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ENVIRONMENTAL SCIENCE PHD SCHOOL

PHD THESIS

- ABSTRACT -

INTEGRATED GEO-ENVIRONMENTAL IMPACT ASSESSMENT IN AGHIREȘ MINING AREA WITHIN THE CONTEXT OF ENVIRONMENTAL REHABILITATION

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Note: The numbering of figures and tables in this abstract is largely the one used in the original thesis.

INTRODUCTION

Our modern society depends on the available geological resources, the way it identifies and how it capitalizes them. The stake of the mineral resources is important, marking the development of several mutual relations which transcend in the *economic-environment-social* triad, the core of the sustainable development concept. The mining industry acts in antagonistic ways within the sustainability triad, with positive results for the economic and social components, but often with destructive effects on the environment. Therefore, the negative effects impose the study and the interdisciplinary assessment of both *environmental aspects* and *environmental impacts* associated to the mining industry, these representing a constant threat for the sustainable development. The scientists should focus on ways to develop eco-efficient technologies in the environmental management field, with the aim of resolving *current* problems, *potential* and *remnant* ones, induced via the anthropogenic activities into the environment. In this context, an important role goes to *environmental geology,* a scientific discipline with a remarkable applicative span, especially in today's globalized economy.

In terms of environmental geology, the necessity to *remediate past environmental damages produced by mining* gets particularly prominent, taking into consideration that the intensive exploitation of the geological environment has left evident marks over extended areas, which are inserted and maintained in the territory array as abandoned sites, either contaminated or rehabilitated. Hence, the new environmental laws, future investments, production processes and environmental "friendly" technological solutions, have to be directed toward minimizing the remnant environmental impacts, through the development of appropriate strategies and integrated rehabilitation methodologies for the contaminated sites or degraded lands.

CHAPTER 1
METHODOLOGICAL AND SCIENTIFIC CONTEXT

The present paper addresses a highly actual topic, namely *the environmental impact of mining activities* from the perspective of sustainable development. The paper is an applied geology thesis (economical geology and environmental geology), emphasizing the last step of the capitalization of mineral resources, namely the one corresponding to mine closure and rehabilitation of environmental components, in which the environmental impact assessment becomes a priority.

The thesis main objective is to *outline a viable methodology concerning the integrated geo-environmental impact assessment in degraded mining sites.* The proposed methodology is intended as a tool with practical use in the decision-making process regarding the development of rehabilitation strategies for quarry mining sites.

CHAPTER 2
GEOLOGY OF THE STUDIED AREA

2.1. GEOLOGY OF THE QUARTZ-KAOLIN DEPOSIT

2.1.1. GEOLOGICAL CHARACTERIZATION OF THE PALEOGENE DEPOSITS FROM AGHIREȘ AREA

From a tectonic-structural point of view, the Aghireș mining area circumscribes to the western edge of the Transylvanian Basin, with genetic-evolutive affiliation to the northwestern compartment. At Aghireș, the most important geological events took place in the Paleogene period, when the alternation of continental and marine depositional environments led to the creation of a very complex stratigraphic structure (Savu, 1973). Therefore, in stratigraphic terms, the region is predominated by Paleogene sedimentary formations.

For a description of the geological formations developed in the studied area, we adhered the model proposed by Rusu (1989) – with additions from Petrescu et al. (1997) and Baciu (2003). By covering the entire northwestern Transylvanian compartment, this model enables the interpretation of the geological formations developed in Aghireș area and their correlation with the surrounding regions.

Prior to developing the model in question, Rusu (1970) and then Popescu (1976), have separated the north-western Transylvanian compartment in three sedimentation areas – *Gilău* (in the South), *Meseş* (in the West), and *Preluca* (in the North) – based on the main differences between the geological formations with similar ages found in these areas. The differentiations in the sedimentation process began in Priabonian and have completely been individualized during the Oligocene. A comparison between the Paleogene formations developed in the three key areas of sedimentation is shown in figure 2.6.

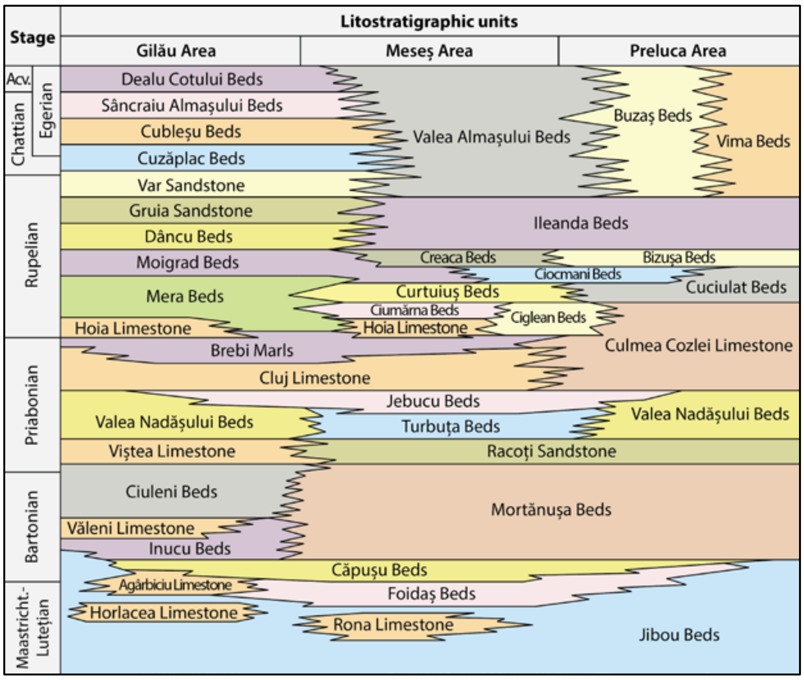

Figure 2.6. *The correlation of the Paleogene litostratigraphic units developed in the north-western part of the Transylvanian Basin (modified after Filipescu, 2001).*

The geological formations found in Aghireş area belong to the Gilău sedimentation area, where the Paleogene sedimentary sequence begins with *Jibou Beds* and ends with the *Sâncraiu Almaşului Beds*, the latter practically making the transition to Miocene. The Paleogene formations developed in this area are characterized by frequent facies variations, both vertically and horizontally (Bedelean et al., 1989).

Of all lithostratigraphic units found in Gilău sedimentation area, within the Aghireş perimeter we identified only Oligocene deposits, represented by the *Mera Beds, Moigrad Beds, Dâncu Beds, Gruia Sandstone, Var Sandstone* and *Cuzăplac Beds* (fig. 2.7 and fig. 2.8). These deposits have been sedimented under a continental-lacustrine and marine regime, with shallow waters, more precisely in an epicontinental shelf area. They have a monoclinic tabular structure on NW-SE direction, with bedding gradients of 3-10° to the NE. This structure imprints a piemonto-coastal configuration consisting of concordant formations (Petrescu et al., 1997).

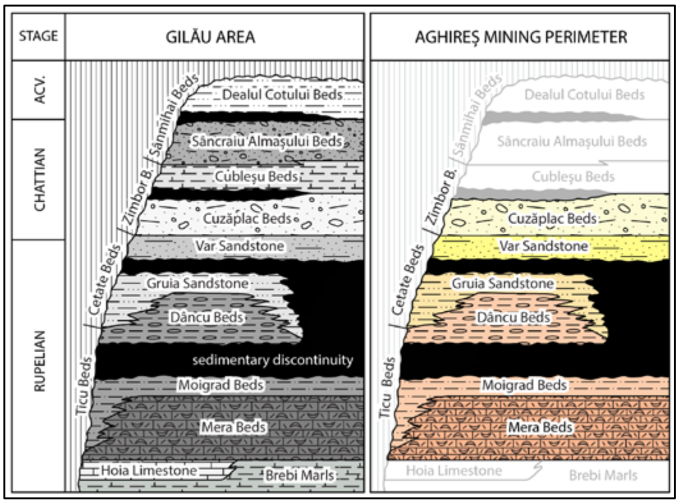

Figure 2.7. Highlighting the Oligocene formations from Aghireş area by extrapolating the current situation in the Gilău area-type (modified after Petrescu et al., 1997).

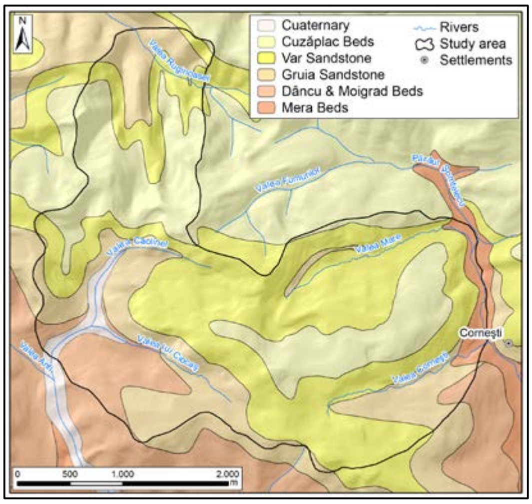

Figure 2.8.Geological map of Aghireş mining area (modified after ICPMSN, 1976).

2.1.2. GEOLOGICAL FEATURES OF THE QUARTZ-KAOLIN SANDS DEPOSIT

The quartz-kaolin sands deposit is disposed over the *Gruia Sandstone* and below the red clays of *Cuzăplac Beds,* thus corresponding to the *Var Sandstone*, which is discordantly disposed over the *Gruia Sandstone*. Chronostratigraphically, Petrescu (1980) assigned the sands deposit from Aghireș to the Upper Rupelian - Chattian interval.

Depending on the sand's qualitative characteristics, the deposit has been divided into five layers, numbered I to V, from top to bottom.

Figure 2.9 shows a synthetic column of the lithological sequence, starting from the one created by Petrescu et al. (1995) based on boreholes and quarry observations.

