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LAND USE CHANGES INDUCED BY CONSTRUCTION MATERIAL EXTRACTION IN SURFACE QUARRIES WITHIN THE INEU ADMINISTRATIVE TERRITORY (BIHOR COUNTY, ROMANIA)

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Abstract

This study analyses land use and land cover changes within the administrative territory of Ineu Commune, Bihor County, Romania, over the period 1990-2025, using GIS techniques and multi-temporal Earth observation data. The methodology integrates CORINE Land Cover datasets for the years 1990, 2000, 2006, 2012, and 2018 with high-resolution Sentinel-2 imagery for 2025, processed in QGIS. To ensure temporal comparability, the 2025 classification was harmonized according to CORINE Land Cover (CLC) schemes. Quantitative indicators, including absolute change, percentage change, and average annual rate of change, were calculated. The analysis reveals a significant expansion of construction material extraction areas and associated artificial lakes, accompanied by a reduction in heterogeneous agricultural surfaces. Mineral extraction sites increased from 0 ha to 243.14 ha, while the formation of 52 anthropogenic lakes was identified. The results indicate a simplification of the agricultural landscape and a transition towards a more specialized and partially industrialized territorial structure. The study also highlights major discrepancies between official local statistics and satellite-derived data, emphasizing the importance of geospatial monitoring for sustainable spatial planning. The research provides a robust methodological framework that can be replicated in other rural areas affected by extractive activities.

Key words*: anthropogenic lakes, CORINE Land Cover, GIS, gravel extraction, Sentinel-2, spatial planning.*

INTRODUCTION

Land use change represents one of the most pressing environmental and socio-economic challenges in Europe, with a particularly strong impact on rural areas affected by resource extraction activities. In Romania, the rapid expansion of sand and gravel quarries has significantly altered local landscapes, leading to the loss of agricultural land and the formation of a considerable number of anthropogenic lakes (Ghirardi et al., 2023).

Although land use dynamics have been extensively studied at national and regional scales, detailed analyses at the level of administrative-territorial units remain limited, despite the fact that transformations are often more intense and spatially heterogeneous at local scale.

Geographic Information Systems (GIS) (https://qgis.org/, 2024), Graser (2013), Mouloudi et al. (2025) and Copernicus programs, particularly CORINE Land Cover and the Sentinel missions, provide essential tools for the long-term monitoring and quantification of these changes.

This study analyses and quantifies land use changes within the Ineu administrative-territorial unit, Bihor County, Romania, over the period 1990-2025. Ineu Commune (Ineu, n.d.), located approximately 20 km east of Oradea Municipality and included within the Oradea Metropolitan Area, is subject to specific anthropogenic pressures generated by gravel extraction activities carried out in the floodplain and former riverbed of the Crișul Repede River. The research highlights the reduction of agricultural land and the emergence of 52 artificial lakes, together with other major landscape transformations.

By integrating multi-temporal CORINE Land Cover (Copernicus, 2025; ESA 2025), datasets

with high-resolution Sentinel-2 (Simonetti et al., 2021) imagery and quantitative indicators, the study proposes a robust methodological framework for assessing the impact of extractive activities and supports sustainable land management in rural areas undergoing transition.

MATERIALS AND METHODS

The study area corresponds to the Ineu Administrative-Territorial Unit, located in the central-eastern part of Bihor County, Romania, approximately 20 km east of Oradea Municipality. The commune is part of the Oradea Metropolitan Area and includes the villages of Ineu (administrative centre), Husasău de Criș, and Botean. The total surface area is 49.51 km² (4,951 ha) (Figure 1).

