

Geomorphological aspects of Putna Valley (Lepşa – Tulnici sector), Romania

Marius-Andrei NEDELUCU

University of Bucharest, Faculty of Geography, Romania
nedelcuandrei2121@gmail.com

Sommaire :

1. INTRODUCTION.....	163
1.1. Geographical setting.....	163
1.2. General geomorphological characteristics	164
2. METHODOLOGY.....	165
2.1. Data and methods	165
2.2. Research history	167
3. RESULTS	168
3.1. Morphogenetic factors	168
3.2. Morphometry and morphography	174
3.3. Current dynamics of the riverbed and slopes	182
4. DISCUSSION.....	185
5. CONCLUSIONS	188
6. ACKNOWLEDGEMENTS.....	189
7. REFERENCES	189

Citer ce document :

NEDELUCU, M.-A. 2026. Aspecte geomorfologice ale Văii Putnei (Sectorul Lepşa – Tulnici), România. *Cinq Continents* 16 (33): ?-??.

Geomorphological aspects of Putna Valley (Lepşa – Tulnici sector), Romania

Marius-Andrei NEDELUCU

Aspecte geomorfologice ale Văii Putnei (Sectorul Lepşa – Tulnici), România. Prin complexitatea fizico-geografică, dar și a factorului antropic, prezent aici încă din timpuri istorice îndelungate, valea Putnei vrâncene reprezintă principala arteră hidrografică de pe teritoriul județului Vrancea. Sectorul analizat este situat în partea de nord-vest a bazinului Putnei, și reprezintă cursul montan inferior al văii, începând din aval de satul Lepşa și până la intrarea în Subcarpații Vrancei, în dreptul localității Tulnici, la confluența cu pârâul Coza. Evoluția îndelungată a rețelei hidrografice este exprimată prin dezvoltarea unor umeri de vale dispuși în lungul văii. Cadrul geologic general al văii Putnei este reprezentat de contactul dintre unitatea de Orogen carpatic și unitatea Platformei valahe din Vorland, iar unitatea de orogen fiind formată din fliș cu depozite cretacice, paleogene și miocene. În funcție de tectonică, dar și de elementele de detaliu, valea Putnei a suferit diferite schimbări de direcție. Din punct de vedere al regimului scurgerii, râul Putna se încadrează din punct de vedere hidrologic în categoria râurilor cu o mare variabilitate a parametrilor scurgerii (lichide și solide). Toate aceste elemente, precum și alcătuirea litologică au determinat o dinamică actuală a râului, cu schimbări aduse peisajului general al văii.

Cuvinte cheie: Putna, umăr de vale, neotectonică, dinamica văii.

Geomorphological aspects of Putna Valley (Lepşa – Tulnici sector), Romania. Defined by its physical-geographical complexity and a long-standing anthropogenic presence, the Vrancean Putna Valley serves as the primary hydrographic artery of Vrancea County. The analysed sector is situated in the northwestern part of the Putna basin, encompassing the valley's lower mountain course. This reach extends from downstream of Lepşa village to the gateway of the Vrancea Subcarpathians, near Tulnici, at its confluence with the Coza stream. The prolonged evolution of the hydrographic network is evidenced by the development of valley shoulders situated along its course. The general geological framework of the Putna Valley is defined by the contact between the Carpathian Orogenic unit and the Wallachian Platform in the foreland; the orogen itself consists of flysch featuring Cretaceous, Paleogene, and Miocene deposits. Influenced by both tectonic activity and localized structural details, the Putna Valley has undergone several changes in orientation. In terms of its discharge regime, the Putna River is hydrologically classified among rivers characterized by high variability in runoff parameters (both liquid and solid). These factors, compounded by the lithological composition, drive the river's contemporary dynamics, resulting in significant alterations to the overall landscape of the valley.

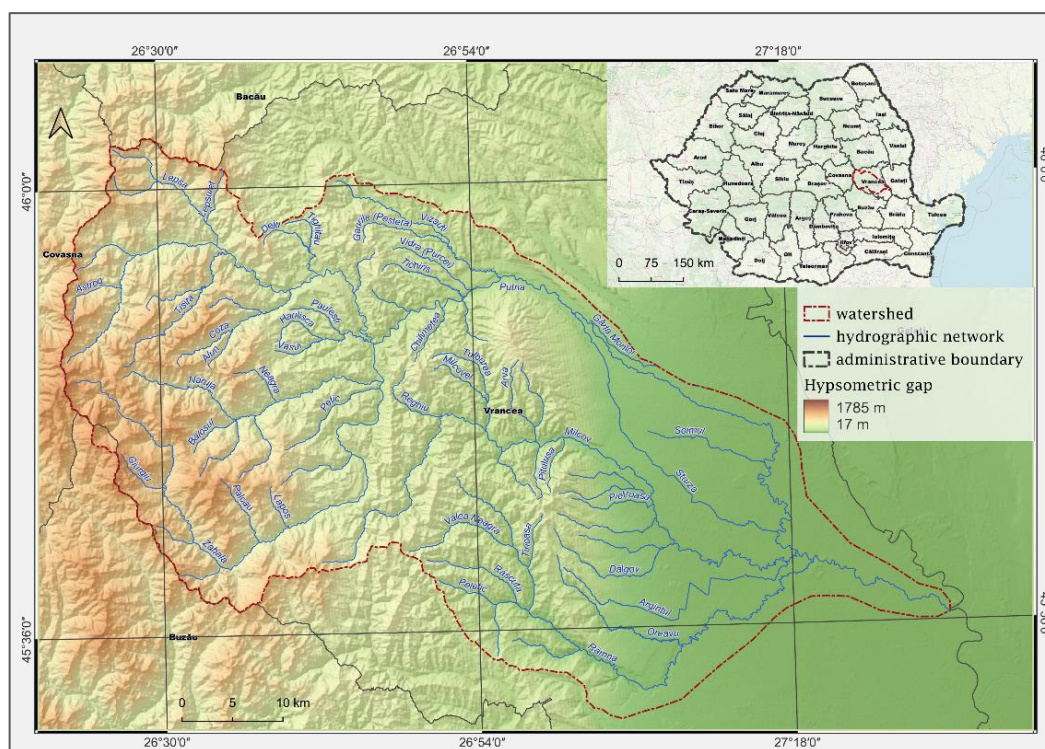
Keywords: Putna, valley shoulder, neotectonics, valley dynamics.

1. INTRODUCTION

1.1. Geographical setting

From the point of view of the geographical belonging of the valley sector, it is located within the Putna hydrographic basin, being part of the river system of the Siret River (Figure 1). The name Putna has numerous origins, one of them is the Slavic one (Puhna or Pucna), meaning "endowed with a road" or "with a path", being a proof of the inhabitation of the valley by the people of Vrancea, since ancient times (Mihăilescu et al., 1970).

The Putna River is located in the south-eastern part of the country, on the outer side of the Curvature Carpathians, sectioning all the relief steps, from west to east: the Vrancea Mountains, the Vrancea Subcarpathians, the north-east of the Romanian Plain. Some general data on its development: L = 160 km, basin area of 2,488 km², with a percentage of 5.37% of the total area of the Siret basin and only 1.04% of the country's.



Source: ANAR, <https://data.gov.ro/dataset/hidrografie>; ANCPI, <https://data.gov.ro/dataset/unitati-administrativ-teritoriale-07-03-2024>

The Putna basin is delimited by the drainage divide to the other neighbouring basins: to the north, the Șușita basin, to the north-west, the Trotus basin, to the west, the boundary is made with the Olt basin, to the south, the Râmnic-Sărat basin, to the south-west, the Buzău basin, and to the east, the delimitation is made on the lower course of the Siret River (Zaharia, 1999). Altitudinally, there are important variations of the hypsometric steps, from west to east there being a difference in level of about 1763 m.

The measured length of the analysed sector is 11.6 km and represents 7.2% of the total length of the river, and the area holds 30.4 km², which means only 1.22% of the total basin. The maximum altitude is recorded in the Tisaru Massif, reaching 1,267 m at the Tisaru Mare peak, while the minimum value of approximately 430 m is found at the floodplain level, where the river enters the Subcarpathians and meets the Coza tributary.

1.2. General geomorphological characteristics

The morphological delimitation of the Putna Valley is addressed in Cristea's work (2011), which employs specific evolutionary and morphometric criteria to identify traces of old leveling surfaces shaped by denudational processes, as well as slope surfaces that represent distinct stages in the valley's deepening.

In the area of the Vrancea Mountains, several levelling surfaces have been identified, which correspond to the stages of evolution of the relief. The first delimitation of these is due to Rădulescu (1937) through his study entitled "Vrancea. Physical and Human Geography" and includes five levels of erosion, three of which are relevant to the present study: the "platform of the medium lands", between 1400-1480 m, medium altitudes, but it is also found lower, at 1100-1180 m (under the Zboina Neagră peak), the "lowland platform" between 1200-1300 m, is also identified north of the Putna River, but between 960-1060 m and the "lower platform", between 1000-1100 m, with a lower development. Their age has been attributed to the Pliocene and Miocene, a period characterized by intense tectonic uplifts.

The morphological features of this valley sector are characteristic of the peripheral mountain units. The mountain unit is located in the west of the basin, highlighted by the Vrancea Mountains, which extends from the western water ridge, to the right of a line, with a general north-south direction, which could be represented by the alignment of the marginal fault of the Carpathian flysch, with altitudes between 800-900 m and passes to the west by the localities of Tulnici, Coza, Păulești, Vetrești – Herăstrău, Păvălari.

According to Roman (1989), the Vrancea Mountains are structured on three main alignments, almost parallel, arranged V – E: the Western Ridge, the Middle Ridge and the mountain border. The western ridge has the highest altitudes, and on this alignment, there are also the maximum altitudes, Lăcăuți (1777 m), Goru (1785 m) and Giurgiu (1722 m).

As a result of the action of the hydrographic network, which led to the fragmentation of the relief, but also under the influence of local factors (lithological and/or structural), 5 depression basins resulted, which occupies 1/2 of the length of the sector: the Ciuta, Porcu, Putna Waterfall basins, one located upstream of the Mociarului

confluence and another downstream of it, all of which make up the "Putna Vrancea Gorge" according to Roman (1989).

If we talk about the orientation of the valley, in the mountainous sector and implicitly, in the analysis sector, 3 changes of direction are observed, due to geological causes. Thus, from the springs to the confluence with the Mărului stream, the Putna valley has an SSV-NNE direction, from the Mărului stream and up to the exit of the Greșu – Lepșa Depression, the Putna river has a west-east orientation, and after leaving the depression, it changes its direction to the south-east, until close to Tulnici.

