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DEPARTMENT OF SCIENCE AND ENVIRONMENTAL TECHNOLOGY
GRADUATE IN ENVIRONMENTAL AND SANITARY ENGINEERING
DISCIPLINE RECOVERY OF DEGRADED AREAS

REPORT:

Evaluation of the environmental and socioeconomic impacts generated by the rupture of the Fundão dam in Mariana, Minas Gerais.

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Belo Horizonte, 2017.

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Academic work presented to the discipline Recuperation of Degraded Areas of the undergraduate course in Environmental and Sanitary Engineering, Federal Center of Technological Education of Minas Gerais.

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Belo Horizonte, 2017.

ABSTRACT

On November 5, 2015, 34 million cubic meters of iron ore tailings were dumped from the mining complex operated by Samarco after the rupture of the Fundão dam. According to the electronic website Ministry of the Environment, 663 (six hundred and sixty-three) kilometers of rivers and streams were hit, 1,469 (one thousand, four hundred and sixty-nine) hectares of vegetation were committed, 207 (two hundred and seven) (two hundred and fifty one) buildings ended up buried only in the district of Bento Rodrigues. Two years after the accident, much is seen of the impacts generated, both in the environment and in the socioeconomic environment. Thus, the objective of this study was to evaluate the environmental and socioeconomic impacts caused by the rupture of the Fundão dam in the Bento Rodrigues District, in the municipality of Mariana-MG. Through the analyzes, it is perceived that the effects on the environment are significant in all scopes. As for the socioeconomic, the death of people, associated with the destruction of Bento Rodrigues, causes the losses to be incalculable. Despite the actions planned for recovery, little was actually accomplished and the marks of the accident are still extremely felt in the Region.

Keywords: Breakdown, Dam, Impacts, Environmental, Socioeconomic.

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SUMMARY

1. INTRODUCTION

On November 5, 2015, 34 million cubic meters of iron ore tailings were dumped from the mining complex operated by Samarco after the rupture of the Fundão dam. In a matter of hours, the mud reached the Doce River, whose basin is the largest in the Southeast of the country, with a total area of 82,646 square kilometers (equivalent to twice the state from Rio de Janeiro). According to the electronic website Ministry of the Environment, 663 (six hundred and sixty-three) kilometers of rivers and streams were affected, 1,469 hectares (one thousand, four hundred and sixty-nine) hectares of vegetation were committed, 207 (two hundred and seven) (two hundred and fifty one) buildings ended up buried only in the district of Bento Rodrigues.

This episode represented the greatest environmental catastrophe in the history of Brazil, one of the most impacting in the world, bringing environmental consequences in the human, water, soil, fauna and flora of the region directly and indirectly affected. In view of this scenario, the Minas Gerais State Public Prosecutor's Office (MPMG) initiated several measures aimed at mitigating environmental damage and preventing further deterioration and further disruption of the remaining structures.

The rupture of the dam and the consequent release of tailings sludge brought as one of the main environmental consequences the increased turbidity of the water along the Rio Doce and its tributaries. Technical Reports of the environmental impacts published by IBAMA (Brazilian Institute of the Environment and Renewable Natural Resources) report that thousands of fish and other animals have died, including endemic and other species in the list of endangered animals.

Bento Rodrigues, a district with 317 years of existence and the first to be reached, housed centennial churches with important sacred works and monuments of notable cultural relevance, as well as being part of the Estrada Real route in the 17th century. The rupture of the dam, in addition to the loss of human life, whose values are incalculable, destroyed a whole historical and cultural heritage, built over centuries.

According to the Activity Report of the MPMG (2016) task force regarding measures related to environmental safety and downstream communities, it was possible to verify, after several technical and expert analyzes, that by the year 2016, the company Samarco Mineração SA was preparing for the reactivation of the mining operations, without, however, taking any

measure to contain the environmental damages and for the security of the structures of the enterprise. The report then emphasizes that the mining company Samarco, prior to the publication of this document, prioritized the resumption of its mining exploration and mining activities to the detriment of effective compensation and compensation for the environmental damages caused.

2. OBJECTIVES

2.1 General objectives

To evaluate the environmental and socioeconomic impacts caused by the elimination of the rupture of the Fundão dam in the district of Bento Rodrigues, in the municipality of Mariana-MG.

2.2 Specific objectives

- To show the changes caused in the region where the dam was broken;
- List the impacts caused on the aquatic environment, soil, fauna and flora as a consequence of the rupture of the Fundão Dam;
- Look for current legislation regarding the parameters most affected and compare them with the observed results;
- Evidence of the results found by the studies that monitor the situation of the means affected by the rupture of the dam;
- Perform the socioeconomic diagnosis of the region before, immediately after the accident and current;
- To show the most significant socioeconomic consequences of the accident.

3. ENVIRONMENTAL IMPACTS

According to (SÁNCHEZ, 2008), environmental impact is the alteration of the environmental quality that results from the modification of natural or social processes resulting from human activities, mainly related to economic ones. Activities that move the economy today, such as agriculture, transportation, energy and mining are responsible for generating environmental and socioeconomic impacts across the globe.

Mining, of course, has significant environmental impacts, both in the affected region and downstream of the site where the mine was installed, with the possibility of discharging dams, contamination of the region's soil, water resources, plant suppression and of the region where the activity is carried out. Dam disruptions are mainly a consequence of large mining activities in Brazil and around the world. The factors that can be the causes of this type of disaster are: the occurrence of a natural phenomenon, in which there is the shaking of the structure and also the human failures associated with bad planning, errors of calculation, use of inadequate materials in construction.

The most recent case and considered to be the greatest environmental disaster occurred in Brazil, occurred on November 5, 2015, due to the rupture of the retention structure at the Fundão dam in Mariana (MG), operated by Samarco, where about 34 million cubic meters of tailings from mining in the region, causing impacts on soil, water courses, fauna and flora (IBAMA, 2015).

3.1 Environmental impacts on water

The disruption of the Fundão and Santarém dam, on November 15, 2015, resulted in the release of approximately 34 million cubic meters of waste in the environment, reaching Permanent Preservation Areas (APP), causing a change in the quality of the courses. (especially fish and invertebrates), mainly due to the amount of sediments that were available in the water column (IBAMA, 2015). The environmental implications associated with the increase in the solids load present in the waters of the Doce River are immense.

