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Abstract: The rehabilitation of abandoned mining sites is an increasingly pressing issue in the context of sustainable development. Recent research has emphasized the need for a holistic approach to the abandoned mining sites and their environmental rehabilitation. Based on field analysis, environmental assessments, satellite imagery processing and geographic information operations, this paper pushes forward the existing knowledge by doing a comprehensive assessment of abandoned mining sites in the Romanian Carpathians and by proposing innovative and sustainable rehabilitation solutions. Our findings highlight that abandoned mining sites and their surrounding territories in the Romanian mountains have significant ecological imbalances and complex socio-economic issues. The findings also suggest that by adopting innovative, integrated, and sustainability-oriented approaches, territories affected by mining can be transformed into valuable and sustainable spaces to meet human needs. We conclude by presenting the importance of innovation in ecological reconstruction and spatial-functional reintegration of mining sites in mountain areas as a useful tool in making fair decisions, both in the context of implementing appropriate development policies as well as for resilience and environmental sustainability of mining-affected mountain areas.

Keywords: environmental sustainability; mining sites; GIS; innovation; rehabilitation; mountain areas; Romania

1. Introduction

Mining constitutes a fundamental component of human civilization, tracing its origins from the extraction sites of the Stone Age to the iron and coal mines crucial for the Industrial Revolution, and extending to the contemporary extraction of materials essential for the transition towards renewable energy. The domain of mining and its derivative products significantly bolsters national economies, evidenced by a tripling in mining value over the previous two decades [1].

The extractive industry is known to be pivotal in effecting fundamental alterations to the environmental frameworks of numerous terrestrial regions. While the footprint of mining operations may be limited in spatial terms, they can nonetheless result in pronounced environmental effects within their immediate vicinity [2]. The environmental impact of mining activities exhibits significant variation, influenced by the extraction techniques utilized, the nature and scale of the mineral deposits, the effectiveness of pollution control measures, waste management practices, and the implementation of appropriate land restoration strategies [3].

Mining activities in Eastern Europe, including Romania, have a long history and tradition, playing a crucial role in the region's beneficial economic development [4,5], activities that have

contributed significantly to job creation, infrastructure development, fostering of local industries [6,7], social welfare [8,9]. According to Haddaway [10] mining can yield a range of societal benefits, but it also has the potential to create conflicts, especially regarding the use of land above ground and underground [11]. The negative consequences are not limited to soil (deforestation, erosion, contamination and alteration of soil profiles), they include also water and air pollution, biodiversity loss, degradation of landscape, displacement of communities [12], mine abandonment, decommissioning and repurposing [13–19]. Needless to say that some of these impacts persist even beyond the closure of mines [20].

The termination of mining operations significantly influences the local economy and job prospects, while also affecting social and economic growth, fundamental to achieving The Sustainable Development Goals (SDGs). Achieving balance among SDGs pillars (society, economy, and the environment)—encompassing individual, political, and corporate interests—is crucial for the enduring viability of mining initiatives throughout their various stages [13,21].

The solution lies in remediation and rehabilitation processes that can lead to positive net effects on environmental systems [22,23], being of utmost importance to recover the degraded land and restore its ecologic, economic and visual principles in accordance with sustainability [24]. In recent years, as a moral and legal duty, mining companies have been mandated to integrate Sustainable Development (SD) principles into their long-term strategies for post-mining restoration, aiming to return the mining sites to a condition deemed environmentally and socially acceptable [13,25,26]. The scientific literature highlights various intervention methods [27–29] with numerous success cases documented globally.

In scientific discourse, three primary terms are frequently associated with the usage of land following mining activities: restoration, reclamation, and rehabilitation [24,25,30,31]. Additionally, certain former mining sites are recognized as unique ecosystems, valued as cultural heritage monuments, and are thus granted protection [32] or serve as novel economic opportunities by transforming them in tourist attractions [33].

The aim of our paper is to conduct an exhaustive assessment of abandoned mining sites in the Romanian Carpathians, alongside proposing novel, sustainable remediation strategies using field surveys, environmental evaluations [34], satellite imagery analysis, and Geographic Information System (GIS) operations. The reason why our research is based in this study area resides in the fact that a total of 60 ecological conflict points have been identified, corresponding to the presence within Natura 2000 sites of areas affected by unrehabilitated mining activities. Among these conflict points, 31 occur within Sites of Community Importance (SCI), while 29 are within Special Protection Areas (SPA) for birdlife.

The specific objectives were to obtain data and information regarding the current state of abandoned mining sites through the dynamic analysis of processes and environmental risk; to identify opportunities for sustainable rehabilitation of areas with closed mining activities within the framework of the circular economy. Other specific objectives include: establishing the methodology for investigation and appropriate research techniques in order to analyze the abandoned mining sites (spatial analysis, proximity analysis, multivariate analysis and raster analysis) and valorizing optimal methods for spatial-functional reintegration of decommissioned mining sites in the mountainous area, as a useful tool in making fair decisions, both in the context of spatial planning actions and in the process of applied research and integrated territorial analysis.

Our endeavor pursued the answers to the following research questions:

RQ1. Is it possible to achieve environmental sustainability in the aftermath of mining?

RQ2. Is there a need for a holistic approach in the ecological rehabilitation of abandoned mining sites?

The study accentuates the role of innovation in ecological restoration and the spatial-functional reintegration of mining sites within mountainous terrains, highlighting its significance in facilitating equitable decisions pertinent to both the enactment of suitable development strategies and the enhancement of resilience and environmental sustainability in mining-influenced mountain regions.

Our research contributes to the existing body of knowledge by offering a comprehensive and integrative perspective on the sustainable rehabilitation of abandoned mining sites, focusing on ways to restore the degraded land included in protected areas like Natura 2000 sites. Along with the novelty brought, it enhances the state of the art offered by international [35–41] and national [13,42] scholarly works interdisciplinary related to the inquiry topic.

The rest of the paper is structured as follows: Section 2 offers an overview of the study area and describes the methodology proposed for the ecological rehabilitation projects. Section 3 provides the results of an illustrative example of the methodology in the case of Apuseni Mountains, Section 4 discusses the results. Finally, Section 5 summarizes the main conclusions drawn from this research.

2. Materials and Methods

2.1. Study Area

The territory investigated overlaps with abandoned mining sites in the mountainous area of Romania, an area delimited according to the joint MADR-MDRAP Order no. 97/1332/2019 [43] (Figure 1). In the current geographical landscape, mining sites are primarily characterized by the existence of different types of anthropic geomorphic structures, due to the long-lasting transformations induced by extractive and processing activities in the mining industry. The specific forms with which they are identified in the territory are marked by the presence of quarries, tailings pits, underground galleries and voids, settling ponds, artificial embankments and mounds. These, in turn, introduce a character of structural-functional discordance in the relationship of association with natural forms, marked both by the extension of the impact area of anthropogenic risks and by the potentially destructive effects induced on the components of local and regional environmental systems.
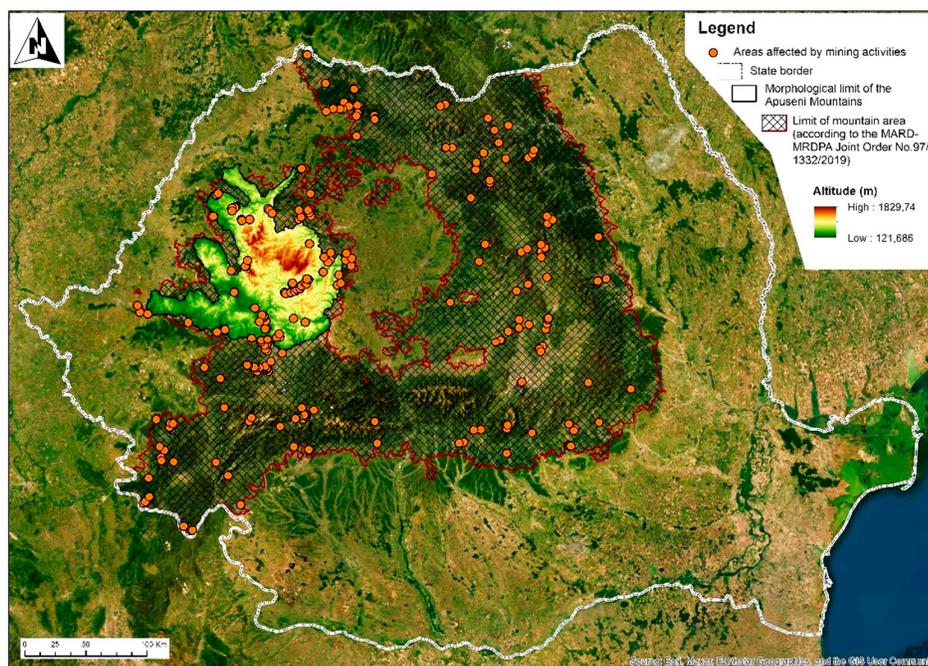
Figure 1. The research area and spatial distribution of mining sites in the mountain area.

Research focused on the topic of landscape reconstruction and spatial-functional reintegration of mountain mining sites in the context of the circular economy has been extrapolated to the level of a case study with strong regional, national and even international resonances. The area in question is the Apuseni Mountains, a region with multiple historical and identity-cultural connotations [44], where gold and silver mining, which began in pre-Roman times, meets contemporary mining.

