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THE MARIANA/MG TRAGEDY AND THE VALUATION OF ECOSYSTEM SERVICES IN THE AREA ACHIEVED

A tragédia mariana / mg e a avaliação dos serviços de ecossistema na área alcançada

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Abstract: The present study presents the environmental valuation of the area affected by the mining company Samarco/Vale/BHP Billiton, due to the rupture of the Fundão and Santarém dams. The method chosen was Costanza, et al (1997), whose objective was to describe and estimate the main ecosystem functions and their natural capital on a planetary scale. The area affected was estimated by EMBRAPA (2016) in 1,430 hectares, where the value perceived by this methodology corresponds to R$ 578,058,795.18/year, which should be understood as the value of the ecosystem loss and natural capital of this territory.

Key words: Tragedy of Mariana; Valuation of Ecosystem Services; Environmental Ecologic and Economics.

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A TRAGÉDIA MARIANA / MG E A AVALIAÇÃO DOS SERVIÇOS DE ECOSSISTEMA NA ÁREA ALCANÇADA

The mariana/mg tragedy and the valuation of ecosystem services in the area achieved

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Resumo: O presente trabalho apresenta o resultado da valoração econômica e ambiental da área atingida pela mineradora Samarco/Vale/BHP Billiton, devido ao rompimento das barragens de Fundão e Santarém. O método escolhido foi o de Costanza, et al (1997), que teve como objetivo descrever e estimar as principais funções ecossistêmicas e seu capital natural em escala planetária. A área atingida foi estimada pela EMBRAPA (2016) em 1.430 hectares, onde o valor percebido pela metodologia neste estudo foi corresponde a R$578.058.795,18/ano, que deve ser compreendido como o valor da perda ecossistêmica e de capital natural deste território anualmente.

Palavras-chave: Tragédia de Mariana; Valoração dos Serviços Ecossistêmicos; Economia Ambiental e Ecológica.

ACEITO EM: 10/08/2019

1. INTRODUCTION

Since November 5, 2015 the mining based economy of Mariana city has never been the same. On this date, the Samarco Group (Samarco / Vale / BHP Billiton Group), one of the mining companies located in the municipality, had two of its tailing dams broken off (Fundão and Santarém), leading to the leakage, according to some estimates,between 55 to 80 million cubic meters (EMBRAPA, 2016, O GLOBO, 2016, TROCATE, & ZONTA, 2016). This figure made it the largest mine-related accident in the world, ahead of the tragedy that occurred in 2014 in Canada, where the disruption of the tailings dam at a copper-gold mine at Mount Polley released 25 million cubic meters of mud (KINROSS WORLD, 2014).

This accident, theme of this work, affected more than 660 km of water bodies; especially the rivers Gualaxo do Norte, Carmo and Doce, entering even more than 80 km² in the Atlantic Ocean. The fact that economic agents are exposed to social and environmental impacts that they do not choose characterizes the concept of "externality" and the use of land (infrastructure) is among the main concerns due to its negative effects on the environment (DEMIR et al. 2017). Thus, all this negative externality fell on the populations of Bento Rodrigues, Paracatu de Baixo and Barra Longa, main affected areas which became, overnight, an extension of the mining complex of Mariana (TROCATE & ZONTA 2016 : 7).

According to estimates by the State Forestry Institute (IEF, 2015), 1,430 hectares of vegetation cover were affected by the mud of the Fundão and Santarém dams, mainly covering the municipalities of Mariana, Barra Longa, Santa Cruz do Escalvado and Rio Doce as well as others localities, with emphasis on Rio Doce Channel and its riparian vegetation, totally destroyed. These territories doesn´t present conditions for the development of economic activities anymore, such as agriculture and livestock, due to soil infertility that will take years to regenerate (EMBRAPA, 2016).

This is not the first reject dam to be broken in the country. A greater environmental inspection to guarantee the constant monitoring of these companies is an alternative to these incidents. In this way, such a measure, is necessary in order to mitigate and even prevent further tragedies. Disasters such as Mariana's, stem from the irreversibility of limits, which according to Romero (2010: 9), arises from the second law of thermodynamics (law of entropy) as opposed to the first (on the transformation of matter), in which this idea makes no sense and on which is implicitly based conventional economic theory.

Since Minas Gerais has already had six dams broken off since 1986 (O TEMPO, 2015), the law of entropy in action can be perceived. To complement this, Cechin & Veiga (2010: 43) considers that the amount of matter and energy incorporated in final goods is less than that contained in the resources used in their production. Thus, part of the energy and the low entropy material immediately becomes waste in this case, characterized as tailings sludge.

In the context that Brazil has, according to the National Water Agency (ANA, 2015), 14,966 dams, of which 663 are for mining tailings and 295 for industrial wastes; but only 402 of these has regular inspection is fundamental that studies like this are made. Thus, the general objective of the present research is to measure monetarily the environmental impact occurred in the so-called "tragedy of Mariana" because the understanding, also financial, of the size of the disaster that has occurred is fundamental so that new "mud rivers" no longer happen.