Initially, it should be pointed out that several localities in the States of Minas Gerais and Espírito Santo were forced to stop water abstraction from the Doce River. This interruption caused situations of water crisis in large cities, such as Governador Valadares (MG) and Colatina (ES), for example. The excess turbidity may have caused the deaths of thousands of fish and other aquatic organisms at first. Then, the fall in photosynthetic activity of algae and other aquatic plants may have compromised the functioning of the entire food chain. The high solids content may also favor the increase and / or maintenance of concentrations of other pollutants and toxic elements in the water and further increase the eutrophication already present in some stretches of the river (COELHO 2015).

As a result of this disruption, the IGAM intensified the monitoring that had already been carried out in the basin on the day following the accident, through the elaboration of an emergency monitoring plan for the water quality of the main bodies of water affected by the disaster. The parameters were selected to evaluate the possible alterations of the water bodies as a function of the characteristics of the tailings and of the dragging capacity of the bottom material with the displacement of the plume, being: electrical conductivity, dissolved aluminum, total arsenic, total cadmium , the total lead, dissolved copper, total chromium dissolved iron, total manganese, the total nickel, dissolved oxygen, pH, total solids, total dissolved solids in suspension, total solids, temperature, turbidity, and total zinc (IGAM, 2016).

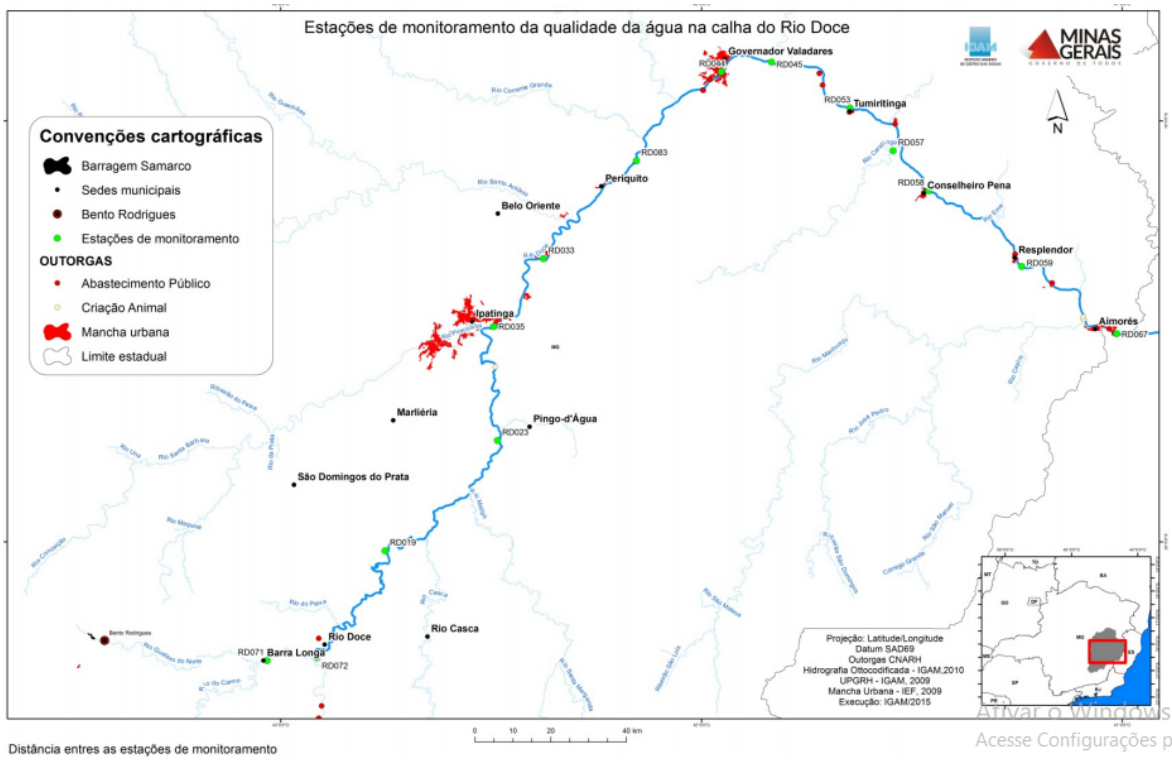
In order to facilitate the visualization of the effects caused on the quality of the waters after the dam of Fundão Dam, the IGAM adopted the division of the region into four sections with different levels of impact analyzed (Table 1, Figure 1).

Table 1: Description of the monitoring stations evaluated in the Doce river and their respective groupings.

Stretch	Description	Stations
1º stretch: Tributaries of the River Doce	Impacted tributaries of the Doce river, namely: Gualaxo do Norte river and Carmo river.	RD011 e RD071
2º stretch: Amount of Candonga	Initial stretch of the river Doce, which runs from its conformation to the dam of Candonga.	RD072
3º stretch: Candonga-Baguari	Excerpt from the Doce River, downstream from the Candonga Dam to the Baguari Dam.	RD019, RD023, RD035, RD033, RD083
4º stretch: GV-Aimorés	Excerpt from the river Doce, downstream of the Baguari dam, which goes from Governador Valadares to Aimorés, before the mouth to the State of Espírito Santo.	RD044, RD045, RD053, RD058, RD059 e RD067

Source: IGAM, 2016.

Figure 1: Water Quality Monitoring Stations in the Rio Doce Channel.



Source: IGAM, 2016.

According to the data provided by IGAM, one year after the precipice dam breaking - 2015/2016, the parameters of the results from November 2015 to October 2016, show very high values at the beginning of monitoring, because of the passage of reject pen, with tendency of reduction over time. This reduction, perceived November 2015 to October 2016, was due to the

rainy season, with a relative stabilization in the dry season in values closer to those seen before the event, arising from historical series of monitoring IGAM. The averages of the October 2016 results are above the legal limit for turbidity, dissolved aluminum and total manganese parameters in at least one of the stretches. In relation to heavy metals and arsenic full, the maximum value obtained indicates that all the passages presented results in accordance with Class 2 limit, except the total lead parameter in the first stretch.

The Rio Doce Bulletin, which aims to provide up-to-date information on the rivers affected by the rupture of the Fundão Dam, in order to update the society about the condition of these rivers during the rainy season (started in November 2016), reported that the values of turbidity in December 2016 (Figure 2) were all above the legal limit (100 NTU-Nephelometric Turbidity Unit), and more current data from the bulletin for September 2017 (Figure 3) reported that values turbidity are below the legal limit in most stations in the dry season 2017 except the stations of Rio Casca municipalities, Marliéria and Ipatinga.

Frame 1. Turbidity results in December 2016 at the collection points of IGAM / MG and IEMA / ES.

