Waste management in mountain areas. A case study for the mountain area Călimani, Suceava County, Romania

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Abstract: As our society evolves, the different types and composition of waste become increasingly more diverse, making waste management a complex challenge. Waste management in mountain areas is particularly difficult as the mountain ecosystems are ecologically sensitive and require increased efforts for the protection of both environment and human communities. The present study evaluates the specific types of waste, waste management and waste impact based on the Global Pollution Index (GPI) method. Several non-conformities were identified such as: a recycling index well below the prescriptions of the Suceava County's Waste Management Plan 2020-2025 and an incorrect evaluation of the composition of municipal waste. A high degree of risk from the extractive waste resulted from sulphur mining and preparation was determined. This study also proposes several measures to limit the impact of the waste deposited in the mountain area Călimani and a profitable industrial synergy solution for its beneficiaries.

Keywords: waste deposits; tailings; global pollution index

1. Introduction

Human communities are shaped by the specific geomorphological, climatic and ecosystem characteristics. Even though mountain areas are very important sources of raw materials (ore, construction material, mineral waters, timber, non-timber forest resources, hydro energy etc.), the unsustainable management and exploitation of these resources is cause for several dysfunctionalities in the natural balance, particularly through deforestation, extractive activities, urbanization (building accommodation facilities, holiday homes in the most isolated mountain areas is a characteristic of the Romanian countryside), landscape changes through the formation of positive or negative relief forms from waste deposits, diversion or drying up of watercourses, contaminated water and poor air quality. These effects directly concern the communities downstream and contribute to habitat fragmentation and degradation.

Every human activity produces waste: household, or production waste. Waste management in mountain areas is a challenge because these areas are ecologically sensitive and therefore require increased efforts to protect the environment [16]. The quality of the services provided by mountain ecosystems also depends on how waste, regardless of its nature, is managed in these areas. Waste collection, difficult transportation due to poor road infrastructure, adverse climatic conditions, and the difficult monitoring of the compliance with environmental regulations in isolated areas, are some aspects causing the pollution of environmental factors, with repercussions on human health, specifically through the pollution of air and water, contaminated forest fruits, extinction of rare species, etc. A literature analysis on the subject of ecosystem services in mountain areas, reveals that one of the issues insufficiently addressed is that of waste management [18].

The present study evaluates the specific types of waste, waste management and waste impact based on the Global Pollution Index (GPI) method. This study also proposes several measures to limit the impact of the waste deposited in the mountain area Călimani (figure 1) and a *profitable industrial synergy solution for its beneficiaries*.

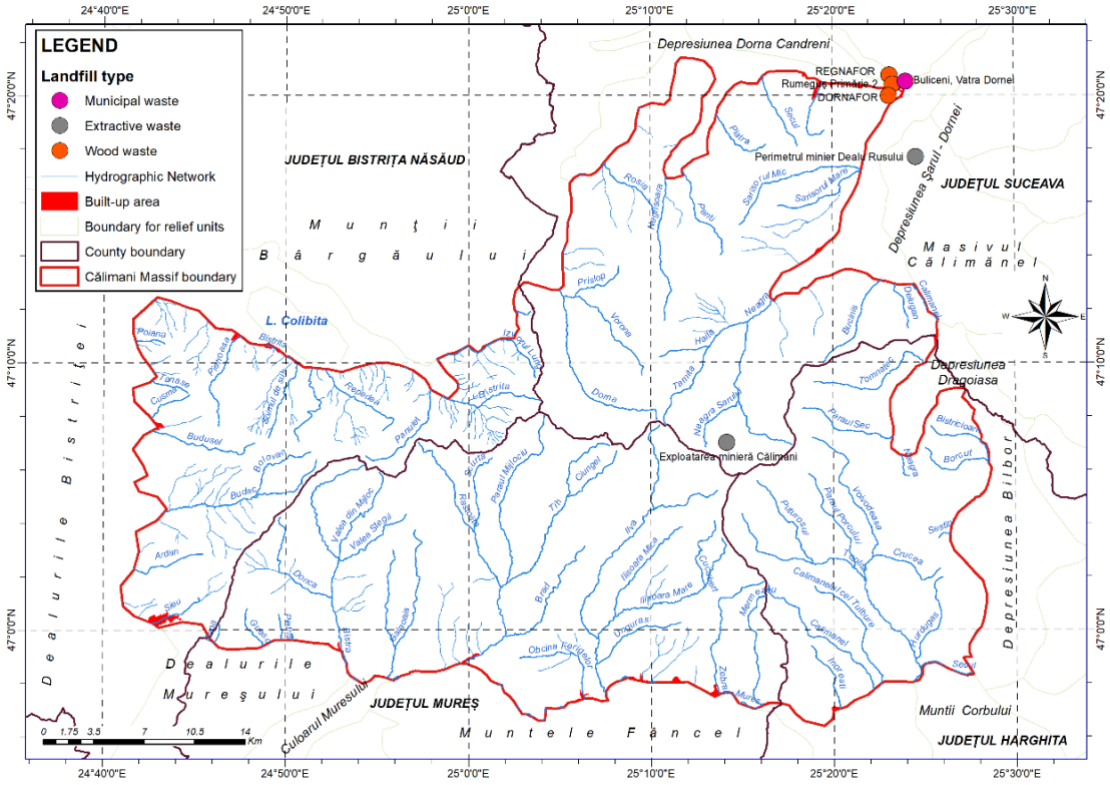

Fig.1 Location of the waste deposits in the Călimani Massif

The study area includes 5 territorial-administrative units: Vatra Dornei Municipality, Poiana Stampei, Dorna Candrenilor, Șaru Dornei and Panaci Communes. The towns are located in the Suceava County, at the foot of the Northern slope of the Călimani Massif, in the Dornelor Depression, along the valleys of the Dorna and Neagra Șarului rivers, right tributaries of the Bistrița Aurie River.