In view of these perspectives and problems, we come to the question of the present work: what is the total monetary value of the ecosystem services affected by the rupture of the tailings dams of the Samarco mining company?

It is worth mentioning that the ecological economy lenses takes into account all the costs (not just the monetary ones) of the growth of material production. It is entirely skeptical about the possibility of indeterminate growth, and even more about the illusion that growth may be the solution to ecological problems. (CECHIN & VEIGA, 2010: 45).

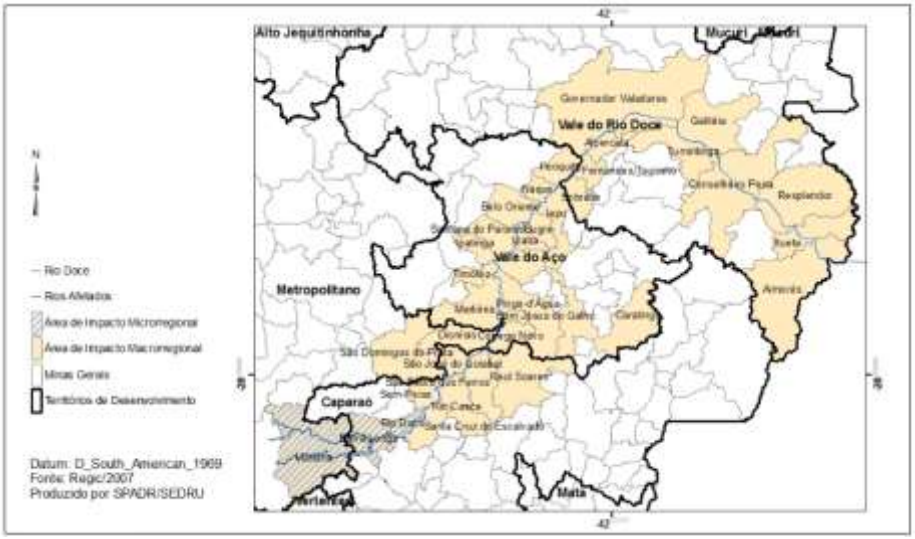
2. CONTEXT

The documents of three organizations were analyzed in order to define the area of study: IEF (2015), Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA, 2015) and Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA, 2016). The IEF calculated the area in two ways, the first one referring to the main scene, which leaves from the Gualaxo do Norte River towards the Carmo River, with an estimated area of 560.35 ha, of which 384.71 are from the Atlantic Forest. After this first estimate, the adjacent areas following the main scene were analyzed, from the Rio Gualaxo do Norte to the outfall of the Doce River, with more than 1,026.54 ha of vegetation coverage, totaling 1,585 hectares (EMBRAPA, 2016).

According to IBAMA's technical note (2015), dams destroyed 1,469 hectares along 77 km of water courses, and many were permanent protection areas (IBAMA, 2015). Finally, Embrapa (2016) estimated about 1,430 hectares of affected area, being important to note that much of the damage fell under rural activities. We chose the Embrapa's estimate (2016), since it has the lowest territorial value, making the valuation present in this study as conservative as possible.

In the technical survey of Embrapa (2016), it was observed that the analyzed data followed three typologies of the problem: environmental, material and human, each one of these types created subcategories of analyzes. First, in the environmental question it was considered: damages in the quality and availability of the water, losses in the quality and availability of the soil, losses in the biodiversity. In the case of material damage measurements, this study analyzed two subcategories: regional economy and infrastructure. Finally, when thinking about human factors, the subcategories were constituted: effects on public health and fundamental issues of people's safety, damage to the symbolic elements and access to education of the affected population and impacts on the forms of social organization of the population involved (EMBRAPA, 2016). The extent of the damage can be observed in Figure 1, which was the reference for the Embrapa task force analyzes.

Figura 1. Region of the ruptures of the Mariana dams



Soucer: EMBRAPA, 2016:8 *apud* SEDRU/MG

For a better understanding of the calculations and results, topic 4, Results and Discussion was divided into four sub-items: Regional Economics, Main Anthropogenic Pressures, Environmental Functions and Calculation of Environmental Value, according to the TEEB methodology

3. DIAGNOSIS AND PROBLEM´S INTERVENTION

In order to estimate the monetary value of the ecosystem services affected by the Samarco / Vale / BHP Billiton, based on the Embrapa report (2016), there was first identification of these services and their main anthropogenic pressures, according to the proposition of Costanza, et al (1997, 2014). This technique comprises the complexity and contradiction of valuating biodiversity given the various methodological problems in its treatment.

