Assessing the Rehabilitation Possibilities of Mining-Affected Areas (Chacapalpa, Peru)

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Abstract

rehabilitation is conceived as the practice of restoring ecosystems impacted by anthropic activities, where mining is one of the most important, hence the valuation is of importance to achieve successful restoration. This study assesses the possibilities for restoration and the associated economic value in areas affected by mining in Chacapalpa (Peru). Various official sources were reviewed from which data on climatological, geological, ecological and land use characteristics were obtained, with which they were analyzed and from this alternatives were proposed, which were evaluated with respect to the investment costs for rehabilitation. Due to the geomorphological and climatological characteristics and the fauna and flora of the area, rehabilitation was proposed through the use of the hydroseeding method with native species in combination with the installation of biomantles, which generates an investment of € 172100 at closing. This proposal aims to recover the affected areas for the use of the communities either for agricultural or tourist use.

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1. Introduction

Peru is the second largest exporter of silver, the third largest exporter of zinc, the fourth largest exporter of lead, the fifth largest exporter of copper and the sixth largest exporter of gold [1]. Despite also having other natural resources, such as natural gas, fisheries, minerals, and forest resources, Peru remains a poor country. In addition, the mining sector is characterized by a lack of trust among its main actors and is prone to be the scene of social conflicts.

The expectations generated by the development offered by mining are interrupted by environmental damage and by limitations in the use and distribution of income. Both events have led to social conflicts that could discourage investors or delay the start of new projects [2, 3].

The Chacapalpa district, located in the province of Yauli, in the region of Junín (Peru), is located at an average altitude of 3748 m above sea level and has an area of 183.06 km², of which 38.89% is occupied by mining concessions [4]. Therefore, the importance of mining concessions in this district in the economic, social and environmental fields is appreciated. Many of these quarries are abandoned (environmental liabilities), others are in operation and others are about to be exploited, so it is necessary to take measures to rehabilitate these areas in their different stages.

The lithology of the area is mainly characterized by the presence of limestones, clays and gypsums. The soil is generally thin, with abundant organic matter and clay, and is suitable for pasture and protection. The average annual rainfall is 685 mm, with a maximum in winter, and herbaceous vegetation predominates. The locations of mining concessions are located in areas of high slopes, and the standard of living of the population is low, as it lacks many social services. The villagers do not have forest species that they can use for cooking or heating, as they are ancestrally linked to the use of their territory and, moreover, receive little support from the State [4].

From the above and from the observation in situ, a series of environmental impacts occur in this area, such as the alteration of the landscape, erosion, mass movements of the land and the destruction of vegetation. These are the main problems that need to be solved and on which this work focuses, but it is also important to point out other impacts, such as the emission of dust and gases, the generation of noise and water pollution, among others.

This paper analyzes the environmental parameters that can influence the environmental impact of mining concessions, with the main objective of assessing the possibilities of rehabilitation of areas affected by mining (quarries), based on geology, soil, climate, social aspects and current laws. With all the existing tools and limitations, it is intended to make a much more specific analysis of each quarry in the future, with multidisciplinary work, to be able to develop it in the field and provide a solution to this problem, with the support of the Peruvian State, international institutions, universities, society, researchers and professionals.

2. Materials And Methods

To carry out this work, different institutional sources in Peru were reviewed, as well as scientific articles related to the case. To do this, and taking into account the purpose of the work, it was necessary to know the current situation of the district of Chacapalpa and its surroundings. The aspects of the areas of the limits of the district where the mining concessions are located were also analyzed, since they are the highest parts of the place and with the greatest slope [4].

In the case of climatology, historical precipitation and temperature data were taken from the Jauja meteorological station, the closest to the study site, from 1964 to 2016, provided by the National Meteorology and Hydrology Service [5]. From these data, potential evapotranspiration was determined using the Thornthwaite method and the calculation of AWCh (available water content).

The different cartographic documents, such as the topographic plan, the slope plan, the geological map and the mining concession plan, were prepared with ArcMap software, in its version 10.3.

