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Scientific Paper

Surface water quality in rural communities in the state of Goiás during the dry season and its relationship with land use and occupation

Qualidade da água superficial em comunidades rurais do estado de Goiás durante a estação seca e sua relação com o uso e a ocupação do solo

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ABSTRACT

Different land uses and occupations can influence water quality and affect the lives of the population, especially of people who live in rural areas. Because rural populations live under conditions of socio-environmental vulnerability, it is necessary to monitor the quality of water resources to prevent diseases. This work aimed to analyze surface water quality in rural and traditional communities in the state of Goiás through the Bascarán Water Quality Index (WQI_B) to evaluate the effects of the predominant land use and occupation of each location. Raw water samples were collected from specific points during the dry season. The presence of pesticides was verified through chromatographic analysis, without quantification, and 11 physical-chemical and microbiological parameters were assessed according to standard methods. The results showed that the WQI_B ranged in quality from "good" to "pleasant". Classification as "pleasant" was statistically related to a high incidence of pasture area (> 80%) and classification as "good" with a percentage of agriculture below 30%. The main land uses and occupations were forest, pasture and agriculture. The apparent parameters color, thermotolerant coliforms and dissolved oxygen also indicated contamination of water courses. The detection of pesticides with a high degree of toxicity in the analyzed water resources, mainly in two rivers (the Facada and Sucuapara creeks), put human health at risk in rural areas, even under conditions of small exposure. Carbofuran, banned since 2017, was detected near the Itacaiú community, making it necessary to alert the local government, residents and tourists who use the Araguaia River for different purposes.

Keywords: water resource; small communities; pesticide; basic sanitation.

RESUMO

Os diferentes usos e ocupações do solo podem influenciar na qualidade da água e afetar a vida da população, principalmente daquela que habita o meio rural. Por residir sob condições de vulnerabilidade socioambiental, faz-se necessário monitorar a qualidade dos recursos hídricos para prevenir doenças. O objetivo deste trabalho foi analisar a qualidade das águas superficiais em comunidades rurais e tradicionais do estado de Goiás por meio do Índice de Qualidade da Água de Bascarán (IQAB), avaliando os efeitos do uso e ocupação do solo preponderantes em cada localidade. Amostras de água bruta dos mananciais foram coletadas de forma pontual, na estiagem. Foi verificada a presença de agrotóxicos por análise cromatográfica, sem quantificação, e foram avaliados 11 parâmetros físico-químicos e microbiológicos. Os resultados demonstraram que o IQAB variou de bom a agradável. A classificação da qualidade da água como "agradável" foi relacionada estatisticamente com a alta incidência de área de pastagem (> 80%), e a classificação como "boa" com o percentual de agricultura inferior a 30%. Os principais usos e ocupações do solo foram florestas, pastagens e agricultura. Os parâmetros cor aparente, coliformes termotolerantes e oxigênio dissolvido também indicaram a contaminação dos cursos d'água. A detecção de agrotóxicos com alto grau de toxicidade nos recursos hídricos analisados, principalmente em dois mananciais (córregos Facada e Sucuapara), colocam em risco a saúde humana no meio rural, mesmo que em condições de pequenas exposições. O carbofurano, proibido desde 2017, foi detectado no rio Araguaia, nas proximidades da comunidade Itacaiú, sendo necessário alertar o governo local, moradores e turistas que utilizam o rio Araguaia para fins diversificados.

Palavras-chave: recurso hídrico; pequenas comunidades; agrotóxico; saneamento básico.

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INTRODUCTION

The lack of public policies and basic infrastructure for housing in rural environments is considered worrying, since the lack of adequate environmental sanitation is one of the main causes of pollution and contamination of water for human supply, thus contributing to the dissemination of waterborne diseases (PAIVA; SOUZA, 2018).

Water supply in rural areas is carried out, in most cases, without prior treatment and using surface water from springs, rivers, streams and lakes (RODRIGUES *et al.*, 2022). These sources, according to Fonseca *et al.* (2019), are more susceptible to contamination due to the superficial carry-over of compounds adsorbed on eroded soil particles or in solution. These, in turn, require greater expenses with complex treatments, in addition to manifesting greater risks to the health of the population.

Conditions of land use and occupation also influence water quality. This is due to, among other factors, an accelerated alteration of the natural landscape combined with deficiency in the management of water resources and planning. Thus, it is important to study the evolution of land use and occupation to better understand the weaknesses of natural environments exposed to anthropic actions so that sustainable processes can be established for the development of human activities (VALADARES, 2017). In this context, there are models applicable to the monitoring of water resources that allow portraying different aspects of water quality (water quality classification, levels of eutrophication and risk to human health), which support the work of professionals in the construction and implementation of appropriate measures to improve water quality (YAN; SHEN; ZHOU, 2022) and, consequently, the living conditions of the population. In addition, the adoption of a Water Quality Index (WQI) allows a population to be informed of water quality conditions in a manner that is easier to understand (BASCARÁN, 1979 *apud* ABRAHÃO *et al.*, 2007).