Among the monetary evaluations propositions that can provide information for decision-making in policies that affect the respective ecosystems, the methodology of Costanza, et al. (1997) is among pioneers, since it started to increase the acceptability of the valuation of environmental services (MYERS, 2008). The robustness of this approach was verified by Costanza et al. (2014) who, using the same method of 1997, updated the estimates of the value of ecosystem services at the global level. In the 1997 model, the estimated value in 1995 was approximately 33 trillion dollars / year, rising to 46 trillion in 2007 and reaching 125 trillion in 2011 (COSTANZA, et al., 2014).

It is understood that this is a necessary tool to contribute to the dialogues on the importance of preserving ecosystems. In this way, alternative actions of the financial markets' agents can be introduced in nature and in their services, which faces scarcity of natural resources, making it possible to give value to each of the natural elements present, such as forests, water, among other elements, made available by nature. Therefore, a hypothetical market is simulated here (ORTIZ, 2003).

This methodology was supported by studies by Costanza, et al. (1997), who advanced the contributions of De Groot (1992), who proposed four categories of ecosystem services: regulation; provision; production and information. In the Costanza, et al (1997) method, were considered eleven biomes (Table 1) and seventeen ecosystem services (Table 2).

Table 1. Main ecosystems of the planet

1. Marine	1.1 Open Ocean	
	1.2 Coast	*1.2.1 Estuary*
		1.2.2 Seaweed
		1.2.3 Coral reef
		1.2.4 Belt
2. Terrestrial	2.1 Forests	*2.1.1 Tropical*
		2.1.2 Temperada
	2.2 Grass and pasture	
	2.3 Marshland	*2.3.1 Tidal mash/mangue*
		2.3.2 Forest marsh
	2.4 Lakes and rivers	
	2.5 Desert	
	2.6 Urban	

	2.7 Cultivated land
	2.8 Ice and rock
	2.9 Tundra

Soucer: adapted by the author, Costanza, *et al*, 1997

Table 2. Ecosystem services and environmental function

N°	Serviço Ambiental	Função Ambiental
1	Gas regulation	Regulation of atmospheric chemical composition.
2	Climate regulation	Regulation of global temperature, precipitation, and other biologically mediated climatic processes at global or local levels.
3	Disturbance regulation	Capacitance, damping and integrity of ecosystem response to environmental fluctuations.
4	Water regulation	Regulation of hydrological flows.
5	Water supply	Storage and retention of water.
6	Erosion control and sediment retention	Retention of soil within an ecosystem.
7	Soil formation	Soil formation processes.
8	Nutrient cycling	Storage, internal cycling, processing and acquisition of nutrients.
9	Waste treatment	Recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds.
10	Pollination	Movement of floral gametes.
11	Biological control	Trophic-dynamic regulations of populations.
12	Refugia	Habitat for resident and transient populations.
13	Food production	That portion of gross primary production extractable as food.
14	Raw materials	That portion of gross primary production extractable as raw materials.
15	Genetic resources	Sources of unique biological materials and products.
16	Recreation	Providing opportunities for recreational activities.
17	Cultural	Providing opportunities for non-commercial uses.

Soucer: adapted by the author, Costanza, *et al*, 1997

With the inverse extrapolation technique applied to Tables 1 and 2 it is possible to measure the ecosystem value of the natural environment throughout the planet. In the case of the present study area the three most important ecosystems were considered as: tropical forest; grass and natural pasture; lakes and rivers. Therefore, the values obtained in the global plan for the site must be transposed (as in Table 3, present in the Results and Discussion section), thus allowing the estimated calculations proposed.

