Analele Universității București. Geografie
Vol. LXXV, p. 263-286
ISSN 1013-4115; e-ISSN 2247-238X
DOI: 10.5719/aub-g/75.1/13

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GEOMORPHOLOGICAL ANALYSIS AND HUMAN SETTLEMENT DISTRIBUTION IN THE LOWER DOFTANA RIVER BASIN (ROMANIA). A CASE STUDY OF THE SECIURI-BREBU MEGIEŞESC-DOFTANA-CÂMPINA ALIGMENT

Abstract. This article explores the relief characteristics of the Lower Doftana Basin (Romania) along the alignment of the Seciuri - Brebu Megieșesc – Doftana - Câmpina localities, and their implications for settlement distribution. The study is based on a Digital Elevation Model derived from 1:25 000 topographic data, complemented by landslides susceptibility data from ELSUS v.2 datasets and population statistics collected through Romania's 2021 Census. The results obtained show that the distribution of human settlements is influenced by relief, with the highest population concentrations being in sectors with relief energy and a medium to low susceptibility to landslides.

Keywords: morphography, morphometry, Doftana River Basin, GIS, relief-settlement relation

1. Introduction

The relation between natural landforms and human spatial organization represents a key topic in both physical and human geography. Geomorphological conditions play an important role in settlement distribution and density, land-use dynamics and infrastructure planning. The morphology of the terrain, hypsometry, geodeclivity, slope orientation and other characteristics

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of the relief influencing the accessibility, exposure and suitability for the land use (Haggett 2001). The Subcarpathians from Romania represent a complex geographical region with steep and moderate slopes and highly fragmented relief, conditions that significantly influence settlement patterns and regional organization. According to Baltălungă (2017), although the Subcarpathian is quite fragmented, it still has accessible corridors that have favored the development of human settlements in valleys and depressions. The great Romanian geographer Ion Conea, in 1931, stated about the Subcarpathians that "they seem to have been created from the beginning to shelter human settlements". The Lower Doftana River Basin is one of the examples of the Subcarpathian area where we can capture the interaction between relief – settlements – human activities.

Regarding the Doftana River Basin, the scientific literature is marked by the comprehensive geomorphological study conducted by Armaș (1999). In this work, the author analyses key geomorphological components: morphographic and morphometric elements, tectono-structural and petrographic potential, genetic types of relief, evolution of the hydrographic network, current relief modeling processes, geomorphological risk. Previous geomorphological investigations and additional data on the study area are mainly included in studies addressing the Subcarpathian sector of the basin or regional syntheses of the Curvature Carpathians and adjacent areas. Armaș (1999) offers a detailed research history of the Doftana River basin, starting with the first references in the studies of the geographer Emmanuel de Martonne (1907) up to the geographical research of professor Mihai Ielenicz (1981 quoted by Armaș I. 1999). Despite its geographical importance, the area has received limited attention in terms of quantitative geo-morphometric analysis linked to spatial development.

The present study aims to identify the morphographic and morphometric characteristics of the Lower Doftana Basin, on the alignment of the Seciuri – Brebu Megieșesc – Doftana – Câmpina localities, and to explore their implications for settlement distribution.

2. Study area

The study area is located in the southeastern part of Romania, in the historical province of Muntenia, occupying the northwestern part of Prahova County

(Fig. 1). From a hydrographic point of view, the study area extends along the lower course of the Doftana River, a left tributary of the Prahova River. The area includes 18 km of the river's length and about 53 km², covering its lower sector, as determined using Geographic Information System (GIS)-based analysis.

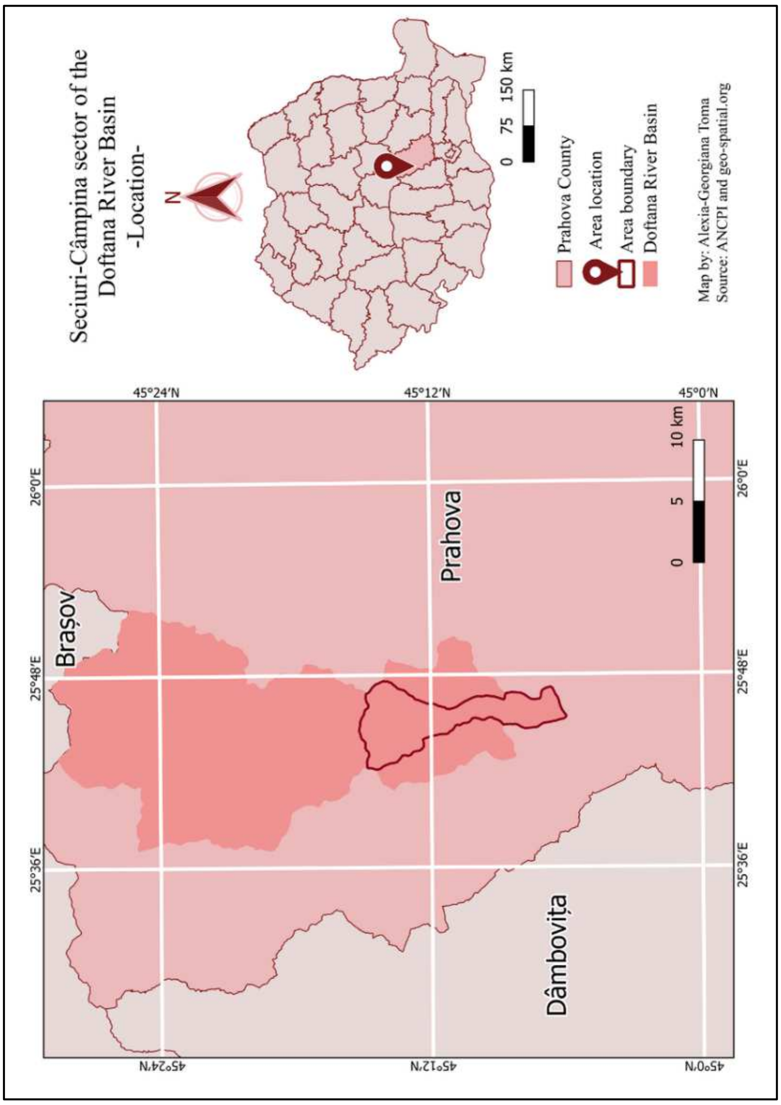

Figure 1. Location of the study area
(*Source:* ANCPI and geo-spatial.org)

