Bioindicators assessing water quality and environmental impacts of water treatment plant sludge

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Abstract: This study had as objectives to assess water quality using macro-invertebrate communities in Gaviao artificial reservoir (Brazil), used to supply potable water to 2.5 million people, and to evaluate how these organisms responded to the discharge of water treatment sludge into a natural wetland. A total of 1,621 specimens across 23 taxa were identified. Mollusca were the dominant and most frequent group while Insecta presented the most richness. Based on feeding mode, there were more predator organisms than scrapers. The Biological Monitoring Working Party (BMWP') method showed to be more sensible to water quality variations than ASPT index, going from polluted to questionable water quality more frequently. The chemical parameters analysed showed no significant variations and were not a sensitive method for assessing water quality. No organisms could be found downstream of the sludge discharge point, indicating a high impact of sludge disposal on local biota.

Keywords: macro-invertebrates; bioindicators; artificial reservoir; water quality; water treatment sludge.

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1 Introduction

Concerns with the deterioration of water resources' quality and the safety of aquatic ecosystems are increasing because of the large amount and diversity of pollutants discharged every day. The problem of deterioration of water quality is magnified in arid and semiarid regions due to irregular rainfall and high evaporation rates (Gheyi et al., 2012; Levy, 2011; Santos et al., 2014). These diverse and complex factors that have an impact on water resources have generated an additional burden to the regional and national economies, since it increases the costs of aquatic ecosystems recovery and water treatment for human consumption. Poor water quality impoverishes local populations and inhibits sustainable development (Alvarez et al., 2013; Tundisi, 2008). In Brazil, most of the sludge generated at water treatment plants (WTPs) is still disposed irregularly into the environment, despite the existing environmental laws governing the matter (Oliveira et al., 2004; Tartari et al., 2011). This inadequate disposal can have negative impacts, both by increasing the amount of solids and turbidity and introducing toxic agents into the water, as well as compromising the stability of aquatic life (Filho et al., 2013; Hoppen et al., 2006). Traditionally, the assessment of these environmental impacts is accomplished by measuring chemical and physical variables (CONAMA, 2005; Fonseca et al., 2014; WHO, 1996). However, many authors (Beneberu et al., 2014; Bere and Tundisi, 2012; Calderon et al., 2014; Rinaldi, 2007) state that the use of biological responses as environmental degradation indicators are more advantageous compared to chemical and physical parameters since these non-biological measurements only represent a snapshot of the moment they were collected. This means a large number of samples to evaluate temporal variation are required. Thus, the study of human interventions through sensitive biological communities or biomarkers represent an advantage over chemical and physical indicators (Demars and Edwards, 2009; Gomes et al., 2014; Roa et al., 2012).

Macro-invertebrate communities have been widely used as biomarkers for a number of reasons: they are ubiquitous, respond to perturbations in all aquatic environments at any given time, and there is a large number of species that offers a broad spectrum of responses. Furthermore, it utilises simple and cost effective collecting methodologies and allows for relatively uncomplicated organism identification (Findik, 2013; Gullan and Cranston, 2008; Vidal-Abarca et al., 2013).

A number of studies have been conducted considering the sensitivity of the macro-fauna in Brazil (Couceiro et al., 2007; Cummins et al., 2005; Magris and Destro, 2010; Ottoni, 2009; Rodrigues and Ferreira-Keppler, 2013). Freire (2007) identified that Gaviao reservoir's aquatic fauna is composed mainly of fish and amphibians. Leitao et al. (2006) studied the zooplankton community composition and abundance in this same reservoir. However, despite its regional importance, no studies have been published focusing on bio-monitoring and invertebrate fauna surveys such as molluscs, annelids, insects and other invertebrates. The present study aims to gain an insight regarding the aquatic macroinvertebrate community of Gaviao reservoir, to elucidate how those organisms respond to the WTP sludge disposal and to categorise Gaviao reservoir water quality using the Biological Monitoring Working Party (BMWP) index.

