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TEMPORAL ANALYSIS OF WATER QUALITY IN THE RIVER: RIO DOCEAND TAXES AFTER 6 YEARS AFTER THE BREAKDOWN OF THE FUNDÃO DAM IN MARIANA/MG

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Abstract: The collapse of the Fundão dam, in Mariana/MG on November 5th, released approximately 47 million m3 of waste into the environment. As a consequence, the water quality standards of the affected rivers were changed, which restricted the various uses of these sources for multiple purposes. Given the scale of the disaster that occurred due to the collapse of the Fundão dam, with the volume of tailings that went down the river and the extent of its consequences, periodic monitoring of the basin's physical, chemical and biological parameters in qualitative and quantitative terms is essential. This way, the Systematic Quali-Quantitative Monitoring Program (PMQQS) was implemented by the Renova Foundation. In this work, the main physical and chemical monitoring parameters of both the PMQQS and monitoring already carried out historically in the River: Rio Doce basin were analyzed, in order to identify trends in water quality, 6 years after the rupture. The Mann-Kendall and Spearman autocorrelation analyzes indicated that the dissolved iron parameter shows a tendency for its concentrations to increase even in sub-basins of the River: Rio Doce tributaries not affected by tailings, such as those of the Piranga, Santo Antônio, Caratinga, Manhuaçu rivers. and Suaçuí Grande. These results may indicate that the observed increase may be related to a general trend in the river basin.

Keywords: Water Quality, Monitoring Programs, Dissolved Iron.

INTRODUCTION

On November 5, 2015, the Fundão dam, belonging to the Germano mining complex, in the municipality of Mariana/MG, collapsed. The dam contained 50 million m³ of iron mining waste. This waste is classified as non-hazardous and non-inert for iron and manganese according to NBR 10.004. A portion, approximately 7 million cubic meters, was retained within the mining company's own area. The spilled waste reached the Santarém dam just downstream, causing it to overtop and forcing a wave of mud to pass 55km along the Gualaxo do Norte river until it flows into the Carmo and River: Rio Doce, continuing to the sea (ANA, 2016).

Along the path of the mud wave, around 20 million m³ spread across the gutters, banks and plains of the watercourses to the Risoleta Neves Hydroelectric Power Plant (UHE), 113 km from Fundão. It is estimated that 10 million m³ have been deposited along the reservoir of the Risoleta Neves hydroelectric plant (UHE). The remainder, the thinnest part of the tailings, passed through this dam. The wave of mud reached approximately 550 km from the Risoleta Neves HPP dam, depositing along the River: Rio Doce channel and in the estuary (mouth of the River: Rio Doce) until it reached the sea (RENOVA, 2018).

As a consequence, changes in water quality caused interruptions in the supply of water to the population of municipalities and districts whose supply systems are directly dependent on the River: Rio Doce. In addition, among other impacts of the dam collapse that affected water use, the impacts on hydroelectric power generation, industrial activity, irrigation and livestock farming, fishing, bathing and tourism can be highlighted.

In this sense, the present work contains an evaluation of the monitoring of the Systematic Quali-Quantitative Monitoring Program (PMQQS), carried out by the Renova Foundation and the Águas de Minas monitoring, carried out by the Minas Gerais Water Management Institute (IGAM). This analysis is an important tool for monitoring the water quality situation and the recovery process of the River: Rio Doce, six years after the collapse of the Fundão tailings dam. The development of this work included the participation of the company Tetra + Consultoria Ltda.

MATERIALS AND METHODS

To assess water quality, the following physical parameters were selected: true color, turbidity, total suspended solids (TSS), total dissolved solids (TSD) and electrical conductivity (EC), as they have a response relationship to climatic factors, such as events precipitation and dry/rainy periods. The following chemical parameters were also considered in the analysis: dissolved aluminum (Al), total arsenic (As), total lead (Pb), dissolved copper (Cu), total chromium (Cr), dissolved iron (Fe), total manganese (Mn), total nickel (Ni) and total zinc (Zn). Special emphasis was placed on metallic compounds, since the passage of the wave of tailings resulting from the dam collapse temporarily increased the concentrations of these constituents in the affected watercourses.