ESTAÇÃO	DESCRIÇÃO	DATA DE AMOSTRAGEM	*RESULTADO (NTU)
RD011	Rio Gualaxo do Norte próximo de sua foz no rio do Carmo	19/12/2016	958
RD071	Rio do Carmo em Barra Longa	19/12/2016	344
RD072	Rio Doce no município de Rio Doce	19/12/2016	452
RD019	Rio Doce entre os municípios de Rio Casca (MG) e São Domingos do Prata	20/12/2016	521
RD023	Rio Doce entre os municípios de Marliéria e Pingo D'Água	20/12/2016	445
RD033	Rio Doce no município de Belo Oriente	20/12/2016	459
RD035	Rio Doce no município de Ipatinga	20/12/2016	485
RD044	Rio Doce na cidade de Governador Valadares	21/12/2016	507
RD045	Rio Doce a jusante da cidade de Governador Valadares	21/12/2016	369
RD083	Rio Doce logo a jusante do município de Periquito	20/12/2016	477
RD053	Rio Doce no município de Tumiritinga	21/12/2016	398
RD058	Rio Doce no município de Conselheiro Pena	21/12/2016	492
RD059	Rio Doce no município de Resplendor	21/12/2016	528
RD067	Rio Doce no município de Aimorés	21/12/2016	608
RD057	Rio Caratinga no Distrito de Barra do Cuieté	14/12/2016	741
IEMA	Rio Doce em Colatina (ES)	20/12/2016	1089
IEMA	Foz- Regência (ES)	19/12/2016	1000

* DN Joint Copam / CERH-MG nº 1/2008 - Turbidity Limit 100 NTU - Nephelometric Turbidity Unit.
Source: Informative River Doce, 2016.

Frame 2. Turbidity results in September 2017 at the IGAM / MG collection points.

Estação	Data de Implantação	Corpo de Água	Município	Pré-rompimento da Barragem Fundão (Série Histórica)			Pós-rompimento da Barragem Fundão	
				Mínimo	Média	Máximo	Máximo	Resultados Atuais SETEMBRO/IGAM
RD011	25/11/2015	Rio Gualaxo	Barra Longa	-	-	-	32.510	12,2
RD071	29/05/2008	Rio do Carmo	Barra Longa	1,85	65,89	744	32.848	6,04
RD072	28/05/2008	Rio Doce	Rio Doce	0,5	57,09	604	435.400	6,73
RD019	29/07/1997		Rio Casca	2,71	51,63	318	597.400	**226,0**
RD023	03/08/1989		Marliéria	2,24	52,05	310	606.200	**476,0**
RD033	30/07/1997		Belo Oriente	3,08	68,01	955	497.500	57,5
RD035	14/12/1999		Ipatinga	2,56	61,15	382	334.600	**135,0**
RD083	28/04/2008		Periquito	3,48	42,66	537	21.480	19,0
RD044	14/12/1999		Governador Valadares	2,56	58,55	794	140.000	7,02
RD045	04/08/1989		Governador Valadares	0,5	63,48	797	81.440	6,16
RD053	31/07/1997		Tumiritinga	2,37	62,17	560	74.160	4,78
RD058	15/12/1999		Conselheiro Pena	2,72	62,89	417	89.220	4,21
RD059	15/12/1999		Resplendor	3,28	70,32	764	28.500	5,27
RD067	15/12/1999		Aimorés	2,16	60,82	540	10.050	7,32

* Bold values - results above the limit of the classification class Resolution CONAMA 357/2005 (100 NTU - Nephelometric Turbidity Unit).
Source: Informative Doce River, 2017.

The research and monitoring cruise with the support of the Soloncy Moura Research Ship of CEPSUL / ICMBio also analyzed samples of water contaminated with the mud between January and February 2016 to identify the concentrations of metals (total or dissolved) , and compare with the limits allowed for Class I waters, as defined by Resolution 357, of March 17, 2005, of the National Environmental Council - CONAMA. The collection points were carried out in the following areas:

- APA Algae Coast and REVIS of Santa Cruz: samples of water and biological material were collected at two collection points (CA1 and CA3);
- EBIO Trains - Foz do Rio Doce: samples of water and biological material were collected at six collection points (RD1, RD3, RD6, RD8, RD9 and RD10);
- Barra Nova / São Mateus: samples of water and biological material were collected at two collection points (BN1 and BN2);
- Abrolhos Region: samples of water and biological material were collected at three collection points (AB1, AB2 and AB4).

The results of the research and monitoring cruise analyzes with the support of the Soloncy Moura Research Ship of CEPSUL / ICMBio, detected concentrations of metals above those permitted by legislation for water samples from the following collection points (Table 2):

Table 2: Metal concentrations and their compliance with legislation.

Bodies of water where there is fishing or cultivation of organisms for intensive consumption purposes:	
MAV* (CONAMA 357)	**Results**
Total Arsenic = 0,14 µg/L	All collection points are analyzed in NO CONFORMITY with current legislation, with concentrations ranging between 0.23 and 4.77 mg / L.
Class 1 water, in compliance with CONAMA Resolution N°. 274/2000; protection of aquatic communities; aquaculture and fisheries):	
MAV (CONAMA 357)	**Results**
Total Arsenic = 10 µg/L	As water samples from all collection points are in compliance with current legislation, with concentrations ranging from 0.23 to 4.77 µg / L.
Total Cadmium = 5 µg/L	Water samples from the following collection points are in NO CONFORMITY with current legislation: RD1, RD3, RD10, AB4, BN1 and BN2. The total concentrations of Cd at the different collection points varied between 0.81 and 17.02 µg / L.
Total Lead = 10 µg/	As water samples from all collection points are in NO CONFORMITY with current legislation, except that collected without point AB2, which features an exciting average of 9.42 mg / L, which is very close to the maximum concentration allowed by law. As total Pb concentrations at the different collection points varied between 9.27 and 130.40 µg / L.
Total Chromium = 50 µg/L	As water samples from all collection points are in compliance with current legislation, with concentrations ranging from 0.12 to 16.45 µg / L.
Total Manganese = 100 µg/L	Water samples from all collection points are in compliance with legislation, with concentrations ranging from 1.33 to 14.00 µg / L.
Copper Dissolved = 5 µg/L	Water samples from the following collection points are NO CONFORMITY with current legislation: RD1, RD8, RD10 and AB1. The concentrations of Cu dissolved in the different collection points varied between 0.41 and 47.52 µg / L.
Dissolved Iron = 300 µg/L	Water samples from all collection points are in compliance with legislation, with concentrations ranging from 18.59 to 239.96 µg / L.