Application of a WQI can be useful for analyzing both spatial and temporal trends (SUN, 2016), with applications for situations involving up to 25 sample points having been reported (GUPTA; GUPTA, 2021). However, the development of a single WQI that can be applied on a global scale is the most challenging aspect for scientists (GUPTA; GUPTA, 2021; UDDIN; NASH; OLBERT, 2021; WU; LAI; LI, 2021).

The Bascarán Water Quality Index (WQI_B), initially developed for Spain (ABRAHÃO *et al.*, 2007) and used in South American countries, is one of 35 models found for determining a WQI. This model presents, as a differential feature, the possibility of using up to 26 parameters, thus generating greater flexibility in including or excluding variables depending on the need for and/or limitations in obtaining data (UDDIN; NASH; OLBERT, 2021). It is also used in other parts of the world, such as Egypt (HUSSIEN; RASHWAN; ELSHEMY, 2021), Ethiopia (MENBERU; MOGESSE; REDDYTHOTA, 2021) and India (DAMODHAR; VIKRAM REDDY, 2013).

Abrahão *et al.* (2007), Hussien, Rashwan and Elshemy (2021), and Cicilinski and Virgens Filho (2022) calculated a WQI for surface water sources in urban areas; however, there remains a lack of information for the rural environment, thus justifying the development of the present research.

Considering the above, the present study aimed to analyze the quality of surface water in rural and traditional communities in the state of Goiás, during the dry season, using the WQI_B to assess the relationship of water quality with the predominant land use and occupation of each locality.

METODOLOGY

Study area

The study area covers 13 hydrographic basins in the state of Goiás, selected based on the presence of rural and traditional communities established within their area and the use of surface water for different purposes by the communities, such as consumption, leisure, vegetable irrigation, and animal watering.

The communities residing in the studied basins, whose typology and respective identification code (ID) are presented in Figure 1, belong to a project entitled "Sanitation and Environmental Health in Rural, Traditional Communities of Goiás" [Saneamento e Saúde Ambiental em Comunidades Rurais e Tradicionais de Goiás].

Characterization of land use and occupation

The area of each basin was obtained through automatic GRASS delimitation, an extension available in QGIS® *software* (version 3.18), using the *r.watershed* algorithm. This was based on data from the digital elevation models of the Shuttle Radar Topography Mission (SRTM), at a resolution of 30 meters, made available by the United States Geological Survey (USGS).

Land use and occupation data were extracted from the MapBiomas database, Collection 3.1 (MAPBIOMAS, 2020).

Physical-chemical and microbiological collection and analysis

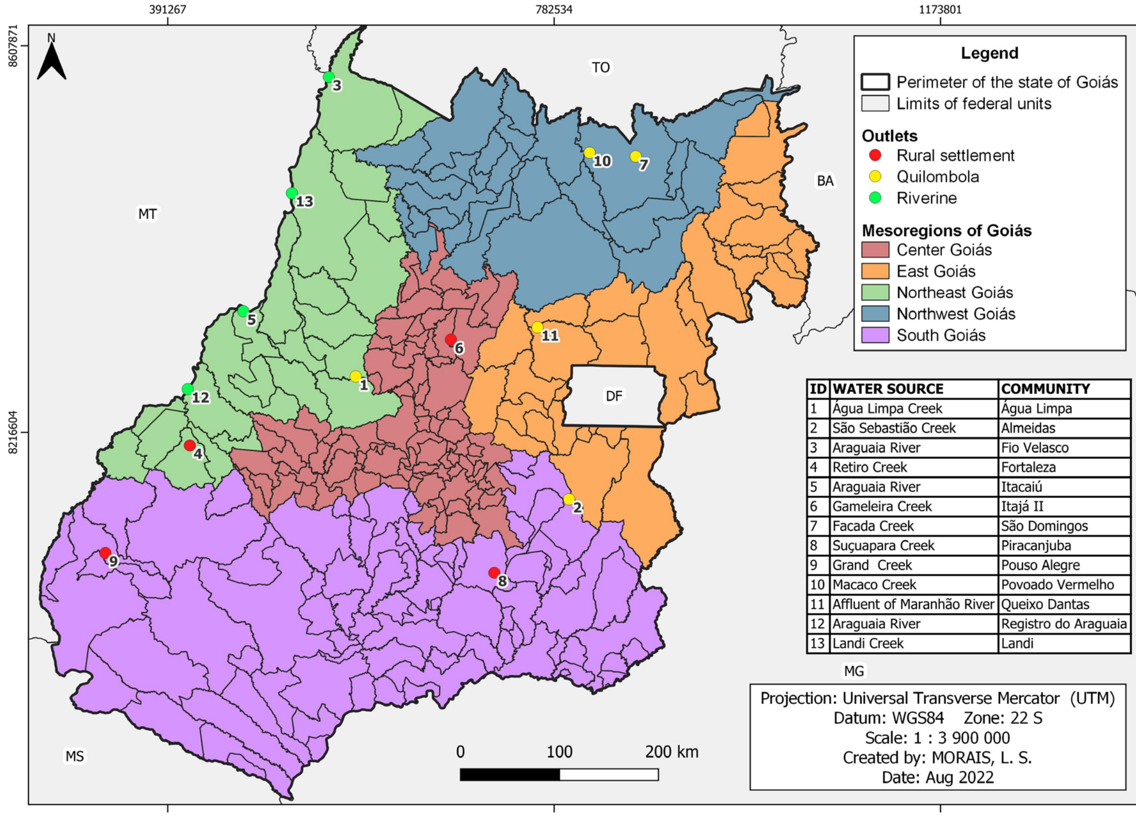
Raw water was collected from surface water sources specifically at the points indicated in Figure 1, in the dry season, between September and October 2020.