Sampling points coinciding between the IGAM and PMQQS monitoring were selected, in places affected by the rupture and in sampling points not affected by the tailings, in the tributaries of the River: Rio Doce, grouped into seven sub-basins (sub-basins of the rivers Carmo, Piranga, Piracicaba, Santo Antônio, Suaçuí Grande, Caratinga and Manhuaçu). IGAM has already been monitoring water quality in rivers in the River: Rio Doce basin since 1997, and the data has historical importance for assessing water quality.

PMQQS data is validated by the program's quality assurance/quality control (QA/QC) criteria, which is regularly monitored by the environmental bodies that make up it and the Program's Technical Monitoring Group (GTA). In addition, to develop robust analyses, data processing was carried out for results below the limits of quantification and for data considered anomalous arising from stochastic events.

In order to test possible trends of increase/decrease in the value of each parameter, the time series were subjected to the Mann-Kendall test and the Spearman autocorrelation test. To carry out the tests, the data was separated into dry and rainy periods. The study region has two distinct periods of rainfall: the rainy season, which extends from October to March, with higher rainfall rates in December (accumulated precipitation varying between 800 and 1,300 mm); and the dry period, which extends from April to September, with a more critical drought from June to August (accumulated precipitation varying between 150 and 250 mm) (ANA, 2015; SRK, 2021).

The analyzes were carried out individually for each section of the River: Rio Doce basin affected by the tailings (Gualaxo section, Carmo, Upper, Middle and Lower sections) and for each sub-basin of the River: Rio Doce tributaries not directly affected by the tailings transport: sub- basins of the Gualaxo do Norte river (in its point upstream of the affected area), the Carmo river (in its three points not affected by the tailings), the Piranga river, the Piracicaba river, the Santo Antônio river, the Suaçuí Grande river, of the Caratinga River, Manhuaçu River and Guandu River. Time series tests were performed using the PAST program (version 4.11).

RESULTS

The temporal comparison by linear regression showed that the year immediately after the rupture had significant differences compared to historical data for 13 parameters, with total chromium being the only exception found, as there was no significant change in any of the sections evaluated. Considering all stretches and periods of drought and rain separately, significant differences were observed to persist over time, and it must be considered that water quality degradation processes continue to occur in the basin, even after the dam collapse, there are other environmental pressure factors in addition to the rupture.

The River: Rio Doce basin functions as a receiving, transporting and self-purifying channel for waste and effluents, originating from domestic sewage loads and from different industrial activities, such as mining, steel mills, cellulose factories, sugar and alcohol plants, meatpacking plants and tanneries. These activities have contributed to the progressive loss of water quality in the River: Rio Doce and its tributaries (ANA, 2001). In the main channel of the River: Rio Doce, the impact on water quality is minimized due to the greater flow available (ANA, 2016). However, there are historical records of high values of thermotolerant coliforms, turbidity and total phosphorus, in addition to the presence of some metals with values above the permitted limits, such as dissolved iron, total lead and dissolved manganese in various parts of the basin, as presented in the Integrated Plan of Water Resources of the River: Rio Doce Basin (PIRH, 2010).

Most of the parameters showed a tendency to reduce the values measured in some of the stretches evaluated, which is evidence that the process of water quality recovery is occurring over time. The exception to this pattern was dissolved iron, which showed an increasing trend in almost all sections affected by tailings, both during dry and rainy periods. The temporal trend analysis in the sections and sub-basins not affected by the tailings showed that, for dissolved iron, even the areas not affected by the rupture showed, for the most part, an increasing and significant trend in the concentrations of this parameter. The concentrations of total dissolved solids, arsenic and nickel in most of the sub-basins formed by tributaries not affected by the tailings also tended to increase over the years, as did the electrical conductivity values.