2. METHODOLOGY

2.1. Data and methods

From a methodological point of view, I used both classical methods, such as the analysis and interpretation of previous geographical studies, field observations, and geomorphological profiling using GPS, and modern methods, such as data processing through Geographic Information Systems (GIS). These were based on a Digital Elevation Model (DEM) to generate maps for hypsometry, morphography, slope inclination, aspect (slope exposure), and the depth and density of relief fragmentation. Additionally, using GIS applications, morphometric parameters of the riverbed and key indices for the valley's dynamics were automatically calculated. As for the DEM used to obtain the mentioned maps, it was made on the basis of the interpolation of contour lines, with an equidistance of 10 m altitude, resulting in a raster with a pixel size of 1 meter.

The morphometric and morphographic analysis of the study area was carried out in relation to the main morphometric parameters, calculated with the help of the measuring instruments of the QGIS 3.34 program, based on the topographic maps at a scale of 1:25,000, developed by the Military Topographic Directorate. The mapping process renders the following aspects: the hypsometric features of the sector (altitude steps), the degree of horizontal fragmentation (fragmentation density), where the cartogram method was used, the degree of vertical fragmentation (depth of fragmentation), the main morphographic characteristics, through a map that renders the landforms on 10 categories depending on the geometry of the surfaces identified based on a DEM, slope by slope categories, slope exposure by slope categories (rendered for 8 cardinal and intercardinal points).

Regarding the evolution and genesis of the valley, lithology, geological structure, and tectonics are crucial factors; furthermore, the diversity of rocks and their distribution across various facies provide this sector with a distinct character. Geological data concerning the distribution and composition of the main lithological formations were derived from the 1:100,000 scale Geological Map of Romania – Bârsești sheet

(Dumitrescu, 1958). Subsequently, using GIS tools (QGIS, version 3.34), the geological data were processed, simplified, and categorized to determine the percentage distribution of the various rock types.

To characterize the climatic features of the analysed sector, data from the Lăcăuți meteorological station (1,777 m) were used for the mountain area (1961–2013), alongside data from Tulnici (571 m) for the Subcarpathian sector (1961–2003); these datasets were used to generate monthly and seasonal average precipitation graphs. The thermal regime varies between the western and eastern parts of the valley: the average annual temperature ranges from approximately 1°C (e.g., Lăcăuți Peak at -1.2°C) to over 10°C in the plain area (e.g., Focșani at 10.6°C). The studied valley sector falls within the 5°C to 7°C range, typical of low-mountain environments.

From the point of view of the runoff regime of the Putna River, it fits into the courses with a great variability of liquid and solid flows, due to its basin located in the Curvature region of the Carpathians, a region considered to have the intense sedimentary dynamics in the temperate zone of Europe (Ichim et al., 1998).

The characteristics of vegetation and land use influence riverbed and slope processes, with direct implications for valley dynamics. In the analysed area, the primary influencing factor is the altitudinal zonation of vegetation. Consequently, the study sector is situated within the forest zone, comprising two main belts: boreal (coniferous) and deciduous forests, each containing several mixed sub-zones. Data regarding land use and the proportions of each category were extracted from the Corine Land Cover (CLC 2018) database and processed using QGIS.

An additional argument that can strengthen a geomorphological study or analysis is the field practice, which brings new and topical elements and contributes to the formation of an overview of the researched element. Thus, the creation of geomorphological profiles, necessary to understand some aspects of the peaks and slopes, required several field trips to establish the points necessary to mark the profile and its subsequent processing. Three trips were made in September, respectively on 5.09.2024, 7.09.2024 and 21.09.2024, which resulted in the completion of five slope geomorphological profiles, including secondary ridges (with special regard to the valley shoulders).

Furthermore, riverbed and slope dynamics, along with channel geometry, were observed in detail during fieldwork, resulting in an extensive photographic record. Key insights into the factors favouring specific geomorphological processes can also be derived from the analysis of anthropogenic microforms; these are highly prevalent in inhabited areas, manifesting through both residential development and road infrastructure.

For the analysis of the chosen sector, the approach is an interdisciplinary one, using geographical and geological knowledge from the nineteenth – twentieth centuries, useful for knowing the paleogeographical evolution of the valley. The multitude of data and information found in more recent studies offers numerous concepts related to neotectonic evolution, and the consequences of tectonic uplifts in the current dynamics of the riverbed.

2.2. Research history

The numerous scientific contributions made to the Putna Valley have had the effect of better understanding its evolution. The existence of theories regarding the initiation and evolution of the hydrographic network at the Carpathian Curvature provides an overview of the complexity of the study area. In particular, starting with the twentieth century, several geologists and geographers, among whom stand out: Martonne (1907), Mateescu (1927), Rădulescu (1937), Paucă (1942), Sîrcu (1966), and Grumăzescu (1973).

According to De Martonne (1907), who synthesized the geological data that appeared at the beginning of the twentieth century, the sub-Carpathian depression of Vrancea would have a tectonic origin, as a result of the collapse of the dissolved salt formation. He also assumes that in the Lower Quaternary there would have been a longitudinal river, which was later disturbed by several transverse courses, which advanced regressively from the plain.

Mateescu (1927) adopted and further developed these ideas, demonstrating the existence of two primary evolutionary phases: the first occurred during the Early Quaternary, when the rivers were longitudinal in character, followed by a second phase (Middle Quaternary), during which the drainage network reorganized into a transverse pattern due to neotectonic movements.

Rădulescu (1937) demonstrated the existence of two longitudinal courses: one presenting a south-north direction, also called "the southern course of Vrancea", and one with a north-south direction, "the northern course of Vrancea". Later, Paucă (1942) proposed a contrary hypothesis, arguing that the valley sectors—from their headwaters in the mountains through the Subcarpathian area—exhibit a predominant west-east orientation alternating with north-south sections; this view is based on the general eastward tilt of the relief. Subsequently, Orghidan (1969) reinforced this hypothesis, providing additional evidence based on the significant thickness of Pleistocene-Quaternary gravel deposits along the line of the outer Subcarpathian peaks.

Sîrcu (1966) and Grumăzescu (1973) substantiate the theory of initial transverse courses and correlate specific terraces to highlight the developmental stages of the drainage network.

Utilizing data from more recent studies supports ongoing efforts to resolve tectonic issues and, by extension, the evolution of the hydrographic system. The study conducted by Fielitz, Seghedi (2005) determines that the development of the current drainage system (Figures 2 and 3) began during the Early to Middle Miocene (20–11 million years ago).

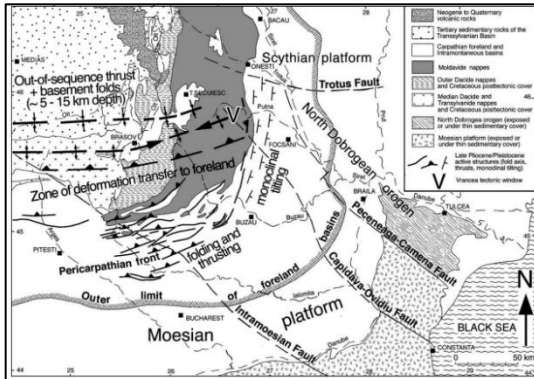


Figure 2. Geotectonic sketch of the Curvature Carpathians, highlighting active neotectonic structures from the late Pliocene and Pleistocene (after Fielitz, Seghedi, 2005).

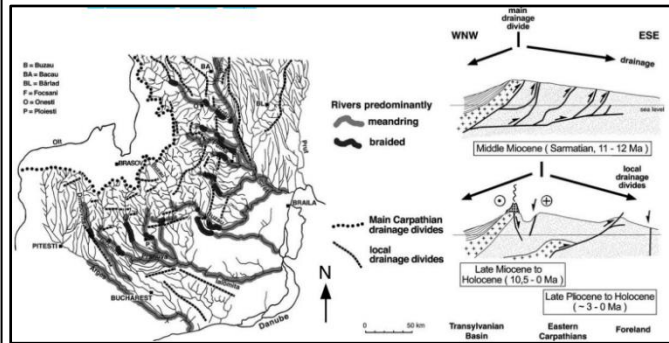


Figure 3. Characteristics of riverbed planform typology in the SE Carpathians and its relationship with transverse structural uplifts (left); correlations between the emergence and development of drainage divides and the recent neotectonic evolution of the Eastern Carpathians (after Fielitz, Seghedi, 2005).

3. RESULTS

3.1. Morphogenetic factors

The formation and, specifically, the paleogeographical evolution of the Putna Valley were conditioned by numerous morphogenetic factors: internal forces (lithology, structure, tectonics, and neotectonics) and external forces (climate, vegetation, hydrography, and soils). The general geological framework of the Putna Valley consists of the Outer Moldavides (Outer Nappes) of the Eastern Carpathians and the Carpathian Foredeep. The external flysch deposits belong to two tectonic units: the Tarcău Nappe and the Vrancea Nappe (Dumitrescu, 1952). The primary geological and structural elements were synthesized and simplified into a map (Figure 4), where the represented formations are delineated either by clear tectonic contacts (faults, thrust planes, etc.) or by discontinuities resulting from sedimentation cycles.

Regarding the distribution of lithological facies (Figure 5), the most representative category in this sector comprises the Cașin Strata, Buciaș, and conglomerates (Figures 6 and 7), which account for 25% of the total area. The following two categories have similar weights: Lower Menilite and Kliwa Sandstone (23%), and Upper Menilite and Kliwa Sandstone (18%). Consequently, more than half of the sector's surface is

developed on high-resistance (hard) rocks, significantly influencing the morphogenesis and evolution of the valley.

Among the aforementioned sedimentary formations of the Carpathian flysch, those belonging to the Vrancea Nappe are clearly predominant within the analysed sector; these are found in the Vrancea Half-window (which also constitutes the autochthon of the Tarcău Nappe). This unit consists of Cretaceous, Paleogene, and Miocene deposits that succeed one another from west to east. Tectonically, it is divided into two subunits—the Greșu and Coza digitations—the latter being the most extensive and including the aforementioned deposits.

