GIS-BASED ASSESSMENT OF POST-MINING SUBSIDENCE AND CADASTRAL PROPERTY EXPOSURE IN FORMER UNDERGROUND COAL MINING AREAS: CASE STUDY FROM THE JIU VALLEY, ROMANIA

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Abstract. Historical underground mining activities may generate persistent geomechanical effects capable of influencing terrain stability and affecting surface properties located above former exploitation areas. Despite these long-term impacts, underground mining infrastructure is generally not integrated within conventional cadastral registration systems, creating significant informational gaps regarding potential subsurface hazards associated with land ownership.

Mining subsidence represents one of the most significant long-term geomechanical consequences associated with underground coal exploitation, capable of producing delayed surface deformation long after mine closure (Kratzsch, 1983; Peng, 1992; Bell *et al.*, 2000).

This study investigates the spatial relationship between subsurface mining works and surface cadastral properties located within the Maleia mining sector, part of the Jiu Valley coal basin, Romania. Multiple spatial datasets, including historical underground mining plans, surface property boundaries, geological information and geodetic monitoring data, were integrated within a Geographic Information System (GIS) environment in order to evaluate the spatial interaction between underground mining works and registered surface properties.

A multi-buffer spatial model was developed using progressive influence distances of 50 m, 100 m and 150 m around underground mining galleries. Spatial analysis identified direct intersection between underground mining influence zones and analyzed parcel 67007. Complementary subsidence analysis based on long-term geodetic monitoring data recorded cumulative vertical displacement values ranging from -0.082 m to -3.853 m, with the maximum subsidence observed at monitoring point R14.

The results demonstrate that former underground mining infrastructure may continue to generate long-term geomechanical effects capable of influencing terrain stability decades after mine closure. The proposed GIS-based methodology provides an efficient framework for subsidence assessment, geohazard identification and territorial planning in former underground mining regions.

Key words: Mining subsidence; GIS analysis; Underground mining; Geohazard assessment; Ground deformation; Spatial modelling

1. INTRODUCTION

Coal mining activities have shaped the economic development of numerous industrial regions worldwide (Peng, 1992; Bell *et al.*, 2000). However, former underground mining operations frequently generate long-term geomechanical effects that remain active even decades after mine closure (Whittaker and Reddish, 1989).

One of the principal challenges associated with former underground mining regions is the absence of correlation between underground mining infrastructure and conventional surface cadastral registration systems (Williamson *et al.*, 2010; Lemmen, 2012). In many cases, surface properties remain legally registered without publicly accessible information regarding underground galleries or historical mining works located beneath privately owned land.

This lack of spatial integration generates important technical, administrative and legal limitations, particularly in regions where historical underground exploitation may continue to influence terrain behavior through progressive deformation processes such as subsidence or local ground instability (Van Oosterom *et al.*, 2006). Similar long-term deformation processes have been documented extensively in post-mining regions of Poland, Germany and China where abandoned underground excavations continue to generate progressive surface instability (Singh, 2000; Zhang *et al.*, 2018).

Surface deformation induced by underground mining activity has been extensively investigated through various geodetic and remote sensing monitoring approaches developed for long-term terrain displacement assessment (Massonnet and Feigl, 1998).

Recent advances in satellite-based deformation monitoring techniques have significantly improved the capability of detecting long-term ground movement phenomena associated with mining-related subsidence processes (Ferretti *et al.*, 2001).

Recent GIS technologies have made it possible to combine geological, cadastral and mining-related datasets within a common spatial environment, allowing a more accurate evaluation of underground mining impacts (Burrough, 1986; Longley *et al.*, 2015).

This study aims to investigate the spatial relationship between underground mining infrastructure and surface properties located within former mining regions using GIS-based spatial analysis techniques.

Modern land administration systems increasingly rely on integrated spatial databases capable of supporting property management, legal security and territorial planning processes (Lemmen *et al.*, 2015).

2. STUDY AREA

The study area is located within the Maleia mining sector, associated with E.M. Livezeni, situated in the Jiu Valley coal basin, Romania, one of the country's most important historical underground coal mining regions.

The Jiu Valley is characterized by a complex geological framework consisting predominantly of coal-bearing sedimentary formations affected by tectonic fragmentation and ... extensive underground galleries developed during more than one century of mining activity (Peng, 1992; Bell *et al.*, 2000).