As for the geological map and the mining concessions, they were prepared based on data provided by the Geological, Mining and Metallurgical Institute [4] of Quadrant 24-L (WGS-84). The number of mining concessions located in the place, the main non-metallic minerals that are extracted and the total percentage of the area of the mining concessions in the place were also determined, among other data.

With regard to the capacity for major land use and soil types, data were taken from the National Office of Natural Resources Assessment [6] and the National Geographic Institute [7], respectively. These data were conceptually determined according to the WRB soil classification [8].

With regard to the topographic and slope map, it was based on information from the National Chart of Peru, available in the spatial information of the Geological, Mining and Metallurgical Institute of Peru [9]. To determine the results of the slope map, an algorithm was used that consists of the rates of change (Δ) of the surfaces in horizontal (dz/dx) and vertical (dz/dy) directions from the central cell that determine the slope [10]. The basic algorithm used to calculate the slope is:

$$slop-degrees = ATAN\left(\sqrt{\left(\frac{dz}{dx}\right)^2+\left(\frac{dz}{dy}\right)^2}\right) * 57.29578 \qquad (1)$$

To determine the flora and fauna, data from the National Institute of Natural Resources [11] and the Descriptive Report of the Wildlife Study of the Department of Junín [12], respectively, were consulted.

On the social side, the amount of population, the supply of social services and infrastructure, mainly water and electricity, as well as access to education and health, were determined. All this was based on data from the National Institute of Statistics and Informatics [13] from the last national census: the XII of Population, VII of Housing and III of Indigenous Communities.

3. Results

3.1. Characteristics of the study area

The Chacapalpa district is located in the province of Yauli, in the region of Junín (Peru), at an average altitude of 3748 m a.s.l. and has an area of 183.06 km² [9] (Figure 1). In turn, the district is surrounded in almost all its limits by mining concessions (7119 ha), most of which are located in areas of high slope and where some rivers are born [4] (Figure 2).

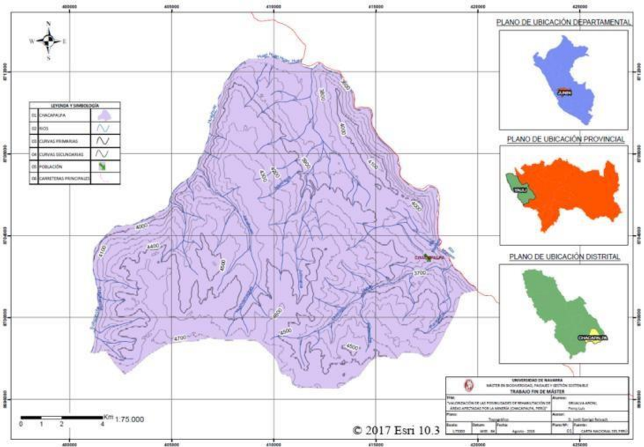

Figure 1. Location and topographic map of Chacapalpa

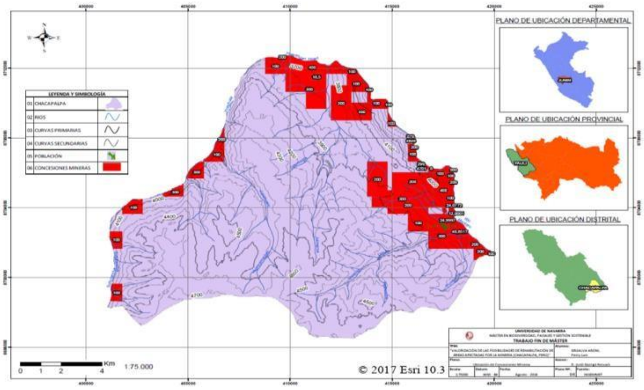

Figure 2. Map of the location of mining concessions

The mining-affected area has a predominantly steep relief, as it is located on the edge or top of the slopes that frame the district. The relief becomes somewhat gentler on the border with the moorland areas, which have moderate slopes, and much gentler in the central areas of the district [11].

