IMPACTS OF URBAN SOLID WASTE DISPOSAL ON THE QUALITY OF SURFACE WATER IN THREE CITIES OF MINAS GERAIS - BRAZIL

Impactos da disposição de resíduos sólidos urbanos na qualidade da água superficial em três municípios de Minas Gerais - Brasil

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ABSTRACT

The environmental impact of three different urban solid waste facilities (USWF) on the quality of the surface water. The studied areas were the Campo Belo sanitary landfill (Varões River), the controlled landfill of Santo Antônio do Amparo (Fabiano River), and the closed dump of Elói Mendes (Mutuca River), which are cities located in southern Minas Gerais state, Brazil were evaluated. At each sampling point water samples were collected at five occasions in the raining season (October - March) and in the dry season (April - June) at three sampling points: (P1) upstream the solid waste facility, (P2) downstream nearby the point of influx from the sewage treatment plant in the sanitary landfill, or at the drainage point from the surface flow of the dump and controlled landfill, and (P3) downstream the solid waste facility. Physicochemical and bacteriological analyses were performed, and the results were analyzed based on descriptive statistics. The data were also compared with reference values from the National Environmental Council (CONAMA) Resolution 357/2005 and were used to calculate the water quality index (WQI). It was not possible to detect a significant effect of the solid waste facility on the water quality indicators. The water conditions were unsatisfactory due to violations of the concentrations of phosphorus, ammonia, fecal coliform, and the biochemical oxygen demand/chemical oxygen demand ratio (BOD/COD), probably related to other uses along the drainage area upstream the solid waste facility. These conditions were more critical in the Mutuca river, where the WQI was classified as bad during the entire period at all sampling points.

Index terms: Environmental contamination, water quality index, sanitary landfill, controlled landfill, dump.

RESUMO

Os impactos ambientais de três diferentes tipologias de áreas de disposição de Resíduos Sólidos Urbanos - ADRSU, sobre a qualidade das águas superficiais situadas nas proximidades do aterro sanitário de Campo Belo (Córrego dos Varões), do aterro controlado de Santo Antônio do Amparo (Córrego do Fabiano) e do lixão encerrado de Elói Mendes (Ribeirão Mutuca), municípios situados no Sul de Minas Gerais – Brasil foram avaliados. Para cada curso d'água foram coletadas 5 amostras de água no período chuvoso e 5 amostras no período seco, em três diferentes pontos para cada um dos três cursos d'água sendo: (P1) a montante das ADRSU, (P2) logo após o local de descarga da Estação de Tratamento de Esgoto - ETE (no aterro sanitário, e nas outras tipologias, após ponto de lançamento do escoamento superficial proveniente das ADSRU, e (P3) à jusante das ADSRU. Realizaram-se análises físico-químicas e bacteriológicas, cujos resultados foram analisados com base na estatística descritiva e comparados com valores de referência da Resolução CONAMA 357/2005, bem como utilizados para cálculo do índice de qualidade de água (IQA). Não foi possível detectar efeito significativo das ADRSU, nos parâmetros indicadores da qualidade da água, a qual se apresentou em condições não satisfatórias em função das violações dos parâmetros fósforo, amônia, coliformes termotolerantes e da relação DQO/DBO mesmo à montante da ADSRU. No Ribeirão Mutuca, essa situação foi ainda mais crítica pois o IQA foi classificado como ruim em todos os pontos durante o período monitorado.

Termos para indexação: Contaminação ambiental, índice de qualidade de água, aterro sanitário, aterro controlado, lixão.

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INTRODUCTION

The steady growth of urban populations and rapid increase in solid waste generation has emerged as one of the main pressing issues of human society, especially in developing countries (BRUNNER; BROWN, 1988; D'ALMEIDA; VILHENA, 2000; POKHREL; VIRARAGHAVAN, 2005; MARKANDYA, 2006). Improper disposal of solid waste leads to contamination of soil, air, and surface and groundwater. This contamination alters physical, chemical, and biological characteristics of the environment and places human health at risk. Urbanization leads to spatial concentration of solid waste, what reduces

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the potential that environments have to assimilate contaminants. Environmental contamination resulting from solid waste can reach high levels and negatively affect people and the local fauna and flora (CASTILHOS JÚNIOR, 2006).

