Vol.66: e23220117, 2023
https://doi.org/10.1590/1678-4324-2023220117
ISSN 1678-4324 Online Edition

Article - Engineering, Technology and Techniques

Aquatic Macroinvertebrate Community Structure Affected by Chromium Contamination in the Monte Alegre Stream (SP): a Historical Comparative Case Study)

Bruna Nayara Cardoso Silva[1]*
https://orcid.org/0000-0002-7569-1710

Juliano José Corbi[1]
https://orcid.org/0000-0003-0249-9370

[1]Universidade de São Paulo, Escola de Engenharia de São Carlos, Departamento de Hidráulica e Saneamento, Laboratório de Ecologia de Ambientes Aquáticos, São Carlos, São Paulo, Brasil.

Editor-in-Chief: Alexandre Rasi Aoki
Associate Editor: Marcos Pileggi

Received: 17-Feb-2022; Accepted: 04-Jul-2022.

*Correspondence: brunanayara_15@hotmail.com (B.N.C.S.).

HIGHLIGHTS

- We evaluated the influence of chromium contamination on water quality in ten years.
- Aquatic macroinvertebrate community structure was influenced by land use.
- The area impacted by chromium showed lower macroinvertebrate richness and diversity.
- There were better environmental conditions in 2007 when compared to 2017.

Abstract: In 2001, 150 tons of tannery waste was incorporated in the soil as a source of organic matter on the Monte Alegre Farm. This waste, which originates from the tannery industry and contains high chromium concentrations, was irregularly used as a soil fertilizer by farmers to produce mangoes, sugarcane, coffee, oranges, corn and lemons, contaminating the soils. This irregular application of tannery waste also contaminated stream sediment and bioaccumulated in some aquatic macroinvertebrate. The present study aims to collect current information about the aquatic macroinvertebrate community to make a comparison between chromium contamination in the Monte Alegre stream sediment with a study carried out in 2007 in the same place. The aquatic macroinvertebrate community was collected from April to September 2017 using an Ekman-Birge grab at two sampling points: one point at the forested area (Upstream Point) and another near the place of the contaminated soil (Downstream Point). Sediment samples were collected to analyze chromium concentration. The current concentration of chromium in the downstream point (impacted area) was higher than that obtained in 2007. The community metrics confirm that the taxonomic structure and diversity of the aquatic macroinvertebrate community to the Monte Alegre stream were affected by chromium. The results suggest that the environmental impact was maintained after ten years.

Keywords: tannery waste; community indexes; contamination; aquatic invertebrates; metal.

INTRODUCTION

Pollution of aquatic ecosystems by metals has aroused interest in terms of the effects on the environment and aquatic biota [1-3]. Once adsorbed to the sediment, metals can become bioavailable to the water column, affect aquatic biota and be transferred along the food chain [4]. They can also bioaccumulate in toxic concentrations to organisms and cause changes in their structure and distribution [5-7], interfere with growth, development, reproduction, DNA biosynthesis and even cause mortality [8,9]. In the aquatic environment, the sediment represents a compartment responsible for metal accumulation [10].

The aquatic macroinvertebrate community is essential for freshwater ecosystems as they act in ecological processes of nutrient cycling and energy transfer in the environment [11]. These individuals represent the ecological diversity of the environment and can respond to impacts of human activities and have been used as water quality bioindicators and biomonitoring of environmental conditions [12-15]. The presence of copper and zinc from the deposition of urban waste was related to increasing the incidence mentum deformities in Chironomidae [16]. In another study, aquatic macroinvertebrates as bioindicators were used to detect metal pollution in the Brazilian Cerrado streams [6].

On the Monte Alegre farm, located in the municipality of Bueno de Andrada, State of São Paulo, approximately 150 tons of leather waste was disposed of in the soil as a source of organic matter. Near this region, several industries that produced leather gloves irregularly discarded leather shaving waste in the settlement soil, where sugarcane, mangoes, lemons, oranges, tangerines, corn and legumes were grown, which are a source of livelihood for families and commercialization in the region. This discard caused not only soil contamination but also contamination of the aquatic biota and sediment of the Monte Alegre stream, located close to the settlement [17].