Sampling was not performed in the rainy season due to difficulties with access, as well as the dilution factor (which could prevent the detection of compounds in the samples), as already found in other studies (ANDRIETTI *et al.*, 2016; ALVES; GIRARDI; PINHEIRO, 2017; MUNIZ, 2019).

Procedures followed Brazil's Guide for the Collection and Preservation of Samples [*Guia Nacional de Coleta e Preservação de Amostras*] (CETESB, 2011): 1.0 L polyethylene flasks were used for physicochemical analyses; 100 mL sterilized plastic bottles for microbiological analysis; and 1.0 L amber bottles for pesticide analysis.

Physical-chemical and microbiological analyses were carried out in accordance with the *Standard Methods for Examination of Water and Wastewater* (APHA; AWWA; WEF, 2017) at the Water Analysis Laboratory (LAnA) of the Federal University of Goiás (UFG). The parameters analyzed were: apparent color, turbidity, electrical conductivity, alkalinity, pH, chloride, nitrite, dissolved oxygen (DO), biochemical oxygen demand (BOD), total dissolved solids (TDS) and *Escherichia coli* (*E. coli*). However, for comparison of the results obtained with the National Environment Council's (CONAMA) Resolution nº 357 (BRASIL, 2005), the quantity of the parameter thermotolerant coliforms was obtained by the multiplication factor of 1.25 x *E. coli*.

The presence of pesticides was determined using the conventional technique of chromatographic analysis in the system High Performance Liquid Chromatography - Mass Spectrometry (HPLC-MS/MS), performed in duplicate. One-hundred and fifty samples of standards of different pesticides were injected to determine the peak for each typology. The results of the search for



Source: The authors.

Figure 1 – Locations of the outlets of hydrographic basins, indicating surface water sources, typologies, and community names, as distributed in the mesoregions of the state of Goiás (Brazil).

pesticides were evaluated according to the presence or absence of contaminants in the water samples based on comparisons with the standard peaks. The procedures were carried out at the Multi-User Laboratory of Chemical and Biological Analyses for Development and Innovation [Laboratório Multiusuário de Análises Químicas e Biológicas para Desenvolvimento e Inovação] (LabMulti) of UFG.

Bascarán water quality index

The WQI_B was evaluated as established by Bascarán (1979 *apud* ABRAHÃO *et al.*, 2007), using all monitored parameters, with the exception of pesticides, and Equation 1. Values of the index vary from 0 to 100, and are associated with the following scales: terrible ($0 \leq WQI_B < 10$), very bad ($10 \leq WQI_B < 20$), bad ($20 \leq WQI_B < 30$), disagreeable ($30 \leq WQI_B < 40$), inappropriate ($40 \leq WQI_B < 50$), normal ($50 \leq WQI_B < 60$), acceptable ($60 \leq WQI_B < 70$), agreeable ($70 \leq WQI_B < 80$), good ($80 \leq WQI_B < 90$), very good ($90 \leq WQI_B < 100$) and excellent ($WQI_B = 100$).

$$WQI_B = K * (\sum Ci * Wi / \sum Wi) \qquad (1)$$

where:

Ci = the percentage value of each parameter, according to Table 1;

Wi = the corresponding weight of each parameter, according to Table 1;

K = the adjustment constant depending on the visual appearance of the water (1.00 for clear water; 0.75 for water with slight unnatural color, foam and turbidity; 0.50 for contaminated water with a strong odor; 0.25 for water with fermentation and odors).

The value of K adopted here was 1.00. The same condition was implemented by Cicilinski and Virgens Filho (2022), since this constant tends to overestimate the pollution of a water source due to the visual impression of apparent color and turbidity parameters, which may be of natural origin and not correlated with pollution.

