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Research paper

Water quality analysis based on the presence of aquatic macroinvertebrates applied to water springs covered with soil-cement technique

Análise da qualidade da água de nascentes recuperadas com técnica solo-cimento utilizando macroinvertebrados aquáticos

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ABSTRACT: Human activities, such as deforestation and inappropriate waste disposal have had negative impact on watercourses, including water spring areas. The soil-cement technique is a low-cost and easily implementable option to safeguard water springs and to preserve watercourses. The aim of the preset study is to assess water quality in water springs in Prudentópolis City, Brazil by using this technique based on aquatic macroinvertebrate communities and land use in this location. In total, 1,236 macroinvertebrates belonging to 18 taxa were collected from 5 water springs. Species belonging to family Chironomidae prevailed in points A, B, C and E, since they represent approximately 42% of all collected insects. Tree Cover was the primary land use form in the assessed points. According to Canonical Correspondence Analysis (CCA), different taxonomic groups had different responses to the assessed environmental factors. In conclusion, soil preservation, sustainable management and the cement technique, in combination to a set of preventive actions, were effective measures to ensure the conservation of aquatic ecosystems and water quality.

Keywords: Bioindicators; Watercourses; Land use; Land cover.

RESUMO: *Atividades humanas, como desmatamento, descarga de efluentes e disposição inadequada de resíduos, têm impactado negativamente os cursos d'água. A técnica de solo-cimento é uma opção de fácil implementação e baixo custo para proteger nascentes e conservar os cursos hídricos. O presente estudo analisou a qualidade da água de nascentes em Prudentópolis – PR onde estão implantadas esta técnica, considerando a comunidade de macroinvertebrados aquáticos e o uso e ocupação do solo. Foram coletados 1236 macroinvertebrados de 18 táxons em cinco nascentes. Nos pontos A, B, C e E, a família predominante foi de espécie Chironomidae, representando cerca de 42% de todos os insetos coletados. A forma predominante de uso do solo nos pontos estudados foi da classe Cobertura Arbórea. A análise de CCA (Canonic Correspondence Analysis) mostrou que diferentes grupos taxonômicos responderam de maneira diferente aos fatores ambientais avaliados. Conclui-se que a preservação do solo, o manejo sustentável e a técnica de proteção solo-cimento, aliadas a um conjunto de ações preventivas são medidas eficazes para garantir a conservação de ecossistemas aquáticos e a qualidade da água.*

Palavras-chave: *Bioindicadores; Cursos d'água; Uso do solo; Cobertura do solo.*

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INTRODUCTION

River basins are geographical areas where water is drained from both a main river and its tributaries, delimited by a watershed. They form the very basis for social, industrial and agricultural activities to be achieved, despite being the habitat of several species and the essential water source to existing flora and fauna ecosystems (REBOUÇAS, 2002; BRAGA; TUNDISI, 2002; VALENTE et al., 2005).

Water springs can be featured as any natural surface water discharge capable of flowing into small watercourses. They can be classified as perennial, intermittent or temporary, and their preservation is crucial for aquatic ecosystems' maintenance, water flow regulation, drinking water supply to local communities and biodiversity preservation (DAVIS et al., 1996; VALENTE et al., 2005; REIS et al., 2016). The legislation provides on water springs' protection, such as the case of law n. 12.651/2012 (BRASIL, 2012). Given their extreme relevance, water springs are often subjected to studies and are kept under constant protection by researchers and environmental regulations.

Therefore, in addition to their conservation, it is necessary to monitor water quality in water springs, in entire watercourses and in their respective surrounding areas, or in Permanent Preservation Areas (PPAs). This procedure is supported by law n. 12.651/2012, which states, in Article 7: "The vegetation in Permanent Preservation Areas must be maintained by the landlord, land possessor or occupant, at any capacity, be it an individual or legal entity, governed by public or private law" (BRASIL, 2012). Monitoring must aim at identifying pollution or other environmental changes, since many factors can change the quality of water in a river basin and, consequently, the structure of aquatic ecosystems. Riparian forest reduction or removal, land use for farming purposes, discharge of untreated urban and industrial effluents, pollutants transport by water flowing from sealed areas, among others (QUEIROZ, 2012; CRISIGIOVANNI et al., 2020; MEZA-SALAZAR et al., 2020).