In the study conducted by Santos and coauthors [17], concentrations of chromium were detected in the soil on the Monte Alegre (SP) farm totaling 30.93 and 55.85 mg kg^{-1} in the sugarcane cultivation areas and 40.2 and 567.2 mg kg^{-1} in the contaminated soil. This impact led to the accumulation of chromium in the sediment and consequent changes in the aquatic macroinvertebrate community structure of the Monte Alegre (SP) stream, causing a reduction in species diversity and richness in the chromium contaminated area [18].

Thus, it is believed that chromium contamination can still affect the aquatic macroinvertebrate community of the Monte Alegre stream and that the chromium concentration would decrease over time. Based on this hypothesis, the present study aimed to carry out a historical comparative study 10 years after the study conducted by Corbi and coauthors [18]. The aim was to analyze the chromium concentrations in the sediment in the Monte Alegre stream and the impacts on the richness and taxonomic diversity of the macroinvertebrate community.

MATERIAL AND METHODS

Study area

The present study was developed in the Monte Alegre stream, located on the Monte Alegre farm, in the municipality of Bueno de Andrada, State of São Paulo, Brazil (Figure 1). The Monte Alegre stream is the low order, it has a has water velocity of 2.0 m s^{-1}, a depth of 0.8 m, a width of 1.5 m and is located at about 570m altitude, within in the Cerrado area.

Two sampling points were selected close to the collection points in the study by Corbi and coauthors [18]. Point one was established as the reference (Upstream) and is located above the point of chromium contamination in the coordinates within closed and preserved forest. The other point (Downstream) is located close to the contaminated area by chromium in the coordinates. This point is influenced by agriculture and the presence of the settlement. Sediments and stream macroinvertebrates were collected in two periods, April and September 2017.