Located in a depression with favourable conditions for living and a rich hydrographic network, good passageways connecting Moldova with Transylvania and richness in mineral resources, human settlements in this mountain area have experienced a period of strong development [9]. In the beginning of the 20th century, there was already a strong industrial activity including mining, and the exploitation and processing of wood resources throughout the Dornelor Basin. The National Timber Authority of Bucovina had built a furnace for the dry distillation of pine and spruce wood in Dornișoara, Poiana Stampei Commune, in the proximity of the forestry railway connecting the timber factory with the operation units at the foot of the Călimani Massif. The same railway line also ensured the transport of andesite from the two large Dornișoara and Dorna Burcut quarries. The logs were transported on the Dorna, Neagra Șarului and Neagra Boștenilor rivers to the Bistrita Aurie river on rafts. Going along the northern slope towards the east of the Călimani mountains, the activities of the inhabitants are predominantly based on agro-zootechny and exploitation and primary processing of wood [14] (pp.142-157).

The mining activity from 1970-1995 focused on the exploitation and preparation of sulphur and required a semi-urbanization of the localities in the northern and north-eastern area of the massif (Neagra Șarului, Șaru Dornei, Panaci, Dârmoxa). After the mining activities were ceased and the mines closed, a large number of miners together with their families- who arrived here from different parts of the country for employment- were forced to return to their native land; the local population had to reorientate towards other economic endeavours to sustain a living, focusing on the only other significant resource- forests. The following years were marked by a massive exploitation of forest funds, until the fall of the Communist regime, when the land was retroceded to its initial owners; however, the exploitation of forest resources was not carried out by the locals and to their direct benefit, but by large, foreign companies. This phenomenon was recorded throughout the Călimani mountain area. Past activities have left behind significant waste deposits.

Agro-Zootechny, an activity that developed alongside the establishment of the National Agency of the Mountain Zone (founded in 2019), has ensured funding sources as well as the promotion of small farms for the diversification of their products. As part of the mountain ecotourism development actions, in addition to the agritourism

guesthouses, local gastronomic points have been established, which contributed significantly to the amount of biodegradable waste generated.

2. Materials and Methods

The data sources of this study are presented in table 1.

Table 1. Parameters evaluated and data sources

Type of data	Parameters evaluated	Data sources
Municipal waste	Indicators of sustainable development: municipal waste rate collected; municipal waste recycling rate collecte	EPA* Suceava, Suceava County Waste Management Plan 2020-2025
Household waste deposit	Geometry, emissions	EPA Suceava
Extractive waste deposit	Geometry, emissions	CONVERSMIN SA, ICPM** Baia Mare
Wood waste	Quantity, management mode	EPA Suceava
Wood waste deposits	Geometry, emissions	EPA Suceava
Manure managemen	Number of cattle and sheep to calculate the amount of manure produced	VSFSD*** Suceava
Water quality	pH, dissolved O_2; Fe_{total}; sulphates- mining area	ABA**** Siret Bacău, CONVERSMIN SA
	pH, CCOCr, NH_4, H_2S- municipal wast deposit	EPA Suceava
	pH, CCOCr, phenols- wood waste deposits	EPA Suceava
Air quality	SO_2, metals in sedimentable powders; precipitation pH (mining area)	CONVERSMIN SA, EPA Suceava
	Emissions of CH4 and N_2O (converted into CO_2e)	For calculus: National Institute of Statistics; IPCC Guidelines for National Greenhouse Gas Inventories [3,7]; Order no.140/2019 [13]
Soil quality	pH, ions of Cu, Zn, S, alluvial deposits mining area	ICPM Baia Mare, CONVERSMIN SA, Order no. 756/1997 [11]
Ecosystem quality	Conservation status of species and habitats, degree of fragmentation of natural areas	Natural area management plans, studies

* Environmental Protection Agency
** Institute of Mining Research and Design
*** Veterinary Sanitary and Food Safety Directorate
**** Basinal Water Administration

For the evaluation of the impact produced by the specific categories of waste in the Călimani mountain area, a quantitative method for the assessment for the quality of the environment- the *global pollution index*- was chosen. For each indicator studied, a value is chosen based on a rating scale from 1 to 10, where 10 corresponds to an environment in its natural state and 1 an environment irreversibly deteriorated. The *Global Pollution Index* is then a result of the ratio between the value representing the ideal state (Si) and the value representing the real state (Sr) at a given moment. For the evaluation, quality indicators specific to the environmental factors analysed were chosen [15], (pp.459-469). The method is recommended when at least 3 environmental components are considered [17], (pp. 240-247).
The estimation of the global pollution index (GPI) of the environment is carried out on an empirical scale, with values ranging from 1 to 6 (table 2):

