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Environmental Diagnostic of the Aurá River Basin (Pará, Brazil): Water Pollution by Uncontrolled Landfill Waste

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Authors' contributions

This work was carried out in collaboration between all authors. All authors participated of the samples collection. Authors GWS, FA and AD were responsible for date and statistical analysis and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The objective of this research was to evaluate the water pollution levels in the Aurá River basin and to provide subsidies to public decisions for the protection, preservation and conservation of basins for the supply the Metropolitan Region of Belém (MRB).

Study Area and Methodology: During periods of rain and drought from 2008 to 2012 were analyzed 16 environmental parameters (transparency, temperature, pH, electrical conductivity, total dissolved solids, dissolved oxygen, alkalinity, Cl-, total Fe and P, Total Kjeldahl Nitrogen, turbidity, BOD, COD, total coliforms and fecal coliforms) in 15 surface waters sampling sites in Aurá River basin at the MRB. The methodology followed international procedures, and a Water Quality Index (WQI) was applied.

Results and Conclusion: Aurá River suffers influence of the dump, as well as the surroundings of its watershed, which includes housing and agricultural areas. The data showed wide variability in

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the course of the Aurá River, especially as the Coliform content, conductivity, phosphorus and TDS. This behavior is related to the local geology; the superficial runoff due to rainfall in the basin; the resident population on the river edges and especially by the presence of the dump. Almost 90% of the Aurá River water is unfit to conventional treatment for public supply and can have a negative influence on the water quality intended to the local reservoirs.

Keywords: Pollution; contamination risk; water supply; city dump; water quality index.

1. INTRODUCTION

The environmental assessment of water resources is an important tool for conservation, control and remediation of impacts of human activities on the environment. In the Aurá River basin, the environmental assessment aimed to evaluate the level of water pollution due to the direct influence of an uncontrolled landfill (Aurá city dump), which has caused many social and environmental problems for the population of the MRB. Besides, the Aurá River basin exerts some influence on the right edge of the Guamá River, and consequently on the reservoirs designated to public supply.

The basic premise of public water supply for a determined population is that the water must be free of contaminants and pollutants, ensuring a quality supply, which reflect the social health and economic development. The increase of the urban population, industrialization, often without quality control, and agricultural processes, including waste pesticides, generates a huge volume of solid waste and effluents that are contaminating soil, surface water, sediments and waters, especially near the metropolitan areas.

An aggravating factor of the water pollution is the continuous and exponential increase in the diversity of waste and effluents, many with unknown contaminants properties and consequently with unpredictable results for terrestrial and aquatic biota. According to Siqueira et al. [1], in recent years, due to population growth combined with urban development, it has been the diversification of water uses in the Amazon region. This leads to an increase of waste production and the destruction of riparian forests, producing totally inadequate environmental conditions. As a result of human activities occurs degradation of water sources and increase and emergence of new waterborne diseases.

The maintenance of water resources, both for domestic consumption and industrial use, needs constant control of effluents in nature, based on parameters established to the preservation of fauna and flora, as well as reuse of water from reservoirs. In this sense, this research established environmental parameters that allow the implementation of the Water Quality Index (WQI) nationally recognized and used.

In MRB there is an extensive and diverse fluvial mesh of streams and channels, which in most cases are occupied irregularly, especially in marginal areas to rivers. This violates the terms of preservation under Brazilian federal law of conservation of basins. Thus, the results of this research may provide the basis for legal institutions developing better public policies for the preservation and conservation of Brazilian rivers basins.

2. MATERIALS AND METHODS

2.1 Study Area

Aurá River basin is the third largest basin in the MRB. This region includes the cities of Belém, Ananindeua, Marituba, Benevides, Santa Bárbara do Pará and Santa Izabel do Pará beyond Icoaraci and Mosqueiro districts, totaling according to IBGE Census 2010–2,100,319 inhabitants [2]. About 90% of the population of the MRB is served by treated water distributed by the Pará Sanitation Company (COSANPA), and the reservoirs Bolonha (2,100,000 m^3) and Água Preta (10,550,000 m^3), near the Aurá basin, account for 75% of supply in the municipalities of Belém and Ananindeua [2,3].

The Aurá River forms a watershed belonging to the Guamá River basin, with small drainage and continuous flow by the difference of 10 to 15 meters between the headwaters and its mouth. The Aurá basin is formed by an extensive system of channels and streams interconnected, and the Aurá River flows into the Guamá River, where the COSANPA Company catch water from Water Pumping System (WPS) located about 200 meters downstream from the Aurá mouth. Water is then sent to Bolonha and Água Preta lakes and after to Bolonha Water Treatment Plant

(WTP; Fig. 1). It should be noted that the reservoirs are located approximately 1400 meters west of the Aurá city dump, which steepness is contaminating the waters of the Aurá and Guamá rivers, as well as many streams of the region. Moreover, Bolonha and Água Preta reservoirs may have been affected by the housing around and by the waste-dump, it located upstream of the Aurá River headwaters (Fig. 1). Detailed descriptions of the Aurá River basin including hydrology, geology and climate, social and historical aspects of the dump were presented by [4-10].

