., a more contorted and rugged structure. Rivers with sinuosity coefficients near 2.00—such as Dəvəçiçay, Qaraçay, Ataçay, and Quruçay—have also developed under complex relief conditions. The lowest sinuosity coefficient was found in Qudyalçay (1.49), indicating that it lies in relatively smoother terrain. As for drainage density, Qudyalçay, with a value of 0.50 km²/km², possesses the densest network, indicating a well-developed and closely spaced drainage system. The lowest density values were recorded in Vəlvələçay, Ataçay, and Quruçay (0.39 km/km²), which may indicate a less developed drainage network or a predominance of infiltration processes in those basins.

Table 1

Morphometric coefficients of river basins according to the research of R.Kh. Piriyev

№	Rivers	Basin area, km²	River length, km	Number of rivers	Basin length, km	Basin Width, km	Perimeter, km	Circularity Index	Elongation ratio	Sinuosity Index	Drainage density, km/km²
1	Qusarçay	879.6	382.6	93	60.0	25.5	223.5	0.26	1.59	1.59	0.43
2	Qudyalçay	776.0	389.5	82	52.5	25.0	216.0	0.26	1.77	1.49	0.50
3	Qaraçay	770.6	310.5	76	50.0	23.5	200.0	0.28	1.42	1.92	0.40
4	Vəlvələçay	914.5	378.0	90	55.0	25.0	210.0	0.27	1.49	1.92	0.41
5	Şabrançay	884.8	348.5	85	53.0	24.5	205.0	0.27	1.58	1.92	0.39
6	Dəvəçiçay	781.5	330.5	83	50.0	23.5	195.0	0.28	1.52	2.00	0.42
7	Qaraqaçay	726.0	308.0	80	48.0	22.5	188.0	0.29	1.50	2.05	0.42

№	Rivers	Basin area, km²	River length, km	Number of rivers	Basin length, km	Basin Width, km	Perimeter, km	Circularity Index	Elongation ratio	Sinuosity Index	Drainage density, km/km²
8	Ataçay	724.5	298.0	78	47.0	22.0	185.0	0.30	1.49	2.20	0.41
9	Quruçay	783.0	305.0	85	49.0	23.0	192.0	0.28	1.52	2.00	0.39
10	Tuğçay	690.0	275.0	75	44.0	20.5	175.0	0.32	1.46	2.35	0.39

Overall, the morphometric indicators reveal that the Qudyalchay and Qusarchay basins possess more developed river networks and morphologically dynamic catchments. In contrast, basins such as Quruchay and Tughchay have evolved under more complex relief conditions but can be assessed as relatively weakly drained areas. When R.X. Piriyev compared the compactness coefficients of the studied river basins with their other morphometric features, he observed that this coefficient provides critical insights into the shapes of the river basins (Piriyev, 1958). For instance, in basins starting from Qusarchay, the value of this coefficient, for example, Qusarchay – 0.06, and for the basins from Velvelachay to Turyanchay, ranges between 0.12 and 0.26. He identified that the lowest G coefficient values were observed in the Qusarchay, Atachay, and Qarachay basins (0.06), while the highest value was recorded in the Devechichay basin (0.24). A comparison between the compactness coefficients and the mean basin width suggests a specific correlation between them. Specifically, the minimum and maximum values of both coefficients appear to correspond with each other. The G coefficient reflects the extent to which a basin has reached compact morphological development. The larger the compactness coefficient, the greater the frequency and flatness of short-term floods in the river will be (Piriyev, 1986; Strahler, 1957).

Modern research results

In previous studies of the morphometric characteristics of rivers in Northeastern Azerbaijan, primary attention was focused solely on the general hydrographic structure and geographical location of the rivers. However, indicators such as slope, aspect (exposure) characteristics, and the overall morphometric parameters of the basins (form factor, length-to-width ratio, compactness coefficient, etc.) were not systematically analyzed. Consequently, earlier works lacked comprehensive scientific conclusions regarding the interactions between the river network and the relief, the morpho-hydrological dynamics, and their relationships with the landscape. In recent years, the use of Geographic Information Systems (GIS), Digital Elevation Models (DEM), and high-resolution topographic data has enabled the accurate calculation and visualization of slope, aspect, and spatial morphometric parameters of river basins by subdividing the area into sub-basins. Through these methods, the analysis of the geomorphological and hydrological structure of the region has entered a new stage, enabling a more objective evaluation of the development patterns of river basins and their relationship with the relief. Thus, modern research approaches have enabled multidimensional and complex analyses of river basins.