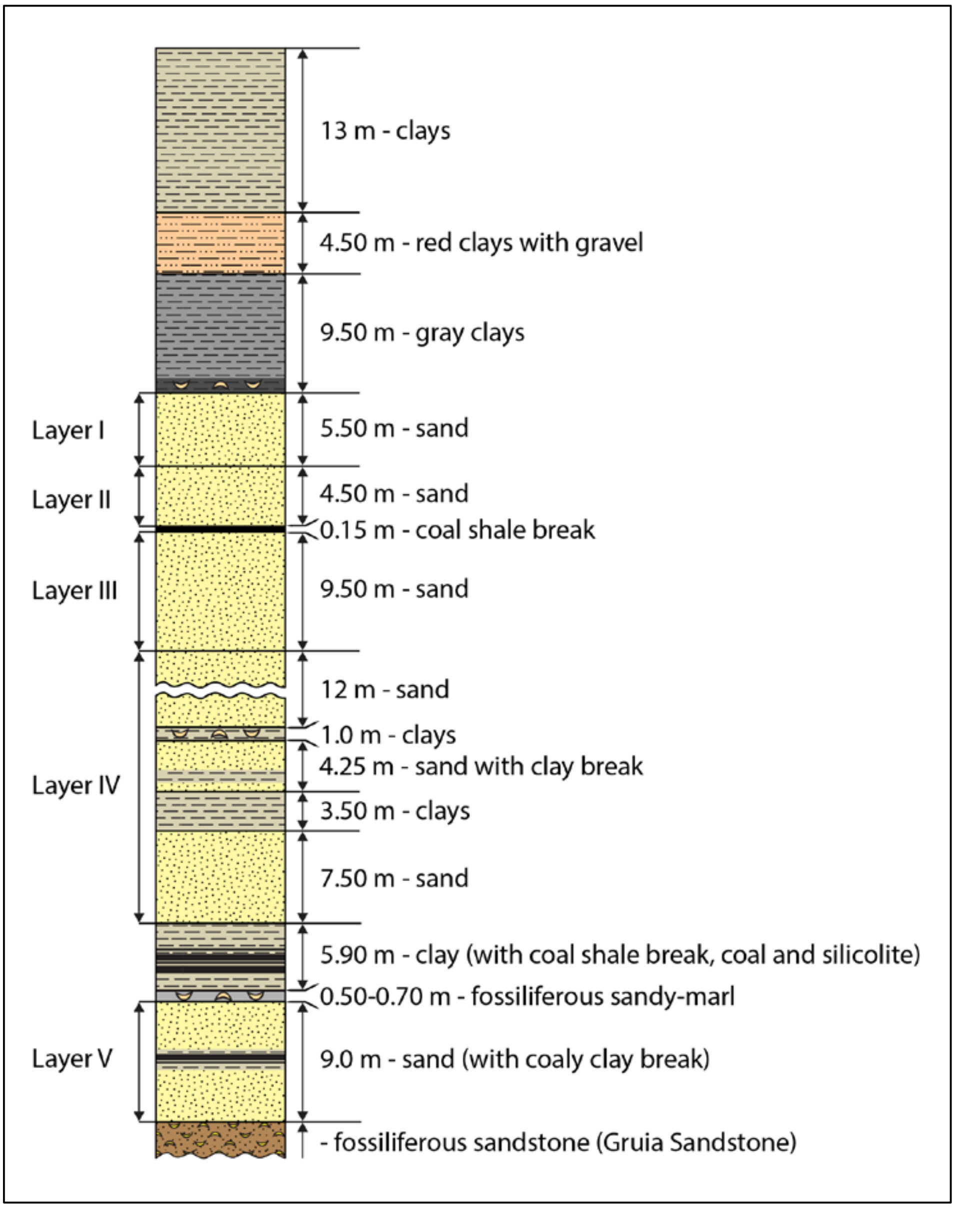

Figure 2.9. *Lithological section performed through the quartz-kaolin sands deposits from Aghireş (modified after Petrescu et al., 1995).*

Figure 2.10 illustrates a general geological section of the Aghireş mining area.

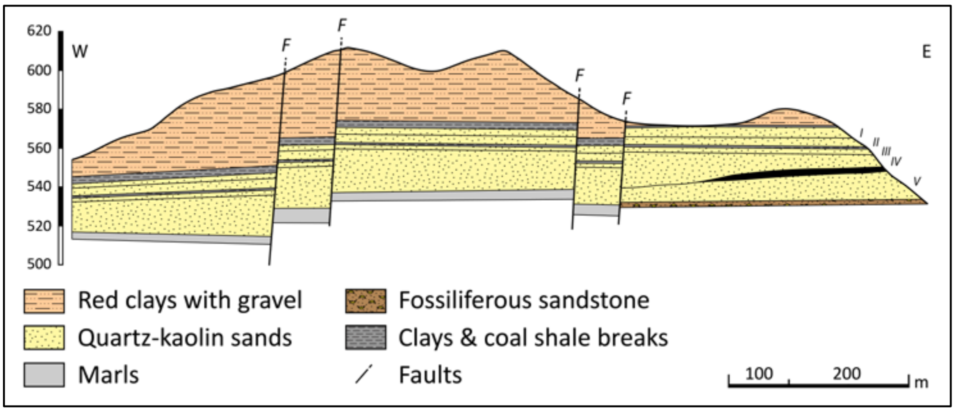

Figure 2.10. *Geological section in the mining fields of Aghireş quarry (modified after Petrescu et al., 1997).*

CHAPTER 3
GEO-ENVIRONMENTAL ANALYSIS OF THE STUDY AREA

3.1. TERRITORIAL FRAMING

Aghireş mining area is located in the northwestern part of Transylvanian Depression, in its regional subdivision known as the Someșan Plateau. The mining perimeter is situated approximately 3 km north-east of AghireşFabrici industrial village, 1 km west of Cornești village, and 27 km north-west of Cluj-Napoca Municipality. Regionally, it is located at the boundary of Cluj and Sălaj counties (fig. 3.1).

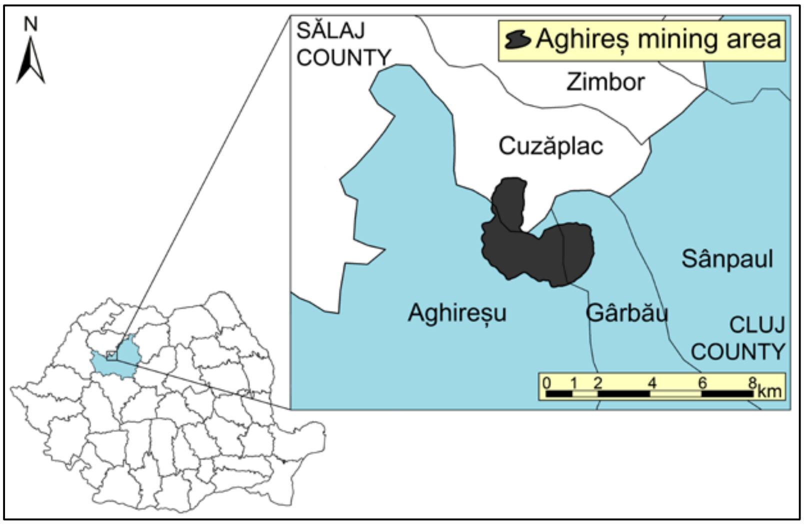

Figura 3.1.*Territorial framing of the study area.*

3.2. GEOMORPHOLOGICAL ANALYSIS OF THE MINING AREA

Following the quartz-kaolin sands exploitation from Aghireș area, due to a friable lithology (clays, marls, sands, sandstones, micro-conglomerates), the landforms underwent a profound change, from the initial fluvial configuration – considered primary (fig. 3.5 and 3.6), to an anthropogenic one – considered derivative (fig. 3.7 and 3.8).

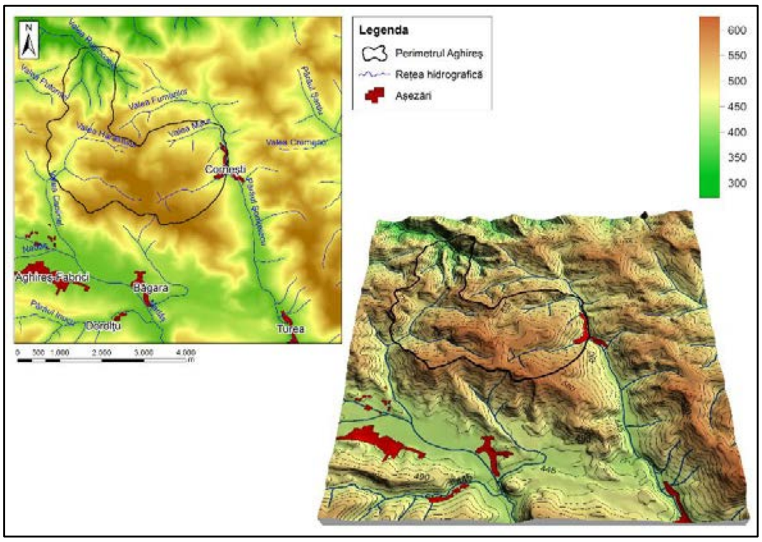

Figure 3.5. *Landforms configuration prior to mining.*

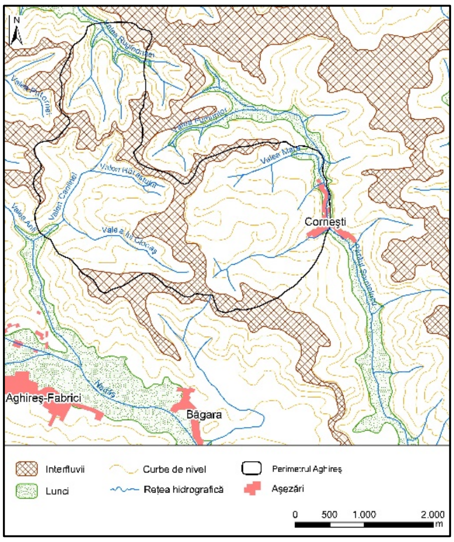

Figure 3.6. *Geomorphological map prior to mining.*

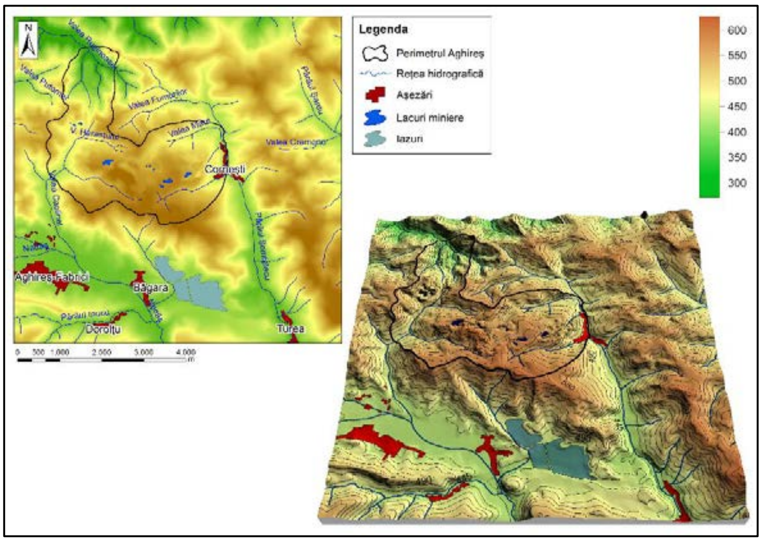

__Figure 3.7.__ Current landforms configuration.

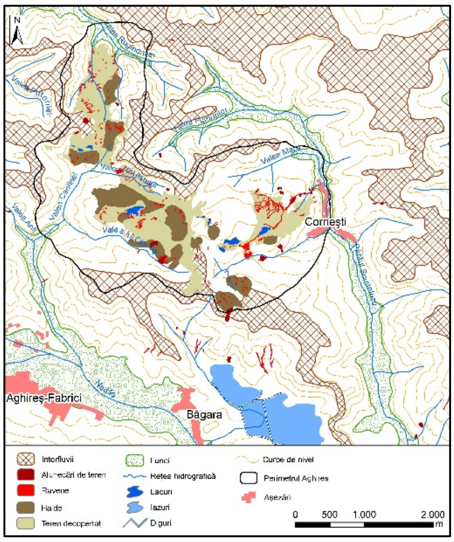

__Figure. 3.8.__ Current geomorphological map.

Under the shown conditions, the current landforms are, on the one hand, the result of the anthropogenic mining activities (underground galleries, land stripping, excavations, exploitation benches and embankments, land leveling, storage of raw materials, waste dumps etc.) and on the other hand, the effect of the atmospheric action and the water exchange (the air masses dynamics, the precipitation, the freezing-thawing phenomena, the water drainage, the substrate moistening) on the morphology resulted after the mining operations.