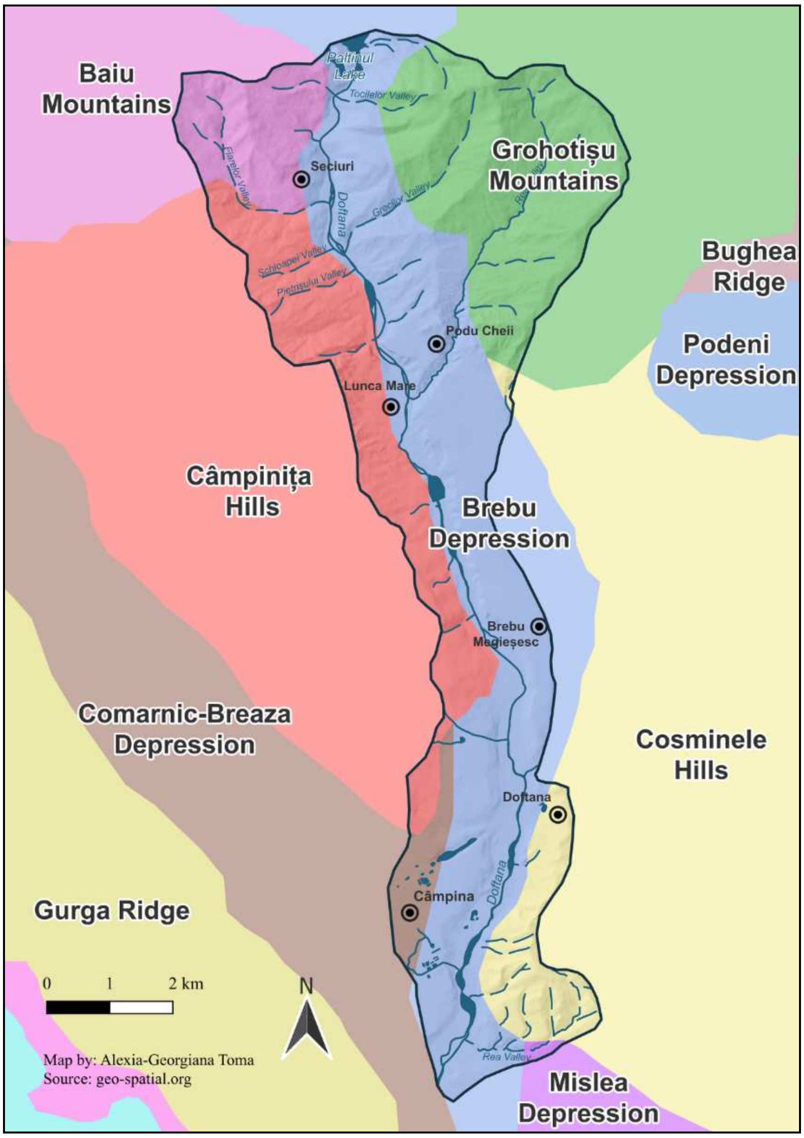

Figure 2. Distribution of relief units
(*Source*: geo-spatial.org)

Geomorphologically, the area overlaps primarily with the Curvature Subcarpathians (specifically the Prahova Subcarpathians) and a smaller portion of the Curvature Carpathians (namely the Baiu Mountains and Grohotiș Mountains). The relief units intersected include: Brebu Depression throughout the study are in the north-south direction, Baiu and Grohotiș Mountains in the nortwest and northeast, respectively, Câmpinița Hills to the central-west, Cosminele Hills to the east, Comarnic-Breaza Depression to the southeast, a small portion of the Mislea Depression to the south. The arrangement of these relief units reveals the geomorphological complexity of the area: mountainous region in the north (Baiu and Grohotiș Mountains), hilly region in the center, a transition zone from hills to plains in the south (Fig. 2).

The Doftana Valley runs transversely over an anticlinal-synclinal alignment, and the orientation of its tributaries is longitudinal (Armaș 1999). Clayey and marl-clay rocks, found in over 12% of the area (Fig. 3 a), play an essential role in the emergence of geomorphological processes. Combined with steep slopes and water infiltration into clay and schist layers, they create favorable conditions for landslides. Most of the area (72%) is covered by schists, sandstones, marls, and clays. Salt diapirs, gypsum, clay-schists, and sandstones cover less than 2%. Gravels and sands make up about 26% (Fig. 3 a) of the region, especially near rivers and streams. These deposits largely correspond to the fluvial terraces of Câmpina and Brebu and are composed of recent and subrecent alluvium, as well as Meotian sediments. The mountainous area consists of Senonian, Paleocene and Eocene sedimentary formations, together with Oligocene and Senonian flysch deposits (Fig. 3 b). According to Armaș (1999) "relief influences the intensity of current geomorphological processes through its degree of fragmentation, which determines the proportion of slopes in valleys, interfluves, and riverbeds, as well as their differential exposure to energetic fluxes crossing the system." Following the 1977 earthquake, measurements confirmed that south-facing slopes retreated 5–7 times more than north- or west-facing slopes (Armaș 1999).

The studied area includes six settlements: Seciuri, Podu Cheii, Lunca Mare, Brebu Megieșesc, Doftana and Câmpina (Fig. 4 a). The built-up areas represent 16% of the analysed area, which shows a development of the settlements adapted to the local conditions of relief and accessibility. The largest share is held by forested areas, which represent 34% of the analysed area. The second place is occupied by agricultural lands (20%), which are concentrated especially in low and relatively stable sectors (Fig. 4 b).