In Figure 1, slope degrees are classified into five categories: very gently sloping (0–5.51°), gently sloping (5.52–14.5°), moderately sloping (14.6–24.1°), steeply sloping (24.2–37.5°), and very steeply sloping (37.6–87.8°). Based on color coding, areas shaded in green represent very gentle and gentle slopes encompassing plains and foothill zones. In contrast, yellow and orange shades indicate moderate and steep slopes, and red areas depict very steep slopes. The map reveals that the most widely distributed categories within the study area are gentle and moderately sloping terrains. In the flat and low-relief regions (particularly along the Caspian Sea coast), slopes generally range between 5–15°, while in foothill areas, moderately sloping terrains of 15–25° dominate. In mountainous highlands, slopes are mostly steeper than 25°, with localized areas exceeding 37°, which aligns with Azerbaijan's typical orographic structure. For example, an analysis of the Vilashchay basin showed that approximately 22.5% of the area falls within the 0–10° range, 40% within 10–20°, 26% within 20–30°, and slopes steeper than 30° constitute only around 12% of the area (Mammadbeyov & Guliyeva, 2018). The spatial distribution of slope classes across the study area is also noteworthy. The mountainous region (western and northwestern parts of the map) primarily comprises steep and very steep slopes where inclines exceed 20–30°, forming a complex topography dissected by deep ravines.

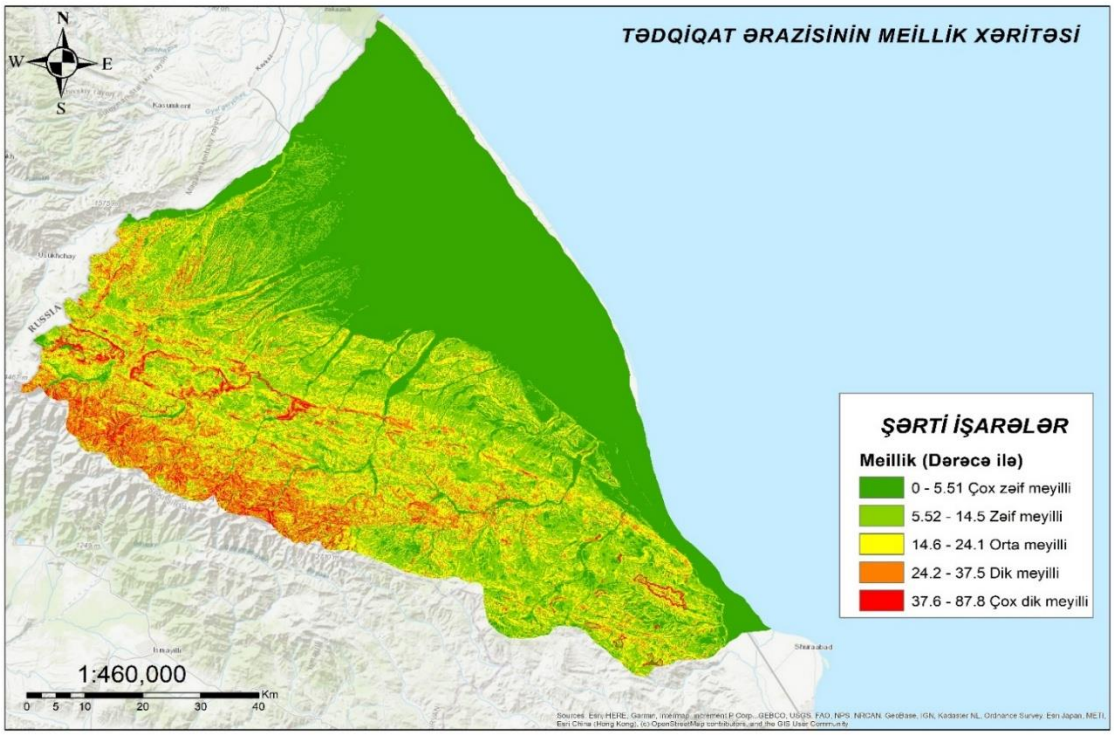


Fig. 1. Slope map of the study area. (Legend: Slope (in Degrees); 0 – 5.51: Very low slope; 5.52 – 14.5: Low slope; 14.6 – 24.1: Moderate slope; 24.2 – 37.5: Steep slope; 37.6 – 87.8: Very steep slope)