4. RESULTS AND DISCUSSIONS[1]

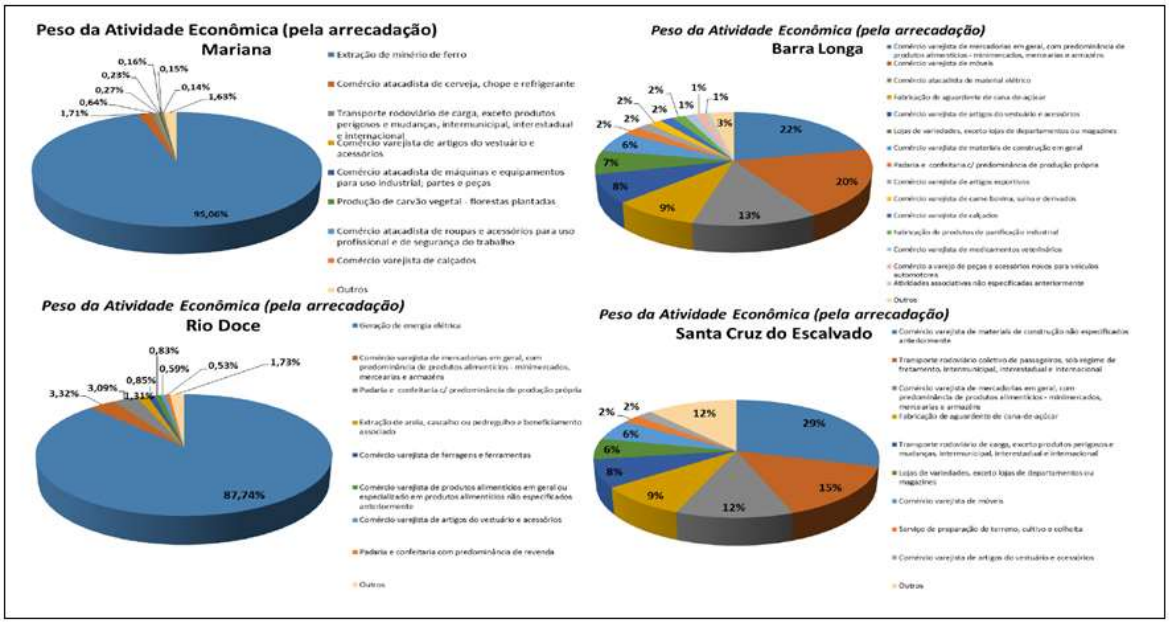
4.1.REGIONAL ECONOMY

In order to understand the environmental impacts provided by the Samarco / Vale / BHP Billiton dams, the EMBRAPA technical report (2016) was used, which shows the main impacts to the regional economy of the affected area, on a microregional scale. the four municipalities most affected by the mining company were: Mariana, Barra Longa, Rio Doce and Santa Cruz do Escalvado.

When analyzing the weights of each economic activity, compounded in some cases by the extraction of iron ore, wholesale trade, power generation, transportation, retail trade, industry, among others, where, within these informed municipalities, especially with regard to tax collection, it can be observed that in Mariana, 95.06% (Figure 2) comes from the extractive activity of iron ore (EMBRAPA, 2016).

> The daily living and working conditions of these populations, socially reproduced in rural communities, places of agrarian reform and settlements, were ruined by the tailings mud, compromising local sources of income generation and threatening the material and immaterial conditions of permanence in their territories. This process makes explicit the approximations between injustice, environmental racism and the social and environmental impacts caused by the Samarco / Vale / BHP Billiton disaster[2] (MANSUR, M. et al, 2016: 33)

Figure 2. Weight of economic activities measured by tax collection of the municipalities under study



Soucer: EMBRAPA, 2016:31-32.

[1] Free translation of the literal quotations

[2] As condições cotidianas de vida e trabalho destas populações, reproduzido socialmente nas comunidades rurais, assentamentos de reforma agrária e povoados, foram arruinadas pela lama de rejeitos, comprometendo fontes locais de geração de renda e ameaçando as condições materiais e imateriais de permanência nos seus territórios. Esse processo explicita novamente as aproximações entre injustiça e racismo ambiental e os impactos socioambientais provocados pelo desastre da Samarco/Vale/BHP Billiton.

Considering the information presented in Figure 2, we can see in the municipality of Mariana an economy of enclave, which should be understood as a:

> [...] the establishment of an export economy that creates no or little beneficial link to other sectors of the local economy. The enclave is characterized by the installation of artificial structures that are extraneous and qualitatively different from the local reality. The enclave economy and surrounding infrastructure, such as housing, health services and education, are artificial and vertical. However, even though it is different, the enclave economy has strong links with local reality, including leveraging the local structure to reduce the cost of its operations. What gives the character of enclave is the fact that it does not generate benefits for the local social structure, on the contrary, it deteriorates its situation[3] (COELHO, 2015: 58).

Thus, the economy based in mineral extraction makes the public sector and the community dependent on these resources, without generating alternative economies in order to foster a more sustainable economic development of their populations. It can be perceived that:

"The mining industry has always been developed in Brazil by a dependent and underdeveloped capitalism based on a reprimarized economy, with a growing process of violence that has determined that a caste of society is only a social actor, vaguely and surplus, in the fringes of all this mineral wealth and gears of the great farm in the formation of the export model that would shape the whole economy in the last five centuries. (TROCATE & ZONTA, 2015: 10)."

Another problem that is observed in the mining industry, besides the enclave economy, is the finding that there is an ecologically unequal trade in this sector, according to SAES (2017), the "iron ore peripheries". This process, according to the researcher, creates a dematerialization among the richest economies, in which the more developed economies "increasingly depend on" hidden "iron and steel stocks in other countries (SAES, 2017: 62). The author complements:

> By not considering this evidence of North-South asymmetry and not visualizing social metabolism in a global way, betting on uniquely technological solutions does not seem to be enough to prevent that the environmental damage of economic growth will be continually shifted to the South, or even to solve issues such as global warming[4] (SAES, 2017: 62).