Preservation measures should apply to watersheds to keep and/or improve the quality of watercourses. According to Crispim et al. (2012), the aim of the Soil-Cement Spring Protection Technique (SPT) is to seal water springs by using low-cost and environmentally friendly materials to protect water from external factors and to keep water springs' natural balance, as well as their volume and quality, overtime. According to Alemão (2015), this technique consists in cleaning water spring's surroundings, removing all organic material and weathered rocks, to leave it bare. After installing the pipelines, the water spring area is filled with gravel and waterproofed with soil-cement, which is a mix of sieved soil and cement. The rocks form an 'armor' over the water spring, which is then covered by a layer of soil-cement mortar to support the pipelines and allow water to flow (**Figure 1**).

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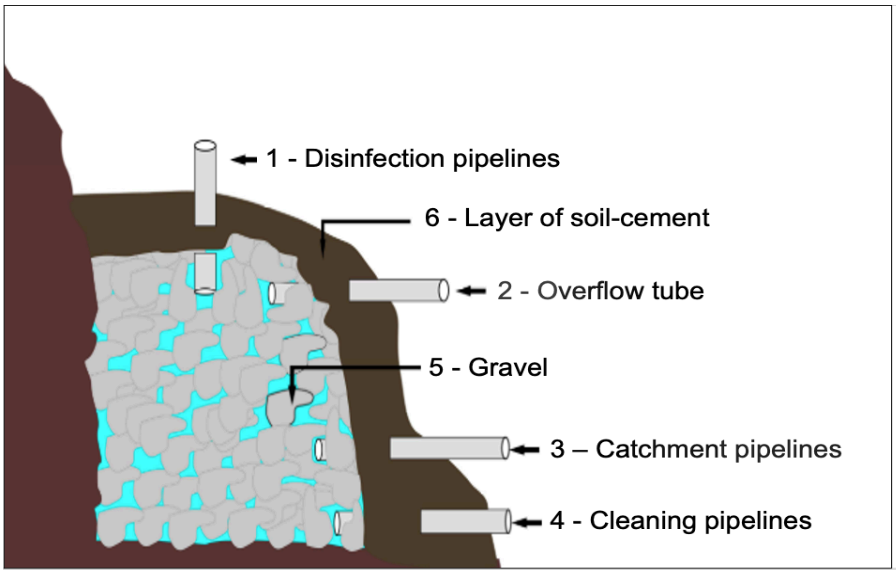
Figure 1. Application model of the Soil-Cement Spring Protection Technique for recovering springs.



Source: Modified from Crispim et al., 2012.

Crispim et al. (2012) reported that this technique application led to significant increase in the quality of water supplied to farmers, besides protecting these springs from being exposed to polluting elements that could change its quality, since it prevents alien materials from entering the springs. Although some studies state that this technique likely safeguards water springs' structure and function in rural areas (CRISPIM et al., 2012; ATHAYDES, 2022) and small towns (ANTONIETTI et al., 2013), little is known about the quality of water coming from water springs covered with SPT.

Aquatic macroinvertebrates are essential to river ecosystems because they are food sources for predators and contribute to organic matter decomposition by turning it into usable nutrients for other aquatic organisms. The health and diversity of aquatic macroinvertebrates led to water and habitat quality, as they are sensitive to environmental changes, such as chemical composition, physical structures, and available resources in aquatic ecosystems (VANNOTE et al., 1980; DOMÍNGUEZ et al., 2009; FERREIRA et al., 2016; PINTO et al., 2020).

Aquatic macroinvertebrates are widely used as bio-indicators in lotic ecosystems to feature water quality given their sensitivity to environmental changes, abundance, easy collection and identification (OLIVEIRA et al., 2010; CASTRO et al., 2018; RESTELLO et al., 2020; CAMPOS et al.., 2021). Analyzing these organisms' communities, in association with land use and occupation analyses, can provide valuable information on rivers and streams' conservation status, as well as help developing conservation and water resource management strategies (MELLO et al., 2011; CRISIGIOVANNI et al., 2022; DALA-CORTE et al., 2020).