Statistical analyses

Multiple correspondence analysis was performed in the program R 4.0.2 (R CORE TEAM, 2020) using the packages FactoMineR (for analysis) and Factoextra (for data visualization). This exploratory technique allows the association between the categories of different variables to be visualized through geometric proximity in graphing. Cluster analysis was adopted to define groups of parameters that have characteristics in common.

The data were transformed into qualitative variables for analysis. Land use and occupation data were classified as "less than 30%", "between 30 and 50%", "between 50 and 80%" and "greater than 80%", and the WQI_B was associated with the established ranges of Bascarán (1979 *apud* ABRAHÃO *et al.*, 2007).

RESULTS

The parameters highlighted in Table 2 (apparent color, TC and DO) exceeded the limit established in CONAMA's Resolution nº 357 (BRASIL, 2005) for class 2 rivers intended for human consumption, protection of the aquatic community, recreation activities, food irrigation and fishing.

Surface water sources ID 1, 2, 4 and 6 presented unfavorable microbiological conditions for human consumption, vegetable irrigation and fishing activities, as they exceeded the value of 1.000 NPM/100 mL (Table 2).

Surface water sources ID 7 and 8 showed the greatest variety of agrochemicals belonging to the insecticide, pesticide, herbicide, fungicide and organic fertilizer group.

Figure 2 provides the WQI_B values for the analyzed surface water sources, with all samples within the agreeable and good ranges.

Land use data (Figure 2) verify the predominance of forest within the basins of water sources ID 6, 7, 10 and 11, with percentages greater than 50%. Pasture had percentages greater than 50% in basins of water sources ID 1, 3, 4, 5, 12 and 13, while agriculture was dominant in those of ID 2 and 8, with percentages between 30 and 50%.

Figure 3 presents the results with the most important relationships of the set of analyzed variables, in which dimensions 1 and 2 were able to explain 65.10% of the variation in the data. "Forest" and "pasture" land uses were best represented by Dimension 1, while "agriculture" was more dependent on Dimension 2.

Figure 3 shows that surface water sources classified as having "agreeable" water quality were better associated with pasture occurrence between 50 and 80%, since the value is close to 1 (one), with forest occurrence in 30 to 50% and non-forest formation in under 30% of the basin area, as well as with pasture occurrence in over 80% of the basin area. On the other hand, a pasture percentage of below 30% is an excellent indicator of water characterized as of "good" quality, as well as, with a lesser degree of association, forest in 50 to 80% of the area, non-forest formation in 30 to 50% and forest in over 80%.

Figure 4 shows that variables with similar profiles were organized into five clusters. Water coming from surface sources belonging to basins with a high incidence of pasture (above 80%) is seen to be classified as "agreeable", and an agriculture percentage of less than 30% showed an association with water classified as "good".

DISCUSSION

Surface water sources ID 1 and 4 had the worst WQI_B values with 72.50 and 77.92, respectively, which are classified as "agreeable" (Figure 2). The adoption of water quality indices is of paramount importance in making information about the environmental conditions of the watercourse accessible to users (FERREIRA *et al.*, 2015), especially in rural areas, where satisfactory conditions of hygiene, sanitation and environmental health are lacking (RODRIGUES *et al.*, 2022).

Analysis of the variables used to obtain WQI_B values (Table 1) revealed that the decrease in water quality to the "agreeable" class is related to the parameters of apparent color, TC and DO, parameters that have a high relative weight in the calculation of WQI_B, as well as the high incidence of pasture in the basin (Figure 4).

The variable DO concentration had values lower than the minimum established by CONAMA's Resolution nº 357 (BRASIL, 2005) only in the basin of ID 1. This variable is one of the main indicators of the level of water pollution, as it is used to verify the aerobic conditions of a surface water source that receives effluent discharge (BAUMGARTEN; POZZA, 2001). However, it can also be related to the natural characteristics of the aquatic ecosystem, since the main sources of origin of this oxygen are the atmosphere and photosynthesis, and the main sources of losses consist of the decomposition of organic matter and photosynthesis and respiration of aquatic animals (ESTEVES, 2011).

Vasco *et al.* (2011) documented DO concentrations of below 5 $mg.L^{-1}$ in seasonal samples of water from the Poxim river in Sergipe (Brazil), making it possible to associate this with anthropic activities releasing untreated urban and industrial effluents.

Similar results were obtained by the study of Barros, Guimarães and Santana (2018), in which the advance of urbanized areas and the agricultural frontier

Table 1 – Percentage (C) and weight (W) values assigned to parameters used in Bascarán Water Quality Index calculation.