Table 2. GPI Value (source: Rojanschi V., 2002)

GPI Value	Meaning of GPI value
1	natural environment unaffected by human activity
1< IPG <2	environment affected by human activities within admissible limits
2< IPG <3	environment affected by human activities, causing discomfort to life forms

3< IPG < 4	environment affected by human activities, causing disturbances to life forms
4< IPG <6	environment seriously affected by human activities, dangerous for life forms
6	degraded environment, unsuitable for life forms

The following indicators were considered for the GPI assessment for each type of waste: water quality; air quality; soil quality; the quality of ecosystems. The last indicator is relevant as the Călimani Massif includes important protected natural areas: the Mountain pine scientific reserve with Pinus cembra; the Călimani National Park; RAMSAR site Tinovul Mare Poiana Stampei; sites of community importance: ROSCI0249 Peat Bog Șaru Dornei, ROSCI0019 Călimani – Gurghiu, ROSCI0051 Cușma; avifaunistic special protection area ROSPA0133 Călimani Mountains. The evaluation of the quality of ecosystems can also be done using a series of biodiversity indicators, recommended by the Guidelines for the development of the European State of the Environment Report (SOER). From these, based on the available data, the following indicators were chosen:

• Species of European interest- it is a descriptive, status indicator, codified for Romania: RO 07; the code given by the European Environmental Agency is CSI 007/SEBI 003, suggesting changes of the conservation status of species of conservation interest, monitored at European level according to the mandatory directive from the Habitats Directive 92/43/EEC (mentioned in art. 11 of the normative act).

• Habitats of European interest in Romania- it is also a descriptive status indicator, codified as RO 40 for Romania and at the European level SEBI 005, which describes the changes in the favourable conservation status of the habitats, monitored according to art. 17 of the Habitats Directive 92/43/EEC.

• Fragmentation of natural and semi-natural areas. This is a pressure indicator, Romanian code RO 44/ European code SEBI 013, which addresses the issue of ecosystem integrity, considering that a significant reduction of these areas negatively impacts habitats and, consequentially, the conservation status of the species dependent on these habitats.

We have therefore developed the following rating scale:

Table 3. Rating scale for ecosystems

Rating	Favourable conservation status for:		Natural habitat fragmentation degree (%)
	RO 07	RO40	
9 - 10	Favourable	Good	0 - 10
6 - 8	Unfavourable-inadequate	Unfavourable - inadequate	10 - 30
4 - 5	Unknown	Not evaluated	30 - 40
1 - 3	Unfavourable-totally inadequate	Unfavourable – totally inadequate	40 - 100

For the other environmental factors, the analysis results were compared with the emission limit values imposed by the Romanian normative acts in force, assigning marks from 1 to 10, where 10 "*corresponds to a natural environment unaffected by human activity, and 1 corresponds to environmental factors that have been irreversibly and severely affected*" [5].

The emissions of greenhouse gas were estimated using the *2006 IPCC Guidelines for National Gas Inventories, Volume 4 Agriculture, Forestry and Other Land Use - Chapter 10: Emissions from Livestock and Manure Management* [7]. Methane emissions from agro-zootechnical activities result from the following processes: Enteric Fermentation and Manure Management. To calculate the CH4 emission factor for enteric fermentation, equation (1) was used:

$$EF = \frac{GE \times \left(\frac{Ym}{100}\right) \times 365}{55{,}65} \qquad (1)$$

Where:

EF= emission factor, kg CH4 head-1 yr-1

GE= gross energy intake, MJ head-1 day-1

Ym=methane conversion factor, per cent of gross energy in feed converted to methane

The value of 55,65 (MJ/kg CH4) represents the energy content of methane.

For the calculus of the CH4 emission factor from manure management, the following equation was utilised (2):

$$EF_{(T)} = \left(VS_{(T)} \times 365\right) \times \left[B_{0(T)} \times 0{,}67\ kg/m^3\right] \sum_{S,k} \frac{MCF_{S,K}}{100} \times MS_{(T,S,K)} \quad (2)$$

where:

EF (T) = emission factor for livestock category T, kg CH4 animal-1yr-1

VS(T) = daily volatile solid excreted for livestock category T, kg dry matter animal-1day-1
365 = basis for calculating annual VS production, day-1
B0(T) = maximum methane producing capacity for manure produced by livestock category T, m3 CH4 kg-1 of VS excreted
0,67 = conversion factor of m3 CH4 to kilograms CH4
MCF(S, K) = methane conversion factors for each manure management system S by climate region K, %
MS(T, S, K)= fraction of livestock category Ts manure handled using manure management system S in climate region k, dimensionless
For calculating N2O emission factor from manure management, the following equation was used (3):

$$N_2O = \left[\sum_T \left(N_{(T)} \times Nex_{(T)} \times MS_{(T,S)}\right)\right] \times EF_{(S)} \times \frac{44}{28} \quad (3)$$

Where:
N2O=direct N2O emissions from manure management, kg N2Oyr-1
N(T) = number of head of livestock category T
Nex(T) = annual average N excretion per head of category T, kg N animal-1 yr-1
MS(T,S) = fraction of total annual nitrogen excretion for each livestock category T that is managed in manure management system, dimensionless
EF(T) = emission factor for N2O direct emission from manure management system, kg N2O-N /kg N
44/28 = conversion of N2O-N emissions to N2O emissions
CH4 and N2O were converted to CO2eq, using the latest established values for the global warming potentials (GWP) relative to CO2, extracted from the IPCC Fifth Assessment Report (AR5) (28 for CH4 and 265 for N2O).
For estimating the CO2eq emissions from the household waste landfill, the Jaspers Methodology for greenhouse gas emissions in waste was utilized [13].