* Maximum Allowed Value.

Source: Adapted ICMBio / Coral Live Project 2016.

The effects of the accident on water quality occur throughout the watercourse, from the site of dam rupture, through the Gualaxo do Norte River, the Carmo River and the Doce River, as well as some of its smaller volume tributaries, to the delta of Doce River, on the coast of Espírito Santo (State Government of Minas Gerais, 2016). At the microregional scale, the sedimentation of the Gualaxo do Norte and Carmo Rivers is highlighted, as well as a stretch of 12 km within the Doce River, up to the dam of UHE Candonga. Since the accident until April 2016, there has been a continuous process of sediment transport and deposition in the waterways.

This soil erosion is greatly enhanced by the deposit of material from the mining sludge adjacent to the water course. In this way, the river beds continue to be permanently silted and lose their natural ability to transport suspended particles towards their mouths. The pellet material on the banks of the rivers has led, also, water supply problems, both for production purposes as well as for human and animal consumption (BELT; Magalhaes, 2016).

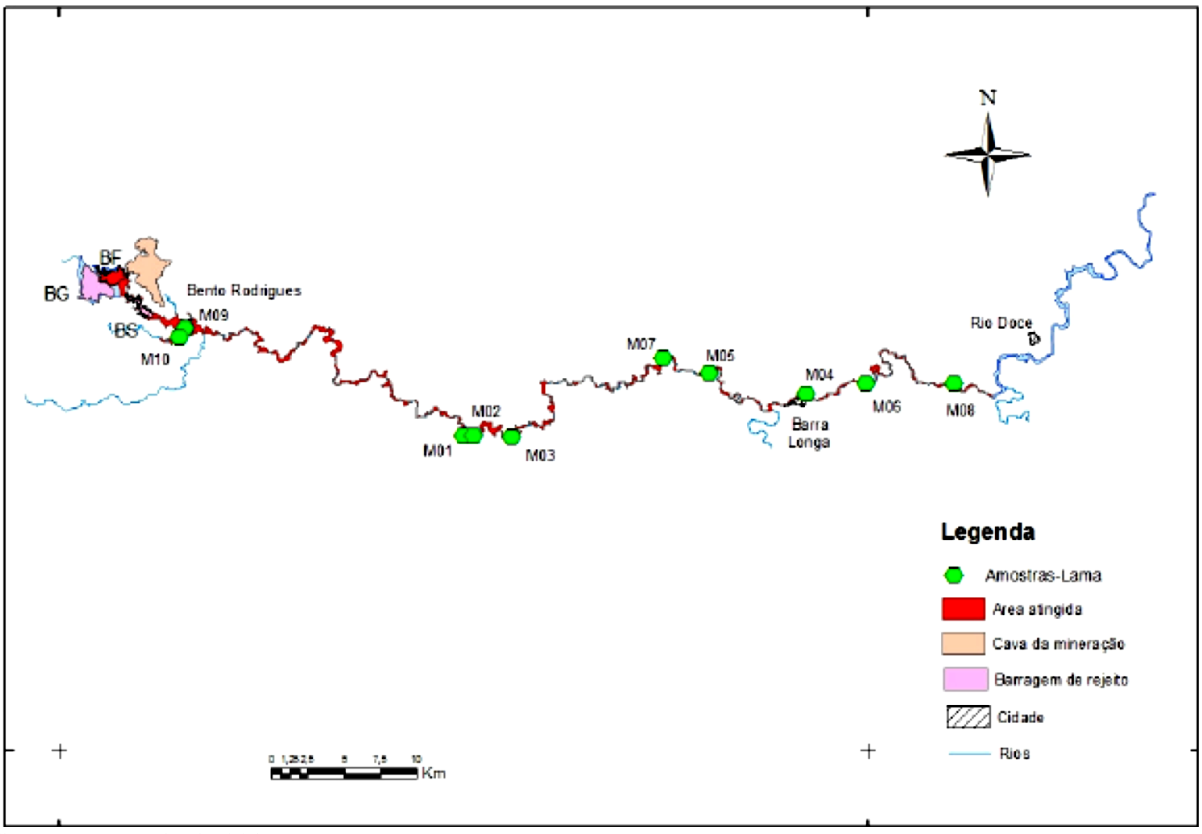
In addition to the impacts caused in the Rio Doce Basin, when it reaches the sea, the mud may also have potentially directly or indirectly affected marine life in the coastal region of Espírito Santo and Bahia. In the coastal region in question, there are several areas of Conservation Units in their surroundings, areas of focus of action plans, between the north of Espírito Santo and the south of Bahia, such as: APA Costa das Algas, RVS Santa Cruz, REBIO Trains, RESEX Cassurubá and PARNA Marinho dos Abrolhos (ICMBio-MMA / CORAL VIVO PROJECT 2016).

3.2 Environmental impacts on the soil

The deposition of the mud on the soil of Bento Rodrigues - MG generated a remodeling of the relief, either by deposition in lower areas or soil revolting and even rock breakage. Considering that rocks are one of the main factors of soil formation, its repositioning can cause several changes in the local environmental dynamics. According to the Final Report of the Task Force (MINAS GERAIS, 2016), there were generally changes in floodplain, flood plains and colluvial areas; in the line of the talvegue, causing in changes in the course of the river and, consequently, in the fluvial dynamics; and in the occurrence of ravinamento, which intensified the erosive processes, especially in the rainy periods.

Embrapa Solos (EMBRAPA, 2015) evaluated the contents of chemical and metallic compounds present in the sedimentated material from the tailings dam at several collection points along the valley of the rivers affected (Figure 2). It should be pointed out that the results indicate lower values than those adopted as reference for the evaluation of contamination of metals in the soil, according to CONAMA (2009).

Figure 2: Sediment sampling sites along the valley of the affected rivers.



Source: EMBRAPA, 2015.

The results obtained in relation to the physical quality of the soil indicated granulometric homogeneity of the deposited materials, as high levels of fine sand and silt (grain size less than 2 mm) in 90% of the soil fraction. The clay content represented only 10% of this total fraction, significantly reducing the cation exchange capacity (CTC) of the soil (CORREIA; MAGALHÃES, 2016; EMBRAPA, 2015). Considering that the CTC corresponds to the total number of cations that a soil is capable of withholding, due to the amount of its negative charges, it is understood that the CTC reduction of the analyzed soil indicated the low fertility of the soil (MATOS, 2017).