Leachate and gases are the major problems caused by garbage decomposition, although a series of other problems is also observed such as: a) pollution of soil, nearby surface waters, and ground waters; b) visual pollution; c) unpleasant odors; d) presence of animal scavengers; e) presence of people scavenging discarbe resources including children; f) increased occurrence of disease vectors, which directly impact the local and regional human; g) presence of gases with greenhouse and explosive effects, dioxins, and furans resulting from burning; h) intense landscape degradation; i) increase of fire hazard; and j) devaluation of local real estate (LANZA, 2009).

Landfill leachate is generated by excess rainwater percolating the waste layers. Physical, chemical, and microbial processes transfer pollutants from waste to percolating water (CHRISTENSEN; KJELDSEN, 1989). The effects of leachate on the quality of the surface and ground waters depend on the leachate's composition. However, the biodegradability of the organic content in the solid waste and the compaction of the waste layers make the landfill an anaerobic environment, conferring similarities to the leachate composition among different landfills (KJELDSEN et al., 2002). Leachate is by far the most significant threat to groundwater because it can reach the deepest layers of landfills (OLIVEIRA; PASQUAL, 2001). Through percolation, leachate carries soluble substances and may flow laterally to nearby areas, move upwords and reach the surface or move through the base of the landfill toward the subsurface (WALLS, 1975; ZANONI, 1972).

In Brazil, more than 300 g of waste per capita are generated daily from sweeping and cleaning streets and garbage (PEÑIDO; ZVEIBIL, 2001). The national average production urban solid waste 900 g/day/person. However, this estimate depends on the size of the city and may reach 1,300 g/day/person in cities such as Rio de Janeiro and São Paulo. In 50.8% of Brazilian cities, open-air dumps are still the final destination for solid waste (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA –IBGE, 2008). However, solid waste management has changed significantly in the last 20 years. The use of sanitary landfills, which is the most appropriate way to dispose of solid waste, has increased from 17.3% of cities in 2000 to 27.7% in 2008. In the state of Minas Gerais, the number of cities disposing waste in open-air dumps decreased significantly from 96% in 2001 to 37% in 2010 (FUNDAÇÃO ESTADUAL DE MEIO AMBIENTE – FEAM, 2010). The law 12305/2010 of the National Policy on Solid Waste establishes policies for the integrated management of solid waste (including hazardous waste), defines responsibilities of those generating waste and of the public administration, and specifies applicable economic measures (BRASIL, 2010).

In general, there are 3 kinds of facilities for disposal of urban solid waste: a) dumps, or the simple deposition of waste on the soil without technical criteria or measures to protect the environment or public health; b) controlled landfill, a method preferable to a dump but features a level of quality considerably inferior to the sanitary landfill; and c) sanitary landfill, which is the most appropriate one (AZEVEDO et al., 2003). This disposal facility produces localized pollution because there is no impermeabilization of the base (compromising the soil and groundwater quality), no percolated liquid treating system (leachate plus infiltrated water), or extracting and controlling the burning of the gases generated.

Intensification of industrialization, urbanization, agricultural activities, and population growth have resulted in increased demand for water as well as in an increased flow of contaminants into water bodies, (HOLT, 2000; PINTO, 2009). Urban activities have a direct influence on water quality within hydrographic basins because effluents flow into waterways in many cases without passing through any treatment process. The most significant contamination routes are those related to direct and indirect emissions of treated and untreated sewage, runoff, atmospheric deposition, and pollution. The quality of surface water has become a critical issue in many countries, especially due to concern about the scarcity of water, requiring a program for monitoring the surface and groundwater to protect this resource (PESCE; WUNDERLIN 2000). Various water monitoring technologies are necessary to monitor the quality of the local water. In this context, the objective of this study was to evaluate the environmental impact of three different types of urban solid waste facilities–dump, controlled landfill, and sanitary landfill, on quality of surface waters under field conditions.