In foothill zones, slopes range from moderate to somewhat steep (approximately 10–25°), forming regular terrain steps between mountain masses and plains. In the flatlands, slopes are very gentle (mainly <5°), resulting in a nearly horizontal relief. In the study area, steep slopes (greater than 24°) are the most erosion- and landslide-prone zones. Surface runoff from such slopes rapidly erodes the bedrock, forming deep gullies and debris channels, which in turn reduces slope stability. Particularly, slopes exceeding 37° can be regarded as zones of high geodynamic instability, frequently subjected to rockfall and gravel washouts. This conclusion is supported by scientific literature, which indicates that increasing the slope angle heightens landslide risk and intensifies erosion processes. That is, sloped areas (especially above 15–20°) are more vulnerable to natural disasters compared to plains [6,7]. Slope gradient is a crucial factor in the hydrological cycle, directly affecting stream network density and the volume of surface runoff. Generally, on steep slopes, rainfall infiltrates the soil less and instead flows rapidly as surface runoff, whereas in gently sloping areas, infiltration increases and runoff slows down (UBC Geography Project, 2018). The effect of slope on runoff intensity can also be quantitatively explained using the LS-factor (the product of slope length and steepness). The longer and steeper a slope, the greater the concentration power of surface flow and the higher its erosion potential. Therefore, in mountainous areas, even short-term torrential rains can lead to significant flooding events, while in plains, prolonged intense rainfall is necessary to generate substantial surface runoff. According to climatic data for the study area, on mountainous slopes, a portion of precipitation quickly converts to surface runoff, resulting in 70–75% of the annual river discharge occurring during spring and autumn rains. In contrast, during winter, precipitation remains as snow, reducing runoff (İsmayılov, 2020). Deep and narrow ravines and V-shaped valleys observed in the mountainous parts of the study area are a result of this process. When slopes are steep, water energy is high, quickly carving channels by eroding rock and soil layers. Consequently, slope gradient determines several key aspects of hydrology: flow velocity, stream network density, runoff regime, and even the amount of sediment transported through water erosion are closely related to slope steepness. Considering this factor, cartographic analysis can be utilized in water resource management and flood risk mitigation. The slope map plays a fundamental role in modeling flood and debris flow hazards by indicating which zones within river basins are more prone to generating runoff and are actively eroding.