This increasing trend in the basin in general can be explained, in part, by the high rates of susceptibility to erosion, and to these intrinsic characteristics, added to the history of occupation of the basin and the intense use of the soil for different uses. According to PIRH (2021), an area of only 28,773 km^2 of the River: Rio Doce basin (33.4% of the total area) has vegetation cover, with the majority of the River: Rio Doce basin area falling into the strong erosive susceptibility class. (58.4% of the total). These factors contribute greatly to the removal of soil and acceleration of erosion processes, carrying more and more solids to the riverbed, especially during the rainy season (ANA, 2015). In Table 1, the results of the Mann-Kendall and Spearman autocorrelation tests can be seen, demonstrating the temporal trend (increase ↑ or reduction ↓) of the dissolved iron parameter, in the affected sections and in the sub-basins not affected by mining waste. in the River: Rio Doce basin. In Figures 1 and 2 you can see the graphs obtained by comparing the temporal evolution trends for the dissolved iron parameter, in the pre- and post-breakdown scenarios of the Fundão dam, in the dry and rainy periods. The dashed line in the graphs corresponds to the straight line obtained by linear regression.

Section / Sub-basin	Period	I reject	Season of the year	Spearman correlation*	Mann-Kendall test		
					z	p**	Tendency
River: Gualaxo do Norte	Post breakup	Reached	Rain	0,73	2,4	0,02	↑
			Dry	0,5	17	0,07	
		Not reached	Rain	0,39	2,1	0,04	↑
			Dry	-0,76	-3,8	0,0001	↓
River: Rio do Carmo	Pre breakup	Reached	Rain	-0,13	-0,4	0,69	
			Dry	-0,08	-0,1	0,91	
	Post breakup		Rain	0,38	1,9	0,06	
			Dry	-0,03	0	1	
	Pre and post breakup	Not reached	Rain	0,63	3,4	0,0006	↑
			Dry	0,22	1,2	0,23	
River: Alto Rio Doce	Pre breakup	Reached	Rain	-0,35	-1,9	0,053	
			Dry	-0,19	-1,1	0,26	
	Post breakup		Rain	0,8	3,1	0,002	↑
			Dry	0,21	0,5	0,64	
Médio Rio Doce	Pre breakup	Reached	Rain	-0,46	-2,2	0,02	↓
			Dry	0,05	0,2	0,83	
	Post breakup		Rain	0,72	2,7	0,006	↑
			Dry	0,08	0	1	
River: Baixo Rio Doce	Pre breakup	Reached	Rain	-0,48	-2,3	0,02	↓
			Dry	-0,15	-0,8	0,43	
	Post breakup		Rain	0,45	1,6	0,09	
			Dry	0,16	0,3	0,75	
River: Rio Piranga	Pre and post breakup	Not Reached	Rain	0,38	2,3	0,02	↑
			Dry	0,23	1,4	0,16	
River: Rio Piracicaba	Pre and post breakup	Not Reached	Rain	0,16	0,9	0,32	
			Dry	0,21	1,4	0,16	
River: Rio Caratinga	Pre and post breakup	Not Reached	Rain	0,42	2,3	0,02	↑
			Dry	0,22	1,4	0,16	

River: River: Rio SantoAntônio	Pre and post breakup	Not Reached	Rain	0,59	3,7	0,002	↑
			Dry	0,72	4,4	0,00001	↑
River: Rio SuaçuíGrande	Pre and post breakup	Not Reached	Chuva	0,36	2,2	0,02	↑
			Seca	0,28	1,5	0,12	
River: Rio Manhuaçu	Pre and post breakup	Not Reached	Chuva	0,33	2,2	0,03	↑
			Seca	0,34	2	0,04	↑
River: Rio Guandu	Pre and post breakup	Not Reached	Chuva	0,75	25	0,01	↑
			Seca	0,33	6	0,27	

Table 1: Results of temporal trend analyzes of the dissolved iron parameter, in the sections affected and in the sub-basins not affected by mining waste in the River: Rio Doce basin.