The human interventions on the substrate had a series of indirect effects, both in geomorphological processes (pluviodenudation, surface erosion, water drainage, rockfalls, wallcavings, landslides) and landforms (gullies, alluvialcones, landslidebodies etc.). Even if these manifestations were developed in conformity with the natural modelling, they are induced by human activities. As a result, the lack of strategies and rehabilitation measures led to uncontrolled geomorphological processes.

3.3. METEO-CLIMATIC COMPONENT

Located in the north-western part of the Transylvanian Basin, Aghireș mining area is influenced by a moderate temperate-continental climate. Since Aghireșu perimeter is not provided with a meteorological station, in order to describe the climate features we used the information received from the stations located in the proximity of the studied perimeter (Cluj-Napoca and Huedin). The most important parameters related to the climate component, namely the temperature and precipitation indicate hill level specific characteristics. Thus, the annual average temperature is estimated at around 8°C, while the precipitation annual average is around 600 mm. It is worth noting that the anthropogenic component and the mining activities generated specific topoclimates in the studied perimeter, by influencing the meteorological elements at local level.

3.4. ANALYSIS OF THE HYDRIC COMPONENT

UNDERGROUND WATER RESOURCES

In the mining perimeter, the hydrostatic level is situated below the useful formations (the *Var Sandstone)*, a situation which allowed a normal exploitation over time, without issues in terms of the underground water. In conformity with the documentation provided by the mining license holder *(SC Bega Minerale Industriale SA)*, the water flows determined by the hydro-drillings are very low (aprox. 2.1 m^3/day), and the active pits are dry, without water infiltrations.

SURFACE WATER RESOURCES

The surface hydrographic network consists mainly of valleys with torrential character and streams with irregular flow (especially during dry periods), the permanent watercourses being poorly represented. The mining perimeter overlaps three river basins or watersheds: the first one is that of Valea Ruginoasei (with a northern drainage unto Bohozelnicu creek, a right tributary of Almașu river), the second is represented by Valea Caolinel (a tributary of Nadăș river), and the third one is that of Valea Mare (tributary of Șomtelec river, which is a left tributary of Nadăș) (fig. 3.21).

Alongside the hydrographic network, several lacustrine units are present in the mining perimeter, these having a specific mining genesis. Thus, once the underground exploitations have been replaced by open-pit mining, the resulting excavations were flooded by precipitation and re-ascending groundwater, which led to the formation of permanent or ephemeral lacustrine units, referred to as „mining lakes" in this paper.

Overall, a total of 10 lakes have been identified in the whole mining area (fig. 3.22), these being an important element of the local environment, much more since they fulfill specific environmental, socio-economic and landscape functions.

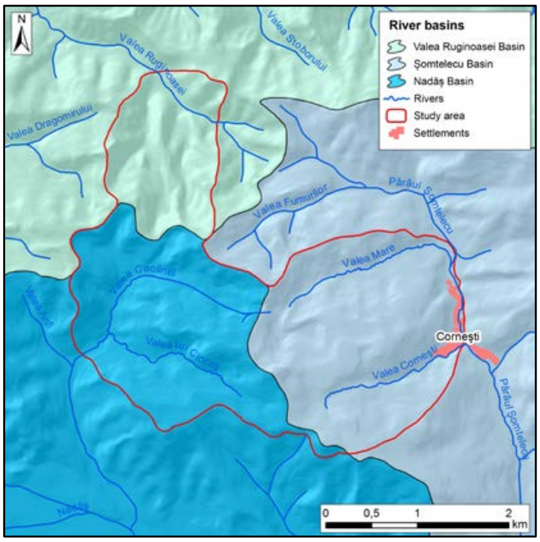

Fig. 3.21. *The watersheds and hydrographic network.*

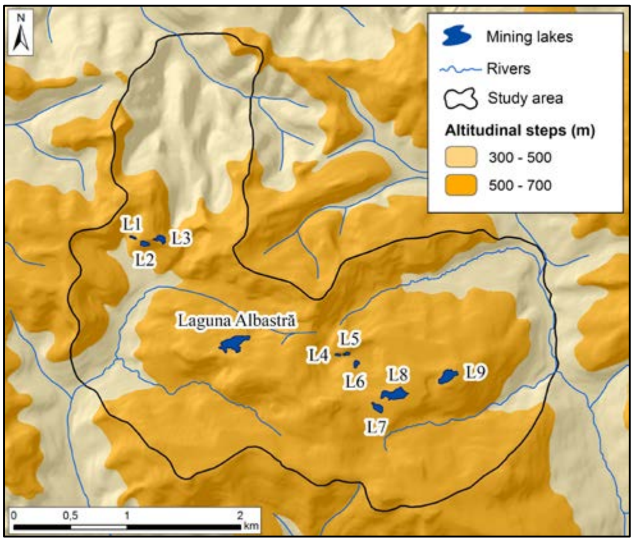

Fig. 3.22. *The distribution of the mining lakes.*

3.5. PEDOLOGIC COMPONENT

In Aghireş area, the soils have a fairly high diversity, mainly determined by the topography evolution, the geological structure, the hydrologic conditions and the human activities.

The knowledge and understanding of soil types and classes is an important requirement for a proper Environmental Impact Assessment process, given that the soil is an accurate indicator of the geo-environmental changes from various territories. For the studied area, seven classes and ten types of soil were identified (fig. 3.24 and fig. 3.25), as it follows: *protisol class* (with aluviosol and entiantrosol types), *cernisol class* (phaeozem and rendzinas types), *cambisol class* (eutricambosol type), *luvisol class* (preluvosol and luvosol types), *pelisol class* (vertosol type), *hydrisol class* (ultisol type) and *antrisol class* (erodosol type).

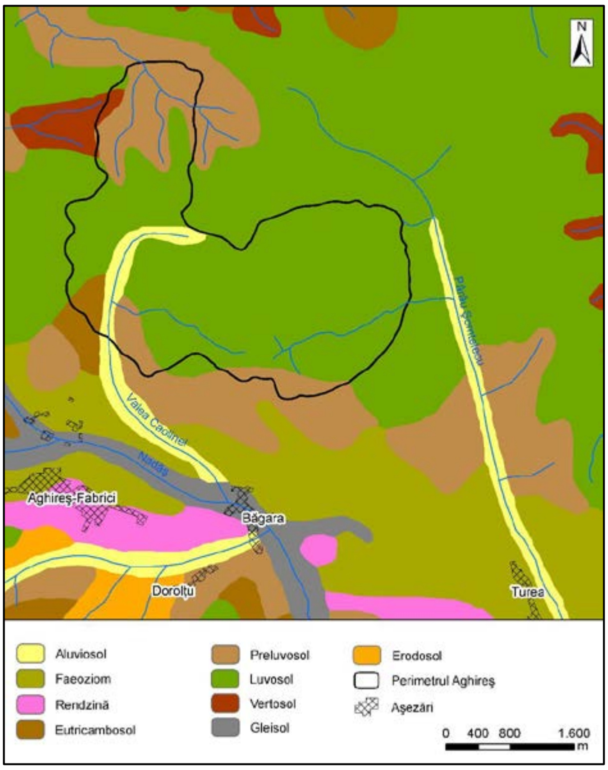

Fig. 3.24. *Zonal soil types from Aghireş area.*

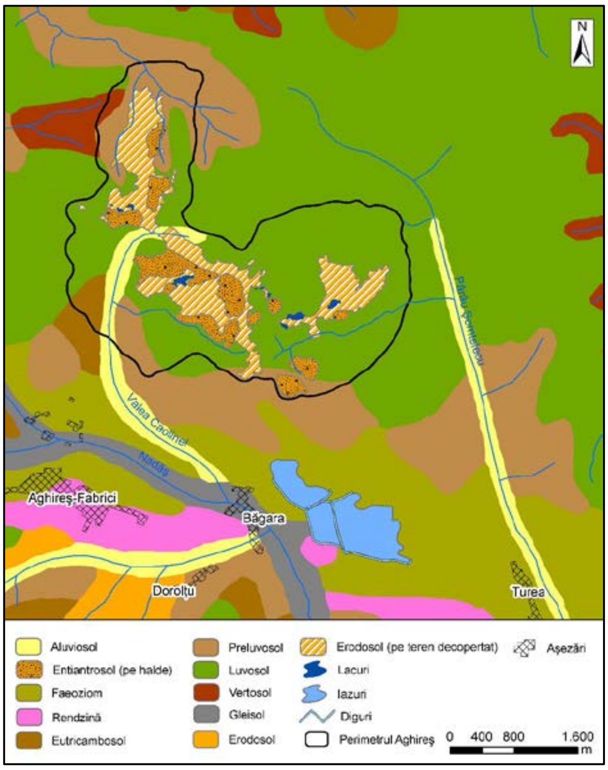

Fig. 3.25. *Zonal and athropogenic soils from Aghireş area.*

3.6. BIOTIC COMPONENT

In the biogeographic regionalization of the national territory, Aghireş area is included in the Dacian biogeographic province, under the Transylvanian Basin province. To this effect, the natural ecosystems are characterized by a Central European flora, with a significant number of endemic elements.

