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MULTITEMPORAL ANALYSIS OF THE RELATIONSHIP BETWEEN LANDFORMS AND URBAN EXPANSION. CASE STUDY: CLUJ-NAPOCA, ROMANIA

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ABSTRACT. – Multitemporal Analysis of the Relationship between Landforms and Urban Expansion. Case Study: Cluj-Napoca, Romania. Given the current trend of urban development in Cluj-Napoca, the growing demand for land, and the expansion of the built-up area, this study aims to analyze the effects of urban development on landforms, while also establishing their functionality in an urban context. A multitemporal and multidisciplinary approach is essential for understanding the dynamics between relief and urban expansion, combining data from geomorphology, history, and urban planning. Field research is fundamental to this study for observations and direct verification of data. The analysis method exploits the principles of data overlay and spatial analysis using GIS (Geographic Information System). The starting point was the premise that within the urban area, the dynamics of the relief and/or the evolution of the geomorphological landscape are strongly influenced by anthropogenic action. The multidisciplinary integration of data facilitated the recognition and reconstruction of geological and geomorphological characteristics and changes in the function of the relief during urban expansion and the reconfiguration of land use: areas that were previously classified as unsuitable for construction and delimited as extra-urban, used mainly for agriculture, are now revalued as buildable land as a result of pressure from urban expansion. In other words, land is undergoing a process of functional reevaluation, in which the values and roles of landforms are reinterpreted according to the needs of urban development.

Keywords: *urban geomorphology, multitemporal analysis, multidisciplinary approach, Cluj-Napoca*

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1. INTRODUCTION

Cities around the world have developed on different geological and geomorphological structures, which has led to urban geomorphology studies being of great interest worldwide. This is due to the challenges that contemporary society must respond to in relation to the increase in urban population density and the intensification of anthropogenic activities in cities, and implicitly, the increase in the rate of urbanization. 70% of the world's population will live in cities by 2050, the growing demand for land will favor the uncontrolled expansion of built-up areas, affecting and disrupting any type of natural system surrounding the urban area itself (United Nations, Department of Economic and Social Affairs, Population Division. Revision of the World Urbanization Prospects, 2018).

Urban geomorphology is a recent subject, and its theory and practice require continuous updates. However, few studies have focused on issues specifically related to historical changes in landforms in urban areas, with the aim of reconstructing and clarifying the physical landscape, as well as determining the role attributed to landforms by the population. The IAG has set up an Urban Geomorphology Working Group with specialists from several countries with the aim of developing research methodologies to better understand the effects of urban development on geomorphological processes and landforms, in the context of increased hydrogeomorphological risk, also linked to climate change scenarios (P. Brandolini *et al.*, 2012). An additional theme is the assessment and consolidation of cultural geo-heritage in urban areas (Z. Zwoliński *et al.*, 2018).

In the field of urban geomorphology, there are specific studies and methodologies at the national level for analyzing the relationship between urban planning and geomorphological support in terms of favorability and/or restrictiveness. Among the major collective field works, one should mention those relating to the "systematization" plans of over 66 cities (initially), guided by the Institute of Geography, under the coordination of researchers V. Mihăilescu, V. Tufescu, and N. Pop (1949), and T. Morariu (1978).

In the field of urban geomorphology, humans act as geomorphic agents that transform the natural morphology into an urban landscape. Urban geomorphology represents the surface component of urban geology and constitutes an important subfield of environmental geology (D. Coates, 1976). Human settlements in general, and urban settlements in particular, expand in accordance with the configuration of the topographic surface, which undergoes changes depending on planning and construction needs (F. Ahnert, 1996). Other factors influencing geomorphological processes in urban environments include the degradation of building material due to air pollution (H.A. Viles *et al.* 1993).

F. Anhert (1996) argued that the geography of human settlements is incomplete without taking into account the morphology and hydrology of the area. Thus, it is essential to understand the dynamic interaction between different aspects of urban expansion, such as: the expansion of built-up areas, construction activities that affect natural elements, leading to the diversion and destruction of aquifers and geomorphological features specific to the urban area. Local landforms or geomorphic features have played a fundamental role in the location and development of human settlements throughout the history of civilization (A. Łajczak *et al.* 2021). In order to prosper, human communities have always assessed the local topographic configuration and favorable hydrological conditions.

With urban expansion and construction activities carried out over the years, the topography of the area is gradually changing (A. Łajczak and R. Zarychta, 2024). These transformations ultimately influence the rate of geomorphological processes such as erosion, areal processes, and weathering of rocks (H. A. Viles *et al.*, 1993).

Recent studies have attempted to propose new strategies for detecting and mapping human-induced changes in topography, and the classification of anthropogenic landforms has recently been further developed in the revised Italian national guidelines for geomorphological mapping proposed by AIGeo (Italian Association of Physical Geography and Geomorphology) and ISPRA (Institute for Environmental Protection and Research). Geomorphological studies in urban environments allow the reconstruction of the physical landscape before human changes and the implementation of innovative methodological tools, as well as an effective legend to represent urban landforms and their evolution over time (F. Vergari *et al.*, 2022).

Therefore, at the international level, current research focuses on developing methods and tools for assessing, defining, and monitoring the impact of metropolitan growth on geomorphology (P. Mozzi *et al.*, 2016; M. Del Monte *et al.*, 2016), the constraints imposed by geomorphology on urban development (R.U. Cooke 1976); the suitability of different landforms for areas of urban functionality (M. Del Monte, 2022); the creation of anthropogenic landforms in the urban landscape (I. Douglas 2016; J. Szabó *et al.,* 2010; M. Del Monte *et al.,* 2013); geomorphological risks in urban environments (F. Pratesi *et al.,* 2016); methods of geomorphological research and mapping in urbanized areas and/or areas profoundly modified by human activities (P. Brandolini *et al.,* 2018; Z. Zwoliński *et al.*, 2018); relationships between geomorphological changes in urban areas and archaeological and historical data (P. Mozzi *et al.*, 2016; M. Del Monte *et al.*, 2016); the geological model of anthropogenic resources (and their interactions with geotechnics, hydrogeology, and underground infrastructure design) (G.M. Luberti *et al.*, 2019).

