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Morphometric analysis of drainage basins in the Carpathian mountain range using GIS

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Abstract

Mountain drainage basins are among the most sensitive geomorphic units on the planet, and their shape, size, and internal network geometry carry direct information about tectonic setting, lithology, and climate history. This research performed a morphometric analysis of 28 drainage basins in the Romanian sector of the Carpathian Mountain Range using GIS-based methods. SRTM digital elevation data (30 m resolution) were processed in ArcGIS 10.8 to extract linear, areal, and relief parameters. Stream ordering followed the Strahler system, and basins ranged from third to sixth order. Bifurcation ratios fell between 2.91 and 5.37, indicating moderate to strong structural control. Drainage density varied from 1.04 to 3.21 km/km², with higher values in areas underlain by impermeable flysch lithologies. Circularity ratios ranged from 0.28 to 0.67, suggesting elongated to semi-circular basin shapes. Relief ratios and ruggedness numbers were highest along the eastern Carpathian arc where recent tectonic uplift is best documented. A negative correlation ($r = -0.68$) between basin area and drainage density confirmed that larger basins tend to have coarser channel networks. These morphometric signatures offer a rapid screening tool for flood susceptibility and erosion hazard mapping in mountain environments.

Keywords: Morphometric analysis, drainage basin, GIS, watershed, mountain geomorphology, stream order, bifurcation ratio, drainage density, carpathian range, relief parameters

Introduction

Drainage basin morphometry is the quantitative measurement of landscape geometry, and it remains one of the most accessible entry points into understanding how rivers, slopes, and divides interact over geological time ^[1]. Since Horton first formalised the laws of drainage composition in the 1940s, hundreds of investigations worldwide have applied morphometric indices to rank basin maturity, predict flood response, and infer tectonic influence ^[2, 3]. The approach is especially powerful in mountain regions, where steep gradients and variable lithology produce a wide spread of index values across short distances.

The Carpathian Mountains form a 1,500 km arc across central and eastern Europe, passing through Romania, Ukraine, Poland, Slovakia, and the Czech Republic ^[4]. The Romanian Carpathians alone contain more than 60 major river basins draining toward the Danube and Black Sea. Despite this, basin-scale morphometric comparisons across the range have been surprisingly few. Most published work has focused on individual catchments or on single morphometric parameters such as hypsometry ^[5, 6].

GIS technology and freely available digital elevation models have removed the main barriers that once limited morphometric research to field-surveyed topographic sheets ^[7]. Automated stream extraction, basin delineation, and parameter calculation can now be completed in hours rather than months. That said, the reliability of results still depends on DEM resolution, flow-routing algorithms, and threshold choices for channel initiation ^[8].

This research aimed to (a) extract and compare linear, areal, and relief morphometric parameters for 28 Carpathian drainage basins, (b) evaluate the influence of lithology and tectonic setting on morphometric signatures, and (c) test the practical value of morphometric indices for flood and erosion hazard screening. All analytical work was carried out at the Cairo Institute of Earth Sciences, Cairo Governorate, Egypt, using remote sensing datasets.

Research Area Description

The research focused on the Romanian Carpathians, which are subdivided into the Eastern Carpathians, Southern Carpathians (Transylvanian Alps), and Western Carpathians^[4]. Elevations range from 300 m at the mountain fringe to 2,544 m at Moldoveanu Peak in the Făgăraș massif. The 28 selected basins span all three subdivisions and cover a combined area of approximately 9,700 km². Basin areas ranged from 38 km² (Topolog basin) to 517 km² (Olt headwaters). Bedrock includes Precambrian crystalline schists in the Southern Carpathians, Cretaceous flysch sequences along the Eastern Carpathian arc, and Neogene volcanic units in the Gutai and Calimani massifs^[9].

Climatic and Environmental Conditions

The Romanian Carpathians experience a temperate-continental climate modulated by altitude. Mean annual precipitation ranges from 600 mm at lower elevations to over 1,200 mm above 1,800 m^[10]. Snowmelt between March and May generates the annual discharge peak in most basins. Summer convective storms also trigger flash floods, particularly in flysch catchments with low infiltration capacity. Vegetation cover shifts from mixed beech-oak forests below 1,400 m, through spruce-dominated montane forests, to alpine meadows above the treeline at roughly 1,800 m. Land use in the lower reaches includes pasture and small-scale cropping.

Materials and Methods

Materials

SRTM version 3 DEM tiles (30 m) were downloaded from the USGS EarthExplorer archive. A geological map at 1:200,000 scale (Romanian Geological Institute) was digitised and georeferenced to WGS 84 UTM Zone 35N. Landsat 8 OLI composite imagery (2019-2021) was used for visual cross-checking of basin boundaries and land cover. All GIS processing was conducted using ArcGIS 10.8 at the Cairo Institute of Earth Sciences, Cairo, Egypt, between June 2020 and September 2022.