After these considerations and with the analysis of Figure 2, a degree of dependence of the municipality of Mariana is observed. Enriquez (2007), analyzed the degree of "vulnerability" of some municipalities that have a mineral base in their economy. This index is measured by the "imminence of the exhaustion of direct and indirect sources of income from mining" (ENRIQUEZ, 2007: 348). according to the author, Mariana Town's degree of

[3] [...]instalação de uma economia exportadora que cria nenhum ou pouco link benéfico para os outros setores da economia local. O enclave é caracterizado pela instalação de estruturas artificiais que são alheias e qualitativamente diferentes da realidade local. A economia de enclave e a infraestrutura que a cerca, como a habitação, serviços de saúde e educação, têm caráter artificial e vertical. No entanto, mesmo sendo diferente, a economia de enclave tem intensas ligações com a realidade local, inclusive aproveitando a estrutura local para diminuir o custo de suas operações. O que dá o caráter de enclave é o fato de não gerar benefícios para a estrutura social local, pelo contrário, deteriora sua situação.

[4] Ao não considerar esta evidência de assimetria Norte-Sul e não visualizar o metabolismo social de uma maneira global, a aposta em soluções unicamente tecnológicas não parece ser suficiente para impedir que os danos ambientais do crescimento econômico sejam continuamente deslocados para o Sul, ou mesmo resolver questões globais como o aquecimento climático.

vulnerability, based on data from 2005, places the municipality among the most dependent, with a forecast of mine exhaustion estimated in 30 years.

In contrast to Mariana, the economic activities of other municipalities under study show greater dynamics, except Rio Doce, which has 87.74% of its revenue based on energy generation. Barra Longa has a greater economic diversity, where 22% of its revenue comes from the general retail trade, 20% from the retail furniture trade and 13% from the wholesale trade of electrical material. Rio Doce concentrates its tax collection, about 87.74%, in the generation of electric energy, also affected by the mining waste. Finally, Santa Cruz do Escalvado presents its collection based on the retail trade of construction materials, collective road transport and general retail trade, respectively 29%, 15% and 12% (Figure 2) of municipal revenues (EMBRAPA , 2016).

The region's specialization in non-renewable natural resources reflects the case of the Brazilian economy as a whole which, in turn, also has an international marketing agenda based on products of low technological intensity. It is observed that local economies are fragile, with little diversification that maximizes such impacts, being susceptible to exogenous impacts, as happened in the "Mariana tragedy". According to EMBRAPA (2016), private losses accounted for R$ 253,056,436.42, while public losses were R$ 5,205,052.51, while infrastructure damage was R$ 45,624,450.00. The total amount, in material costs, was R$ 303,885,938.93. Expressive values, which can be analyzed in Tables 3, 4 and 5.

Tabela 3. Micro-regional scale of private economic losses

Affected by the dam	Private economic losses					
	Agriculture	Pecuária	Industry	Trade	Service	Total private losses
Mariana	R$ 878.340,00	R$ 6.273.210,50	R$ 215.000.000,00	R$ 500.000,00	R$ 400.000,00	R$ 223.051.550,50
Barra Longa	R$ 743.882,08	R$ 14.567.881,00	-	R$ 1.000.000,00	R$ 500.000,00	R$ 16.811.763,08
Rio Doce	R$ 256.000,00	R$ 414.000,00	R$ 11.539.704,84	R$ 100.000,00	R$ 194.000,00	R$ 12.503.704,84
Santa Cruz do Escalvado	R$ 100.000,00	R$ 110.000,00	-	R$ 479.418,00	-	R$ 689.418,00
Total	R$ 1.978.222,08	R$ 21.365.091,50	R$ 226.539.704,84	R$ 2.079.418,00	R$ 1.094.000,00	R$ 253.056.436,42

Soucer: EMBRAPA, 2016:36

It is important to highlight that, according to Embrapa (2016), the corresponding values in agriculture are related to the loss of planting, machinery and equipment (tractors, trucks, among others). Livestock costs were due to animal deaths and loss of infrastructure (corral, chicken coop, pasture, among others). The industrial losses are linked to Samarco and UHE Risoleta Neves revenues. In the commerce and services sector, small merchants and tourism (inns, hotels, among others) were affected.

It is worth mentioning that the same study presented a synthesis of the extension of the rural losses. The number of properties affected was 195, directly reaching 295 people, with an area of 1,270.50 hectares, within 216 constructions, and with the loss of 1,596 animals, which recorded a total loss of R$ 26,595,425.43 (EMBRAPA, 2016).

Table 4. Micro-regional scale of material damage to infrastructure

Affected by the dam	Material damage to the infrastructure							
	Housing units			Public health facilities		Public facilities and education		
	Destroyed	Damaged	Estimated value	Destroyed	Valor estimado	Destroyed	Damaged	Estimated value
Mariana	349		R$ 51.756.700	2	R$ 380.715	4		R$ 4.383.625
Barra Longa	40	93	R$ 2.657.600			2	1	R$ 700.000
Rio Doce								
Santa Cruz do Escalvado		1	R$ 60.000					
TOTAL	389	94	R$ 54.474.300	2	R$ 380.715	6	1	R$ 5.083.625

Soucer: EMBRAPA, 2016:59

The estimated values above, according to Embrapa (2016), refer to the municipalities that had their infrastructure destroyed or damaged by Samarco. As pointed out by the survey, it does not mean that these values will be the same for reconstruction or reform of the properties, due to other factors such as land and construction techniques.