As for the slope, as can be seen on the map (Figure 3), the slope of the area is variable. Areas with slopes greater than 50% can be distinguished, which are located on the boundaries of the district [8]. It is precisely in these areas that the largest number of mining concessions are located [4] and, therefore, they present a greater risk of soil erosion, earth movements, landslides and other factors that limit their use to natural reserves. It is also possible to differentiate between those areas with slopes between 30 and 50%, which, due to their erodibility, cannot be used for agriculture either, although they can be used for other activities such as extensive livestock farming or forestry with limitations.

In the central part of the district and in the vicinity of the permanent watercourses, the slope decreases, to between 0 and 30%. These areas are considered to be conserved from an agricultural point of view (slope less than 3%) to lands with many agri
cultural constraints (10 to 30%).

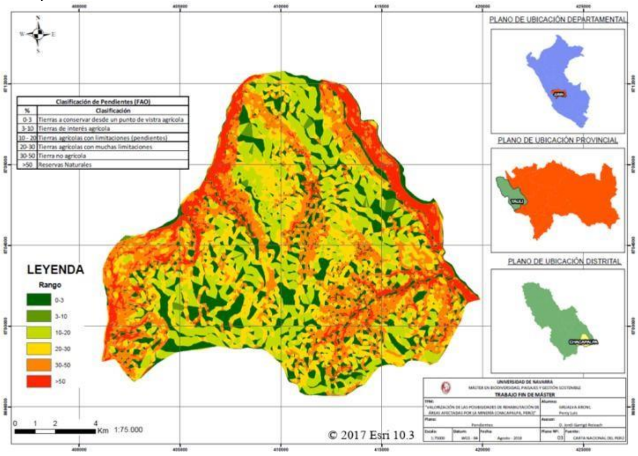

Figure 3. Slope Map

Regarding geology (Figure 4), various stratigraphic units emerge in the study area, ranging in age from the Jurassic to the Quaternary. In this case, three formations were covered for the examples of the study, since they are the ones that are concentrated in the largest number of mining concessions in these places [14]. These formations are as follows:

— Pariatambo Formation.
— Chulec Training.
— Celendín Training.

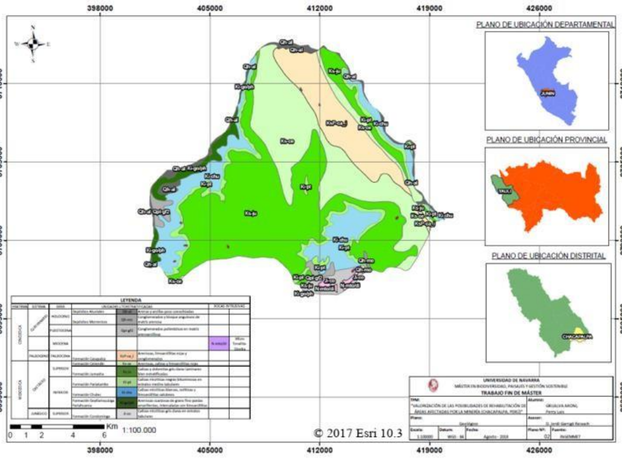

Figure 4. Geological map of Chacapalpa

The Chulec Formation belongs to the Mesozoic Era and the Early Cretaceous Series and comprises the following elements: dark gray calcareous clays and light gray patina, gray clayey calcareous mudstones and calcareous siltstones.

The Pariatambo Formation belongs to the Mesozoic Era and the Early Cretaceous Series. This formation is presented with alternating limestone and marl. The limestones are somewhat sandy in strata between 20 and 40 cm and their colour varies from beige grey to light ochre and pink, the latter related to weathering. Sandy loamy beds between the limestones are also interspersed between 5 and 10 cm thick and yellow to red in colour. Limestones still contain organic matter and give off a foul smell when cut fresh.

Finally, the Celendín formation belongs to the Mesozoic Era and the Upper Cretaceous Series and has gypsum, which is sometimes exploited. These gypsum formations are red to purple in color and account for the presence of numerous dissolution funnels.