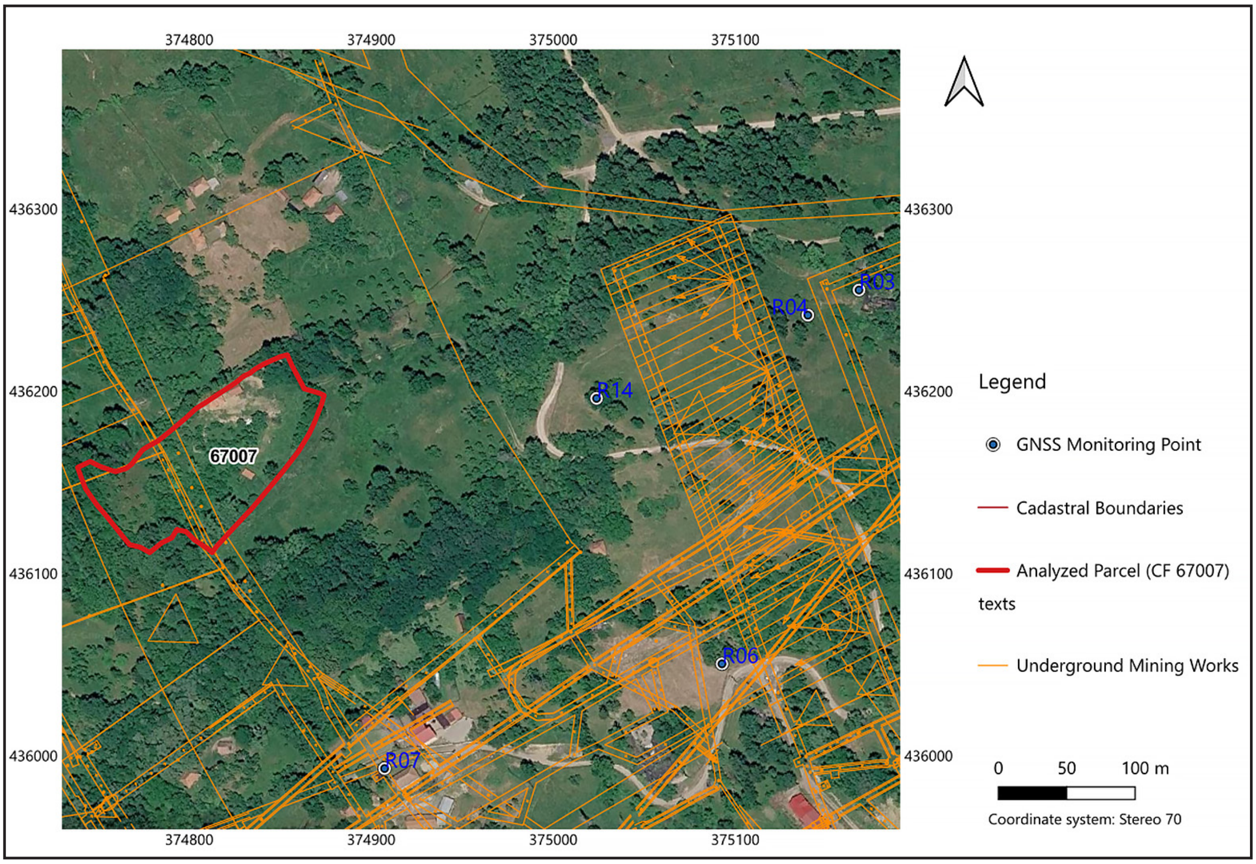

Fig. 1. Spatial distribution of the GNSS monitoring network installed within the Maleia mining sector (E.M. Livezeni, Romania), used for monitoring long-term vertical ground displacement between 2007 and 2026.

The Jiu Valley coal basin represents one of the most extensively exploited coal-bearing sedimentary formations in Romania, characterized by complex tectonic structures, fractured lithological sequences and extensive underground galleries developed during more than one century of mining activity.

The Maleia sector contains an extensive network of underground galleries and mining works developed at various depths beneath surface terrain currently occupied by residential properties, transport infrastructure and privately owned registered land parcels registered within the Romanian national cadastre system.

Due to prolonged underground mining activity and the presence of abandoned historical exploitation works, the area presents favorable conditions for progressive mining-induced subsidence processes capable of generating cumulative terrain deformation and potentially affecting the long-term stability of surface properties located above former underground mining infrastructure.