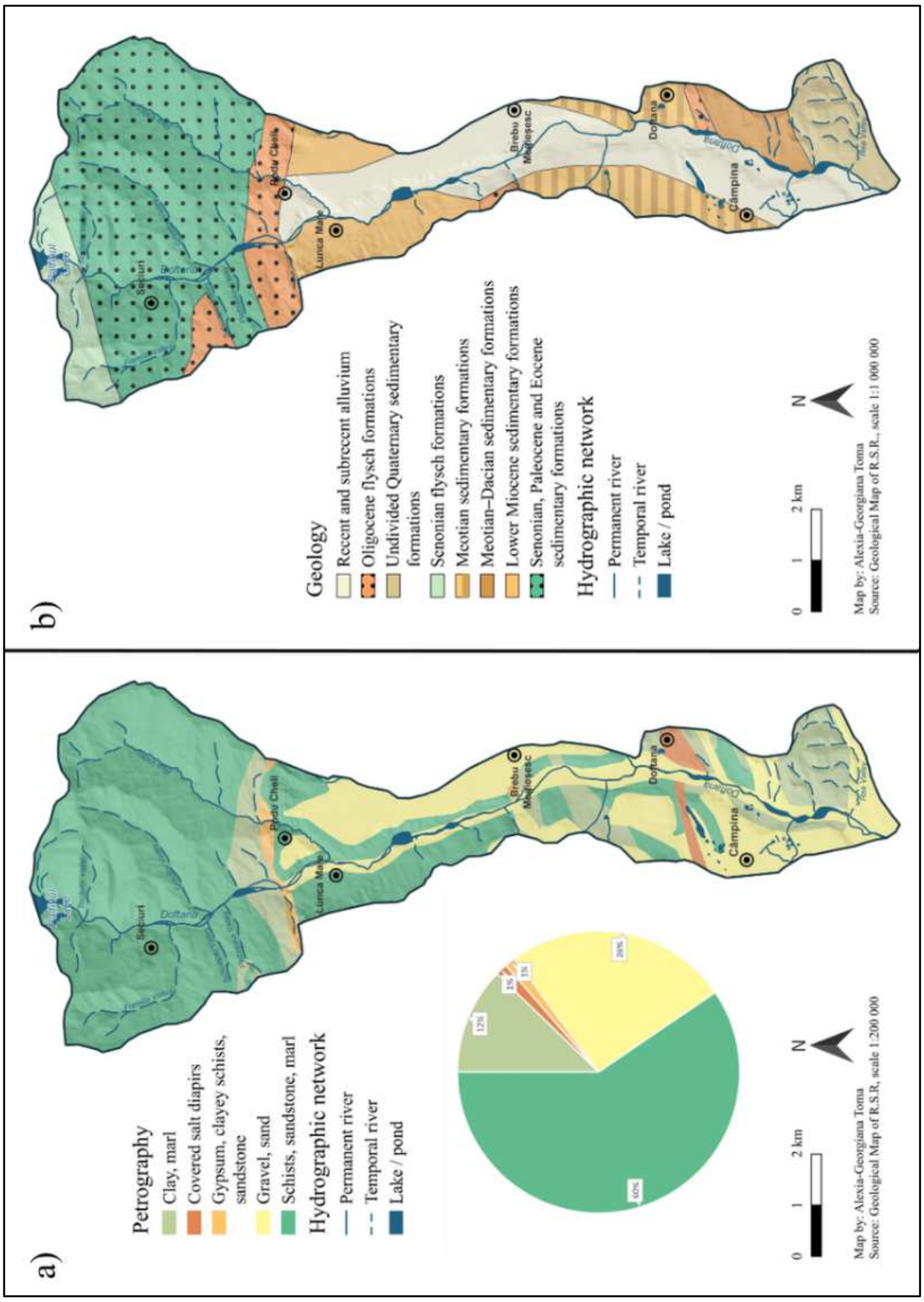

Figure 3. a) Petrography map b) Geology map
(*Source*: Geological Map of R.S.R., scale 1:200 000 and 1:1 000 000)

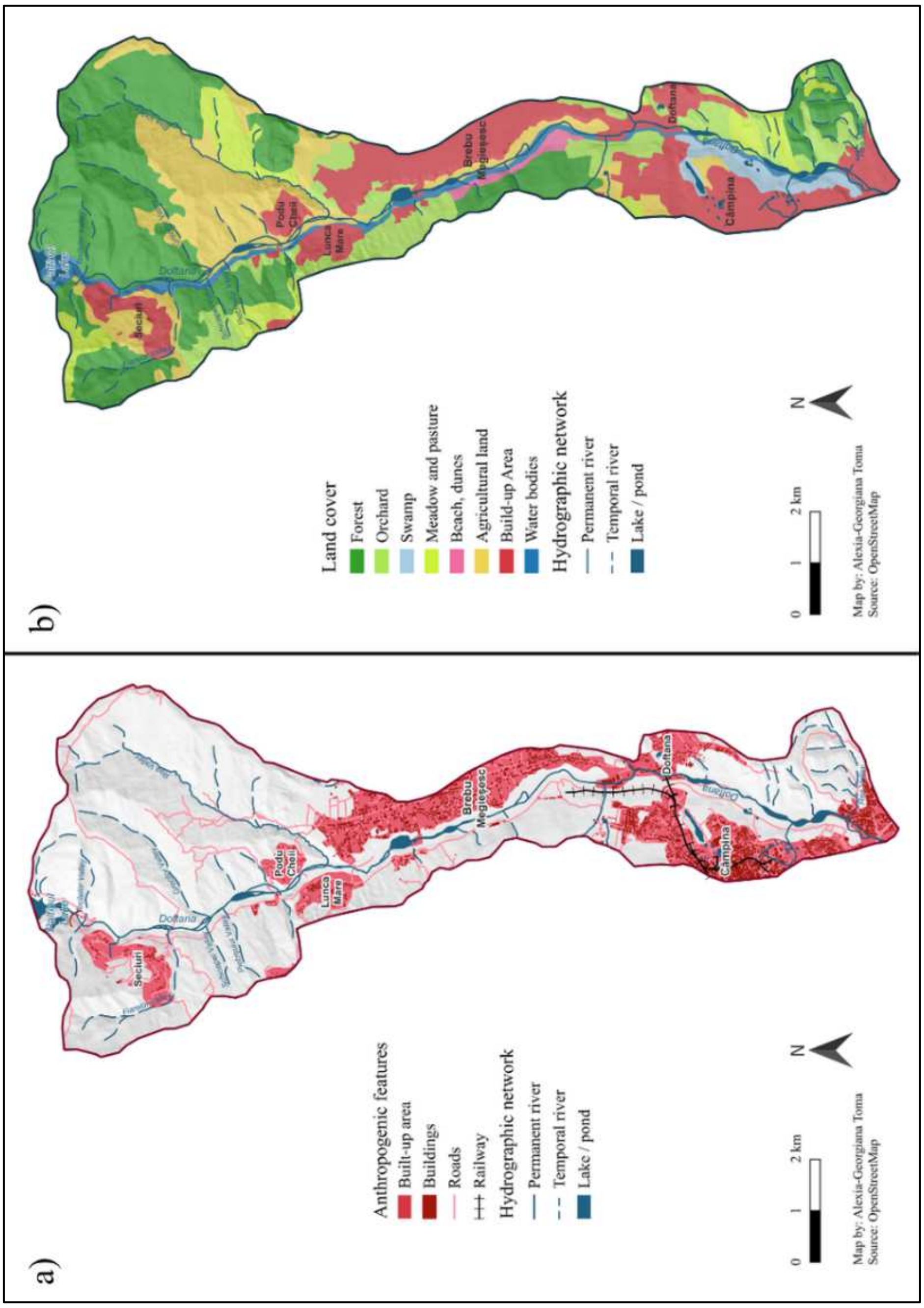

Figure 4. Distribution of the human settlements
(*Source*: OpenStreetMap)

The anthropic factor influences the relief through economic activities carried out in the area. In the studied zone, the main human interventions impacting the relief include construction of settlements, deforestation and soil pollution with hydrocarbons, due to the exploitation of numerous local oil fields. According to Armaș (1999), there are two categories of anthropogenic geomorphological landscapes: a lightly human-modified agro-pastoral landscape, typical of the mountainous area and a strongly a human-modified agro-industrial landscape, typical of the Subcarpathian zone. To this second category, we can also add the urban-industrial landscape found in the city of Câmpina.

3. Methodology

The methodology focuses on analysing the relief and their implications for settlement distribution and organisation, using geospatial data (table 1) and Geographic Information System (GIS) techniques. The first stage involves creating a Digital Elevation Model (DEM) based on the contours lines and altimetric points from the 1:25.000 Romanian Topographic Map.

Triangulated Irregular Network (TIN) interpolation method was used to combine the two datasets, which resulted in the DEM used for the analysis, with a spatial resolution of 25 meters. The Topographic Map of Romania, scale 1:25.000 is available on the OpenGIS Server for students, teachers and researchers from Faculty of Geography (University of Bucharest) following an agreement between the institution and the Military Topographic Directorate (currently Defense Geospatial Information Agency "Division General Constantin Barozii").

In the second stage, based on the DEM, the main landforms were extracted and a series of morphometric parameters (hypsometry, geodeclivity, slope aspect, relief energy and fragmentation density), were calculated. The relief classification included in the study utilises an algorithm developed by Jasiewics and Stepinski (2013), which calculates the forms using a machine-vision technique called geomorphons.