2.2 The Landfill Turned Waste Dump

The "Santana do Aurá Landfill" is located 19 km from the city center of Belém (PA), and occupies a total area of 120 ha, 25% for the solid waste landfill. Despite the large number of lakes, rivers and streams in the region, studies carried out in 1989 determined that area as the best option for the landfill implementation. The presence of compacted clay soil and an old mine of laterite abandoned were the main arguments for the choice of location. Actually, Aurá Landfill receives non-hazardous solid waste from various sources including agricultural waste, totaling 1200 tons/day of waste [9]. The city dump is active, although there is a term signed by the Public Ministry of the Pará State and the municipalities of Belém and Ananindeua to close it.

In 1993 it was created the Environmental Protection Area of Belém (Belém - EPA) and the State Park Utinga (PEUt), both in order to preserve the reservoirs that supply of the MRB. Thus, the municipal landfill became part of the EPA, defined as State Unit of Conservation, that objectives ensuring water potability of the reservoirs, by restoring and maintaining the environmental quality of the Bolonha and Água Preta lakes and of the Aurá River (Fig. 1). The legal conflict generated by the superposition of municipal (SESAN - PMB) and state (SEMA) powers has hindered the actual management of the Aurá Landfill, which since 2007 has not environmental license to operate as landfill [7,9,11]. In addition, many irregularities have been observed through inspections, complaints and researches, such as low soil sealing allowing effluents reach groundwater; an inefficient drainage system for slurry; contamination of streams network, and the presence of garbage collectors groups and irregular communities

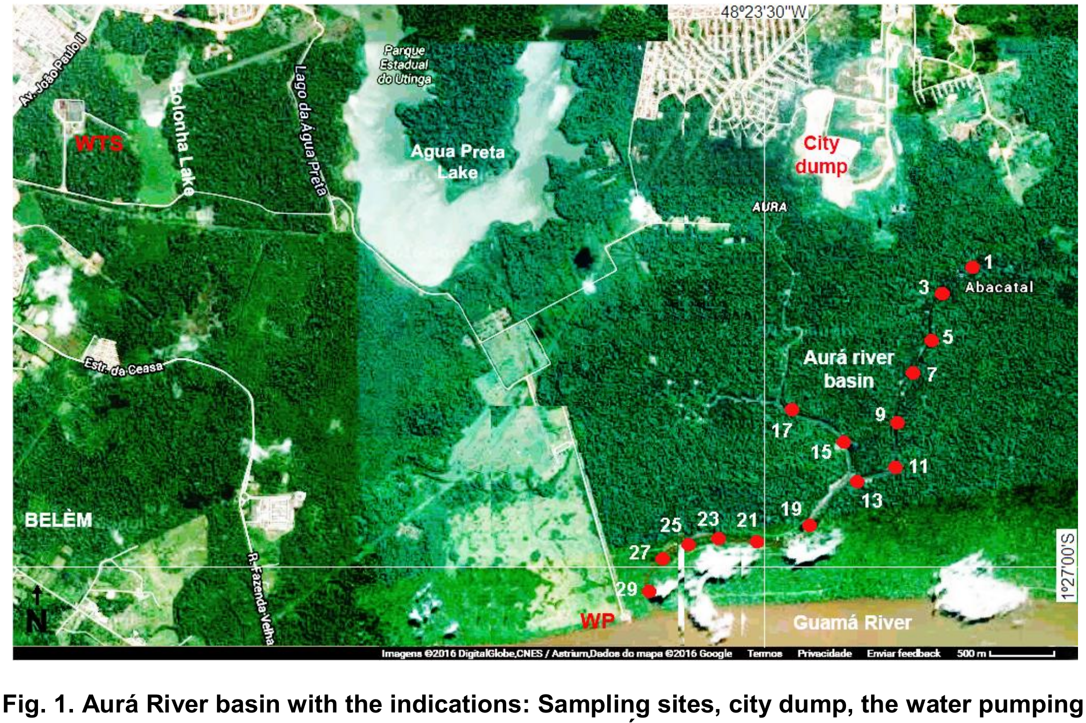

Fig. 1. Aurá River basin with the indications: Sampling sites, city dump, the water pumping system of the COSANPA (WPS), the Bolonha and Água Preta reservoirs and the Water Treatment Plant (WTP) used for public supply of MRB

living and working within the "landfill" area. For these reasons it is that currently the "Aurá Landfill" is considered according to the words of the Public Ministry of Pará (MPE-PA) a “dump in the open". The MPE-PA since 2010 investigates the complaint of riverside communities about a possible environmental contamination by sewage from the dump, which may be contaminating the underground aquifer and therefore the wells used by locals. The Federal Law 12,305/2010, which established the National Policy on Solid Waste, defined that could not be more dump in the open in the country since 2014, making the Aurá dump totally irregular.

2.3 Analytical Procedures

For the environmental assessment of the Aurá River basin were analyzed 16 physico-chemical and biological parameters in surface water (0.30 m) at 15 sampling sites distributed between the headwaters and mouth of the Aurá River basin (Fig. 1). The samples were taken in the morning before 10 AM, during periods of rain and drought between 2008 and 2012. Water samples were collected and preserved for analysis according to criteria established by [12]. Analytical procedures followed the protocols described in CETESB [13,14] and APHA/AWWA/WEF [15]. All chemical and biological analyzes were performed in the Chemistry Teaching Laboratory of the UFPA Faculty of Chemistry.