The regional system of the Apuseni Mountains constitutes a mountain subunit with distinct morphostructural and metallogenic features, which have given a specific socio-economic profile to the development of settlements in the mining areas. It is highlighted both by the historical value and the importance of the mineral resources contained/exploited, as well as by the order of magnitude expressed by the share of industrial-extractive surfaces and the density of mining sites. To all this must be added the impact of industrial-mining activities on the local community and on the development profile of the entire mountain area.

The rationale for the multiscale regional approach in the analysis carried out is due, on the one hand, to the typological differences in mining anthropostructures (gold-silver, copper, uranium, refractory clay, bauxite, limestone and coal) and, on the other hand, to the possibility of a gradual assessment of the elements and structures that make up the territorial systems in the areas affected by mining, given restricted access to data and information sets.

At the same time, the suitability of the territories for the implementation of the most appropriate spatial-functional reconstruction and reintegration measures was taken into account, in accordance with the specificity of the local physical-geographical conditions and the harmonization of the strategic directions of regional development with the integrated spatial planning actions of the settlements in the mountain mining areas.

2.2. Research Methodology

The main stage consisted in identifying an appropriate research methodology which, through the processing of thematic data structures, would lead to quantitative and spatial information on which to base the entire exploratory process [45] pursued in the research conducted. Thus, the research methodology implemented in the present study was based on the combined use of several methods of data and information collection, such as inductive, deductive, direct and in-direct observation, diachronic, analysis and synthesis. Alongside these methods, several specific working procedures were used, which involved sorting, processing and interpreting relevant statistical data, drawing up maps, synthesizing literature, consulting public documents and field research [46].

As an analytical research method with applicability in geosciences, the information-geographic technique was used, since it was necessary to perform a series of operations related to the collection, storage and analysis of the dataset. In this sense, the study required the implementation of a multivariate methodology for the analysis of the parameters that define the content elements associated with abandoned mining sites in the mountain area. Thus, geo-referencing of different images from external sources, advanced analysis based on spatial and/or alphanumeric criteria, and complex DEM operations were used.

Using satellite images from the Landsat 8 mission (sensor ID OLI_TIRS), a series of useful information was extracted for the analysis process, in particular for the identification and location of abandoned mine sites (Figure 2). ERDAS Imagine 16.8 software was used to process the Landsat images, through which the normalized building differentiation index (NDBI) was calculated, according to the formula: [47]

$$NDBI = (TM6 - TM5) / (TM6 + TM5), \text{ where:}$$

TM5 - near infrared spectral band;
TM6 - mid-infrared spectral band.

The final result allowed the transformation of images with values between -1 and +1 into descriptive data, which facilitated the investigation of the analyzed territory based on the interpretation of the biophysical information obtained. Thus, it was possible to redistribute information by value differentiation between different types of surfaces extracted from the spectral space. Man-made and remodeled areas show the highest values (between 0.01 and +0.99), while water bodies and vegetated areas have negative values (between -1 and -0.01).
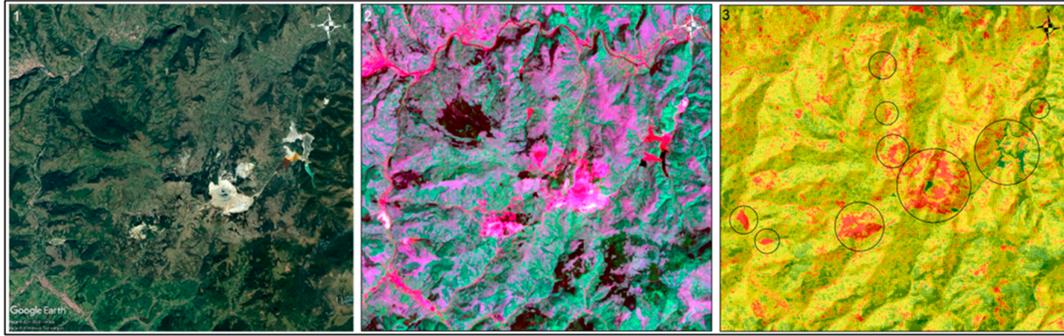
Figure 2. Roșia Montană and Roșia Poieni mining sites. Identification of areas affected by mining based on aerial imagery (1), satellite imagery (2) and the Normalized Difference Building Index - NDBI (3).

Geospatial data obtained through direct ways involved the use of mapping solutions integrated into mobile applications and the activation of developer settings to increase the accuracy of collection. In this way, topographic data in raw format (in the form of points of interest/density), attribute data without spatial references or graphical representation and overviews were obtained, together with plans and maps in physical format. Microscale analysis also involved investigations of mine water outlets, the current state of the mine sites in terms of reconstructive stages (in operation, with stopped activity, undergoing greening, greened) and post-mining stability of depositional and excavation morphology.

Indirect methods were used to extract data in different formats, downloaded through platforms dedicated to users of geospatial products and GIS programs. This facilitated comparative spatial analysis between abandoned mining sites and protected natural areas, ecological corridors, water bodies and other important natural areas, as well as the assessment of direct and indirect impacts on inhabited areas. All the graphical materials produced involved several stages of work during which the geographical reality in the field was adjusted and validated (direct observation) with that rendered by the previous cartographic supports: Google Earth Pro, Google Basemap - QGIS 3.6 Noosa (indirect observation).

The research methods were complemented by GIS techniques, which proved very useful in combination with some of the methods in the list presented above, allowing relational operations to be performed on different types of geographic data structures, together with their display and manipulation for maps, queries and thematic editing. It was taken into account that the application of specific geospatial analysis tools be suitable for mountainous territorial systems affected by industrial-mining activities in all the working stages (variable generation, application of calculation equations, operations on raster structures). Such a data analytical approach at different scalar levels is necessary to identify the degree of suitability of structures resulting from industrial-mining activities for landscape reconversion and spatial-functional reintegration [48] and to develop integrated territorial rehabilitation models linking resource opportunities with social needs in the context of defining viable alternative economic solutions.

The algorithm used in the spatial analysis of mountain structures affected by anthropogenic mining activities is based on specific investigation techniques and procedures (complex data processing, cartographic representations, diachronic evaluations, correlative-integrative analyses) aimed at expressing the current state of the mountain environmental system, evaluating the landscape impact of mining sites on the mountain environment and assessing the degree of resilience and functional reorganization after mining. The analytical approach aimed at geo-processing the data using GIS tools and generating multiple thematic layers on the distribution of mining sites by locality.

At the same time, several alternative solutions for sustainable reconstruction and spatial-functional reintegration have been identified, in line with the European Union's Circular Economy Package, linked to Directive 2006/21/EC [49]. The possibilities for sustainable development of

mountain localities with abandoned mining industry were also analyzed, where local communities are still affected by numerous risks with cumulative post-exploitation propagation [50], such as: depopulation [51,52], demographic ageing, decline of single-industry mining towns [53], socio-economic isolation, environmental degradation [54] and increasing poverty.

2.3. Data Collection

The present research is based on the collection and structuring of a large volume of data and information from which the necessary and essential elements have been extracted, in the form of graphs, tables or thematic layers, for detailed observations and multiscale analyses. Thus, the structure of the database used includes both Landsat satellite image processing and heterogeneous GIS thematic datasets, which provides the necessary consistency to achieve a methodological analysis framework that meets the objectives proposed in this research.

In order to build the database for the selection of the analysis variables, several classical and digital cartographic sources were used (Table 1), such as the geological map of Romania (1:200,000), topographic maps (1:25,000 and 1:50,000), orthophotos at 0.5 m resolution (for the year 2012, updated using Google Earth Pro 2020-2024 captures), CORINE Land Cover dataset (2018).

Table 1. The structure of the database used.

Layer	Data format	Data processing software	Data source
DEM [1]_12,5 m	raster	ArcGIS 10.8	ALOS PALSAR RTC
UAT [2] limits	vector	ArcGIS 10.8	ANCPI [5]
River network	vector	ArcGIS 10.8	OSM [6]
Road network	vector	QGIS 3.6 Noosa	OSM
Protected areas	vector	ArcGIS 10.8	ANPM [7]
Landsat 8 OLI_TIRS images (2023)	raster	ERDAS [4] Imagine 16.8	USGS [8]
CORINE Land Cover (2018)	raster	ArcGIS 10.8	EEA [9]
INS [3] data	.xml/.csv	Microsoft Excel/ ArcGIS 10.8	INSSE [10]/ TEMPO-Online
Geological map of Romania (1:200 000)	raster	ArcGIS 10.8	IGR [11]
Orthophotoplanes _0,5m (1:2000)	raster	ArcGIS 10.8	ANCPI
Map of Romania's mineral resources (1:500 000)	raster	Global Mapper V 25.1	IGR
Limits of Romania's mountain area	vector	ArcGIS 10.8	MADR [12]
Topographic map of Romania (1:50 000/ 1:25 000)	vector	ArcGIS 10.8	ANCPI
Aerial images (2020-2024)	raster	ArcGIS 10.8	Google Earth Pro

[1] Digital Elevation Model; [2] Administrative-territorial unit; [3] National Institute of Statistics; [4] Earth Resources Data Analysis System; [5] National Agency for Cadaster and Real Estate Publicity; [6] OpenStreetMap; [7] National Environmental Protection Agency; [8] United States Geological Survey; [9] European Environment Agency; [10] National Institute of Statistics and Economic Studies; [11] Geological Institute of Romania; [12] Ministry of Agriculture and Rural Development.