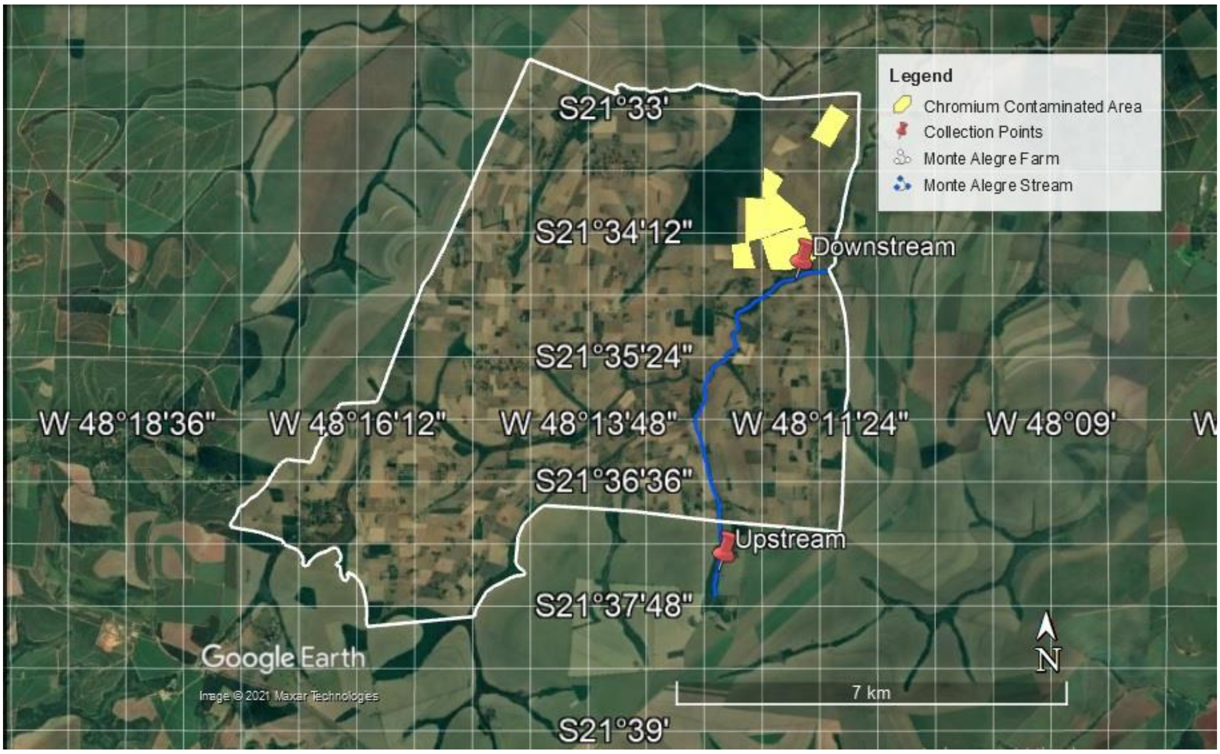

Figure 1. Location of the sampling points (Upstream and Downstream) in the Monte Alegre stream (Google Earth, 2021).

Physical and chemical characterization

The physical and chemical water variables of pH, temperature, dissolved oxygen, and electrical conductivity of the water were measured *in situ* using the Yellow Springs multimeter, model 556, only once period (September 2017).

Sediments for chromium and organic matter analysis were sampled using a standard Ekman-Birge grab (standard area of 225 cm²) in two periods (April and September 2017). Sediment samples (about 2.0 g) for the chromium determination were oven dried at 65 ºC and digested with nitric acid (HNO_3) at 90 ºC on a hot plate [19]. The solutions of metal were analyzed by atomic absorption spectrophotometry. The organic matter of the sediments was analyzed, in triplicate, by mass loss on ignition (550 ºC, 4 hours) [20].

Community sampling

The aquatic macroinvertebrate community was collected, in triplicate, in two periods, April and September 2017, using an Ekman-Birge grab (standard area of 225 cm²). The samples were placed in plastic pots, sent to the laboratory, and then washed in a 0.250 mm mesh sieve. The organisms were selected on a transilluminated tray and fixed in 70% alcohol for taxonomic identification at the family level, based on the keys available from [21-22].

Data analysis

To verify the difference in chromium and organic matter concentrations between the two sampled points, the Kruskal-Wallis test was applied using the PAST Program. The stream macroinvertebrates were analyzed by the participation of each taxonomic group and by the total organisms collected in each sampled point. The following parameters were determined for the macroinvertebrates: Margalef richness index; Shannon diversity index; %EPT (Ephemeroptera, Plecoptera and Trichoptera); EPT/total of families X 100; EPT/Chironomidae X 100; Chironomidae/total X 100; BMWP Biotic Index (Biological Monitoring Working Party) and IBB Biotic Index (Belgian Biotic Index) based on [23]. To determine the richness index (Margalef) and the diversity index (Shannon), the PAST program (Paleontological Statistics) was used [24]. Afterwards, the results of the present study were compared with the results obtained by Corbi and coauthors [18].

RESULTS

Physical and chemical characterization

The temperature varied from 19.5 to 21.5ºC. The upstream point showed acidic pH (6.72) and the downstream point was within the tolerable limits for most fauna and flora, which is 5.0 to 9.0 [25]. The dissolved oxygen was low in the two sampled points, varied from 2.3 mg L^{-1} to the upstream point and from 0.6 mg L^{-1} to the downstream point. The decomposition process of dead organic matter may be related to low concentrations, as chemical processes and anaerobic respiration require a high demand for dissolved oxygen to occur [26]. The low concentration of the downstream point which is related to the characteristics of the location, has stagnant water and low turbulence. The electrical conductivity of the impacted area (338 µS cm^{-1}) was higher than reference area (22 µS cm^{-1}).