As for soils, and using the WRB nomenclature [8], two types of soil associations dominate: the luvic Phaeozems - Luvic Kastanozems (HK) and the Humic Cambisols - Humic Andosols - Litosols (Bh) [7].

Both luvic Phaeozems and luvic Kastanozems are well-evolved soils that normally appear on stable surfaces with a characteristic profile: A, E, Bt. They are characterized by a subsurface horizon of clay accumulation (argill, Bt) and a dark A horizon with a marked accumulation of organic matter and saturated in bases, without secondary calcium carbonate (Phaeozems) or with such accumulation (Kastanozems).

The other association (Bh) is formed by less evolved soils, either in colluvial deposits of geological materials of a wide range of rocks (the humic Cambisols) or in deposits of materials of volcanic origin (the humic Andosols), both with a characteristic profile A, B and obscured by the richness in organic matter, especially those of volcanic origin. They are also found on escarpments and rocky outcrops (the Lithosols), which are thin soils (with a thickness of less than 10 cm) of profile A, R, limited by the hard parent material and, sometimes, discontinuous. This limits vegetation development to grasslands.

With respect to the evaluation of soils or types of use, Chacapalpa has lands with the following aptitudes: lands suitable for pasture (Plc), which are those not suitable for agricultural purposes, but which meet the ecological characteristics for the propagation of natural pastures, which allows the development of an economically profitable livestock activity, and protected lands (X). which are those with characteristics that are inappropriate for agricultural development and forestry within economic margins, but that can have a great economic value for other uses, such as the development of mining activity, energy supply, wildlife conservation and areas of landscape and tourist interest, among others [6].

In terms of climatology (Table 1), the absolute maximum and minimum temperatures are 28.2 °C and -9.2 °C, respectively, and the average temperature is 11.8 °C. The average annual rainfall is 685 mm, with a maximum of 48.8 mm in 24 hours, according to the rainfall history from 1964 to 2016 [5].

According to Werren Thornthwaite, the climate type is semi-frigid rainy (tundra), characterized by average annual rainfall of 700 mm, average annual temperatures of 7 °C and perpetual snowfall in the high mountains, as well as rainy summers and dry winters with moderate frost [5]. This coincides with the analyses carried out with the data from the local weather station.

As can be seen in Tables 2 and 3, the ETP depends on the depth of the soil. In areas with soils of 50 mm, the dry period will be 141 days, so it is considered arid soil. In 100 mm soils, the dry period will be 103 days, so it is considered an arid/ustic soil. In soils of 150 mm, the water deficit will be 64 days, so it is considered a ustic soil. In soils of 200 mm, there is no water deficit throughout the year, so it is considered a ludic/perudic soil. Therefore, it can be deduced that in shallow soils the time of water availability is shorter, which limits to a certain extent the development of forest species, while in deeper soils the time of water availability is much longer, which allows the installation of forest species. This can also be seen in Figure 5.

Table 1. Climatic parameters of the Jauja Station (1964 – 2016)

Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Ago.	Set.	Oct.	Nov.	Dec.	Annual (Absolute/average values of accumulated T and P)
Max. temp. abs. (°C)	25.2	28.2	23.6	25.2	24.7	24.0	25.0	27.0	25.8	27.2	26.0	26.6	28.2
Temp. med. Max. ABS. (°C)	22.2	21.7	21.0	21.5	21.8	21.4	21.5	22.3	22.8	23.1	23.3	23.0	22.1
Temp. med. max. (°C)	18.6	18.2	18.0	18.9	19.6	19.3	19.2	19.7	19.8	20.0	20.2	19.4	19.2
Temp. media (°C)	12.5	12.3	12.1	12.0	11.1	10.1	9.7	10.7	11.9	12.7	13.9	12.8	11.8
Temp. med. min. (°C)	6.5	6.5	6.3	5.0	2.7	1.0	0.3	1.8	4.0	5.3	5.7	6.1	4.3
Temp. med. min. abs. (°C)	3.3	3.3	3.1	1.4	-1.4	-2.9	-3.5	-2.3	0.0	1.9	2.4	3.0	0.7
Temp. min. abs. (°C)	-1.8	-1.8	-0.4	-3.8	-5.2	-9.2	-8.0	-6.8	-3.8	-1.0	-1.2	-0.8	-9.2
Precipitation (mm)	114	116	111	48.7	11.9	5.46	4.27	8.34	28.2	65	70.5	102	685
Max. rainfall 24 h (mm)	38.9	34.6	35.6	45.4	19.4	13.4	14.0	16.0	28.5	34.7	48.8	48.2	48.8