3. Results

3.1. Generated waste

3.1.1. Municipal waste

Municipal waste consists of generic household waste from the population, from economic operators who produce similar waste and waste from municipal services (roads, maintenance of green spaces an agro-food markets). All 5 administrative territorial units in the Călimani mountain area are served by sanitation services in a percentage of 100%. From the calculation of the two sustainable development indicators analysed, the following results were obtained, presented in table 4:

Table 4. Municipal waste indicators

Indicator	2019	2022
Municipal waste rate collected (kg/resident/year)	205,21	214,39
Municipal waste recycling rate collected (%)	11,80	12,72
Biodegradable waste that has been eliminated ar collected through storage (%)	12,9	12

3.1.2. Wood waste

The main industrial activity in the study area is the exploitation and primary processing of wood, as forests cover 67% of the surface area. From the primary processing of the logs and the secondary processing activity (manufacturing of wood pallets and small furniture) the following results (table 5) were obtained:

Table 5. The amount of wood waste produced and utilized in 2022

Amount of wood waste produced (m^3)	Amount (m^3) of wood waste recovered for:	
	Thermal energy production	Electric energy production
64.322	50.081	62

The amount of 14,179 cubic meters was used in the following manner: a part of the sawdust as bedding for animals and the rest of the wood waste for heating in private households and in small-capacity thermal plants from accommodation and food business facilities.

3.1.3. Waste generated by agro-zootechny

Although the analysed mountain area has 44% of its surface covered by pastures, agro-zootechny is poorly represented- only in small farms or individually, at household level. Manure generates significant amounts of CH_4 and N_2O through its decomposition during storage (tables 6, 7):

Table 6. Methane emissions from agrozootechnical activity (year 2022)

No. animals	CH_4 for enteric fermentation (tons)	CH4 emission from manure management (tons)	Total (tons)	CO_2 eq. (tons)
807 dairy cattle	101	5,5	106,5	2982
78 other types of bovines	4,9	0,2	5,1	142,8
2244 ovine	21,3	0,51	21,81	610,7

Table 7. N_2O emissions from manure management (year 2022)

No. animals	Emissions N_2O (tone)	CO2 eq. (tons)
807 dairy cattle	0.27	71,6
78 other types of bovines	0,01	2,65
2244 ovine	0.134	35,5

3.1.4. Extractive waste

The extractive waste from the Călimani mountain area is primarily generated by the Călimani Mining exploitation of sulphur and from the preparation of technical sulphur by autoclaving (the activity stopped in 1995 and continued until 1997 with the exploitation and mechanical processing of ferruginous quartzites); the Dealu Rusului mining sector, where the exploitation and mechanical-thermal preparation of manganese deposits took place (activity stopped in 2006). Therefore, after 1997 (for sulphur) and 2006 (for manganese) no more extractive waste was produced.

3.2. Waste deposits

3.2.1. Municipal waste deposit

In the mountain area Călimani, Suceava County, between 1980 and 2003, industrial and household waste was eliminated by storage in the non-hazardous landfill in Buliceni, Vatra Dornei. After 2003, part of the waste (from Vatra Dornei municipality) was transported to the landfill in the Iacobeni Commune, located approx. 17 km away. The communes Poiana Stampei, Dorna Candrenilor, Panaci and Șaru Dornei had non-compliant warehouses for household waste. Since 2019, the Integrated Waste Management Center in Moara, located approx. 120 km away from the Călimani Massif, where all the municipal and assimilated waste from Suceava county is stored, the legislation no longer allows mixing with industrial waste. The Buliceni landfill occupies an area of 1,698 ha, has a volume of compacted waste of 63,750 m3, and a height of 5-6 m; the closure works were carried out through the project: Integrated Waste Management System from Suceava County.

For the calculus of the Global Pollution Index, the following rating was obtained (table 8):

Table 8. Rating scale for environmental factors- household waste deposit Buliceni

Environmental factors	Rating	Observations
Air	8	*No detectable effects.* Emissions: 53 t/year CO_{2eq}. Biogas capture systems are installed
Water	7	The leachate exceeds the CBO5 parameter by about 400 times when discharged into the final receiver, the Bistrița River, which, having an average flow rate of 47.5 mc/s, dilutes the pollutant; the Bistrița River belongs to quality class II for downstream storage
Soil	7	High values for the parameter Pb, however under the alert level for less sensitive lands

Biodiversity	7	Downstream on the Bistrița River is the special conservation area ROSAC0196 Pietrosul Broștenilor – Cheile Zugrenilor

The GPI obtained is 1.9, suggesting a natural environment unaffected by human activities.