It was also observed a high density of the particles after drying, this suggests a physical barrier of high intensity (ferruginous concretions) and low porosity, preventing the infiltration and root growth of the plants and, consequently, difficult the recovery of the affected areas. However, ferruginous concretions are only surface formations, keeping the bottom of the sludge as unconsolidated material and thus exposing the soil to erosion. In addition, a high concentration of iron was observed in the analyzed soil samples, which also contributes to the surface hardening and consequent impediment of root growth of species, reforestation and agricultural reuse (EMBRAPA, 2015; MINAS GERAIS, 2016).

The chemical quality of the soil samples presented low values for the main nutrients of the soil (N - Nitrogen, P - Phosphorus and K - Potassium), proving the soil fertility compromise. It should be noted that local areas were classified, prior to the accident, as eutrophic, that is, naturally fertile soils. Carbon contents lower than 0.1% were observed, indicating a low amount of organic matter present in the soil, again compromising CTC. It was also verified that the hydrogen ionic potential (pH) of the soil presented extremely acidic values. Thus, corrective measures are necessary in relation to soil pH and the introduction of organic material for the recovery process of degraded areas (EMBRAPA, 2015; MINAS GERAIS, 2016).

3.3 Environmental impacts on wildlife

The tailings mud stream from the breeding of the Fundão Dam severely compromised the local fauna. The ichthyofauna was the worst affected by the environmental disaster. The fish mortality with the impact of the mud avalanche throughout the Gualaxo do Norte, Carmo and Doce Rivers. In addition, IBAMA (2015) suggests that many fish died of asphyxiation due to the increased turbidity of the water, which prevents the penetration of sunlight. Some endemic species may have been extinct, or are at the highest risk of extinction (Table 3).

Table 3. Threatened species of the Rio Doce River Basin.

Species	Category
Brycon devillei (Castelnau, 1855)	EN
Henochilus wheatlandii (Garman, 1890)	CR
Hypomasticus thayeri (Borodin, 1929)	EN
Microlepidogaster perforatus (Eigenmann & Eigenmann, 1889)	CR
Pareiorhaphis mutuca (Oliveira & Oyakawa, 1999)	EN
Pareiorhaphis nasuta (Pereira, Vieira & Reis, 2007)	CR
Pareiorhaphis scutula (Pereira, Vieira & Reis, 2010)	EN
Prochilodus vimboides (Kner, 1859)	VU
Rachoviscus graciliceps (Weitzman & Cruz, 1981)	EN
Steindachneridion doceanum (Eigenmann & Eigenmann, 1889)	CR
Xenurolebias izecksohni (Da Cruz, 1983)	EM

CR – Critically endangered; EN – In danger; VU – Vulnerable

Source: IBAMA, 2015.

Impacts on ichthyofauna resulted in habitat destruction, destruction of fish breeding areas and replacement nursery areas (larval and juvenile feeding areas), alteration and impoverishment of the trophic chain, impairment of fish stocks, among others. The impact is even greater, since at the time of the disaster, fish and crustaceans were in the breeding season.

The ICMBio / Vivo Coral Project (2016) observed in its analysis a pattern of body bioaccumulation of metals in zooplankton at the collection points closest to Mouth of Doce

River. It was also found that in most of the muscle samples of the analyzed fish (crustaceans and fish), the levels of contamination are above the limits permitted by current legislation (Resolution of the Collegiate Board of the National Agency of Sanitary Surveillance RDC No. 42, August 2013), which provides for the MERCOSUR Technical Regulation on "Maximum Limits of Inorganic Contaminants in Foods".

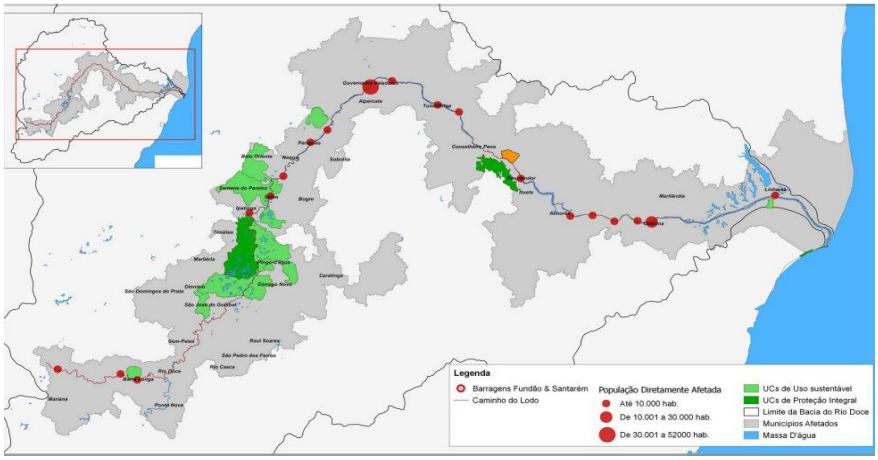
The birdlife was also severely hampered by the environmental disaster. The consumption of dead fish by mud can lead to the intoxication of birds, interfering in their reproduction with the bad formation of eggs and the involvement of organs and structures responsible for the reproduction of the species (MINAS GERAIS, 2016). There was also a compromise in the migratory flow of birds, leading to the scaring of the species and the search for new spaces for habitat and reproduction. The endemic species of the region are *Todirostrum poliocephalum* (Teque-teque) and *Tangara cyanoventris* (Saira-douradinha) (IBAMA, 2015).

In relation to the mastofauna, IBAMA (2015) reports that populations of fossorial and small animals were decimated in those places where the banks of the watercourses were taken by the tailings mud. However, the essence of the impact on the mastofauna is defined in the capacity of restricted locomotion and in the difficulty of watering the species of the region due to the tailings mud being concentrated near the margins and in the own waterways.

3.4 Environmental impacts on the flora

The Rio Doce Basin is predominantly part of the Atlantic Forest biome, which accounts for only 15% (19,676,120 ha) of its original cover (COELHO, 2015). The swarm of 34 million cubic meters of tailings from the rupture of the Fundão Dam has resulted in the destruction of the vegetation cover of an area of 1,587 ha, of which 511.08 ha is from the Atlantic Forest, to the mouth of the Rio Doce (Figure 3) (SILVA; FERREIRA; SCOTTI, 2015).

Figure 3. Vegetation cover affected by the rupture of the Fundão dam.



Source: BBC Brasil, 2015.

Due to the rupture of the Fundão dam, there was a devastation of approximately 374.81 ha of riparian forest cover (Figure 4) and APPs and, due to the contribution of sediments (waste sludge from the iron ore exploitation), buried the species and suppressed arboreal individuals (MINAS GERAIS, 2016; CORREIA E MAGALHÃES, 2016).