Given the current trend of urban development in Cluj-Napoca, the growing demand for land, and the expansion of the built-up area, this study aims to analyze the effects of urban development on landforms, while establishing their functionality in an urban context. A multitemporal and multidisciplinary approach is essential for understanding the dynamics between landforms and urban expansion, combining data from geomorphology, history, and urban planning.

2. STUDY AREA

Cluj-Napoca has an area of around 179.5 km² and borders the local administrative units of Feleacu, Tureni, Apahida, Chinteni, Baciu, Florești, and Ciurila (fig. 1a).

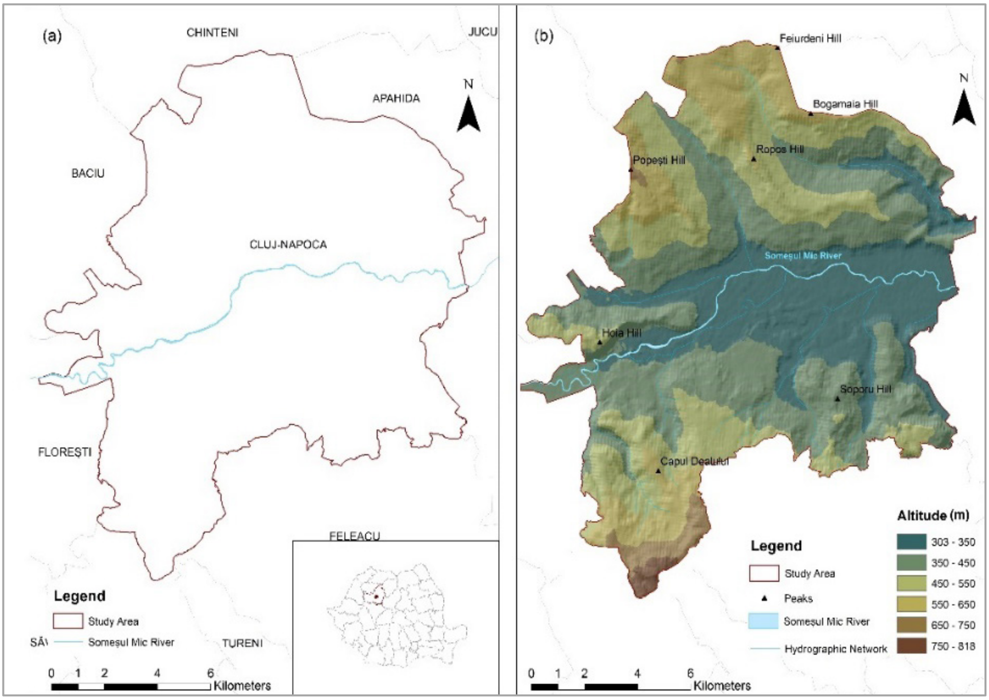


Fig. 1. a. The study area in relation to neighboring administrative units. The map shows the location of the study area within Romania; b. Hypsometric characteristics of the study area.
Source: the authors

A note of originality can be found in the contact between several landform units, as is the case with the territory surrounding the city of Cluj-Napoca. It is located at the confluence of Someşul Mic and Nadăşul rivers, at the contact point of three major morphological units - the Apuseni Mountains, the Someș Plateau, and the Transylvanian Plain - borrowing from the characteristics of each, which leads to a combination of landform features and makes it difficult to decipher the different geomorphological sectors.

In the study area, from a hypsometric point of view, there are values between 300-350 m a.s.l., which correspond to the floodplain and lower terraces of Someșul Mic River and the floodplain of Nadăș River; 350-450 m. a.s.l, representing the upper river terraces and limited portions of the low-lying areas. The altitude level of 450-650 m above sea level is attributed to the high-lying areas, structural areas, and slopes. These altitudes occupy the northern, southern, and southeastern parts of the study area. Altitudes higher than 650-700 m above sea level cover a small portion, in the form of peaks, developed on resistant rocks within the high interfluvial areas (fig. 1b).

We chose to study the municipality of Cluj-Napoca because it represents one of the urban structures with the most dynamic urban expansion in Romania, with an increasing demand for land and expansion into extra-urban areas. All of this leads to significant pressure on the relief with major changes in the initial surfaces.

3. MATERIALS AND METHOD

3.1. Multitemporal and multidisciplinary approach

Urban geomorphological studies on European cities have contributed substantially to the development of a methodological approach. In this paper, we will use the methodology developed and proposed in 2016 (M. Del Monte et al., 2016) and improved in 2020 (G.M. Luberti et al., 2020) by the Working Group on Urban Geomorphology of the Italian Association of Physical Geography and Geomorphology (AIGeo). The methodological approach is structured in three sequences: (a) storage of data from scientific literature and cartographic materials; (b) multitemporal and multidisciplinary interrogation; (c) field research and data completion.

The multitemporal and multidisciplinary methodological approach is based on: (a) interpretation of aerial photographs; (b) analysis of historical cartographic documents and comparison of data with current morphology; (c) analysis of rock types and deposits from data taken from geotechnical studies; (d) morphographic and morphometric evaluation; (e) data collection from historical documents and archaeological reports.

The strength of the method lies in its multidisciplinary approach: it integrates historical data on urban evolution in relation to the relief, field data, and multi-temporal geological, geomorphological, and geognostic data. Furthermore, this method, which is well known in Western and Mediterranean Europe, can be applied to all expanding European urban areas. The municipality of Cluj-Napoca is an example of such an urban area, so we would like to apply this methodological approach to this city as well. More specifically, we want to apply a method that is highly useful in international urban geomorphology studies to a territory in Romania. The GIS environment allows for the management of data overlay and the morphometric processing of historical data. ERDAS Imagine is used to interpret satellite images.