The parameters analyzed were: transparency (m) with Secchi disk; temperature (°C), pH, electrical conductivity (EC μS_{25}/cm), total dissolved solids (TDS mg/L) and dissolved oxygen (DO mg/L) all determined by direct reading with multiparameter probe electrodes; alkalinity (HCO_3^- mg/L) by potentiometric titration; Cl^- (mg/L) for automatic spectrophotometer with Hg thiocyanate (APHA Method 4500-CL - item F); total iron (Fe mg/L) by spectrophotometry with 4-aminoantipyrine (APHA Method 5530-C); total phosphorus (P mg/L) by the colorimetric method with ammonium molybdate and ascorbic acid (APHA Method 4500-P - item F); Total Kjeldahl Nitrogen (N mg/L) by acid digestion followed by automatic spectrophotometry isocianídrico acid (APHA Method 4500-Norg - item B); Turbidity (NTU) by turbidimeter; biochemical oxygen demand (BOD_{5-20} mg/L) for dilution and incubation at 20°C and 5 days (APHA Method 5210-B); chemical oxygen demand (COD mg/L) by spectrophotometry in closed reflux with dichromate (APHA Method 5220-D); total coliforms (MPN/100mL) by membrane filtration technique with incubation 24-48 h and 35ºC (CETESB NT L5.214); and Fecal coliforms (MPN/100ml) by membrane filtration technique (cellulose acetate 0.45 µm pore) followed by incubation for 24 hours at 44.5ºC (CETESB NT L5.221).

In order to establish an environmental assessment for the Aurá River permissible limits described in CONAMA Resolution Nº. 357 of 17/03/2005 [16] were adopted, which provides for the classification of water bodies and environmental guidelines for its framework. Thus, considering that 1) the river is located within a state unit of conservation; 2) the Aurá mouth in the Guamá River is located about 200 m upstream of the COSAMPA catchment point (WPS), and 3) the waters from Guamá River are transported to the reservoirs and after used for public supply of MRB, was established for the Aurá River the conditions and standards of freshwater class 1. From the results was applied the Water Quality Index (WQI) at the CETESB (regulatory agency) to the basin. For this, were used average curves of variation and calculus of weighted product of the variables temperature, pH, total phosphorus and nitrogen, STD, turbidity, dissolved oxygen, BOD and thermotolerant coliforms described in CETESB [17]. In this study also were adopted the terms of sanitation: untreated domestic sewage or tributaries and treated sewage or effluent.

3. RESULTS AND DISCUSSION

Table 1 shows the results of the environmental parameters used in the Aurá River basin. The transparency had little variation during the sampling period, ranging between 0.30 and 0.55 m (average 0.45±0.05 m). Low measured values for transparency are evidence of high load of suspended material in areas of the river, largely of terrigenous origin due to erosion of marginal soils, because many of these soils are already without the natural vegetation cover. The transparency is less near to the city dump influence, due to the runoff in the vicinity and the constant process of silting. The largest tributary of the Aurá River has an average width of 20 m, length of 3 km and its is situated 300 meters Southwest of the dump.

Due to the standardization of the timing of collection (in the morning), there was no significant variation in water temperature during the study period, which ranged between 25.9 and 29.5ºC (average 28.3±0,8ºC). However, it is noted that in site 1 wherein the lower temperature values were recorded, the river has a width of 15 meters and most of the water surface has shading, interfering with the heating of the water column. In rivers of this region the longitudinal and seasonal variations in temperature are always very small due to the equatorial location and other factors such as flow. The pH is an important parameter indicator of environmental quality, since most chemical reactions and biological processes that occur in aquatic systems are directly affected by this variation. According to Wupcenter – MTU [18] aquatic organisms are very sensitive to pH variation, with established range "great" for the biological functions between 6.5-8.5 and below 6.0 aquatic lives would be at risk. Of course this classification does not fall to the Amazon region, where lentic and lotic systems have slightly acidic to acid characteristics, being in "ecologically adapted" group to pH values between 4.5 and 7.5.

The use of established classifications for environmental parameters is very delicate, since many of these values do not represent the regional reality. This is true even for the limits established by CONAMA Resolution Nº. 357 adopted in this study, which deals of the classification of the general water bodies for the entire national territory. The pH ranged from 6.5 to 7.9 (average 7.3±0.3) remaining within the limits designated by law [16], which for class 1 of fluvial waters establishes pH values between 6.0 to 9.0. The slightly alkaline condition of the water in lakes may be associated with increased photosynthetic activity, which would explain the sequestration of CO_2 from the water. The pH and temperature have a strong influence on the distribution of dissolved substances in rivers and lakes, especially on organic material and metals, mainly when a gradient is observed between the surface and deeper layers. Low values in the background should be often the predominance of breathing on the photosynthesis. There was no influence of slurry from the landfill on the pH. This can be attributed to the dilution of the effluent or the good buffering capacity of the system by alkalinity.