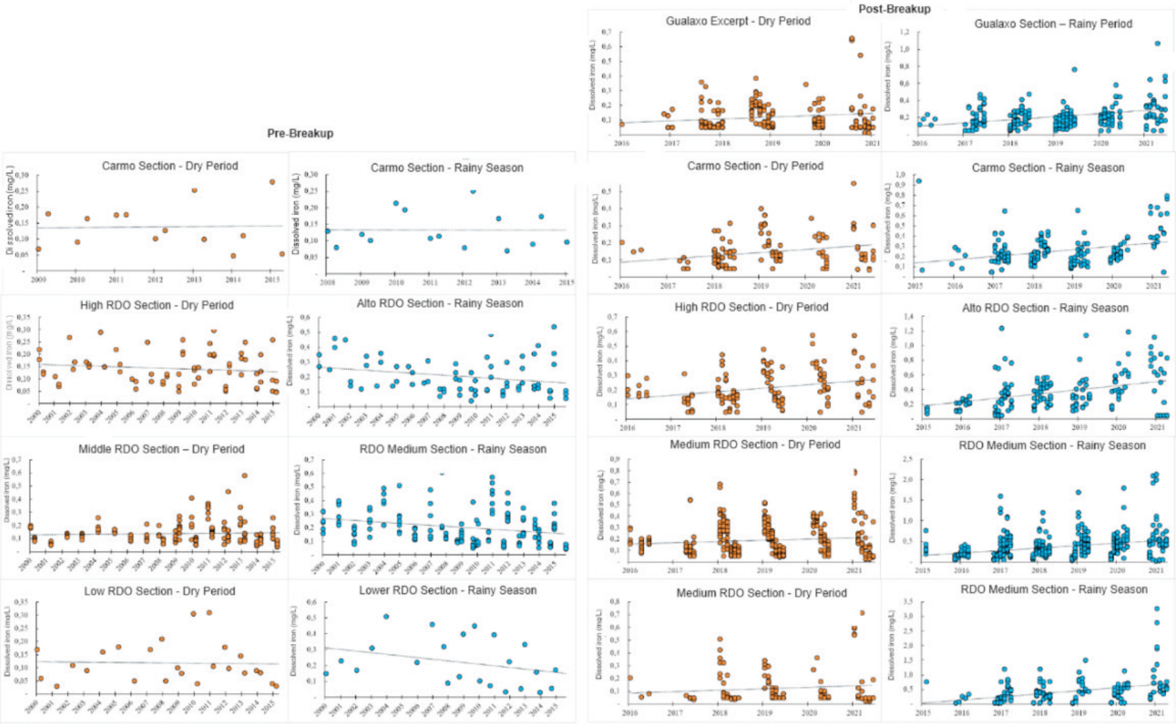

Figure 1: Comparison of temporal evolution trends for the dissolved iron parameter, in the pre- and post-breakdown scenarios of the Fundão dam, in dry and rainy periods.

Source: TetraMais, 2022. Note: the graphs follow different scales.