2 Materials and methods

2.1 Geographic location

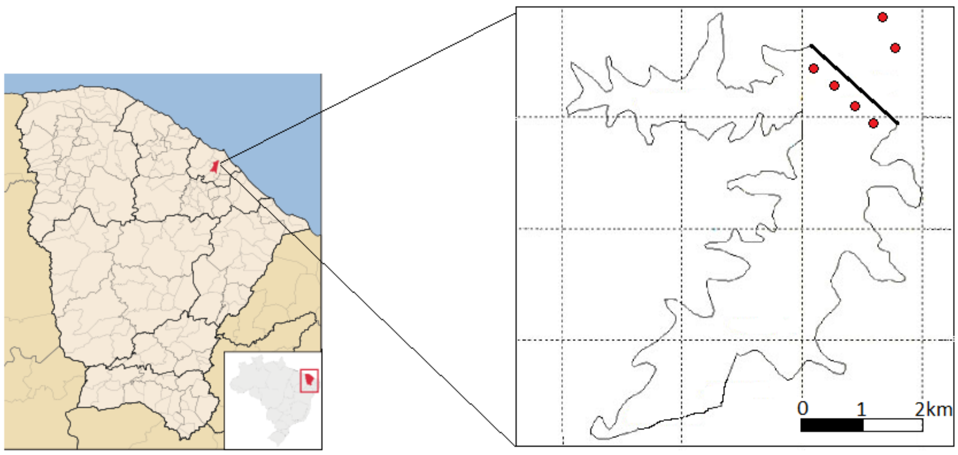
This research was conducted in Gaviao reservoir witch has a total capacity of 33.30 × 10^6 m^3, a hydraulic detention time of approximately 40 d, and it is located 30 km south of Fortaleza, Ceara, Brazil. Gaviao reservoir is included in the Fortaleza Metropolitan Region (FMR) watershed and receives contribution from the Gaviao river during the rainy season (February to May) and from the Pacajus-Pacoti-Riachao reservoir system, all year long, through two channels that transport water from the Jaguaribe river and Castanhao reservoir. It is responsible for supplying water to approximately 2.5 million people and to the industrial complexes located in the FMR (Freire, 2007).

The FMR WTP is located downstream of Gaviao dam. It utilises descendent direct filtration, using poly aluminium chloride (PAC) and a cationic organic polymer as coagulation agents, chlorine dioxide and chlorine as pre oxidant and disinfectant agents, respectively, and fluorosilicic acid as recommended by the Brazilian Ministry of Health. The filters backwash process utilises treated chlorinated water. The backwash water, as well as the water treatment sludge is discharged without any treatment to a natural wetland located downstream and besides the reservoir dam, before it reaches the Gaviao river.

2.2 Sampling locations

Six sampling locations were selected, four located upstream from and two further downstream of the dam, where the waste from the WTP is disposed (Figure 1). Criteria when considering sampling site locations were: accessibility, different substrates such as macrophytes or rocks and a depth between 1 and 2 m. Because for most lakes and reservoirs the amount of benthic taxa is higher in the coastal zone (Smiljkov et al., 2008; Trichkova et al., 2013), the four points upstream were selected alongside the dam, spaced at regular intervals.

Figure 1 Geographical location of Gaviao reservoir and sampling locations (see online version for colours)



Source: Adapted from Abreu (2006)

The rainy season contributes over 75% of the mean annual precipitation, which is 1,066 mm a^{-1} on average. Evaporation can reach up to 1,700 mm a^{-1} and the average annual temperature is 26°C (Datsenko, 2000).

The metropolitan watershed has a crystalline foundation, represented by a Gneiss-Migmatite Complex and granitic rocks, predominantly Acrisol and Arenosol (COGERH, 2010). The reservoir's permanent protection area is composed almost entirely of arboreal vegetation and anthropised areas are limited.

2.3 Macro-invertebrate sampling

The reservoir's epifauna was collected from between 1 to 2 m depth from October 2012 to May 2013. Except for the months of March and April, samples were collected monthly at the four selected locations across the dam (P1, P2, P3, and P4), in addition to two other locations downstream of the dam (J1 and J2). At each location, three samples were collected with a trawl net (0.5 mm mesh) supported by a 25 cm wide square frame, as suggested by ISO standards (AQEM, 2002). To facilitate the capture of organisms, the net was passed on the bottom and sides, near the vegetation and sediment of the reservoir and the wetland (Sterz et al., 2011). The invertebrates removed from the sampled material were placed in a micro tubes fixed with aqueous ethanol (90%) and then sealed within 48 h (INAG, 2008).

