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Environmental Impact Generated by Anthropogenic Activities in the Pisba Paramo (Tasco-Boyacá)

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The Pisba paramo is a strategic ecosystem and critical water recharge area for the departments of Boyacá and Casanare in Colombia. However, in the jurisdiction of the municipality of Tasco, different mining and agricultural projects have been conducted that have deteriorated the quality of the ecosystem. Therefore, this work presents an evaluation of the environmental impact generated by anthropogenic activities in the Pisba paramo, specifically within the jurisdiction of the municipality of Tasco. Based on the methodology of Conesa (1997), the environmental impact evaluation was carried out where the effects of anthropogenic activities in the Pisba paramo on the quality of life of the population, the vegetation and fauna, the soil, the water, air, and ecosystems present in the area were assessed. The matrices were determined, and water samples were taken from the collection points of the aqueducts and at points that presented mining activity, as well as soil samples; in total, six water samples and three soil samples were taken. Two severe positive impacts were found related to the increase in vegetation cover due to mining activities, and four severe negative impacts related to the water component according to agricultural activities. The presence of heavy metals in the water was evident in high levels of iron, nickel, cadmium, lead, and arsenic. The water samples analyzed showed concentrations 0.123-0.131 mg/L of cadmium, 0.485-0.54 mg/L of lead, and 45.39-576.3 μg/L of arsenic, which represents a clear indication of the pollution generated by mining activities.

1. Introduction

Colombia is considered one of the countries with the greatest biodiversity on the planet. Among Colombian ecosystems, the paramo is a natural water reservoir and has been affected by significant changes in land cover class. The Pisba paramo, located between the departments of Boyacá and Casanare, is a water recharge ecosystem that is home to different species endemic to the region, which is why it is classified as an area of great environmental and ecological importance for Colombia. The environmental impacts that have occurred in the Pisba paramo have generated significant environmental deterioration and impact on local populations since it has affected the quality of the water sources that supply this resource to the community of the municipality of Tasco. Tasco is known for its extensive dedication to livestock and agriculture; however, in recent years, underground coal mining has been on the rise, which affects the ecosystem and water resources. Estupiñan (2020) evaluated the water quality in the Pisba paramo through the physicochemical and bacteriological characterization of the water of the main rivers. The results showed that the water quality is good, however, high concentrations of fecal coliforms were found in some sampling points, indicating the presence of contamination from anthropogenic activities. Perez et al. (2018) analyzed the environmental impacts in this paramo related to the environmental problems caused by mining exploitation, finding that mining has caused a great transformation in the habitats of the paramo, which has negatively affected biodiversity and ecosystem services. Research of this type on the Pisba paramo allows us to address various dimensions of its ecological and socio-environmental importance, as well as the challenges it faces for its protection and conservation.

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For this reason, in this work, the evaluation of environmental impacts generated by anthropogenic activities is carried out. In the Pisba paramo in the jurisdiction of the municipality of Tasco, the goal is to determine the significant different effects.

2. Methodology

2.1 Identification of environmental impact

In this work, the methodology of Vicente Conesa Fernandez-Vitora (1997) was used to carry out the environmental impact assessment. With this methodology, the effects of anthropogenic activities in the Pisba paramo on the quality of life of the population, the vegetation and fauna, the soil, water, air, and the function of the ecosystems present in the area are understood and estimated. When developing this methodology, it seeks to identify and evaluate environmental impacts and propose different measures that minimize their harmful effects. According to Conesa, to carry out any environmental impact assessment, the sign, the degree of qualitative manifestation, and its magnitude must be understood. To evaluate the impact, items such as intensity, persistence, extension, moment, reversibility, synergy, accumulation, periodicity, effect, and recoverability with which the quantification of environmental impacts is carried out, where the rating ranges are assigned according to the meaning, scope, and incidence. According to Conesa (1997), to achieve a rating that allows determining the rank of importance (I) of the impacts analysed, Eq. (1). Likewise, each component is classified as presented in Table 1.

$$I = (3i + 2EX + MO + PE + RV + SI + AC + EF + PR + MC) \tag{1}$$

Table 1: Evaluation criteria of the matrix Conesa (1997)