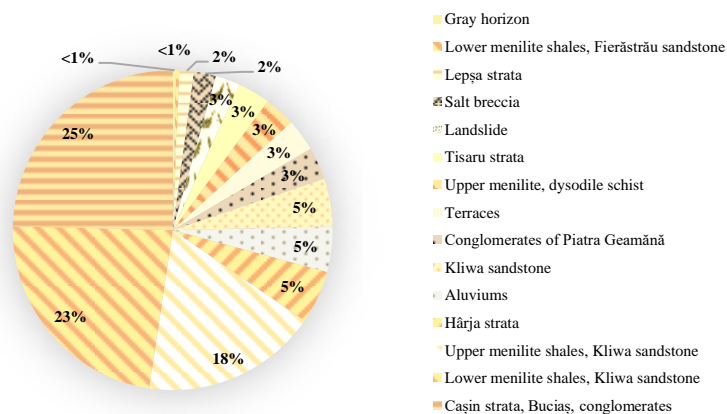
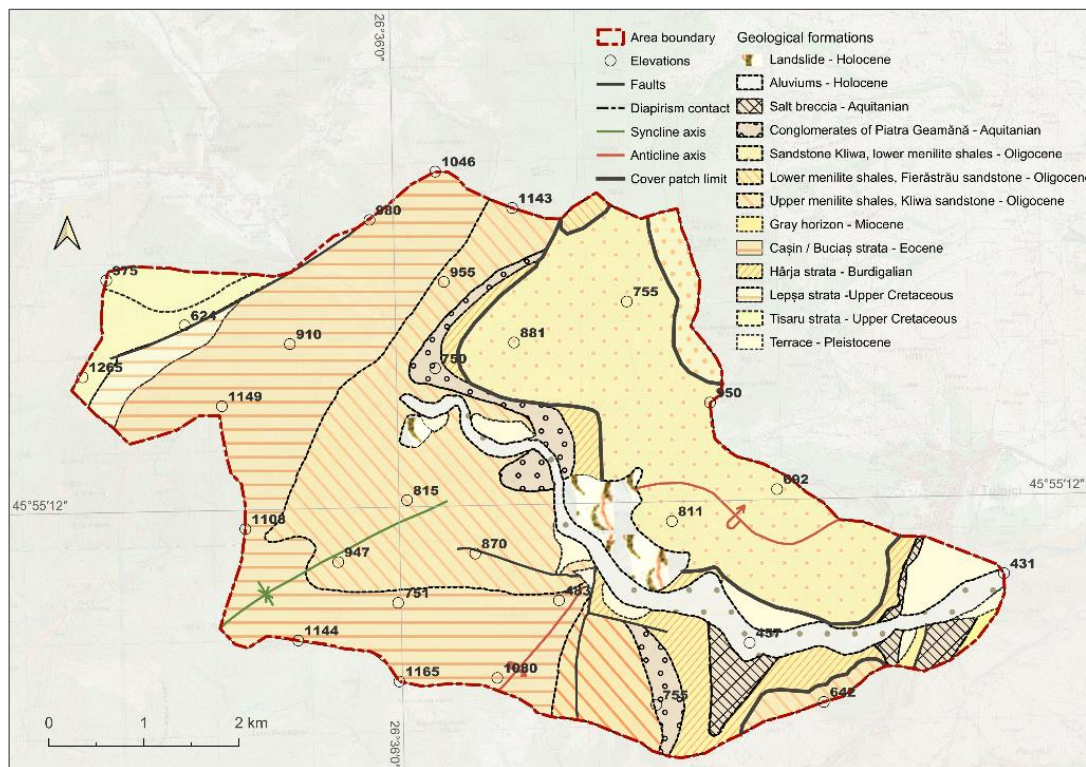


Figure 4. (upper) The main lithological subdivisions in the Lepsa – Tulnici area; source: QGIS 3.34 and processing of the Bârsești geological sheet – 1:100.000
 Figure 5. (lower) Percentage distribution of geological formations in the studied area



Figure 6. (left) Opening at the level of the Buciaș strata, arranged in successive horizons, on the left slope of the Putna valley
Figure 7. (right) The development of the Twin Stone Conglomerates imposed the appearance of towers and other landforms

From a structural perspective, the western part of the basin consists of folded formations with a general NNE–SSW orientation. The Putna Valley has undergone several changes in direction, influenced by both regional tectonics and detailed structural elements. For instance, in the upper sector, the course of the Putna Valley is aligned with fault systems (Cristea, 2011).

Thermochronological data indicate that the highest rate of tectonic uplift occurs within the Vrancea Nappe, with values of approximately 3.2 ± 0.3 mm/year (Necea, 2010). This uplift has contributed to the restructuring of the drainage network, leading to a predominantly transverse orientation. The development of a tectonic axis of elevation (horst-type) along a SW–NE direction forced changes in the hydrographic network; this resulted in the current configuration of the Putna Valley, characterized by a longitudinal character in its upper course and a predominantly transverse character throughout the rest of its mountain sector.

From a climatic perspective, the Putna basin is characterized by a temperate-continental transitional climate. However, factors such as the degree of topographic fragmentation (more pronounced in the west), the predominantly north–south orientation of the ridges, and varying slope aspects have fostered local atmospheric circulations and climatic differentiations between the mountainous area and the extra-Carpathian space.

The dynamics and frequency of air masses influence climatic elements, causing variations in temperature and precipitation regimes that are directly reflected in geomorphological processes.

In addition to the thermal regime, precipitation characteristics are relevant for analysing valley dynamics. The rainfall regime is influenced by humid air masses and the general orientation of the main ridges exposed to advection. Consequently, the directly

exposed western slopes and higher peaks receive greater amounts of precipitation, exceeding 800 mm (e.g., Lăcăuți – 827 mm); these amounts are significantly reduced to the east, where the foehn effect occurs (e.g., Tulnici station – 645 mm).

The nature of precipitation is crucial for current geomorphological processes, with a key indicator being exceptionally rainy years, such as the intervals 1966–1967, 1969–1972, 1978–1982, and 2000–2005. At the monthly level, the highest precipitation occurs in May, June, and July in the mountain area, with values at the Lăcăuți station exceeding 100 mm.

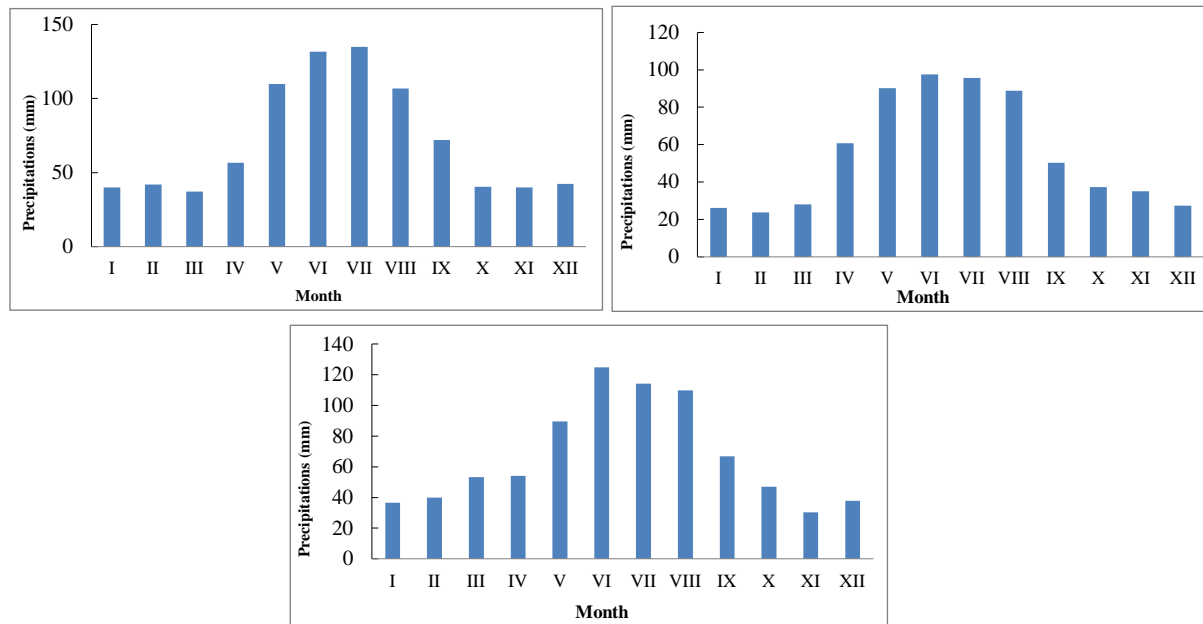


Figure 8. (upper left) The monthly rainfall regime at the Lăcăuți meteorological station Figure 9. (upper right) the monthly rainfall regime at the Tulnici meteorological station; modified after Zaharia, 1999; Figure 10. (lower) Monthly rainfall at the Lăcăuți meteorological station (1991 – 2013); processed according to meteorological data of the National Meteorological Administration

In the upland area of the Putna Valley (Lăcăuți station), precipitation distribution for the 1961–1990 period (Figure 8) varied from 37.1 mm in March to 134.9 mm in July. During the winter season, precipitation occurs in solid form, generating a significant snowpack; this constitutes a major component of the river runoff regime during the spring months and can lead to increased discharge and even flooding. At the contact with the Subcarpathians (Tulnici station), precipitation levels range from 23.7 mm in February to 97.5 mm in June, reflecting a reduction in total annual precipitation and a distinct eastward decline (Figure 9). Between 1991 and 2013 (Figure 10), the precipitation distribution underwent shifts, particularly at the monthly level, with values ranging from 30.3 mm (November) to 124.8 mm (June). Compared to the 1961–1990 interval, the maximum monthly precipitation decreased slightly, and a discernible gap emerged during the summer months.

The seasonal distribution of precipitation (Figures 11 and 12) reflects these monthly characteristics. Summer accounts for 34% to 44% of the annual total, while spring contributes 23.8% at Lăcăuți and 27% at Tulnici. In winter and autumn, the values range from 17.9% to 14.6% at Lăcăuți, and from 19.5% to 11.7% at Tulnici (Zaharia, 1999).