MATERIAL AND METHODS

The characteristics of the cities and identification of the USWF are summarized in table 1 and description of the rivers in table 2 and figure 1. The methods for surface water sample collection, preservation, and parameters analyses followed the standard methods for the examination of water and wastewater (APHA, 1998).

Table 1 – Characteristics of the studied cities and their waste disposal plants.

City	Geographic coordinates	Area (ha)	Human population	Solid waste production (tons/day)	Solid waste disposal method	Adjacent river
Elói Mendes	21°37'55" S 45°34'21" W	2.5	21,907	12.5	dump	Mutuca
Santo Antônio do Amparo	20°58'34" S 44°56'45" W	3.0	17,255	9.0	controlled landfill	Fabiano
Campo Belo	20°51'47" S 45°17'45" W	10.5	51,544	30.0	sanitary landfill*	Varões

* In an adjacent area there is a dump that has been closed.

Table 2 – Characteristics of rivers under the influence of the studied waste disposal plants.

River	Main drainage uses	Drainage area (km^2)	Average declivity (%)	Average flow (m^3/s)	Geographic coordinates of sampling points	
					upstream	downstream
Mutuca	coffee growing, livestock	7.95	2.0	0.093 0.341	21°38'15.8" S 45°34'26.9" W	21°38'0.2" S 45°34'10.5" W
Fabiano	pasture, livestock	2.31	1.9	0.072	20°58'40.4" S 44°56'30.7" W	20°58'18.8" S 44°56'37.2" W
Varões	corn growing	0.90	4.4	0.016	20°51'49.7" S 45°17'56.7" W	20°51'51.3" S 45°17'53.8" W