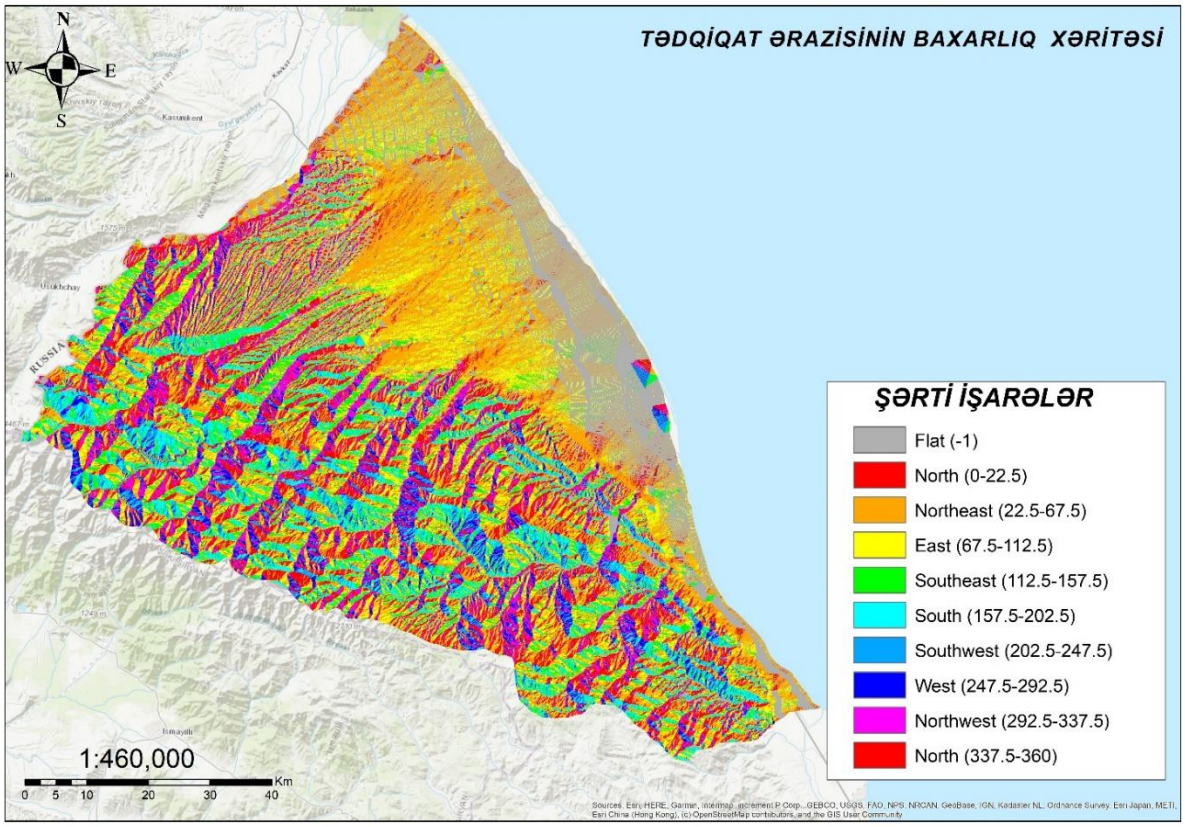


Fig. 2. Aspect map of the study area

The aspect map, which displays the geographical orientation of slopes, serves as an essential tool for understanding the general geomorphological characteristics and microclimatic conditions of a given area. Such a map is generated using a Digital Elevation Model (DEM) through GIS software. Aspect analysis provides valuable insights into relief asymmetry, the intensity of slope-related processes, and the ecological status of landscapes (İmrani & Yusifova, 2018). Based on the aspect map, slopes are classified according to primary geographical directions (north, northeast, east, southeast, south, southwest, west, northwest), and the percentage of area occupied by each aspect category is calculated.

Calculations conducted within the study area indicate that the majority of slopes are oriented towards the southern sector. In other words, sun-facing slopes predominate—these slopes account for approximately 87–88% of the total area. Conversely, slopes with northern exposure (i.e., shaded slopes) constitute only about 12–13% of the area. These figures indicate an uneven distribution of slope aspects across the region, with a clear dominance of one directional orientation. A more detailed classification reveals that southeast- and southwest-facing slopes are the most widespread subcategories, as they encompass both eastern and western components of sun-exposed slopes, covering the majority of the area. Northeast- and northwest-facing slopes are relatively less common.

To visualize this distribution, a table can be created showing the percentage area for each aspect direction. Additionally, a rose diagram can be constructed to present the areal distribution of slope aspects clearly. Overall, such classification reveals the “preferred orientation” of the terrain and aids in understanding the spatial distribution of geomorphological processes and climatic influences.

Morphometric-cartographic analysis of the aspect map for the study area reveals that slope aspect influences a wide range of domains, from the structural configuration of relief and the state of ecosystems to hydrological regimes and the spatial organization of human activity. The analysis has revealed the dominance of slopes in specific orientations, which is attributed to relief asymmetry. A table and diagram depicting the areal distribution of major aspect categories can be prepared to provide a clear explanation of the data. Differences in morphodynamic risks (e.g., erosion, flooding, landslides) were identified by slope aspect, and significant impacts on the hydrological water balance were observed. Moreover, the analysis has substantiated which aspect-oriented areas are more favorable for optimizing anthropogenic activities.

Ultimately, an aspect map developed using modern GIS technologies plays a crucial role in geomorphological studies, landscape planning, and ecological assessments. In summary, aspect analysis helps to decode the "hidden code" of the terrain, bearing significant theoretical and practical importance.

Table 2

Cross-Distribution of Slope and Aspect Categories (in %)

Slope\ Aspect	Flat	North	N-E	East	S-E	South	S-W	West	N-West
Very low (0–5.51°)	2.0	1.4	0.8	1.0	0.8	1.4	0.8	1.0	0.8
Low (5.52–14.5°)	0	2.6	1.5	1.8	1.5	2.6	1.5	1.8	1.5
Moderate (14.6–24.1°)	0	3.5	2.0	2.4	2.0	3.5	2.0	2.4	2.0
Steep (24.2–37.5°)	0	5.2	3.1	3.7	3.1	5.2	3.1	3.7	3.1
Very steep (37.6–87.8°)	0	4.3	2.6	3.1	2.6	4.3	2.6	3.1	2.6

In Table 2, the sum of the rows represents the total area share of the corresponding slope class, while the sum of the columns indicates the overall area share of the respective aspect direction.