2.4 Sample triage and data analysis

The invertebrate screening process consisted of separating large groups and discarding exuvia, empty shells and fragments such as legs, antennas or wings. All collected organisms were stored in aqueous ethanol (70%) for identification into their taxonomic families. A stereomicroscope (Nikon SMZ745T) was used (10 to 50× magnification), according to a method adopted from several researchers (Agudo-Padron, 2008; Bennetti et al., 2006; Froehlich, 2007; Garcia-Davila and Magalhaes, 2003; Leite and Sa, 2010; Pes et al., 2005), and by pictorial keys (Almeida et al., 2008; Bis and Kosmala, 2005; Kannowski, 1992; Moretti, 2004; Pinho, 2008; Segura et al., 2011).

Five categories were used to classify the macro-invertebrates' feeding mode:

1 gathering collectors

2 filtering collectors

3 shredders

4 predators

5 scrapers (Cummins and Merritt, 1996).

The BMWP score system (National Water Council, 1981) is a water quality assessment method that consists of attributing a score ranging from 1 to 10 to each taxonomic family according to their tolerance to water pollution. Taxonomic families that are intolerant to pollution are ranked highest while families that are capable of tolerating pollution have lower scores (Armitage et al., 1983). When summing all scores obtained for each family present in each sample, it was possible to frame the values obtained into seven biological quality classes (Table 1).

Table 1 Relationship between BMWP and water quality (see online version for colours)

Class	*Quality*	*Range*	*Significance*	*Colour*
I	Excellent	> 150	Very clear water (pristine water)	Lilac
II	Good	121–150	Clear water, unpolluted or system is not perceptibly altered	Dark blue
III	Acceptable	101–120	Very little pollution, or system is slightly altered	Light blue
IV	Questionable	61–100	Moderate effects of pollution are clear	Green
V	Polluted	36–60	Contaminated or polluted water (altered system)	Yellow
VI	Very polluted	16–35	Very polluted water (system is significantly altered)	Orange
VII	Extremely polluted	< 16	Extremely polluted water (system is strongly altered)	Red

Source: Modified from IAP (2003)

In this work, the BMWP adaptations by Alba-Tercedor and Sanchez-Ortega (1988), Alba-Tercedor (1996, 2000), Baldan (2006), Cota et al. (2002), Junqueira (2009), Loyola (1998), Monteiro et al. (2008) and Toniolo et al. (2001) were used, referred to as BMWP'.

In order to establish a correlation between the BMWP' biotic index and the water quality in the reservoir, the scores attributed to families detected at sampling locations P1, P2, P3, and P4 were summed, and compared to the global water contamination index (GWCI).

The average score per taxon (ASPT) index, which represents the ratio between the BMWP' value and the total families found in sampling locations (P1, P2, P3, and P4) was also used. The use of the ASPT index is important to confirm the results obtained by BMWP' (Cota et al., 2002; Junqueira, 2009). By using the ASPT index, the following water classification can be obtained: clear (> 6); questionable quality (5 to 6); moderately polluted (4 to 5); and severely polluted (< 4), according to Mandaville (2002).

Rainfall data were obtained in a rain gauge station located at Itaitinga (FUNCEME, 2013) from October 2012 to May 2013. Raw water from Gaviao reservoir and the WTP sludge were analysed for pH, total hardness, conductivity, total aluminium and total dissolved solids based on APHA et al. (2005). Those parameters were used since they are utilised by the State Water and Wastewate Company to assess water quality and the environmental impact of the sludge.

3 Results and discussion

3.1 Chemical variables

The Gaviao reservoir inflow and outflow were approximately 8,200 L s^{-1} with a total volume ranging from 90 to 95 % of its maximum capacity. From October to December 2012 no rainfall was observed in the reservoir or in the Pacajus-Pacoti-Riachao Reservoir system watersheds. Rainfall was detected in Gaviao reservoir watershed during January (61 mm), February (228 mm) and May 2013 (124 mm), as well as in its tributary reservoirs' watersheds: Pacajus (53; 43; and 150 mm) and Pacoti-Riachao (14; 93; and 120 mm) (FUNCEME, 2013).