Table 1

Datasets used in the analysis

Dataset	Format	Source
Contour lines	Vector – ESRI Shapefile	Topographic map of Romania 1:25 000 (1975-1980) – Military Topographic Department (currently Defense Geospatial Information Agency "Division General Constantin Barozii")
Altimetric points		
Landslide susceptibility	Raster	European Landslide Susceptibility Map version 2 (ELSUS v2) – ESDAC European Commission – https://esdac.jrc.ec.europa.eu/
Geology	Vector – ESRI Shapefile	Geological Map of Romania 1:1 000 000 (1978) – Geological Institute
Petrography	Vector – ESRI Shapefile	Geological Map of Romania 1:200 000 (1960-1968) – Geological Institute
Geomorphology	Vector – ESRI Shapefile	Geomorphological Map of Romania 1:1 000 000 (1976) – Geography Institute; Armas I. (1999)
County boundari es of Romania	Vector – ESRI Shapefile	National Agency for Cadastre and Land Registration (ANCPI)
Land use	Vector – ESRI Shapefile	OpenStreetMap (OSM) – https://extract.bbbike.org/
Buildings		
Roads		
Railways		
Settlements		
Population Data	Raster	The National Institute of Statistics of Romania – The Romania's 2021 Census – data processed by geo-spatial.org

Source : Author's own elaboration based on data from multiple sources

The algorithm can be accessed through the r.geomorphon module. It results in 10 classes based on the distribution and structure of the values of neighboring pixels: flat, peak, ridge, shoulder, spur, slope, pit, valley, footslope, hollow (Ioniță et. al. 2024). Hypsometry was obtained by classifying the DEM into hypsometric intervals, set every 100 meters. The geodeclivity and slope aspect were calculated using the r.slope.aspect module, which calculates values based on a 3x3 neighborhood in the raster elevation map (GRASS Development Team, 2022). For the classification of the geodeclivity in slope classes we used the Grigore's classification from 1979 (cited by Săndulache, 2015). The relief energy and fragmentation density were calculated by the method of squares.

For the assessment of landslide susceptibility, we employed the ELSUS v.2 dataset, which was developed using the same semi-quantitative methodology applied in ELSUS 1000. This approach integrates landslide frequency ratio information with a spatial multi-criteria evaluation model based on three thematic predictors: slope angle, shallow subsurface lithology, and land cover. The updated map also incorporates an expanded landslide inventory, providing approximately 30% more locations for model calibration, map validation, and classification, and a revised lithological dataset derived from the International Hydrogeological Map of Europe (IHME). The latter covers a large portion of Europe at a spatial resolution of 200 m (Wilde et al. 2018).

All maps for this study were created in the Dealul Piscului 1930/ Stereo 70 projection (EPSG:31700). The software programs used for the study are QGIS (version 3.26) and GRASS GIS (integrated into QGIS) for generating maps and numerical data, Microsoft Excel for graphical representation of numerical data, Inkscape and Canva for graphic refinement of the results.

4. Results

4.1. Landforms classification map

The landforms classification map shows an integrated view of the geomorphological structure of the study area. The largest part of the studied surface is covered by slopes (52%), indicating a fragmented relief, with high potential for slope processes (torrentity, landslides). Totally flat surfaces occupy approximately 8% of the area, being located especially on terraces and floodplain sector, areas favorable for settlements and agricultural activities (Fig. 5 a). The main valley is that of the Doftana River, located in the center of the study area. On both sides are valleys of temporary or seasonal rivers, as well as valleys of permanent rivers, a total of 22. Of these, only four are valleys of permanent rivers. The most important secondary valleys here are: Valea Fiarelor, Valea Șchioapei, Valea Pietrișului on the right bank, and Valea Tocilelor, Valea Grecilor, and Valea Rea on the left bank.

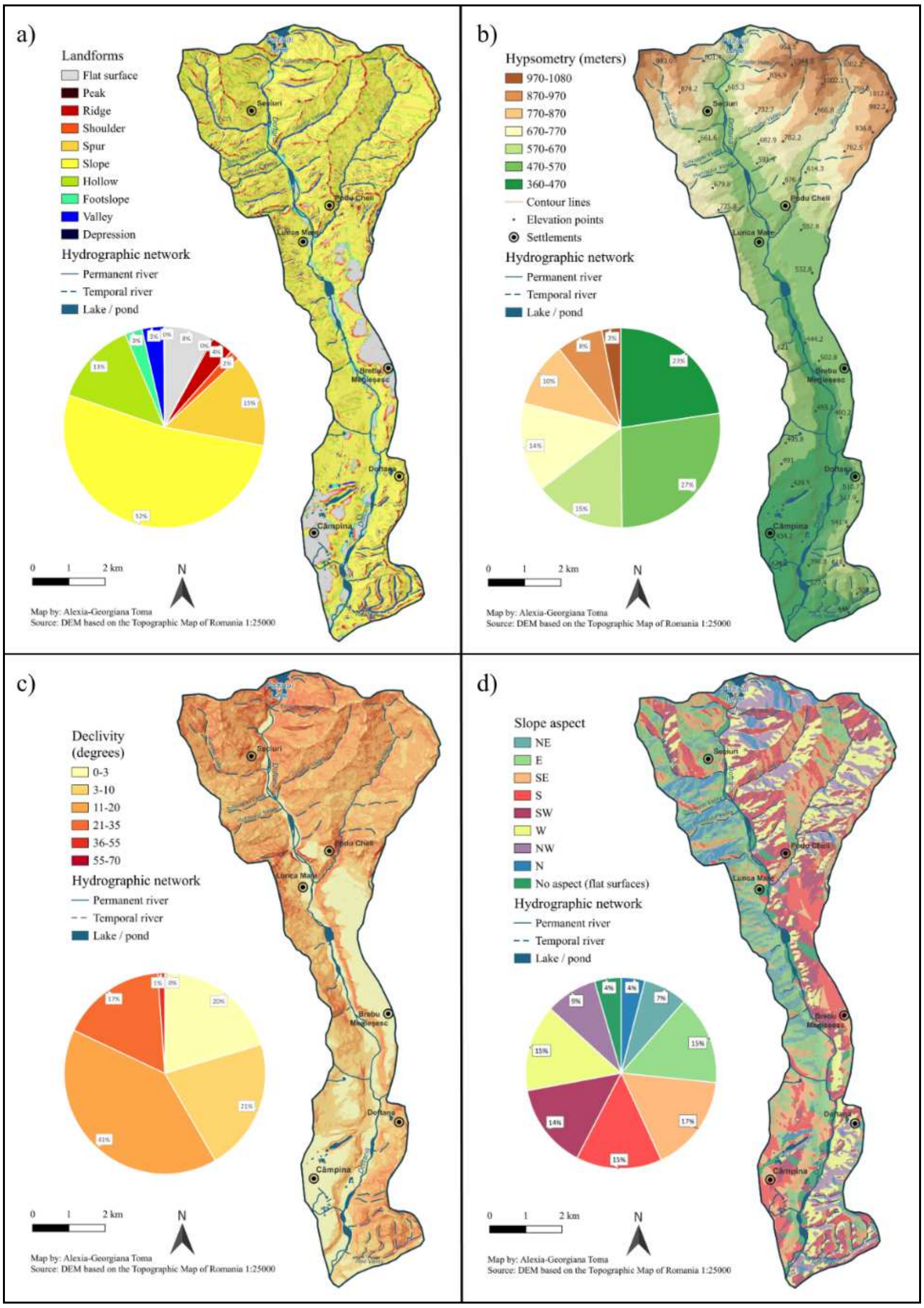

Figure 5. a) Landforms; b) Hypsometry; c) Slope; d) Slope aspect
(*Source*: DEM based on Topographic Map of Romania 1:25 000)

Within the study area, two types of interfluves can be found: flat and rounded (Armaș 1999). "Flat interfluves, initially much broader, are gradually transformed, through the branching and headward (regressive) advance of tributaries, as well as through slope evolution, into rounded sectors or even into a series of erosion remnants separated by wide saddles" (Armaș 1999: 94). In the studied area, these interfluves are located in the central and southwestern parts (identified on the map as flat surfaces), and today they form the main interfluves: Prahova–Doftana, Doftana–Lupa, and Lupa–Mislea (Armaș, 1999). Rounded interfluves are represented by the remaining interfluves in the territory.