Figure 4. Devastation of the riparian forest due to the rupture of the Fundão dam.

Source: IBAMA, 2015.

With the firing of trees by the force of the tailings mud wave and the sedimentation of the mud on the litter and its seed banks, the gallery forests affected by the disaster had their

resilience and succession processes compromised. However, the natural recovery of each stretch will depend on its specific resilience (the ability of a disturbed / degraded ecosystem to naturally return to its original characteristics, or as close as possible, without human intervention) (CORREIA; MAGALHÃES, 2016).

According to IBAMA (2015), the most endangered species at the site of the environmental disaster are: *Dalbergia nigra* (jacarandá-cabiúna), *Melanoxylon brauna* (braúna) and *Euterpe edulis* (palmito), all in the vulnerable category, as shown in Figure 5, respectively.

Figure 5. Threatened plant species that were in the vegetation cover devastated by tailings mud.

Source: MELO, 2017.

4. SOCIOECONOMIC IMPACTS

4.1 Socioeconomic diagnosis before the disaster

Located in the state of Minas Gerais, in the southeastern region of Brazil, Bento Rodrigues was a small sub-district of the municipality of Mariana (Figure 1). With an estimated population of 600 inhabitants in 2015 (BRAZIL, 2015) and very modest characteristics, the sub-district was an important center of mining activities in the eighteenth century.

Figura 6. Location of Bento Rodrigues, on map.

Source: G1.com

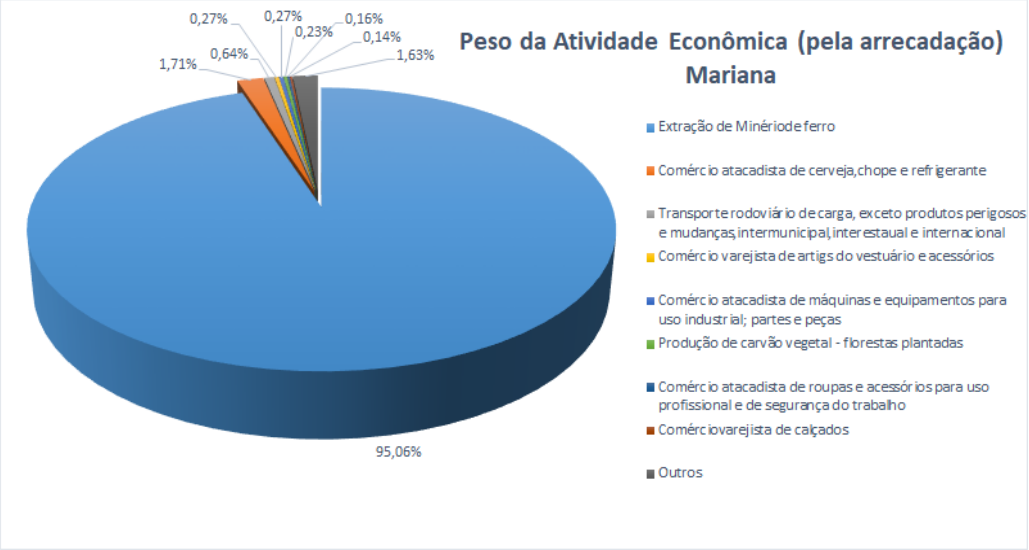
According to Lopes (2016), Bento Rodrigues was a district with 317 years of existence, and possessed a majestic history and worthy of pride among its citizens. It housed centenary churches with important sacred works and monuments of notable cultural relevance.

With a little diversified economic system, Mariana's micro-region is highly dependent on mining, with a small share of agricultural activity and small trades (Chart 1) (MINAS GERAIS, 2016).

The graph shows the economic fragility of the region, due to the small variety of sectors and the large mining sector, since approximately 95% of the economic activity of the municipality is represented by the extraction of iron ore. However, according to the Report of the Task Force (MINAS GERAIS, 2016), it is important to emphasize the presence of other mining companies in the municipality besides Samarco, such as Vale, a fact that must be taken into account in the figures referring to the collection of activity in the municipality.

In addition to mining, the local economy is also driven by tourism and small businesses. According to a survey carried out in 2016 by the Task Force at the Trade Council of Minas Gerais - JUCEMG, regarding the activities registered in Bento Rodrigues, in the sub-district were micro-enterprises of the retail trade sector, related to horticultural products, food and drinks. There is also the registration of a small factory and specialized business consulting activity.

Graphic 1. Main economic activities in Mariana-MG.



* Note: elaboration by the team of the Subsecretaria de Investimentos Estratégicos / SEDE - aggregated information of the municipal collection for the period between January of 2013 and November of 2015 *.
Source: Secretaria de Estado de Fazenda de Minas Gerais (2015) apud Minas Gerais (2016).

4.2 Socioeconomic diagnosis immediately after the accident

The disruption of the Fundão Dam in Mariana led to the destruction of the sub-district, leaving 19 dead, more than 600 homeless, and thousands of people without water. This has compromised the services of water supply and the collection of municipalities resulting from the interruption of economic activities dependent on this resource (MINAS GERAIS, 2016).

The effects of the rupture of the dam extended to 35 cities of Minas Gerais and three of Espírito Santo, Brazil. In addition to the socio-economic impact, the mud caused a great loss in the diversity of fauna and flora, accounting for more than 11 tons of dead fish, threat of extinction for many species and destruction of natural habitats (MINAS GERAIS, 2016). According to NBR 10.004, the waste is classified as non-hazardous and non-inert, such as iron and manganese, resulting in a composition consisting primarily of sand and metals.

The Minas Gerais Government established a Task Force, Decree nº 46.892 / 2015, as an alternative to quantify and qualify disasters resulting from the disruption of the Fundão and Santarém dams (Figure 7). The regional economy was largely affected, from the interruption of the mining activity, with emphasis in the municipality of Mariana, to agricultural activities, being interrupted due to the damage caused by mud (MINAS GERAIS, 2016).

Figure 7. a) e b). Area affected by the rupture of the dam in Mariana.

Source: Magazine Publicitta (Antonio Cruz/Agência Brasil).

(a) **(b)**

As already mentioned, a large part of the economic activities in Mariana are related to the Samarco mining company (approximately 95%), and there are other companies, such as Vale, which have several mines for the exploitation of iron ore. Therefore, the analysis of the stoppage of the mining activity should not be linked only to the suspension of Samarco activities, but also to the fall in the price of iron ore in the international market and, consequently, fall in the price of the commodity (MINAS GERAIS, 2016).