The water pH in Gaviao reservoir varied from 7.6 in November to 8.4 in January, a typical pH value for Brazilian semiarid region superficial water storage (COGERH, 2010). According to Sprague's (1985) classification, total hardness varied from moderately hard in October (130 $mg_{CaCO3}.L^{-1}$) to hard in December (174.7 $mg_{CaCO3}.L^{-1}$). The concentration of aluminium varied between 0.04 $mg_{Al}.L^{-1}$ in November and 0.02 $mg_{Al}.L^{-1}$ in January and February (Table 2), below the threshold of 0.1 $mg_{Al}.L^{-1}$ established for freshwater by CONAMA (2005). The raw water conductivity ranged from 832.5 $\mu S.cm^{-1}$ in December to 728.9 $\mu S.cm^{-1}$ in May. In the case of the state of Ceara, due to high evaporation rates, conductivity should not be used as an indicator of pollution or anthropogenic impact. The WTP sludge displayed pH between 6.9 and 7.3 and aluminium concentration varied from 0.08 $mg_{Al}.L^{-1}$ in December to 1.08 $mg_{Al}.L^{-1}$ in January (Table 2). Although neither federal nor state legislation establishes a maximum amount of aluminium allowed in the wastewater, Schmidt et al. (2002) showed that dissolved aluminium concentrations as low as 0.18 $mg_{Al}.L^{-1}$ can strongly impair benthic macroinvertebrate communities.

Table 2 Chemical characteristics of Gaviao reservoir raw water (RW) and sludge (SL) from the WTP from October 2012 to May 2013

Parameters	*2012*						*2013*					
	October		*November*		*December*		*January*		*February*		*May*	
	RW	*SL*	*RW*	*SL*	*RW*	*SL*	*RW*	*SL*	*RW*	*SL*	*RW*	*SL*
pH	8.0	7.1	7.6	6.9	8.0	7.1	8.4	7.3	8.3	7.1	-	-
Total hardness ($mg_{CaCO3}.L^{-1}$)	130.0	Na	155.3	Na	174.7	Na	172.8	Na	172.8	Na	166.9	Na
Conductivity ($\mu S.cm^{-1}$)	788.8	Na	802.7	Na	832.5	Na	828.0	Na	811.9	Na	728.9	Na
Total aluminium ($mg_{Al}.L^{-1}$)	0.03	0.22	0.04	0.42	0.04	0.08	0.02	1.08	0.02	0.71	-	-
Total dissolved solids ($mg.L^{-1}$)	433.8	Na	441.4	Na	457.8	Na	517.2	Na	446.5	Na	400.9	Na

Notes: Na – not analysed; Ab – absent; Ps – present.

3.2 Macroinvertebrate characterisation

A total of 1,621 invertebrate specimens were collected from October 2012 to May 2013. Those organisms were distributed across four phyla (Annelida, Mollusca, Platyhelminthes, Arthropoda), six classes (Clitellata, Gastropoda, Turbellaria, Arachnida, Malacostraca, Insecta) and 23 families. Only two specimens could be classified up to their order. Based on this identification, a table with the scores for each taxon was drawn for the Gaviao reservoir (Table 3).

Table 3 Scores used for Gaviao reservoir

Taxon	*Score*	*Pollution tolerance*
Lestidae, Libellulidae	8	Smaller tolerance
Polycentropodidae	7	↓
Thiaridae, Palaemonidae, Ancylidae	6	
Noteridae*	5	
Caenidae, Baetidae, Stratiomyidae, Hydracarina (Pionidae, Mideopsidae, Arrenuridae)	4	
Gerridae, Mesoveliidae, Notonectidae, Corixidae, Glossiphonidae, Physidae, Planorbidae, Hydrobiidae, Ampullariidae**	3	
Chironomidae	2	Higher tolerance

Source: Adapted from Alba-Tercedor and Sanchez-Ortega (1988) and Alba-Tercedor (1996, 2000); *Junqueira (2009); **Miller et al. (2008)

A total of 338 specimens were collected in October, November and December 2012 (dry season), and 1,283 specimens occurred in January, February and May 2013 (rainy season). Taxonomic richness was scarce in the dry season, especially in November 2012 and abundant in wet period especially in February 2013. This correlates with Abilio et al. (2007), who noted greater taxonomic richness during the wet season in Taperoa II and Namorado reservoirs, located in the state of Pernambuco, on the South-central border of Ceara state.

The communities present during the rainy season may be different from that of the dry season (Bispo and Oliveira, 2007), due to differing reproductive cycles. However, according to Sonoda (2010), this seasonal variation should not affect the method's water classification capability.