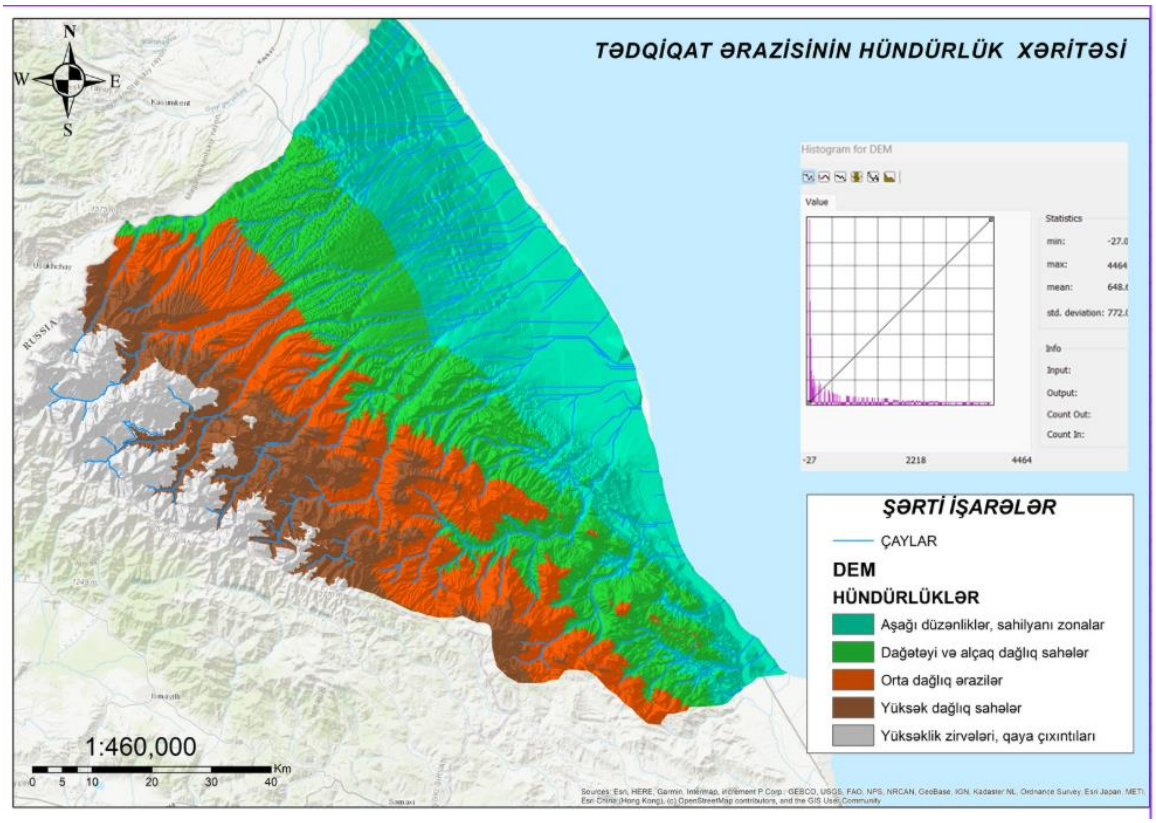


Fig. 3. Elevation map of the study area. (Legend: rivers, DEM elevation (Lowland plains, coastal zones, Foothills and low mountainous areas, Medium elevation mountainous regions, High mountainous areas, Elevation peaks, rocky outcrops))

Based on DEM data (Figure 3), the average elevation of the area is approximately 648.6 meters, indicating that the region is predominantly characterized by foothill and low-mountainous relief. Elevation values range from -27 meters to 4464 meters, reflecting the presence of both below-sea-level coastal zones and high mountain peaks. A high standard deviation of 772.02 meters confirms that the terrain has a diverse and complex structure. Using this data, a histogram of the study area was generated. The hypsometric integral (H_i) of the area is 0.15, which provides significant scientific insights into the degree of topographic development and erosion. A low hypsometric integral value, such as 0.15, typically indicates a well-developed, mature terrain. This suggests that long-term erosional processes have led to a concentration of the terrain's surface at lower elevations. Although elevation differences still exist, large areas are situated at lower altitudes. A low H_i value indicates intense denudation, suggesting that

erosion processes predominate in the landscape (Gojamanov & Azizli, 2024). Such regions are typically characterized by stabilized fluvial dynamic systems resulting from prolonged river erosion. According to Strahler (1952), when H_i is around 0.3, the area is classified as a denudational, mature landform. This implies that tectonic activity is either weak or occurred in earlier geological periods, and current morphodynamic processes are mainly of exogenous origin.