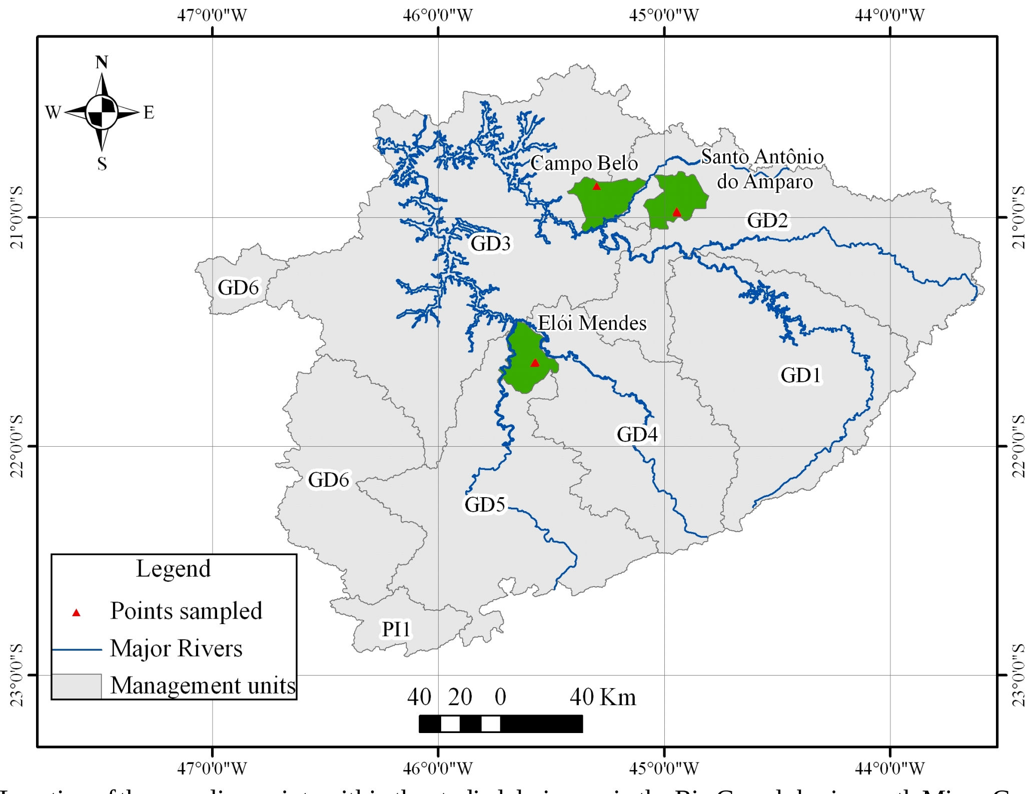

Figure 1 – Location of the sampling points within the studied drainages in the Rio Grande basin, south Minas Gerais, Brazil.

Water samples were collected using 2-L flasks; samples collected for bacteriological tests were collected in sterilized flasks. All samples were stored at 4° C. Samples were collected at three sampling points along each of the three studied rivers: (P1) upstream the solid waste facility; (P2) downstream nearby the point of influx from the sewage treatment plant in the sanitary landfill, or at the drainage point of surface flow of the dump and controlled landfill; and (P3) downstream the solid waste facility. At each sampling point water samples were collected at five occasions in the raining season (October - March) and in the dry season (April - June). The water parameters measured were: air temperature, water temperature , pH, turbidity, electric conductivity, dissolved solids (DS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), color, chlorides, total solids (TS), fixed solids (FS), volatile solids (VS), total suspended solids (TSS), and total and fecal coliforms. The samples were analyzed in the Laboratory of Water Analyses, Department of Engineering, Federal University of Lavras. The levels of nitrate, total phosphorus, and ammonia nitrogen were analyzed in the Laboratory of Environmental Sanitation, Veterinary School, Federal University of Minas Gerais. River flow rate measurements were taken in situ by the floater method at each sampling occasion. In the Mutuca river, flow measurements were taken both upstream and downstream the point of convergence of an affluent creek.

Descriptive statistics of the water physical, chemical, and bacteriological parameters, were compared with reference values for Class II, indicating potability level of freshwater, of the Resolution 357/2005 of the National Environmental Council (CONSELHO NACIONAL DE MEIO AMBIENTE, 2005). Averages were compared using the *t*-test with a 95% significance level ($p<0.05$) for each parameter monitored. Another evaluation was based on the Water Quality Index (WQI) proposed by the Water Management Institute of Minas Gerais state (INSTITUTO MINEIRO DE GESTÃO DAS ÁGUAS-IGAM, 2004).

RESULTS AND DISCUSSION

Water quality parameters

The factor for the position of the sampling point for surface water for the three rivers (Mutuca, Varões, and Fabiano) did not show significant differences for any of the parameters (statistical *t*-test). Analysis of descriptive statistics identified that some water parameters were above the reference values from CONAMA Resolution 357/2005 (Table 3).

Table 3 – Descriptive statistics for water quality indicators in the tree sampling points in the studied rivers.

	Water parameters (mg/L)	Mutuca River		Varões River		Fabiano River		Reference values**
		Average	CV(%)	Average	CV(%)	Average	CV(%)	
P1	BOD	0.92	46.74	2.03	92.61	0.66	124.24	5.00
	FC***	**$1.04x10^{4*}$**	0.30	63.8^{*}	366.62	66.5^{*}	171.38	$1x10^3$
	Ammonia	**5.42**	64.02	**4.76**	78.36	**7.05**	39.72	-
	Phosphorus	**2.83**	76.33	**1.42**	128.17	**1.48**	120.95	0.05
	COD/BOD	**21.67**		**7.63**		**12.85**		
P2	BOD	1.10	77.27	1.94	87.11	0.81	88.89	5.00
	FC***	**$2.96x10^{4*}$**	0.01	**$1.21x10^{3*}$**	15.55	205^{*}	150.33	$1x10^3$
	Ammonia	**7.05**	39.72	**4.87**	45.38	**7.69**	36.80	-
	Phosphorus	**1.82**	34.62	**1.11**	32.43	**0.57**	73.68	0.05
	COD/BOD	**12.78**		**8.32**		**6.7**		
P3	BOD	1.16	72.41	2.29	63.76	1.19	92.44	5.00
	FC***	**$2.69x10^{3*}$**	2.60	420^{*}	57.83	**$1.49x10^{3*}$**	12.93	$1x10^3$
	Ammonia	**7.60**	41.84	**4.90**	46.12	**7.76**	27.71	-
	Phosphorus	**2.10**	38.10	**0.94**	18.09	**0.59**	83.05	0.05
	COD/BOD	**10.07**		**8.34**		**19.81**		