Alkalinity is defined as the ability of an aqueous system has to neutralize acids without disturbing of extreme form the biological activities occurring in it (natural buffering effect of water). The alkalinity is mainly due to bicarbonate and carbonate ions and, secondarily, to the ions borate, hydroxide, silicate, phosphate and ammonia. If a system has high alkalinity, it is more stable and resistant to pH variations. Moreover, increasing volumes of humic acids from organic decomposition in the system, its buffering capacity is consumed. In the Aurá River carbonate alkalinity ranged from 9.1 to 53.0 mg/L (average 29.9±9.6 mg/L). It should be noted that in sampling site 1, under the influence of residues (slurry waste) from the dump, the largest alkalinities were recorded. The slurry has higher density than the waters of the river, and so initially reaches the deeper layers of the fluvial channel. Thus, the effect of mixture to the river will only be reflected in more downstream of their entry. This fact may contribute to the reduction of

Table 1. Results of the environmental parameters applied to the Aurá basin between 2008 – 2012

		Min.	Max.	Aver.	SD	Md	S^2	CV (%)
Transparency	(m)	0.30	0.55	0.46	0.05	0.05	0.00	11.5
Temperature	(ºC)	25.90	29.50	28.35	0.77	0.63	0.59	2.7
pH		6.55	7.95	7.32	0.35	0.30	0.12	4.8
Alkalinity	(mg/L)	9.10	53.00	29.93	9.63	7.41	92.66	32.2
Cl^-	(mg/L)	20.00	43.10	34.90	6.18	4.70	38.17	17.7
E.C.	(uS_{25}/cm)	32.00	274.00	117.61	58.91	46.59	3470	50.1
Total Fe	(mg/L)	0.09	1.23	0.84	0.31	0.23	0.09	36.5
Total P	(mg/L)	0.11	3.44	1.80	0.79	0.62	0.62	43.9
Total N	(mg/L)	3.42	9.14	6.17	1.67	1.38	2.79	27.1
TDS	(mg/L)	32.00	232.00	105.69	44.79	34.78	2006	42.4
Turbidity	(NTU)	7.20	38.00	22.20	7.95	6.75	63.17	35.8
D.O.	(mg/L)	0.66	2.57	1.51	0.61	0.52	0.37	40.3
BOD_{5-20}	(mg/L)	6.12	42.25	21.59	8.52	7.01	72.62	39.5
COD	(mg/L)	9.60	55.20	29.79	11.26	9.53	126.77	37.8
Total coliforms	(NMP/100 ml)	950	11000	3093	3130	2237	9795990	101.2
Fecal coliforms	(NMP/100 ml)	280	3670	1016	788	534	620809	77.5

** SD= standard deviation; Md= medium deviation; S^2= variance; CV= coefficient of variation* buffer capacity, as can be noted at sampling sites more downstream, where the values of alkalinity were reduced to half the amount registered to upstream. In general the alkalinity values determined were significant bit, which according [19] are typical values of streams or of Amazon rivers with influence of quaternary soils.

The main natural sources of Cl^- in freshwater are the aerosols produced by oceanic evaporation, which Aprile et al. [20] defined as "marine spray", and dissolution of minerals leached from the soil. Already anthropogenic sources include: domestic sewage, industrial effluents, fertilizers and pesticides. Sewage has great contribution in changing the Cl^- levels in receiver systems, which is an important indicator of Cl^- contamination by residues of anthropogenic origin. CONAMA Resolution Nº. 357 it classifies natural waters into three categories according to their salt concentrations, and the limit for freshwater class 1 is 250 mg/L of Cl^-. All Cl^- values obtained in this study were below the resolution limit, ranging from 20.0 to 43.1 mg/L (average 34.9±6.2 mg/L). This is another case in which the average levels recorded in Amazonian waters [21,22] are very different from those allowed by the Resolution. Cl^- values recorded in the Aurá River are almost 10 times higher than the average found in Amazonian rivers and, however, are in accordance with the law. Based on this information it is pertinent to say that the levels of Cl^- in Aurá waters are from anthropogenic sources, in particular from the dump.

The electrical conductivity is probably the most environmental parameter that has varied in the region. In this study, the conductivity ranged 32-274 μS_{25}/cm with average 117.6±58.9 μS_{25}/cm. These values are characteristic of muddy water with high sediment loads in suspension. However, it should be noted that in natural courses of water, a variation as this only occurs if there are sources external the river course. Thus, the conductivity measured along the Aurá basin is certainly due to a high load of dissolved ions originating from the dump added to clay minerals leached from the riverbanks. The use and illegal occupation of the river basin have entailed increased eroded soil load and leached into the water system receiver, a fact evidenced by the increase in conductivity especially during the rainy season. Despite CONAMA Resolution Nº. 357 no set limit for electrical conductivity in its classification of the waters, it should be emphasized that in streams and rivers in general the large increase in the values of conductivity of the water necessarily indicate anthropogenic origin of dissolved ions. Thus, the authors consider the evaluation of values and variation of conductivity in streams as of great importance for the interpretation of external influences to the water environment.