Sign		Intensity (i)		Effect (EF)		Accumulation (AC)		Synergy (SI)		Persistence (PE)	
Beneficial	+	Low	1	Indirect	1	Simple	1	No synergy	1	Fleeting	1
Harmful	-	Total	12	Direct	4	Cumulative	4	Synergistic	2	Temporary	2
								Very synergistic	4	Permanent	4
Extension (EX)		**Moment (MO)**		**Recoverability (MC)**		**Periodicity (PR)**		**Reversibility (RV)**			
Punctual	1	Long term	1	Immediate recovery	1	Irregular	1	Short term	1		
Partially	2	Medium term	2	Recoverable	2	Periodicity	2	Medium term	2		
Extensive	4	Immediate	4	Mitigable	4	Continuous	4	Irreversible	4		
Total	8	Critical	8	Irrecoverable	8						
Critical	12										

Table 2 presents the values that the importance and description of this qualification can take according to the Conesa matrix. For this, the matrix of environmental impacts of mining activities in the study site was carried out, taking as reference a mining project called PM1, which relates the exploitation of the coal deposit in addition to the analysis of agricultural activities. For these two activities, the geomorphic environmental components, landscape, soil, water, atmosphere, flora, fauna, and socio-cultural are addressed.

Table 2: Description of the Conesa matrix qualification

Value I (13-100)	Qualification	Meaning of impact
I<25	Low (L)	It is irrelevant compared to the aims and objectives of the project in question.
25<I<50	Moderate (M)	Not require intensive corrective or protective practices.
50≤I<75	Severe(S)	Requires the recovery of environmental conditions through corrective or protective measures. The recovery time required is a long period.
I ≥75	Critical(C)	Its impact is higher than the acceptable threshold. There is a permanent loss of quality in environmental conditions. There is no possibility of recovery.

2.2 Water sampling

The stratified sampling plan for water used during a field visit to the Pisba paramo included the selection of six sampling points representative of different water sources. Stratified sampling was used to collect samples from each stratum of interest. First, an unimpacted paramo water sample was selected as a reference. Then, two strata of interest related to mining are identified, and two samples are taken from each one: leachate mining downstream of the passive that dissolves with runoff from the wasteland. Finally, a water sample was collected before entering the village aqueduct treatment plant. The simple random sampling technique was used to select the sampling points within each stratum. The samples were subsequently analyzed in the laboratories of the Pedagogical and Technological University of Colombia. The identification of each water sample from the Pisba paramo was carried out as follows: name of the sample (sample point; coordinates): M1 (Dam El Oro; N1137627 / E 1152009), M2 (first mine exit; N1137693 / E 1150868), M3 (10m below the mine; N1137677 / E 1150869), M4 (Main road drain pipe; N1140353/E 1149425), M5 (Mine 2 Water intakes, N1140391 /E 1149486); M6 (River main road - aqueduct entrance; N1140404 / E 1148286). To evaluate the water quality index corresponding to the 6 samples, the methodology of the National Sanitation Foundation (NSF) of the United States of America was used through the online system developed by Oram called the Water Research Center Calculator.

2.3 Soil sampling

Stratified sampling was used as a useful tool to obtain a representative sample of the different types of soils present in the area. The stratified soil sampling plan for three representative samples of the Pisba paramo and describing the environmental impact in the area was carried out as follows: the area was divided into three strata: a soil sample affected by mining (M7), a sample of soil affected by agriculture (M8; N 1137901/E 1151318) and a sample of standard soil without environmental impact (M9; N 1138014 / E 1151335).

2.4 Water characterization

In the different water samples, the following characterizations were determined: by the potentiometric method pH, conductivity, and total dissolved solids; by the titration method, total acidity, total alkalinity, apparent color, total hardness, calcium hardness, magnesium hardness, calcium, magnesium, sulphates; by the argentometric chloride method; turbidity (nephelometric method) in addition to measurement of nitrites, nitrates, phosphates, total phosphorus, dissolved oxygen (direct measurement, ASTM 888-09) and apparent color (colorimetry). In addition to the above, the atomic absorption spectrometry technique was used to determine zinc, iron, copper, molybdenum, and nickel. Using the electrothermal atomic absorption technique by EPA Digestion Metals, the content of cadmium, lead, and arsenic was determined. As part of the microbiological analysis, the content of total coliforms and E. Coli was determined using the Membrane Filter Method technique.