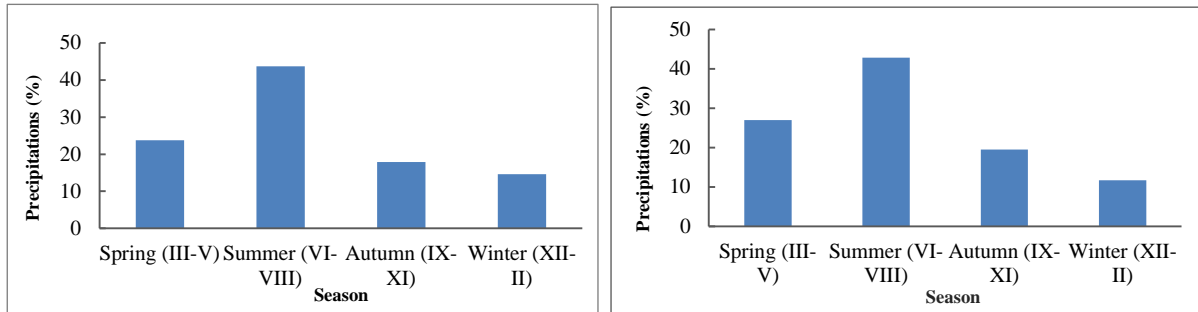


Figure 11. (left) The seasonal rainfall regime at the Lăcăuți meteorological station
 Figure 12. (right) the seasonal rainfall regime at the Tulnici meteorological station; modified after Zaharia, 1999

The water resources within the analysed sector belong entirely to the Putna drainage basin. Their spatial distribution (Figure 13) highlights the most significant permanent and seasonal watercourses; these were extracted using the military topographic map as a primary base map. The discharge from tributaries occurs perpendicular to the main channel, locally influencing the lateral migration of the floodplain and contributing to the maintenance of a dynamic equilibrium.

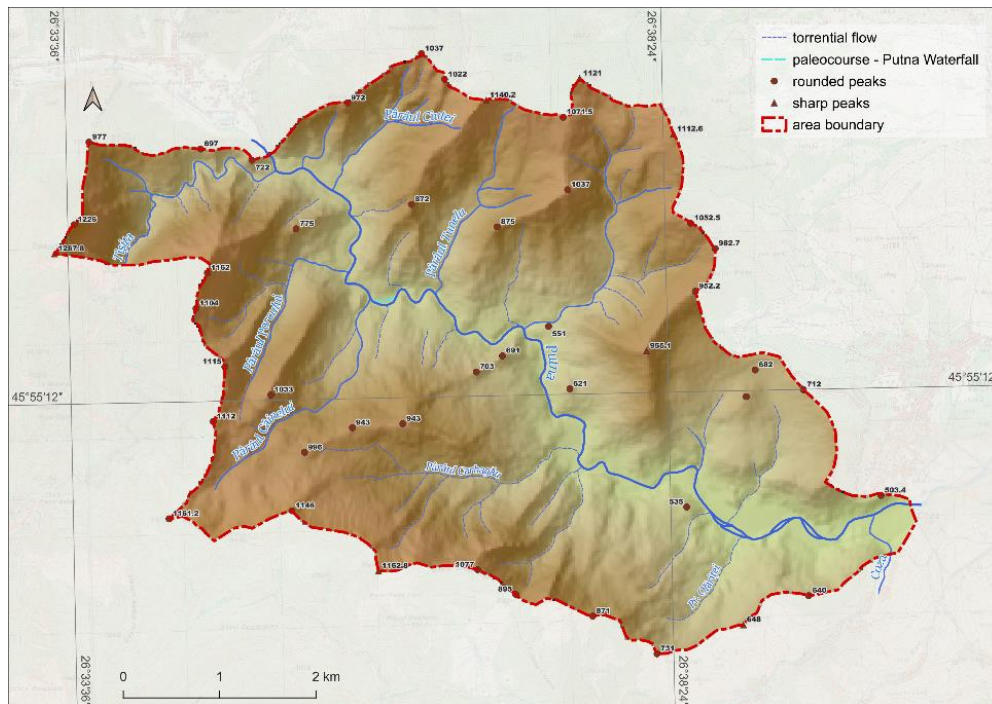


Figure 13. Distribution of water resources in the Lepsa – Tulnici sector

The most significant liquid discharge is contributed by the Tișița River, which, after carving an impressive system of gorges, flows into the Putna downstream of Lepșa on the right bank; at the confluence, it forms a small alluvial fan composed of gravels. Other significant tributaries influencing fluvial dynamics include the Porcului and Căinelui streams (with confluences near the Putna Waterfall), the Coza (noted for its high sediment input), and the Mociaru and Ciuta streams on the left bank.

The analysis of land-use categories (Figure 14), based on 2018 processed data, identified eight distinct types of land cover. The current vegetation composition has also been slightly influenced by human activity, specifically through the development of settlements and land-use patterns (Figure 15).

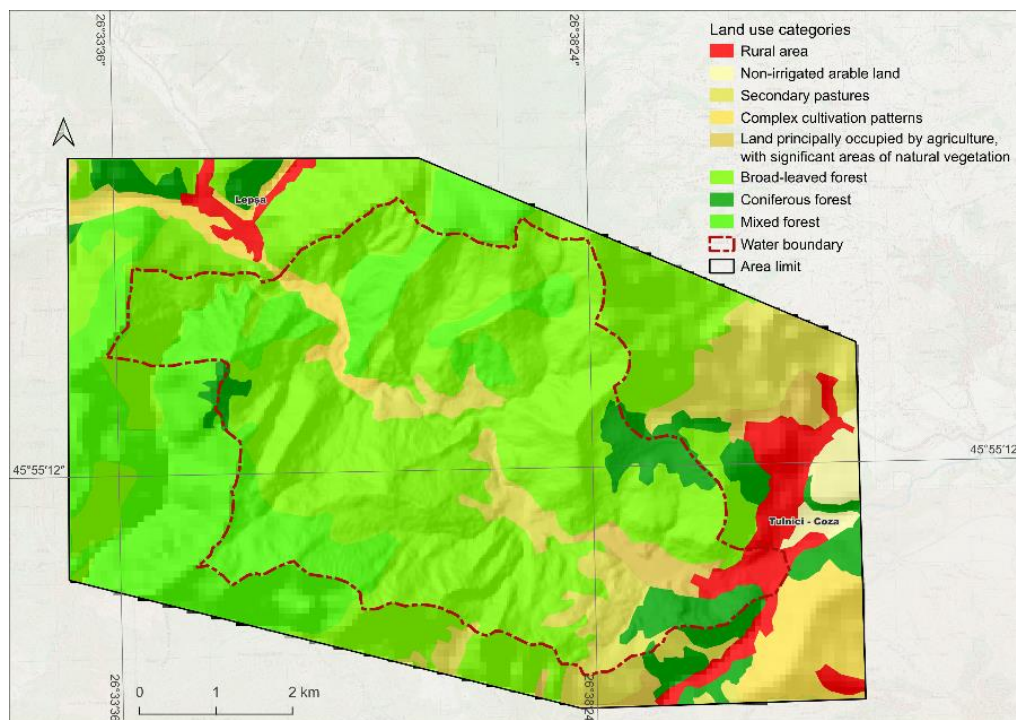
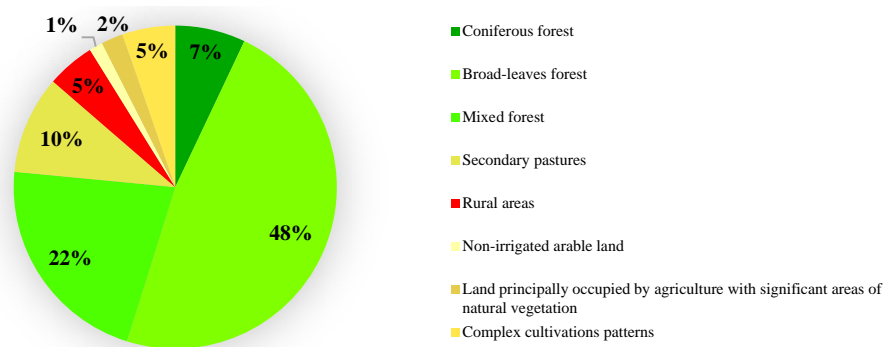


Figure 14. (upper) Percentage distribution of land use categories, according to CLC data – 2018
 Figure 15. (lower) Degree of vegetation cover and land use, processing according to CLC data – 2018
 (from the Corine Land Cover database);

Deciduous forests occupy the largest area, accounting for 48% of the total, with a relatively uniform distribution. These are followed by mixed forests (transitional between coniferous and deciduous) at 22%, and coniferous forests at 7% (represented by isolated patches of artificial pine plantations).

Secondary grasslands account for 10% of the area; these are confined to the lower valley levels, having replaced former forested areas. Rural built-up areas (comprising the villages of Tulnici, Coza, and Lepşa, located on the periphery of the study sector) and complex cultivation patterns each occupy 5%. The smallest shares are recorded by land principally occupied by agriculture with significant areas of natural vegetation (2%) and non-irrigated arable land (1%). The latter are identified on the terraces located east of the Tulnici perimeter.

3.2. Morphometry and morphography

In order to summarize the main morphometric parameters of the study sector (Table 1), the results of the calculations and measurements were briefly presented, using analysis tools from the QGIS program.

Table 1. Main morphometric parameters of Lepşa – Tulnici sector

Morphometric parameters	Unit of measurement
Area of the sector analysed	30.49 km ²
Perimeter of the secondary water divide	28.62 km ²
Length	11.6 km
General relief energy	834.8 m
Shape of the area	If = 0.33 (Form factor)

From a hypsometric perspective, the dominant altitudes characterize a typical mid-altitude mountain relief (reaching a maximum of 1,267.8 m at Tisarú Mare Peak). Lower altitudes occur along the valley sectors; towards the contact with the Vrancea Subcarpathians, the floodplains broaden significantly in the eastern part, where elevations drop below 500 m (with a minimum of 433 m) within the Putna riverbed.

The graphical representation of the hypsometric belts (Figure 16) reveals that the highest percentages, 21% and 19%, correspond to the 601–700 m and 701–800 m altitudinal intervals, respectively. The lowest weights are found below 500 m (6%), located within the floodplains and terraces along the valley, while the 1,100–1,200 m range (2%) covers several peaks (e.g., Fântâna lui Bucur, Porcului Peak). Additionally, peaks exceeding 1,200 m (within the Tisarú Ridge) are noteworthy, though they occupy less than 1% of the total area.

percentages are assigned to density values $> 6 \text{ km/km}^2$ accounting for only 2% and occurring sporadically towards the eastern limit of the valley (Figure 18). Low values are also recorded in the 5–6 km/km^2 interval (less than 1%), corresponding to the Tisaru Mare peak and the gorge sectors formed by the Tișița River in the western extremity (Figure 19).