* Geometric average. ** Reference values from CONAMA Resolution 357/2005; Values in bold are greater than the reference value. *** (NMP/100 mL).

Phosphorus levels in all 3 sampling points of the three rivers were higher than the reference value (0.05 mg/L), what may lead to eutrophication of these rivers. Phosphorus may originate from natural dissolution of soil compounds and organic matter decomposition as well as from anthropogenic activities, such as domestic effluents, animal excrement, and fertilizers. Excess phosphorous in the studied rivers may be related to agricultural activities, which are the main uses of these drainages upstream from the USWF (Table 2).

Ammonia levels also were above the average reference value of 3.7 mg/L for pH < 7.5. Occurrence of ammonia in waterways usually results from the conversion of organic nitrogen originated from animal excrement and fertilizers. Ammonia in its free form is highly toxic to fish (VON, 2005). The coefficients of variation for ammonia averages were relatively low, suggesting that the pollution level was stable for the whole period, or that variations in water flow compensated variations in the pollution level.

Another indicator for which the values were over the maximum allowed by the CONAMA Resolution 357/2005 is the thermotolerant fecal coliform group. In the Fabiano River, there was a violation at the point downstream from the solid waste facility. This contamination was likely related livestock raising activities in adjacent areas, which negatively impacts water quality (MERTEN; MINELLA, 2002). In the Varões River, a violation occurred at P2 (where the treated effluent from the sewage treatment plant of the sanitary landfill flows into the river) as well as due to the surface drainage of the closed dump Because the sewage treatment plant is inefficient in removing nutrients and coliforms, it can be inferred that this contamination is associated with the solid waste facility. In the Mutuca River, there were violations of the reference values at all the sampling points, reflecting the negative effects of upstream extensive livestock raising on water quality. The low coefficients of variation for the fecal coliform average suggest that the source of contamination is continuous.

The COD/BOD ratio was very high (above 6.7) for all the rivers, especially for P1 in Elói Mendes and P3 in Santo Antonio do Amparo, reflecting a high level of non-biodegradable organic matter.

In the Varões River, downstream the solid waste facility, the BOD concentration exceeded the reference value, reaching 6.35 mg/L (Figure 2). These high values may be associated with the lower river flow for the entire period monitored (0.004 m^3/s) and therefore a lower capacity of dilution of the upstream contaminant load.

The downstream DO in the Mutuca river decreased due to the biological degradation of organic effluents. This interpretation is supported by the lower DO average values (4.2 and 3.0 mg/L) found downstream the solid waste facility, which are below the reference value. This finding suggests that there is a source of diffuse pollution upstream the sampling point because no point source of pollution was found on the river and the flows occurring during the period were relatively high (0.386 m^3/s). A DO of 4.4 mg/L was observed under lower flow (0.283 m^3/s), which may be explained by a lower assimilation capacity by the river.

Water quality index

Higher WQI values at all sampling points were associated with periods of higher flow rate (Figures 3A, 3B, and 3C). The concentration of pollution indicators was attenuated when there was an increase in flow rate while the pollution load remained constant.

The lowest WQI values occurred at P2 (nearby the downstream point of influx from the Elói Mendes dump) (Figure 3A), being relatively lower in the raining season (October – March) than in the dry season (April – June). This fact is related exclusively to the parameters for turbidity and fecal coliform, which show different averages for the rainy and the dry seasons. Both turbidity and fecal coliform are highly influenced by the rainy season, when increased surface water flow carries loose soil and coliform sources.