2.5 Soil characterization

The soil samples were analysed according to the techniques of pH (saturated paste method), humidity (gravimetric method), temperature, organic matter (dry combustion method), and conductivity (potentiometric method). In addition, the content of zinc, iron, molybdenum, copper, and nickel was determined by atomic absorption spectroscopy, and the concentration of lead and cadmium was determined by electrothermal atomic absorption by EPA Digestion Metals.

3. Results and Discussions

Table 3 and Table 4 present the structure of the matrix of impacts of mining activities on the physical environment and for the biotic and sociocultural environments, respectively. With this same structure, the environmental impacts of agricultural activities were also developed. According to the matrix of environmental impacts of mining activity (Table 3 and Table 4), it is observed that this mining project generates severe negative impacts regarding the physicochemical contamination of water due to the alteration of the hydrological cycle, the decrease in vegetation and the loss of biodiversity due to modification of the structure of the vegetation cover and the modification and loss of habitat due to the displacement and distribution of the species present in the area due to the removal of plant material. Two severe positive impacts were found regarding the increase in vegetation and three severe negative impacts related to the decrease in vegetation and loss of biodiversity (Figure 1). Compared to impacts evaluated with a low rating, some were found related to soil erosion, the reduction of water availability, transportation, and the installation of signage in risk areas, the first two being considered negative impacts and the latter two as positive impacts. All other impacts were rated as moderate impacts. In the case of the impact matrix generated for agricultural activities for the components (and their impacted factor) landscape (visibility), soil (erosion, soil quality); water (flows, atmosphere), flora (vegetative cover and diversity), fauna (habitat; population), community and economy (Population, employment and social well-being) and culture (use and management of the environment) were all moderate. It is highlighted that it was severe for the cases of the water component (surface and groundwater: physical-chemical quality, water quality) and low in terms of flows related to its availability. Table 5 and Table 6 present the results of the characterization of the water and soil samples from the Pisba paramo area.