3.2.2. Wood waste landfills

In the Călimani mountain area, Suceava county, there are 3 wood waste deposits (bark waste and sawdust) that were used by factories for the primary processing of wood mass.

The Chilia deposit occupies an area of 0,92 ha; the volume of stored wood waste is 55200 m^3. The Bodnăraș warehouse occupies an area of 0,5 ha and has a volume of 25000 m^3. The two warehouses are located on the left bank, respectively on the right bank of the Bistrița River, in the municipality of Vatra Dornei. The Poiana deposit has an area of 0,5 ha and a volume of 5250 m^3 and is located on the banks of the Dorna river, a right tributary of the Bistrița River.

The storage of waste in the 3 dumps was stopped in 2006, due to the legislative norms that require the recovery of these types of waste, as well as the appearance of thermal power plants that use wood waste as fuel. They are located in the Dornelor Depression, in the Bistrita hydrographic basin.

For the calculus of the Global Pollution Index, the following rating was obtained (table 9):

Table 9. Rating for environmental factors- wood waste landfills

Environmental factors	**Rating**	**Observations**
Air	8	*No detectable effects*. The deposits were planted with grass and are located in the Dornelor Depression, which provides good aeration for the material
Water	7	Analyses were made for the Chilia deposit, both upstream and downstream, that took into account the existence of an uncoded watercourse bordering its western slope and crossing at its base (with the river Bistrița as the emissary). The values obtained for the parameters CCOCr an fenols place the water course into the quality class II
Soil	8	Determinations for the parameters: pH, Zn, Cu, Pb
Biodiversity	8	All deposits feature grassy vegetation and shrubs specific to the area

The GPI value is 1,6, therefore we have a natural environment unaffected by human activity.

3.2.3. Extractive waste deposits

Considering the types of mineral substances exploited and the extent of the impact which is still observable more than 25 years after the cessation of the mining activity in Călimani and after a series of closure and ecological rehabilitation works, the impact analysis of the two deposits will be assessed separately for manganese and sulphur.

3.2.3.1. The extractive waste deposits from the Călimani Mining perimeter

In the Călimani Mountains, the sulphur exploitation (initially through underground works, and later from a quarry) and the subsequent preparation of technical sulphur by autoclaving took place between 1970 and 1995. The mountains have the aspect of a massif and belong to the Eastern Carpathians, part of the southern sector of the volcanic chain Oaș - Gutâi - Țibleș - Bârgău - Călimani - Gurghiu - Harghita. These activities were some of the *most destructive and polluting events during the communist period*: the quarrying led to the disappearance of the Negoiu Românesc Peak (1889 m); the mining works destroyed a unique morphological complex- the Luanei Caves, a karst phenomenon discovered on the eastern slope of the Negoiul Românesc peak, with metallic stalactites and stalagmites [10], (p.32); acid rains affected the communities along the border area (the nearest human settlement being 8 km away from the mining perimeter). Between 2008 and 2014, a series of closure and ecological rehabilitation works were carried out intermittently in the mining perimeter; the works prescribed in the environmental agreement issued are not yet completed due to lack of funds. The mining area is an enclave in the Călimani National Park.

The material in the dumps is composed of: topsoil, siliceous white rock, heavily altered andesite, volcanic agglomerate, unaltered pyroxenic andesite (fig. 2 a,b).

(**a**) Tailings (**b**) Retention dams

Figure 2. Extractive waste from the Călimani mining perimeter, Șaru Dornei commune

In table 10 are presented the characteristics of the extractive waste deposits.

Table 10. The geometry of the extractive waste deposits in the Călimani mining perimeter

Type of deposit	Surface (ha)	Volume (mil. m^3)
Dumps from the exploitation of the sulphur deposi	53,24	33,4
Settling basins (sterile from the sulphur preparatior unit)	11,4	2,4
Retention dams (collecting basins for material entrained from landfills and accidentally spilled industrial tailings)	5,38	1,35

The following ratings were obtained for the GPI calculation (table 11):

Table 11. Ratings for environmental factors - Călimani extractive waste deposits

Environmental factors	Rating	Observations
Air	8	After the cessation of the activity and until present day, the sources of air pollution are: sedimentable powders entrained from the surfaces not yet covered by vegetation (quarries, slopes of tailing dumps), sulphur oxides and hydrogen sulphide (formed by the photochemical oxidation of the sulphur present on dumps and the open surface of the quarry). Systematic analyses for air quality monitoring in Călimani were carried out only in the period 2009-2010 and 2019-2021 by the company designated by the beneficiary of the closure works, in the following sampling points: 6 locations on the waste dumps, 2 locations on the settling basin, 2 locations in the perimeter area of the quarry, on the dominant wind directions (N and NW), and 2 locations downstream on the edge of the Neagra Șarului valley at the limit of the mining perimeter (the mining area is located in the hydrographic basin of the Neagra Șarului River). According to the approved monitoring program, it was not considered necessary to carry out air quality determinations during the later developments of the closure procedure. The analysed parameters were: sedimentable powders; CO; NO_2; SO_2 and H_2S (4 samples from the slopes of the quarry; 6 samples on the Puturosu, Pinu and Ilva dumps; 2 tests on the settling pond). The main sources of air pollution during the monitoring period are: landfills and the sulphur quarry which are sources of dust, sulphur oxides and H_2S (formed by the photochemical oxidation of sulphur present in the tailings in the dumps and the uncovered surface of the quarry). There is a close correlation between the topoclimatic conditions in Călimani and the dispersion of pollutants. Pollutants spread circularly, mainly towards the valley of Negra Șarului, on the descending component of the mountain circulation. Abundant precipitation stops the dispersion of sedimentable powders far from the sources, and the snow cover during the winter period covers the sources of dust and nox emissions.