Although there are studies showing how this technique improves water springs' structure and function in rural areas (CRISPIM et al., 2012; ATHAYDES et al., 2022) and small towns (ANTONIETTI et al., 2013), little is known about the quality of water coming from springs covered with soil-cement as preservation technique. Accordingly, the aim of the current study was to analyze the quality of water from different springs subjected to this

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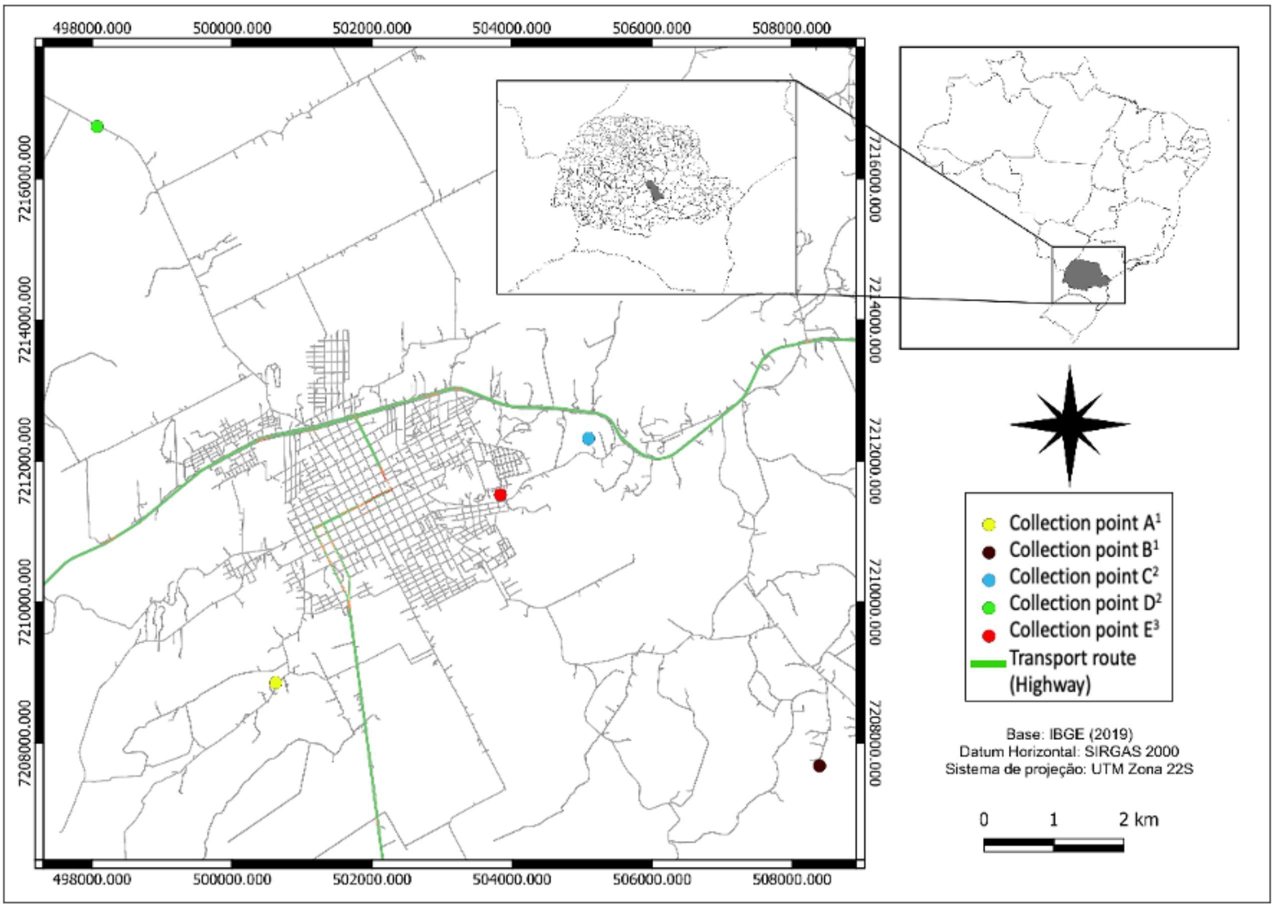
technique, in Prudentópolis municipality, Paraná State, by assessing aquatic macroinvertebrates, and land use and occupation, around these springs.

MATERIAL AND METHODS

Prudentópolis municipality is in Paraná State, 204 kilometers from Curitiba, at latitude -25.2155 and longitude -50.9689, and altitude of 744 meters. It covers an area of 2,236.579 km², and approximately 59.35% of it is rural and 40.65% is urban, climate in the region is defined as humid subtropical (IBGE, 2022). Prudentópolis is in Central-Southern Paraná State, on the Second Paraná Plateau and on the Southern Plateau (IBGE, 1991). Its rainfall regime is relatively well-distributed, with mean yearly rainfall of 1,446 mm - the largest number of rainy days is recorded in January (21.33 days) and the lowest number of it is observed in August (6.87 days). Climate in the region is classified as Cfb, according to the Köppen-Geiger climate classification, with mean temperature of 18.4ºC (WREGE et al., 2012; CLIMATE DATA, 2022).