Tabela 5. Micro-regional scale of public economic losses

TYPE OF SERVICE / SECTOR	Public economic losses				
	MARIANA	BARRA LONGA	RIO DOCE	SAN. CRUZ DO ESCALVADO	TOTAL
Medical Assistance, Public Health and Emergency Medical Assistance	R$ 744.407,89	R$ 50.000,00			R$ 794.407,89
Drinking Water Supply	R$ 30.000,00	R$ 30.000,00		R$ 20.000,00	R$ 80.000,00
Pluvial Sewer and Sewage System	R$ 85.000,00	R$ 1.000.000,00			R$ 1.085.000,00
Urban Cleanup and Garbage Disposal and Disposal System	R$ 8.000,00	R$ 500.000,00			R$ 508.000,00
Habitat Disinfestation / Disinfection System / Pest and Vector Control		R$ 30.000,00			R$ 30.000,00
Generation and Distribution of Electric Energy		R$ 70.000,00	R$ 855.770,89	R$ 1.200.000,00	R$ 2.125.770,89
Telecommunications		R$ 70.000,00			R$ 70.000,00
Local, Regional and Long-Haul Transport	R$ 318.442,33	R$ 52.305,00	R$ 14.126,40		R$ 384.873,73
Distribution of Fuels, Especially Domestic		R$ 52.000,00			R$ 52.000,00
Public security		R$ 10.000,00			R$ 10.000,00
Teaching	R$ 25.000,00	R$ 40.000,00			R$ 65.000,00
Total Public Loss	R$ 1.210.850,22	R$ 1.904.305,00	R$ 869.897,29	R$ 1.220.000,00	R$ 5.205.052,51

Soucer: EMBRAPA, 2016:48

The cost above (Table 5) refers to emergency actions during and after the Mariana / MG disaster, which were financed by the municipal governments. To score the public losses, this survey of Embrapa (2016) was carried out through questionnaires sent to municipalities and state public agencies.

Another contribution of this report is about the human damages, in other words, a first screening of people who were affected by the mining company. It has been classified into three categories: 1. public health and safety conditions of people; 2. damages on symbolic elements and access to the education of the affected population; 3. impacts on the social organization of the affected population, totaling 10,482 people (EMBRAPA, 2016: 62).

As the theoretical framework of the present research is based on the Ecological Economy, which is a critical counterpoint to the Neoclassical Economics, it has been tried to demonstrate that the social and environmental costs of the rupturing of the Samarco mining dams are not only reflected in the prices of commodities minerals. As Montibeller Filho (1999: 100) points out, "ecological costs are not manifested in prices since they do not incorporate negative externalities". There is the so-called ecological dumping, where "it is social movements, not prices that reveal the real ecological costs. The political pressure of the environmental movement in relation to a certain degraded area makes the cost necessary for its recovery appears, at least in part "(MARTÍNEZ ALIER, 1994: 203).

Dumping is a trade practice (domestic and international) where a product is placed on the market at a price below the cost of production. The objective of this strategy is to eliminate competition and take a bigger share in the market, being illegal and disloyal. Ecological dumping comes from this perspective, because of the gentle legislation of some countries with respect to the environment, companies will have a lower production cost than the international market, with direct impacts on local ecosystems. In this way, companies' prices and costs do not account for the damages caused to the environment, leaving such liabilities to the local populations that suffer negative externalities in the productive process.

The data exposed so far are within a micro-regional scale, analyzing the four municipalities most affected by the mine dams breakdown. On a macro-regional scale, the impacts are related to the use of water, totaling private losses in the amount of R$ 287,410,380.00 and public losses in R$ 140,861,402.00, which amount to R$ 428,271,782.00 (EMBRAPA, 2016). The total amount of public and private losses in both spatial scales is around R$ 732,157,720.93, which represents the sum of the micro-regional values, R$ 303,885,938.93, and macro-regional, R$ 428,271,782.00.

4.2.ANTHROPIC PRESSURES

Any change in a natural environment capable of causing any type of impact can be considered as anthropic pressure (IEF, 2013), so it can be said that in the case of this accident, the main ones were soil contamination of soil, water and ciliary vegetation of the municipalities of Mariana, Barra Longa, Doce River and Santa Cruz do Escalvado (study area).

According to the Evaluation Report on the effects and consequences of the breach of the Fundão Dam in Mariana-MG (MINAS GERAIS, 2016), the soil in affected areas no longer has conditions for agricultural activities. The local infertility is due, in particular, to the large volume of accumulated mud, generating a new compacted layer of sediments on the A horizon of the soil that is capable to block the water infiltration and the germination of agricultural crops.