4.2. Morphometric characteristics

The hypsometric map highlights the altimetry of an area, divided into hypsometric classes. It is based on the absolute elevation indicated by contour lines, which allows the assessment of the heights of each relief step (Săndulache 2015). Depending on the general distribution of altimetric values at the level of the lower Doftana River basin and the maximum difference of 1044.5m, regular hypsometric intervals were chosen, in principle, every 100 meters. So, according to the Fig. 5 b), in the studied area, the highest elevations (1044.5 m, the highest spot height, and 1,080 m, the highest altitude deduced from contour lines, both in the Grohotișu Mountains) are found in the northern part, in the transition zone between mountains and hills. At the transition between hills and plains, in the Doftana River valley, the lowest altitudes are found (377.4 m, the lowest spot height, and 365 m, the lowest altitude deduced from contour lines) within the area. The average altitude is 715 m. The largest surface area (27%) falls within altitudes of 470–570 m. Moreover, although elevations reach 1.080 m, half of the area lies below 570 m.

Regarding geodeclivity, there is a predominance of surfaces with moderate or sharp inclination, which reflects a fragmented hilly and mountainous relief. Slope classes between 11º-20º and 21º-35º represent approximately 58% of the total, highlighting a strong geomorphological potential with possible linear erosion, landslides and/or solifluction (Săndulache 2015). Steeper slopes are found almost entirely in the transition zone between the mountains and the hills, in the northern part of the area. Another zone with somewhat steeper slopes is found in the southeast, in the Cosminele Hills. They cover approximately 18% of the area and do not exceed inclinations greater than 55°. Very slightly inclined surfaces, respectively with a small inclination (below 10º) amount to 41% of the total analyzed surface. These are concentrated especially along the Doftana River, in the floodplain sector, but also on the bridge of its two terraces, where the localities of Câmpina and Brebu Megieșesc are located (Fig. 5 c).

The aspect of slopes determines the duration of sunlight received by surfaces. Together with slope steepness, slope aspect influences the thermal regime of the surfaces. The thermal regime is an important factor in the organization of agricultural activities. Slope aspect also determines vegetation inversions, the layout of technical works, landform modeling, and more (Săndulache 2015). According to their orientation, slopes are classified into four categories: sunny – S, SW (28%); semi-sunny – SE, W (21%); semi-shaded – E, NW (21%); shaded – N, NE (30%) (Fig. 5 d). From the strict perspective of slope aspect, the left bank of the Doftana within the study area is the most favorable for agriculture, as it is the sunniest.

The depth of relief fragmentation represents the difference between the maximum and minimum altitude (m) within each square (1 km²). Relief energy has its highest values, over 546 m/km², in the northern part of the area, closest to the mountainous region. Minimum values appear in areas with the smallest slopes, which coincide with the most humanized zones. Thus, the northern part has very high relief energy, while the southern part has very low relief energy. The central area serves as a transition between the two. High relief energy values cover 30% of the area (Fig. 6 a), making them the most common at the level of the entire study area.

Relief dissection density represents the ratio between the length of the hydrographic network (km) and the area (1 km²), highlighting the morphodynamic potential of the relief. Low values, 0–4 km/km², are usually recorded in flat areas (Fig. 6 b), which correspond to the terraces of the Doftana River. These values are the most frequently found across the study area (28%). The highest values are recorded at the upper limit of the area and in the southeastern part, reaching maximum values of 18 km/km².