The management of field data, indirect observations and intermediate and final results was carried out in a unified database management system and the processing of this data was based on the use of different software. In addition, other sources of data obtained through comparative observations of the investigated mining sites in the mountainous area, in particular those in the Apuseni Mountains, were also used for the in-depth analysis of the territory. Among these, we can mention the data structures obtained from in situ observations and measurements, geographic information extracted through various operations using ArcGIS 10.8 software, analysis of studies and research projects carried out in the investigated area and consultation of the normative-legislative framework in force.

The completion of the database was extrapolated for the whole mountain area of Romania by extracting the value sets of the parameters used from different cartographic supports (geomorphological, soil and vegetation maps). The thematic layout types were used both in the spatial analysis process, carried out in the digital quantitative data collection stage, and for obtaining the information needed [55] for morphometric, morphodynamic, environmental and landscape analyses.

The structuring and processing of the data sets thus obtained aimed to match the coverage area with the delineation and analysis of the biophysical parameters of the studied area. At the same time, the relational database also included the variables needed to assess anthropogenic intervention by industrial-mining activities on the mountain territorial system, as well as the inventory of abandoned mining sites and the mapping of risk processes with major environmental impact. The first structures imported into the database were those in vector format, brought in through the PostGIS Manager import/export application. Several thematic layers have been added through this application, which have been kept spatially re-referenced by filling the SRID field with the EPSG code: 3844, corresponding to the official projection system of Romania (Stereo 1970).

The necessary theoretical criteria were also evaluated and substantiated to actively contribute to the systematization of the geospatial data workflow for abandoned mining sites in the mountain area. To this end, several geospatial data were collected and processed on the location of surface and underground mining perimeters, as well as the location of mining waste dumps, included in the category of tailings ponds and settling ponds.

The cartographic and satellite materials were georeferenced in Global Mapper V.25.1 and ArcGIS 10.8. The satellite images used in this analysis were downloaded by accessing the Landsat database [56], with the aim of ensuring that the months of capture (July-September) provided the most fitting possible clarity.

Another part of the indicators used in the research process was based on quantitative data obtained by accessing data sources and information held by various national institutions: the National Agency for Cadaster and Real Estate Publicity (ANCPI), the National Agency for Environmental Protection (ANPM), the National Institute for Statistics and Economic Studies (INSSE), the Geological Institute of Romania (IGR) and the Ministry of Agriculture and Rural Development (MADR).

3. Results

The analyses carried out have provided a wealth of data and information on abandoned mining sites in Romania's mountain area. The content elements were based on the current morphodynamics of the mining pits, as well as on the state of the physical parameters of the tailings ponds and settling ponds, factors that underlie the characteristics of the existing mining technostructures, as well as the possibilities of sustainable reconstruction and resilient spatial-functional reintegration.

The research procedures used provided information on the location of the abandoned mine sites and field observations have collected data on their current condition. The research aimed at establishing specific landscape reconstruction procedures in the perimeter of abandoned mining sites, dominated by anthropostructures resulting from mining activities in the mountain area.

Based on spatial correlation analysis and proximity analysis, areas with high ecological sensitivity and the highest probability of impact from mining activities were identified. The

correlation analysis of the territory, focused on the geospatial distribution of the elements, allowed the representation of the central indicators, of the orientation, shape and dispersion of the different spatial entities, as well as the highlighting of some elements on the older cartographic material, in order to capture the evolutionary character of the phenomena.

In order to highlight the mountain areas where there are high values of mining sites, the Kernel density was calculated (Figure 3), which is a method of estimating the probability density according to known points, with values very close to those given by the histograms [57].
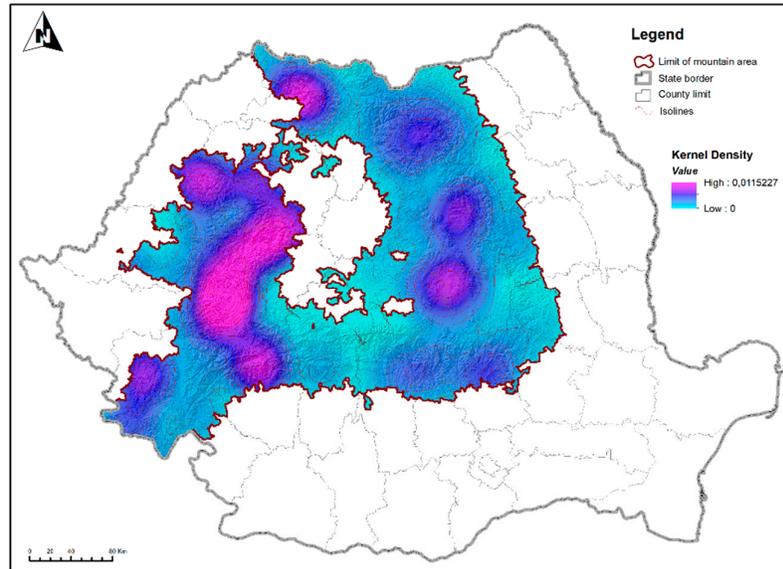
Figure 3. Kernel density of areas affected by mining activities in mountain areas.

In this way, the analysis carried out has identified the existence of several mining hotspots in the counties of Hunedoara, Alba, Maramureș, Caraș-Severin, Bihor, Covasna, Cluj, Harghita, Suceava and other counties. The areas marked by high densities are associated, in almost all cases, with regional forms of environmental and landscape impact.

The study of the historical and current use of mining sites in the mountain area was carried out in relation to a series of general and specific indicators. Thus, the research was based on observations made in correlation with the local and regional geological structure, the morphology of the territory, the current morphodynamics, the local climatic conditions [58], the type of hazardous substances used, the location of inhabited areas and the functions of the surrounding areas. Data and information on land use, key receptors and their relation to mining sites, environmental and landscape risks also contributed significantly.

The methodology used for the rehabilitation of anthropostructures caused by mining is in line with the trends mentioned in the international and national literature. The analyses carried out focused on the state of the closure and greening of the settling ponds, used for the storage of the tailings flotsam resulting from mining activities. The geomorphological assessment of solutions for the functional reintegration and landscaping of land systems in mountain areas affected by mining is a contemporary need, whose applicability has both immediate and long-term effects.

3.1. The Impact of Mining on Mountain Territorial Systems

The mining sector in Romania's mountain area has occupied large land areas that have undergone profound transformations as a result of excavation works in quarries, storage of tailings in tailings ponds, underground mining, construction of access roads, construction of mining platforms and dams. Depending on the extent of anthropogenic interventions associated with the increase in the degree of entropy and the destruction of the internal self-sustainability of mountain

territorial systems, over time important categories of land have been taken out of agricultural, forestry or other uses, requiring urgent post-exploitation sustainable eco-rehabilitation works.

In 1989 Romania recorded the maximum extension of mining activity, the mining sector constituting a way of life for 10% of the active population [59]. Since 1999, through the application of the Mine Closure and Ecological Mining Programme, according to H.G. no. 418/1999 and CONVERSMIN (by H.G. 1158/2004), the closure and conservation of more than 550 mining operations, together with a number of about 30 preparation plants, have been carried out. At present, all mining units where iron ore, non-ferrous, light metals or precious metals were mined have been closed, with the exception of the copper deposits at Roșia Poieni (S.C. Cuprumin Abrud).

Industrial mining activities generate an impact that affects both the long-term demographic component of mining areas (through displacement of settlements and vulnerability of human communities [60], changes in the spatial dynamics of population flows [61], affecting the health and well-being of inhabitants) and the quality of environmental factors.

The work associated with the specific nature of mining (discovery, transport, extraction of useful minerals, storage of waste material) is highly destructive and has repercussions on the mountain habitat and local fauna. A series of negative effects with a high impact and persistence on valuable natural environments is thus produced, which makes ecosystems containing rare flora and fauna species or protected elements vulnerable [62–66].

In the processing and storage stages of mining waste, in most cases no preventive measures were taken due to the lack of a legislative framework, and as a result most of the sites currently closed down have a significant impact on the health of the population and biodiversity [67], mainly due to settling ponds and tailings ponds, together with former processing facilities. There is a lack of a clear methodology for the remediation of contaminated land and polluted groundwater, which has major implications for the implementation of sustainable remediation of contaminated sites.

Mining activities are responsible for the pollution of soil and groundwater with a wide variety of pollutants, especially cyanides, heavy metals (Zn, Cu, Fe, Ni, Mg), sulphate ions, hydrocarbons, colloidal compounds, carbonates and oxides, causing local damage and even destruction of aquatic bios in mountain waters up to long distances from industrial mining perimeters (25-30 km). As stated in the National Strategy and National Action Plan for the Management of Contaminated Sites in Romania "heavy metal contamination can only be remedied after assessing the acidification potential of deposited rocks and encapsulating areas with acidification potential" [68]. In Romania there are 1183 contaminated/potentially contaminated sites [69].

The amplification of the negative impact of mining activities on mountain environmental systems is closely linked to a series of factors that describe the characteristics and extent of the effects produced by mining (methods and technologies used, type of mining (surface, underground) and duration of mining, but also to the physical and geographical characteristics of the territory (geomorphic factors, hydro-climatic factors, edaphic factors).