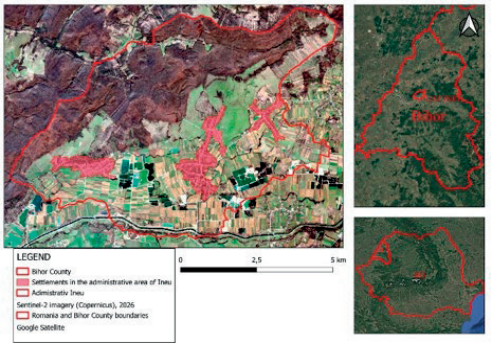


Figure 1. Geographic location of the Ineu Administrative-Territorial Unit within Bihor County, Romania (source: Sentinel-2 imagery, 2025, and administrative boundaries)

The territory is situated within the Oradea–Vad Borod Depression, on the floodplain and former riverbed of the Crișul Repede River, and is characterized by predominantly low plain relief with Quaternary deposits consisting of sands, gravels, and clays. The comparative analysis between the georeferenced historical map from 1782 and the current territorial configuration indicates a significant spatial overlap between the former riverbed of the Crișul Repede River and the main present-day mineral aggregate extraction areas (Figure 2).

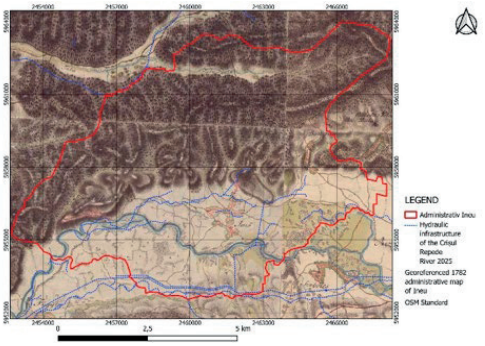


Figure 2. Comparative overlay between the 1782 historical map and the current landscape (2025), highlighting extraction areas on the former Crișul Repede riverbed

The multi-temporal analysis was based on two main categories of geospatial data and GIS processing techniques. The methodological workflow applied in the present study, including data acquisition, georeferencing, spatial processing, land use classification, vectorization, quantitative indicator calculation, and change detection analysis, is summarized in Figure 3.

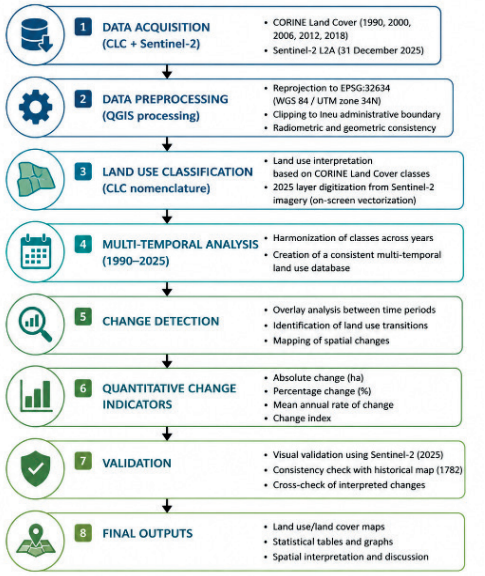


Figure 3. General methodological workflow applied for land use change analysis

CORINE Land Cover (CLC) (Copernicus, 2025; EEA, n.d.) datasets for the years 1990, 2000, 2006, 2012 and 2018 were downloaded from the Copernicus Land Monitoring Service (LandMonitoring, 2021; Şener & Arslanoğlu, 2023; Gómez-Fernández et al., 2024) (100 m spatial resolution, minimum mapping unit of 25 ha). A Sentinel-2 Level-2A multispectral image acquired on 31 December 2025 was downloaded from the Copernicus Data Space Ecosystem (10 m resolution for visible bands and 20 m resolution for vegetation bands). Applications of this type, made available to users, are employed in a wide range of fields, including urban spatial planning, forest management, water management, agriculture, food security, nature conservation and restoration, rural development, ecosystem accounting, and climate change mitigation and adaptation (Skilodimou et al., 2021; Alzurqani et al., 2024). All spatial datasets were clipped to the administrative boundary of Ineu commune. Polygon vector layers were generated through manual digitization and spatial overlay procedures in QGIS. Surface calculations were extracted from the polygon attribute tables and converted into hectares and percentages.

Land use classification was performed consistently for all six temporal reference periods using the CORINE Land Cover nomenclature (Skilodimou et al., 2021). The 2025 layer, derived from Sentinel-2 imagery, was harmonized with this nomenclature to ensure temporal comparability. The evolution of the surface areas and proportions of the main land use classes is presented in Table 1.