Field research is fundamental to this study for observations and direct data verification. The analysis method exploits the principles of data overlay and spatial analysis using GIS software. We start from the premise that in urban spaces, the dynamics of the relief and/or the evolution of the geomorphological landscape are strongly influenced by anthropogenic action. Multidisciplinary data integration allows for the recognition and reconstruction of geological and geomorphological characteristics and changes in relief function during urban expansion.

3.2. Data

In this study, the methodological approach described above was based on consultation, analysis of cartographic materials, interrogation, and superimposition of data layers (table 1).

Table 1. Summary of the cartographic supports used in this study

Data type	Year	Producer/ Provider	Process	Result
Map of the Roman site	2012	Acta Musei Napocensis, 49/I, 2012, pp. 83–108	Establishing the boundaries of the Roman city	Layer with the boundaries of the built-up area
The 2011 Cluj-Napoca PUG Baseline Study for determining protected areas with significant cultural value	2010	Cluj-Napoca	Establishing the boundaries of the first medieval enclosure and the medieval fortress	Layer with the boundaries of the built-up area
Historical map (Josephine)	1763	First Habsburg topographic campaign. Arcanum Maps	Georeferencing digitization	Layer with built-up area boundaries

Data type	Year	Producer/ Provider	Process	Result
Historical map (Franciscan)	1853	Second Habsburg topographic campaign. Arcanum Maps	Georeferencing digitization	Layer with the boundaries of the built-up area,
Historical map (Neue Aufnahme)	1869	Third Habsburg topographic campaign. Arcanum Maps	Georeferencing digitization	Layer with the boundaries of the built-up area
General Urban Plan	1976–1998	Cluj-Napoca City Hall	Georeferencing digitization	Layer with the boundaries of the built-up area
General Urban Plan	1998–2011	Cluj-Napoca City Hall	Georeferencing digitization	Layer with the boundaries of the built-up area
General Urban Plan	2011	Cluj-Napoca City Hall	Georeferencing digitization	Layer with built-up area boundaries
General Urban Plan	2014	Cluj-Napoca City Hall	Georeferencing digitization	Layer with built-up area boundaries
Geological Map of Romania 1:200,000	1964	Romanian Institute of Geology	Geoprocessing	Geological map of the study area
EUDEM_ STEREO70	2000	Copernicus Land Monitoring	Geoprocessing	Hypsometric map of the study area
CLC 1990	1990	Copernicus Land Monitoring	Geoprocessing	Land use map 1990
CLC 2018	2018	Copernicus Land Monitoring	Geoprocessing	Land use map 2018
P199R027_2X19750430 (satellite image)	1975	Earth Explorer. USGS. Landsat2	Photo interpretation	view of urban landforms
P185R027_5X19920925 (satellite image)	1992	Earth Explorer. USGS. Landsat5	Photo interpretation	Visualization of landforms
LE71850272005280AS N01 (satellite image)	2005	Earth Explorer. USGS. Landsat7	Photo interpretation	Visualization of landforms
LT51850272011241MO R02 (satellite image)	2011	Earth Explorer. USGS. Landsat5	Photo interpretation	Visualization of landforms
1:25,000 military topographic map	1975-1987	Defense Geospatial Intelligence Agency	Geomorpho-logical mapping of river terraces	Map of the river terraces of Someșul Mic
Historical photographs	End of the 19th century Early 20th century Mid-20th century Late 20th century	Collection “History of Photography in Cluj”	Interpretation	Determination of changes undergone: the bed of the Morii Canal, the bed of the Someșul Mic River, the Cetățuii Hill

Source: the authors

3.2.1. Geological data

The territory of Cluj-Napoca municipality contains Paleogene (Upper Eocene, Oligocene), Neogene (Lower-Middle Miocene), Pleistocene, and Holocene deposits structured into several formations with local names.

The geology of the study area is represented by processing the geological map at a scale of 1:200,000 and 1:50,000 produced by the Geological Institute of Romania (IGR) (fig. 2).