The extractive industry provides many of the basic raw materials needed for economic activity and for raising the level of development of society. There are, however, situations where industrial-mining plans and projects may conflict with the regulatory-legislative framework responsible for nature conservation and in particular with EU directives on birds and habitats. Thus, the analysis carried out in the investigated mountain area identified 60 points of ecological conflict, corresponding to the presence within Natura 2000 sites of areas affected by mining works, which have not been ecologically protected. A higher density was reported in the northern region of the Apuseni Mountains (ROSPA0115: Crișului Repede gorge - Valea Iadului), the southern Banat Mountains (ROSCI0206: Porțile de Fier) and in the central group of the Eastern Carpathians (ROSPA0133: Călimani Mountains and ROSPA0082: Bodoc-Baraolt Mountains). When assessing the potential impact of extractive activities on mountain ecosystems it is important to specify that this impact refers not only to the extraction site itself, but also to other secondary works and associated facilities, such as: clearing, earthworks, access roads, conveyor belts, crushers, fuel and chemical storage sites, extraction residues and plant platforms.

In the Report on the Inventory and Visual Inspection of Landfills and Settling Ponds in Romania (2017), 29 counties were identified as having industrial waste landfills on their territory (Figure 4), respectively: Alba, Arad, Argeş, Bacău, Bihor, Bistriţa-Năsăud, Braşov, Buzău, Caraş-Severin, Cluj, Constanţa, Covasna, Dâmboviţa, Dolj, Galaţi, Gorj, Harghita, Hunedoara, Maramureş, Mehedinţi, Mureş, Neamţ, Prahova, Sălaj, Satu Mare, Suceava, Timiş, Tulcea and Vâlcea. Of these, 25 counties (out of 27) belong to the mountain area, while no industrial landfills were identified in Sibiu and Vrancea counties [70] (Figure 5).

The total number of inventoried tailings pits in mountain counties was 1030, of which 994 are mining sites. The counties with the highest number are Suceava county (224) and Maramureş (180). A number of 141 ponds were located near protected natural areas and 35 tailings ponds were declared unstable. As regards the situation of the settling ponds, a number of 17 mountain counties were identified as having settling ponds on their administrative territory. The total number of inventoried settling ponds was 108, of which 31 are in the vicinity of protected natural areas and 15 ponds were in operation/active/operational [71].
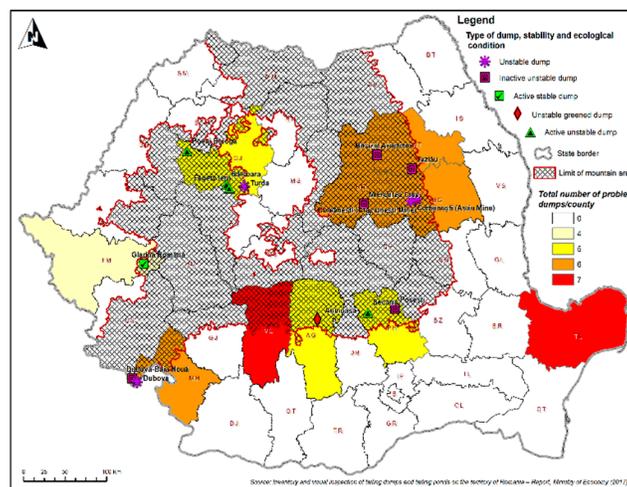

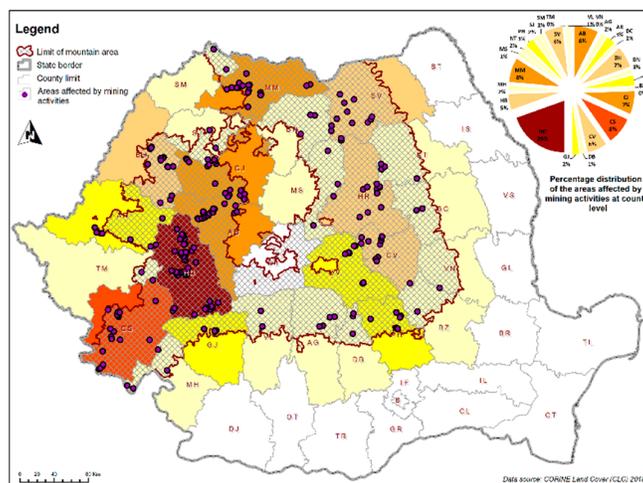**Figure 4.** Spatial distribution of the identified ponds with issues.

Figure 5. Areas affected by mining activities (%) at county level.

3.2. Sustainable Reconstruction and Rehabilitation of Abandoned Mining Sites in the Apuseni Mountains

The mining of non-ferrous ores, particularly gold-silver ores, has been practiced in the Apuseni Mountains for over two millennia, mining activity being quasi-continuous since pre-Roman times in several mining groups, which has left a number of industrial-extractive (mining) areas that justify the

need to implement appropriate measures to reintroduce them into the productive ecological and economic circuit, in accordance with the provisions of the legislative framework in force (Figure 6).

Following the analysis carried out by Kernel density calculation, two main mining hotspots were highlighted (Figure 7), with a southern, i.e. central-eastern location within the Apuseni Mountains and a secondary one, located in the north-western part (Pădurea Craiului Mountains).
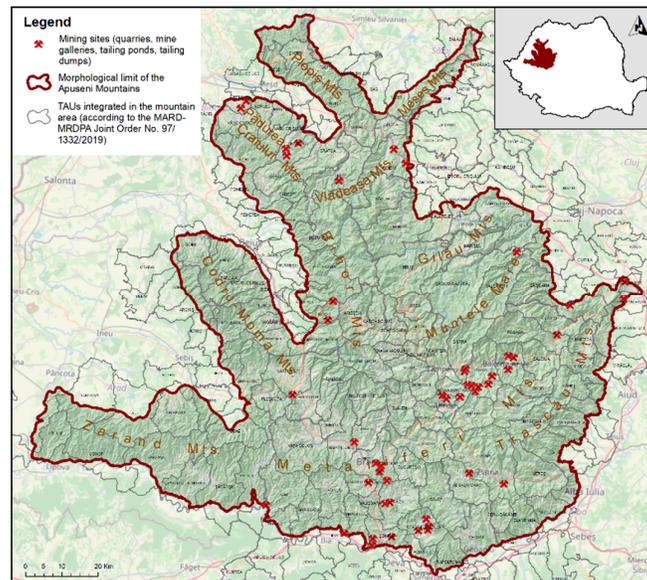

Figure 6. Spatial distribution of mining sites in the Apuseni Mountains.
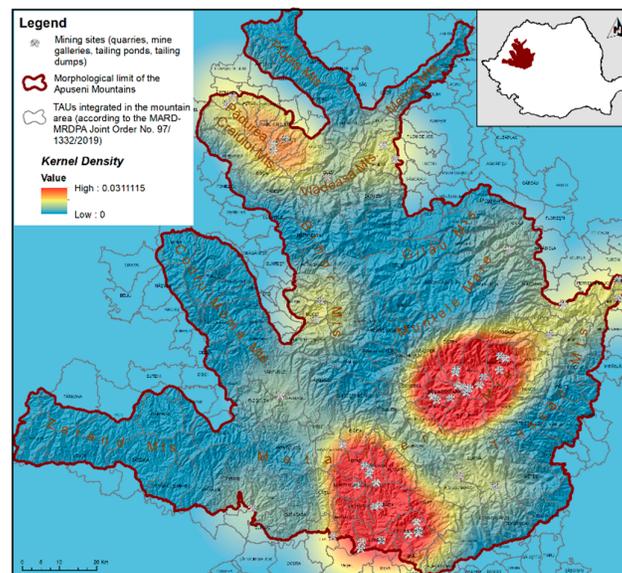
Figure 7. Kernel density of mining sites in the Apuseni Mountains**.**

The investigated territory presents, in terms of the altitudinal distribution of the 49 identified mining sites, an altitudinal range between 202 m (TUA Zam) and 1347 m (TUA Poieni). The largest share of mining sites (23%) is in the hypsometric range of 600-700 m, while the lowest number of mining sites, only 8% of the total, is located at altitudes between 1000-1347 m. Therefore, from the point of view of the distribution of mining sites by altitude, the analyzed territory does not present restrictive conditions in terms of suitability for ecological reconstruction works.

The slope, talus and watershed surface gradients in the region under analysis are conditioned by the specificity of the stripping processes, the structural-petrographic typology, the degree of evolution of the relief forms and the dynamics induced by mining activities on the different types of mountain geomorphostructures. When the influence of declivity is combined with that of horizontal fragmentation, relief amplitude, slope exposure, climatic conditions and the degree of anthropogenic intervention, these parameters can condition the propagation of risk factors for mining-affected perimeters in mountain areas.

The morphometric analysis of the distribution of mining sites through the slope index reveals a percentage distribution by slope categories with geomorphological significance on the way the current processes are carried out at the anthropostructural level in the investigated area. Thus, 12% of the total sites have a slope between 0-2°, 6% between 2.01-5°, 16% between 5.01-15°, 35% between 15.01-35°, 21% between 35.01-55° and 10% between 55.01-64.72° (maximum value - Poieni ATU). It should be noted that most of the mining sites in the Apuseni Mountains (56%) are located on very steep and steep slopes, which translates from a morphodynamic point of view into a high susceptibility to complex stripping processes (landslides, mudflows, intense gullies, gravitropic displacements of materials in dry state – tumbles and landslides), which are closely related to geological, climatic, hydrological, soil-phyto-geographical and anthropogenic factors. This aspect maintains relatively restrictive conditions in terms of ecological reconstruction and redevelopment of areas affected by mining.