Table 1. Evolution of land use/land cover classes in the Ineu Administrative Territory, Bihor, Romania (1990-2025)

CLC	CORINE LAND COVER LEGEND	1990		2000		2006		2012		2018		2025	
		Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
324	Transitional woodland-shrub	0,00	0,00	0,00	0,00	0,00	0,00	30,99	0,60	30,99	0,60	90,82	1,83
211	Non-irrigated arable land	1307,33	26,40	1307,71	26,30	1804,28	36,40	1766,59	35,60	1735,00	35,00	1598,11	32,27
222	Fruit trees and berry plantations	0,00	0,00	0,00	0,00	107,53	2,20	107,53	2,20	107,53	2,20	83,10	1,68
231	Pastures	745,97	15,10	745,97	15,10	783,98	15,80	775,64	15,70	775,64	15,60	748,24	15,12
221	Vineyards	192,21	3,80	192,21	3,90	82,32	1,70	82,32	1,70	82,32	1,70	82,55	1,67
131	Mineral extraction sites	0,00	0,00	0,00	0,00	33,26	0,70	155,20	3,10	186,78	3,80	243,14	4,91
242	Complex cultivation patterns	161,74	3,30	161,78	3,30	45,37	0,90	45,37	0,90	45,37	0,90	40,98	0,83
243	Land principally occupied by agriculture, with significant areas of natural vegetation	521,52	10,50	521,41	10,50	156,15	3,20	64,58	1,30	64,58	1,30	77,30	1,56
112	Discontinuous urban fabric	304,56	6,20	304,56	6,20	259,50	5,20	275,17	5,60	275,17	5,60	313,70	6,34
311	Broad-leaved forest	1657,78	33,50	1657,60	33,50	1618,86	32,70	1587,87	32,10	1587,87	32,10	1613,57	32,59
511	Water courses	60,34	1,20	60,34	1,20	60,34	1,20	60,34	1,20	60,34	1,20	60,34	1,20
	TOTAL		100,00	4951,58	100,00	4951,59	100,00	4951,60	100,00	4951,59	100,00	4951,85	100,00

Considering the limitations of the CORINE Land Cover nomenclature at local scale, the newly formed lakes resulting from mineral aggregate extraction activities were mapped as water surfaces associated with extractive activities (Ghirardi et al., 2023).

To ensure a quantitative and comparable assessment of land use and land cover dynamics within the Ineu administrative-territorial unit over the period 1990-2025, a set of mathematical indicators was applied. These indicators allow the evaluation of both the magnitude and the intensity of changes across different land use categories.

In order to capture the specific temporal dynamics and the inflection points of landscape transformations, the quantitative indicators were calculated separately for two distinct periods: 1990-2006 (the post-communist agricultural intensification period) and 2006-2025 (the period of accelerated expansion of extractive activities and transition towards a partially industrialized landscape).

Quantitative indicators of land use change

Relative percentage change (%) of land use categories

$$\Delta P(\%) = \frac{A_{t2} - A_{t1}}{A_{t1}} \times 100$$

where:

$\Delta P(\%)$= relative percentage change of the land use category;

A_{t1}= area of the land use category at the initial time period (ha);

A_{t2}= area of the land use category at the final time period (ha).

Absolute change: $\Delta A = A_{t2} - A_{t1}$

where:

ΔA= absolute change (ha);

A_{t1}= area at the initial time period;

A_{t2}= area at the final time period.

Average annual rate of change

$$R = \frac{A_{t2} - A_{t1}}{t_2 - t_1}$$

where:

R= average annual rate of change (ha/year);

A_{t1}= area at the initial time period (ha);

A_{t2}= area at the final time period (ha);

$t_2 - t_1$= time interval between the two reference periods (years).

Change index

$$I_c = \frac{A_{t2}}{A_{t1}}$$

where:

I_c= change index (dimensionless);

- $I_c > 1$= increase;
- $I_c < 1$= decrease;
- $I_c = 1$= stability.

All calculations were performed in Microsoft Excel and validated in QGIS.

Change detection was performed through post-classification analysis based on the spatial overlay of vector layers. For the year 2025, an additional validation procedure was carried out through overlay analysis with the georeferenced historical map from 1782, confirming that the majority of anthropogenic lakes were formed on the former riverbed of the Crișul Repede River.