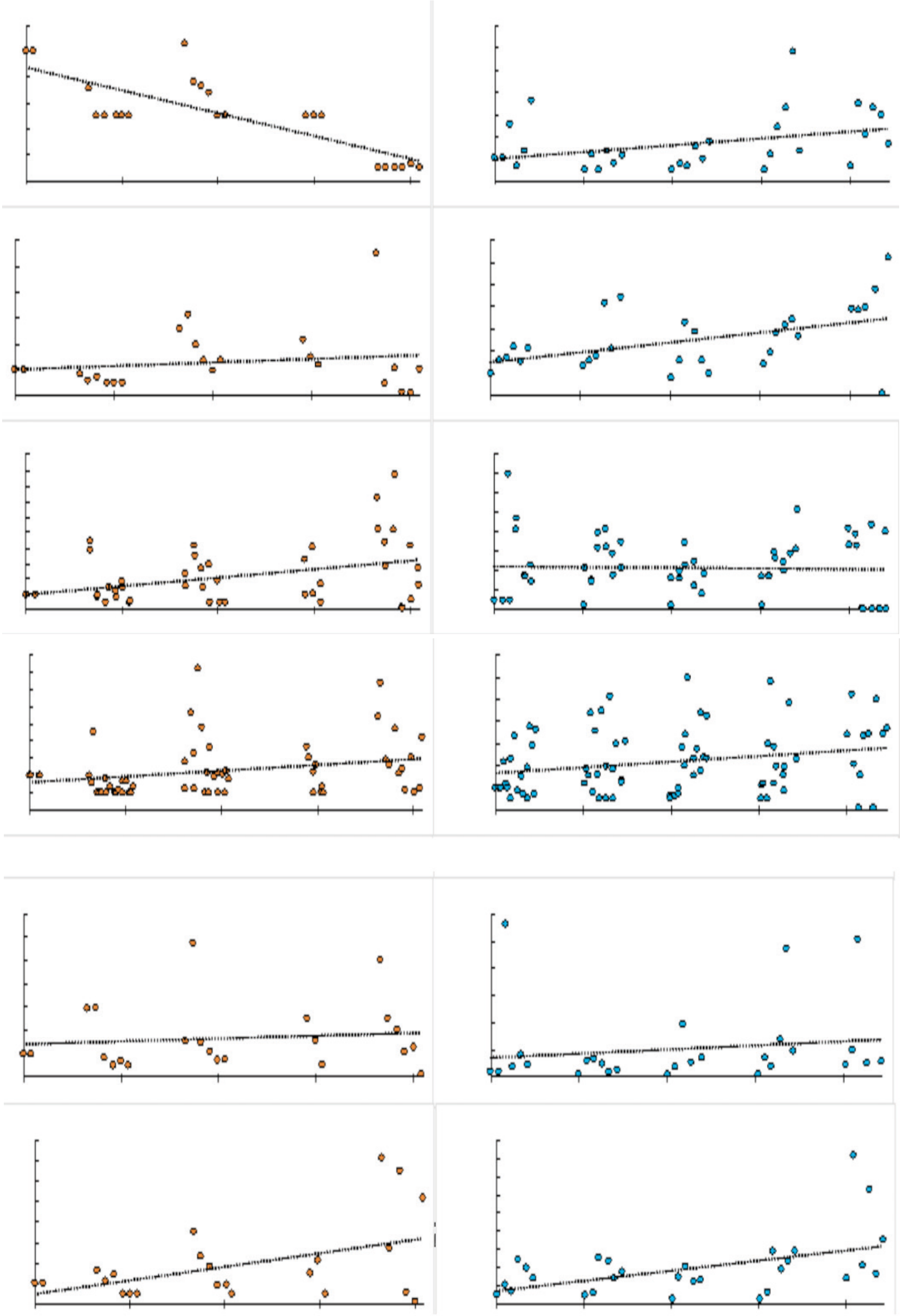

Figure 2: Comparison of temporal evolution trends for the dissolved iron parameter, in tributaries of the River: Rio Doce and sections of sub-basins not affected by tailings, in dry and rainy periods

Source: TetraMais, 2022. Note: the graphs follow different scales.

CONCLUSIONS

It is concluded that all sections show evidence of being in the process of recovery, that is, they show a tendency to return to their original conditions. The dissolved iron parameter, however, shows a tendency for its concentrations to increase even in sub-basins of the River: Rio Doce tributaries not affected by tailings, such as those of the Piranga, Santo Antônio, Caratinga, Manhuaçu and Suaçuí Grande rivers; and this result may indicate that the observed increase may be related to a general trend of the river basin in response to land use and occupation by human activities.

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