The exposure/orientation of the slopes is a factor that induces differences in the duration of solar insolation depending on the slope, thus generating different heat regimes, which will influence the soil moisture content and, through cumulative effects, the quality of the vegetation cover, soil characteristics, the types of morphodynamic processes that take place and land use.

On flat/quasi-horizontal topographical surfaces, only 8% of the total number of mining sites were identified, the largest share (42%) being favorable locations (sunny slopes - SW and semi-sunny - W) for carrying out vegetation regeneration works on the slopes. On the shaded (N, NE) and semi-shaded (E, NW) slopes are spread 41% of the mining sites, in this case being a higher degree of vulnerability to superficial landslides, solifluction and disaggregation, because a large part of the runoff from the transitional periods of the year (spring/autumn) take place on the frozen surface of the ground.

Following the analyzes carried out on the abandoned mining sites in the Apuseni Mountains, it was found that they lend themselves to the implementation of two types of reconstruction technologies used in the post-exploitation eco-rehabilitation process. We are talking about the technologies of purification and monitoring of the mining environment pollution and the technologies of recycling-reuse of the waste from the extractive industry, but also from the rehabilitation of the lands affected by their storage. The rehabilitation of areas occupied by deposits of solid mining residues requires the realization, in a first stage, of a mine redevelopment, which must create the necessary conditions for the regeneration of soil fertility and the cultivation of plants or conditions for constructive purposes, and in another stage of a biological redevelopment, which consists of the environmental recovery of the surfaces of the deposits.

The landscaping stages of the mining sites in the Apuseni Mountains require a partial or total realization, depending on the final destination of the tailings ponds. Environmental rehabilitation involves establishing a final goal for the future use of the land, and in this sense the technique used in the process of ecological reconstruction is considered to have achieved its goal if the site becomes an ecosystem with its own structure, which is able to function by self-maintenance and develop over time through specific self-regulation mechanisms.

The application of recycling-reuse technologies offers the possibility of recycling waste through re-mining works, i.e. the recovery of the content of precious metals or other useful mineral substances left in the body of tailings ponds and settling ponds due to the use of less efficient previous technologies. At the same time, re-mining represents an alternative applicable in the case of many mining operations in Romania, which can reduce or eliminate the large amounts of tailings stored in the form of settling and tailings ponds in the mountain area (Figure 8).

The concentration of remediation costs of various abandoned mining sites must be approached from a wider framework, which must necessarily be aimed towards a sustainable development of territorial systems. Therefore, the action directions must lead to the identification and application of creative solutions for the amplification of the value potential through changes at the level of the policies and fiscal incentives offered in this regard.

In accordance with the National Strategy and the National Action Plan for the Management of contaminated Sites in Romania, the problem of contaminated sites that require urgent intervention had to be solved by 2020, and this action should be continued, in the long term, until 2050.

The redevelopment of spaces affected by mining activities must be seen as a component of integrated development strategies and can be defined as the methodical remodeling of areas with stopped industrial-mining activities, taking public interests into account. By means of post-mining reconstruction plans, greening and sustainable redevelopment, it is necessary to recreate the previous economic potential of the territory, adapted to the current conditions of use (Figure 9). Following the analysis carried out on the abandoned mining sites in the mountain area, it is found that the territorial reconversion and reuse of the areas affected by mining constitute both a regional and a national priority. The most compatible ways of reusing lands affected by industrial-mining activities in the case of abandoned sites in the Apuseni Mountains aim at reconversion into agricultural areas, fisheries, forest areas, recreational areas, adventure parks, sports fields, mining museums, architectural-mining reserves, geological parks, waste dumps [72–76], industrial parks, mine galleries set up for tourist purposes, photovoltaic parks and reserve habitats.

Figure 8. Solutions regarding the economic circularization of mining waste from the mountain environment.

Figure 9. Greening of the Gura Roșiei settling pond (work stages: 2008-2023).

The most frequent design and execution deficiencies reported in the processes of ecological reconstruction and territorial rehabilitation of abandoned mining sites are related to the lack of re-profiling works of long and steep dump slopes, the use of simple waterproofing membranes, without honeycomb, three-dimensional structure (geo-cells, geo-grids) and the choice of some of the most economic methods of greening, by covering with vegetation. We can also mention those related to the low thickness of the applied soil state (15 cm), the failure to carry out the integrated monitoring of the spatial-functional reintegration processes of the mining sites, as well as the lack of an integrative vision of the rehabilitation process of abandoned mining sites, with long-term ecological, social, economic and cultural impact.

Restoring the areas affected by mining involves the return to the economic circuit of the degraded lands from the mining industry. The soil decontamination process includes excavation works and redepositing of the excavated contaminated material in warehouses provided with protective barriers such as waterproof rubber tires/honeycomb type geo-cells and clay layer. New deposits must be covered with clay, geo-membranes/geo-composites with drainage micropipes and topsoil to prevent infiltration. The stabilization of the slopes through re-profiling, cylindering and covering with geo-synthetic materials must be completed with the provision of all conditions for vegetation regeneration [77], and the contaminated underground water requires pumping and purification. For the abandoned mining sites in the Apuseni Mountains area, there are numerous surfaces affected by degradation and pollution processes that present a wide variety, in terms of provenance and conditions offered, for different types of alternatives regarding the achievement of both a sustainable reconstruction and a spatial-functional and resilient reintegration.

Mining from the Apuseni Mountains left its mark on the mountainous environment of the North-East Metalliferous Mountains region, due to the richness of the subsoil in non-ferrous ores (gold, silver, copper, zinc, lead), but it also left a rich and valuable identity-cultural heritage **[78–81]**. The oldest mining town in Romania, Roşia Montană, documented in 131 AD, is currently one of the most important archaeological sites of ancient mining in Europe. The existent cultural landscape of universal value, recently entered in the UNESCO World Heritage List, indicates the undeniable fact that in this case tourism must be the "engine" of future development.

4. Discussion and Conclusions

Recent research has indicated that ecological restoration, as a practice, endeavors to achieve a degree of native ecosystem recuperation in response to disturbances that span from degradation to total ecosystem annihilation [39,82]. Within this expansive field, a specialized sub-discipline has evolved, concentrating exclusively on the restoration of landscapes post-mining. This focus separates post-mine rehabilitation from other restoration endeavors, attributing to the significant disturbance levels encountered. Consequently, recovery goals tend to favor the establishment of novel or hybrid ecosystems, comprising both native and non-native species, to ensure an acceptable degree of stability and ecosystem functionality [30,83].

Nowadays, governments worldwide acknowledge the significance of post-mining rehabilitation in accordance with the principles of ecological sustainability, implementing specific legislation that is striving for best practices and key elements such as: financial guarantees, gradual restoration and objectives that are safe and non-polluting [84–89]. Even if today mine rehabilitation is an integrated part of the mine life-cycle, in the past, the insufficient legislative framework and the absence of suitable financial instruments caused the appearance of abandoned mine lands, identified in almost all regions known for their mining industry [90], a fact also present in Romania. The talk about abandoned mining sites' rehabilitation is more extensive and intense because of the difficulties encountered concerning the absence of clearly defined responsibilities, of standards and criteria for rehabilitation, the high costs involved and the lack of funds, given the ceasing of mining economic activity [90,91]. Several factors must be considered when evaluating an abandoned or inactive mine site for rehabilitation. These factors encompass the site's age, its environmental impact, public health and safety concerns, social implications, government support availability, and the community's dedication to the rehabilitation endeavor [91].

The results of our study reveal substantial ecological disturbances and intricate socio-economic challenges in the regions around these deserted mining sites from the Romanian Carpathians. Moreover, the findings advocate for the adoption of innovative, holistic, and sustainability-focused measures to convert mining-impacted territories into resourceful and enduring environments catering to human necessities. The industrial-mining activity in Romania had, before 1989, an intense pace of development, being based on the unsustainable exploitation of non-energy and energy mineral resources. The socio-economic and political transformations that occurred later require the urgent finding of theoretically grounded solutions with local applicability for the re-greening and rehabilitation of mountain regions with environmental dysfunctions and imbalances. All of this must be aimed at restoring the long-term equilibrium, both in the areas directly affected by mining activities and in the neighboring areas.

The information and data necessary for the characterization of abandoned mining sites were collected both on the basis of the elements relevant and appropriate to the thematic context on which the research was based, as well as through sampling and regional validation. The methodological-logical system of analysis of the process of ecological reconstruction of mining sites highlights a series of specific research methods, which allow the extraction of objective and real results with the role of creating the optimal framework for action in order to reintegrate the territory spatially and functionally. Thus, the investigation of landscape recovery and reconstruction methods were carried out both by applying specific methods of geographical research and by using interdisciplinary procedural resources, with an innovative character, connected to the current realities of the territory.

In the current context, the implementation of new industrial eco-cycles, landscape rehabilitation and integrated reconstruction of abandoned mining sites and degraded areas due to industrial-mining activities is required. Although the inventory of mining waste deposits was carried out at the national level (in 2017), it is imperative to continue the actions of their identification, expertise and monitoring, as well as the implementation of good practices, in accordance with the provisions of the European normative-legislative framework. The forms of intervention must be based on rigorous analyzes in terms of differentiated application in relation to local and regional territorial specificities, because they will have a series of implications in the social-economic plan as well (valuation of the local workforce by creating jobs, redefining activities in the context of the circular economy, the reconsideration of economic cycles based on the concept of eco-efficiency and the development of alternative economic activities).