Note: Since no official CORINE Land Cover product is available for 2025, the Sentinel-2-derived layer was manually created and harmonized with the CLC nomenclature in order to ensure temporal comparability.

RESULTS AND DISCUSSIONS

Comparison between official statistics and satellite-derived data:

According to the Sustainable Development Strategy of Ineu Commune (2021-2027) (Lillemets et al., 2025; ZMO), agricultural land represents the dominant land use category, covering 60.41% of the total surface area (2,991 ha), followed by forest areas (32.94%), built-up surfaces (3.43%), water surfaces (1.01%), and communication routes (2.20%).

The comparison with CORINE Land Cover 2018 data reveals significant differences (Bodog et al., 2024) (Table 2).

Table 2. Comparative Analysis of Land Use Categories According to the Sustainable Development Strategy of Ineu Commune (2021-2027) and CORINE Land Cover 2018

Category	Strategy (ha)	Strategy (%)	CLC 2018 (ha)	CLC 2018 (%)	Difference (ha)	Difference (%)
Agricultural land	2991	60,41	2807,99	56,71	-183,01	-3,70
Forest land	1631	32,94	1617,85	32,67	-13,15	-0,27
Built-up areas	170	3,43	320,86	6,48	+150,86	+3,05
Water bodies / Lakes	0	0	144,57	2,92	+144,57	+2,92
Total	4951,59	100	4951,59	100		

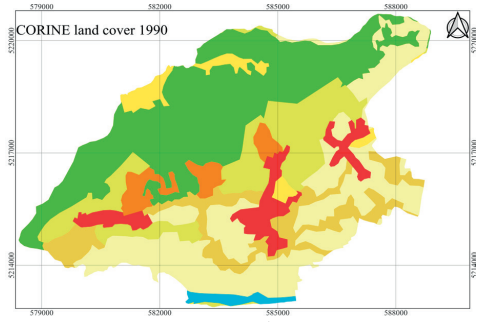
The share of agricultural land decreases to 56.71%, while built-up surfaces increase to 6.48%, and water bodies reach 2.92%. The most significant discrepancy concerns water surfaces: the local Strategy reports 0 ha of lakes, whereas satellite-derived data identify 144.57 ha, most of them representing anthropogenic lakes generated by extraction activities.

These discrepancies highlight the limitations of administrative statistics and the superiority of satellite-based monitoring in capturing recent anthropogenic transformations.

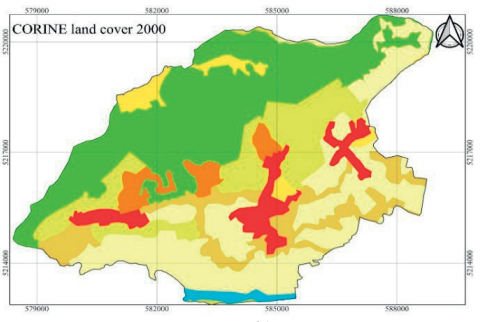
The analysis of the six temporal reference periods (1990, 2000, 2006, 2012, 2018, and 2025) highlights profound structural transformations of the landscape within the Ineu Administrative-Territorial Unit (Table 1, Figure 4). Table 3 presents the detailed evolution of the surface area and proportion of the main land use classes throughout the entire analysed period.

The general dynamics reveal two major processes:

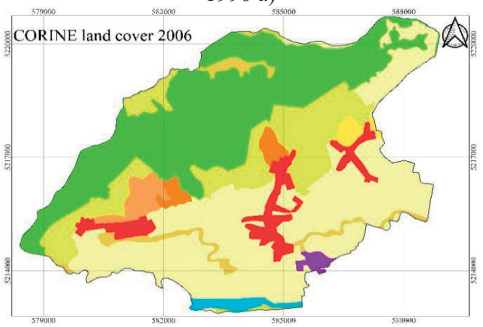
1. Intensification and simplification of agricultural land use during the first part of the analysed period (1990-2006) (Table 3).
2. Strong expansion of extractive activities after 2006, accompanied by the formation of anthropogenic lakes and the fragmentation of agricultural land (Table 4).