Parameter	Weight (W)	Analytical value of the parameter										
Apparent color (uC)	2	> 250	100	60	40	30	20	15	10	5	4	< 3
pH	1	1	2	3	4	5	6	6,5	9	8,5	8	7
Chloride ($mg.L^{-1}$)	1	> 1,500	1,000	700	500	300	200	150	100	50	25	0
Nitrite ($mg.L^{-1}$)	2	> 1	0.5	0.25	0.2	0.15	0.1	0.05	0.025	0.01	0.005	0
Turbidity (NTU)	2	> 400	250	180	100	50	20	18	15	10	8	< 5
Alkalinity ($mg.L^{-1}$ $CaCO_3$)	1	> 1,500	1,000	800	600	500	400	300	200	100	50	< 25
EC ($\mu S.cm^{-1}$)	4	> 16,000	12,000	8,000	5,000	3,000	2,500	2,000	1,500	1,250	1,000	> 750
BOD ($mg.L^{-1}$)	2	> 15	12	10	8	6	5	4	3	2	1	< 0.5
DO ($mg.L^{-1}$)	4	0	1	2	3	3.5	4	5	6	6.5	7	7.5
TDS ($mg.L^{-1}$)	2	> 20,000	10,000	5,000	3,000	2,000	1,500	1,000	750	500	250	< 100
TC* (NMP.100 mL^{-1})	3	> 14,000	10,000	7,000	5,000	4,000	3,000	2,000	1,500	1,000	500	< 50
Percentage value (C)	-	0	10	20	30	40	50	60	70	80	90	100

EC: Electrical conductivity; BOD: Biochemical oxygen demand; DO: Dissolved oxygen; TDS: Total dissolved solids; TC: Thermotolerant coliforms; *Abrahão *et al.* (2007) adopt the parameter total coliforms, but to meet Resolution nº 357 of Brazil's Environment Council (BRASIL, 2005) values of thermotolerant coliforms were used.
Source: Adapted from ABRAHÃO *et al.* (2007).

over permanent preservation areas of the Guanandy stream, in Mato Grosso do Sul (Brazil), was responsible for WQI classifications as "very bad" and "bad". It is noteworthy that this study adopted the WQI of the National Sanitation Foundation (NSF), and the variables thermotolerant coliforms and DO also contributed to the degradation of water quality.

Figure 4 shows that the predominance of pasture in 70.29% of the basin of ID 1 and in 87.80% of the basin of ID 4 (Figure 2) was associated with the deterioration of water quality (Figure 4). However, as the collection of water samples was carried out at specific points, it was not possible to indicate the source of pollution in these watercourses.

Several studies have been carried out with the aim of evaluating the relationship between land use and occupation and water quality in hydrographic basins. Pellizzaro *et al.* (2008) showed that better quality water is found in regions with less anthropized characteristics; a relationship corroborated by Hussien, Rashwan and Elshemy (2021), who found agricultural activities to be among the main causes likely to be considered as anthropic activities that influence the quality of surface water.

Furthermore, Pellizzaro *et al.* (2008) concluded that maintaining the environmental quality of water sources is the result of planning and management of land use and occupation. These are designed based on knowledge of occupation

Table 2 – Results of physical-chemical and microbiological parameters for water from surface water sources, as well as the maximum values allowed according to Resolution nº 357 of Brazil's Environment Council (BRASIL, 2005).

Parameter		ID													Maximum Permitted Value
		1	2	3	4	5	6	7	8	9	10	11	12	13	
Physical	Apparent color (uC)	8.4	15.55	50.7	**93.6**	39.6	0.9	33.9	21	7.9	22.7	6.1	7.3	67.6	**75[1]**
	Turbidity (NTU)	2.62	4.14	19.3	7.74	21.7	3.67	2.11	3.8	11.8	5.07	1.38	17.6	26.4	**100**
	TDS ($mg.L^{-1}$)	125	45	15	85	10	105	15	25	65	-	145	115	20	**500**
	EC ($\mu S.cm^{-1}$)	183.5	13.93	35.2	37.74	26.33	181	13.63	16.54	35.72	27.19	213.2	23.98	27.8	**NR**
Chemical	pH	7.5	6.9	7.2	6.1	7.4	8	6	6	7.6	7.4	8.1	6.9	7.7	**6.0 - 9.0**
	Chloride ($mg.L^{-1}$)	23.07	3.16	21.54	13.88	17.8	10.15	15.03	6.13	24.22	16.56	22.3	10.62	17.9	**250**
	Nitrite ($mg.L^{-1}$)	0.002	0.005	0.013	0.006	0.007	0.007	0.003	0.004	0.012	0.004	0.001	0.015	0.02	**1**
	Alkalinity ($mg.L^{-1}$ $CaCO_3$)	72.25	8.63	37.5	18.75	35.75	98.5	26.5	8.25	31.38	37.75	110.38	11.63	38	**NR**
	BOD ($mg.L^{-1}$)	0.82	0.36	0.97	1.33	2.39	0.81	0.30	1.08	4.81	1.02	3.58	0.74	1.60	**5**
	DO ($mg.L^{-1}$)	**4.83**	7.22	6.85	7.2	7.2	6.62	6.49	6.96	7.66	7.75	5.94	7.34	7.36	**> 5.00**
Microbiological	TC[2] (NMP.100 mL^{-1})	**13,103**	811	26	**2,166**	23	**5,764**	431	**1,226**	49	249	216	107	33	**1000**
Insecticide	Acephate							X							**NR**
	Acetamiprid					X		X	X						**NR**
	Carbaryl												X		**0.02**
	Cyromazine					X	X	X	X	X					**NR**
	Dicrotophos					X		X	X						**NR**
	Disulfoton				X		X	X	X						**NR**
	Propoxur				X			X	X	X					**NR**
Pesticide	Carbofuran					X									**NR**
	Fenamiphos							X	X						**NR**
	Methyl-parathion					X		X	X	X					**NR**
Herbicide	Alachlor							X	X						**20**
	Chlorpropham					X		X	X						**NR**
	Metribuzin				X			X	X			X	X		**NR**
Fungicide	Cyproconazole							X	X						**NR**
	Fenpropimorph							X	X						**NR**
	Flutolanil					X									**NR**
	Hexaconazole									X					**NR**
Organic fertilizer	Aminocarb					X		X	X						**NR**