Among the economic activities that had suspended their operations should be emphasized Samarco, HPP Risoleta Neves Rio Doce and small industries present in the districts, as an example Biquinho pepper jelly factory in Bento Rodrigues. The District, because it was lacking in the presence of companies and industries, was largely affected by the disaster. The most notorious example of the microenterprise affected was the Pimenta de Biquinho jelly company, which, although the processing unit was not reached, went through a process of loss of the raw material and, consequently, had its entire production process suspended (MINAS GERAIS, 2016).

Frame 3 shows the microenterprises that were registered by the Commercial Junta of Minas Gerais (JUCEMG) in the districts of Paracatu de Baixo and Bento Rodrigues.

Frame 3. Micro-enterprises registered.

Distrito	Início das atividades	Enquadramento	Atividade econômica
Bento Rodrigues	03/01/2002	Microempresa	Venda de produtos alimentícios
Bento Rodrigues	01/03/2013	Microempresa	Comércio de hortifrutigranjeiros
Bento Rodrigues	24/02/2014	Microempresa	Fabricação de produtos diversos
Bento Rodrigues	20/05/2014	Microempresa	Lanchonetes, casas de chá e sucos
Bento Rodrigues	01/10/2002	Microempresa	Comércio varejistas de bebidas
Bento Rodrigues	01/02/2008	Microempresa	Atividades de consultoria em gestão empresarial
Distrito Paracatu	01/04/2002	Microempresa	Bares e outros estabelecimentos

Source: Report of the Commercial Board of Minas Gerais.

Human damages are counted in categories of dead, injured, sick, homeless, homeless, missing and others affected. According to Frame 4, it is possible to see the magnitude of the dam disaster, being more than 300 thousand people in the affected macro-region.

Frame 4. Human damages in the macroregion affected by the accident (February 2016).

Atingidos pela barragem	Danos humanos diretos e indiretos							
	Mortos	Feridos	Enfermos	Desabrigados	Desalojados	Desaparecidos	Outros Afetados	Total de Afetados
Aimorés	-	-	-	-	-	-	12.000	12.000
Belo Oriente	-	-	-	-	-	-	10.000	10.000
Bugre	-	-	-	-	-	-	300	300
Caratinga	-	-	-	-	-	-	38	38
Conselheiro Pena	-	-	-	-	-	-	-	46
Galileia	-	-	100	-	-	-	-	100
Governador Valadares							275.000	275.000
Ipaba	-	-	-	-	-	-	1.000	1.000
Resplendor	-	-	-	-	-	-	12.660	12.660
Total	0	0	100	0	0	0	310.998	311.144

Note: According to civil defense, the category other affected are those harmed in some way by the disaster directly or indirectly. Of particular note are those affected in the municipality of Governador Valadares, 275 thousand people affected by the interruption of water supply.

In Mariana and the region alone, approximately 329 homeless families living in houses rented by Samarco have been counted, and it is estimated that approximately 1265 people were allocated to hotels and inns in the region.

Less than a week after the accident, Bento Rodrigues was isolated and had all his access blocked by military police. Initially, the safety zone was three kilometers, but was increased to ten kilometers. The justification for this was the possibility of a new breach of the Germano dam, which he had cracked. According to Lieutenant Nogueira of the Military Police, the city of Bento Rodrigues was doomed for at least 30 days (VALE, 2015).

The Voluntary Service of Social Assistance (Servas) worked with the Task Force, which was determined by the governor of Minas Gerais, and also with the Public Prosecutor's Office to provide assistance to affected families. Servas was responsible for receiving donations (water, toiletries and food). In addition, the Secretary of State for Labor and Social

Development (Sedese) set up a joint effort to replace the lost documentation. Specifically, the mutirão was responsible for civil registration actions, such as issuance of identity cards, among other services (MINAS GERAIS, 2016).

According to data presented by the mayor of Mariana, Duarte Jr., after a month of the accident occurred, the unemployment rate rose from 300 people to 3 thousand people, in a city with a population estimated at 59 thousand people. Still in the wake of his testimony, given a month after the tragedy, Mayor Duarte Jr. thought it essential to reduce dependence on the mining activity, so as to avoid further consequences of the rupture of the dam (VALE, 2015).

One month after the tragedy, the punishments applied to the mining company totaled R $ 23.2 billion, equivalent to nearly ten times the Samarco net profit in 2015 (CRUZ, 2015). The highest bill comes from the Federal Government, through a public civil action that requested R $ 20 billion from the company only for the recovery of Rio Doce. In addition, the mining court charged R $ 1 billion reais, through the Public Prosecutor's Office of Minas Gerais, an amount to be used to guarantee the beginning of recovery of degraded areas. Finally, Samarco was fined R $ 250 million by IBAMA and R $ 112 million by SEMAD (State Secretariat for the Environment and Sustainable Development) (CRUZ, 2015).

In March 2016, a foundation was created called the Renova Foundation, with the objective of repairing the damage caused by the rupture of the Fundão dam. The Foundation was established through a Transaction and Adjustment of Conduct Agreement (TTAC), signed between Samarco, Vale and BHP Billiton, the Federal Government, and the governments of the states of Minas Gerais and Espírito Santo, as well as a series (such as Ibama, Chico Mendes Institute for Biodiversity Conservation (ICMBio), National Water Agency (ANA), State Forestry Institute (IEF), Funai, Secretariats of the Environment, among others), in March 2016 (FUNDAÇÃO RENOVA, 2017).

The Mediated Indemnity Program (PIM), created by the Renova Foundation, aims to reimburse those affected by the damages caused by the rupture of the Fundão dam. The initial phase consists of an indemnity of R $ 1,000 per adult resident in the same house, in addition to R $ 1,100 for people over 60, with special needs, pregnant women or children under 12 years, living in the same residence. The expectation of the Renova Foundation is to indemnify about 280 thousand people in up to seven months. However, in order to have access to this indemnity, the citizen must cancel any lawsuit he or she has initiated against Samarco, considering that the indemnity amounts cover all damages that have been suffered (FUNDAÇÃO RENOVA, 2017).

4.3 Current socioeconomic diagnosis

After two years of the breakdown of the Fundão Dam in Mariana, it is observed that as social and economic situations are unfavorable for a population of Mariana and for the former residents of Bento Rodrigues.