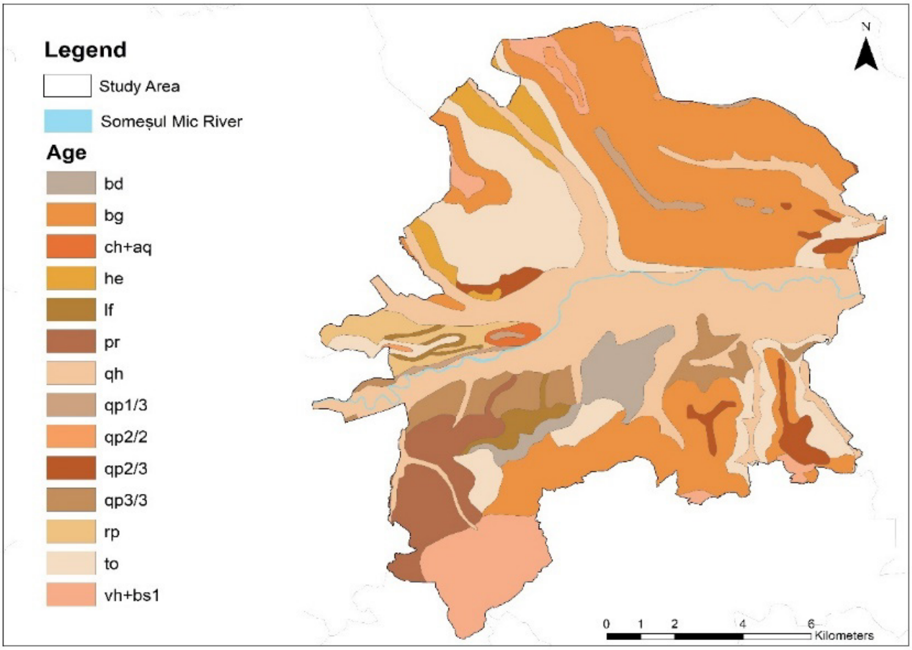


Fig. 2. Map of geological deposits in the city of Cluj-Napoca. The symbols indicate the age of the sediments: bd (Miocene-Eggenburgian -greenish sandy clays); bg (Miocene-Sarmatian-marls, sandstones, clays, tuffs); ch+ aq (Pliocene-Rupelian-sandstones); he (Miocene-Helvetian-conglomerates, sandstones, marly clays); if (Oligocene-Rupelian-sandstones, limestones); pr (Eocene-Priabonian-sands, red variegated clays); qh (Holocene-sands, silts, gravels); qp 1/3 (Upper Pleistocene basal-gravels, sands); qp 2/2 (Upper Pleistocene middle-sands, gravels); qh 2/3 (Upper Middle Pleistocene: sands, gravels); qh 3/3 (Upper Terminal Pleistocene – sands, gravels); rp (Oligocene-Rupelian-red streaked clays, gravels, limestones); to (Tortonian – marly clays, salt, gypsum, tuffs); vh+bs1 (Miocene-Volhynian-Bessarabian – sands, gravels with concretions).

Source: Geological Map 1: 200,000 (1968), Geological Institute of Romania

The Eocene-Priabonian deposits form a sedimentary series, the lower level of which consists of sands and the upper level of red clays. The sandy layer has aquifer potential, while the clays at the top are impermeable. As a foundation soil, it is stable only on flat surfaces, behaving unsteadily on slopes and in conditions of variable humidity (A. Vîjdea *et al.*, 2013).

Cluj limestones, also known as "upper coarse limestones", were formed in a carbonate platform environment with rich marine fauna. Although limestone is a soluble rock, it performs well as foundation soil, provided there is no acidic groundwater. It can also function as an aquifer, but the humidification of slopes favors their instability (A. Vîjdea *et al.*, 2013).

The Oligocene-Rupelian deposits consist of sandstones, sands, clays, and limestones with marine fauna. In the Cluj area, its base is represented by the Hoia Limestones. This formation behaves well as foundation soil and does not favor significant accumulations of groundwater. In the Tăietura Turcului and Cetățuie area, the Oligocene-Rupelian deposits are formed of red continental clays with layers of sand, sandstone, and conglomerates (A.R. Marat *et al.*, 2022).

The Oligocene-Rupelian sandstone geological deposits, called the Gruia Sandstone Formation, consist of a succession of more or less calcareous sands and sandstones, clays, and microconglomerates.

The Miocene-Eggenburgian geological deposits are composed of sand, sandstone, and microconglomerates with marine fauna. It has a transgressive character and represents good foundation soil, with the possibility of functioning as an aquifer reservoir. The Câmpie Group is developed over extensive areas in the northern, eastern, and southeastern parts of the Cluj area. At its base there are tuffs interbedded with marls, followed by gypsum deposits and, in some areas, salt.

The Feleac Formation, consisting of sands, sandstones, and conglomerates, has favorable characteristics for foundations. However, it can accumulate water, negatively affecting unstable underlying formations. Clay intercalations can also promote landslides (A. Vîjdea *et al.*, 2013).

On Cluj sheet map at the 1:50,000 scale, only Quaternary formations are newer than the above-mentioned ones. They are present both as terrace deposits and as floodplain deposits along all the valleys in the studied area and are represented by sands and gravels.

3.2.2. Land use data

For a better understanding of the reasoning behind the current urban expansion, it is necessary to analyze land use at two distinct points in time. To this end, open-source datasets were downloaded from the Copernicus platform, namely the CORINE Land Cover (CLC) datasets for 1990 and 2018 (table 2).

The CORINE Land Cover product, in its current form, is a pan-European inventory of land cover and land use, comprising 44 thematic classes ranging from extensive forest areas to individual vineyards.

This inventory is updated every six years, with the inclusion of new layers of status and changes, the last update having been carried out in 2018. CLC has multiple practical applications, such as environmental monitoring, land use planning, climate change impact assessment, and emergency management. In this study, the CLC dataset was used to determine changes in built-up area relative to natural area.

Table 2. Characteristics of CLC 1990 and CLC 2018

Characteristics	**CLC 1990**	**CLC 2018**
Satellite data	Landsat-5 MSS/TM, single date	Sentinel-2 and Landsat-8 (to fill gaps)
Time interval	1986–1998	2017–2018
Geometric accuracy	≤ 50 m	≤ 10 m (Sentinel-2)

Source: Copernicus Land Monitoring website

Based on the vector datasets, two maps representing land use patterns for 1990 and 2018 were created using ArcMap 10.8 software.

Subsequently, based on the attribute tables of the downloaded data (table 3), information on the area corresponding to each type of land use was extracted.