Table 2. Potential Evapotranspiration (ETP) – Thornthwaite and AWCh

ETP (mm)	**54,3**	**49,2**	**54,8**	**53,7**	**51,9**	**45,4**	**44,5**	**49,0**	**52,3**	**56,6**	**59,9**	**55,2**	**626,6**
P-ETP	59,7	66,8	56,2	-5,0	-40,0	-39,9	-40,2	-40,7	-24,1	8,4	10,6	46,8	
AWC 50mm	50,0	50,0	50,0	45,0	5,0	-34,9	0,0	0,0	-24,1	8,4	19,0	50,0	Recharge
AWC 100mm	100,0	100,0	100,0	95,0	55,0	15,1	-25,1	0,0	-24,1	8,4	19,0	65,8	Excess
AWC 150mm	125,5	150,0	150,0	145,0	105,0	65,1	24,9	-15,7	-24,1	8,4	19,0	65,8	Usage
AWC 200mm	135,7	200,0	200,0	195,0	155,0	115,1	74,9	34,3	10,2	18,6	29,2	76,0	Deficit

Table 3. Dry period

S.M.R.															
151	5,0	181	-34,9	-1,33	206	**155**	273	-24,1	304	8,4	1,05	-310	**296**	**141**	**Aridic**
181	15,1	212	-25,1	-1,30	250	**193**	273	-24,1	304	8,4	1,05	-310	**296**	**103**	**Arídic/ustic**
212	24,9	243	-15,7	-1,31	303	**231**	273	-24,1	304	8,4	1,05	-310	**296**	**65**	**Ustic**
														0	**Udic/Peruvian**