Regarding the economic situation, Mariana has a high number of unemployed (about 15,000 people), and the city has approximately 60,000 inhabitants (IBGE, 2017). The paralysis of SAMARCO's activities, in addition to the decrease in VALE's production, provoked this scenario, since Mariana is a city with a strong economic dependence on mining activity. This fact has caused an uprising in Mariana's population, since quality standards and ways of life have changed in a negative way (Personal communication, 2017).

The Renova Foundation has as project to take to Mariana different projects of the mining with the intention to break this dependency and to improve the current economic situation. As quality and ways of life have changed in a negative way, which has caused a revolt in the population, the anxiety for SAMARCO to start working again is great (Personal communication, 2017).

It is seen that, currently, the former residents of Bento Rodrigues (approximately 600) live in apartments, and are distributed in different districts of Mariana. According to Stopa, a member of the Civil Defense of Mariana, the Renova Foundation pays the families rent, a basic basket, a minimum wage, 80% of the electricity bill and 20% of the minimum wage per dependent. In addition, the state prosecutor's office has been working too hard to guarantee the rights of the affected community. Still according to Stopa, the Renova Foundation contracted, at the request of the State Public Ministry, a consulting firm to oversee matters regarding the rights of the affected community of Bento Rodrigues. Thus, Caritas was hired to perform this function.

So far no family affected by the accident has been compensated. However, it is known that there are 350,000,000 million reais blocked for this purpose (Personal communication, 2017).

The District of Bento Rodrigues is compromised, being unfeasible the permanence of people to live (Figure 8). According to coach Stopa, former residents have access to the affected area on Wednesdays, Saturdays, Sundays and holidays from 8:00 am to 6:00 pm. Approximately 30 residents visit Bento Rodrigues on a constant basis.

Figure 8. a) e b) Bento Rodrigues scenario two years after the accident.

Source: Own.

(a) **(b)**

There are still commemorative and religious celebrations held in the city, receiving in those times a greater number of former residents. With this, we realize that even after the tragedy, the essence and culture of the community was not lost. Bento Rodrigues owned a church, which represents a symbol of the community. Archaeological studies are underway for its recovery (Figure 9).

Regarding education, a school was built in a house for the community of Bento Rodrigues and Paracatu, maintaining the same organizational body of the existing school in Bento Rodrigues before the accident (Figure 10).

Figure 9. a) Fireworks for celebrations **b)** Bento Rodrigues Church two years after the accident

(a) **(b)**

Source: Own.

Unfortunately, it is seen that the children affected by the accident are discriminated against by the population of Mariana. Second (El Pais, 2016) these children are called "mud boys" by other colleagues.

Figure 10. **a)** School in Bento Rodrigues two years after the accident **b)** New school of Bento Rodrigues located in Mariana-MG.

(a) **(b)**

Source: Own.

In the corresponding micro-enterprises, according to Mariana Prefecture, the production of Biquinho pepper jelly was resumed in early 2016, in a neighborhood located in the city. However, there is no place for planting pepper, as it was done before the accident occurred (Renova Foundation, 2017). According to Keila dos Santos, whose testimony is available on the website of the Renova Foundation, jelly is very well accepted in the market because the workers took care of the whole process, from planting (without pesticide) to the final product. In addition, Keila claims that finding a place to plant in Mariana is difficult.

The reports of former residents of Bento Rodrigues have something in common: the dream of being able to live in a house, similar to the ones they lived before the accident occurred. It is observed that the inhabitants are accustomed to live in places that have space, close to nature (near Bento Rodrigues existed waterfalls), and in places favorable to have a vegetable garden, for example. And the new standard of living of these residents is different from the previous one (Personal communication, 2017).

The anxiety of these residents, who now live in apartments, is high to return to live in homes. There is a project underway by the Renova Foundation, which is expected to be

completed in 2019, with the objective of building a "new" Bento Rodrigues, that is, a location that will have similar physical characteristics to the District. Approximately 200 homes will be made for the residents affected by the accident. (Today, 2017). However, according to coach Stopa, there was a misconception in the choice of location due to this being 3 km from the landfill of Mariana.

Unfortunately, the feeling of humiliation is present among the former residents of Bento Rodrigues. According to Jose, a former resident, the affected population feels humiliated in the face of what happened, since they have lost memories, memories, community with the community (there are friends he has not seen since the accident occurred), besides existing several advocates to defend SAMARCO, not the population. In addition, João (another former resident) reported that the population of Mariana treats the former residents of Bento Rodrigues with disdain, placing the blame for the economic crisis of the City on them (Personal communication, 2017).

José says that too many promises are made, but he does not see the fulfillment of them, and that he believes that they will one day be fulfilled. Regarding the future, José hopes that someday the community will return to being as before. However, he assumes that this will not happen immediately, since two years of the accident happened and nothing was done. He states that rent payment, basic food basket and minimum wage is SAMARCO's obligation, not just a favor.

According to João, the community was not fully aware of the risks that existed with the presence of the Fundão dam. Despite the fact and the irreparable impacts caused, they want SAMARCO to work again, because they believe that Mariana depends on the venture to reestablish itself economically.

It is seen that the measures taken in favor of the community of Bento Rodrigues were insignificant taking into account all the social impact that the accident caused. The projects in progress, such as the construction of a "new" Bento Rodrigues, for example, if it is implemented, will be a progress for the former residents, rescuing the bonds of friendship and union between them, in addition to being able to resume a life similar to which they had before the accident.

5. CONCLUSION

Although current programs for the recovery of springs and the management of tailings are currently in progress, the horizon of forest recovery, according to experts, is at least a decade. In addition, the residents of Bento Rodrigues are still kept in rented premises, waiting to resume, as far as possible, routines close to those they had before the disaster.

The impacts listed in this report, despite being divided between environmental and socioeconomic, show the interdependence between the factors, which are directly related. It is possible, through the evaluation carried out, to understand that the impacts generated by the accident range from the loss of human lives, to the increase in the treatment of water supply to the population and to the degradation of fauna and flora.

Despite two years of this, the effects are felt in a variety of ways in the region. Economic activities have been hampered, the environment overly modified, and what has been done for compensation is still little compared to the damage done. The residents of Bento Rodrigues feel helpless, the fauna suffers with changes in the environment and the recovery of the environment remains a distant idea.

It is also important to emphasize the importance of the role of Public Authorities in the practice of mining activity. Its performance is paramount for the effective protection of the environment. Through public policies to control the use of natural resources, the appropriate punishment resulting from non-compliance with regulatory regulations and the education of the Brazilian people in favor of conscious consumption, the ecologically balanced environment can be effectively achieved.

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