Most species were obtained at location P1 (1,030), followed by P2 (369), P3 (209), and P4 (13). This difference between locations may be related to the presence of macrophytes, which were abundant at locations P1, P2 and P3 but were sparse at sampling point P4. According to Shimabukuro and Henry (2011), the littoral community is more diverse where higher macrophyte densities are present. According to Taniwaki and Smith (2011) macrophytes also maintain substrate stability, allowing for greater organism density.

Groups identified in the Gaviao reservoir were also found in other reservoirs in Brazil. Eight reservoirs along Paranapanema River, in the state of Sao Paulo, presented a total of 96 taxa. The benthic macroinvertebrates were represented by 7 major zoological groups, presenting the greatest richness with the class Insecta, with 60 taxa (Jorcin and Nogueira, 2008). Eight of these families were also found in Gaviao reservoir (Polycentropodidae, Chironomidae, Stratiomyidae, Ceratopogonidae, Glossiponiidae, Thiaridae, Ancylidae, Physidae, Planorbidae and Hydrobiidae).

In Americana reservoir, also in the state of Sao Paulo, Pamplin et al. (2006) collected 19 taxa of macro-invertebrates, among which the following families also were present in Gaviao reservoir: Chaoboridae, Chironomidae, Ceratopogonidae, Glossiphoniidae, Thiaridae, Polycentropodidae and Stratiomyidae). The Bodocongo reservoir, located in the same semi-arid region, presented 11 families (Viana et al., 2013), among which eight families (Chironomidae, Thiaridae, Ampullaridae, Ancylidae, Planorbidae, Libellulidae, Physidae e Baetidae) were also found in Gaviao reservoir.

Table 4 Analysis of macroinvertebrates of Gaviao reservoir from October 2012 to May 2013

Taxa (feeding groups)	*Frequency*	*Oct/12*	*Nov/12*	*Dec/12*	*Jan/13*	*Feb/13*	*May/13*
Turbellaria							
Specimen 1 (1)	f	+	--	--	--	--	+
Annelida							
Glossiphoniidae (4)	ff	--	--	--	--	--	+
Gastropoda							
Ampullaridae (5)	F	+	--	+	+	--	++
Thiaridae (5)	FF	+++	++++	+++	+++	++	+++
Ancylidae (5)	FF	+	+	+	+	+	+
Physidae (5)	ff	--	--	--	--	+	--
Planorbidae (5)	FF	++++	++++	++++	++++	+++	++++
Hydrobiidae (5)	FF	+	+	+	+++	++++	++
Hydracarina							
Mideopsidae (4)	f	--	+	--	--	+	--
Arrenuridae (4)	f	+	--	--	+	+	--
Pionidae (4)	ff	--	--	--	--	+	--
Decapoda							
Palaemonidae (4)	F	--	+++	++	+	+	--
Isopoda							
Specimen 1 (1, 2)	f	--	--	--	+	+	+
Odonata							
Lestidae (4)	FF	+	+++	++	+	+	+
Libellulidae (4)	F	--	+	++	+	--	+
Hemiptera							
Corixidae (4)	F	+	+	++	+	+	--
Notonectidae (4)	F	+	--	+	+	+	--
Mesoveliidae (4)	f	+	--	++	--	+	--
Gerridae (4)	f	--	--	+	--	+	+
Coleoptera							
Noteridae (4)	ff	+	--	--	--	--	--

Notes: According to feeding mode: (1) gathering collectors; (2) filtering collectors; (3) shredders; (4) predators; (5) scrapers. According to dominance [+++++ (eudominant – over 60% relative abundance); ++++ (dominant – from 25 to 59% relative abundance); +++ (almost dominant – from 10 to 24% relative abundance); ++ (not very dominant – from 5 to 9% relative abundance); + (not dominant – less than 5% relative abundance]; and according to frequency [FF (when the taxon was recorded throughout the entire period of study); F (when the taxon was recorded in at least four months during the study); f (when the taxon was recorded for a period of less than four months); ff (when the taxon was recorded in only one month throughout the study)].