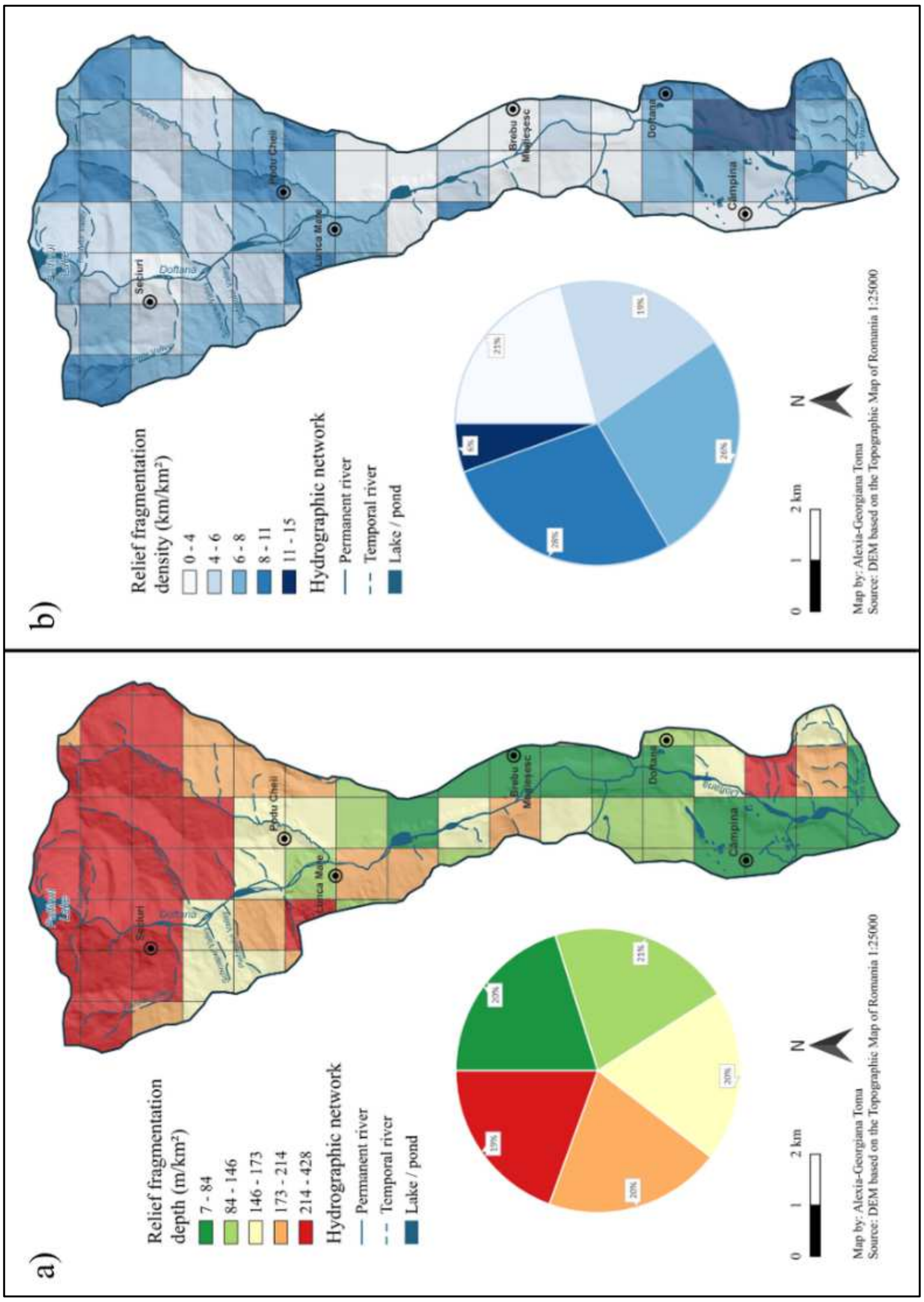

Figure 6. a) The depth of relief fragmentation; b) The relief fragmentation density
(*Source*: DEM based on Topographic Map of Romania 1:25 000)

They occupy only 15% of the area (Fig. 6 b), making them the rarest values found on the map. Overall, the relief dissection density is relatively uniform throughout the study area. However, lower values tend to be slightly more common than higher ones.

4.3. Landslides susceptibility

The studied area is characterized by moderate altitude (over 800-1000 m) and a lithological complex formed by layers of hard rock such as sandstone, which alternate with layers of soft rock (marls and clays). Also, according to Rujoiu-Mare et al. (2016) the region is crossed by a dense network of faults and presents a highly fragmented relief, on which significant anthropogenic interventions and a varied land cover are superimposed. All these characteristics influenced an intense spatial pattern of geomorphological processes (Fig. 7). Landslides are one of the most dynamic, active and intense processes in the Subcarpathian region, representing a significant issue in territorial management and spatial planning (Rujoiu-Mare et al. 2016).

In the low-altitude area the floodplain and the terraces of the Doftana River are present. In this area, landslides occur at the contact between the terrace slopes and the floodplain (Fig. 8 a). As highlighted by Posea (2006a), "the hilly region is characterized by steep slopes and pronounced fragmentation, accompanied by landslides and intense soil erosion. These degradation processes are further intensified by the predominance of soft rocks (clays, marls, sands), as well as by deforestation, intensive grazing, and, in some cases, plowing"). In the vicinity of the locality of Seciuri lies the Doftana Gorge (Fig. 9 b), caracterized by steep slopes affected by surface erosion and shallow landslides or shallow debris slides. Eroded slopes are also present south of the Doftana Gorge, in the vicinity of the locality of Lunca Mare, at the confluence of Doftana River with Rea Valley (Fig. 9 a).

The landslides susceptibility map for the analyzed area reveals a qualitative overview of areas with five susceptibility classes: very low, low, medium, high and very high (Fig. 8 b).

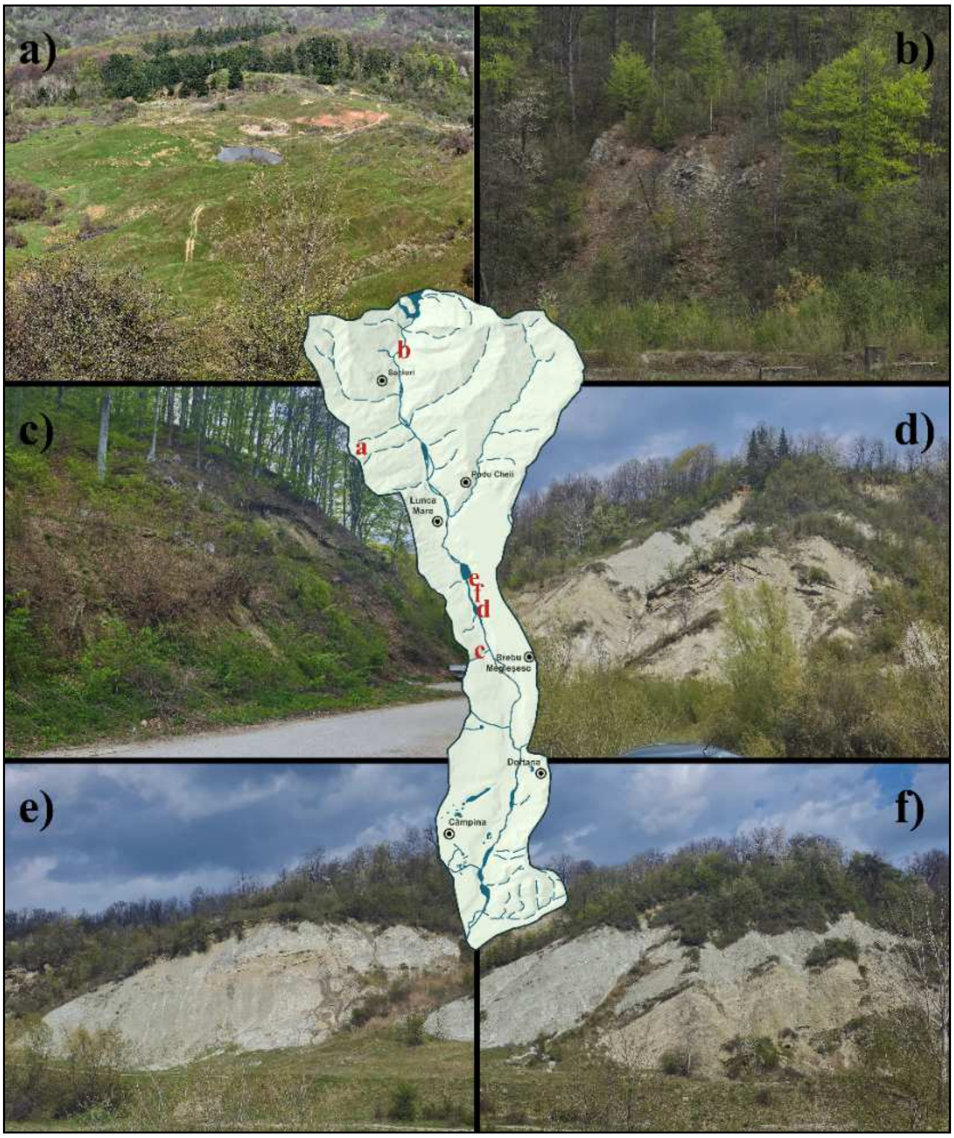

Figure 7. Active geomorphological processes observed in the study area (April 2026): a) Landslide; b) Shallow debris slide; c) Shallow landslide; d, e, f) Surface erosion and gullies (*Source*: own elaboration)