The WQI for the Mutuca river was bad (25< WQI <50) at all sampling points (Table 4), what may be related to the fact that this river's basin is used for dairy farming.

In the Varões River, the lowest WQI also occurred at P2 (point after the discharge influx point from the sewage treatment plant) (. In the rainy season, the WQI was also lower and increased over the course of the period culminating in the dry season. However, some WQI peaks observed in the dry period, were influenced by an increase in fecal coliform. The average WQI was classified as medium (50<WQI<70), which is associated to a relatively well preserved area with difficult access (Table 4 and figure 3B).

In the Fabiano river, the worst WQI were found at P1 and P3, possible due to cattle raising in the areas that drain in the river (Figure 3C and table 4). The WQI at P3 showed extreme oscillations in the dry season, probably due to the presence of cattle that have free access to the river. The average WQI in the sampling point (66.31) was classified as medium (50< WQI <70).

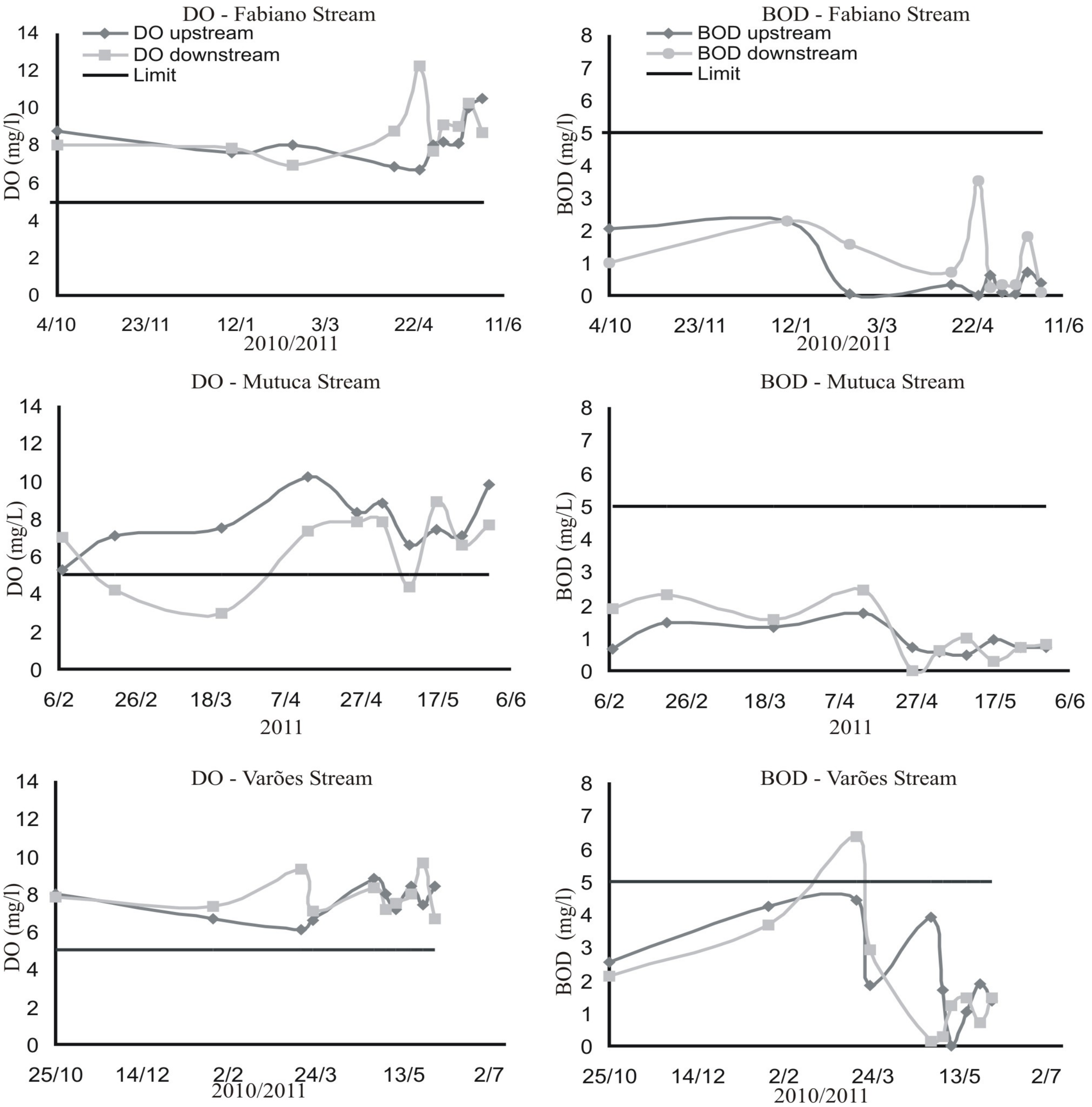

Figure 2 – Concentration of dissolved oxygen and biochemical oxygen demand upstream and downstream the solid waste facility during the study period.

The worst average WQI values were associated with the dump typology of the solid waste facility. However, when the sampling point is considered, Mutuca river (Elói Mendes city), is classified as having bad WQI at all three sampling points, suggesting that other factors in addition to the dump are contributing to this environmental picture.