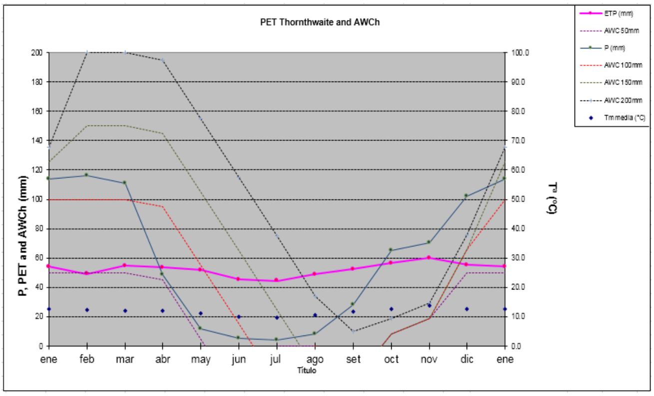

Figure 5. Diagrama de PET Thornthwaite and AWCh

The natural vegetation of the area is mostly herbaceous, although there are also small homogeneous groups of residual forest species in which chachacomo *(Escallonia sp.*) and quinual (*Polylepis sp*.) can be found, as well as small heterogeneous groups made up of species of the genera Gynoxis, Polylepis, Baccharis, Solanum, etc.
Both quinual (*Polylepis sp*.) and elderberry (*Sambucus peruviana*) are found near houses, giving the impression that they are under rigorous care as if they were cultivated plants. The mutuy (*Cassia sp.*), a yellow-flowered shrub, is also very common, as is the tarhui or wild chaco (*Lupinus mutabilis*) near the roads.
In the upper parts of this area there are also large extensions of natural high Andean grasses, mainly made up of species of the grass family, such as Stipa, Calamogrostis, Festuca and Poa, among the most important [11].
This habitat is characterised by the presence of rocky outcrops associated with low-lying and herbaceous shrubs. Birds such as the hummingbird (*Aglaeactis castelnaudii*), the red-breasted canastero (*Asthenes ottonis*), the Peruvian canastero (*Asthenes pudibunda*), the southern long-tailed calzadito (*Eriocnemis sapphiropygia*), the crowned scissor (*Leptasthenura pileata*), the firebeard metallura (*Metallura eupogon*), the black metalura (*Metallura phoebe*), the hummingbird Andean (*Oreotrochilus melanogaster*) and the Tschudi's tapaculum (*Scytalopus acutirostris*).
Among the mammals are the ketocui (*Abrothrix jelskii*), (*Akodon juninensis*), the painted long-eared pericote (*Auliscomys pictus*), the laucha (*Calomys sorellus*), the wild guinea pig (*Cavia tschudii*), the Fuegian dog (*Lycalopex culpaeus*), the mountain bat (*Montane myotis*), the *Oecomys phaeotis* and the *Oxymycterus inca*.
As for amphibians and reptiles, it is likely to find species of the genera Gastrotheca, Pleurodema and Rhinella. Regarding threatened species, there are no data, but it is likely that there are species classified as of least concern (LC): *Gastrotheca griswoldi, Gastrotheca marsupiata, Gastrotheca peruana, Gastrotheca testudinea, Pleurodema marmoratum, Rhinella poeppigii, Rhinella spinulosa* and *Rhinella veraguensis* [12].
In Chacapalpa there are 46 mining concessions, of which 32 are titled, 3 are extinguished, 9 are in the process of being processed and 2 are processing plants, covering a total of 7119 hectares [4]. Among the main non-metallic minerals they obtain when processing the aggregates they extract are marble, gypsum, silica, limestone, carbonates and their derivatives.
The population of the district is 918 inhabitants (446 men and 472 women), of which the economically active employed population (EAP) is 28.40% (27.66% employed and 0.74% unemployed) and those who are not in the EAP correspond to 71.60%; of which of the total population dedicated to mining activity is 2.07% (all men), 11.98% is dedicated to agriculture, livestock, hunting and forestry and 10.35% is dedicated to other activities.
Regarding the supply of social services and infrastructure, 57.85% have a public water network inside the home and 42.15% are supplied by rivers, ditches, wells, among others; Regarding drainage, 23.14% have a public network inside the home and 76.86% use septic tanks, latrines, among others; and as for public lighting, 49.59% of homes have electricity and 50.41% without energy.
Regarding educational level and health, 89.07% have some type of study at a different level and 10.93% do not have any type of education; and 31.81% have some type of insurance, while 68.19% are uninsured [13].
For all the reasons analyzed, in terms of the physical aspects of the area, the activity carried out (mainly the extraction of non-metallic minerals) and the laws enacted by the Peruvian Government, it is necessary to propose some environmental rehabilitation measures, such as preventive and/or corrective activities, concurrent or progressive closure activities and final closure activities. all this taking as a reference a farm of 5 hectares.

3.2. Valuation proposals

Among the preventive and/or corrective activities, it is proposed to carry out some actions, indicating their respective cost (Table 4).

Table 4. Preventive or corrective activities

Preventive and/or corrective activities	Estimated investment per year (€)

1. Placement of notices and/or panels related to environmental conservation.	100
2. Training of workers related to the prevention of environmental impacts and occupational safety.	500
3. Adaptation and installation of the organic matter court	2000
4. Adaptation and installation of the clearing court	2000
5. Installation of a perimeter fence with wire that surrounds the upper part of the work.	500
6. Construction of diversion channels in the upper part of the quarry in order to prevent the entry of water as a result of precipitation.	3000
7. Construction of diversion channels around the clearing fields in order to prevent erosion of the temporarily stored material.	1000
8. Construction of sedimentation wells at the end of the diversion channels in order to prevent the entry of sediments into the natural system.	1000
Total	**10100**

The application of all these measures is intended to prevent and/or correct the damage that affects or could affect these places, with a total cost of € 10100.00 per year, which is the time that their implementation would last. But apart from the activities that prevent and/or correct, it is necessary to carry out progressive or concurrent closure activities, which are detailed in Table 5.