Table 3: Matrix environmental impacts, physical, mining activity

COM	Impacted Factor	Activity	*Sign*	*I*	*EX*	*MO*	*PE*	*RV*	*SI*	*AC*	*EF*	*PR*	*MC*	*II*	*Value*
Geoforms	AA	Excavation	-	4	1	4	2	2	2	1	4	4	1	34	M
	Stability	Adaptation of collection center	-	4	2	4	2	2	2	1	4	4	2	37	M
		Drilling (iron and coal mining) and/or blasting	-	4	2	4	2	2	2	1	4	4	2	37	M
		Reconfiguration of exploitation tunnels	+	1	1	2	2	4	2	1	4	4	2	26	M
		Redefinition and stabilization of collection centers	+	1	1	2	4	4	2	1	4	4	2	28	M
Landscape	Visibility	Adaptation of the collection center and camp	-	5	4	4	2	2	2	4	4	4	4	49	M
		Redefinition and stabilization of collection centers	+	4	1	2	2	2	2	1	4	4	1	32	M
		Closure and dismantling of roads	+	4	1	2	2	2	2	1	4	4	1	32	M
		Revegetation	+	7	1	2	2	2	2	1	4	4	1	41	M
Soil	Use	Removal of plant material	-	4	1	2	2	1	1	1	4	4	1	30	M
		Adaptation of the collection center and camp	-	4	1	2	2	1	2	1	4	4	1	31	M
		Redefinition and stabilization of collection centers	+	5	1	4	2	2	2	1	4	4	2	38	M
		Closure and dismantling of roads	+	5	1	4	2	2	2	1	4	4	2	38	M
		Revegetation	+	5	1	4	2	2	2	1	4	4	1	37	M
	Soil quality and loss	Removal of plant material	-	4	4	4	2	4	1	1	4	2	2	40	M
		Excavation	-	5	4	4	2	2	1	1	4	2	4	43	M
		Adaptation of the collection center and camp	-	5	1	4	4	4	1	4	1	4	4	43	M
		Track maintenance	-	6	1	4	2	2	2	1	4	2	2	39	M
		Camp	-	1	1	4	2	2	1	1	4	2	2	23	L
		Revegetation	+	3	1	4	2	1	2	1	4	2	1	28	M
	AF	Removal of plant material	-	4	1	4	2	1	2	1	4	2	2	32	M
Water	Flow rates	Removal of plant material	-	7	4	2	2	2	2	1	4	2	2	46	M
		Camp	-	1	1	4	2	2	2	1	4	2	2	24	L
		Revegetation	+	3	1	4	2	2	2	1	4	2	2	30	M
	Surface waters	Removal of plant material	-	7	4	4	2	2	2	4	4	2	2	51	S
		Excavation	-	5	4	4	2	2	2	4	4	2	4	47	M
		Adaptation of the collection center and camp	-	5	4	4	2	2	2	4	4	2	2	45	M
		Drilling	-	7	1	4	2	2	2	4	4	2	2	45	M
		Blasting	-	7	1	4	2	4	2	4	4	2	4	49	M
		Camp	-	4	1	4	2	2	2	1	4	2	1	32	M
		Transport	-	2	4	4	2	2	2	4	4	2	2	36	M
		Revegetation	+	4	1	4	2	1	2	4	4	2	1	34	M
Atmosphere	Air quality	Removal of plant material	-	7	2	4	2	1	2	4	4	2	1	45	M
		Excavation;	-	4	1	4	2	2	2	4	4	4	2	38	M
		Adaptation of collection center	-	5	2	4	2	2	2	4	4	4	2	43	M
		Camp	-	2	1	4	2	2	2	4	4	4	4	34	M
		Ore loading	-	5	2	4	2	2	2	4	4	4	4	45	M
		Closure and dismantling of roads	+	4	1	4	2	2	2	4	4	4	1	37	M
		Revegetation	+	4	1	4	2	2	2	4	4	4	1	37	M
	Noise	Removal of plant material	-	4	2	4	2	1	1	1	4	1	1	31	M
		Excavation	-	8	2	4	2	1	1	1	4	1	2	44	M
		Adaptation of collection center	-	6	2	4	2	1	1	1	4	1	1	37	M
		Drilling/ Blasting	-	8	2	4	1	1	1	1	4	1	1	42	M
		Ore loading and transportation	-	6	2	4	1	1	1	1	4	1	1	36	M

AA: Geomorphology; AF Fertility; II: importance of the impact; COM: Component

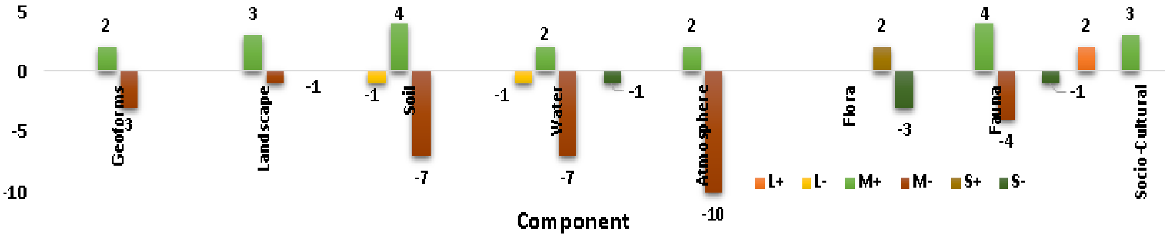

Figure 1: Qualification of the environmental impacts, mining activity

Table 4: Matrix of environmental impacts, biotic and socio-cultural, mining activity