The organic matter was low, ranging from 17.3% (upstream point) to 31.9% (downstream point). Statistical tests show a significant difference between the two areas ($p<0.05$). Chromium was detected in higher concentrations in the impacted area, confirming the results obtained in 2011 [18]. In the reference area, the chromium concentration was 29.62 mg kg^{-1} and in the impacted area it was 38.42 mg kg^{-1} (Table 1). The Kruskal-Wallis test showed no significant difference between the reference and impacted areas (p value 0.35).

Table 1. Comparison of chromium concentrations in the sediment of the Monte Alegre stream analyzed by the present study and by Corbi and coauthors [18] for the points equivalent to the reference area and the area impacted by chromium.

	Chromium concentrations (mg.kg^{-1})	
	Present study*	**Corbi and coauthors (2011)****
Upstream	29.6 ± 1.5	8.0 - 10.9
Downstream	38.4 ± 11.3	30.1 - 32.4

*Values averages. ** Minimum and maximum values for the period of study

Aquatic macroinvertebrate community

In this study, a total of 333 organisms were observed, distributed into 12 families (Table 2). The most representative family was Chironomidae (Diptera), found in the two sampled points. The reference area showed greater richness and diversity of families compared to impacted area. The Trichoptera and Ephemeroptera orders had abundance only in the reference area, with the occurrence of the families Leptoceridae, Calamoceratidae and Leptophlebiidae. In impacted area, there were no organisms of these orders and the Ceratopogonidae and Chironomidae families were the most prevalent. In both areas, the presence of the Libellulidae, Ceratopogonidae, Tipulidae, Chironomidae and Oligochaeta families was observed.

Table 2. Macroinvertebrate community of the Monte Alegre stream analyzed for the points equivalent to the reference area (Upstream) and the area impacted by chromium (Downstream)

Taxonomic Group	Upstream	Downstream
Coleoptera		
Elmidae	-	2
Syrtidae	1	-
Diptera		
Ceratopogonidae	79	20
Chironomidae	138	3
Simuliidae	1	-
Tipulidae	3	1
Ephemeroptera		
Leptophlebiidae	1	-
Odonata		
Coenagrionidae	5	-
Gomphidae	1	-
Libellulidae	13	2
Oligochaeta	42	1
Trichoptera		
Calamoceratidae	14	-
Leptoceridae	6	-
TOTAL	**304**	**29**

Concerning community metrics and biotic indexes (Table 3), the upstream point was the one with the largest number of families (11) and downstream point was the smallest, with only 5 families. The Shannon Diversity index and Margalef richness index were higher than the upstream point. The percentage of EPT represented 7% at the upstream point, while at the other point, no such organisms were found. For the ratio of the number of EPT families to the total family and of EPT for Chironomidae, the values of 25 and 0.05 were found, respectively, for the upstream point and zero for the downstream point, due to the absence of organisms in the EPT group. The presence of Chironomidae represented 45% at the upstream point and 10% at the downstream point. The water quality classification for the upstream point was good and moderately polluted for the BMWP index and the IBB index, respectively. On the other hand, the water quality at the downstream point was classified as very poor (BMWP Index) and poor (IBB).

In general, the reference point presented better environmental conditions, such as greater richness and diversity of organisms and good water quality. On the other hand, the community metrics showed evidence of environmental impacts in the downstream point.

Table 3. Comparison of community metrics of the Monte Alegre stream analyzed by the present study and by Corbi and coauthors [18] for the points equivalent to the reference area and the area impacted by chromium

	Present study[1]		**Corbi and coauthors [18]** [1]	
Community metrics	**Upstream**	**Downstream**	**Upstream**	**Downstream**
Number of families	11	5	16	15
Dominance	0.15	0.49	0.15	0.20
Shannon Diversity index	2.24	1.16	2.3	2.0
Margalef Richness index	3.50	1.78	3.3	2.9
EPT (%)	7	0	15	16
(Family number EPT/total family) x 100	27	0	32	26
(EPT/Chironomidae) x 100	0.050	0	68	42
(Chironomidae/total) x 100	45	10	25	40
Biotic Index BMWP[2]	68 (Good)	23 (Very poor)	87 (excellent)	69 (good)
Biotic Index IBB[2]	5 (Moderately polluted)	4 (Poor)	7 (good)	5 (Moderately polluted)

[1] The sampling methods between the present study and the one Corbi and coauthors (2011) were different and should be analyse with caution [18]. The present study used an Ekman-Birge grab, Corbi and coauthors (2011) used a D-frame to collect the macroinvertebrates [18].
[2] Water quality classification based on [23].