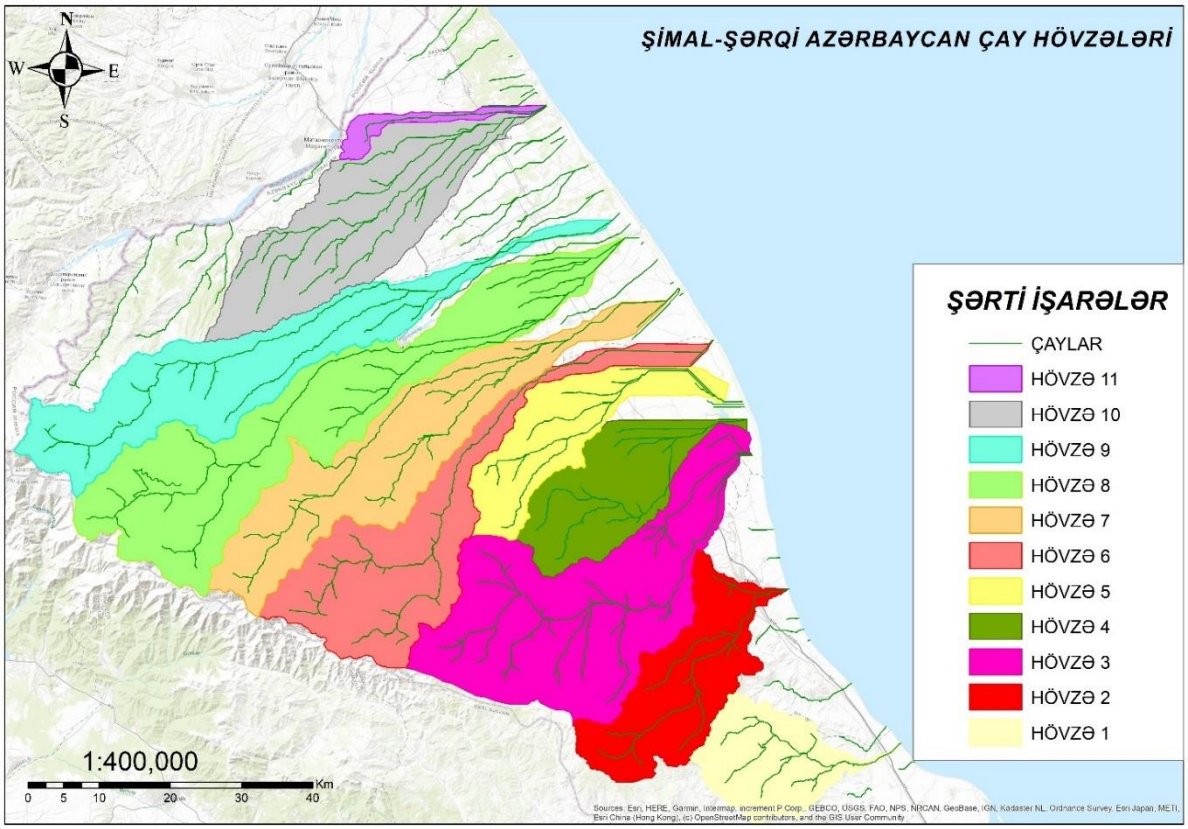


Fig. 4. Hydrographic basin map of the study area. (Legend: rivers and basin №)

An analysis based on the morphometric indicators of river basins in Northeastern Azerbaijan reveals that the hydrological and geomorphological conditions vary significantly from one basin to another. These differences are particularly evident in parameters such as form factor, circularity ratio, stream frequency, and drainage density. These indicators provide valuable information regarding the structural features of the basins' relief, the intensity of erosion processes, and the prevailing hydrological regime.