Table 3. Land use data for 1990 and 2018

Label CLC	Cod CLC	1990	2018	Modificare (+-%)
Continuous urban fabric	111	387,52	0,00	100
Discontinuous urban fabric	112	2905,83	4593,60	58,08
Industrial or commercial units	121	1264,52	1611,04	27,40
Airports	124	0,00	127,68	100
Mineral extraction sites	131	0,00	35,46	100
Dump sites	132	0,00	45,05	100
Construction sites	133	25,96	717,62	2664,25
Green urban areas	141	255,68	198,89	-22,21
Non-irrigated arable land	211	18121,01	10501,00	-42,05
Vineyards	221	59,47	0,00	-100
Fruit trees and berry plantations	222	1673,84	1496,67	-10,58
Pastures	231	4400,00	8065,81	83,31
Complex cultivation patterns	242	1235,00	986,43	-20,13
Land principally occupied by agric	243	1097,37	1393,45	26,98
Broad-leaved forest	311	6694,55	6598,29	-1,44
Coniferous forest	312	28,65	26,50	-7,50
Transitional woodland-shrub	324	193,42	71,00	-63,29
Inland marshes	411	54,74	0,00	-100
Water courses	511	107,10	107,10	0

Source: Copernicus Land Monitoring website

This data was organized into a new table in Microsoft Excel, based on the two years selected for analysis. Then, the percentage changes in area were calculated by applying the following formula:

$$(Ln-Kn)*100/Kn,\ n\in[4,22]$$

L and K are the names of the columns in Excel; n is the row number

In the final stage, the areas were grouped into two categories: built-up areas and natural areas. For each type of area, the corresponding percentages for the years studied were determined, and the results were represented graphically in the form of pie charts to facilitate data interpretation. By extracting the built-up areas between 1990 and 2018 and superimposing them on the slope map and digital elevation model, the current trend in the urban expansion of Cluj-Napoca was analyzed.

4. RESULTS AND DISCUSSIONS

4.1. Trends in land use

To determine the dynamics of geomorphology and urban expansion, it is not enough to assess the evolution of the official built-up area. Even if it coincides to some extent with the real built-up area, in this case it is only a convention. This was found following an analysis of the General Urban Plan published in 2018, in which the proposed built-up area boundary far exceeded the current built-up area boundary. We therefore resorted to using the CLC datasets from 1990 and 2018 to determine the changes undergone by the natural space in favor of the built-up space.

Based on the data, land use maps were created (fig. 3 and 4) to visualize the changes in the terrain.

Firstly, only by analyzing the maps can we observe the disappearance or appearance of certain land use patterns. More specifically, in 1990 there were continuous urban areas and vineyards, but these disappeared by 2018 due to urban or agricultural conversion. Furthermore, built-up areas are diversifying, and new types of land use are emerging: mineral extraction sites, waste disposal sites, and construction sites.

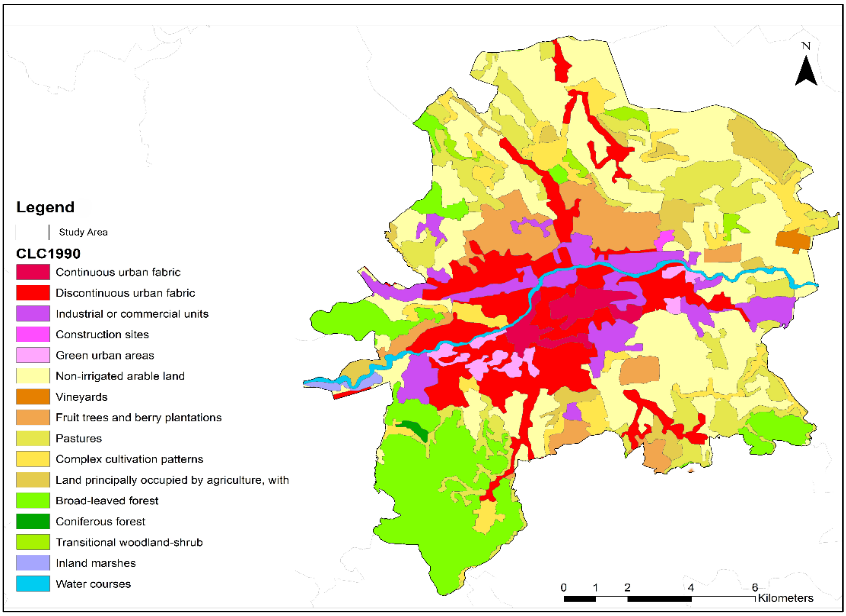


Fig. 3. Land use map of Cluj-Napoca (1990).
Source: 1990 CLC

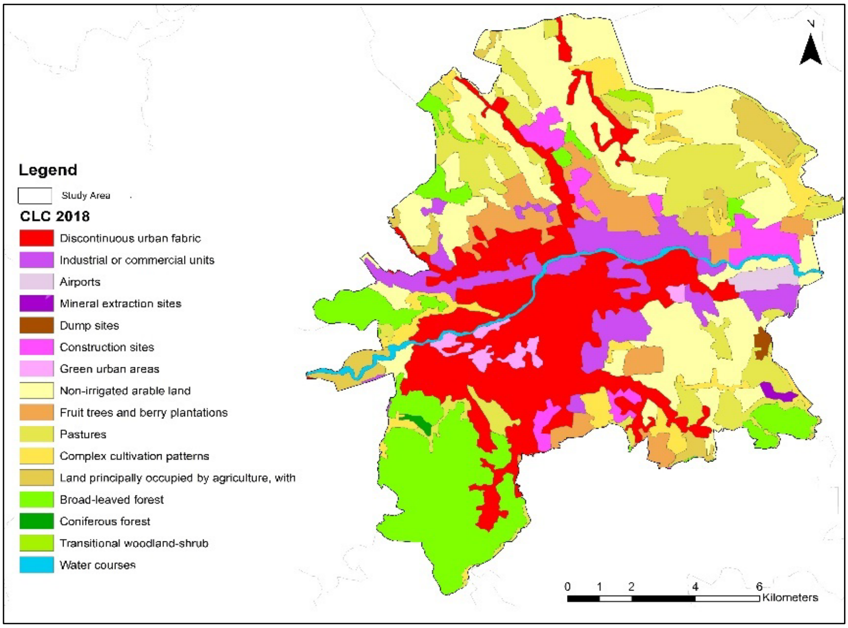
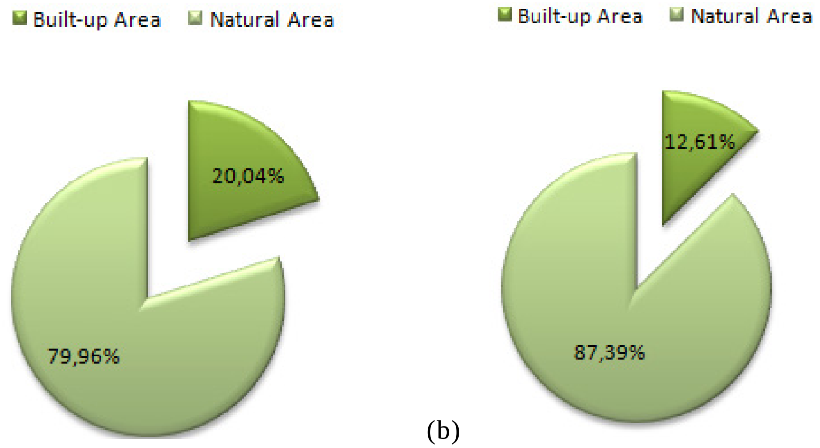