DISCUSSION

Our results showed that chromium is still accumulated in the sediment of the Monte Alegre stream after ten years. Studies conducted in sugarcane growing areas have also shown the persistence of chromium in sediments over several years [27]. In streams adjacent to banana plantations, chromium accumulation in sediment was identified, with concentrations ranging from 0.99 mg kg^{-1} to 28.99 mg kg^{-1} [29]. Concentrations between 45.0 and 161.0 mg kg^{-1} were detected in urban occupation areas [30].

The current concentration of chromium in the downstream point (impacted area) was higher than that obtained in 2007. It is known that the occurrence of chromium may also be related to agriculture and waste and sewage deposition [28]. At the downstream point, some plantations and areas occupied by the residents of the settlement were observed, which may have contributed to the increase in chromium concentrations at this point. Note that in this point, the oxygen concentration was very low, the water had low turbulence and there was no presence of EPT, which contributed to the deterioration of the environmental quality of the stream in relation to the upstream point.

The presence of metals in the environment can also cause damage to the aquatic biota. The community metrics confirm that the taxonomic structure and diversity of the aquatic macroinvertebrate community to the Monte Alegre stream were affected by chromium. It can be observed that the section near the chromium contamination point showed less diversity and richness of organisms, showing the sensitivity of some organisms, such as the EPT group, to survive in environmental stress conditions. The Chironomidae community structure and the distribution of richness of EPT species was influenced by exposure to sugarcane and banana plantations [31, 32]. Exposure of Chironomidae larvae to hexavalent chromium and copper showed that these metals significantly affected the endogenous composition of the host bacterium community [33]. In another study, reproduction and survival of *Daphnia magna* were affected by exposure to sediments from areas near tanneries [34].

Comparing the current results of the aquatic macroinvertebrate community with the results obtained in 2007, it can be observed that after ten years, the ecological conditions of the stream of the impacted area did not improve due to exposure to chromium. There was an increase in chromium concentrations in the sediment. Although the present study used different methods of sampling the aquatic macroinvertebrate community, results suggest that the environmental impact was maintained after ten years.

Funding: This research received no external funding.
Acknowledgments: We are grateful to the National Council for Scientific and Technological Development (CNPq) for financing this research.
Conflicts of Interest: The authors declare no conflict of interest.