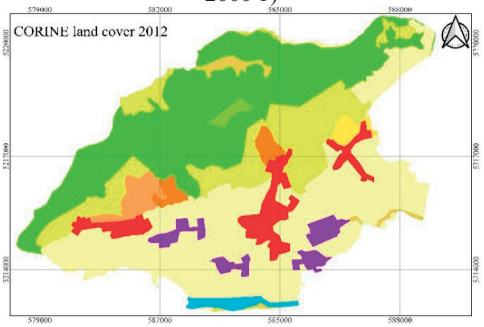
1990 a)



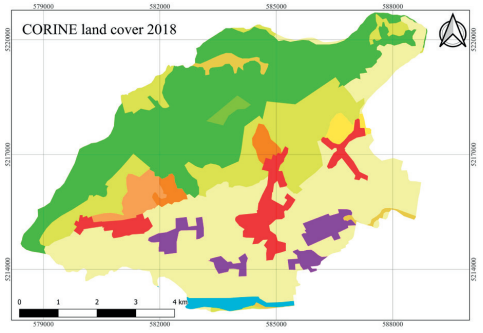
2000 b)



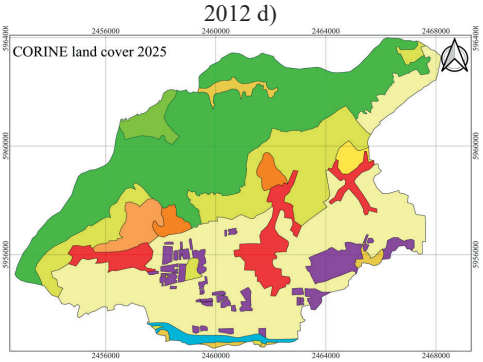
2006 c)



2012 d)



2018 e)



2025 f)

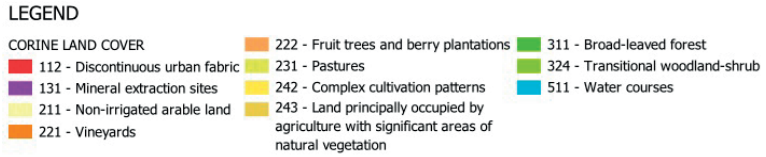


Figure 4. Temporal evolution of land use changes within the administrative-territorial unit of Ineu: 1990 a), 2000 b), 2006 c), 2012 d), 2018 e), and 2025 f). (CORINE Land Cover and Sentinel-2 data).

Table 3. Land use changes during the period 1990-2006 (16 years)

CLC class (code)	1990 (ha)	2006 (ha)	Absolute change (ha)	Percentage change (%)	Average annual rate of change (%)
Non-irrigated arable land (211)	1307,33	1804,28	+496,95	+38,01	+2,03
Pastures (231)	745,97	783,98	+38,01	+5,10	+0,31
Vineyards + Fruit trees and berry plantations (221+222)	192,21	189,85	-2,36	-1,23	-0,08
Complex cultivation patterns + Land principally occupied by agriculture, with significant areas of natural vegetation (242+243)	683,26	201,52	-481,74	-70,50	-7,45
Total agricultural land (211+221+222+231+242+243)	2928,77	2979,63	+50,86	+1,74	+0,11
Mineral extraction sites (131)	0,00	33,26	+33,26	–	–
Discontinuous urban fabric (112)	304,56	259,50	-45,06	-14,80	-1,00
Broad-leaved forest (311)	1657,78	1618,86	-38,92	-2,35	-0,15
Water courses (511)	60,34	60,34	0,00	0,00	0,00

Table 4. Land use changes in the Ineu Administrative-Territorial Unit during the period 2006-2025