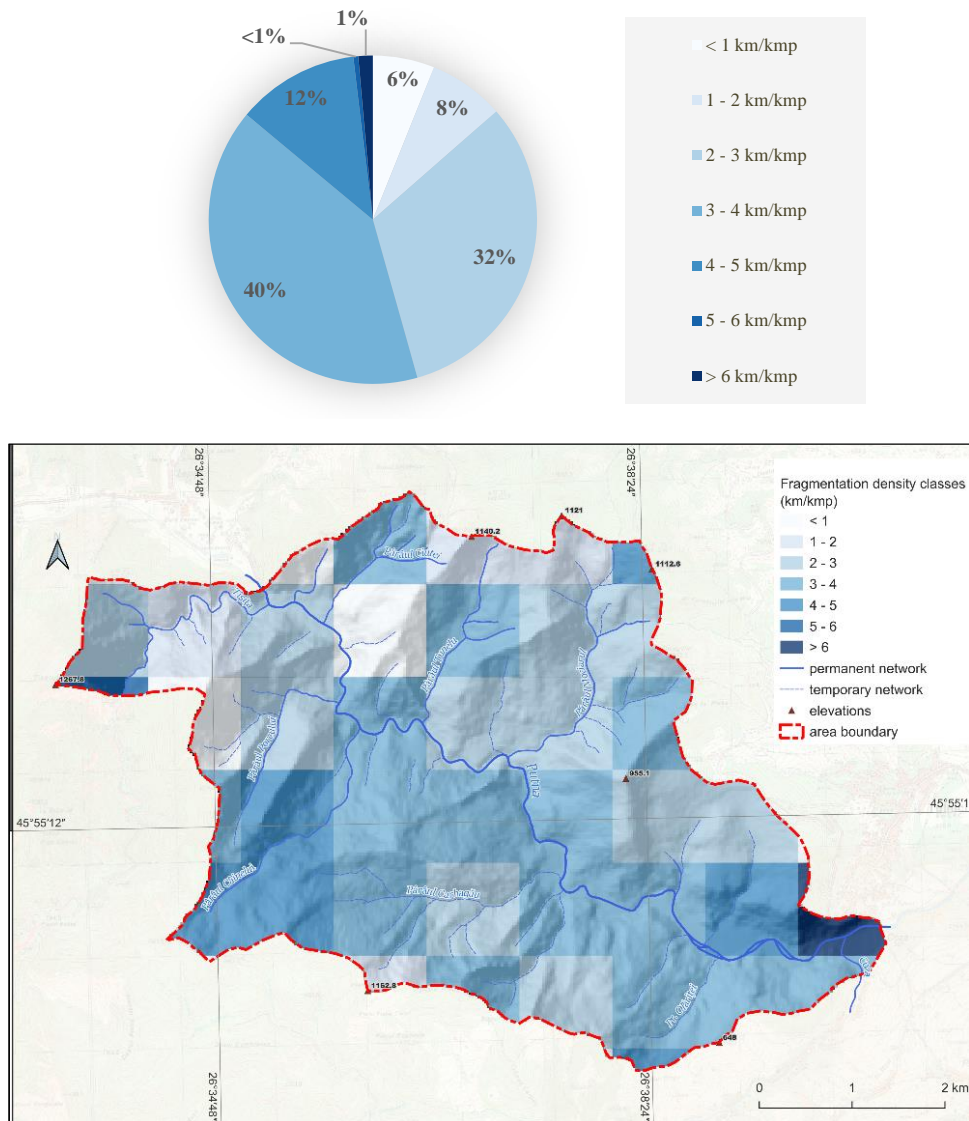


Figure 18. (upper) Percentage distribution of horizontal fragmentation of the relief
 Figure 19. (lower) Distribution of horizontal fragmentation of the relief

The degree of vertical fragmentation (relief energy or fragmentation depth) results from erosional processes acting upon the lithological substrate (Marcu, 2013). Following the generation of the fragmentation depth map, seven intervals were identified, with values ranging from 15 to 620 m/km^2 . Notably, nearly half of the entire sector's surface (47%) exhibits fragmentation depth values between 300 and 400 m/km^2 , which represent the average vertical fragmentation for the area (Figure 20). The least

represented classes are those below 100 m/km² (<1%) and those exceeding 600 m/km²; the latter are restricted to the western part (2%) and are conditioned by the higher altitudes of the Tisaru Massif. The 200–300 m/km² range (25%), covering one-quarter of the sector with an uneven distribution, also holds significant weight. The 100–200 m/km² (9%) and 400–500 m/km² (13%) classes are influenced, in terms of their spatial distribution, by their proximity to areas of high (over 500 m/km²) and low (less than 100 m/km²) relief energy, which have limited spatial coverage (Figure 21).

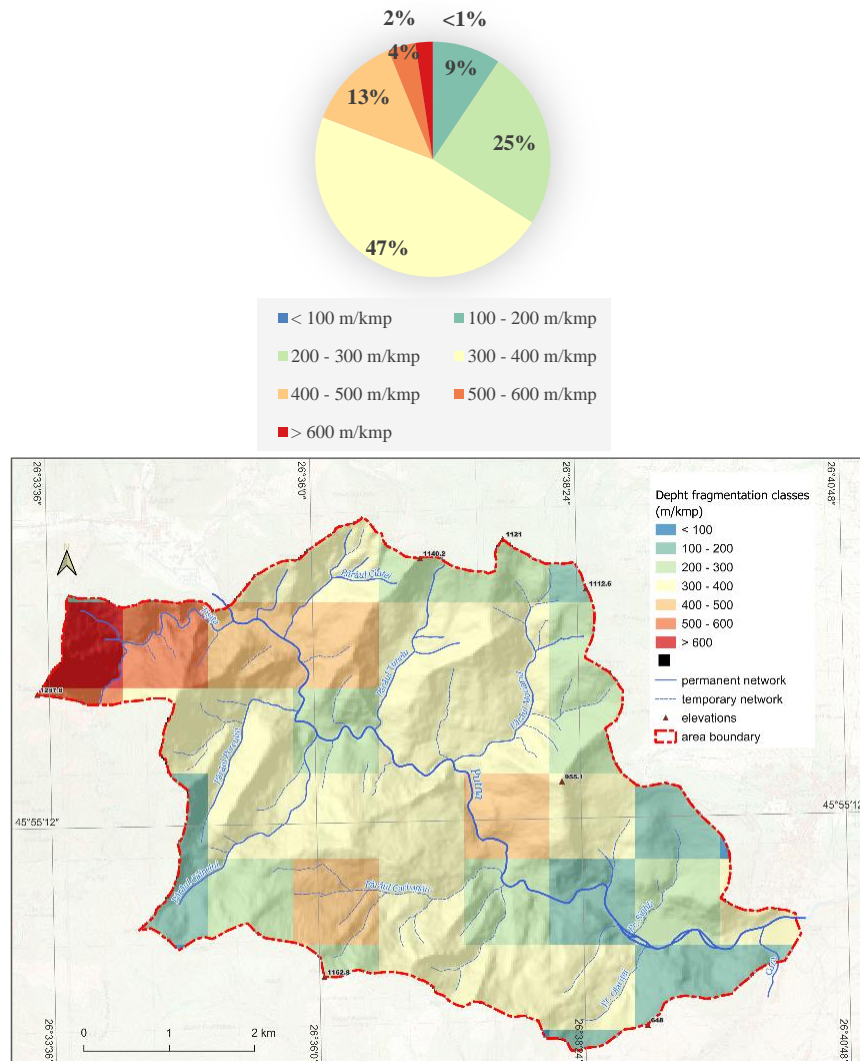


Figure 20. (upper) Percentage distribution of vertical relief fragmentation

Figure 21. (lower) Distribution of vertical relief fragmentation

The general morphographic characteristics of the Putna Valley and the detailed features of the study area highlight the dominance of slopes (Figure 22), which account for 60% of the total surface (Figure 23). Ridge areas, in all their forms (main ridges or valley shoulders), occupy 13% of the valley area. These are followed by valley-floor landforms (12%), while the channels themselves—characterized by permanent or

seasonal runoff and significant incision depth—occupy only 5%. The smallest shares are recorded by flat surfaces (< 1%), which occur locally on terrace treads, and isolated peaks (< 1%).

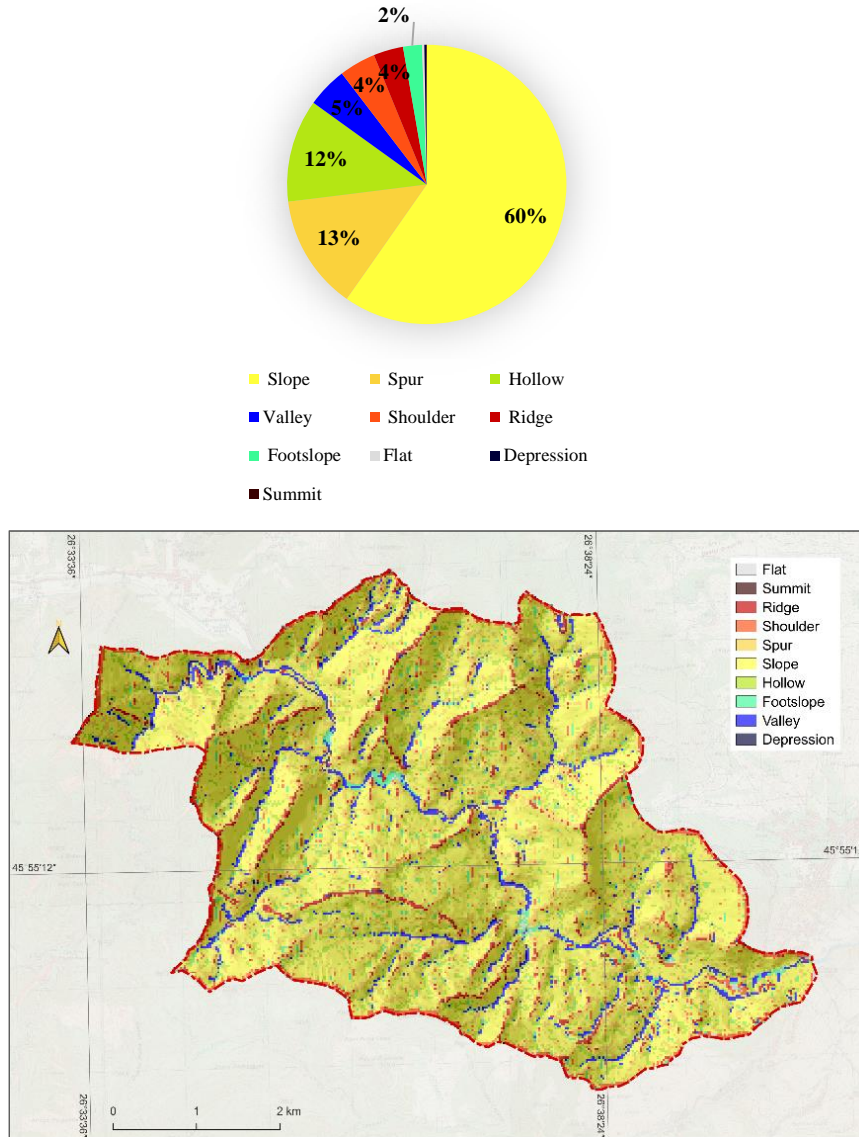


Figure 22. (upper) Percentage distribution of landforms

Figure 23. (lower) The main categories of landforms

Slope, as a fundamental property of surfaces, is a decisive factor in the development of geomorphological processes and the density of vegetation cover (Marcu, 2013). Six slope categories were defined, ranging from a minimum interval (0–3°) to values exceeding 55°. According to the percentage distribution of these categories (Figure 24), a significant share is held by the 20–35° range (46%), which characterizes most of the valley's slopes (Figure 25). The extremes—slopes above 55° and below 3°—account for less than 1% and 2%, respectively.