REFERENCES

1. Corbi JJ, Froehlich CG, Strixino ST, Santos AD. Bioaccumulation of metals in aquatic insects of streams located in areas with sugar cane cultivation. Quim. Nova. 2010; 33(3):644-8.
2. Wang X, Su P, Lin Q, Song J, Sun H, Cheng D, et al. Distribution, assessment and coupling relationship of heavy metals and macroinvertebrates in sediments of the Weihe River Basin. Sustain Cities Soc. 2019; 50: 101665.
3. Arnold A, Murphy JF, Pretty JL, Duerdoth CP, Smith BD, Rainbow PS, et al. Accumulation of trace metals in freshwater macroinvertebrates across metal contamination gradients. Environ. Pollut. 2021; 276: 116721.
4. Khan R, Israili SH, Ahmad H, Mohan A. Heavy Metal Pollution Assessment in Surface Water Bodies and its Suitability for Irrigation around the Neyevli Lignite Mines and Associated Industrial Complex, Tamil Nadu, India. Mine Water Environ. 2005; 24(3):155-61.
5. Milesi SV, Biasi C, Restello RM, Hepp LU. Efeito de metais Cobre (Cu) e Zinco (Zn) sobre a comunidade de macroinvertebrados bentônicos em riachos do sul do Brasil [The effect of metals (Cu and Zn) on the benthic macroinvertebrate community in streams in southern Brazil]. Acta Sci. Biol. Sci. 2008; 30(3):283-9.
6. Souto RDMG, Corbi JJ, Jacobucci GB. Aquatic insects as bioindicators of heavy metals in sediments in Cerrado streams. Limnetica. 2019; 38(2):575-86.
7. Corbi JJ. Invertebrados aquáticos como ferramenta para a avaliação do impacto de metais em córregos adjacentes ao cultivo de cana-de-açúcar [Aquatic invertebrates as a tool for assessing the impact of metals in streams adjacent to sugarcane cultivation]. 1st ed. Ciências Ambientais: Recursos Hídricos; 2020.
8. Dornfeld CB, Rodgher S, Negri RG, Espíndola ELG, Daam MA. *Chironomus sancticaroli* (Diptera, Chironomidae) as a sensitive tropical test species in laboratory bioassays evaluating metals (copper and cadmium) and field testing. Arch. Environ. Contam. Toxicol. 2019; 76(1):42-50.
9. Colombo-Corbi V, Gorni GR, Sanzovo-Falcoski T, Costa PI, Corbi JJ. Genetic diversity loss in *Chironomus sancticaroli* (Diptera: Chironomidae) exposed to Pyrimethanil Fungicide: An Analysis Using RAPD technique. Water Air Soil Pollut. 2017; 228:399-401.
10. Mozeto AA. Critérios de qualidade de sedimentos (CQS) para metais pesados: fundamentos teóricos e técnicos para implementação [Sediment quality criteria (CQS) for heavy metals: theoretical and technical foundations for implementation]. Anexo do relatório de Pós-doutorado FAPESP; 2001. 86p.
11. Valdovinos C, Figueroa R. Benthic community metabolism and trophic conditions of four South American lakes. Hydrobiologia. 2000; 429:151-156.
12. Pimenta SM, Boaventura GR, Peña AP, Ribeiro TG. Estudo da qualidade da água por meio de bioindicadores bentônicos em córregos da área rural e urbana [Study of water quality using benthic biological indicators in rural and urban streams]. Rev. Ambient. Agua – An Interdisciplinary Journal of Applied Science. 2016; 11:198.
13. Cardoso JT, Lopes HSS, Neto EAS, Zambelli NLN, Pollheim TS, Manrich S, et al. Monitoramento da qualidade da água no Planalto Sul de SC, através da comunidade de macroinvertebrados bentônicos [Monitoring of water quality in the Southern Plateau of SC, through the community of benthic macroinvertebrates]. Rev. UNIPLAC. 2017; 5(1).
14. Li Z, Wang J, Liu Z, Meng X, Heino J, Jiang X, et al. Different responses of taxonomic and functional structures of stream macroinvertebrate communities to local stressors and regional factors in a subtropical biodiversity hotspot. Sci. Total Environ. 2019 Mar; 655:1288-1300.
15. Goncharov AV, Baturina NS, Maryinsky VV, Kaus AK, Chalov SR. Ecological assessment of the Selenga River basin, the main tributary of Lake Baikal, using aquatic macroinvertebrate communities as bioindicators. J. Great Lakes Res., 2020; 46(1):53-61.
16. Deliberalli W, Cansian RL, Pereira AA, Loureiro RC, Hepp LU, Restello RM. The effects of heavy metals on the incidence of morphological deformities in Chironomidae (Diptera). Zoologia (Curitiba). 2018; 35.
17. Santos AD, Oliveira LC, Botero WG, Mendonça AG, Santos FA, Rocha JC, et al. Distribuição e biodisponibilidade de crômio em solos contaminados por resíduos de couro [Distribution and bioavailability of chromium in contaminated soils by tannery residues]. Quim. Nova. 2009; 32(7):1693-1697.
18. Corbi JJ, Santos FA, Zerlin R, Santos AD, Froehlich CG, Trivinho-Strixino S. Assessment of chromium contamination in the Monte Alegre stream: a case study. Braz. Arch. Biol. Technol. 2011; 54(3):613-20.
19. De Paula FC, Mozeto AA. Biogeochemical evolution of trace elements in a pristine watershed in the Brazilian southeastern coastal region. Appl. Geochem. 2001; 16(9-10):1139-1151.
20. Carmo DL, Silva CA. Métodos de quantificação de carbono e matéria orgânica em resíduos orgânicos [Quantification methods of carbon and organic matter in organic residues]. Rev. Bras. Cienc. Solo. 2012 ago; 36(4):1211-1220.