In terms of the landscape, even before the initiation of the mining activities, the studied area was affected by a high degree of anthropization, due to the reduction of the natural and semi-natural ecosystem share, detrimental to agricultural crops. But even in these circumstances, several ecosystems can clearly be distinguished, as it follows: *forest ecosystems, grassland ecosystems, lakes/rivers banks ecosystems* and *agrosystems.*

A particular situation is that corresponding to the mine dumps and the exploitation benches and embankments, which are, in most of the cases, bare of vegetation or covered only by pioneer vegetation. The structure of the phytocenosis found on the mine dumps is not fully outlined, the plant communities being in continuous shifting with regard to their structure and floristic composition, and having different formation and consolidation stages.

In terms of fauna, a reduction of the initial species and populations has been observed, simultaneous with the reduction of the areas occupied by natural vegetation. On the other hand, the appearance of new species was noticed, these being represented by the fauna associated with the mining lakes, such as insects and fish. As a matter of fact, this type of fauna is present in all the permanent mining lakes, with exception to Lake 1, Lake 2 and Lake 3 (fig. 3.22) which show an improper aquatic environment for the ecosystem development. To this effect, the rehabilitation and the development of habitats, especially of those related to the wetlands, will have a significant positive impact for the entire mining area.

3.7. ANTHROPOGENIC COMPONENT

The presence of the anthropogenic component and its specific activities within the studied area is relevant in the Environmental Impact Assessment process. This component contributes to the environmental edification through demographic factors (number of inhabitants), types of rural habitats, economic activities (industry, transportation etc.), as well as through the specific land uses.

The Aghireş mining area overlaps the territory of three administrative units (fig. 3.1): Aghireșu, Gârbău and Cuzăplac. Overall, these three townships have a total of 11870 inhabitants, whereof the Aghireşu residents were the most involved in the economic activity of quartz-kaolin sand extraction, in the last decades. Over time, the local communities have benefited both from positive effects of the mining industry (especially during the period of the full mining operational capacity), as well as from negative consequences (especially in the last period), manifested by the restriction of the mining activity, the revenue shortfalls and the unemployment augmentation following the privatization and the modification of the technological procedures.

CHAPTER 4
DESCRIPTION OF AGHIREȘ MINING EXPLOITATION

4.1. HISTORY OF THE MINING EXPLOITATION

At the end of the 18th century, in addition to agriculture and farming, a new preoccupation started to emerge among the inhabitants of Aghireşu: *mining*. In this regard, Wenczel (1880) states that in 1788 several outcrops of coal were discovered around Aghireşu, these belonging to the Ticu - Șorecani (Aghireş) coal basin. Around the 1850s, the first actions of coal prospecting and exploration were initiated near Aghireș, the coal mining debuting shortly after with two openings: Arghişu and Tămașa (Mateescu, 1970; Magda et al., 1972). In 1863, the mining activity from Băgara (Emil Mine) starts, followed by those from Aghireșu (Fortuna Mine) and Dâncu (Elisabeta Mine).

In 1903, the Aghireșu-Fabrici village was founded, proceeded by the opening of quartz-kaolin sands deposits mining in 1928, near Cornești village. The mining activity started as underground exploitation but due to the high costs, low productivity and unsafe geological structure it was replaced in 1954 by open-pit mining, an exploitation method which ensures high productivity and minimal losses of useful minerals.

Between 1957 and 1959 the preparation plant of kaolin and washed sand is being built in Aghireșu-Fabrici – the current administrative headquarters of the mining area. Ten years later, due to the great loss in the coal mining value, the activity of Ticu - Șorecani mines is suspended. From this point forward, the only active operations will be those related to Aghireș quarry exploitation.

After 1989, amid a declining demand on the selling market, correlated with the general economic situation, the production capacity of the quartz-kaolin sands also declined, causing the cessation of several mining fields. Therefore, after 1990 the production declined steadily, entailing massive reduction in the staff department.

From 2001, the Aghireș mining exploitation is taken over by the *SC Bega Minerale Industriale SA* company, which now holds the majority equity stake. Following the takeover, the sands production begins to increase.

Currently, the specific activity carried out in the Aghireș mining facility is exploitation of the existing deposit of quartz-kaolin sands and processing of the extracted minerals in order to obtain and market the finished products.

In the future, the *SC Bega Minerale Industriale SA* company aims to continue the exploitation of the quartz-kaolin sands deposit from Aghireș mining area, by methods according to the regulations in force and based on authorizations and approvals obtained from the competent authorities.

4.2. QUARRY TECHNICAL DESCRIPTION

The mining area has a total surface of 2,467 km^2, distributed over two sectors *(Aghireș-Cornești Sector* and *Stoguri Sector)* which include, overall, four mining fields: *CM I - Pillar strips*, *CM II - Aghireș Mine*, *CM III - Cornești*, *CM V - Stoguri*. To these, the Laguna Albastră Mining Field (CM IV) is added, this currently being abandoned (which is why it is not included in the current exploitation sectors) (fig. 4.7).

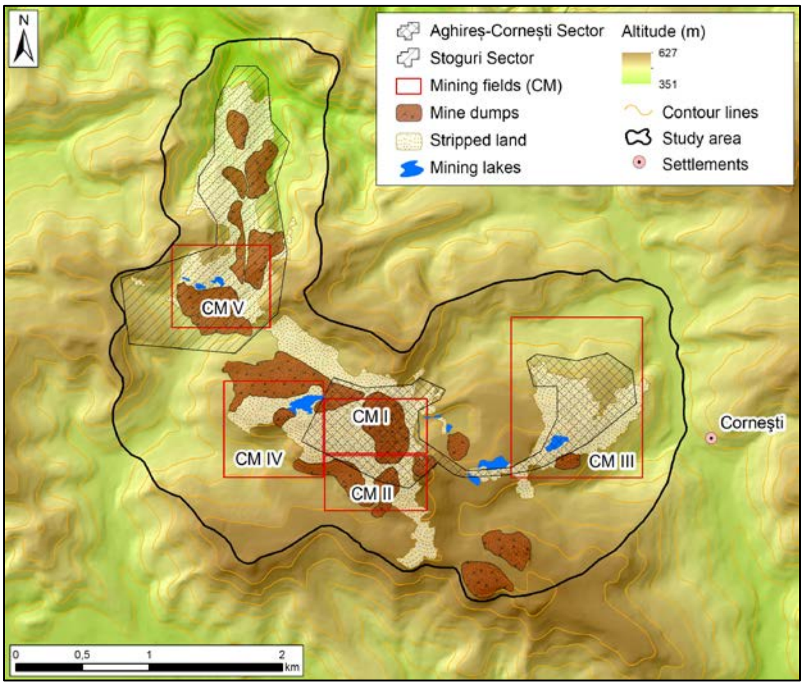

Figure 4.7. *Mining fields from Aghireș quarry.*

At the moment, the extractive operations are carried out only in Aghireș-Cornești Sector, with the final processing activities taking place in the technological installation from Aghireșu-Fabrici, where the entire range of finished products is made: washed and graded sands, kaolin (kaolin mass), granular quartz and adhesives.

The exploitation method for the quartz-kaolin sands deposit is *quarrying, on stages with downward progress, dislocation through drilling-blasting, mechanical loading of the dislocated material, and inner or outer tailing dumping.*

In short, the basic activities of the general technological process of mining are systemically and gradually succeeding as follows:

ENSURING ACCESS IN THE EXPLOITATION AREA → STERILE REMOVAL → DRILLING → BLASTING → CONTROLLING THE WORKING FRONT → LOADING → TRANSPORTATION → (TAILING DUMPING) → PROCESSING IN THE GRINDING INSTALLATION → DELIVERY

After the quartz-kaolin sands extraction and initial processing within the grinding installation, the sands are transported to the final processing-preparation plant from Aghireșu-Fabrici, where the finished products are obtained.

CHAPTER 5

INTEGRATED ASSESSMENT OF ENVIRONMENTAL ASPECTS AND SIGNIFICANT IMPACTS

5.1. IDENTIFICATION AND ASSESSMENT OF ENVIRONMENTAL ASPECTS

5.1.1. MATERIALS AND METHODS

In order to assess the environmental aspects arising from the mining activities carried out in Aghireș area, together with their significance determination in relation to the basic environmental components - abiotic, biotic and anthropogenic, a new method is proposed in the present thesis, with the potential of being successfully used in other similar studies. The method is based on general principles borrowed from procedural and legislative context of the ISO 14000 family of standards – regarding the development, implementation, maintenance and improvement of environmental management systems – and is compatible with any geographical, cultural, social, economic or organizational framework.

The proposed method is oriented towards assigning an *assessment score* for each environmental aspect in order to assess its significance. The scores are assigned based on specific criteria that reduce the subjectivity degree of the whole process; these criteria are: ***R*** *– the* ***R****egulations regarding the environmental aspect;* ***N*** *– the* ***N****ature of the environmental aspect;* ***S*** *– the* ***S****patiality of the environmental aspect;* ***T*** *– the* ***T****emporality of the environmental aspect.*

By assigning an assessment score to each criterion, we set out levels (or values) of their significance in relation to the environmental aspect. Then, by combining the results obtained for different criteria we can assess the significance of the environmental aspect. Also, by using threshold values we can decide which aspects are significant; these will be considered for further investigations in order to determine the real impact in the territory. Therefore, the identification of significant environmental aspects and their associated impacts is necessary in order to determine whether the control and monitoring is required, as well as to establish the priorities regarding the rehabilitation actions.

5.1.2. RESULTS AND DISCUSSIONS

Based on the obtained results we drafted a list of activities and anthropogenic processes, along with the environmental aspects associated with them, for each of the environmental components analyzed. Then, we outlined the assessment scores and the significance of each environmental aspect. A summary of these lists, containing only the significant aspects is presented in table 5.1.

Table 5.1

The list of anthropogenic activities and significant environmental aspects from Aghireș mining area.

Activity/process	Environmental aspect	Assessment score	Significance
Soil and geological substratum			
Blasting and excavation	Land stripping	125	significant
Tailing dumping	Creation of mine dumps	75	significant
Surface water and groundwater			
Deposit uncovering	Emergence of artificial lakes	75	significant
	Modification of the hydrological regime	225	significant
Rainwater charging with various contaminants	Contaminating the drainage water	225	significant
Air			
Blasting and excavation	Emissions of particulate matter	225	significant
Deposit uncovering and creation of open excavations			
Grinding			
Loading/unloading			
Transportation on the conveyor belt			
Road transportation			
Tailing dumping			

5.2. INVESTIGATION OF SIGNIFICANT IMPACTS ASSOCIATED WITH THE ENVIRONMENTAL ASPECTS

Following the identification of significant environmental aspects, and according to the applied methodology, it resulted that these have the potential to generate significant environmental impacts which require further investigation in order to determine their actual magnitude and spatial extent on the environmental components.