NR: not referenced; EC: electrical conductivity; BOD: biochemical oxygen demand; DO: dissolved oxygen; TDS: total dissolved solids; TC: thermotolerant coliforms; X: quantitative value; [1]value limit for true color; [2]*E. coli* analysis was performed and multiplied by 1.25 to obtain thermotolerant coliforms (CETESB, 2017).
Source: The authors.

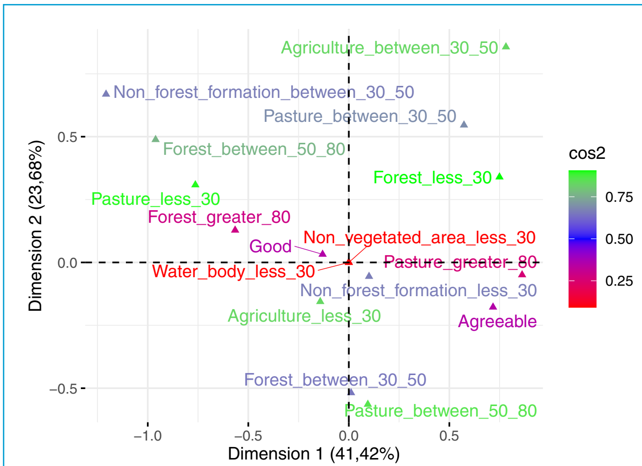
characteristics and socio-environmental relationships, considering their consequences on the quality of life of the population and on the environmental balance of the area.

The interference of land use characteristics with water quality has been observed in other studies. Silva, Cunha and Lopes (2019) pointed out the influence that the parameters pH, turbidity, DO, TC, BOD, total phosphorus and chlorophyll-*a*, as well as characteristics of land use and occupation, have on low WQI values of waters in hydrographic basins located in Northeast Brazil that were classified as "regular" and "bad". Among the activities identified in the basin of such a study, agricultural work, the release of domestic effluents, degradation of riparian forest, construction of buildings and inadequate disposal of solid waste stood out.

The surface water sources of ID 6 and 8 showed concentrations of thermotolerant coliforms that did not comply with current legislation and, consequently, the WQI_B values were 81.67 and 82.92, respectively (Figure 2). These values indicate that the water quality of the source is characterized as "good"; however, attention should be paid to the individual concentrations of this parameter, especially in case this water is used for human consumption without prior treatment.