Fig. 4. Map of land use in the Cluj-Napoca UAT (2018).
Source: 2018 CLC

Therefore, following the analysis of the table of changes in land use (table 3), we find that the artificial area is expanding, while agricultural and vegetative areas are shrinking or disappearing altogether. By adding up the areas of all artificial land use types, we obtained the value of the built-up area; and by adding up the areas of all agricultural and vegetated land use types, we obtained the value of the natural area.

Thus, after examining the table, we can see the dynamics of built-up areas in relation to natural areas over the reference period (fig. 5 a, b).



(a) (b)

Fig. 5. Percentage representation of built-up areas in relation to natural areas: (a) 1990; (b) 2018.
Source: the authors, based on CLC datasets

The built-up area expanded by 7.43%, or 2489.84 ha. Urban development is therefore evidenced by the multiplication and diversification of artificial land uses, and urban expansion is supported by the increase in built-up area.

Following the intersection of the two cartographic materials presented above, the areas of expansion of the built-up area from 1990 to 2018 were rendered. The resulting data layer was superimposed on the slope data to facilitate data querying and interpretation (fig. 6).

The analysis of cartographic materials highlights a marked trend towards urban expansion into areas considered less favorable for construction, mainly due to slopes with values above 15°, but also due to unfavorable geology. This direction of urban development is driven by the significant increase in demand for land in the context of the real estate boom that began in 2009 in the municipality of Cluj-Napoca.

The expansion of built-up areas is evident in several sectors of the city, especially in sloping areas, such as the Europa, Mănăștur, Făget, Becaș, Zorilor, Bună Ziua, Borhanci, and Sopor neighborhoods, located on the northern slopes of Feleac Hill and along the right slope of the Someșul Mic Valley. In the northern part of the city, new developments are spreading on the slopes of Chintău Valley towards Ropos Hill, with similar slope values. There is also an expansion of the Dâmbul Rotund neighborhood to the North, towards Lomb Hill, and the Iris neighborhood is advancing northwards towards Fânațele Clujului area.

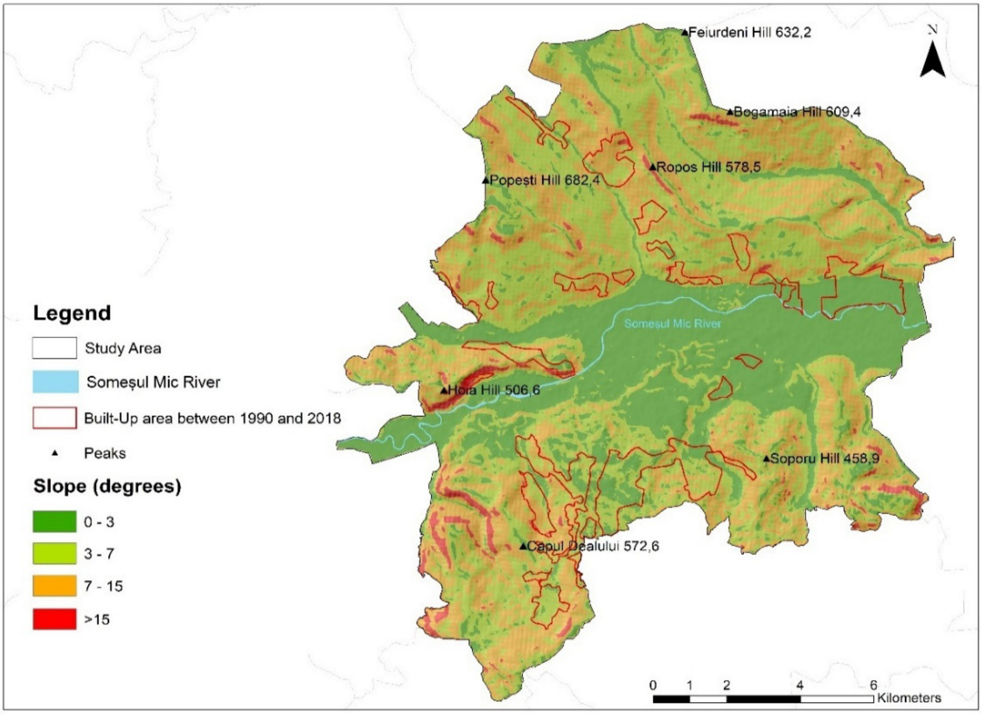


Fig. 6. Expansion of the built-up area within the Cluj-Napoca UAT between 1990 and 2018, overlaid on slope classes.
Source: the authors, based on CLC datasets

In addition, new industrial units are appearing on the southern slopes of Hoia Hill, within the perimeter of Grigorescu neighborhood, as well as on the slopes of Cetățuii Hill. This general trend confirms that urban development pressure is driving the expansion of construction into geomorphologically vulnerable areas, despite the associated natural risks, such as slope instability, erosion, or infrastructure difficulties.