Table 3

Morphometric coefficients of river basins based on contemporary research

No.	River	Basin ID	Basin area (km²)	Total stream length (km)	Basin length (km)	Form factor	Basin perimeter (km)	Circularity ratio	Number of stream segments	Stream frequency (segments/km²)	Drainage density (km/km²)
1	Qusarçay	9	619.7	218.4	228.7	0.01	228.7	0.15	195	0.31	0.35
2	Qudyalçay	8	874.8	284.6	241.7	0.01	241.7	0.19	68	0.08	0.33
3	Qaraçay	2	380.2	101.0	124.4	0.02	124.4	0.31	52	0.14	0.27
4	Vəlvələçay	6	569.1	149.7	201.2	0.01	201.2	0.18	73	0.13	0.26
5	Şabrançay	5	308.1	119.7	117.6	0.02	117.6	0.28	78	0.25	0.39
6	Dəvəçiçay	4	329.1	105.1	98.3	0.03	98.3	0.43	99	0.30	0.32
7	Ataçay	2	380.2	101.0	124.4	0.02	124.4	0.31	52	0.14	0.27
8	Gilgilçay	3	845.9	233.6	173.9	0.03	173.9	0.35	213	0.25	0.28
9	Tuğçay	1	254.9	75.6	89.8	0.03	89.8	0.40	25	0.10	0.30

No.	River	Basin ID	Basin area (km²)	Total stream length (km)	Basin length (km)	Form factor	Basin perimeter (km)	Circularity ratio	Number of stream segments	Stream frequency (segments/km²)	Drainage density (km/km²)
10	Çiğəcuqçay	7	619.5	205.0	200.2	0.02	200.2	0.19	67	0.11	0.33
11	Quruçay	10	559.1	237.0	139.6	0.03	139.6	0.36	300	0.54	0.42

In most basins, the form factor ranges between 0.01 and 0.04, indicating that they possess an elongated shape. In such elongated basins, precipitation is rapidly directed toward the main flow channel, which increases the risk of flooding. This is particularly critical in the Qusarçay, Qudyalçay, and Çiğəcuqçay basins, where the form factor is as low as 0.01, suggesting a high likelihood of rapid and intense flood events. In terms of circularity ratio, most basins also exhibit non-circular shapes. The lowest circularity ratio is observed in the Qusarçay basin (0.15), while the highest values are found in the Dəvəçiqay (0.43) and Tuğçay (0.40) basins. A low circularity ratio implies increased concentration of water from peripheral zones toward the center of the basin, which can lead to the formation of rapid flows. In such terrains, the centralization of water can result in more abrupt and short-lived floods. Stream frequency values also reveal interesting variations. Basins such as Qusarçay (0.31), Dəvəçiqay (0.30), and Şabrançay (0.25) exhibit high stream frequencies, indicating a well-developed and dense hydrographic network. In contrast, the Qudyalçay basin has a very low value (0.08), which could be attributed to either a sparsely branched stream system or a relatively more straightforward topographic structure. In terms of drainage density, the highest values are recorded in the Şabrançay (0.39 km/km²), Qusarçay (0.35 km/km²), and Dəvəçiçay (0.32 km/km²) basins. This indicates a high degree of relief dissection and surface runoff in these areas. A dense drainage network may also reflect low infiltration capacity and poor permeability of the soil cover.

Comparative analysis of classical and modern research results. The comparative study of morphometric characteristics of river basins, based on both classical and modern research, clearly demonstrates the methodological differences in calculation approaches and the impact of technological advancements in this field. In classical studies, basin areas and river lengths were generally overestimated. For instance, while the Qusarçay basin area was reported as 879.6 km² in classical studies, modern analyses determined this value to be 619.7 km². Similarly, river lengths were also recorded as higher in earlier periods—Qusarçay's length was measured at 382.6 km in classical approaches but was recalculated as 218.4 km in modern assessments. These discrepancies stem from the classical methods' reliance on generalized map materials for defining boundaries and flow lines. In contrast, modern techniques employ satellite imagery and Digital Elevation Models (DEMs) for more precise delineation. In terms of river count, modern studies have yielded higher numbers. This increase is attributed to the inclusion of micro-streams in modern analyses and the use of more refined measurement tools for evaluating the river network. While 93 streams were recorded in Qusarçay in classical studies, this number reached 195 in contemporary research. This increase also influenced stream frequency, with higher stream density and frequency identified in modern evaluations. Differences are also observed in morphometric parameters such as circularity index and form factor. In classical studies, the circularity index ranged between 0.26 and 0.35, whereas in modern research, it was measured between 0.15 and 0.43. These variations can be attributed to the enhanced accuracy of modern methods in capturing relief forms and basin contours. Although the differences in length and curvature coefficients are relatively minor, it is evident that modern calculations more accurately reflect real relief conditions. Regarding drainage density, classical research reported values ranging from 0.39 to 0.50 km/km², while modern measurements fall between 0.26 and 0.42 km/km². This difference is likely due to more accurate area calculations using modern methods and the filtration of secondary flow lines. In conclusion, the comparison highlights that the application of modern technologies has significantly enhanced the accuracy of morphometric analysis, while classical approaches tended to provide generalized and approximate results. This advancement supports more reliable decision-making in the fields of hydrology and geomorphology.