The impact investigations were based on methodological tools (methods, techniques and indicators) that have been differently adapted to each environmental component, as follows:

- For the *land stripping* environmental aspect, we investigated the current geomorphological processes and the soil erosion rate, by using the GIS technique.
- For the *creation of mine dumps* environmental aspect, we investigated all the mine dumps from the mining perimeter, by applying specific physico-mechanical and physico-chemical methods of analysis on representative samples of soil and sterile.
- For the environmental aspects like the *artificial lakes emergence, modification of the hydrological regime* and *contaminating the drainage water,* we investigated the water bodies (surface and groundwater) identified in the territory, by applying specific physico-chemical methods of analysis on representative samples of water.
- For the *emissions of particulate matter* environmental aspect, we investigated the air in the mining area, by applying in situ methods of analysis.

5.2.1. SOIL EROSION AND GEOMORPHOLOGICAL PROCESSES ANALYSIS

5.2.1.1. SLOPES DECLIVITY AND TERRAIN STABILITY

The introduction of geomorphological criteria in environmental rehabilitation projects is a fundamental premise so that the planned activities would be successfully implemented, and the endeavors would have a long-term application in terms of territorial realities imposed by the random geological and geomorphological infrastructure existent. In this context, the evolution of the natural and anthropogenic slopes, along with the issues related to the soil erosion, are essential aspects to be taken into consideration for providing a proper rehabilitation planning process.

Therefore, the rehabilitation project proposed in this paper will take into account the landforms declivity values (determined by applying the GIS technique) and the geomorphological processes specific to each terrain stability class.

For the Aghireș mining area, the results indicate slope declivity values ranging between 0 and 48°, these being divided into five classes (fig. 5.11): *quasi-horizontal surfaces* (0 to 2°), *slightly inclined surfaces* (2.1 to 5°), *moderately inclined surfaces* (5.1 to 8°), *highly inclined surfaces* (8.1 to 15°), *extremely inclined surfaces* (15.1 to 48°). All of these classes have geomorphological significance.

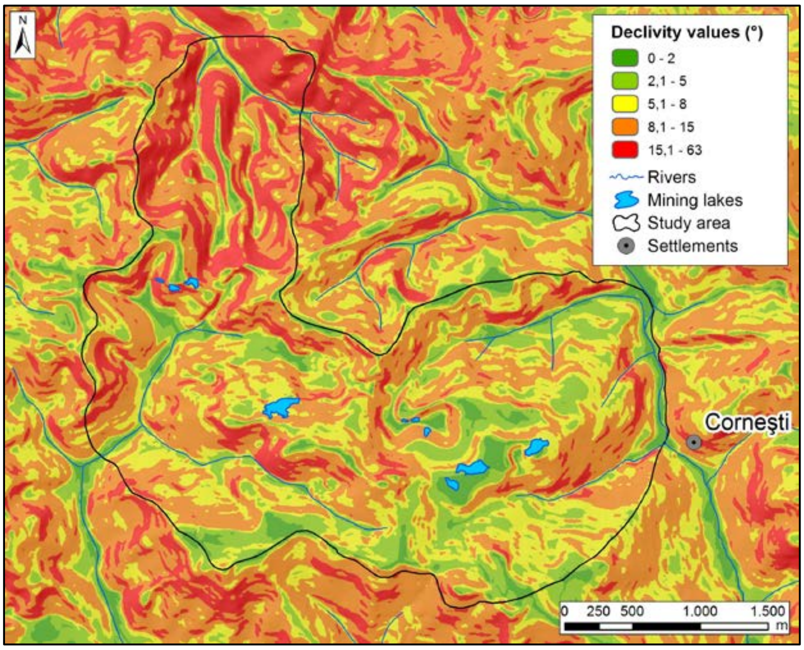

Figure 5.11. *Slope declivities in Aghireș mining area.*

5.2.1.2. SOIL EROSION RATE INVESTIGATION (RUSLE MODEL)

The mining activities form Aghireș area lead to the degradation of land, which caused a pronounced change in the natural erosion rate and the intensification of soil removal processes (erosional soil loss).

The actual sheet erosion rate was determined by using the Revised Universal Soil Loss Equation model (RUSLE), developed by Renard et al. (1997) and revised by USDA-ARS-NSL[1]

[1] *U.S. Department of Agriculture, Agricultural Research Service, National Sediment Laboratory*

in 2003. This model allows a standardized approach for the issues of interest and lends itself perfectly to the needs of the present work. For the model application, we took into account the Universal Soil Loss Equation model (USLE), developed by Wischmeier & Smith (1965, 1978) and adapted to the national context by Moțoc et al. (1975), as well as the Romanian Soil Erosion Model (ROMSEM), developed by Moțoc et al. (1979) and revised by Moțoc & Sevastel (2002).

The RUSLE model is a tool used to estimate the soil loss rate based on environmental conditions specific to a particular location, but at the same time a guide for selecting and designing the proper control systems of erosion and sediment accumulation processes, for that specific location. For a better representation and interpretation of the RUSLE data, the model was corroborated with the technical means provided by GIS analysis using ESRI ArcGIS 10 software.

Based on the field and laboratory data (digitized from the orthophotomaps, topographic and soil maps), a series of graphical GIS entities were obtained, which formed the basis of the visual representation of the annual soil erosion rates distribution for the analyzed area (fig. 5.14).

The final results indicate a maximum erosion rate of 38.52 tons/ha/year, with an average of 0.11 tons/ha/year for the investigated perimeter. However, these values are unevenly distributed, with the highest erosion rates being found in the quarry area, while and the rates in the surrounding (forested) area are approaching the null value. In this respect, Anghel & Todică (2008) mention that the accepted value for the soil erosion rate is 3 tons/ha/year, a value which is far exceeded in the investigated perimeter, on an area of approximately 1.16 ha. This area corresponds mainly to the stripped lands and the mine dumps, which require adequate protective measures.

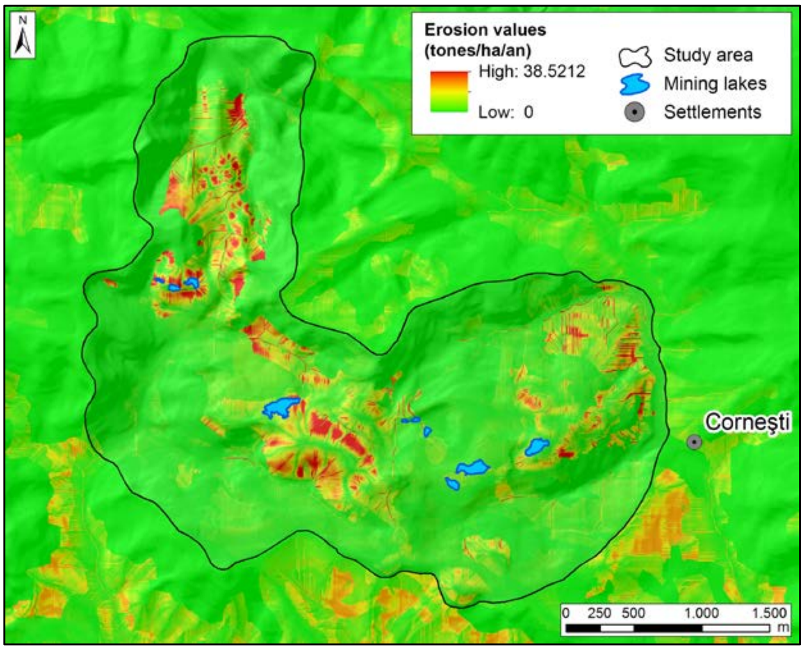

Figura 5.14. *Rata de pierdere a solului în perimetrul minier Aghireș.*

The RUSLE model obtained for the mining perimeter is an essential component for the present study, given that the rehabilitation measures proposed in Chapter 6 are largely dependent on the erosion rates present in our area of investigation.

5.2.2. MINE DUMPS ANALYSIS

5.2.2.1. MATERIALS AND METHODS

The mine dumps analysis targeted, on the one hand, the investigation of the impacts generated by the mine dumps on the soil and the geological substratum, and on the other hand the determination of the mine dumps solification degree, together with the characteristics of the newly developed dump soils. These elements have a practical importance concerning the potential of rehabilitation for the targeted mine dumps. For that purpose, a series of physico-mechanical and physico-chemical analysis were effectuated for both soil and mine dump samples.

Some of the physico-chemical indicators (such as the *pH,* the *electrical conductivity,* the *oxidation-reduction potential,* the *salinity* and the *total dissolved solids*) were determined in the laboratory, by using a *WTW 720 Series* multiparameter. The *carbonates* were determined by applying an estimative method with HCl, the *humus content* by using an estimative method with solid NaOH (STAS 7107/1-76), the *anions* by applying the ion-chromatographic method and the *heavy metals* by using the atomic absorption spectrometry method.

The physico-mechanical indicators were determined as it follows: the *humidity* by using the stove drying method (STAS 1913/1-82), the *absorption capacity* by applying the free expansion method (STAS 1913/2-88), the *density* by hydrostatic weighing method (STAS 1913/3-76), the *plasticity* and the *consistency* by using the Casagrade cup method and the soil cylinders methods (STAS 1913/4-86), and the *granulometry* by applying the the sedimentation method and the sieving method (STAS 1913/5-85).

The sampling points were chosen as to allow the investigation of all the mine dumps from the studied territory. As a result, 20 sampling points and three control samples were required (fig.5.16). The control samples were collected from the soils outside the exploitation area.