Sites were selected in different areas of this municipality, mainly in urban, rural and industrial neighborhoods. They were divided into five collection points: Point A (500615 m and 7208846 m), Point B (508470 m and 7207718 m), Point C (505143 m and 7212365 m), Point D (498118 m and 7216795 m) and Point E (503883 m and 7211565 m), based on coordinates in the SIRGAS 2000/UTM 22s reference system (**Figure 2**).

Figure 2. Collection points distributed throughout the municipality of Prudentópolis-PR.



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[1] non-urbanized, [2] peri-urban, [3] urban.

Single collections of aquatic macroinvertebrates were gathered on November 3 and 24, at each of the set points with the aid of Surber sampler (30 x 30 cm collection area and 250 micrometer mesh). The sampled material was stored in plastic bags filled with 70% alcohol for further sorting. The material was taken to the Conservation Biodiversity Laboratory of the Midwestern State University, Irati *campus*, for sorting and subsequent identification to taxonomic family level based on the identification keys by Mugnai et al. (2010). The organisms were added to the Aquatic Invertebrates and Coleoptera Collection of the State University of the Center West, kept at the Conservation Biodiversity Laboratory.

Results were tabulated and Diversity (H') and Equitability (J) indices were calculated in PAST software, which was also used to calculate Chironomidae and EPT (Ephemeroptera+Plecoptera+Trichoptera) rates, the BMWP' index, based on the identified families (**Table 2**).

The analysis of BMWP (Biological Monitoring Working Party) values must be included in the calculations, since this index is often used to assess water quality based on the presence and abundance of benthic macroinvertebrates in it. This index can provide additional insight about the ecological status of the investigated aquatic ecosystems. BMWP values associated with different taxa found in the samples can provide data on environmental health, since certain taxa are indicative of cleaner and less disturbed water, whereas other taxa are associated with more degraded environments (WRIGHT et al., 2000; MARTINS et al., 2008).

The manual classification technique was applied for the interpretation and vectorization on canvas of high spatial resolution satellite images to analyze land use and occupation. These images were collected from Google Satellite and Google Traffic, found in g the QGIS application, version 3.28.2 and in the Quick Map Services plugin. The following classes were defined: Urban Area, Agriculture, Tree Cover, Watercourse, Exposed Soil and Transport Route. This classification was applied to high-resolution images from areas surrounding the 50-meter radius around the water spring collection points, in compliance with law n. 12.651/2012.

Canonical correspondence analysis (CCA) was carried out to assess the association among macroinvertebrates, water quality, and land use and occupation. This analysis is a statistical technique used to identify groups of macroinvertebrates associated with different environmental conditions (GONÇALVES et al., 2022; SAHM, 2016). P-value<0.05 was considered significant for all analyses, including the canonical correlation. All analyses were carried out in R Studio software, in the vegan and ggplot2 packages.

RESULTS

Urban area was one of the least common land uses among the five assessed PPA areas. The highest rate of urban area was recorded for the water spring PPA area at point E. Exposed soil was among the least common land uses, given its significant variation between the assessed areas. Tree cover, on the other hand, was the most prevailing land use in all the areas, since it recorded high prevalence rate in all assessed springs, except for the water spring at point E (**Table 1**).

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Table 1. Land use and occupation at the points of the springs recovered using the soil-cement technique in Prudentópolis-PR.

Class	PPA A[1]		PPA B[1]		PPA C[2]		PPA D[2]		PPA E[3]	
	Area (%)	Area (M²)	Area (%)	Area (M²)	Area (%)	Area (M²)	Area (%)	Area (M²)	Area (%)	Area (M²)
Urban Area	2	140	0	0	0	0	0	0	26	1688
Agriculture	2	152	0	0	0	0	0	0	0	0
Tree Cover	75	4787	79	5071	86	5502	84	5400	49	3213
Transport Route	4	258	0	0	0	0	15	984	0	0
Exposed Soil	16	1028	13	831	13	851	0	0	18	1134
Watercourse	0	0	7	472	0	0	0	0	5	347
Total	100	6294	100	6397	100	6401	100	6405	100	6400

[1] non-urbanized, [2] peri-urban, [3] urban.