3. MATERIALS AND METHODS

The methodological framework applied in this study consisted of integrating multiple spatial datasets derived from historical underground mining documentation, cadastral records, geological information and geodetic monitoring measurements within a unified GIS environment (Longley *et al.*, 2015).

The primary spatial datasets included historical underground mining plans associated with the Maleia mining sector, cadastral parcel boundaries extracted from the Romanian land registration database, geological maps describing the local lithological context and geodetic monitoring measurements collected during long-term subsidence observation campaigns conducted between 2007 and 2026. Historical monitoring campaigns were performed using Leica SR520 and Leica SR530 dual-frequency GNSS receivers (Leica Geosystems AG, Switzerland), while the recent field verification campaign conducted in 2026 was carried out using a Leica GS18T GNSS receiver operating in static differential positioning mode (Leica Geosystems AG, Switzerland). All spatial datasets were standardized using the Romanian national coordinate reference system Stereo 70 (EPSG:3844) in order to ensure geometric compatibility and enable spatial overlay analysis, in accordance with INSPIRE spatial data interoperability principles (European Commission, 2007). GNSS-based geodetic monitoring represents a widely applied method for detecting long-term surface displacement with high positional accuracy in deformation monitoring studies (Leick *et al.*, 2015).

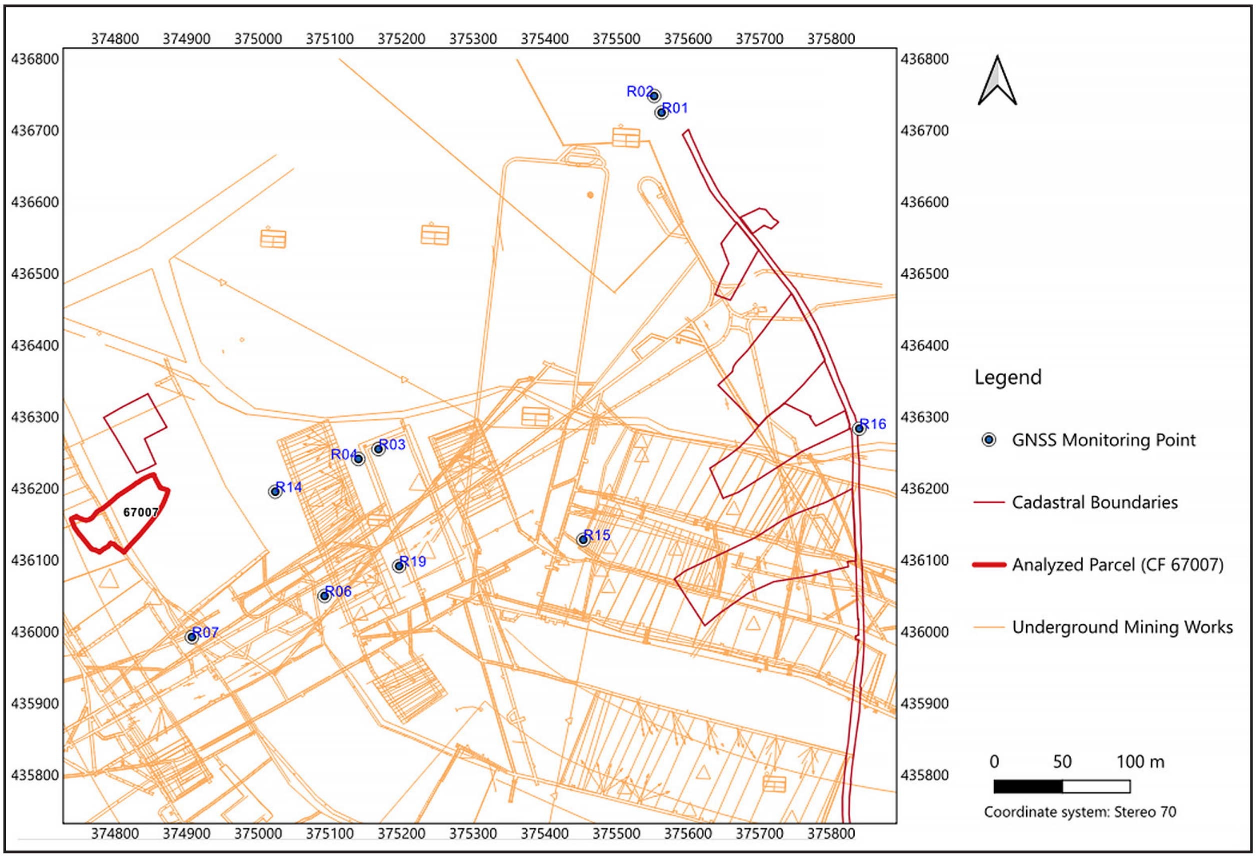

Fig. 2. Integrated spatial distribution of underground mining works, GNSS monitoring network and cadastral parcel boundaries within the Maleia mining sector.

The spatial analysis workflow followed established GIS analytical principles commonly applied in geospatial modelling and spatial decision-support systems (Burrough and McDonnell, 1998).

The first stage of analysis consisted of digitizing historical underground mining galleries and integrating underground exploitation plans within the GIS environment. Subsequently, cadastral parcel boundaries corresponding to registered surface properties located above historical underground mining works were incorporated.