4.2. The impact of urban expansion on the dynamics and functions of the landscape

This dynamics involves a reconfiguration of the functions assigned to land: areas that were previously classified as unsuitable for construction and delineated as extra-urban, used mainly for agriculture, are now revalued as buildable land as a result of the pressure exerted by urban expansion. In other words, land is undergoing a process of functional reevaluation, in which the values and role of landforms are reinterpreted according to the development needs of the urban territory.

In the case of Cluj-Napoca, the local morphology has always been a determining factor in shaping the city's expansion, influencing not only the directions of development but also the architectural and functional characteristics of the new neighborhoods. Thus, by superimposing three sets of data: (1) maps of urban expansion; (2) map of river terraces; (3) digital terrain model, it is possible to analyze the supporting function of the relief in the urbanization process (fig. 7).

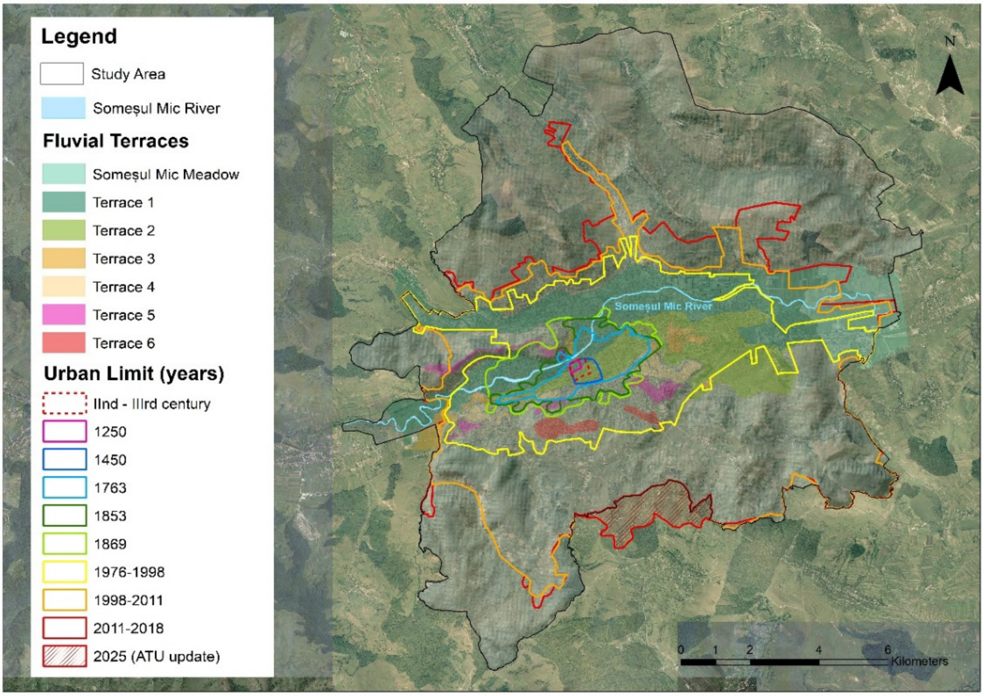


Fig. 7. The relations between fluvial terraces and urbanization process within Cluj-Napoca City.
Source: the authors

This spatial analysis, supplemented by the analysis of historical studies, urban planning reports, and period photographs, allows for the reconstruction of the evolution of the functions attributed to these landforms over time, as well as the identification of the physical and spatial transformations that have occurred as a result of urbanization. This outlines a model of interaction between the natural dynamics of the relief and the socio-economic needs of the urban population, a model that underpins decisions on territorial planning and sustainable development of the city. Therefore, depending on each period of urban development, the landforms that transform into geomorphological supports in the dynamics of urbanization were analyzed.

The first medieval enclosure (circa 1250) took advantage of the Someșul Mic Valley, more precisely the first river terrace. The gentle slopes and relatively flat surface allowed for construction. The proximity to the watercourse can be explained both by the need for water supply and by a possible defensive function, as mentioned by T. Morariu (1957) in his study on the urban evolution of the Municipality of Cluj.

Calvaria Church in Cluj-Mănăștur (first mentioned in documents in 1222) also dates from the same period and functioned as a fortified abbey, surrounded by walls and defensive moats (T. Morariu, 1957). Thus, the hill of the same name acquired a defensive function. Although this area was not part of the built-up area of Cluj-Napoca at that time, it is essential to analyze it, as it reflects an important landform in the current landscape of the city.

In 1558, the Morii Channel was dug to supply water to the mills and later to irrigate the gardens (L. Barbu, 2009).

The fortified medieval city developed on terrace 1 (t1) and terrace 2 (t2) of Someșul Mic River, benefiting from the stability offered by the flat relief. The territory occupied by the medieval city coincides with that of the old Roman city, suggesting that the same geomorphological factors (flat terrain, stability) favored their location. The adjacent hills and slopes were not exploited during this period, as the flat terrain was sufficient for the development of the town, according to the requirements of that stage of development.

In 1763, construction continued to develop around the old fortifications, extending along the t1 and t2 of Someșul Mic River. Development can be observed along the river axis, with a clear preference for land with gentle slopes. Also noteworthy is the crossing of the Someșul Mic River and the expansion of construction to the North. An interesting element during this period is the expansion of the built-up area on the slope of Cetățuia Hill (J. Lukács, 2005). At its top, Cetățuia (1715–1735) was built, a fortification erected during the Habsburg domination. Thus, a previously unutilized relief feature took on a strategic role in the defense and control of the city under Austrian authority, given its position on terrace 5 (t5), above the low terraces. The role of the Someșul Mic River remained dual—water supply and natural defense. Urban expansion to the west took place in parallel with the route of Morii Channel.