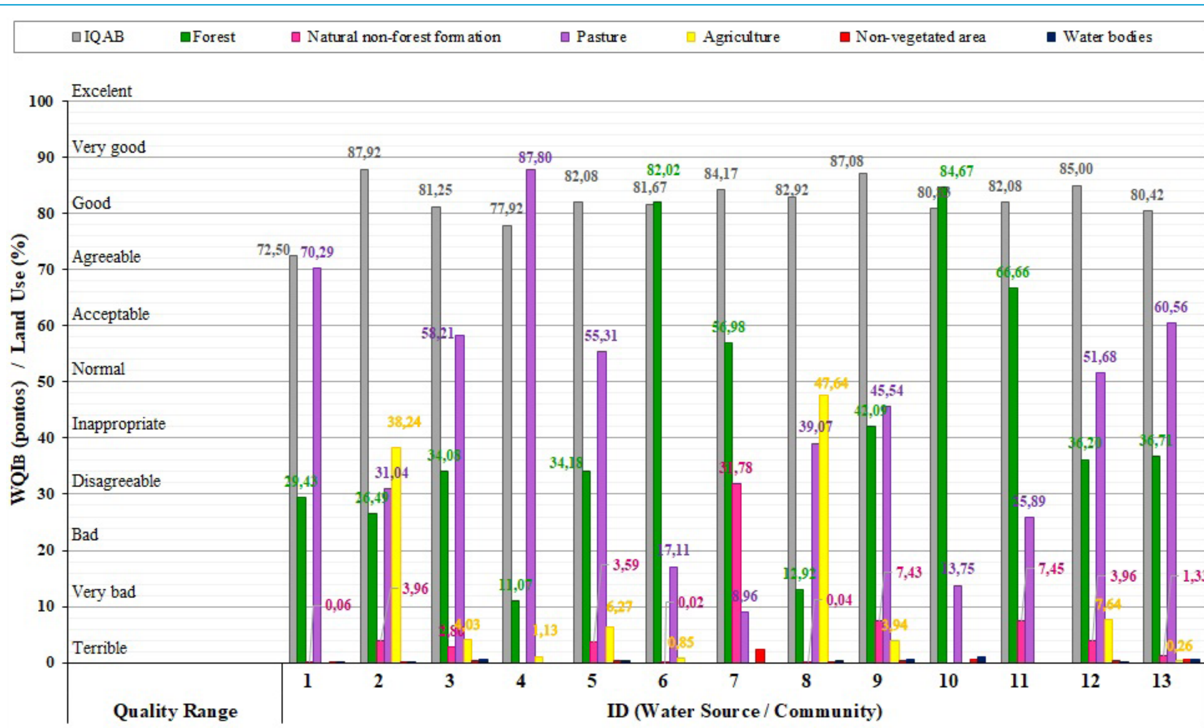
The hydrographic basin of ID 6 has a predominance of forest in 82.02% of the area, followed by pasture in 17.11% (Figure 2). Andrietti *et al*. (2016) obtained WQI values classified as "good" for the Caiabi river in Mato Grosso (Brazil), due to the presence of riparian forest and vegetation along the river.

Analysis of land use conditions of ID 8 at specific points revealed that it had the highest percentage of agriculture among the studied basins, with 47.64% (Figure 2), and a predominance of soybean and sugarcane (MAPBIOMAS, 2020). Water bodies located in areas where this activity predominates are particularly affected, since the main problems of agribusiness include the large-scale use of pesticides, soil and water contamination with nitrogenous compounds,



Source: The authors.

Figure 3 – Biplot graph showing the degree of association among variables used in Multiple Correspondence Analysis.



ID: Water Source / Community; 1 = Água Limpa Creek / Água limpa Community; 2: São Sebastião Creek / Almeidas Community; 3: Araguaia River / Fio Velasco Community; 4: Retiro Creek / Fortaleza Community; 5: Araguaia River / Itacaiú Community; 6: Gameleira Creek / Itajá II Community; 7: Facada Creek / São Domingos Community; 8: Suçuapara Creek / Piracanjuba Community; 9: Grande Creek / Pouso Alegre Community; 10: Macaco Creek / Povoado Vermelho Community; 11: Affluent of Maranhão River/ Queixo Dantas Community; 12: Araguaia River / Registro do Araguaia Community; 13: Landi Creek/ Landi Community.
Source: The authors.

Figure 2 – Bascarán Water Quality Index values and characterization of land use relative to the hydrographic basins where rural and/or traditional communities are located.

exposure of population to pesticides causing health problems, impacts on the environment and erosion (CODEVASF, 2017; MATTHIENSEN, 2017; NICODEMO *et al.*, 2018).

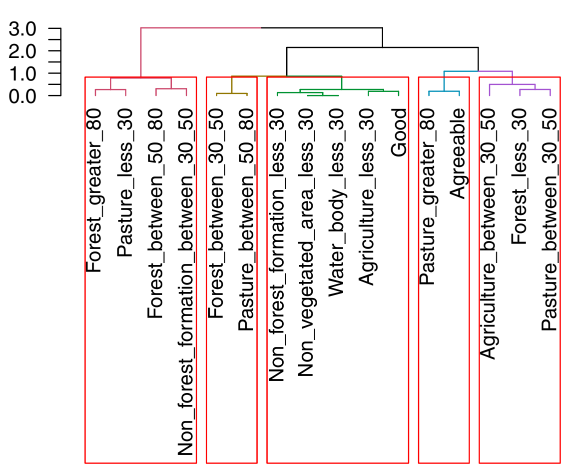
Table 2 shows the predominance of pesticides in the water sources ID 7 and 8, with emphasis on substances that have a high degree of toxicity, identified by the red band on the label, namely disulfoton, propoxur, fenamiphos, cyproconazole and fenpropimorph, according to the toxicological classification of the Resolution of the Collegiate Board nº 294, of July 29, 2019 (ANVISA, 2019). In addition, there was the presence of actives dicrotophos, methyl parathion and chlorpropham, which are not authorized to be sold in Brazil (Table 2).

Red band pesticides pose a risk to human health even in cases of minor exposure (MELLER; REOLON-COSTA; CEOLIN, 2021), since, when used in the environment, they undergo biotic and abiotic transformations, generating by-products with greater or similar toxicity to the original pesticide (COELHO; BERNARDO, 2017).