Iron is one of the most abundant elements in the earth's crust, and for this reason many surface and underground natural waters have total iron levels and dissolved above the potability limits established by law. Iron can be in the reduced form (Fe^{2+}) or oxidized (Fe^{3+}). The stability of ions Fe^{2+}, Fe^{3+}, $Fe(OH)^{2+}$, $Fe(OH)^+$ in relation to the $Fe(OH)_2$ and $Fe(OH)_3$, precipitated or in colloidal form, depends especially on the pH and Eh. Under the conditions observed in Aurá River near neutral pH (average 7.3) the tendency is the predominance of ferrous iron in suspension and the complex-precipitated $Fe(OH)_n$ (n= 2, 3 or 4). The total iron content in the surface water of the Aurá River ranged between 0.09 and 1.23 mg/L (average 0.84±0.31 mg/L). Natural sources of iron include leaching of marginal soils and erosion of the rocks of the basin bed. However, it is believed that the waste dump should be responsible for transporting most of the examined iron, especially facilitated by the acid pH of the slurry. As effluents are mixed with the natural waters of the Aurá River carbonates started to consume H^+ ions increasing the pH of the mixture. Thus, the precipitation of iron to sediment in the form of hydroxides tends to increase. Studies conducted by [8] in the sediments of the Aurá River showed average levels of total iron 2.5% or 25 g/kg. CONAMA Resolution Nº. 357 and Ordinance Nº 518 of the Ministry of Health [23] both established maximum values of 0.3 mg/L as standard for fresh water class 1. In this aspect, only the sampling sites 7 and 21 showed up within permissible limits.

Phosphorus is an essential element for the growth of algae and bacteria responsible for the stabilization of organic matter, but in large amounts can establish eutrophication of aquatic ecosystems. Phosphorus can be found in water as orthophosphate (PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$), polyphosphate, and organic phosphorus. The main sources of phosphorus are the leaching of soil and litter, decaying organic matter, including slurry leachate from dumps, domestic and industrial wastes, fertilizers (NPK), detergents and animal waste. In natural waters usually dissolved total phosphorus is present in low concentrations, except in coastal systems, which by the location received considerable phosphorus inputs through the "marine spray" [20]. In Aurá River basin was recorded high total phosphorus content and large longitudinal variation (from 0.11 to 3.44 mg/L and average 1.80±0.79 mg/L). Knowing that there is a vast net of channels in the headwaters and along the Aurá River, it can be suggested that these components of the river basin contribute large amounts of P from different organic matter mineralization processes in the basin. These channels carry organic matter of waste dump as well as all around the basin, which includes areas of agriculture especially the East of the headwaters of Aurá River (Fig. 1). The comparative analysis with current legislation showed that all sampling sites are above the standard set by CONAMA Resolution Nº. 357 of 0.1 mg/L.

In the study area N ranged from 3.42 to 9.14 mg/L (average 6.17±1.67 mg/L). The variation of the N followed the same trend of P in the different ranges of concentrations in the river. Thus, the highest levels occurred at the three sites more upstream (average 8.45 mg/L), on influence of the dump. Almost all sampling sites had values above the CONAMA Resolution Nº. 357 for water class 1 of 3.7 mg/L for Total Kjeldahl Nitrogen. The ratio N/P (Table 2) calculated had variation between 2.1 to 34.3 (average 5.1±6.3), with the exception of site 15 all other monitored sites presented ratios lower than 10:1, indicating high load of total phosphorus in surface waters of the river Aurá. The presence of phosphorus and nitrogen in reservoirs in high concentrations result in algal blooms, with damage to water supplies. The results of this research suggest eutrophication of the Aurá River basin, since the concentration of P and N were 180 and 20 times higher than the natural levels in equatorial rivers.

The total dissolved solids (TDS) are the sums of the contents of all mineral components in water. In this study the STD values ranged between 32.0 and 232.0 mg/L (average 105.7±44.8 mg/L). The maximum value allowed for STD is 500 mg/L according to CONAMA Resolution Nº. 357 for water class 1 and therefore, the contents analyzed in the Aurá River fitted all within the limits established by law. Still, the largest STD values were found in sampling sites 1, 3 and 17 (this main tributary of the Aurá River). It is more probable that these values be originate in the erosion processes on the drainage basin associated with effluents from the dump. The levels of TDS have wide range in the upstream – downstream direction. This suggests that as the water flow occurs both deposition in the channel and edges as suspension and addition of suspended solids in its waters, which after extensive variation, flow into the Guamá River with levels around 80 mg/L.