Table 4 Analysis of macroinvertebrates of Gaviao reservoir from October 2012 to May 2013 (continued)

Taxa (feeding groups)	*Frequency*	*Oct/12*	*Nov/12*	*Dec/12*	*Jan/13*	*Feb/13*	*May/13*
Trichoptera							
Polycentropodidae (1, 2, 4)	f	--	--	--	+	+	++
Diptera							
Chironomidae (1, 2, 4, 5)	FF	+	+	+	+++	++	+++
Stratiomyidae (1)	f	+	--	--	--	+	--
Ephemeroptera							
Baetidae (1, 5)	f	--	--	--	+	+	--
Caenidae (1)	ff	+	--	--	--	--	--

Notes: According to feeding mode: (1) gathering collectors; (2) filtering collectors; (3) shredders; (4) predators; (5) scrapers. According to dominance [+++++ (eudominant – over 60% relative abundance); ++++ (dominant – from 25 to 59% relative abundance); +++ (almost dominant – from 10 to 24% relative abundance); ++ (not very dominant – from 5 to 9% relative abundance); + (not dominant – less than 5% relative abundance]; and according to frequency [FF (when the taxon was recorded throughout the entire period of study); F (when the taxon was recorded in at least four months during the study); f (when the taxon was recorded for a period of less than four months); ff (when the taxon was recorded in only one month throughout the study)].

Predation (13) was the most abundant feeding mode, followed by scrapers (8). It should be observed that no shredders we detected in this study. These results can be explained by the fact that predators and scrapers are less restrictive and can be found in several types of environments (Vannote et al., 1980).

The presence of scrapers may also have been influenced by the presence of periphyton, which thrive in lentic water bodies (Callisto and Esteves, 1998) and are the main food source for scraper organisms. The absence of shredders may have been caused by the fact that they are more common in areas with a dense dossal, such as lakes or rivers with riparian forest, which is not the case for the sampling locations in this investigation (Taniwaki and Smith, 2011).

Most frequently encountered were the taxonomic families of the Thiaridae, Ancylidae, Planorbidae, Hydrobiidae, Lestidae and Chironomidae, found throughout the entire period of study. The Glossiphoniidae, Pionidae, Noteridae, Caenidae, and Physidae families were less frequent and were only encountered during one month. The most abundant family was Planorbidae, with 559 collected specimens (34%), followed by Hydrobiidae and Thiaridae with 318 (20%) and 234 (14%) specimens, respectively. Physidae, Caenidae, Notoeridae and Glossiphonidae were represented by only one specimen each (<1%) (Table 4). No eudominant families were encountered, that is, none with over 60% relative abundance throughout the period of study.

Molluscs were the most frequent, dominant and abundant taxon. From the six sampled families, Planorbidae, Hydrobiidae, Thiaridae represented 68% of total collected specimens. This abundance of molluscs can be related to the water pH levels (average pH 8.0) found in the Gaviao reservoir (Table 2). Abilio (2002) studied water resources in the semi-arid region of Paraiba state, Brazil, and also noted greater abundance of molluscs in high pH environments. According to Leite (2001), electric conductivity and water pH can influence mollusc population composition and abundance.

According to Rosenberg and Resh (1993), aquatic environments' macro-invertebrate family abundance is reduced with decreasing environmental quality. Usually, when there is a predominance of one specie or when the community is dominated by few species, there are strong indications of negative environmental impacts.

Two mollusc families collected are related to water-borne diseases: Planorbidae, intermediate host of *Schistosoma mansoni* (schistosomiasis) and *Fasciola hepatica* (fasciolosis), and Thiaridae, intermediate host of *Paragonimus westermani* (paragonimiasis) and *Clonorchis sinensis* (oriental liver fluke) (Pointer, 1993). Furthermore, the family Thiaridae to which the invasive species *Melanoides tuberculata* belongs may be harmful to endemic fauna, since it is highly adaptable and competes for food and habitat.

By applying the BMWP' method to organisms collected a score of 91 was obtained, which indicates that the water in Gaviao Reservoir is of questionable quality. More families occurred in February (19), October (16), and November (10). As shown in Table 5, after correlating the BMWP' biotic index with the IAP (2003) index, water quality ranged from questionable (October 2012, January and February 2013) to polluted (November and December 2012 and May 2013).

Table 5 BMWP' scores for the Gaviao reservoir, from October 2012 to May 2013 (see online version for colours)

Month	*Taxa number*	*BMWP'*	*Class*	*Quality*	*Significance*	*Colour*
Oct/12	16	63	IV	Questionable	Moderate effects of pollution are clear	Green
Nov/12	10	49	V	Polluted	Contaminated or polluted water	Yellow
Dec/12	13	57	V	Polluted	Contaminated or polluted water	Yellow
Jan/13	15	66	IV	Questionable	Moderate effects of pollution are clear	Green
Feb/13	19	76	IV	Questionable	Moderate effects of pollution are clear	Green
May/13	13	52	V	Polluted	Contaminated or polluted water	Yellow

Results obtained with the ASPT index responded differently from those of BMWP' during the sampling period. In October 2012 the ASPT method showed severe pollution, while the BMWP' method showed questionable water quality. As for the other months, the ASPT remained at moderate pollution levels (Table 6) while BMWP' varied to polluted, moderate pollution and back to polluted water.