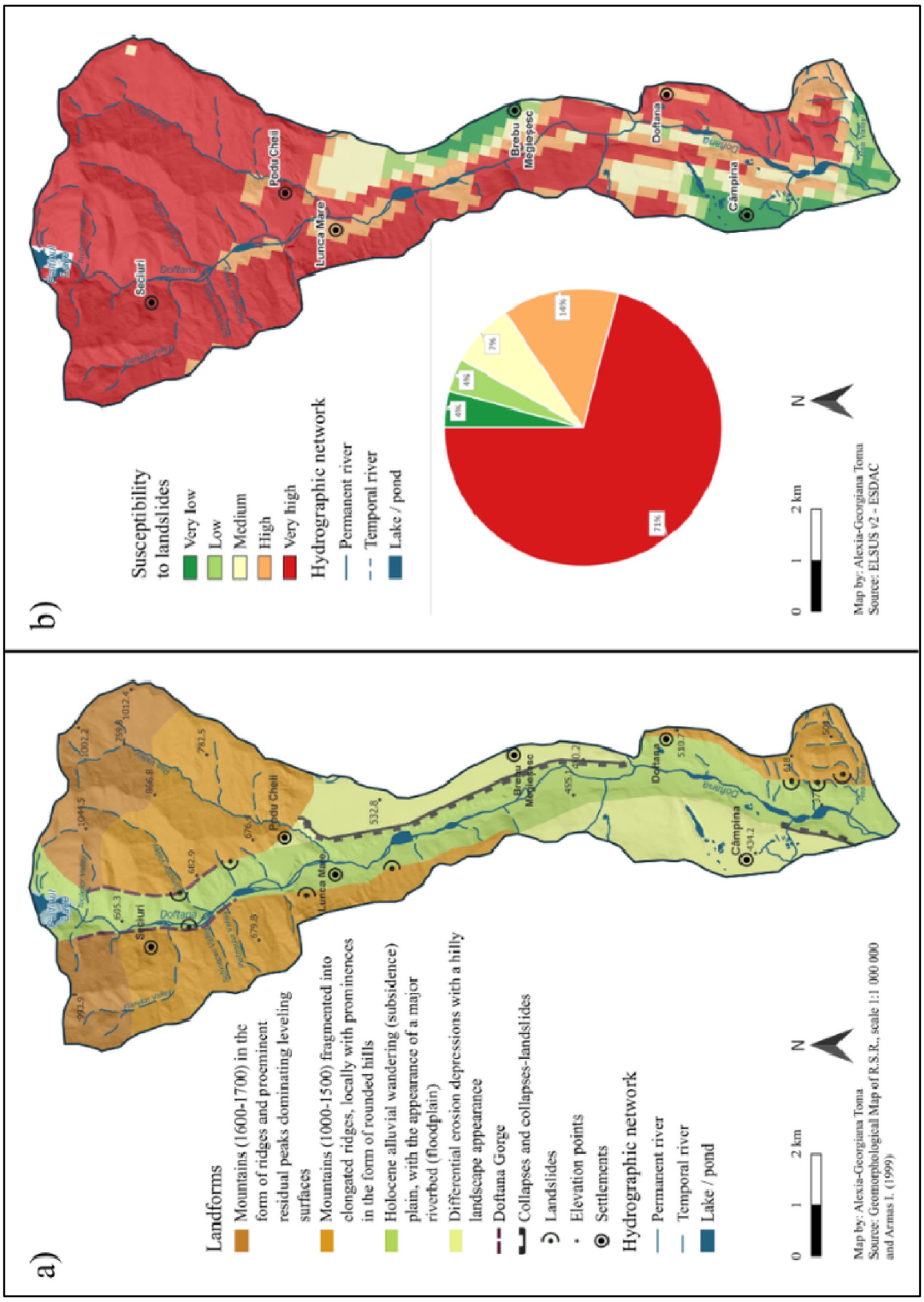

Figure 8. a) General Geomorphological Map; b) Landslide susceptibility map
(*Source*: Geomorphological Map of R.S.R., scale:1 000 000, Armas I. (1999) and ELSUS v2 – ESDAC)

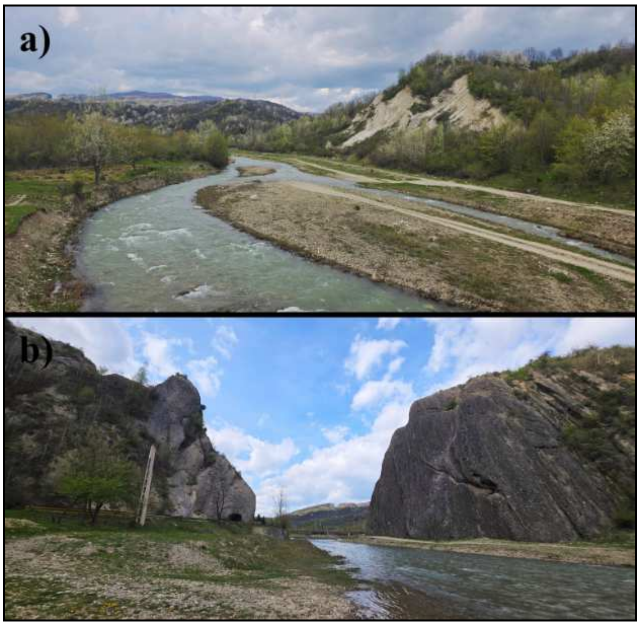

Figure 9. a) Doftana floodplain near Lunca Mare; b) Doftana Gorge (April 2026)
(*Source*: own elaboration)

The areas with very low landslide susceptibility match to the stable areas represented by the terrace treads such as Brebu and Câmpina terrace where localities with the same names are developed. On the other hand, terrace fronts are susceptible to landslides but also to other geomorphological processes preceding landslides (such as deep erosion, torrentiality). For example, in the Brebu terrace area, slopes are strongly affected by rill erosion and dissection, forming gullies and ravines, which may evolve into massive landslides and unstable zones called "badlands." These landslides contribute to the transfer of material into the riverbed (Armaș 1999).

5. Discussion

The relationship between relief and human spatial organization is an essential aspect of regional geography, especially in areas where geomorphological processes actively influence land stability and accessibility. In the study area, morphological (morphographic and morphometric) characteristics play an important role in the distribution and density of settlements. They also reflect the functional relationship between the slopes and Doftana Valley. Slopes act as sources of materials as a result of erosion processes and mass movements, while the valley and riverbed as the main axes of transport and accumulation. This interaction directly influences the spatial constraints and opportunities for human settlements. Similar aspects have been identified in neighboring Subcarpathian regions, such as the Prahova Valley (Vartolomei and Armaș 2010). Table 2 shows how the relief characteristics control the distribution and development of localities. Settlements located in mountainous units (Seciuri, Lunca Mare) have high average altitudes and a higher relief energy, factors that lead to very high susceptibility to landslides. These conditions represent a significant constraint in the development of localities and infrastructure. For example, at the level of the administrative unit of Șotrile, which includes the villages of Seciuri and Lunca Mare, the population is under 3500 inhabitants as shown by the population distribution map (Fig. 10).

A similar pattern is observed in the case of Doftana village, which is part of Telega commune. The area is characterized by a hilly relief and a high susceptibility to landslides, which leads to a limitation in the expansion of settlements and a smaller number of inhabitants.