Table 5. Progressive or concurrent closure activities

Concurrent Closing Activities	**Estimated investment per year (€)**
1. Maintenance of the notices and/or panels installed.	100
2. Training of workers related to the prevention of environmental impacts and occupational safety.	500
3. Maintenance of the dismantling.	1000
4. Maintenance of the field of organic matter through revegetation.	1000
5. Maintenance of the perimeter fence	100
6. Maintenance of the quarry's diversion channels.	300
7. Maintenance of the diversion channels of the clearing field and organic matter.	500
8. Maintenance of the wells sedimentation.	800
9. Recovery of the land profile (filling and levelling of the exploitation areas).	1000

Total	**5300**

All these activities will be carried out during the life cycle of the quarry. Although it is very complicated to schedule and carry them out during the exploitation activities, it is intended to advance as much as possible to obtain a better result in the final rehabilitation of the site at the time of closure. The total cost of these progressive or concurrent closure activities would be € 5300.00 per year.
Once the useful life of the quarry is over, it is necessary to carry out rehabilitation activities of the environment, which are considered the final closure of the quarry, although after this the post-closure of the quarry must be carried out. In this paper, however, we only intend to mention the activities up to this point (Table 6).

Table 6. Final Closing Activities

Final Closing Activities	**Estimated investment (€)**	**Execution period**
1. Placement of warning signs.	300	1 month
2 Training for workers related to the prevention of environmental impacts and occupational safety.	300	1 year
3. Recovery of the final profile of the land (quarry, clearing field, organic matter, access roads, among others).	10000	1 year
4. Revegetation of the affected areas (access roads, clearing fields, organic matter fields, silica, among others), using native species of the area	5000	1 year
5. Revegetation of the quarry through hydroseeding and using biomantles.	50000	1 year
6. Removal of auxiliary equipment and facilities.	500	6 months
Total	**66100**	**5 years and 6 months**

The total cost of the implementation of all these measures would cover € 66100.00, this without considering the subsequent follow-up work of the activity carried out.
Considering that the useful life of a quarry is approximately 20 years, the total cost of its concurrent and final closure would be € 172100.00 (Table 7). However, it is important to note that this cost only includes the materials, equipment and tools necessary to carry out these rehabilitation works, and does not include professional remuneration, labour, etc.

Table 7. Total cost of a mining unit's closure plan

Closure Plan	**Estimated investment (€)**	**Execution period**
1. Concurrent Closure Plan	106000	For 20 years
2. Final Closure Plan	66100	Year 21
Total	**172100**	

3. Discussion

It is not feasible to propose the installation of forest species in this area (upper part) because the mining concessions are located in areas of high slope, which is counterproductive for a reforestation project since they require slopes ranging from gentle to moderate, depending on the activity to be carried out in the area [15]. Another reason is the shallow depth of the soil, which leads to moderate potential evapotranspiration and therefore a shorter time of water availability for plants [5], [16], which makes it difficult to plant new species in the area. However, it is necessary to clarify that, despite the fact that the geological and lithological structure of the site is, to a certain extent, favorable to combat erosion [14], and that the soil has a high content of organic matter and humus [17], these places are basically stable.

These conditions limit the installation of forest species, but facilitate the existence of pastures and the revegetation of the soil, mainly with herbaceous species [18, 19]. It is important to note that there are concave areas where there is a greater amount of organic matter, a larger soil surface and, at the same time, more time of water available for plants. In these areas, the installation of native forest species could be carried out, such as quinual, colle and tara, mainly, since they are species that grow and adapt well to poor and shallow soils, with a high percentage of stoniness, and that withstand drought seasons very well [20]. However, this installation would be carried out to a greater extent in the lowland areas, where the conditions are much more favorable and where, at the same time, the population benefits, since the local community makes use of natural resources (forest species), since the inhabitants are ancestrally linked, from the social point of view, economic and cultural, to community ownership of land and to community work. They use forest species mainly for firewood, living fences and windbreaks [21], and thus contribute to a certain extent to alleviate the lack of social services they demand [13].