		The values determined for the concentrations of metals powders are below the limit provided by the regulations in force. For SO_2, the following clarifications are necessary: the averaging period for determinations was 30 minutes; Order 592/2002 provides for a 1-hour averaging period for the evaluation of measurements with the hourly limit value for the protection of human health. However, the measured values are on average 267 μg/m2. The hourly limit value for the protection of human health is 350 μg/mc. Similarly, for NO_2, the measured values are very close to the hourly limit value accepted by Order 592/2002
Water	4	The mining perimeter is crossed by a dense hydrographic network. The Pinu, Alb and Puturosu streams cross under the homonymous dumps; as a result, the quality of the watercourses is strongly influenced by the exfiltration from the deposits as well as by the alluvium entrained from them. The pH values vary between 2 and 4.4, the water is loaded with sulphates and ions of Fe_{total} that place them in the quality class V. The final emissary of all the waters that cross the mining perimeter is the Neagra Şarului river which, in the upstream sector exiting the mining area, from where it receives tributaries with a large flow of clean water, has a pH of the sediments that makes it incompatible with the life of benthic organisms [6]
Soil	6	The analyses carried out on the soil samples taken have revealed important exceedances compared to the normal thresholds provided in the regulations in force, especially for the quality indicators: - pH - for all analysed samples, values ranging between 3 - 5.5 - elemental S - in all samples analysed, exceedances of the alert threshold for less sensitive lands were recorded The effects of acid rock drainage (pH<2) are also felt in the soil quality downstream of the tailing dumps; thus, a pronounced acidification is noted compared to the soil outside the area of influence of the deposits.
Biodiversity	4	According to the Călimani National Park Management Plan and the studies carried out in the area [1] (pp.171-175), [4], the mining area continues to affect the ecological coherence and the quality of ecosystem services through: - fragmentation of habitats (especially the association of Mountain pines with Pinus cembra); - the destruction of the vegetation in the area of the mining perimeter affects the long-term viability of small mammal populations (Rhinolophus ferrumequinum Schreb., Miniopterus schreibersii Kukl, Myotis myotis Bork. etc.); - the diffuse pollution of surface waters determined by uncovered surfaces and waste deposits without vegetation exerts a negative influence on aquatic habitats, mountain rivers and herbaceous vegetation along the banks; - affecting the favourable conservation status of insects: Osmoderma eremita Scop., Rosalia alpina L., (priority species), etc. Bats and the birds that feed on them depend on the health of forest and insect ecosystems along the food chain; - affecting aquatic ecosystems: the Neagra Şarului river, up to the confluence with the Dumitrelu p., is still considered a river without aquatic fauna.

The GPI value is *3.34* , suggesting an environment affected by human activities, causing disturbances to life forms.

3.2.3.1. The extractive waste deposits from the Dealu Rusului Mining Sector

From the mining activity (through underground works) of manganese ore, 3 tailing dumps have resulted that occupy an area of 2,823 ha and have a total volume of 93712 m^3. The dumped material consists of metamorphic shales, black quartzites and rocks with low mineralization (manganese oxides and carbonates).
For the calculation of the Global Pollution Index, the following rating was given (table 12):

Table 12. Ratings of environmental factors - Dealu Rusului tailing dumps

Environmental factors	Rating	Observations
Air	10	*Natural quality*. In the mining perimeter - located in a wooded area - closure and greening works were carried out, not being sources of air pollution.

Water	8	During periods of significant precipitation, mine waters come out of the mine galleries, loaded with Mn and Fe ions load, however within admissible limits
Soil	8	Affected by material entrainment from the dumps
Biodiversity	8	High degree of natural grassland and spontaneous arboreal vegetation, especially spruces, specific for areas with manganese mineralization.

The GPI value is 1,64, therefore suggesting an environment subjected to the effects of human activities within admissible limits.

4. Discussion

4.1. Management of municipal and assimilated waste in the Călimani mountain area, Suceava county

The 2020-2025 County Waste Management Plan for Suceava County, developed by the Suceava County Council and monitored by the Suceava Environmental Protection Agency, provides with a recycling index of at least 50% for household and assimilable waste by 2025; although this indicator has a slightly increasing trend, the value of 12.72% in 2022 is not encouraging for reaching the target. A waste collection initiative by the Asociația Montană Carpați (Mountain Association Carpați) in 2022 (along the tourist routes), led to the collection of *14 tons of abandoned waste* from the Șaru Dornei - Călimani National Park alone.