CLC class (code)	2006 (ha)	2025 (ha)	Absolute change (ha)	Percentage change (%)	Average annual rate of change (%)
Non-irrigated arable land (211)	1804,28	1598,11	-206,17	-11,43	-0,64
Pastures (231)	783,98	710,37	-73,61	-9,39	-0,52
Vineyards + Fruit trees and berry plantations (221+222)	189,85	165,65	-24,20	-12,75	-0,72
Complex cultivation patterns + Land principally occupied by agriculture, with significant areas of natural vegetation (242+243)	201,52	118,28	-83,24	-41,30	-2,79
Total agricultural land (211+221+222+231+242+243)	2979,63	2592,41	-387,22	-12,99	-0,73
Mineral extraction sites (131)	33,26	243,14	+209,88	+631,03	+11,04
Discontinuous urban fabric (112)	259,50	313,70	+54,20	+20,89	+1,00
Broad-leaved forest (311)	1618,86	1613,57	-5,29	-0,33	-0,02
Water courses (511)	60,34	98,21	+37,87	+62,76	+2,60

The period 1990-2006 is characterized by an intensification of agriculture on arable land (+496.95 ha, +38%), accompanied by a drastic reduction in heterogeneous and complex agricultural surfaces (-481.74 ha, -70.5%). This period reflects the transition from an extensive and fragmented agricultural system towards a more specialized form of agriculture after 1990. Mineral extraction activities emerged on a limited scale (33.26 ha), while the total agricultural surface recorded a slight increase (+1.74%).

The period 2006-2025 marks a major structural transformation of the landscape. Agricultural land experienced a continuous and significant decrease (-387.22 ha, -12.99%), particularly affecting arable land (-206 ha) and pastures (-73.61 ha). At the same time, mineral extraction sites expanded dramatically (+209.88 ha, +631%), while the surface occupied by discontinuous urban fabric increased steadily (+54.20 ha, +20.89%). The increase in water surfaces (+37.87 ha) corresponds to the formation of 52 anthropogenic lakes generated by gravel extraction activities in the former riverbed of the Crișul Repede River (Petrovszki & Timár, 2010; Pınar & Karahasan, 2024).

At the same time, important hydrotechnical interventions were carried out, especially on the

Crișul Repede River, which underwent major modifications, as well as within the secondary network of streams, ponds, canals, and drainage systems (Osei et al., 2025). The embankment and canalization of secondary watercourses were primarily intended to protect the locality of Ineu from floods (Osawa, 2024), contributing to significant alterations of the natural landscape.

These trends confirm the transition from a predominantly rural agricultural landscape towards a more specialized and partially industrialized landscape dominated by extractive activities. Similar land use transitions associated with agricultural restructuring and extractive activities have also been reported in other European rural regions (Alawode et al., 2025; Lillemets et al., 2025).

The identified transformations also highlight the increasing importance of efficient and transparent territorial governance. The guiding principles of public administration in many democratic countries include flexibility, transparency, autonomy, and efficiency, considered essential for the proper functioning of administrative systems. In the contemporary context, citizens increasingly expect public administration to become more efficient, flexible, and transparent in managing territorial resources and environmental transformations (Timofte, 2023; Timofte & Racz, 2025).

Spatial analysis indicates that the most significant transformations are concentrated within the floodplain and former riverbed of the Crișul Repede River.

The expansion of gravel quarries and the formation of 52 anthropogenic lakes have led to a pronounced fragmentation of agricultural land and to the reconfiguration of the local hydrographic network (Figures 5 and 6).

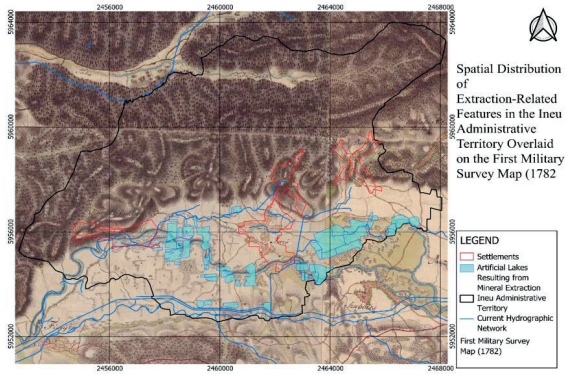


Figure 5. Comparative overlay between the 1782 historical map and the current situation (2025), highlighting the location of quarries on the former Crișul Repede riverbed.