In contrast, localities such as Brebu Megieșesc and Câmpina, located on fluvial terraces, benefit from low altitudes, slopes and lower relief energy, which favors the development of settlements, land stability and a medium to low susceptibility to landslides. Between the two, the larger population is concentrated in Câmpina – the most important locality from the study area due to its urban functionality and position în the proximity of a major circulation axis (DN1) with access to the Prahova Valley – one of Romania's major tourism and transport corridors. Brebu Megieșesc is part of the Brebu Territorial Administrative Unit (TAU), which includes three other villages, including Podu Cheii. In the Subcarpathian sector, the expansion of settlements influences the occurrence of geomorphological processes such as landslides. Older buildings are typically located on terraces, while newer constructions are scattered across peripheral and hilly areas and only rarely on terraces, thus becoming a contributing factor to landslide development (Vartolomei and Armaș 2010).

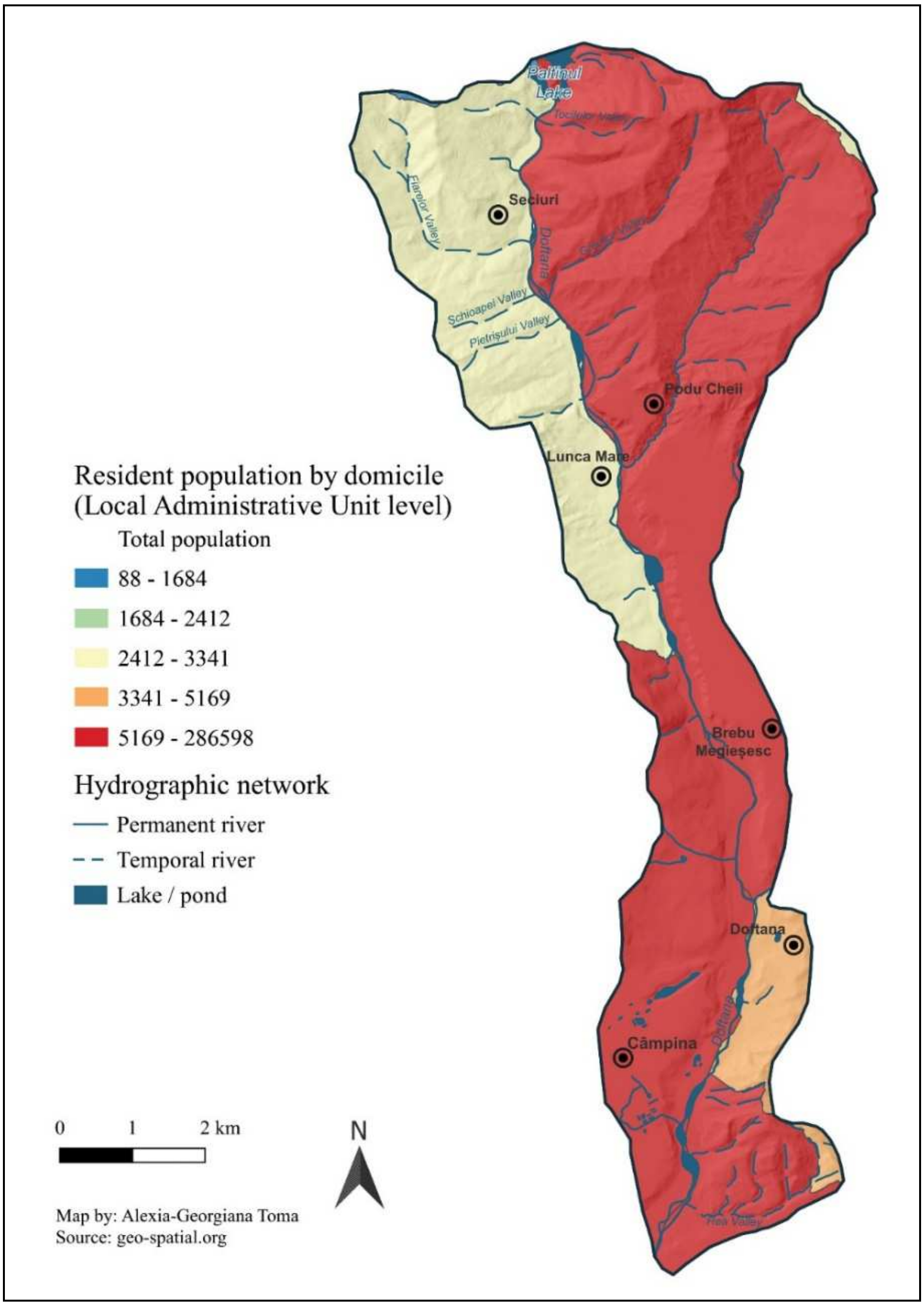

Figure 10. Resident population by domicile (in 2021)
(*Source*: geo-spatial.org)

Table 2

Statistical summary of geomorphological parameters and land cover at localities level

Locality	Relief Unit	Mean Altitude (m)	Mean Slope (°)	Mean Relief Energy (m/km^2)	Land Cover	Land Slides Susceptibility
Seciuri	Mountains	670.6	17.6	627	Built-up area, Agricultural, Water, Forest	Very high
Podu Cheii	Depression	556.7	8.4	379	Built-up area, Agricultural	Very high
Lunca Mare	Hills	515.8	9.4	485	Built-up area, Orchards, Water	Very high
Brebu Megieșesc	Depression	501.9	4.3	195	Built-up area, Orchards, Agricultural, Water	Medium
Doftana	Hills	467.0	10.5	352	Built-up area, Orchards	Very high
Câmpina	Depression	431.5	2.3	152	Built-up area, Agricultural, Orchards, Marshes, Water	Low

Source: Author's own elaboration based on GIS analysis

Overall, this comparative interpretation highlights the fact that relief is among the natural factors that can favor or constrain population concentration in mountainous and hilly areas.

To protect settlements, several measures can be implemented for slowing down or preventing landslides, the greatest hazard in the area: "contour ploughing, avoiding overgrazing, constructing gently inclined terraces with reinforced fronts or planted with shrubs and provided with drainage ditches, and afforestation" (Posea 2006b). Furthermore Posea (2006b) emphasizes that, in some cases a landslide can be prevented by just a few well-placed drainage ditches that ensure the runoff of water which could otherwise trigger slope failure.

6. Conclusions

The present study shows the role of geomorphological conditions in population concentration and settlement distribution. The Lower Sector of the Doftana River Basin is characterized by moderate altitudes, which deacresing from north to south (from 1080 to 365 meters). The same trend can be observed for the slopes, as well as for the depth of the relief fragmentation. Although some human settlements (Seciuri, Podu Cheii) are present in areas with higher relief energy and very high susceptibility to landslides, the majority of the population is concentrated in localities (Câmpina, Brebu Megieșesc) situated in areas with a more stable relief (flat surfaces, gentle slopes, low relief dissection) and a medium to low susceptibility to landslides. Datasets from multiples sources were used for this analysis: from National Topographic Map to European Landslide Susceptibility Datasets, from OpenStreetMap to the 2021 Romanian Census. All of these data used in the analysis helped to highlight the fact that the relief characteristics and geomorphological processes (such landslides) influence the accessibility, exposure and distribution of the human settlements.

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All links were verified by the authors and found to be functioning before the publication of this text in 2026.

DECLARATION OF CONFLICTING INTERESTS
The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

FUNDING
The authors received no financial support for the research, authorship, and/or publication of this article.