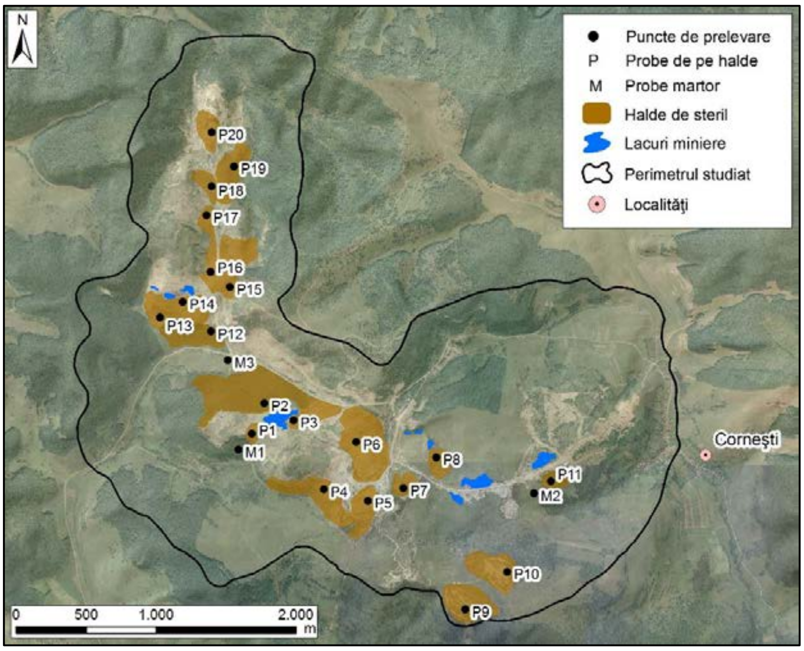

Figure 5.16. *The position of the mine dumps sampling points.*

The analyses were performed during a three year period (2011, 2012 and 2013), with one annual sampling session conducted during the summer.

5.2.2.2. Results and discussions

The physico-mechanical parameters

The physico-mechanical parameters of the mine dumps samples were analyzed particularly with the aim of establishing the level of soil formation, taking into consideration the presence and/or the absence of the vegetation cover.

The results indicate soils mostly composed by non-cohesive materials (clayey sands, sandy clays and/or sandy-siltic clays), with a poor content of humus (only 5 of the 20 investigated samples presented values higher than 5%), and with a low absorption capacity. This fact determines the acceleration of the erosional processes such as the landslides and the gully erosion. These processes could be avoided by fixing the affected areas with vegetation, after the preliminary improvement of the soil conditions.

The physico-chemical parameters

The physico-chemical parameters were analyzed in order to determine the mine dumps impact in the territory and the rehabilitation potential of the studied area. These aspects will facilitate the selection process of the plant species capable of revegetating the targeted territory.

Regarding the final results, a valuable indicator for the present study is the pH, the analyzed samples ranging from strongly acidic to slightly acidic, with the exception of P9, P10 and P11 samples (fig. 5.29).

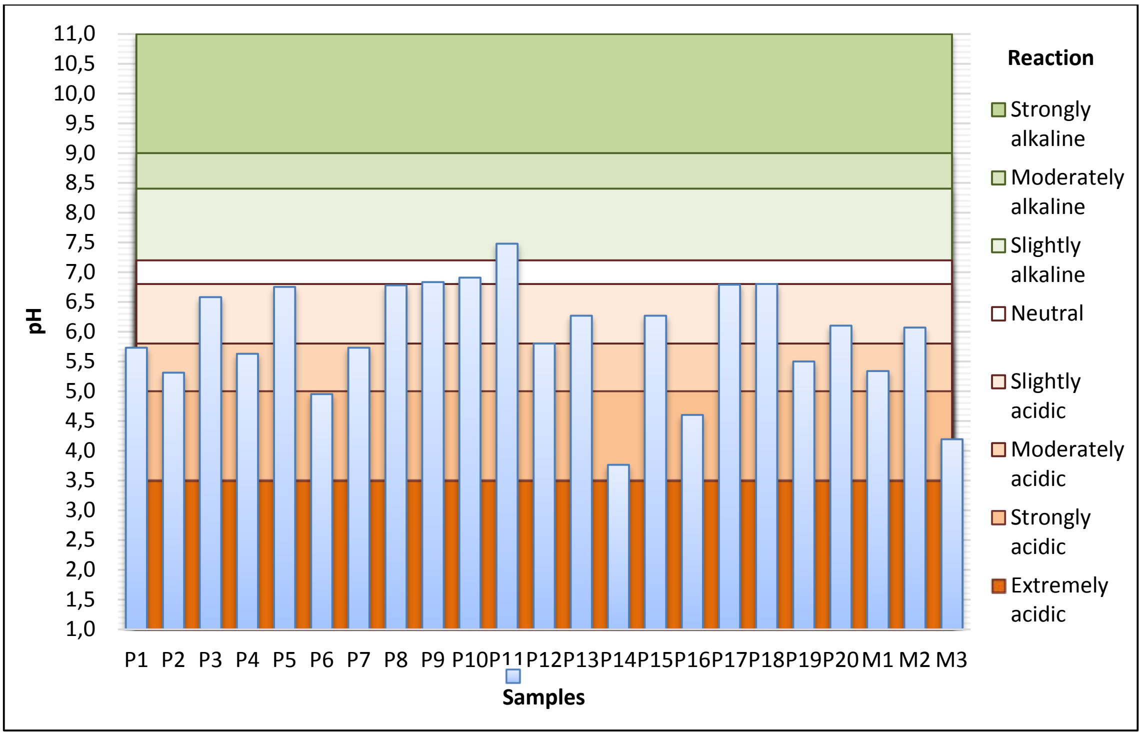

__Figure 5.29.__ The estimation of soil and mine dump samples reaction by the pH values.

Regarding the anions, the absence of the nitrite ion is evident in almost all the analyzed samples, excepting the P3, P5, P17, P19 samples and the M2 control sample, where the determined values are rather low. On the other hand, the nitrates are present in each sample, with a high concentration in P12 and M2. It is known that the nitrates are transformed in nitrites by the nitrifying bacteria, thus the absence of nitrites being explained by their absence in the analyzed samples. The presence of the SO_4^{2-} anion provides information about the acidity of the studied soils. In this case, a positive correlation can be observed between the mentioned parameters. Thus, the P6, P14, P16 samples and the M3 control sample show high values of this anion, while having much lower pH levels than the rest of the samples.

In terms of heavy metals, the soil/sterile quality in some of the investigated points exceeds the normal values, although not getting beyond the alert threshold values and the intervention values for less sensitive commonages, as defined by the *Order no. 756/1997 for the approval of the Reglementation regarding the environmental pollution assessment.* In accordance with the provisions of art. 9, lit. a) from the mentioned normative, *„within the situations when the pollutants concentrations in the soil is under the alert threshold values for the sensitive commonage of the fields, the competent authorities will not establish special measures”*. Therefore, even if the present situation indicates exceeding of the normal values provided in the legislation for Cu (P1, P3, P5, P8, P11, P12, P13, P14, P20), Ni (P2, P3, P4, P5, P8, P9, P10, P12, P13, P14, P17, P20) and Cr (P2, P6, P8, P14, P16), as long as the heavy metals do not exceed the alert threshold values, it is considered that these do not represent a significant environmental aspect in the investigated area, thus the associated environmental impact being negligible.

5.2.3. GROUNDWATER AND SURFACE WATER ANALYSIS

5.2.3.1. MATERIALS AND METHODS

In order to quantify the intensity and the real magnitude of the impacts associated to the significant environmental aspects, it was mandatory to investigate the water resources from the mining territory, namely *the groundwater, the hydrographic network* and *the lacustrine units.* To this aim, eight important indicators were analyzed, as it follows: *pH, electrical conductivity, oxidation-reduction potential, total dissolved solids, salinity, anions, cations* and *heavy metals.* The obtained values allowed the qualitative description of the water bodies identified in the area. The *pH, electrical conductivity, oxidation-reduction potential, total dissolved solids* and *salinity* were determined in situ by using the portable multiparameter *WTW 720 Series*. The *anions* and *cations* concentrations were determined by applying the ion-chromatographic method and the *heavy metals* by using the atomic absorption spectrometry method.

In order to investigate the groundwater quality, a total of four sampling points were chosen for the whole mining perimeter, of which three samples (F1-F3) were taken from the household fountains localized in the proximity of the mining area, and one sample (I1) was collected from a spring located between the exploitation sectors, this being equipped as a drink-water supply. The described sampling points represent the single locations that offer access to the groundwater in Aghireș area. Regarding the surface water, one sampling point has been chosen for each of the five water courses of the mining perimeter (P1-P5), and three sampling points for each of the 10 mining lakes located in the territory (L1-L9 and Laguna Albastră). The position of all the sampling points is shown in figure 5.32.

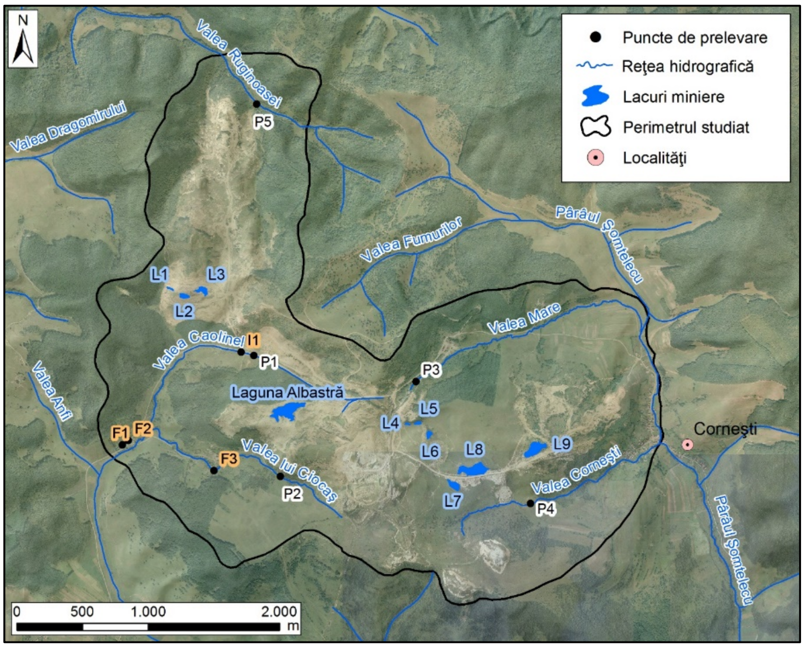

Figure 5.32. *The position of the water sampling points.*

The analyses were performed during a three year period (2011, 2012 and 2013), with one annual sampling session conducted during the summer.