COM	Impacted Factor	Activity	*Sign*	*I*	*EX*	*MO*	*PE*	*RV*	*SI*	*AC*	*EF*	*PR*	*MC*	*II*	*Value*
Flora	Plant covers and plant diversity	Removal of plant material	-	8	4	4	4	4	1	1	4	4	2	56	S
		Excavation	-	8	4	4	4	4	1	1	4	4	2	56	S
		Adaptation of the collection center and camp	-	5	4	4	4	4	1	1	4	4	5	50	S
		Closure and Dismantling of Roads	+	7	4	4	4	4	1	1	4	4	2	53	S
		Revegetation	+	6	4	4	4	4	2	4	4	4	2	54	S
Fauna	Habitat	Removal of plant material	-	8	4	4	2	2	2	1	4	4	2	53	S
		Adaptation of Collection Center	+	4	2	4	1	1	2	1	4	4	1	34	M
		Camp	-	4	2	4	2	2	2	1	4	1	1	33	M
		Redefinition and stabilization of collection centers	-	4	2	4	2	2	2	1	4	2	1	34	M
	Fauna Diversity and Population	Removal of plant material	-	5	2	2	2	2	2	1	4	1	1	34	M
		Ore loading and transportation	-	4	2	4	2	2	2	1	4	1	1	33	M
		Redefinition and stabilization of collection centers	+	3	2	2	2	2	2	1	4	2	2	30	M
		Closure and dismantling of roads	+	3	1	2	2	2	2	1	4	2	2	28	M
		Revegetation	+	5	1	2	2	2	2	1	4	2	2	34	M
Socio-Cultural	Population, employment, and social well-being	Labor Hiring	+	5	2	4	2	2	1	4	4	2	1	39	M
		Track maintenance	+	5	2	2	2	2	1	1	4	2	2	35	M
		Transport;	+	2	1	2	1	2	1	1	4	2	2	23	L
		Installation of signage for risk areas	+	1	1	4	2	1	1	1	4	4	1	23	L
		Revegetation	+	4	1	2	2	2	2	1	4	4	2	33	M

Table 5: Results of the characterization of water samples

Parameter	Unit	Water sample results						Parameter	Unit	Water sample results					
		M1	M2	M3	M4	M5	M6			M1	M2	M3	M4	M5	M6
Turbidity	NTU	0.9	2.5	2.5	900	320	16	Nitrites	mg/L	0.009	0.013	0.006	0.008	0.008	0.01
pH	-	7.97	2.89	2.79	3.73	3.46	6.02	Nitrates	mg/L	0.7	12	6.5	0.8	1.2	1.3
Conductivity	µs/Cm	18.5	2120	2120	1561	1587	29.9	Ca	mg/L[b]	4.8	208	224	256	144	8
TDS	mg/L	10	1091	1112	770	798	16	Mg	mg/L	2.9	87.5	92.3	87.5	87.5	3.4
DO	mg/L[a]	6.42	6.84	6.79	6.65	6.87	7.03	Zn	mg/L	0.217	1.094	0.871	0.243	0.229	0.28
Total acidity	mg/L[b]	14	374	324	34	84	24	Fe	mg/L	0.528	37.6	30.42	77	36.64	3.8
Total alkalinity	mg/L[b]	12	0	0	16	12	30	Cu	mg/L	0.023	0.047	0.031	0.028	0.025	0.02
Chlorides	mg/L	16	980	940	480	660	10	Mo	mg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Apparent color	Pt-Co	17	36	30	2564	1184	149	Ni	mg/L	0.537	0.734	0.713	0.564	0.563	0.54
Total hardness	mg/L[b]	24	880	920	1000	720	34	Cd	mg/L	0.123	0.127	0.129	0.131	0.129	0.13
Calcium[C]	mg/L[b]	12	520	540	640	360	20	Pb	mg/L	0.524	0.533	0.511	0.514	0.485	0.54
Phosphates	mg/L	0.19	0.6	0.47	0.82	0.65	1.41	As	µg/L	45.39	537.5	558.7	575.4	576.3	379.5
Magnesium[C]	mg/L[b]	12	360	380	360	360	14	TC	UFC/ 100ml	36					
TP	mg/L	0.06	0.2	0.15	0.27	0.21	0.46	E. Coli		1					
Sulfates	mg/L	1	4800	4100	4300	4400	2								

a:O_2 b: $CaCO_3$ c: hardness DO: Dissolved oxygen; TDS: Total dissolved solids; TP: Total phosphorus TC: Total coliforms