Both by developing the integrated model of territorial reconversion, adapted to the social, economic, cultural and environmental needs of the community [92], and by identifying alternative solutions to capitalize on the endogenous potential, the result of this research proves its usefulness especially within the actions of sustainable spatial planning in mountain territorial systems affected by mining. In essence, several criteria were followed to evaluate the risk factors for mining sites in the mountain area, extracting those variables that express the number of anthropogenic geomorphostructures, the favoring factors that can amplify the negative effects of anthropogenic-mining action, their degree of stability depending on the geotechnical arrangements, the possibility of triggering related geomorphological processes with destructive potential and the identification of optimal solutions for the reintegration of degraded post-exploitation surfaces.

Therefore, our answer to the first research question, based on the results of the analysis carried out, confirms that there are all the necessary prerequisites for achieving the environmental rebalancing of abandoned mining sites in the mountain area and ensuring optimal functionality in terms of environmental sustainability. In order to reduce and eliminate the risks associated with tailings ponds, settling ponds, underground galleries and quarries (material detachments and gravity movements, accidental discharges of acidic waters, pollution with toxic substances, degradation of the landscape and biodiversity) resulting from long mining processes in the Apuseni Mountains, there is a need for ecological rehabilitation and reconstruction measures adapted to the insertion environment.

The answer to the second research question lies in the fact that in order to ensure the most appropriate ecological rehabilitation, a holistic approach to the perimeters affected by mining is

mandatory. This conclusion is based on the need to provide an integrated monitoring both at the level of the territorial components, of the relationships and vulnerable structures inside the mining sites, as well as regarding the assessment of positional risks in the vicinity.The integrated sustainable management of post-exploitation eco-rehabilitation mining sites is a procedure that must be extended to all perimeters in the mountain area where industrial-extractive and processing activities took place, with the objective of promoting a development strategy based on the sustainable rehabilitation of all environmental components (relief, soils, waters, biodiversity, landscape) to ensure long-term ecological reconstruction and spatial-functional reintegration of territorial systems in the productive economic circuit.

The ecological reconstruction and rehabilitation of the areas affected by mining must gather the acceptance of all interested parties (territorial-administrative institutions, businesses, local community) and be carried out in accordance with the national and regional strategic development objectives. A difficult situation is represented by the uncertain legal regime of the lands on which closure and greening works are carried out or regarding the execution of the modernization works of the mine water treatment stations located in the patrimony of the Ministry of Economy.

Certainly, our study has some limitations. We do not claim that our findings could be generalized for other mountain areas worldwide which have passed similar post-mining sites problems. However, we consider that the outcomes of our study could be further developed by gaining an insight into the post-mining areas through interviews and surveys with the people living in mountain mining areas.

Several recommendations resulted from the analysis carried out, both for the state institutions, which are responsible for managing the problems of abandoned mining sites, and for the specialists in the mining field. First of all, there is a need to revise the legislation in the field of mining waste deposits and reassess them from the point of view of risks, but also of the potential to recover the valuable minerals contained within.

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The second recommendation relates to the need to clarify the legal regime of the lands on which the mining waste is located, because delaying this action can compromise the greening works already carried out. The third recommendation refers to the reconsideration of the forms of valorization of the cultural heritage of mining exploitations with sustained activity, both in terms of tourism and in the context of the development of the circular economy.

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References

1.   Young, R.E.; Gann, G.D.; Walder, B.; Liu, J.; Cui, W.; Newton, V.; Nelson, C.R.; Tashe, N.; Jasper, d.; Silveira, F.A.; Carrick, P.J. International principles and standards for the ecological restoration and recovery of mine sites. *Restoration Ecology* **2022**, *30*, p.e13771.
2.   Salomons, W. Environmental impact of metals derived from mining activities: processes, predictions, prevention. *Journal of Geochemical exploration* **1995**, *52*, 5-23.
3.   Luís, A.T.; Teixeira, P.; Almeida, S.F.P.; Matos, J.X.; da Silva, E.F. Environmental impact of mining activities in the Lousal area (Portugal): chemical and diatom characterization of metal-contaminated stream sediments and surface water of Corona stream. *Science of the Total Environment* **2011**, *409*, 4312-4325.
4.   Zobrist, J.; Sima, M.; Dogaru, D.; Senila, M.; Yang, H.; Popescu, C.; Roman, C.; Bela, A.; Frei, L.; Dold, B.; Balteanu, D. Environmental and socioeconomic assessment of impacts by mining activities—a case study

in the Certej River catchment, Western Carpathians, Romania. *Environmental Science and Pollution Research*, **2009**, *16*, 14-26.

5. Păcurar, B.N.; Nicula, S.A.; Strinu, O.; Surd, V. Indexing the Innovative Capability of Romanian NUTS 3 Subdivisions (Counties*). Journal of Settlements and Spatial Planning*, **2016**, *7*(1), 45-49.

6. Fleming, D.A.; Measham, T.G. Local job multipliers of mining. *Resour Policy* **2014**, *41*, 15-19.

7. Knobblock, E.A.; Pettersson Ö. Restructuring and risk-reduction in mining: employment implications for northern Sweden. *Fenn Int J Geogr.* **2010**, *188*, 61–75.

8. Farjana, S.H.; Huda, N.; Parvez Mahmud, M.A.; Saidur, R. A review on the impact of mining and mineral processing industries through life cycle assessment. *J. Clean. Prod* **2019**, *231*, 1200–1217.

9. Farahani, H.; Bayazidi, S. Modeling the assessment of socio-economic and environmental impacts of sand mining on local communities: A case study of Villages Tatao River Bank in North-western part of Iran. *Resour. Pol.* **2018**, *55*, 87–95.

10. Haddaway, N.R.; Cooke, S.J.; Lesser, P.; Macura, B.; Nilsson, A.E.; Taylor, J.J.; Raito, K. Evidence of the impacts of metal mining and the effectiveness of mining mitigation measures on social–ecological systems in Arctic and boreal regions: a systematic map protocol. *Environmental Evidence* **2019**, *8*, 1-11.

11. Hilson, G. An overview of land use conflicts in mining communities. *Land Use Policy* **2002**, *19*, 65–73.

12. Nicula, A.S.; Stoica, M.S.; Bîrsănuc, E.M.; Man, T.C. Why Do Romanians Take to the Streets? A Spatial Analysis of Romania's 2016-2017 Protests. *Romanian Journal of Political Science*, **2019**, *19*(2), 201-222.

13. Botezan, C.; Constantin, V.; Meltzer, M.; Radovici, A.; Pop, A.; Alexandrescu, F.; Stefanescu, L. Is there sustainable development after mining? a case study of three mining areas in the Apuseni region (Romania). *Sustainability*, **2020**, *12*(23), 9791.

14. Svobodova, K.; Sklenicka, P.; Molnarova, K.; Salek, M. Visual preferences for physical attributes of mining and post-mining landscapes with respect to the sociodemographic characteristics of respondents. *Ecol. Eng.* **2012**, *43*, 34–44.

15. Sonter, L.J.; Moran, C.J.; Barrett, D.J.; Soares-Filho, B.S. Processes of land use change in mining regions. *J Clean Prod*. **2014,** *84*, 494–501.

16. Swenson, J.J,; Carter, C.E.; Domec, J.-C.; Delgado, CI. Gold mining in the Peruvian Amazon: global prices, deforestation, and mercury imports. *PLoS ONE* **2011,** *6***,** 18875.

17. Warhate, S.; Yenkie, M.; Chaudhari, M.; Pokale, W. Impacts of mining activities on water and soil. *J Environ Sci Eng*. **2006**, *48*,81–90.

18. Mchaina, D. Environmental planning considerations for the decommissioning, closure and reclamation of a mine site. *Int J Surf Min Reclam Environ*. **2001**, *15,* 163–176.

19. Navarro, M.; Pérez-Sirvent, C.; Martínez-Sánchez, M.; Vidal, J.; Tovar, P.; Bech, J. Abandoned mine sites as a source of contamination by heavy metals: a case study in a semi-arid zone. *J Geochem Explor*. **2008**, *96*, 183–193.

20. Amirshenava, S.; Osanloo, M. A hybrid semi-quantitative approach for impact assessment of mining activities on sustainable development indexes. *J. Clean. Prod*. **2019**, *218*, 823–834.

21. Jain, R.; Cui, Z.; Domen, J. Environmental impacts of mining. In: Jain R, Cui Z, Domen J, editors. Environmental impact of mining and mineral processing: management, monitoring, and auditing strategies. Amsterdam: Elsevier; 2016. p. 53–157.

22. Tost, M.; Hitch, M.; Chandurkar, V.; Moser, P.; Feiel, S. The state of environmental sustainability considerations in mining. *J. Clean. Prod*. **2018**, *182*, 969–977.

23. Andronache, I.; Marin, M.; Fischer, R. et al. Dynamics of Forest Fragmentation and Connectivity Using Particle and Fractal Analysis. *Sci. Rep*. **2019**, *9*, 12228.

24. Mert, Y. Contribution to sustainable development: Re-development of post-mining brownfields. *J. Clean. Prod*. **2019**, *240*, 118–212.