The study also revealed that although a lot of construction works are carried out on the site (especially after 2019 when the Țara Dornelor area, which the localities in the study are also part of, received the status of ecotourism destination), *they do not appear to be quantified in the statistics for construction and demolition waste.* Part of this waste (bricks from demolitions, stripped material) is used for land levelling; however, during this study, the presence of asbestos was detected in the roofs of household annexes which, according to the legislation, should have been out of use since 2003. There is no up-to-date status of asbestos-containing materials still in use or, where they have been replaced, what was the route of the resulting waste (asbestos falls into the category of hazardous waste).

The amount of biowaste collected and disposed through landfills at CMID Moara is quite low in the study area (approx. 12% of the amount of waste collected by sanitation operators), well below the percentage per county; this is because the area is mountainous, predominantly rural, with nutrient-poor soils, where the population is practicing composting in their own households and using it in their gardens.

Another deficiency in which the way household waste is managed is the mixed, unrecorded collection, making it difficult to separate expired medicines, insecticide packaging, etc.

At the Buliceni municipal waste deposit, because the waste is both domestic and industrial of origin, the post-closure monitoring imposed by the Suceava County Integrated Waste Management System offers a comprehensive guide that must be followed to avoid a possible negative impact on the environment.

As a continuation of the study, *we propose to carry out an inventory* of the areas where asbestos building materials still exist and an assessment of their quantity. It is also necessary to assess the quantities of hazardous waste produced in households – an aspect we want to analyse in the future.

4.2. Wood waste management in the Călimani mountain area, Suceava county

After the fall of the communist regime in the 1990s and because of the drastic restrictions of mining activities, and up until the mine closure (mining used to be an important source of income for approx. 65% of the population of the area), there was a period of massive, partially illegal logging. Large amounts of wood waste (of the order of hundreds of thousands of cubic meters) were found in abandoned mining perimeters, and especially on the banks of mountain watercourses. Only 3 bark and sawdust warehouses were environmentally regulated: Chilia, Bodnăraș and Poiana. The emergence of environmental legislation regarding the management of such types of waste, the emergence of high-capacity biomass thermal power plants and the grant opportunities to finance the production of pellets and briquettes have led to the valorisation of wood waste, the demand being greater than the supply in the Suceava County.

During our study, a *potential industrial synergy was identified*, that is now close to completion, for the 3 warehouses previously mentioned. An analysis of sample material from the tailing dumps revealed a slightly acidic pH, a good phosphorus and potassium supply, which make it *suitable for use in a mixture with peat as a fertilizer for greenhouses or as an ameliorant for degraded land on extractive waste dumps*. The company that purchased the wood

waste deposits (Fertisol SRL) also conducts exploitation activities of an acid peat (Poiana Stampei) and an alkaline peat to produce flower soil. *A recipe for a product is to be developed and approved soon.*

4.2. Management of agrozootechnical waste in the Călimani mountain area, Suceava County

Agricultural activities have been largely reduced in the rural areas where many families used to possess 10 to 15 cows and hundreds of sheep. Because of the very low prices for milk and meat, these small farms no longer have the capacity to cover the production costs, facing strong competition from larger processing companies that prefer to contract larger farms (usually with foreign capital). Even the traditional brands, such as the La Dorna Dairy, now belong to a French corporation and since 2020 no longer produce in Suceava, where they were initially created. Nevertheless, through the facilities created by the National Agency for Mountain Areas, small farms are starting to diversify their activity.

Since there are only small amounts of agro-zootechnical waste produced (approx. 15 tons/year from cattle and approx. 2,5 tons/year from sheep), they are used as fertilizers by the locals. GHG emissions are low, and their negative influence cannot be quantified considering the large areas of land occupied by carbon dioxide sinks: 67% of the area is occupied by forests and approx. 2% by wetlands (part of which are protected areas: the RAMSAR site Tinovul Mare Poiana Stampei, Tinovul Șaru Dornei- both peatlands).

The amount of agrozootechnical waste being low and accessibility in the area difficult, it is not considered necessary, at this moment, to build a zonal storage for them.

3.1. Extractive waste management

Although extractive waste has not been produced in the Călimani mountain area since 2006 (although few andesite quarries are in operation, with small amounts of inert waste from unearthing), the extractive waste deposits left from the Călimani Mining Exploitation *still have a significant impact*. A previous study and a subsequent analysis of the evolution of the quality of environmental factors revealed that the closure works focusing on safety and ecological rehabilitation are effective in terms of reducing the impact sources [4].

The unfinished closure works in combination with climatic factors has led to the strong gullying of the Pinu dumps slope (the dump occupies a surface of 18 ha and contains the largest volume of extractive waste of approx. 7,36 x 10^6 m^3) causing the entrainment of material downstream and the drying of the tree vegetation on the route.

Since the environmental agreement no. 3/27.02.2006, revised on the 25th of November 2010 issued by EPA Suceava for the closure and greening of the mining perimeters Pietricelu - Negoiu Românesc – Călimani, does not prescribe ecological rehabilitation works for the entire surface of the waste dumps Pinu and Puturosu, and based on the impacts evaluated for the post-closure period, it can be concluded that the *restoration of vegetation by non-invasive methods, adapted to the technical, environmental conditions and within the framework of the biodiversity legislation for the buffer area between the mining perimeter and the scientific reservation (with the natural association of Mountain pine and Pinus cembra) is imperative*. It is recommended that the authorities responsible for the mining closure (S CONVERSMIN SA) monitor the planted vegetation on the tailing dumps in the National Park Călimani and actively prevent the installation of allogenous, invasive species.