According to the water quality (Table 5) index used, the following results were found for each of the samples analysed: M1 79%, M2 65 %, M3 66 %, M4 75 %, M5 74 %, and M6 80.5 %, which corresponds to a classification on its scale of good, average, average, good and good, respectively. The lowest values were found in water samples near the mines. Samples M2 and M3, when compared with Resolution 631 of 2015 of Colombia in which the parameters and maximum permissible limit values were established in specific discharges to surface water bodies, had a high content of chlorides, sulphates, iron, nickel, lead, and arsenic. A wide presence of arsenic is observed in all the water sources analysed. Arsenic is a highly toxic and carcinogenic element that represents a significant risk to human health and the environment. Lead toxicity can have serious consequences for local fauna and flora. Exposure to high concentrations of this heavy metal can affect the nervous system of some animals, causing damage to their behavior, reproduction, and survival. In addition, some plants may suffer damage to their growth and development due to the accumulation of lead in soil and water (Zaimee et al., 2021). Sample M1 was planned as a standard sample point to evaluate the water quality of the ecosystem before interventions and thus be able to compare the change due to mining activities. The results of samples M2, M3, and M5 demonstrate an alteration in the physicochemical parameters in the water quality seen in sample one. The samples analysed as a whole reveal clear evidence of mining activity and its negative impacts on the paramo ecosystem. The results obtained demonstrate a significant alteration in the physicochemical parameters and reveal high concentrations of heavy metals, which represent a threat to both flora and fauna and human health. For the three soil samples (Table 6), the pH found is less than 6, which may imply deficiencies of Ca, Mg, and K; however, for paramo soil, a value such as 5.21 may be normal. Regarding conductivity, in all cases, it meets a value of less than 2000 µs/Cm, which places it in the non-saline category, reflecting the characteristic that no crop is affected. For its part, the percentage of organic matter present in the three samples reflects a high percentage for samples M7 and M9 and a medium percentage for sample M8. Regarding heavy metals in all soil samples, it complies with the maximum permitted concentrations reported by Kabata and Pendias (2001).

Table 6: Results of the characterization of soil samples

Parameter	Unit	Soil sample results			Parameter	Unit	Soil sample results		
		M7	M8	M9			M7	M8	M9
pH	-	2.85	4.52	5.21	Fe	mg/kg	15.556	101.94	3.385
Humidity	%	9.245	2.63	8.91	Cu	mg/kg	0.020	0.027	0.040
Temperature	°C	17	19	18.2	Mo	mg/kg	<0.01	<0.01	<0.01
Organic matter	%	21.49	65.944	7.73	Ni	mg/kg	0.039	0.057	0.0895
Conductivity	µs/Cm	1218	53.7	150.9	Cd	mg/kg	0.0029	0.010	0.0099
Zn	mg/kg	0.098	0.058	0.286	Pb	mg/kg	0.048	0.057	0.0335

4. Conclusions

For the most part, there has been contamination of water sources, soil degradation, and alterations to the ecosystems present in the area, and, although the entities in charge established several requirements for the different mining owners, it is necessary to monitor compliance with said obligations, being they must commit to carrying out activities while maintaining adequate management of natural resources and preventing or mitigating any type of negative environmental impact that may occur in the area as a consequence of the execution of their work. In the case of agricultural activities, it is also necessary to implement environmental management measures that promote good agricultural practices in the inhabitants of the area, which mitigate the impacts related to excessive grazing, the use of fertilizers and pesticides, and excessive irrigation of crops. The presence of heavy metals in the water was evident in high levels of iron (0.528-37.6 mg/L), nickel (0.537-0.734 mg/L), cadmium (0.123-0.131 mg/L), lead (0.485-0.54 mg/L), and arsenic (45.39-576.3 µg/L), which represents a clear indication of the pollution generated by mining activities. These metals, known to be toxic, have harmful effects on aquatic organisms and the entire food chain. According to Castro and Molina (2019), phytoremediation can be a strategy to reduce the degree of contamination because it achieves the reduction and/or elimination of the concentration of various contaminants, such as heavy metals, from biochemical processes carried out by both terrestrial and aquatic plants.

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