25. Asr, E.T.; Kakaie, R.; Ataeia, M.; Mohammadi, M.R.T. A review of studies on sustainable development in mining life cycle. *J. Clean. Prod*. **2019**, *229*, 213–231.

26. Ilovan, O.R.; Dulamă, M.E.; Boțan, C.N.; Havadi-Nagy, K.X.; Horvath, C.; Nițoaia, A.; Nicula, S.; Rus, G.M. Environmental education and education for sustainable development in Romania. Teachers' perceptions and recommendations. *JEPE*, **2018**, *19*(1), 350-356.

27. Cao, X. Regulating mine land reclamation in developing countries: The case of China. *Land Use Policy* **2007**, *24*, 472–483.

28. Rooney, R.C.; Bayley, S.E. Development and testing of an index of biotic integrity based on submersed and floating vegetation and its application to assess reclamation wetlands in Alberta's oil sands area, Canada. *Environ. Monit. Assess*. **2011**, *184*, 749-761.

29. Zipper, C.E.; Burger, J.; Barton, C.; Skousen, J. Rebuilding soils on mined land for native forests in Appalachia, USA. *Soil Sci. Soc. Am. J*. **2013**, *77*, 337–349.

30. McKenna, P.B.; Lechner, A.M.; Phinn, S.; Erskine, P.D. Remote sensing of mine site rehabilitation for ecological outcomes: A global systematic review. *Remote Sensing* **2020,** *12(21)*, 3535.

31. Dragastan, O.; Damian, R.; Csiki, Z.; Lazăr, I.; Marinescu, M. Review of the bauxite-bearing formations in the Northern Apuseni Mts. Area (Romania) and some aspects of the environmental impact of the mining activities. *Carpathian Journal of Earth and Environmental Sciences* **2009,** *4*(2), 5-24.

32. Sinnett, D.E.; Sardo, A.M. Former metal mining landscapes in England and Wales: Five perspectives from local residents. *Landsc. Urban Plan*. **2020,** *193*, 103685.

33. Mitchell, C.J.; O'Neill, K. The Sherrif Creek Wildlife Sanctuary: further evidence of mine-site repurposing and economic transition in northern Ontario. *Extr Ind Soc*. **2017**, *4*, 24–35.

34. Nistor, M.; Nicula, A.S.; Cervi, F.; Man, T.; Irimuș, I.A.; Surdu, I. Groundwater vulnerability GIS models in the carpathian mountains under climate and land cover changes. *Applied Ecology and Environmental Research*, **2018**, *16*, 5095-5116.

35. Rodolaki, C.; Barakos, G.; Hitch, M.The role of intercultural differences and challenges faced in negotiating active mine sites' rehabilitation objectives from Africa to Europe. The Extractive Industries and Society, **2023**, 16, p.101362.

36. Alonzo, D.; Tabelin, C.B.; Dalona, I.M.; Beltran, A.; Orbecido, A.; Villacorte-Tabelin, M.; Resabal, V.J.; Promentilla, M.A.; Brito-Parada, P.; Plancherel, Y.; Jungblut, A.D. Bio+ Mine project: Empowering the community to develop a site-specific system for the rehabilitation of a legacy mine. International Journal of Qualitative Methods, **2023**, 22, 16094069231176340.

37. Salom, A.T.; Kivinen, S. Closed and abandoned mines in Namibia: a critical review of environmental impacts and constraints to rehabilitation. South African Geographical Journal, **2020**, 102(3), 389-405.

38. Cornelissen, H.; Watson, I.; Adam, E.; Malefetse, T. Challenges and strategies of abandoned mine rehabilitation in South Africa: The case of asbestos mine rehabilitation. Journal of Geochemical Exploration, **2019**, 205, p.106354.

39. Gann, G.D.; McDonald, T.; Walder, B.; Aronson, J.; Nelson, C.R.; Jonson, J.; Hallett, J.G.; Eisenberg, C.; Guariguata, M.R.; Liu, J.; et al. International principles and standards for the practice of ecological restoration. Second edition. *Restor. Ecol*. **2019**, *27*, S1–S46.

40. Mhlongo, S.E.; Amponsah-Dacosta, F.; Mphephu, N.F. Rehabilitation prioritization of abandoned mines and its application to Nyala Magnesite Mine. Journal of African Earth Sciences, **2013**, 88, 53-61.

41. Fadda, S.; Fiori, M.; Matzuzzi, C. Developing rehabilitation design for the abandoned mine excavations in Central Sardinia, Italy. International Journal of Mining, Reclamation and Environment, **2010**, 24(4), 286-306.

42. Rîșteiu, N.T.; Crețan, R.; O'Brien, T. Contesting post-communist economic development: Gold extraction, local community, and rural decline in Romania. Eurasian Geography and Economics, **2022**, *63*(4), 491-513.

43. Ministry of Agriculture and Rural Development Order no. 97/1332/**2019**. Available online: https://legislatie.just.ro/Public/DetaliiDocumentAfis/211979.

44. Nicula, A.S.; Stoica, M.S.; Ilovan, O.R. The Cultural-Historical and Political Spheres of Influence of Alba Iulia. *Transylvanian Review*, **2017**, *26*, 299-315, Suppl. 2.

45. Adorean, E.C.; Nofre, J.; Ilovan, O.R.; Gligor, V. Exploring nightlife in the university city of Cluj-Napoca (Romania): a mixed methods research study. *Fennia*, **2020**, *1-2*, 180-195.

46. Dulamă, M.E.; Ilovan, O.R.; Boţan, C.N.; Havadi-Nagy, K.X.; Gligor, V.; Ciascai, L. Geographical field trips during university studies. Where to. *European Proceedings of Social and Behavioural Sciences*, **2018**, *41*, 494-502.

47. Zha, Y.; Gao, Y.; Ni, S. Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. *International Journal of Remote Sensing*, **2003**, *24*(3), 583-594.

48. Maroşi, Z.; Adorean, E.C.; Ilovan, O.R.; Gligor, V.; Voicu, C.G.; Nicula, A.S.; Dulamă, M.E. Living the urban cultural landscapes in the city centre of Cluj-Napoca/Kolozsvár/Klausenburg, Romania. *Mitteilungen der Österreichischen Geographischen Gesellschaft*, **2019**, *161*.

49. European Union's Circular Economy Package, linked to Directive 2006/21/EC. Available online: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2006L0021:20090807:EN:PDF (accessed on 8 April 2024).

50. Bîrsănuc, E.M.; Cociș, E.A.; Gligor, V.; Man, T.C.; Nicula, A.S.; Stoica, M.S. Performing Democracy An Analysis of Church-Based Electoral Capital in Romania. *Transylvanian Review*, **2020**, *29*, 291-309.

51. Avădănei, V.; Surdu, I.; Medveschi, I.; Cociș, E.-A.; Păcurar, B.-N.; Nicula, A.-S. Analysis of Discording Geodemographic Structures and Space Polarization in Regional Context Using GIS Technology. Case Study: Apuseni Mountains (Romania). In Proceedings of 5th International Conference on Economic Scientific Research - Theoretical, Empirical and Practical Approaches (ESPERA), Bucharest, Romania, **2019**.

52. Nicula, A.-S.; Medveschi, I.; Avădănei, V.; Surdu, I.; Cociș, E.-A. Accessibility and Ecclesiastic Polarization of Monastic Settlements in the Romanian Carpathians. Case Study: Monastic Settlements in the Occidental Carpathians. In Proceedings of 5th International Conference on Economic Scientific Research - Theoretical, Empirical and Practical Approaches (ESPERA), Bucharest, Romania, **2019**.

53. Vesalon, L.; Crețan, R. Mono-industrialism and the struggle for alternative development : the case of the Rosia Montana project, *Tijdschrift voor economische en social geografie*, **2013**, *104* (5), 539-555.

54. Vesalon, L.; Creţan, R. 'Cyanide kills!': environmental movements and the construction of environmental risk at Rosia Montana, *Area,* **2013**, *45*(4) 442-451.

55. Nicula, A.S.; Boţan, C.N.; Gligor, V.; Cociş, E.A. Celebrating the Great Union through smart digital solutions: lessons from Alba Iulia, Romania. *Journal of Urban History*, **2022**, *48*(2), 425-443.

56. Landsat database. Available online: https://earthexplorer.usgs.gov (accessed on 5 April **2024**).

57. Nistor, M.M.; Nicula, A.S.; Dezsi, Ş.; Petrea, D.; Kamarajugedda, S.A.; Carebia, I.A. GIS-Based Kernel Analysis for Tourism Flow Mapping. *Journal of Settlements & Spatial Planning*, **2020**, *11*(2).

58. Nistor, M.M.; Mîndrescu, M.; Petrea, D.; Nicula, A.S.; Rai, P.K.; Benzaghta, M.A.; Dezsi, Ş.; Hognogi, G.; Porumb-Ghiurco, C.G. Climate change impact on crop evapotranspiration in Turkey during the 21st Century. *Meteorological Applications*, **2019**, *26*(3), 442-453.

59. Mironovici, R.; Turdean, N. Considerations on manual mine clearance. *Mine Magazine*, **2001**, No.*10-11.*

60. Breabăn, A.I.; Iovănaş, E.I.; Gligor, V. Vulnerability assessment at risk processes from the perspective of urban development of Floreşti, Romania. *International Multidisciplinary Scientific GeoConference: SGEM*, **2016**, *3*, 675-682.