Turbidity is the degree of reduction in the intensity of light passing through the water column. Especially in rivers, turbidity is a measure directly related to the concentration of total suspended solids. Other factors can also interfere with turbidity, such as concentration of algae and microorganisms, domestic and industrial waste, organic waste from tannery and waste dump. The slurry has high total solids load, which reduce the transparency and increase the turbidity of the body water. High turbidity can compromise the process of disinfecting of the water, since the specific surface of the particles in suspension (especially organic matter and clay) easily adsorbs bacteria and viruses [24]. In Aurá River basin, the turbidity varied greatly from upstream to downstream, with the highest values found in the influence area of the dump. Throughout the basin the values ranged between 7.2 and 38.0 NTU (average 22.2±7.9 NTU) to permissible limit of 40.0 NTU according to regulatory agency. In the influence area of the dump the average turbidity was 30 NTU. Paint pigments, dyes and eroded soils containing clay near to city dump may also contribute to elevated turbidity, affecting the photosynthetic activity and concentration of dissolved oxygen. The waters that reach Bologna WTP from the reservoirs usually have variable turbidity. Vasconcelos [3] determined in Bolonha WTP between 2007 – 2009 values from 3.4 to 25.5 NTU. Santos et al. [25] determined turbidity values in Água Preta Lake between 4.0 and 88.0 NTU, and Sodré [26] determined to Bolonha and Água Preta lakes values between 4.0–59.0 NTU. All authors attributed the high turbidity as direct influence of the Guamá River. However, it is necessary to understand that the turbidity in Guamá River is practically constant during the hydrological cycle, since the Guamá is essentially an equatorial river of white-waters, daily subjected to the hydraulic effect of the tides. So, it is possible that the variation of the turbidity on the mentioned reservoirs been more related to the high amount of the local phytoplankton and/or suspension of sediments than the direct influence of the Guamá River.

Table 2. Reasons and numerical relationships between BOD, COD and nutrients

	BOD/N/P	COD/N/P	BOD/N	COD/BOD	Xi	Fi	Xi*Fi	Xi^2*Fi	|di| = |xi-xm|	|di|*Fi
Min.	3:2:1	4:2:1	1,0	1,1	1,081	1	1,1	1,168	0,000	0,000
Max.	144:34:1	205:34:1	7,8	1,6	1,596	1	1,6	2,549	0,348	0,348
Aver.	20:5:1	27:5:1	3,7	1,4	1,390	1	1,4	1,937	0,061	0,061

During the stabilization of organic matter, bacteria make use oxygen in their respiratory processes, and in some cases cause severe reduction in the O_2 concentration in water, and therefore the death of many organisms, including fish [27]. The role of oxygen is not limited to biotic processes, it also acts on chemical processes occurring in the water column as well as control of the release and retention of inorganic phosphorus in the sediment into the water column and vice versa [28]. The concentration of DO in surface waters of the Aurá River ranged from 0.66 to 2.57 mg/L (average 1.51±0.61 mg/L), with the lowest values observed during periods of drought, corroborating with [3], which determined DO levels between 1.00 and 4.80 mg/L in the Guamá River, near the water pumping site of COSANPA. As the Aurá River is a small river, certainly in the dry season with the reduced flow, the internal processes that operate in oxygen consumption become more evident. Although is common low DO levels in Amazonian waters, especially in lentic environments under conditions of stagnation and shaded streams, higher values were expected to Aurá River, since it is inserted in a conservation area and there is significant difference in elevation between the headwaters and the mouth. The sampling sites 1 and 3 in the headwaters and sites 9 and 21 in the middle course presented at various phases of environmental monitoring concentrations <1.00 mg/L in surface waters, indicating strong oxygen consumption, possibly due to natural biological processes associated biological degradation of organic matter carried with effluents from the city dump. The decrease of DO levels in water may also be related to irregular occupation of the basin and sewage releases into the river. At low DO concentrations the anaerobic conditions prevail, causing strong and unpleasant odor in the waters, as was observed in the area of influence of the dump. Environmental legislation for waters class 1 establishes that water samples should contain values ≥6.00 mg/L (or ≥5.00 mg/L for Class 2). Thus, the waters of the Aurá River are totally out of certain standard by law.

The excess organic material is a major cause of water pollution, since in these conditions there will be excessive oxygen consumption in the metabolic processes of use and stabilization of organic matter by microorganisms [27]. The BOD and COD are parameters used to indirectly assess the degree of pollution of the aquatic environment. Thus, BOD depicts the amount of oxygen required to stabilize the carbonaceous organic matter by biochemical processes, being an indirect indication of biodegradable organic carbon or biochemically oxidized. The COD analysis of the measured oxygen consumption occurred due to the chemical oxidation of organic matter, being an indirect indication of the total organic carbon (TOC), and therefore, an essential parameter in characterization studies of sewage and industrial effluents. The BOD varied within the monitoring period between 6.12 to 42.25 mg/L (average 21.59±8.52 mg/L), while the COD ranged from 9.60 and 52.20 mg/L (average 29.79±11.26 mg/L). CONAMA Resolution Nº. 357 for class 1 establishes standard for BOD ≤3 mg/L, which means that all sampling sites were presented nonstandard. For COD the Resolution makes no reference, but an estimated COD/BOD ratio is of prime importance for surface water, as this relationship will indicate both the biodegradable fraction as the type of treatment to be applied in the system. In Aurá River the ratio COD/BOD calculated (Table 2) was always greater than 1.0 (from 1.08 to 1.60), indicating that there is a moderate intake of biodegradable organic carbon fraction of the total carbon. This situation should be explained by the high input of organic matter previously degraded and consumed by bacterial activity in the dump area (old slurry). These data corroborate the low DO levels determined in surface water.