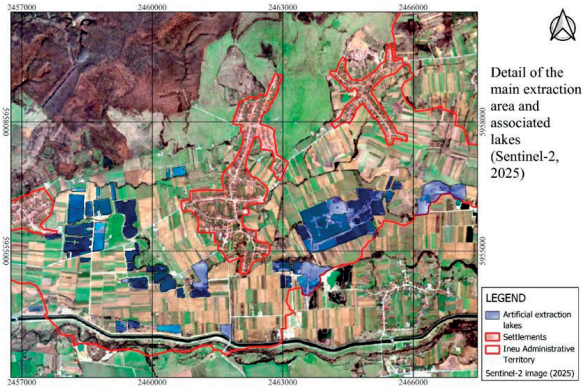


Figure 6. Detail of the main extraction area and the associated anthropogenic lakes. (Sentinel-2, 2025).

The results indicate a clear transition from a heterogeneous agricultural landscape (1990) towards a more specialized and partially industrialized system (2025), dominated by extractive activities.

The identified transformations present a dual character:

- *Negative aspects*: reduction of high-quality agricultural land, landscape fragmentation, and potential impacts on food security.
- *Opportunities:* economic benefits generated by extractive activities, recreational and fishery potential of anthropogenic lakes, and the possibility of using water resources for irrigation purposes.

The integration of high-resolution satellite monitoring (Sentinel-2) with CORINE Land Cover data and quantitative indicators provides a robust methodological framework for local spatial planning and for supporting public policies in rural areas affected by extractive activities.

CONCLUSIONS

This study provides a comprehensive assessment of land use and land cover changes within the Ineu Administrative-Territorial Unit, Bihor County, during the period 1990-2025, through the integration of CORINE Land Cover data, Sentinel-2 satellite imagery, and quantitative indicators.

The results highlight a significant structural transformation of the landscape, marked by the transition from a heterogeneous agricultural system towards a more simplified and partially industrialized landscape. The most important change is represented by the expansion of mineral extraction sites, which led to the formation of 52 anthropogenic lakes and to a major reconfiguration of the territorial structure. At the same time, heterogeneous agricultural land recorded a pronounced decline, indicating a process of agricultural simplification and the gradual disappearance of traditional mixed farming systems. Arable land experienced a moderate increase, while broad-leaved forest areas remained relatively stable, demonstrating the structural resilience of natural landscape components. Quantitative analysis confirms that extractive activities represent the main pressure factor affecting land use, influencing both the spatial configuration and the functionality of the landscape.

The study also reveals significant discrepancies between official local statistics (Sustainable Development Strategy 2021-2027) and satellite-derived data, emphasizing the need to integrate geospatial technologies into territorial monitoring and spatial planning processes. The systematic use of satellite imagery and GIS analyses can contribute to a more objective evaluation, closer to the actual situation in the field, facilitating the development of public policies and administrative decisions based on updated and verifiable data.

From a socio-economic perspective, the identified transformations generate both challenges and opportunities. The reduction of high-quality agricultural land may affect the long-term productive capacity of the area, while the emergence of anthropogenic lakes creates new opportunities for economic diversification through tourism, recreation, and aquaculture.

The methodological approach applied in this study - combining standardized CORINE datasets, high-resolution Sentinel-2 imagery, and quantitative indicators - provides a robust and replicable framework for analysing land use dynamics at local scale, applicable to other rural areas affected by extractive activities. Future research should focus on the integration of higher-resolution datasets, field validation, and environmental impact assessment, particularly regarding soil degradation, water quality, and microclimatic changes.

In the context of the identified transformations, the study results underline the necessity of a rational and balanced use of land resources, especially in rural areas affected by extractive activities. The conversion of agricultural land towards industrial or extractive uses should be carried out on the basis of clear, objective, and sustainable criteria, ensuring the balance between economic development, environmental protection, and the conservation of agricultural resources. At the same time, the regulatory framework governing extractive activities could consider the introduction of territorial indicators and limits adapted to local carrying capacity, including by relating exploited surfaces to the total available agricultural land.

In conclusion, the study highlights the need for sustainable land management strategies capable

of reconciling economic development with environmental protection and the preservation of agricultural productive capacity. Satellite monitoring and quantitative analysis should become essential components of local and regional spatial planning, ensuring informed decision-making in the context of increasingly intense anthropogenic pressures.

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