Land use rates have changed among the different assessed points. It is so, because different urban areas, tree cover, exposed soil, transportation routes, agriculture and watercourses fractions were recorded. This variation could have been influenced by different factors, such as soil features and human action. These results reinforce the need of carrying out further studies to highlight the importance of conserving native forests, as they are essential biodiversity and sustainability resources for ecosystems. They also highlight the relevance of properly managing exposed soils and urban areas to minimize environmental impacts and ensure water and air quality.

Overall, 1,236 individuals were sampled and, altogether, they belonged to 18 taxa distributed into orders Diptera, Trichoptera, Coleoptera, Odonata, Hemiptera and Ephemeroptera, besides representatives of phyla Annelida and Mollusca. Order Diptera accounted for the largest number of individuals, and family *Chironomidae* was the most abundant one: approximately 42% of all sampled individuals. Oligochaeta (Annelida), Ceratopogonidae (Diptera) and Coenagrionidae *(*Odonata) were also abundant, with 281, 168 and 139 individuals, respectively (Table 2).

Based on the results, biological diversity changed among the five assessed points - the highest diversity was observed at point E and the lowest, at point B. The rate of individuals among taxa also changed among points - the highest record was observed at points A and C, and the lowest one at point D. Only four taxa were found at points A, B and C, and eleven taxa were sampled at point E.

The highest rates of resistant taxa were found at points A, B and C, and the lowest rate of them was observed at point D. On the other hand, EPT rate was low, with zero taxa at points A and B - the highest relative abundance of it was found at point C. The BMWP index was low at points A, B and C, which presented heavily polluted water, and water was considered very polluted at points D and E (**Tables 2** and **3**).

BMWP (Biological Monitoring Working Party) water quality indices are often used to assess watercourses, because water springs reflect benthic macroinvertebrates' composition and environmental integrity. Points A, B and C showed critical quality. Points D and E showed slight improvement, but they still present very poor quality.

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Table 2. Distribution and number of organisms sampled in springs recovered with the soil-cement technique and biotic indices and relative percentages of the Chironomidae (%Chirnomidae) and Ephemeroptera+Plecoptera+Trichoptera (%EPT) families calculated for the different sampling points of springs recovered with soil-cement in Prudentópolis-PR.

Taxon	Point A[1]	Point B[1]	Point C[2]	Point D[2]	Point E[3]	Total
DIPTERA						
Ceratopogonidae		1		167		168
Chironomidae	143	21	25	32	300	521
Culicidae	3		2		8	13
Muscomorpha				1		1
Stratiomyidae				1	1	2
Trichoptera						
Hydropsychidae			3	5		8
Sericostomatidae				19		19
ANNELIDA						
Hirudinea	62	1				63
Oligochaeta		7	6		268	281
Coleoptera						
Elmidae				5		5
Odonata						
Aeshnidae					6	6
Coenagrionidae	11				128	139
MOLUSCA						
Hydrobiidae					2	2
Lymnaeidae					2	2
Planorbidae					1	1
Hemiptera						
Notonectidae					5	5
EPHEMEROPTERA						
Baetidae					8	8
Total number of individuals	219	30	36	230	729	1236
Total of Taxons	4	4	4	7	11	
Diversity (H')	0.845	0.816	0.9195	0.9266	1.262	
Equitability (J)	0.609	0.5886	0.6633	0.4762	0.5262	
%Chironomidae	65.3	70	69.44	13.91	41.15	
%EPT	0	0	8.33	1.1	2.81	
BMWP' Index	13	10	10	30	31	

[1] non-urbanized, [2] peri-urban, [3] urban.

According to the CCA analysis, macroinvertebrates' composition is correlated to land use and occupation. The first main axis, which explained 92% of such a correlation, was significant (f=2.70, P=0.051 and R=0.92). Based on the plotted diagram, Ceratopogonidae, Elmidae and Sericostomatidae were associated with the presence of transportation routes and anthropogenic actions (SILVA, 2002; COSTA et. al., 2013).