It is not possible to establish fixed relations between BOD and COD, since the seasonality (precipitation), origin and volume of the waste changing the ratio of these environmental parameters. If the sample consists of compounds oxidized by both processes BOD and COD, the COD can replace analytically the BOD. However, if the sample has predominantly oxidized material chemically but not biochemically, the COD is calculated excessively greater than the BOD, as usually occurs in receiver systems containing toxic components and industrial contributions. Analyzes in different STPs have indicated COD/BOD ratios ranging between 1.25 and 3.30 for untreated sewage and from 1.80 to 6.47 (maximum 8.38) for wastewater [27,29-31]. Values between 1.5 and 2.5 suggest that the pollutants present in the effluent are predominantly biodegradable, whereas values above 5.0 suggest not biodegradable contaminants [32]. Another classification mentions the sewage characteristic "*in natura*" suggesting reasons from 1.25 to 1.90 for weak sewage; 1.70 to 2.30 medium sewage and >2.50 for strong sewage [31], must be biological treatment followed by physical and chemical processes in the effluent. The Pearson correlation analysis between BOD and COD was 0.9912 (strong correlation) indicating that the COD can be used to estimate the BOD by applying direct equation (COD = 1.3097*BOD + 1.5192), as this analysis is rapid (<3 hours) and efficient.

The ratio BOD_5/nutrients (N, P) allows evaluating the significance of the organic fraction in the total content of nutrient. The ratio BOD_5/N ranged from 1.0 to 7.8 (Table 2) indicating to have moderate to low concentration of reduced forms as N-organic and $N\text{-}NH_4^+$ especially in relation to nitrate. This result suggests that although the Aurá River receive significant effluent load from the dump, the system has considerable debugging capabilities. The ratio $BOD_5/N/P$ is considered indicative of the speed of the biological treatment WTPs and STPs, has been adopted according [33] a minimum ratio of 100:5:1 as required to maintain an adequate balance of organic matter and nutrients for biological treatment (aerobic methods) and 350:7:1 in the anaerobic process. In this study the BOD and COD relations with nutrients were quite variable, and the maximum values obtained were 144:34:1 and 205:34:1, respectively (Table 2).

In addition to the sources of pollution by solid waste and waste in general, water intended for supply present the risk of being contaminated by wastewater and excreta of animal origin containing pathogenic organisms. Thus, become an important route of transmission of infectious diseases caused by viruses, bacteria, protozoa and helminthes. Because of its high potential to spread these diseases pose a significant risk to human health, and are responsible for high morbidity and mortality, especially among children in developing countries. Diseases such as cholera, schistosomiasis, amebiasis, diarrhea and childhood hepatitis (A and E) are among the diseases that cause more victims in the world, and all are related to poor sanitation. The United Nations says that 2.1 million children under 5 die each year because of a lack of clean water [34]. The Brazil has serious public health problems, with about 20% of its total population without water and nearly 40% untreated sewage. In the North these rates are higher, and the state of Pará has some of the municipalities with the lowest rate of water treatment and sewage in the country's [24,35]. All Amazonian states show low levels of sewage treatment, reflecting in the low quality of the public health. Consequently, the most part of the sewage producing in the municipal districts are discarding in water-bodies without any treatment [8], resulting in pollution of the aquatic ecosystems by faecal material.

Among the parameters of diagnostic and environmental monitoring is the analysis of total coliforms. The coliforms group includes genres of fecal and not faecal origin, with several bacteria that are exclusively environmental, and can be found in clean waters, seafood and vegetables. For this reason, it is that the restricted analysis of total coliforms is not currently recommended for diagnosis of water supply, been used in the evaluation of treatment effectiveness, cleanliness and integrity of the water distribution systems [36]. The indication of fecal contamination from warm-blooded animals is through the faecal coliforms or thermotolerant. Among the various genres that make up the Coliform group Escherichia, Enterobacter, Citrobacter and Klebsiella are distinguished by being present in large quantities in animal feces. For this reason, these bacteria have been used extensively as indicators of fecal contamination. In Aurá River basin water total coliforms values ranged between 950 and 11,000 MPN/100 mL (average 3093±3130 MPN/100 mL) and thermotolerant coliforms between 280 and 3670 MPN/100 mL (average 1016±788 MPN/100 mL). Considering the presence of the dump upstream of the basin and the irregular occupation around, all sampling sites had values above the allowable (200 MPN/100 mL) by the CONAMA Resolution Nº. 357 for freshwater class 1 [16].

The Water Quality Index (WQI) is an important environmental indicator in the decision making process of public policies and monitoring of their effects on the conservation of water resources. The WQI of the Aurá River basin ranged from 19 to 36, which the classification of CETESB [17] represented 7% of state waters "good" or "acceptable" (sampling site 17); 86% "bad" or unsuitable for conventional treatment before the supply; and 7% in condition "very bad" or "improper" to supply (site 1; Fig. 2). Silva et al. [37] applying WQI the waters of the reservoirs of the region determined index 41 “acceptable” for a sampled site in the Aurá River and mean 55 to three sites sampled in the Guamá River at the water pumping system area (WPS). It is clear that the water taken by the adductor (WPS) has a treatment and decontamination process. Nevertheless, considering that the WPS is less than 200 m downstream from the Aurá mouth, the indication of moderate pollution should be reinterpreted as "Attention Situation" to establish a program effective of monitoring of the basin.