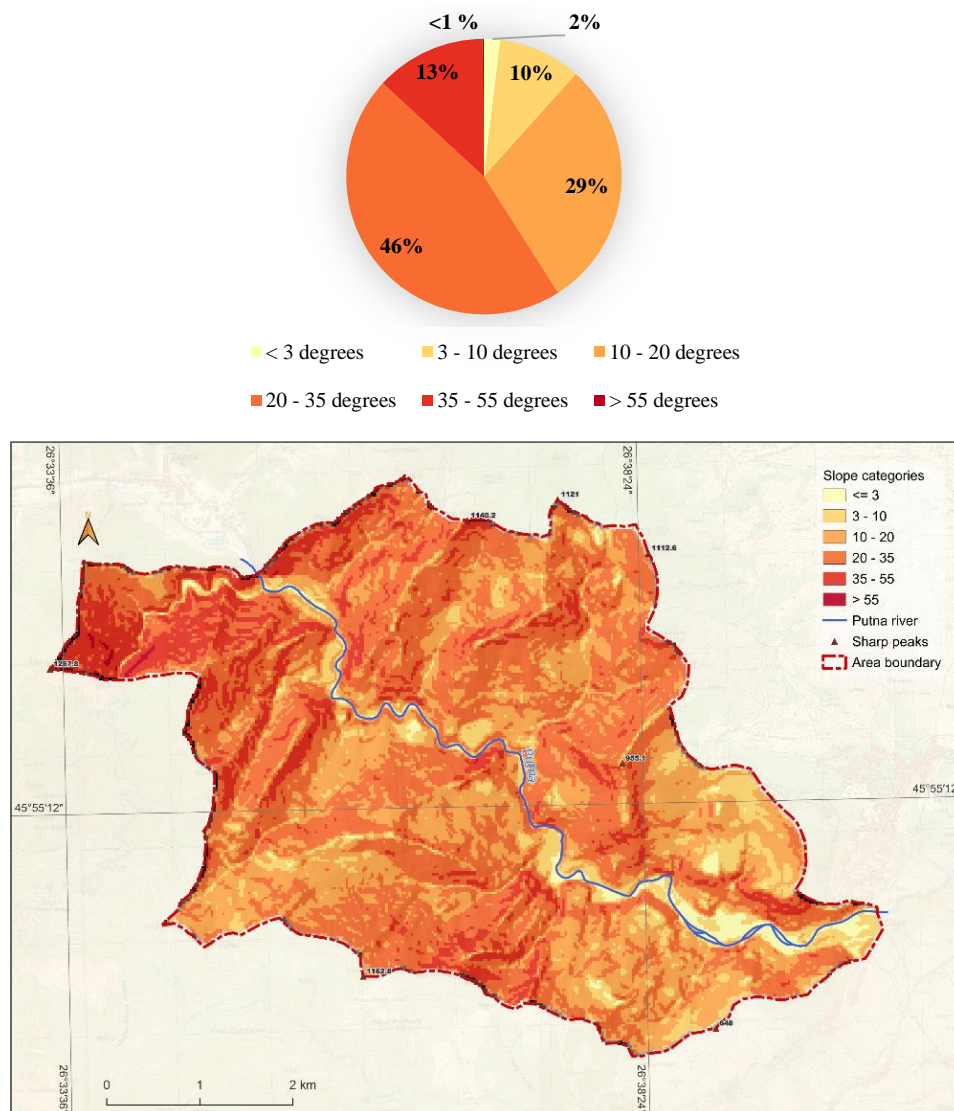


Figure 24. (upper) Percentage distribution of slope categories

Figure 25. (lower) Slopes in the area of the Putna valley

Slope orientation, or aspect, is determined by its position relative to the cardinal and intercardinal points, directly influencing exposure to solar radiation (Marcu, 2013). The distribution of slope aspects is diverse and relatively balanced (Figure 26): southeastern exposure accounts for 18%, followed by eastern (15%), southern (14%), western (12%), and northeastern and northwestern (11% each). Northern exposure represents the smallest share at 7%, while southwestern exposure accounts for 11% (Figure 27).

The geomorphological and morphographic characteristics of the ridges and slopes result from the formation and evolution of the Putna Basin relief. Field-based geomorphological profiles exemplify specific aspects of the valley's dynamics. In the profile (Figure 28a), the rounded appearance of the ridge is evident, prominently marked by Mociaru Peak; this landform is developed on a resistant lithological

substrate, primarily sandstone, which asserts itself within the topography. Mociaru Peak represents a well-defined valley shoulder, with an altitude of approximately 900 m and a length of about 500 m, extending in a NE–SW direction, perpendicular to the axis of the Putna River.

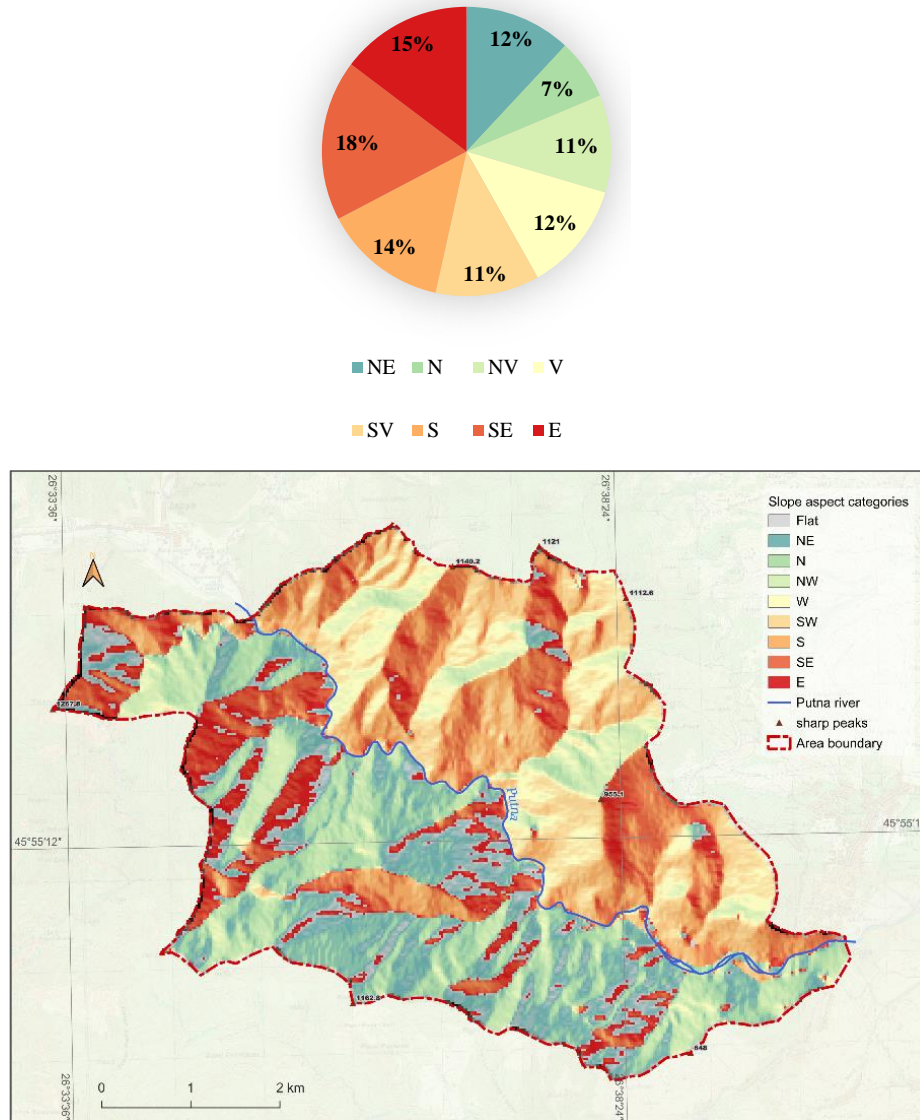


Figure 26. (upper) Percentage distribution of slope orientation
 Figure 27. (lower) Slope orientation in the Putna valley area

The additional profiles (Figure 28b and 28c) reveal the presence of three distinct terraces on the lower slopes, resulting from the valley's evolution during the Pleistocene; additionally, fragments of older, higher-level terraces dating back to the Neogene are also preserved.

The profiles (Figure 28d and 28e) also illustrate the slope characteristics below the valley shoulder marked by Pietricele Peak (955 m). In terms of position and orientation, this landform develops nearly parallel to Mociaru Peak (1,052 m), situated to its east, and asserts itself topographically due to the presence of resistant Kliwa Sandstone. Regarding the evolution of the drainage network, several secondary levels can be identified along the slopes (secondary valley shoulders at +800 m), resulting from successive phases of incision by the Putna River and its tributaries.