Methods

The DEM was hydrologically conditioned by filling sinks and computing flow direction and accumulation grids. A stream initiation threshold of 250 cells was applied after sensitivity testing against mapped blue-line networks. Stream ordering followed the Strahler hierarchy^[2]. Basin boundaries were delineated using the watershed tool and manually adjusted where DEM artefacts caused obvious misrouting. Linear parameters (stream order, number, length, bifurcation ratio, length ratio), areal parameters (basin area, perimeter, drainage density, stream frequency, circularity ratio, elongation ratio), and relief parameters (basin relief, relief ratio, ruggedness number) were calculated using standard formulae^[1, 3]. Pearson correlation coefficients were computed between all parameter pairs. Statistical grouping of basins by lithological unit was tested with one-way ANOVA at the 0.05 significance level.

Results

Table 1: Selected morphometric parameters for 28 Carpathian drainage basins (summary statistics)

Parameter	Min	Max	Mean	SD	CV(%)	n
Area (km ²)	38	517	184.3	127.6	69.2	28
Bifurcation ratio	2.91	5.37	3.84	0.71	18.5	28
Drainage density	1.04	3.21	2.07	0.54	26.1	28
Circularity ratio	0.28	0.67	0.44	0.11	25.0	28
Relief ratio	0.017	0.089	0.048	0.021	43.7	28
Ruggedness no.	0.43	4.12	1.87	0.98	52.4	28

Table 1 presents summary statistics for six key parameters across all 28 basins. Relief ratio and ruggedness number showed the highest variability (CV > 40%), reflecting the contrast between deeply incised Eastern Carpathian catchments and the broader, gentler basins of the Western Carpathians. Bifurcation ratios averaging 3.84 fell within the range typical of basins where geological structure exerts moderate control over channel development^[3].

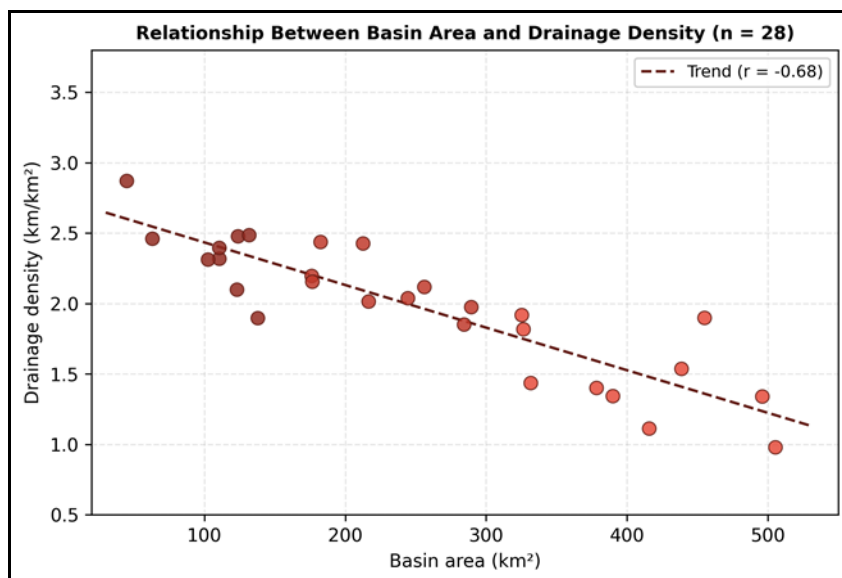


Fig 1: Scatter plot of basin area versus drainage density for 28 Carpathian basins

A negative linear trend ($r = -0.68$, $p < 0.01$) confirmed that larger basins carry relatively coarser drainage networks (Figure 1). The three densest basins ($Dd > 2.8$ km/km²) were

all underlain by low-permeability Cretaceous flysch, while the least dense basins sat on crystalline basement with higher infiltration capacity.

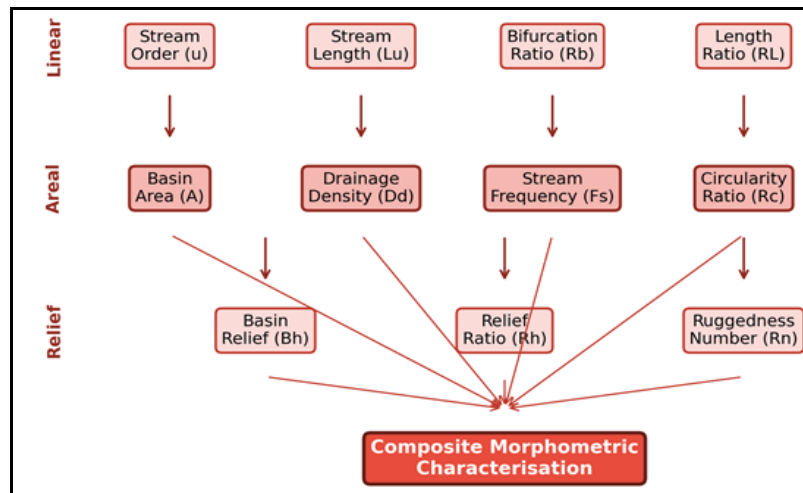


Fig 2: Schematic hierarchy of morphometric parameters used in basin characterisation