To evaluate the potential spatial influence of underground mining infrastructure, a progressive multi-buffer model was generated around underground galleries using three concentric influence distances: 0–50 m, 50–100 m and 100–150 m. These zones were considered indicative geomechanical influence areas associated with underground exploitation (Burrough, 1986).

In parallel, long-term vertical displacement measurements obtained from GNSS monitoring campaigns performed in 2007 and repeated in 2026 were analyzed in order to quantify cumulative terrain subsidence, following methodologies commonly applied in mining deformation monitoring using geodetic networks (Can *et al.*, 2012).

Spatial interpolation of vertical displacement values was performed using geostatistical interpolation methods in order to generate a continuous subsidence distribution model and identify zones characterized by maximum ground deformation (Isaaks and Srivastava, 1989).

Inverse Distance Weighting (IDW) interpolation was applied in order to generate the continuous subsidence surface model based on measured vertical displacement values recorded at monitoring points distributed across the study area. This interpolation method was selected due to the relatively limited number of observation points and its suitability for representing localized deformation gradients commonly observed in mining subsidence studies.

Although the monitoring network presents a relatively limited spatial density, the available observation points were distributed in the sectors historically affected by underground exploitation and were considered sufficient for identifying general deformation trends and the main subsidence concentration zones within the study area.

Finally, spatial overlay analysis was performed in order to evaluate the relationship between subsurface mining works, cumulative subsidence distribution and cadastral parcel CF 67007 selected as representative case study for assessing the interaction between registered surface properties and former underground mining activities.