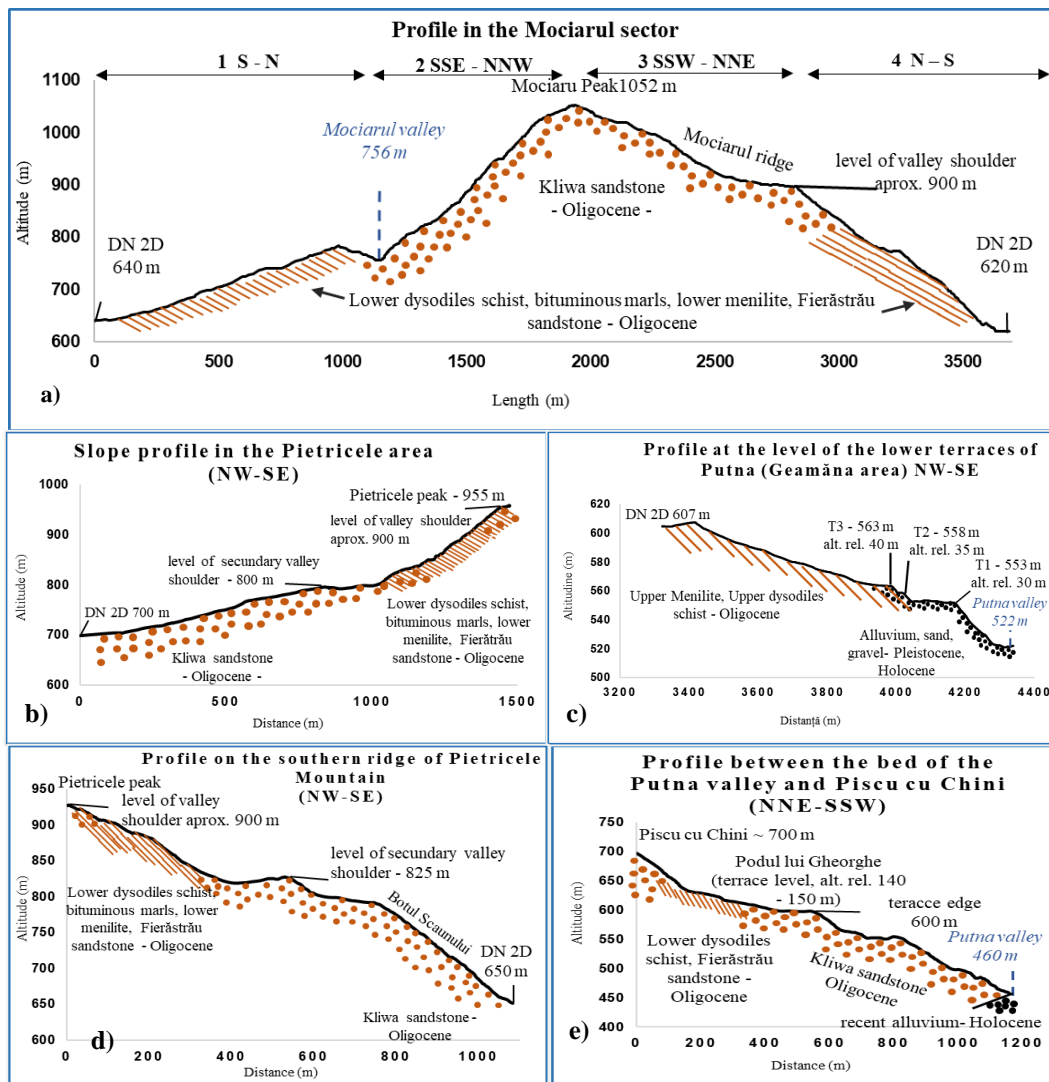


Figure 28. a). Mociaru; b). Pietricele1; c). terraces; d). Pietricele2; e). Piscu cu Chini

Acquiring primary data on the detailed morphology of the ridges and valley shoulders within the study area required the selection of routes relevant to these geomorphological features. The generation of geomorphological profiles was facilitated by the good road accessibility, particularly on the left bank of the Putna Valley (Figure 29).



Figure 29 Satellite image of the Putna valley in the studied sector with the highlighting of the profiles made

The survey routes were recorded via GPS in .gpx format, then processed and converted for visualization in QGIS, maintaining the projection of the corresponding base layer. In the case of the Mociaru Peak profile, specific points were marked (1 to 4) to clearly identify changes in direction, unlike the other profiles, which follow a single primary orientation based on ridge alignment or slope aspect.

3.3. Current dynamics of the riverbed and slopes

Regarding the Putna Basin, current slope processes include various forms of surface erosion (such as rilling) and mass movements, including rockfalls on lithological and structural scarps, landslides on deforested slopes, and mudflows (Cristea, 2011). Within the study sector, we observe slopes affected by active mass wasting, particularly near the contact with the Subcarpathians. In this area, the deposits are younger and more friable (Lower Neogene), and the presence of salt breccia further contributes to instability (Figure 30).

The development of gullies leads to surface degradation on slopes covered by secondary grasslands. Figure 31 illustrates a ravine system modelled by intense rainfall; these features reach depths of one meter or more and act as traps for debris (such as foliage and branches) transported by runoff. Furthermore, large-scale landforms associated with torrential systems (Figure 32) have developed, fed by heavy rainfall and seasonal snowmelt.



Figure 30. Badland Relief



Figure 31. (left) Gully channel developed following the action of intense rainfalls
Figure 32. (right) torrential valley, with temporary runoff, with transport of alluvial material



Figure 33. Forms of deposition in the minor bed of the Putna

The development of braided channels results from the interplay of factors related to the runoff regime—specifically sediment load (bedload)—as well as channel slope, grain size, and bank stability (with easily erodible deposits facilitating accumulation processes). From downstream of Pietricele Peak to the Subcarpathian border near Coza, specific fluvial landforms occur, such as small bars and eyots (river islands), which undergo morphological changes during flood events (Cristea, 2011).

Figure 33 illustrates the characteristics of a braided channel, a configuration particularly prominent towards the contact with the Subcarpathians, where the riverbed widens significantly. Deposition processes along the median axis created an alluvial bar that subsequently evolved into a stable river island following the establishment of riparian vegetation (alders and shrubs).

In analyzing fluvial processes, the morphology of the floodplain is essential, as it borders the active channel belt and, in certain mountainous reaches, completely overlaps with it where resistant rock formations limit lateral valley expansion. Within the studied sector of the Putna Valley, several floodplain terraces can be identified; the most recent of these, with heights of 1–2 m and 2–4 m, are composed of gravels, sands, and boulders deposited by the river. Between Lepşa and Tulnici, the Putna’s floodplain is intermittently narrowed or absent due to lithological and structural constraints. This causes the floodplain width to decrease to less than 20 m near knickpoints, such as the Putna Waterfall (Figure 34), while expanding to 200 m towards the Subcarpathian contact. The 1-meter terrace is situated immediately above the bankfull level, indicating its relatively recent formation.



Figure 34. Putna Waterfall



Figure 35. Rockfall in the Lepsa area, on the national road DN 2D.

Source: <https://shorturl.at/4nBOM>

Mass wasting processes affect slopes and surfaces with inclinations exceeding 30° , causing rock fragments or debris to move under the influence of gravity. In the mountainous sector of the Putna Valley, the extensive forest cover limits the occurrence of rockfalls, collapses, and rock rolls, except on slope sectors anthropogenically modified by road construction and adjacent infrastructure (Figure 35). Additionally, rockfalls occur in areas dominated by conglomerates and massive sandstones, which form prominent scarps due to their resistance. The most representative examples include the scarp below Piatra Streiului (formed on the eponymous conglomerates), where the Putna receives the Tișița stream on its right bank; the scarp at the confluence with Tunelul Stream on the left bank (opposite the tunnel on the DN2D road, km 70); and the scarp on the Piatra Geamăna conglomerates, which is also tectonically controlled by a fault axis.

On slopes or slope segments exposed by vegetation removal, the impact of external factors (such as precipitation and runoff), combined with the absence of effective protection measures, leads to rockfalls that can disrupt traffic on critical road segments.

Figure 36 summarizes the primary geomorphological characteristics of the study area, employing standardized symbols for each landform category in accordance with the general geomorphological legend used for the cartographic outputs. Consequently, landforms were classified based on several criteria—primarily genetic—to highlight both their spatial distribution and the relationships between their various components.

4. DISCUSSION

The presence of tectonic outliers (*covering patches*) at the outer edge of the Vrancea Nappe contributes to its structural complexity; these consist of Oligocene rocks (Kliwa Sandstone) that were originally part of the Tarcău Nappe to the west. Topographically, these features are marked by Munceluș Hill (648 m) on the right bank

of the Putna, and on the left bank by the Mociaru ridge (1,037 m) – Piatra Șoimului (682 m), followed by the Țiua Neagră – Țiua Spână ridge (1,069 m) and Omagu Peak (1,053 m) (according to the Bârsești geological map, 1:100,000 scale, Dumitrescu, 1952).

Associated with the folding of the strata, several tectonic disturbances (*faults*) occurred, as documented on the Bârsești Geological Sheet. A significant fault for the detailed morphology of the Putna Valley is the one intersecting the valley at the exit of the Greșu–Lepșa Depression (to the west); it creates two prominent scarps where the Piatra Streiului Conglomerates outcrop—specifically, the scarp at the base of Tisaru Mare and the one highlighting Piatra Streiului on the left bank (Dumitrescu, 1952).

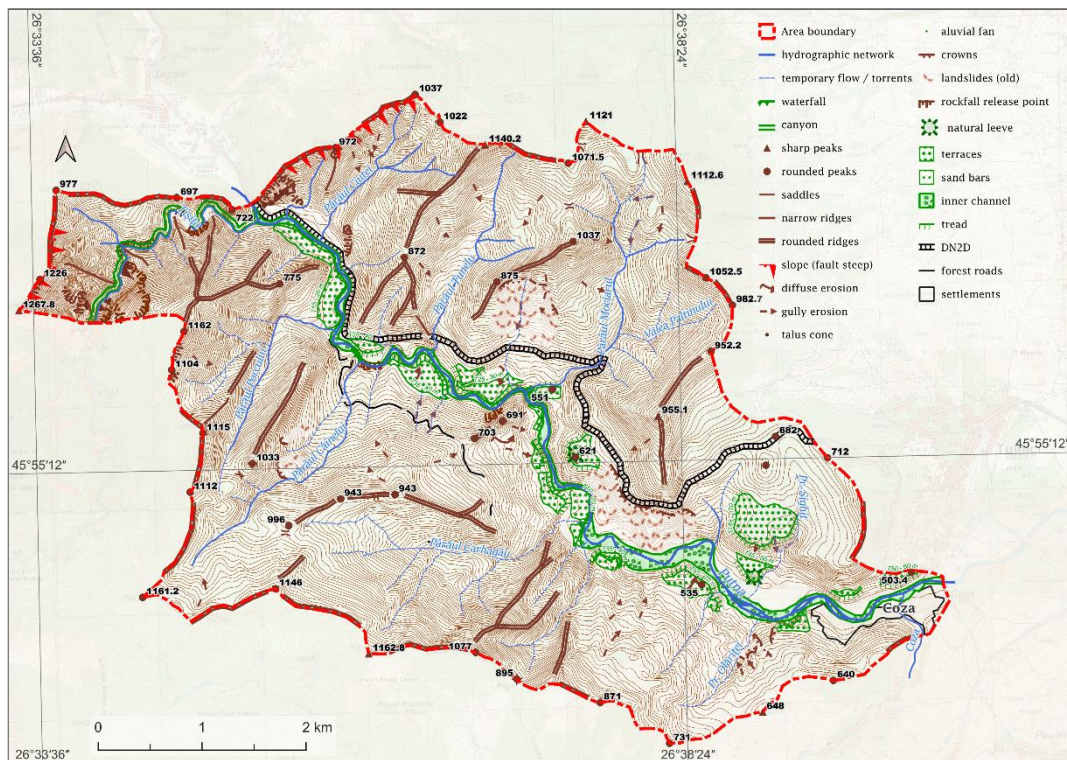


Figure 36. The main landforms and microforms resulting from the action of external and internal factors

The general west-east orientation of the river's flow is a result of large-scale tectonic uplift during the Pliocene–Quaternary period; consequently, the Putna River has incised through the geological formations within this segment. The valley's south-eastward deviation is attributed to the presence of Oligocene formations composed of Kliwa Sandstone, which is harder and more resistant to erosion (Cristea, 2011).