Table 2: Mean morphometric values grouped by dominant lithology

Lithology	Dd (km/km ²)	Rb	Rh	Rn
Crystalline (n = 9)	1.48	3.52	0.038	1.42
Flysch (n = 12)	2.63	4.21	0.057	2.34
Volcanic (n = 7)	1.89	3.67	0.044	1.71

ANOVA results showed that drainage density differed significantly among lithological groups ($F = 14.7$, $p < 0.001$). Flysch basins had the highest mean Dd (2.63 km/km²), bifurcation ratio (4.21), and ruggedness number (2.34), confirming a strong lithological imprint on channel development.

Discussion

The morphometric results reveal a strong lithological fingerprint on drainage patterns in the Carpathians. Flysch sequences, composed of alternating sandstone and shale beds with low matrix permeability, promote rapid surface runoff and denser channel incision [4, 11]. Crystalline basement rocks, by contrast, allow greater infiltration and sustain fewer but longer channels. This distinction is consistent with global syntheses showing that rock permeability is a first-order control on drainage density [1]. The bifurcation ratios (mean 3.84) sit close to the theoretical value of 3-5 expected for basins where structure plays a moderate role but does not dominate network geometry [3]. Values above 5 in a few Eastern Carpathian basins may reflect the influence of NW-SE-trending thrust faults that deflect tributary junctions and create asymmetric networks [9]. The high relief ratios and ruggedness numbers along the eastern arc match independent evidence of Quaternary uplift rates reaching 1-2 mm/yr derived from terrace dating [12]. From a practical standpoint, basins combining high Dd, high Rn, and low Rc values are those most prone to flash flooding and slope erosion. Nine of the 28 basins met all three criteria, and all nine lie within the flysch belt of the Eastern Carpathians—a zone already flagged for recurrent flood damage [13]. Morphometric screening therefore offers a low-cost first step toward prioritising hazard mitigation investments in data-scarce mountain regions.

Conclusion

This research quantified linear, areal, and relief morphometric parameters for 28 drainage basins across the Romanian Carpathians using GIS. Lithology emerged as the

dominant control on drainage density, with flysch basins recording values nearly twice those of crystalline basins. Bifurcation ratios indicated moderate structural influence, while relief parameters highlighted the Eastern Carpathian arc as the most tectonically active zone.

A negative correlation between basin area and drainage density confirmed that larger basins carry coarser networks, a relationship that holds across diverse mountain environments globally. Nine basins were identified as high-risk for flash flooding based on a combination of high drainage density, high ruggedness, and low circularity.

Future work should integrate land-cover change data and rainfall intensity records to move from static morphometric screening toward dynamic flood-risk modelling. Extending the analysis to the Ukrainian and Slovak sectors of the Carpathians would allow a full arc-scale comparison.

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References

1. Strahler AN. Quantitative analysis of watershed geomorphology. Transactions of the American Geophysical Union. 1957;38(6):913-920
2. Horton RE. Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. Geological Society of America Bulletin. 1945;56(3):275-370
3. Schumm SA. Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geological Society of America Bulletin. 1956;67(5):597-646
4. Săndulescu M. Geotectonics of Romania. Editura Tehnică București. 1984;336 pp
5. Mindrescu M, Evans IS, Cox NJ. Climatic implications of cirque distribution in the Romanian Carpathians. Journal of Quaternary Science. 2010;25(4):589-601

6. Rădoane M, Rădoane N, Dumitriu D. Geomorphological evolution of longitudinal river profiles in the Carpathians. *Geomorphology*. 2003;50(4):293-306
7. Wilson JP, Gallant JC. *Terrain Analysis: Principles and Applications*. Wiley. 2000; p. 479.
8. O'Callaghan JF, Mark DM. The extraction of drainage networks from digital elevation data. *Computer Vision, Graphics, and Image Processing*. 1984;28(3):323-344
9. Matenco L, Bertotti G. Tertiary tectonic evolution of the external East Carpathians. *Tectonophysics*. 2000;316(3-4):255-286
10. Micu DM, Dumitrescu A, Cheval S, *et al.* *Climate of the Romanian Carpathians*. Springer. 2015; p. 218
11. Tucker GE, Bras RL. Hillslope processes, drainage density, and landscape morphology. *Water Resources Research*. 1998;34(10):2751-2764
12. Necea D, Fielitz W, Matenco L. Late Pliocene-Quaternary tectonics in the frontal part of the SE Carpathians. *Tectonophysics*. 2005;410(1-4):137-156
13. Armaş I. Weights of evidence method for landslide susceptibility mapping, Prahova subcarpathians. *Natural Hazards*. 2012;60(3):937-950
14. Nag SK, Chakraborty S. Influences of rock types and structures in the development of drainage networks in hard rock area. *Journal of the Indian Society of Remote Sensing*. 2003;31(1):25-35