21. Mugnai R, Nessimian JL, Baptista DF. Manual de identificação de macroinvertebrados aquáticos do Estado do Rio de Janeiro [Identification manual of aquatic macroinvertebrates of the State of Rio de Janeiro]. Rio de Janeiro: Livros Técnicos; 2010. 176 p.
22. Hamada N, Nessimian JL, Querino RB. Insetos Aquáticos na Amazônia brasileira: taxonomia, biologia e ecologia [Aquatic insects in the Brazilian Amazon: taxonomy, biology and ecology]. Editora INPA; 2014. 724 p.
23. Trivinho-Strixino S, Nascimento VM. Indicadores básicos de qualidade ambiental para bacias hidrográficas: macroinvertebrados bentônicos como indicadores biológicos [Basic indicators of environmental quality for watersheds: benthic macroinvertebrates as biological indicators]. Curso teórico-prático sobre bioindicadores de qualidade de água. Organizado pela Embrapa Meio Ambiente, 2000.
24. Hammer Ø, Harper DAT, Ryan PD. PAST: Paleontological statistics software package for education and data analysis. Palaeontol. Electron., 2001. 9 p.
25. Cortes RMV, Carvalho LHM, Carvalho MJPM. Caracterização físico-química das águas dulciaquícolas- Implicações biológicas [Physicochemical characterization of freshwater waters - Biological implications]. Vila Real; 1992. 131 p.
26. Allan JD, Castillo MM. Ecology Stream: structure and function of running waters. 2nd ed. Springer; 2007. 429 p.
27. Corbi JJ, Costa CG, Gorni GR, Colombi V, Rios L. Environmental diagnosis of metals in streams near sugarcane cultivation areas: current and historical analysis in the central region of the State of São Paulo. An Acad Bras Cienc. 2018; 90(3):2711-2719.
28. Azevedo FA, Chasin ADM. Metais: gerenciamento da toxicidade [Metals: toxicity management]. São Paulo: Editora Atheneu, 2003.
29. Corbi JJ, Kleine P, Strixino ST, Santos A. Diagnóstico ambiental de metais no sedimento de córregos adjacentes a áreas de cultivo de banana (*musa* spp.) no Estado de São Paulo, Brasil [Environmental diagnosis of metals in sediment from streams adjacent to areas of banana (*musa* spp.) cultivation in the State of São Paulo, Brazil]. Ecletica Quim. 2013; 38:136-146.
30. Sahm LH. Macroinvertebrados aquáticos como bioindicadores em córregos urbanos do município de Bocaina-SP [dissertação] [Aquatic macroinvertebrates as bioindicators in urban streams in the municipality of Bocaina-SP, dissertation]. Centro Universitário de Araraquara; 2016. 75 p.
31. Corbi JJ, Trivinho-Strixino S. Chironomid species are sensitive to sugarcane cultivation. Hydrobiologia. 2017; 785(1):91-99.
32. Corbi JJ, Kleine P, Trivinho-Strixino S. Are aquatic insect species sensitive to banana plant cultivation? Ecol. Indic. 2013; 25:156-161.
33. Laviad-Shitrit S, Sharaby Y, Sela R, Thorat L, Nath BB, Halpern M. Copper and chromium exposure affect chironomid larval microbiota composition. Sci. Total Environ. 2021; 771:145330.
34. Terra NR, Feiden IR. Toxicidade do sedimento em áreas próximas a curtumes [Sediment toxicity in areas close to tanneries]. Estud. Biol. 2014; 36:65-77.