In the case of water resources, the main bodies of water affected by the mud avalanche were the Gualaxo do Norte river, the Carmo river and the Doce river. According to specialized organizations as Instituto Mineiro de Gestão das Águas (IGAM) and Companhia de Saneamento de Minas Gerais (COPASA), the tests of "turbidity, physicochemical alterations and springs affectation" allowed to conclude that "raw water presents turbidity and physico-chemical characteristics differing from the historical average and outside the standards stipulated by the norms for consumption "(MINAS GERAIS, 2016: 21).

Last but not least, it is worth mentioning the impacts observed on ciliary vegetation. In this same study, IBAMA estimated a devastation of "approximately 374.81 ha of ciliary forest cover" (MINAS GERAIS, 2016: 26).

4.3.ECOSYSTEM SERVICES

In this work, actions that generate direct or indirect benefits to man through environmental services were taken as environmental functions (HUETING et al, 1997). According to Costanza, et al. (1997), these services are not static and unitary, and can be related in different ways, being able to aggregate themselves and generate new forms.

In this study, descriptions of the environmental functions indicated by Costanza, et al. (1997) were used. It should be noted that in Table 2 it is possible to observe the types of environmental services and functions present in a location that are capable of being used for human benefit in a responsible way (HEAL, 2000).

According to De Groot (1992), the Regulation Functions are those in which one seeks the balanced ecosystem maintenance of the ecological relations of a given place; the Provision Functions can be defined as the characteristics that an area offers to the human being without the occurrence of significant anthropic actions in the environment; the Functions of Production are the natural direct benefits that the population can enjoy; and the Information Functions are the spiritual and scientific benefits that the natural asset is capable of offering.

Thus, according to Table 2, it can be said that, before the accident, all the services described there were present, and it is regrettable that they no longer exist.

4.4.ENVIRONMENTAL VALUE (EV) OF ECOSYSTEM SERVICES

Once the anthropic impacts, the lost environmental functions and services were presented, one can calculate the EV of the area impacted by the Samarco / Vale / BHP Billiton mud.

Table 6. Economic Valuation of the Ecosystems

Bioma	**Original - Área (há x 10^8)**	**Adapted - Área (há x 10^8)**
Tropical Forest	1900	0,00005263
Grass and Grassland	3898	0,00010797
Lakes and Rivers	200	0,00000554
Monetary values in *R$*	5998	0,00016614

1 - Gas regulation	**2 - Climate regulation**	**3 - Disturbance regulation**	**4 - Water regulation**
	223	5	6
7	0		3
			5445
R$ 23.300.975,24	R$ 11.885.061,20	R$ 30.911.584,60	R$ 19.374.039,82
5 - Water supply	**6 - Erosion control**	**7 - Soil formation**	**8 - Nutrient cycling**
8	245	10	922
	29	1	
2117			
R$ 29.399.888,22	R$ 10.008.472,59	R$ 920.918,48	R$ 296.692.134,42
9 - Waste treatment	**10 - Pollination**	**11 - Biological control**	**12 - Refugia**
87			
87	25	23	
665			
R$ 39.564.743,20	R$ 2.032.970,99	R$ 7.245.717,13	R$ 2.154.601,74
13 - Food production	**14 - Raw materials**	**15 - Genetic resources**	**16 - Recreation**
32	315	41	112

67		0	2
41			230
R$ 24.082.887,16	R$ 12.527.966,55	R$ 1.372.689,82	R$ 14.161.293,68
17- Cultural	**Amount per há (ha^{-1} yr^{-1})**	**Total amount of global flow (yr^{-1} x 10^9)**	
2	2008	0,105680116	
	244	0,026345572	
	8498	0,047078508	
R$ 52.388.098,70		**R$ 578.058.795,18**	

Area hit	**1430**
Percentage - Tropical Forest	3,680387409
Percentage - Grass and Grassland	7,550605327
Percentage - Lakes and Rivers	0,387409201
Price of the Commercial Dollar - 11/01/2017	*R$ 3,2275*

Soucer: adapted by the author (Costanza, *et al*, 1997)

During this process, it was considered the land service with 100% of its value, this information was important in the monetary transposition process since, with this data, it is possible to draw an equation to relate this environmental phytoform with the total terrestrial service.

The same methodology was repeated for the other presented ecosystems.

Now, it is only necessary to transpose the area and the percentage that each of the biomes represents, multiplying these values to identify the relationship between the Costanza, et al. (1997) Method and the study site. For a better understanding of the proposed technique, it is considered that the region on the planet with tropical forests presents the magnitude of 1,900 ha x 108, while the amount alluding to the surveyed area is 0.00005263 ha x 108.

Considering that the original table 3 y Costanza, et al. (1997) does not explain the origin of the final values of each of the 17 ecosystem services considered, we created here a multiplier factor referring to the sum of each of the ecosystem services divided by the original value of the table.