In fluvial networks, two types of tectonic movements can be identified, uplifts and subsidence, and relations between them led to two types of terraces formed, *strath* (where incision is dominantly) and *fill* (where sedimentation is preponderant) terraces (Necea et al., 2013). The distribution of fluvial terraces reveals that in SE Carpathian, especially in Putna basin, eleven terraces' levels was formed, from T1 to T11 (Necea et

al., 2013). Within the analysed valley sector, there are both *strath terraces* and *fill terraces*. The study led by Necea et al., 2013, focused on identifying and determining the ages of river terraces in the SE Carpathians, but also on understanding the mechanisms of control of their development. Thus, relevant for the sector between Lepşa – Tulnici are the terraces T5 – T7 (*Upper Pleistocene*), between Porcului and Mociarului stream, T8 – T9 (*Holocene*), between Tişiţa and Porcului stream and T2 (*Holocene*), between Carhagău stream and Coza (Necea et al., 2013).

The runoff regime is governed by precipitation input and the geomorphological setting of the drainage basin. At the Tulnici gauging station on the Putna River, the average multi-annual runoff depth is 390.7 mm; this value is higher in mountain basins, driven by more intense rainfall and increasing average altitudes. Regarding the distribution of average annual discharge, the year 2005 brought significant changes to peak runoff parameters, particularly within the Putna Basin (Chendeş, 2011). The highest discharge ever recorded for the Putna River was triggered by the July 2005 flood, which caused substantial material and human damage. At the Tulnici gauging station (located at the Carpathian-Subcarpathian contact), the maximum instantaneous discharge reached 342 m³/s, while the peak specific runoff was 938.9 l/s/km²—a record for July 2005. Consequently, the massive volume of sediment transported during the 2005 flood led to significant accumulation within the channel, forming new fluvial deposits (river islands, sand and gravel bars, etc.), particularly toward the Subcarpathian entrance, upstream of the confluence with the Coza stream.

The influence of lithological and structural factors is evident in the distribution of hypsometric belts, particularly through the maintenance of higher altitudes along the interfluvies (water divides) that delineate the study area. The lithological characteristics described above reflect a diverse composition and varying rock resistance, which are directly manifested in the morphology and orientation of the ridges. These substrate elements dictate the succession of sharp or rounded peaks grafted onto resistant rocks (such as Kliwa Sandstone), as well as a series of secondary ridges characterized by prominent valley shoulders at altitudes of 800–900 m. These features are situated below the general peak level of 1,000–1,100 m, where fragments of a levelling surface are preserved; this surface was termed the '*lower platform*' by Rădulescu (1937) and likely corresponds to the Carpathian marginal surface identified along the borders of mountain ranges at their contact with major depressions (e.g., the Braşov Depression). Furthermore, the valley shoulders below the level of the secondary ridges align with Carpathian erosion levels, locally referred to as either the '*Dacian erosion surface*' or the '*Lower Quaternary erosion surface*' (Ielenicz, 2011).

In the slopes systems, which slopes are the most common features of the landscape, it could be identifying several processes that lead to sediment mobilisation

on hillslopes. Thus, hillslopes represent the main source of sediment for river systems (Harvey, 2022). There had been identified four groups of hillslope processes, depending on the nature of the material entrained and the type of process, erosion – deposition: *scree processes, overland flow, creep, mass movements and landsliding* (Harvey, 2022).

On the other hand, fluvial systems provide, through flowing water, an incisional development on the landscape and represents the main pathway for sediment transfer in the drainage basins. Therefore, fluvial processes include three main processes, which lead to sediment transport and deposition through river channels: erosion, transport and deposition (Harvey, 2022). Depending on the processes mentioned above, it could be separated into two main types of channel morphology: *bedrock channels*, which resulted from a high stream power (erosion is dominant) and *alluvial channels*, which evolved under the influence between erosion and deposition (Harvey, 2022).

5. CONCLUSIONS

In the analysed sector, the Putna Valley exhibits numerous characteristics shaped by its overall morphogenesis and evolution. Specifically, the presence of valley shoulders—resulting from modelling processes—testifies to successive evolutionary phases within the Carpathian valley system. Various hypotheses proposed over the last century, particularly concerning the Curvature Carpathians, have emphasized the initial existence of longitudinal courses (N–S direction). Following the structural completion of the Subcarpathian sector during the Miocene–Pliocene, local drainage axes developed, leading to a reorganization of the pre-existing hydrographic network. According to theories dating back to Paucă (1942), this earlier network followed a predominantly west-east orientation.

Lithological and structural components have played, and continue to play, a decisive role in the current configuration of the valley. The fact that this sector developed exclusively within outer flysch formations provided a significant sediment source, fuelling the vigorous fluvial dynamics of the mountainous Putna basin. The coupled dynamics of the riverbed and slopes are integral to the contemporary processes governing the hydrographic system. Furthermore, the interplay between controlling factors and variables—such as fluctuations in liquid and solid discharge, as well as channel geometry—necessitates continuous morphological adjustments within the riverbed.

Unlike similar hydrographic systems, the Putna River maintains a high sediment load, driven by a dynamic hydrological regime and the specific geological and geographical context of its basin.

6. ACKNOWLEDGEMENTS

I would like to express my gratitude to Prof. Răzvan Săcrieru, PhD, for his invaluable support during field campaigns, his assistance in generating geomorphological profiles, and his insightful observations. I am also grateful for the cartographic materials he provided, which were essential to this study. Special thanks go to Prof. Alexandru Nedelea, PhD, Dean of the Faculty of Geography at the University of Bucharest, for his guidance in selecting the research topic. Additionally, I have greatly benefited from the expertise and references provided by Mr. Florin Roman, a distinguished researcher of the Vrancea region.

7. REFERENCES

- CHENDEȘ, V. 2011. Resursele de apă din Subcarpații de la Curbură. Evaluări geospațiale, Ed. Academiei Române, București.
- CRISTEA, A.I. 2011. Valea Putnei vrâncene – studiu geomorfologic, Ed. Universității Suceava, București.
- DE MARTONNE, E. 1907. Lucrări geografice despre România – Cercetări asupra evoluției morfologice a Alpilor Transilvaniei (Carpații Meridionali), volumul I, (eds.) V. Tufescu, Gh. Niculescu, Ș. Dragomirescu, Ed. Academiei Republicii Socialiste România, 1981, București.
- DUMITRESCU, I. 1952. Studiul geologic al regiunii cuprinse între Oituz și Coza. Anuarul Comitetului Geologic XXIV, București.
- DUMITRESCU, I. 1958. Harta geologică a României, foaia Bârsești, Comitetul Geologic al R.P.R, scara 1:100.000.
- FIELITZ, W., SEGHEDI, I. 2005. Late Miocene - Quaternary volcanism, tectonics and drainage system evolution in the East Carpathians, Romania. *Tectonophysics* 410: 111-113.
- GRUMĂZESCU, H. 1973. – Subcarpații dintre Călnău și Șușița. Studiu geomorfologic, Editura Academiei, București.
- HARVEY, A. 2022. *Introducing Geomorphology*, Ed. Dunedin, Edinburgh.
- IELENICZ, M., OPREA, R. 2011. România – Carpații (I - Caracteristici generale), Vol. V, Ed. Universitară, București.
- MARCU, M.F. 2013. Valea Vâlsan. Studiu geomorfologic, Ed. Transversal, Târgoviște.
- MATEESCU, ȘT. 1927. Cercetări geologice în partea externă a curbării sud-estice a Carpaților Români, An. Instit. Geol. Rom., XII.
- MIHĂILESCU, ȘT., NICOLAE, MIHĂILESCU, N., ȘT., MACOVEI, V. 1970. Valea Putnei cu privire specială asupra Vrancei, Ed. Științifică, București.

- NECEA, D. 2010. High-resolution morpho-tectonic profiling across an orogen: tectonic-controlled geomorphology and multiple dating approach in the SE Carpathian, Vrije Universiteit, Amsterdam.
- NECEA, D., FIELITZ, W., KADEREIT, A., ANDRIESEN, P., DINU, C. 2013. Middle Pleistocene to Holocene fluvial terrace development and uplift-driven valley incision in the SE Carpathians, Romania. *Tectonophysics* 602: 332-354.
- PAUCĂ, M. 1942. Asupra rețelei hidrografice și morfologiei regiunii de la Curbura de SE a Carpaților. *Revista Geografică Română* V, Fasc. I-II.
- RĂDOANE, N., RĂDOANE, M., ICHIM, I., GRASU, C., MICLĂUȘ, C. 1998. Dinamica sedimentelor. Aplicație la râul Putna-Vrancea, Ed. Tehnică, București.
- RĂDULESCU, N. AL. 1937. Vrancea. *Geografie fizică și umană, Studii și Cercetări geografice I*, Societatea Regală Română de Geografie, Atelierele Grafice SOCEC & Co., București.
- ROMAN, F. 1989. Munții Vrancei. Colecția „Munții Noștri”, nr. 47, Ed. Sport-Turism.
- SÎRCU, I. 1966. Terasalele superioare ale Putnei (Vrancea), *Analele științifice ale Universității „Al. I. Cuza”, serie nouă, secț. II b. Geologie-geografie, tomul XII*: 144-148.
- ZAHARIA, L. 1999. Resursele de apă din bazinul râului Putna. *Studiu de hidrologie*, Editura Universității din București.