Table 6 ASPT scores for the Gaviao reservoir, from October 2012 to May 2013

Month	*ASPT*	*Quality*
Oct/12	3.9	Severe pollution
Nov/12	4.9	Moderate pollution
Dec/12	4.3	Moderate pollution
Jan/13	4.4	Moderate pollution
Feb/13	4	Moderate pollution
May/13	4	Moderate pollution

The differences in ASPT and BMWP' in October 2012, January, and February 2013 may be related to the fact that some of the families collected in those months may score lower in the BMWP'. On the other hand, the presence of organisms that are sensitive to organic pollution, such as Trichoptera and Ephemeroptera, in January and February 2013 may reinforce the hypotheses that water quality actually improved in those months. Since chemical parameters analysed during the sampling period had no significant variations, other factors such as rainfall or chemicals that were not monitored, may have contributed to the emergence of these families.

The biological data obtained supports the results of a study conducted by Vidal and Capelo-Neto (2014), who conducted chemical and physical analyses and compared their findings to the time series data (2005 to 2009) provided by COGERH (2010). The authors observed a gradual increase in total concentrations of nitrate, ammonia and phosphorus since 2005. The concentrations found recently were clearly higher than average historical data showing that in general, Gaviao reservoir water quality is progressively worsening, despite seasonal improvements due to rainfall.

Although the sampling frequency undertaken was the same as those upstream of the dam, no macro-invertebrates were observed downstream. Therefore, it was not possible to apply either the BMWP' score or the ASPT index to assess water quality. According Sanches and Junk (2003), the effect of improper disposal into the environment of waste generated by WTPs has proven extremely damaging. The discharge of WTPs wastewater into waterways can introduce sediments in these environments and promote toxicity in aquatic organisms, mainly due to metals such as aluminium, high concentrations of solids, turbidity and increasing the biological oxygen demand (BOD). Untreated sludge released into an aquatic environment with low speed may cause sedimentation and thereby isolation of the benthic layer (Kress et al., 2004), colour changes, and disturbances in the chemical and biological composition on the receiving body (Barbosa et al., 2001; Schmidt et al., 2002).

Another parameter that may have caused this absence of macro-invertebrate is the residual chlorine present in the sludge with possible damage to the food chain. Palmer et al. (2003) mentioned the toxic effects of residual chlorine on aquatic life especially fish and macro-invertebrates. Pasternak et al. (2003) proved the toxicity of residual chlorine and chloramines and concluded that the non-disinfected sewage is less harmful to aquatic biota than chlorinated ones.

4 Conclusions

The macro-invertebrate communities detected in Gaviao reservoir were divided into four phyla (Annelida, Mollusca, Platyhelminthes, Arthropoda), six classes (Clitellata, Gastropoda, Turbellaria, Arachnida, Malacostraca, Insecta), 23 families and 1,621 specimens. No eudominant families were found. Most of these species were collected during the rainy season. Regarding the feeding mode, it was identified that more predators than scrapers were present, no shredders were found.

Invertebrate families Planorbidae, Hydrobiidae, Thiaridae represented 68% of specimens found in the Gaviao reservoir. Mollusc need to be monitored more closely since two families that act as intermediate host of a potentially harmful parasite to humans were found.

ASPT method indicated that Gaviao's water was severely polluted in October 2012 and moderately polluted from November 2012 to May 2013, while the BMWP' method showed apparently to be more sensible to water quality variations, going from polluted to questionable water more frequently. The chemical parameters analysed showed no significant variations and were not a sensitive method for assessing water quality.

No macro-invertebrates were collected or observed downstream from the WTP sludge discharge point, and therefore nether the BMWP' nor the ASPT index could not be applied to assess water quality, despite a monthly sampling effort. It is important to conduct more detailed studies on the impact of untreated WTP sludge and waste water disposal on aquatic biota, analysing in more details the biochemical interactions involved.

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