Conclusions

The conducted research has yielded significant scientific results by systematically

analyzing the morphometric characteristics of the river basins in Northeastern Azerbaijan using both classical and modern digital methods.

- The morphometric indicators of river networks—such as area, length, perimeter, form factor, circularity ratio, stream frequency, sinuosity coefficient, and surface smoothness—have served as fundamental parameters for evaluating the morphodynamic structure of the basins and their interaction with the hydrological regime of the terrain, most importantly revealing their potential capacity.
- The findings obtained during the study have demonstrated that morphometric parameters derived through modern digital methods reflect more accurate and localized characteristics compared to classical research results. Analyses conducted using a DEM (Digital Elevation Model)-based approach revealed significant discrepancies in area and length metrics, showing that classical methods tend to overestimate river lengths and basin areas in some cases. These differences can be interpreted as evidence that morphometric modeling using next-generation technologies yields more precise outcomes.
- Indicators related to stream density and flow frequency have confirmed that the development level of the drainage system and the geomorphological structure of the terrain are closely interrelated. In particular, high flow frequency and surface dissection values observed in basins such as Shabranchay, Qusarchay, and Devechichay indicate the occurrence of intensive morphodynamic processes. At the same time, formal indicators such as circularity and form factor have served as valuable sources for assessing the hydrological regime and flood potential of the regions.
- Map-based analyses—including slope, aspect (exposure), and hypsometric structure—have provided a scientific basis not only for understanding the dynamics of river networks but also for the functional classification of the relief, delineation of hydrological risk zones, and guidance of anthropogenic activities. The analysis of elevation belts has shown that modern river networks primarily form in mid- and high-mountain areas, and as the relief simplifies in downstream regions, network intensity decreases.

Thus, the study demonstrated that the comparative analysis of classical and modern methods not only enhances the accuracy of morphometric evaluation but also enables scientifically grounded conclusions about the structure, hydrological function, and geomorphological resilience of river basins. This approach holds practical potential for managing regional water resources, modeling soil erosion, and mitigating environmental risks.

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ŞİMAL-ŞƏRQİ AZƏRBAYCANIN ÇAYLARININ MORFOMETRİK GÖSTƏRİCİLƏRİ: KLASSİK VƏ MÜASİR METODLARIN MÜQAYİSƏLİ TƏHLİLİ

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Xülasə. Məqalədə Şimal-şərqi Azərbaycanın çay hövzələrinin morfometrik göstəriciləri klassik və müasir metodlar əsasında müqayisəli şəkildə təhlil edilir. Tədqiqatın nəzəri bazasını R.X. Piriyyev tərəfindən formalaşdırılmış morfometrik məktəbin prinsipləri təşkil edir. Müasir mərhələdə isə rəqəmsal yüksəklik modelləri (DEM), kosmik təsvirlər və Coğrafi İnformasiya Sistemləri (GIS) texnologiyaları tətbiq edilərək drenaj şəbəkəsinin quruluşu, hövzə forması və relyefin xətti,sahəvi, forma və hipsometrik göstəriciləri yüksək dəqiqliklə qiymətləndirilmişdir. Alınmış nəticələr göstərir ki, klassik üsullarla əldə olunan göstəricilər ümumi morfodinamik meyilləri müəyyən etməyə imkan versə də, müasir rəqəmsal analizlər morfometrik parametrlərin kəmiyyət dəqiqliyini artırır və hövzələrin inkişaf mərhələlərinin daha obyektiv interpretasiyasını təmin edir.

Açar sözlər: *Morfometrik təhlil; çay hövzələri; R.X. Piriyev məktəbi; CİS; DEM; drenaj şəbəkəsi; relyef parçalanması*

Cite this article as (APA 7):
Azizli, N. (2026). Morphometric indicators of rivers in northeastern Azerbaijan: Comparative analysis of classical and modern methods. *Geography and Natural Resources, 12*(1), 108–119. https://doi.org/10.5281/zenodo.24100448