Riverine population installed in the Utinga State Park (PEUt) has suffered pressure from pollution and environmental contamination by more than two decades. More than 100 families live on the Aurá River edges and live daily with various waterborne diseases. The community of Santana of Aurá, installed surrounding the dumpsite, filed a complaint in the MPE-PA in 2007 on environmental pollution in the community because of the dump waste that would be contaminating the groundwater and wells. Report elaborated by the Evandro Chagas Institute [38] confirmed that there is microbiological contamination in the waters of local community wells. The report also revealed that the pH and fecal coliforms were outside the limits recommended by Ordinance Nº. 518 of the Ministry of Health [23]. Siqueira and Aprile [8] showed that the soil and sediment of the Aurá River basin are enriched in metals by anthropogenic processes. In the dump area there are more than 1000 people in subhuman conditions working as garbage collectors [9], and a cooperative formed by the collectors itself, which adds around 80 collectors of selective collection. All residents and local workers are exposed to various diseases by pollution of the river and the "landfill of the Aurá".

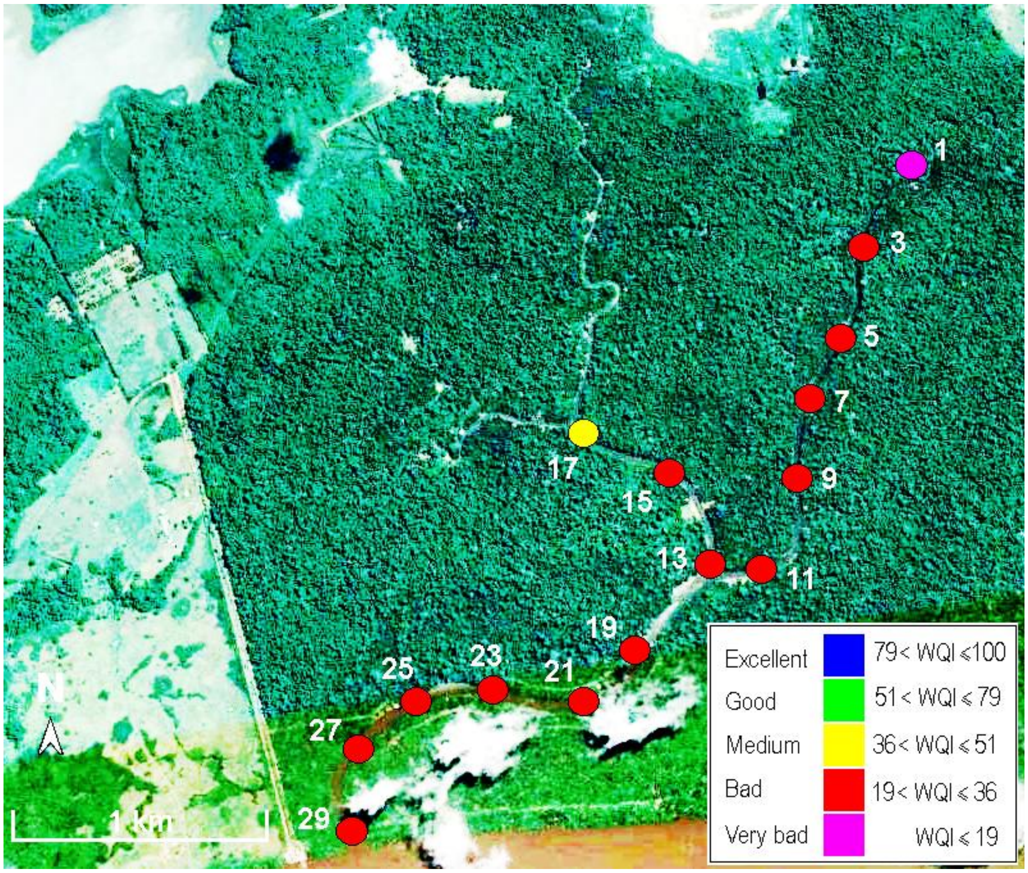

Fig. 2. Spatial analysis of WQI for the Aurá River basin

4. CONCLUSION

From this study we can say that the Aurá River suffers direct and indirect influence of the dump, as well as the surroundings of its watershed, which includes housing and agricultural areas. The wide range of environmental parameters values observed in this study suggests that the entry of effluents into the main channel of Aruá and its main tributary to occur in different points by smaller streams. It is possible to occur this route many natural mechanisms such as self-purification, decomposition of organic matter, erosion of riverbanks and siltation. It is also possible that the waters of the Aurá River after confluence with the Guamá River and already in adduction point for the lakes be with their standard of environmental quality timidly committed.

Based on CONAMA Resolution Nº. 357 for freshwater class 1 it can be concluded that the Aurá River have moderate pollution and contamination environmental. The Pearson correlation analysis between BOD and COD indicated that the COD can be used to estimate the BOD safely and quickly. WQI indicated that most of the Aurá River (86%) is not suitable for conventional treatment of water for public supply. However, the relevant legislation must be followed to be made effective this recommendation. In addition to the environmental sanitation, the health of the basin is at risk due to various degradations that the river is suffering, including the problem with riverine populations that depend on the river to survive.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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