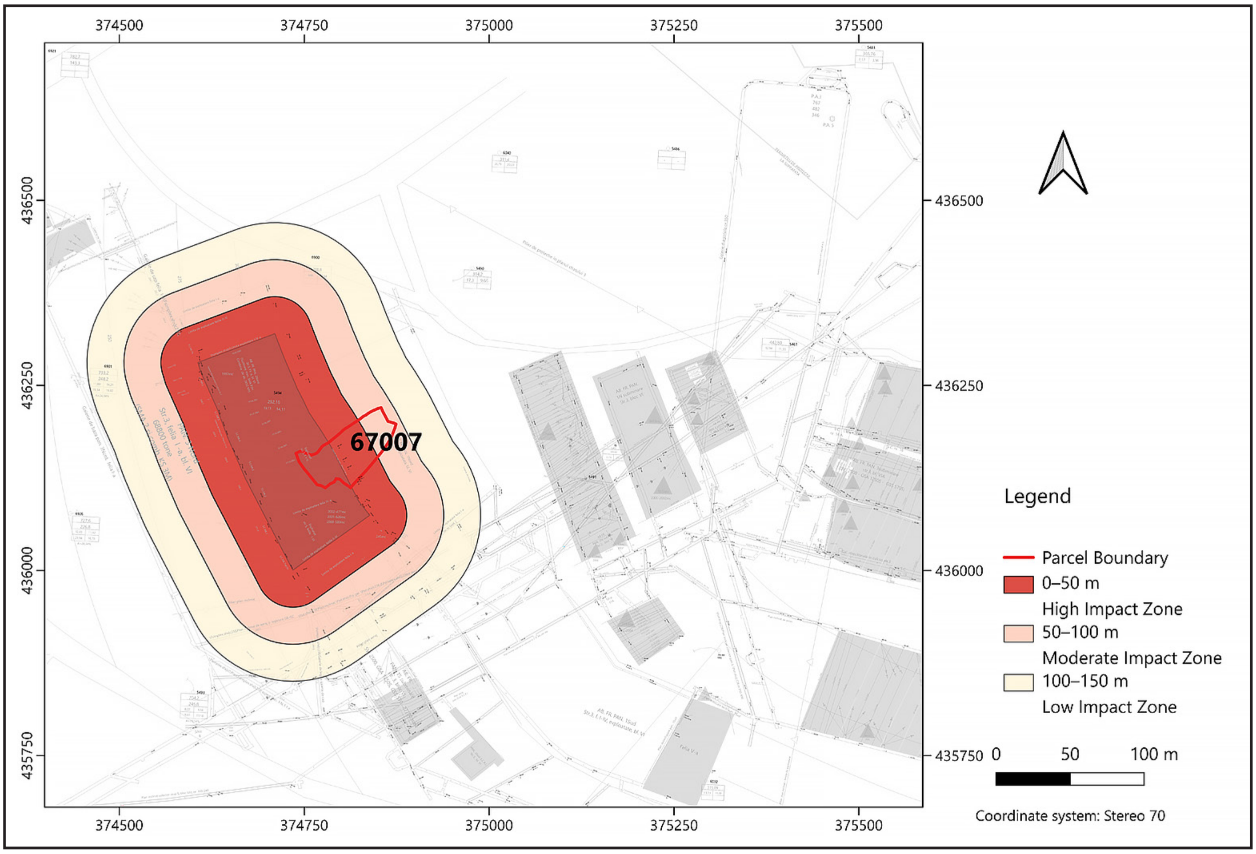

Fig. 3. Multi-buffer spatial model developed around underground mining works in the Maleia mining sector, illustrating progressive geomechanical influence zones and the position of cadastral parcel 67007 located within the direct and secondary underground mining impact areas.

4. RESULTS

Spatial integration of underground mining plans and cadastral parcel boundaries revealed direct geometric overlap between several registered surface properties and historical mine workings located within the Maleia mining sector. Detailed analysis focused on parcel 67007, selected as representative case study because of its direct spatial position above former underground mining excavations.

The multi-buffer spatial model generated around underground mining galleries demonstrated that parcel CF 67007 intersects the immediate underground mining influence area corresponding to the 0–50 m high-impact zone, indicating direct proximity between registered property boundaries and underground mining infrastructure. To complement the spatial proximity analysis, long-term geodetic monitoring measurements were analyzed in order to quantify cumulative terrain deformation associated with historical underground exploitation. Vertical displacement analysis performed using GNSS measurements collected in 2007 and repeated in 2026 revealed cumulative subsidence values ranging between -0.082 m and -3.853 m.

The maximum recorded subsidence value was observed at monitoring point R14, where cumulative vertical displacement reached -3.853 m over the analyzed monitoring period. Spatial interpolation of measured vertical displacement values revealed a progressive subsidence gradient centered around monitoring point R14, indicating persistent deformation processes affecting the surrounding area (Whittaker and Reddish, 1989; Singh, 2000).

Overlay analysis demonstrated that cadastral parcel CF 67007 is positioned within the peripheral deformation influence zone associated with the subsidence hotspot, suggesting potential long-term interaction between underground mining processes and registered surface property boundaries.

Quantitative buffer analysis demonstrated that the analyzed cadastral parcel CF 67007 is significantly influenced by underground mining infrastructure. Most of the parcel surface is located within the immediate geomechanical influence zone situated at less than 50 meters from historical underground mining works. The spatial distribution of affected areas according to progressive buffer distances is summarized in Table 1.

The results indicate that approximately 76% of the total parcel area is located within the high-impact zone (0–50 m), suggesting direct spatial interaction between registered surface property boundaries and underground mining infrastructure.