5.2.3.2. RESULTS AND DISCUSSIONS

THE GROUNDWATER INVESTIGATION

The results for the groundwater parameters show neutral pH values (ranging between 7.14 and 7.6), excepting the I1 sample which has a pH value of 5.03. In accordance with the provisions of *Law no. 458/2002 regarding the drink-water quality, modified and completed by Law no. 311/2004,* the Maximum Allowable Concentrations (M.A.C.) for the pH must be within 6.5-9.5 pH units, this being exceeded by the I1 sample. This aspect is of major importance, considering that the corresponding water spring is used as drinking-supply by the mining workers and the occasional tourists. Moreover, consulting the same normative *(458/2002 Law),* we noticed exceeding also for the sulphate (M.A.C. = 250 mg/l) and nickel (M.A.C. = 0.02 mg/l) both in the I1 sample (SO_4^{2-} = 476.81 mg/l, Ni = 0.2467 mg/l). Correlating these results with the acidic pH levels of the same sample, it is evident that the investigated spring is not a drink-water supply and the access to this water source must be restricted. The other parameters are situated in the Maximum Allowable Concentrations established by the *458/2002 Law*.

THE HYDROGRAPHIC NETWORK INVESTIGATION

The hydrographic network presents neutral values for the pH, excepting the P1 sample, which corresponds to Valea Caolinel, this indicating an acidic pH (6.10). In accordance with the provisions of *Order no. 161/2006 for the approval of the Normative regarding the classification of the surface water quality in order to establish the ecological state of the water bodies,* the pH values must be within 6.5-8.5 pH units. Therefore, there is an inconformity for the P1 sample values, so that additional investigations were mandatory.

In order to identify the causes of acidity, we analyzed the possible acid sources from the proximity of Valea Caolinel. As a result, a left tributary of this watercourse has been identified, which by the reddish color of the riverbed rocks indicated an acid water environment.

For the investigation of the water quality of this potential acidic source, which was named the „Acidic stream", we chose three sampling points, so that all its sectors could be investigated (upstream - sample $P1_a$, central - $P1_b$, downstream - sample $P1_c$) (fig. 5.41). The analyses were performed during a two year period (2012 and 2013), with one annual sampling session conducted during the summer.

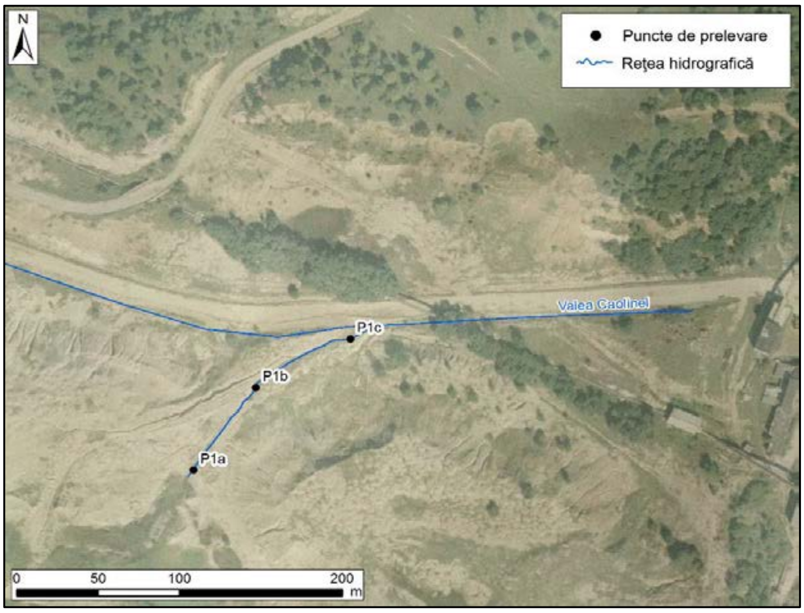

Figure 5.41. *The position of the „Acidic stream" sampling points.*

The results indicate extremely low pH values (2.89-3.48), which confirm that the „Acidic stream" represents the source of acidity for the Valea Caolinel river. Furthermore, the analysis for anions, cations and heavy metals indicate a considerable difference between the „Acidic stream" and the rest of the watercourses, especially regarding the concentrations of sulphate, magnesium and iron, which are higher for the „Acidic stream".

LACUSTRINE UNITS INVESTIGATION

The results for the lacustrine units underline a series of differences between the investigated mining lakes. The parameter that stands out the most is the pH, which for L1, L2 and L3 lakes presents extremely low values (2.91-3.59), indicating a very acidic water environment. By contrast, the rest of the lakes have a neutral to alkaline pH.

Considering that the pH of the surface waters must be within 6.5-8.5 pH units, in order for the aquatic life to develop in proper conditions (Sorocovschi, 2003; Haiduc, 2006; Order no. 161/2006), and the L1-L3 lakes exceed the specified values, these will require a special attention within the environmental rehabilitation context.

The strong differences between the pH levels of the three acid lakes and the other investigated lakes is broadly explained in the studies conducted by Măcicășan et al. (2013, 2014), the information being supplemented with new data in the extended version of the PhD thesis.

The laboratory analyzes for the ions determination also indicate higher concentrations of the acid lakes, particularly regarding the sulphate (L1 = 4003.02 mg/l, L2 = 2819.98 mg/l, L3 = 1687.59 mg/l). Regarding the heavy metals, as expected, a significant augmentation of their concentration is visible along with the pH decrease.

5.2.4. AIR ANALYSIS

5.2.4.1. MATERIALS AND METHODS

In order to quantify the intensity and the real magnitude of the impacts associated to the significant environmental aspects which affect the air quality, in the summer of 2013 we conducted a set of in situ analyzes, oriented towards the determination of particulate matter content (PM2.5 and PM10). The measurements were performed by using a *DustTrak DRX 8533* portable multiparameter. The analyzes were performed in accordance with the requirements of SR EN 12341:2002 / SR EN 14907:2006, and were adapted to the mining location and the physical and geographical context by choosing three sampling points. These are located in the eastern extremities of the principal mining fields, on the predominant wind direction (fig. 5.54).

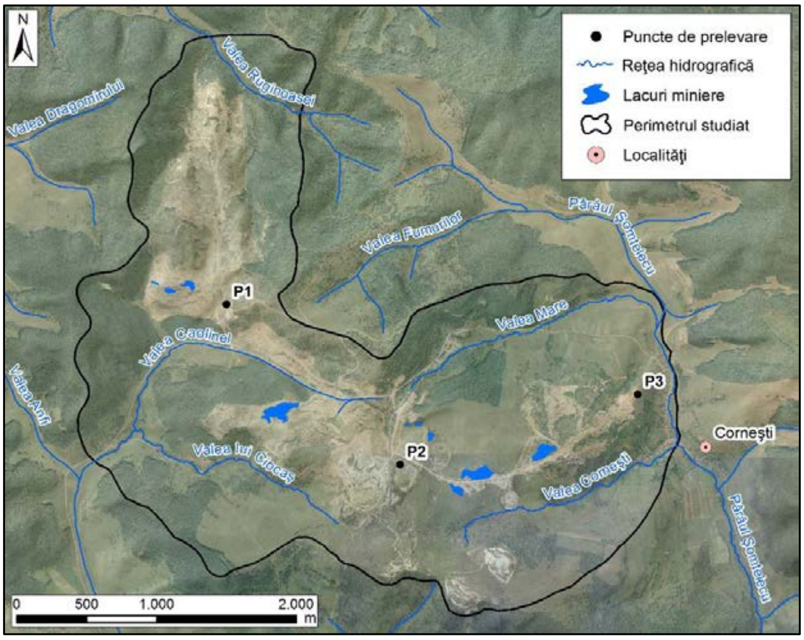

Figure 5.54. *The position of the air sampling points.*

5.2.4.2. RESULTS AND DISCUSSIONS

By comparing the obtained results with the M.A.C. provided in the *Law no. 104/2011 regarding the environmental air quality,* we observed exceeding of PM2.5 for all the air samples and of PM10 for the P1 and P2 samples. Therefore, it is mandatory to rehabilitate the analyzed perimeter with the aim of decreasing the atmospheric PM concentrations and for preventing future exceeding of the Maximum Allowable Concentrations provided by the current legislation. The rehabilitation solutions will focus on the stripped lands and the mine dumps.

5.3. SYNTHETIC ENVIRONMENTAL IMPACT ASSESSMENT

Taking into consideration all the identified environmental aspects within the mining perimeter together with their associated impacts, a synthetic (global) assessment of the anthropogenic pressure on the environment is compulsory. In the present paper, this synthetic assessment was accomplished by using a Rapid Impact Assessment Matrix (RIAM), adapted for the analyzed context on the basis of all the previously obtained results.

The assessment matrix was applied on eight representative areas (fig 5.55), for which we selected thirty geo-environmental and socio-economic relevant components to be analyzed. For every component we assigned specific assessment scores which were subsequently converted into impact categories. The levels of significance and the impact category description comply with the methodological principles used by Pastakia & Jensen (1998), together with all their subsequent revisions (Muntean, 2005; Kuitunen & Hirvonen, 2008; Ijäs et al., 2010).

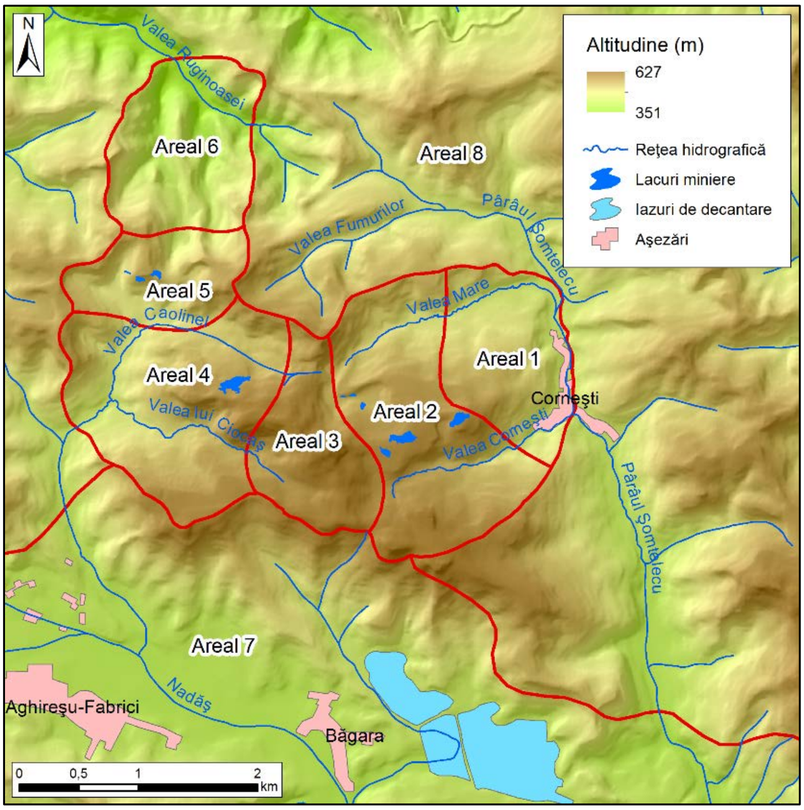

Figure 5.55. *The eight areas subject to the RIAM assessment.*

The impact categories were then converted into *classes of threats and dangers* referring to the environmental components of each of the eight assessed areas (table 5.46). This process facilitated a better representation of the real situation in the analyzed territory. These classes, which can be corroborated with the environmental restoration actions, are the following: *I - **minor** threats and dangers; II - **moderate** threats and dangers; III - **major** threats and dangers.*

The results obtained by applying the RIAM method were the basis of the cartographic representation of the environmental impacts in the investigated territory. Thus, based on the interpretation of the assessment scores for each of the eight representative areas, and by using the GIS technique (ESRI ArcGIS 10) and the interpolation method (the IDW method), we obtained a thematic map which reflects the synthetic (general) impact on the environmental components in the analyzed area (fig. 5.56).