As for the quarry, for its rehabilitation, taking into account the characteristics of the area (mainly slope) and the disadvantages, it is proposed to use the hydroseeding technique, since it allows the creation of vegetation to prevent erosion and stabilize the sloping lands and slopes (which are mechanically stable), while selecting the most appropriate plant species for the conditions of the place. which ensures germination [22], [23]. In addition, biomantles, which are organic and biodegradable mantles, such as straw, wood shavings, coconut fiber or a combination of both, distributed on or between woven polypropylene fibers or biodegradable natural fibers that provide protection against ultraviolet rays, will be used. they help provide erosion protection and promote vegetation establishment [24-26].

As can be seen in the number of mining concessions [4], there are many quarries in operation, which must apply environmental rehabilitation measures before ceasing their activity, which is stipulated in Article 27 of the General Environmental Law [27], which establishes that the owners of all economic activities must guarantee that, when closing their activities or facilities, there are no significant negative environmental impacts, and they must consider this aspect when designing and applying the corresponding environmental management instruments, in accordance with the current legal framework.

On the other hand, Articles 30 of the General Environmental Law [27] and 62 of the Regulations of the Framework Law of the National Environmental Management System [28] mention the decontamination and treatment plans for environmental liabilities, which aim to remedy the environmental impacts caused by one or more investment projects or activities, past or present. These plans must consider in their financing the responsibilities that correspond to the owners of the polluting activities, including compensation for the damages generated, under the principle of environmental responsibility.

With respect to civil liability, Article 147 of the General Environmental Law [27] states that the reparation of environmental damage consists of the restoration of the situation prior to the event harmful to the environment or its components and its economic compensation. If restoration is not technically or materially possible, the judge must provide for the performance of other tasks to recompose or improve the environment or the affected elements. The compensation will be used to carry out actions that compensate for the interests affected or that contribute to meeting the constitutional objectives with respect to the environment and natural resources.

Based on the above, the proposal for the valuation of the restoration of the soils impacted by mining activity was made, as shown in Tables 4, 5, 6 and 7. A time of 21 years was estimated for the definitive closure of environmental restoration, whose investment is not only focused on direct economic benefits, but also the long-term positive impacts that it can produce on social structures, environmental quality and the quality of life of residents [29]. Beyond the economic valuation, the proposal for ecological restoration of the area affected by mining in the Closure Plan can be supported by successful projects such as the one in Alberta, Canada, where reforestation after mine closure has successfully restored the ecological environment and rebuilt the ecosystem [30].

On the other hand, previous studies have shown that the effectiveness of ecological restoration in areas impacted by mining activity is linked to governance, policies, legislation, and monitoring mechanisms in place. In this case, we can mention successful projects such as those in South Africa, the Amazon and Australia, where technologies have been used to reforest native ecosystems and transforest degraded lands into agricultural lands, with positive results, but limited by the factors already mentioned [31].

From the financial perspective, the estimated cost is considered adequate, if it is taken into account that the rehabilitation of soils degraded by mining activity requires significant financial investments. Costs may vary depending on the extent of the impacted area, the restoration strategy selected, and local environmental conditions [32]. On average, rehabilitation projects can cost between USD 500 and USD 5000 per hectare, which will depend largely on the complexity of the restoration. The primary costs associated with these projects typically include site preparation, material procurement, labor, and long-term monitoring [33, 34].

4. Conclusion

Due to the location of the mining concessions and the characteristics of the site, the rehabilitation of the land is proposed through the main use of the hydroseeding method (using native species) in combination with the installation of biomantles. In this proposal, the investment at closure is substantial, however, it is related to the level of complexity of the area and the characteristics of the region's ecosystems, which is consistent with what has been proposed by other researchers.

Due to the lack of forest species and the demand for social services, reforestation policies with native species should be implemented in those places where they can develop. This is recommended because native species have a greater capacity to adapt and can reduce the restoration time of the impacted area

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