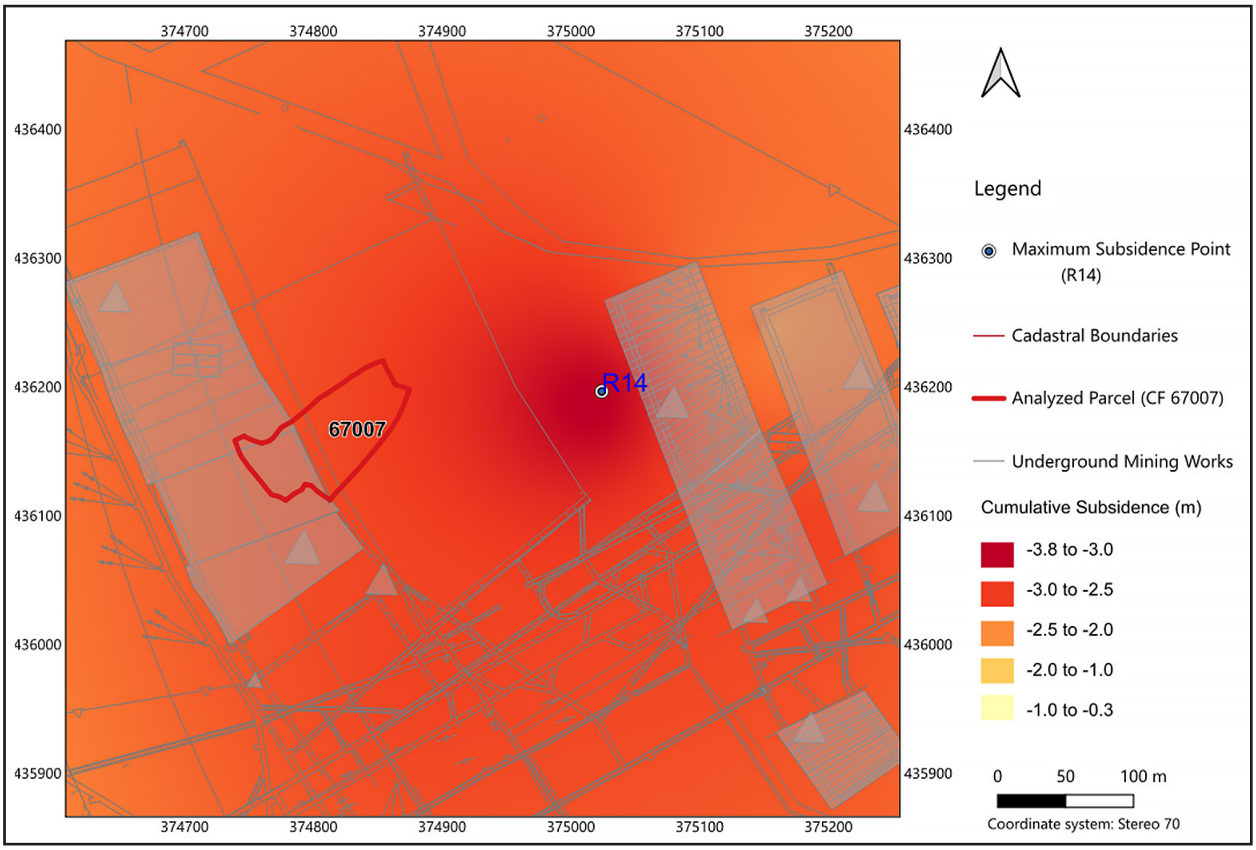

Fig. 4. Spatial correlation between cadastral parcel CF 67007, underground mining works and cumulative subsidence distribution in the Maleia mining sector, indicating the relationship between registered surface property boundaries and long-term mining-induced deformation processes.

Table 1. Distribution of parcel surface located within underground mining influence zones

Influence Zone	Parcel area located within mining influence zones (m^2)	Percentage of Total Parcel Area (%)
0–50 m	5417.27	76%
50–100 m	1747.23	24%
100–150 m	0	0%

The remaining 24% is situated within the secondary influence zone (50–100 m), while no parcel surface extends beyond 100 meters from the analyzed underground mining works.

The high percentage of parcel area located within the immediate underground influence zone suggests significant exposure to potential mining-induced geomechanical processes, including differential settlement, progressive subsidence and local terrain instability commonly reported in former underground coal exploitation regions (Peng, 1992).

5. DISCUSSION

Although underground mining activities may generate persistent long-term geomechanical effects capable of influencing terrain stability, cadastral registration systems generally provide no information regarding the existence of underground mining works located beneath privately owned surface properties (Williamson *et al.*, 2010).