In 1853, the urban expansion continued on terraces t1 and t2, but buildings also appeared on terraces t3 and t4, which were mainly used for agricultural purposes. Orchards, agricultural crops, and housing for the urban population were developed (V. Pop, 2010). After the 1848 Revolution, Cetățuia was turned into a prison, and the hill lost its strategic function, acquiring a negative reputation. Poor people, marginalized by the city itself, began to take shelter on its slopes. Thus, its defensive function was replaced by a social one—that of providing housing in precarious conditions.

In 1869, there was a significant expansion of the built-up area, especially to the west and northwest, on the current territory of the Grigorescu and Gruia neighborhoods. Terrace t1 was used for both construction and agricultural activities. During this period, Someșul Mic River also had an industrial function, supplying the mill located on its left bank. The slopes of Cetățuia Hill were covered with makeshift, unstable dwellings, sometimes even in caves dug into the hill, emphasizing their informal nature. Until 1900, the southern slope of the hill was entirely occupied by such dwellings, their instability being accentuated by the steep slope and the geological characteristics of the substrate (T. Morariu, 1957).

The expansion of the built-up area to the south and west occurred at a much slower pace, with the river terraces being used, at this stage, mainly for agricultural purposes, as this was the basic economic need of the population at that time.

During the communist period, the expansion of the built-up area accelerated, especially towards the East. Nădaș Valley was used for the development of industrial areas and residential neighborhoods. The river terraces in Mărăști and Gheorgheni areas were significantly modified—leveled for the construction of apartment buildings (T. Morariu *et al.*, 1967). Thus, the landforms previously used for agriculture were transformed for housing and urban infrastructure. At the same time, the floodplain of Someșul Mic River, previously an agricultural area, was reconfigured to support industrial platforms. It is also important to mention the construction of Între Lacuri neighborhood, together with Lake 1, which is man-made. Other neighborhoods that appeared during this period are Grigorescu, Plopilor, Zorilor, and Iris. The Mănăștur district of Cluj underwent a significant urban transformation, during which residential houses were demolished to make way for a large-scale apartment housing development.

After 1960, Cetățuia Hill changed its function once again: the precarious dwellings were demolished and the area was turned into a park, thus acquiring a recreational role. The Belvedere Hotel was built at the top of the hill, giving terrace 5 (t5) a tourist role, and the slopes were landscaped to reduce the risk of landslides. Also during this period, the village of Someșeni was integrated into the built-up area.

Furthermore, work was carried out on the bed of Someșul Mic River as a protective measure against flooding. Concurrently with the industrialization of Mărăști and Bulgaria areas, the Morii Channel was given a utilitarian function by collecting wastewater from factories.

After 1998, the built-up areas advanced southwards towards Feleacu Hill and northwards towards Chintău Valley, Lomb Hill, and Fânațele Clujului. The slopes of these areas changed their function from agricultural to urban – areas for construction. Calvaria Hill took on a historical and tourist function. Between 2011 and 2018, there was an expansion of the built-up area, especially to the north, with pressure on buildable land exceeding the constraints related to slope instability. A relevant example is the northern slope of Hoia Hill, which changed its agricultural function to an industrial one with the construction of the TETAROM I technology park.

As a result of the multitemporal analysis of the role of landforms in the urbanization process, we will present the summarized information in table form (table 4).

Table 4. The role of landforms in the urbanization process

Landform	13th–18th centuries	18th century–19th century 1853→1949	1853→ 1949	1948→ 1989	1989→ 2011	2011→ 2025
Cetățuia Hill, Terrace 5	Unexploited → Defense, control	Defense → informal housing	Precarious housing	Green space, park	Recreation, tourism	Recreation, tourism, history
Calvaria Hill, Terrace 3	Unexploited →Defense, control	Defense, control	Defense, control	Defense, control	Historical, tourist	Historical, tourist
The terraces of the Someșul Mic River	Housing (Terrace 1)→ Medieval constructions (first 2 terraces)	Agricultural (upper terraces) Residential	Agricultural, residential	Residential	Mixed urban functions	Mixed urban functions
Someșul Mic River	Water supply, natural protection	Water supply, nascent industry	Industry (paper mill)	Industrial platforms	Reconfiguration for housing	Environmental, ecological, recreational
Hoia Hill	-	-	-	-	Industrial and residential	Industrial and residential

Landform	13th–18th centuries	18th century–19th century 1853→1949	1853→ 1949	1948→ 1989	1989→ 2011	2011→ 2025
Nadăș Valley	-	-	-	Industrial, residential	Industrial, residential	Industrial, residential
Morii Channel	Water supply (medieval mills), irrigation	Continuous supply, irrigation	Utility	Industrial	Partially covered for construction expansion	Environmental, recreational

Source: the authors

5. CONCLUSIONS

A multitemporal and multidisciplinary methodological approach highlighted the complex relationship between the urban evolution of Cluj-Napoca and the geomorphological characteristics of the territory. The multitemporal and multidisciplinary analysis of cartographic documents, corroborated with satellite data and interpretation using GIS (Geographic Information System), allowed for a closer reconstruction of how the expansion of the built-up area and the transformation of land use took place in relation to the local landforms.

It was found that the urbanization process of Cluj-Napoca evolved in distinct stages, influenced by historical, political, economic, and social factors. In particular, the city's development in the post-1989 period saw accelerated expansion towards geomorphological structures less suitable for construction, indicating a trend towards occupying land previously considered unsuitable for construction. This expansion was driven by demographic pressures and real estate market dynamics, culminating in significant transformations in the functional and landscape structure of the city.

The results of the quantitative analysis of land use between 1990 and 2018, based on CORINE Land Cover data, showed a 7.43% increase in built-up area and a decrease in natural and agricultural areas. Thematic maps illustrated that areas such as Hoia Hill, Cetățuia Hill, and Nadăș Valley underwent a process of functional reconfiguration.

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