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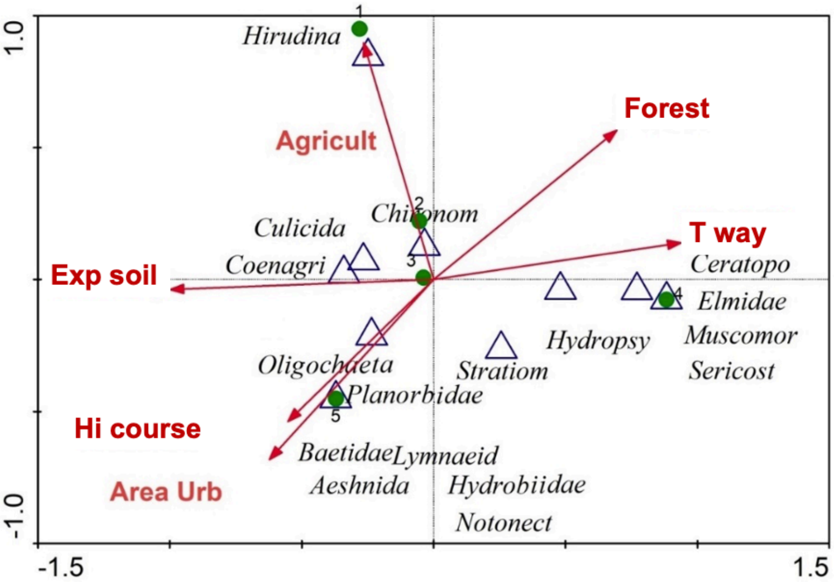
Oligachaeta, Baetidae and Aeshnidae prevailed in urban areas (SANCHES, 2016) and Hirudinea prevalence was closely related to farming areas (**Figure 3**).

Figure 3. CCA diagram of the macroinvertebrate community and environmental variables. Agricult: Agriculture; Forest; T way: Transportation way; Hi course: Hydric course; Urb area: Urban area; Exp soil: Exposed soil.



DISCUSSION

Recent research suggests that taxa belonging to family Baetidae are more abundant in altered or disturbed environments, where riparian vegetation is partially or totally absented. Previous studies (CASTRO et al., 2018; MELLO et al., 2018; SANTOS et al., 2020) have shown that these organisms are resilient to changes in hydrological patterns in lotic ecosystems. These results are following the present study, whose assessed taxon was exclusively found at point E, which was in a highly urbanized area.

In addition, the presence of taxa belonging to order Trichoptera was observed at points C and D, which were in a region mainly featured by native forest. Some taxa belonging to this order showed predilection for environments that keep their original features (CASTRO et al., 2018; MEZA-SALAZAR et al., 2020). Individuals belonging to class Oligochaeta are related to higher levels of nutrients in the water (SOUZA, 2006) and they were found at points B, C, and at large amounts, at point E, which was featured by high urbanization. The presence of families Elmidae and Ceratopogonidae points out good watercourse quality, as they are sensitive to pollution and habitat disturbance (OLIVEIRA et al., 2004; PRAT, 2018) - they were only found at point D, and at small amounts at point A.

CCA was used to investigate likely correlations between environmental variables and the macroinvertebrate fauna identified at each sampling point. It was done to find positive and negative correlations between the assessed variables and to point out the influence of different factors on these organisms. The variable associated with urban areas had strong effect on the largest number of taxa, and this finding suggests its relevance to the distribution and abundance of the herein assessed organisms. Therefore, it can be inferred that CCA

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enabled identifying significant associations between the investigated environmental factors and the taxonomic composition of the analyzed aquatic communities.

Previous and post-intervention analyses have shown improvements in several parameters linked to quality of water, mainly in microbiological parameters, such as Heterotrophic Bacteria, Fungi and *Escherichia coli*, as well as in physical parameters, due to notable reduction in MPS (Suspended Particulate Matter). However, the chemical quality of water in the assessed springs did not show significant changes, and it suggests that a long-term monitoring schedule could provide additional information about water-condition evolution (GOMES, 2019; VILLWOCK et al., 2015).

CONCLUSION

Aquatic ecosystem assessment is an extremely important tool to analyze water quality in water systems, including watercourses originating from water springs treated through the soil-cement technique. Implementing sustainable management practices and conserving soil and PPA's are essential procedures to mitigate erosion and water contamination, to preserve water quality and the biological diversity of aquatic ecosystems. The present results have shown that soil conservation actions and soil-cement technique using are effective strategies to conserve aquatic ecosystems. It is important emphasizing the need of further studies to correlate water conservation to public health.

It is crucial highlighting the relevance of research to set the connection between water conservation and public health. A comprehensive approach, including continuous monitoring and pre- and post-implementation studies on conservation techniques, would improve the reliability of these investigations and further enhance their effectiveness. This integrated approach would contribute to broaden the understanding about the ecological and environmental aspects of macroinvertebrates in Prudentópolis - PR by providing subsidies for the adoption of measures aimed at preserving the quality of water and, consequently, at safeguarding public health.

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