61. Nistor, M.M.; Nicula, A.S. Application of GIS Technology for Tourism Flow Modelling in The United Kingdom. *Geographia Technica*, **2021**, *16*(1).

62. Cocan, D.; Udrescu, B.; Muntean, G.; Constantinescu, R.; Uiuiu, P.; Nicula, A.S.; Houssou, A.M.; Laţiu, C.; Mireşan, V. Fish species distribution and diversity indices from Iara river – Transylvania, Romania. *Scientific Papers. Series D. Animal Science*, **2020**, *63*(2).

63. Laţiu, C.; Cocan, D.; Uiuiu, P.; Matei-Laţiu, M.C.; Ihuţ, A.; Nicula, A.S.; Laţiu, I.; Constantinescu, R.; Mireşan, V. The influence of damming on the distribution of brown trout salmo trutta linnaeus, 1758 and european grayling Thymallus thymallus Linnaeus, 1758 (pisces: salmonidae) from Someşul Cald river. *Scientific Papers. Series D. Animal Science*, **2020**, *LXII.*

64. Laţiu, C.; Papuc, T.; Muntean, G.; Uiuiu, P.; Constantinescu, R.; Matei-Laţiu, M.C.; Nicula, A.S.; Craioveanu, C.; Mireşan, V.; Cocan, D. Fish Species Diversity From Someşul Cald River: 50 Years After Cascade Dam Constructions. *Frontiers in Environmental Science*, **2022**, *10*, 918745.

65. Laţiu, C.; Constantinescu, R.; Mireşan, V.; Nicula, A.S.; Dumitraş, D.E.; Papuc, T.; Uiuiu, P.; Cocan, D. Length-weight relationships and fulton condition factor (K) of freshwater fish species from the Ruscova river, spawning ground of Danube salmon Hucho Hucho, Linnaeus, 1758 (Pisces: Salmonidae). *Scientific Papers. Series D. Animal Science*, **2022**, *65*(1).

66. Laţiu, C.; Moraru, M.F.; Uiuiu, P.; Constantinescu, R.; Nicula, A.S.; Papuc, T.; Mireşan, V.; Cocan, D. Current status and length–weight relation of the European mudminnow, Umbra krameri (Actinopterygii: Esociformes: Umbridae), from Jieţ River, Dolj County, southwestern Romania. *Acta Ichthyologica et Piscatoria*, **2023**, *53*, 19-26.

67. Mihai, A.L.; Mulţescu, M.; Negoiţă, M.; Horneţ, G.A.; Surdu, I.; Nicula, A.S. Nutritional characterization of some Romanian mountain products. *The Annals of the University Dunarea de Jos of Galati. Fascicle VI-Food Technology*, **2022**, *46*(2), 104-124.

68. Ministry of the Environment, **2015**. National Strategy and National Action Plan for the Management of Contaminated Sites in Romania. Available online: http://www.mmediu.ro/beta/wp-content/uploads/2014/02/2014-02-13_STRATEGIA.pdf. (accessed on 5 April **2024**).

69. National Strategy and National Action Plan for the Management of Contaminated Sites in Romania, **2015**. Available online: https://www.fao.org/faolex/results/details/en/c/LEX-FAOC197164/. (accessed on 5 April **2024**).

70. Report on the Inventory and Visual Inspection of Landfills and Settling Ponds in Romania. **2017**. The Interministerial Commission for the National Inventory of Tailings Dumps and Settling Ponds - Report on the stage of September 12, 2017, Technical Secretariat, Dir. Res. Min. Available online: http://www.economie.gov.ro/images/resurse-minerale/Raport%20Halde%20Iazuri%2012%20sept%202017.pdf (accessed on 8 April **2024**).

71. Ministry of Economy, **2017**. Mining Strategy of Romania 2017 – 2035. Interim Report 2. Environmental report – first version. Available online: http://www.economie.gov.ro/images/resurse-minerale/3%20Raport%20intermediar%20de%20mediu%20Strategia%20miniera%202017-2035%20prima%20versiune%2C%20dec%202017.pdf. (accessed on 7 April **2024**).

72. Nicula, E.-A.; Creţan, R.; Nicula, A.-S. Personal Protective Equipment (PPE) during the covid-19 crisis: a review of current knowledge and future directions, *EEMJ*, **2024**, accepted for publication.

73. Cociş, E.A.; Soporan, V.F.; Ilea, P.; Imre-Lucaci, F.; Soporan, B.M.; Bere, P.; Nemeş, O. Characterisation of generated ash from hazardous waste incineration. *Studia Universitatis Babes-Bolyai Chemia*, **2012**, *57*(2), 147-156.

74. Soporan, M.; Soporan, V.; Cociş, E.-A.; Bătrînescu, G.; Nemeş, O. Gas Analysis of Municipal Landfill Emissions. *Studia Universitatis Babeş-Bolyai, Chemia*, **2012**, *57*, 23-30.

75. Soporan, M.B.V.; Soporan, V.F.; Bătrînescu, G.; Cociş, E. Assessment Methodology for Non-Compliant Landfills. *Environmental Engineering and Management Journal*, **2013**, *12*(2), 387-391.

76. Soporan, M.B.V.; Soporan, V.F.; Bătrînescu, G.; Cociș, E. Exploratory Analysis of Gas Emissions from Non-Compliant Municipal Landfill Used for Energetic Evaluation. *Environmental Engineering and Management Journal*, **2013**, *12*(2), 381-386.

77. Bota, V.B.; Neamțu, A.A.; Olah, N.K.; Chișe, E.; Burtescu, R.F.; Pripon Furtuna, F.R.; Nicula, A.S.; Neamțu, C.; Maghiar, A.M.; Ivănescu, L.C.; Zamfirache, M.M.A. Comparative analysis of the anatomy, phenolic profile, and antioxidant capacity of Tussilago farfara L. vegetative organs. *Plants*, **2022**, *11*(13), 1663.

78. Boțan, C.N.; Gligor, V.; Pavel, I.H.; Fonogea, S.F. Regional Identities within the European Union Case study: Țara Moților (Romania). *Transylvanian Review*, **2015**, *24.*

79. Boțan, C.N.; Horvath, C.; Pavel, I.H.; Fonogea, S.F.; Gligor, V. Perceptions Regarding the Land of Năsăud Regional Identity. *Transylvanian Review*, **2016**, *25,* Suppl. 1.

80. Boțan, C.N.; Gligor, V.; Horvath, C.; Fonogea, S.F. Land of Hațeg Identity and Regional Brands. *Transylvanian Review*, **2019**, *28*, Suppl. 2.

81. Boțan, C.N.; Gligor, V.; Fonogea, S.F.; Pavel, I.H. Perceptions Regarding the Identity Elements of Oaș Land. *Transylvanian Review*, **2020**, *29,* 183-204, Suppl. 2.

82. Hobbs, R.J.; Norton, D.A. Towards a conceptual framework for Restoration Ecology. *Restor. Ecol*. **1996,** *4*, 93–110.

83. Doley, D.; Audet, P. Adopting novel ecosystems as suitable rehabilitation alternatives for former mine sites*. Ecol. Process*. **2013**, *2*, 1–11.

84. The European Parliament. Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the Management of Waste from Extractive Industries and Amending Directive2004/35/EC. Strasbourg, The European Parliament. **2006**. Available online: https://eur-lex.europa.eu/eli/dir/2006/21/2009-08-07 (accessed on 4 April 2024).

85. Republic of South Africa. Mineral and Petroleum Resources Development Act; South African Government: Cape Town, Republic of South Africa, **2002**; p. 122. Available online: https://www.gov.za/documents/ (accessed on 04 April 2024).

86. People's Republic of China. Mineral Resources Law; Ministry of Commerce: Beijing, China, **2009**. Available online: http://www.china.org.cn/environment/2007-08/20/content_1034342.htm (accessed on 4 April 2024).

87. Province of Alberta. Environmental Protection and Enhancement Act. Revised Statutes of Alberta 2000 Chapter E-12; Alberta, Canada. **2020**, p. 168. Available online: https://www.qp.alberta.ca/ (accessed on 4 April 2024).

88. Western Australia Government. Mining Rehabilitation Fund Act 2012; Department of Mines, Industry Regulation and Safety: Perth, Australia, **2014**; p. 31. Available online: www.legislation.wa.gov.au (accessed on 4 April 2024).

89. Queensland Government. Mineral and Energy Resources (Financial Provisioning) Bill 2018; Department of Environment and Science: Brisbane, Australia, **2018**; p. 204. Available online: https://www.parliament.qld.gov.au/Documents/TableO ce/TabledPapers/2018/5618T173.pdf (accessed on 4 April 2024).

90. Mavrommatis, E.; Menegaki, M. Setting rehabilitation priorities for abandoned mines of similar characteristics according to their visual impact: The case of Milos Island, Greece. *Journal of Sustainable Mining*, **2017**, *16*(3), 104-113.

91. Mhlongo, S. E.; Amponsah-Dacosta, F. A review of problems and solutions of abandoned mines in South Africa. *International Journal of Mining, Reclamation and Environment*, **2016,** *30*(4), 279e294.

92. Nistor, M.M.; Nicula, A.S.; Haidu, I.; Surdu, I.; Carebia, I.A.; Petrea, D. GIS Integration Model of Metropolitan Area Sustainability Index (MASI). The Case of Paris Metropolitan Area. *Journal of Settlements & Spatial Planning*, **2019**, *10*(1).