Before determining whether it is necessary to build a water treatment plant (a station which, according to the technical documentation for closing the mining perimeter, should take an estimated flow of 116 l/s), it necessary to *first complete safety and revegetation works*, as well as *monitoring* the water courses and the stability of the dumps. An important source of degradation of the quality of the Neagra Șarului water course is the alluvium originating from the mining perimeter, including the leakages due to the accidental discharges of industrial tailings from the hydro-transport pipeline from the preparation plant towards the settling pond.

Conclusions

According to the European Environmental Agency, the health and well-functioning of forest ecosystems is not only vital for biodiversity, but it is also an important source of clean air and water. If affected by human activities, the efficiency for oxygen production and air purification, important regulatory ecosystem services provided by forests, will generate a direct negative impact on the health and wellbeing of human communities. This study represents an important step for the *acknowledgement, study and quantification* of such impacts caused by non-compliant and inefficient waste management measures in the Călimani Massif, focusing on the environmental factors and their response to specific categories of waste, proving that the *Global Pollution Index* can serve as an efficient and reliable tool. It also suggests possible measures and serves as an important base for further studies.

Analysing the data collected and processed, based on the evaluation of ratings obtained for the four factors influencing, the quality of life in the human communities and by and calculating the global pollution index (*Figure 3*), we conclude:

a) The most affected environmental factors are *surface waters and biodiversity* in the influence area of the waste deposits originated from the extraction and processing of sulphur, despite this activity having been discontinued since 1995. Cleaning the bed of the Neagra Șarului river, concurrently with stabilizing and covering the deposits with herbaceous vegetation to prevent sediment entrainment into the watercourses is vital for the communities located in the watershed area of the Neagra Șarului river (where only about 12% of the population is connected to a drinking water supply network) (figure 3).

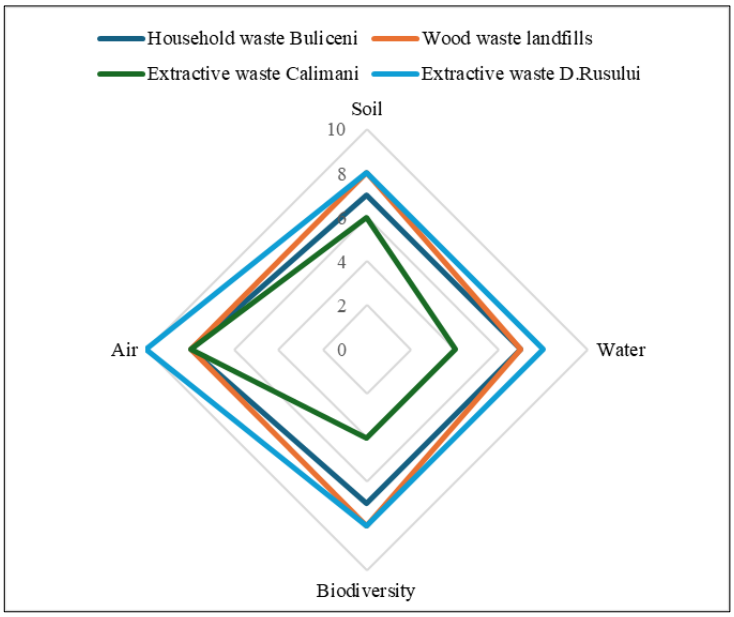

Fig. 3. GPI scores obtained for the environmental factors water, air, soil, biodiversity

b) Household waste and construction demolition waste represent a problem for the mountainous area due to improper management, lack of selective collection for each type of waste, failure to compost biodegradable waste, and the long distance to the compliant municipal waste landfill - approximately 160 km. Even though the old, non-compliant landfill has been closed, it still influences environmental factors.
c) After 2005, with the emergence of wood waste processors and the prohibition (through regulatory acts) of their disposal by landfilling, no more landfills specific for this type of waste have been built. However, significant quantities remain deposited, where leachate represents a risk factor for water quality. A possible solution for eliminating these types of waste would be their utilization in combination with peat and other materials as soil for flowers
d) Due to the natural conditions typical for altitudes of over 1000 m such as terrain morphology and climate, coupled with the proliferation of wildlife as a result of hunting restrictions and the policies of the Călimani National Park (there are frequent incidents of bear and wolf attacks on domestic animals and sometimes humans), only small farms have developed, despite the excellent quality of the mountain pastures; thus the construction of a large-capacity manure landfill has not been considered

Data Availability Statement: Data from EPA Suceava, CONVERSMIN SA (company responsible for the closure of mining perimeters), ABA Siret Bacău, ICPM SA, were obtained by request; the data from the Veterinary Sanitary and Food Safety Directorate Suceava are public and were taken from the institution's website (www.suceava.dsvsa.ro).

Conflicts of Interest: “The authors declare no conflict of interest.”

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