The case study developed for parcel CF 67007 illustrates this limitation clearly. Spatial analysis identified direct intersection between underground mining influence zones and a legally registered surface property without the presence of any explicit cadastral information concerning potential underground mining constraints.

The observed deformation pattern suggests that post-mining subsidence processes remain active even decades after the cessation of underground exploitation, indicating the persistence of delayed geomechanical adjustment mechanisms.

The deformation pattern observed around the central sector suggests that post-mining geomechanical processes remain active over extended time intervals. The integration of mining-related spatial information within GIS-based territorial management systems may significantly improve geohazard awareness, reduce technical uncertainty and support safer land-use planning strategies in former mining regions.

Unlike conventional mining subsidence studies focused exclusively on terrain deformation, the present study introduces a cadastral perspective by evaluating the interaction between underground mining infrastructure and legally registered surface properties through an integrated GIS framework.

The present study highlights the importance of extending conventional cadastral systems beyond surface property registration by incorporating subsurface mining-related information. In former mining regions, property ownership may be affected not only by visible surface characteristics, but also by hidden underground infrastructure capable of generating long-term terrain instability.

Comparable mining-induced subsidence phenomena have been reported in Upper Silesia (Poland), Ruhr Basin (Germany) and multiple coal mining districts in China, where long-term deformation monitoring has been performed using both geodetic measurements and remote sensing techniques (Ng *et al.*, 2010; Zhang *et al.*, 2018).

The integration of historical underground mining documentation with contemporary spatial analysis methods demonstrates the importance of multidisciplinary approaches for evaluating post-mining geohazards. In many former mining regions, surface deformation processes remain insufficiently documented despite the existence of persistent underground infrastructure capable of generating delayed terrain instability. GIS-based methodologies provide an effective framework for integrating geological, geodetic and mining-related datasets in order to improve long-term risk assessment.

The spatial concentration of deformation around the central subsidence zone suggests the existence of a delayed post-mining deformation process controlled not only by former underground excavations but also by the local geological framework of the Jiu Valley coal basin.

The obtained results indicate that historical underground mining infrastructure may continue to influence surface stability long after mining activity cessation. This confirms the importance of considering post-mining terrain behavior when evaluating land use compatibility in former underground coal exploitation regions.

It should be noted that no geodetic monitoring benchmark was located directly within cadastral parcel CF 67007. However, the analysis was based on the spatial correlation between the parcel boundaries and the surrounding deformation field derived from nearby monitoring benchmarks, particularly point R14, which recorded the maximum cumulative subsidence within the study area. This approach allows indirect evaluation of the potential influence of long-term mining-induced deformation processes affecting the analyzed property.

Although the absence of monitoring points directly located within the analyzed parcel and the relatively limited spatial density of the monitoring network represent methodological limitations, these factors do not invalidate the general research findings. The objective of the present study was not to establish precise parcel-scale deformation values, but rather to evaluate the spatial relationship between registered cadastral properties, underground mining infrastructure and the broader subsidence pattern affecting the surrounding mining sector. Consequently, the obtained results should be interpreted as an indicator of potential geomechanical influence rather than a direct high-resolution deformation assessment at parcel level.

6. CONCLUSIONS

This study demonstrated the applicability of GIS-based spatial analysis techniques for evaluating the relationship between historical underground mining infrastructure and registered surface cadastral properties located within former mining regions.

The integration of underground mining plans, cadastral parcel boundaries and long-term geodetic monitoring measurements allowed the identification of direct spatial interaction between underground mining works and cadastral parcel CF 67007 located within the Maleia mining sector.

Multi-buffer analysis revealed that the analyzed parcel intersects the immediate underground mining influence zone, while subsidence interpolation based on GNSS monitoring data identified cumulative vertical displacement values ranging between -0.082 m and -3.853 m, with maximum deformation recorded at monitoring point R14.

The results highlight the necessity of improving interoperability between mining cadastre information and conventional land registration systems in order to provide more complete information regarding subsurface conditions associated with property ownership.

The proposed GIS framework may support long-term geohazard assessment, territorial planning and environmental management strategies in post-mining regions affected by persistent underground-induced terrain instability.

Future investigations may benefit from increasing benchmark density and integrating InSAR-based deformation monitoring in order to improve spatial resolution of parcel-scale deformation assessment.

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