Finally, it is necessary to convert the original value (dollars) into Brazilian currency (reais). The calculation formula (I) is obtained:

Value of area x 10^8 x Value of ecosystem services x factor multiplied x Value of Real / Dollar (I)

Thus, the value of the perceived ecosystem loss in the study area corresponds to R$ 578,058,795.18/year, a highly significant amount when compared to other environmental valuation work already carried out

The amount presented corresponds in terms of public and private losses. From a micro-regional perspective, the total value was R$ 428,271,782.00, which refers to the areas close to the disruption (Mariana, Barra Longa, Rio Doce and Santa Cruz do Escalvado). The total impact, due to the macro-regional aspect, reached R$ 732,157,720.93. These losses, as the EMBRAPA report (2016) points out, are the initial estimates. In the case of public services, these values tend to increase, especially in relation to the health of the residents.

Using this same methodology, Camargo et al. (2014) identified the value of R$ 73,196,258.93 / year in environmental benefits for Cachoeira da Serrinha, located in the municipality of Mariana / MG, with an area of only 1,193,293 km^2 . Barcelos, et al. (2017) used this same method to evaluate the Serra dos Martírios / Andorinhas, located in the municipality of São Geraldo do Araguaia in the state of Pará, with an approximate area of 26,787.75 hectares, and estimated the amount of R$ 101,008,218, 10 / year. Comparing both studies with the results presented here, it is clear the magnitude of the amount lost with the accident in the Mariana-MG dams.

Obviously, like any tool for calculating ecosystemic valuation using the TEEB methodology, it is possible that there is uncertainty in some points, especially because this method uses predefined values for the world biomes.

According to Agencia Brasil (2017), the Brazilian courts suspended Samarco, Vale and BHP Billiton from depositing R$ 1.2 billion related to environmental fines, which was the guarantee "of future actions to recover and repair the socio-environmental damages resulting from the tragedy of Mariana / MG ". The damages repairs were estimated by the Termo de Ajustamento de Conduta (TAC) in the amount of R$ 20 billion over 15 years. The Environmental Value estimated in the present study, considering the same temporal perspective, would be equivalent to the amount of R$ 8.6 billion, thus demonstrating the importance of this kind of research for decision making of public and private organizations. It is important to point out that the methodology used considers only the ecosystem services of the affected area, not entering in other social and economic issues.

Impacts such as those described here are likely to occur both in the short term and in the very long term (secular term), in which these companies may no longer exist, with all costs being borne by local populations.

The current mineral model, as well as the so-called mining royalties, need to be discussed under a municipalist bias, since several studies, such as de Enriquez (2007), Trocate & Zonta (2014, 2015) and Saez (2017), show that isn´t possible to observe, in absolute terms, the improvement in quality of life and reduction of inequalities in places where there is mining activities

5. TECHNOLOGICAL AND SOCIAL CONTRIBUTION

The scope of this work was to discuss the impacts of the rupture of the Samarco/Vale/ BHP Billiton dams, with a methodological effort to improve the process of ecosystem valuation. Two important studies were used as a premise, the first was developed by Costanza et al. (1997), which sought to value the main ecosystems on a planetary scale; the second one was the EMBRAPA (2016) task force report, which provided the necessary subsidies to understand the problems that the rupture of the dams caused to the populations, public and private sectors of the studied region

The tool used had as pillar the economic-ecological modeling, seeking to understand its dynamics and thus incorporating monetary values of assets that are not possible to be commercialized.

There is a range of environmental valuation methodologies, usually from the Neoclassical Economics, where values are linked to their purpose and form of analysis. We emphasize that these techniques need to be careful in their understanding, due to the fact that one seeks to value the invaluable.

It is observed that the damage provided by the trio Samarco / Vale / BHP Billiton is much higher than any estimate made by the competent bodies. For the Ecological Economy the costs are more comprehensive and complex than just the monetary values. Many of the impacts and costs mentioned above will be borne by the population itself, emphasizing that many of these have no direct relationship with the mining company or its surroundings.

Finally, the identified value of the natural and eco-systemic capital affected by the Samarco mining dam is in the range of R$ 578,058,795.18 / year, which is not recorded in commodity prices. There is a clear unequal exchange in the country's mining sector, which concentrates wealth and disseminates poverty with natural resources that belong to the population, and it is important to rethink a new mining development project for the country.

In addition to these problems, it is also worth highlighting the enclave economy, another factor that damages the present and future generations, and it is also important to be thought by the public managers, real solutions capable of diversifying the economic potential of Mariana and region, before new tragedies will once again impact one of the richest regions of the state of Minas Gerais.

Methods of valuation are not able to analyze the ecosystem value as a whole, although it is a way of contributing to the ecological-economic debates. This type of study starts as an effort to assign monetary value to ecosystem services, and it is always important to contextualize the territory of analysis. The uncertainties associated with this method are unavoidable; however, they may assist in policy decisions in all spheres.

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