Table 5.46

The synthetic environmental impact assessment matrix (RIAM) and the conversion of impact categories in threats and dangers over the environmental components.

	RIAM assessment score							
	Area 1	**Area 2**	**Area 3**	**Area 4**	**Area 5**	**Area 6**	**Area 7**	**Area 8**
Total assessment score	**-222**	**-65**	**-343**	**-114**	**-418**	**-154**	**-76**	**+5**
Anthropogenic impact category	**-D**	**-B**	**-D**	**-C**	**-D**	**-D**	**-B**	**+A**
Threats and dangers class	III Major	II Moderate	III Major	II Moderate	III Major	III Major	II Moderate	I Minor

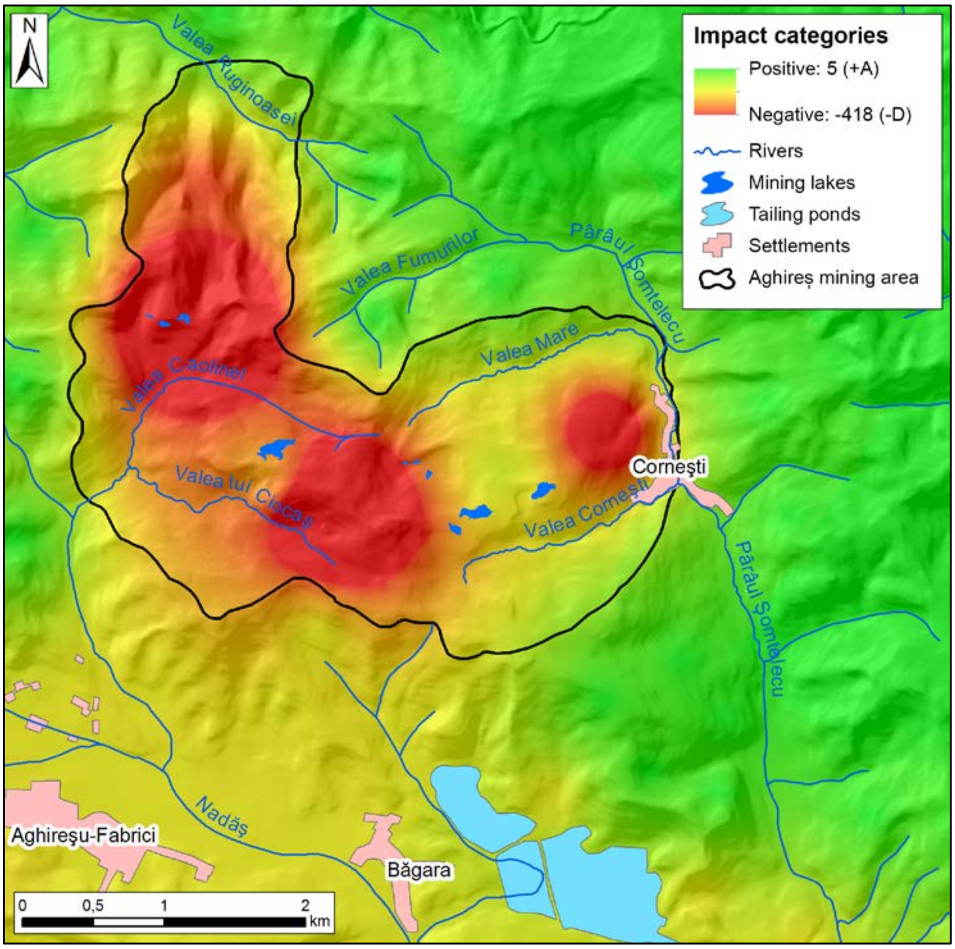

Figure 5.56. *The synthetic environmental impact map.*

The assessment matrix and the thematic map are the results of the global environmental impact assessment, which facilitated the development process of the rehabilitation measures and strategies for the Aghireș mining area. Thus, according to the obtained results, the necessity of specific rehabilitation measures and the intervention location was determined. To this regard, we note that the areas most affected by the mining activity are the Mining Fields I, II, III and V. This fact confirms the results obtained following the environmental aspect assessment and the investigation of the significant impacts. These areas will require priority measures for rehabilitation.

CHAPTER 6
PRIORITY INTERVENTION STRATEGIES AND ENVIRONMENTAL REHABILITATION MEASURES

Regarding the rehabilitation strategy, given the current status of the mining facility, namely a partially active one, in which both active and inactive (abandoned) mining fields are found, we consider that the best approach concerning the environmental rehabilitation strategy would be a sequential one. This should be accomplished by applying a progressive rehabilitation, starting with the currently inactive sectors, and proceeding with the rest of the mining fields, as the affected areas are relieved of duties.

The rehabilitation strategy design had as a starting point the environmental components upon which the negative effects of the significant aspects and impacts were exerted, or, better said, the targets of the environmental aspects and impacts. Therefore, the proposed rehabilitation measures were differently adapted for each of the analyzed environmental component, depending on the typology and the nature of the significant environmental aspects and impacts exerted over these components, as following:

- for the *creation of mine dumps* environmental aspect, with the corresponding impact of *occupying large areas of land by placing the mine dumps,* specific rehabilitation measures for the mine dumps were proposed;
- for the *land stripping* environmental aspect, with the associated impacts like *modifying the landforms and altering the landscape, initiating and amplifying the geomorphological processes, land degradation* etc., specific rehabilitation measures for the stripped lands were proposed;
- for the environmental aspects like *contaminating the drainage water* and *emergence of artificial lakes,* with their associated impacts like *acidifying the water courses and mining lakes,* specific remediation measures for the acidic waters were proposed.

Alongside the rehabilitation of these components, we also proposed specific measures for the industrial units decommission and air protection. Moreover, the agricultural lands in the vicinity of the mining perimeter were considered, these being affected by gully erosion and landslides.

The proposed rehabilitation scenario is oriented to the conceptual elements of the "Several Small" approach – part of the „Single Large or Several Small" (SLOSS) concept, to which the intention of delivering large areas of eco-tone and intergradation is furthermore added.

Through a proper implementation, the environmental rehabilitation strategies and specific measures proposed in the thesis will reshape the mining perimeter from its current degraded state (fig. 6.1) to a better, more stable one (fig. 6.2), in which the environmental problems will be remediated. Furthermore, the proposed measures will contribute to the landscape restoration and terrain enhancement, for lands currently regarded as unusable.

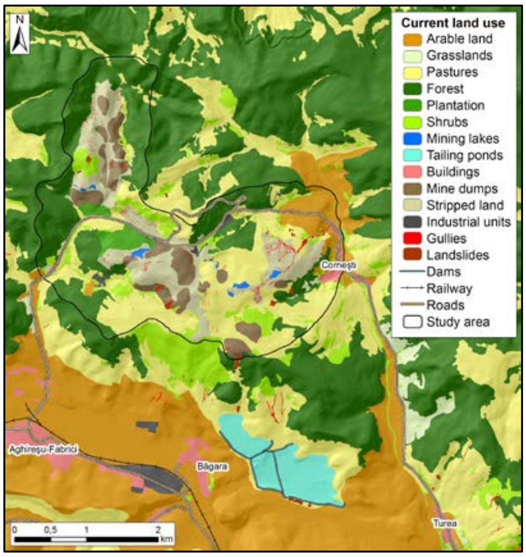

Figure 6.1. *The current state of Aghireș mining area (current land use).*

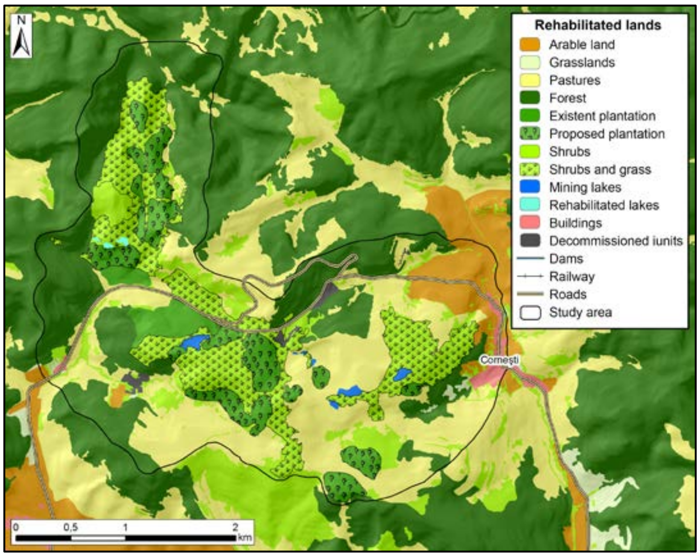

Figure 6.2. *The improved state, resulted after implementing the rehabilitation scenario.*

Applying such a rehabilitation scenario could illustrate the true ecological potential of the mining area, the rehabilitated perimeter thus becoming a real hotspot for the biodiversity. Hence, the Aghireș mining area could be well developed and emphasized, giving to the whole region a new value, with effects beyond its borders.

CONCLUSIONS

In conclusion, we consider that the present study can serve as a *model of integrated analysis, assessment and mitigation of environmental impacts in mining areas with historic and recent pollution,* this satisfying both the legal procedural requirements (the pre-project approach) and the current scientific-methodological process (the post-project approach), and providing an essential foundation for the environmental rehabilitation process and the priority intervention actions associated with it.

Furthermore, the structured and integrated endeavor of investigating the environmental aspects, as well as the methodological tools and the practical results obtained within the thesis, can be exploited in the development of best practices documentation on the analysis of the significant aspects and Environmental Impact Assessment. And finally, this paper could prove useful for the environmental rehabilitation deployment, which is an obligation and a corporative responsibility specific to the mining industry of nowadays.

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