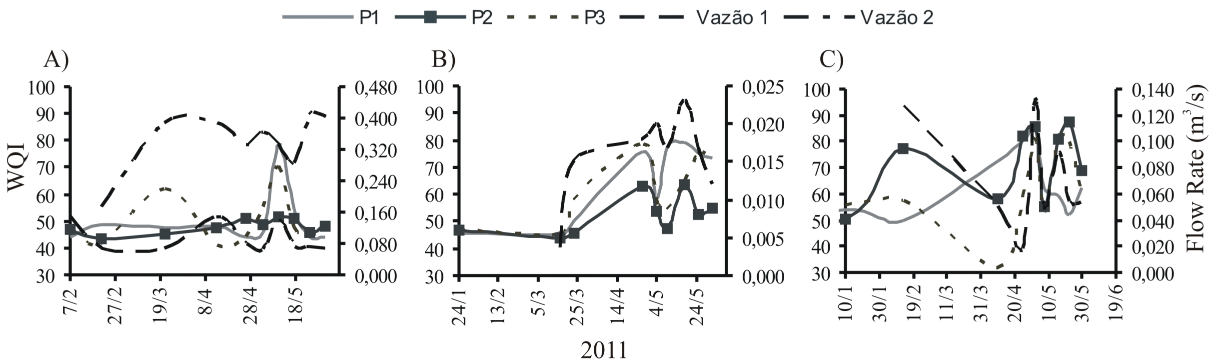

Figure 3 – Temporal and spatial variation of the water quality index related to flow rate for Mutuca (A), Varões (B), and Fabiano (C) rivers.

Table 4 – Average values for the water quality index during the study period and classification according to Igam (2004).

Sampling points	Water Quality Index		
	Mutuca River	Varões River	Fabiano River
P1	49.94	64.45	62.56
P2	47.95	52.37	68.96
P3	49.99	61.57	60.68
Average	49.29	59.46	66.31
Water Quality Index Classification	Bad	Medium	Medium

CONCLUSIONS

It was not possible to clearly identify significant effects of the solid waste facilities on the water quality indicators likely because of interference from other sources of contaminants. This study identified that water conditions were unsatisfactory due to violations to the allowable levels of phosphorus, ammonia, fecal coliform, and the biochemical oxygen demand/chemical oxygen demand ratio (BOD/COD). Among the three studied rivers, the lowest water quality was observed in the Mutuca river, where the WQI was classified as bad during the entire study period at all three sampling points. The multiple contaminants violations were likely related to other land uses in the drainage area upstream the solid waste facilities. This study suggests that diffuse sources of pollution may be widespread in the region. Further efforts are necessary to comprehensively evaluate sources of pollution in this region and to propose mitigation actions to restore water quality.

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