It is noteworthy that none of the compounds analyzed in this research were quantified (Table 2) and may be in concentrations below the limit necessary to cause a health risk, as recommended by CONAMA's Resolution nº 357 (BRASIL, 2005) and by the Ministry of Health's Ordinance GM/MS nº 888 (BRASIL, 2021), which establishes potability standards for drinking water. Even so, their analyses are of paramount importance, given that pesticide residues accumulated in the environment can impact the quality of water sources intended for human consumption, recreational activities and food irrigation (SABATIER *et al.*, 2013; SYBERG *et al.*, 2017), and consequently, cause damage to the health of the exposed population (LOPES; ALBUQUERQUE, 2018).

The state of Goiás had the highest percentage of human intoxication during 2011–2013 in work environments and non-work places (BERNARDO *et al.*, 2019). In the case of farmers, even though most are aware of the risks associated with pesticide exposure, they do not use protective equipment or fail to use it appropriately, especially in rural areas (MELLER; REOLON-COSTA; CEOLIN, 2021).

Carbofuran was detected in surface water source ID 5 (Table 2). The use of this active principle has been prohibited by the Brazilian Health Regulatory Agency (Anvisa) since 2017 because of its high environmental persistence and acute dietary risk to the Brazilian population, mainly rural workers (ANVISA, 2018). The detection of this compound can come from the use of the pesticide itself or from the application of carbosulfan (PARA, 2019). This discovery generates an alert for the Araguaia River region, due to the use of this surface source for tourism, leisure, fishing and primary contact recreation activities; it also indicates a lack of clarity by rural producers regarding good agricultural practices (GAPs), making it necessary to implement actions aimed at raising awareness among producers (REPÓRTER BRASIL, 2020).



Source: The authors.

Figure 4 – Dendrogram of the qualitative variables used in the Multiple Correspondence Analysis, grouped in five clusters.

Pignati *et al.* (2017) found that the predominant agricultural crops in the state of Goiás in 2015 were soybean (53%), followed by corn (23%), sugarcane (15%), beans (2%) and cotton (1%). Furthermore, the active ingredients used in soy were glyphosate, 2.4-D, methachlorine, tebuthiuron, trifluralin, paraquat, flutriafol and carbofuran, while in sugarcane the highest incidence was for glyphosate, metribuzin, trifluralin, tebuconazole, diuron, sodium hydrogen methylarsonate (MSMA) and carbofuran.

Surface sources ID 2, 9 and 12 showed the highest WQI_B values, with 87.92; 87.08 and 85.00, respectively. The parameters of DO and thermotolerant coliforms were decisive in improving water quality, since the relationship between them suggests low polluting loads in these surface sources. Therefore, the risk of transmission of waterborne diseases may be lower (FUNASA, 2014).

Similar studies, with sampling only during the dry season, have been carried out elsewhere (PEDROSO; COLESANTI, 2017; ROSANOVA *et al.*, 2018; MUNIZ, 2019; POLHEIM; CARDOSO; SCHEIN, 2019). Other research, carried out in the dry and rainy seasons, indicated superior quality in the dry season (SILVA; SÁ-OLIVEIRA, 2014; MEDEIROS; LIMA; GUIMARÃES, 2016; SILVA; CUNHA; LOPES, 2019). These studies corroborate Wu, Lai and Li (2021), who found statistically higher WQI in autumn (without rainy events) than in the rainy season, while WQI in the dry season was statistically higher than in the rainy season. In contrast, Sun *et al.* (2016) found slightly lower WQI values in the dry season. Pereira *et al.* (2020) found higher values of turbidity, COD and total phosphorus in the rainy season and higher nitrate and electrical conductivity in the dry season. Thus, seasonality can influence the WQI, but so can other variables, such as the rainfall index and the characteristics of the basin, as well as the analyzed parameters.

Evaluations of a single sample were carried out by other researchers (ARYAL, 2022; FATIMA *et al.*, 2022) and bring important contributions, stressing the need for the implementation of public policies and continuous monitoring programs. In general, the results of the analyses make it possible to identify whether there is a risk of the presence of pollutants in the water intended for different uses by the population, a problem that is aggravated when the water is not treated before consumption. Therefore, we recommend that awareness programs be implemented for the local population and that monitoring of water quality is conducted to ensure that it is safe to drink (ARYAL, 2022).

CONCLUSIONS

The results obtained lead to the following conclusions:

- In general, the water quality classes identified in this research were related to land occupation characteristics and the individual parameters detected in water samples.
- The occurrence of water classified as "agreeable" was associated with a high prevalence of pasture in the basin, as well as with the

concentration of the parameters apparent color, thermotolerant coliforms and DO, as they are in non-compliance with CONAMA's Resolution nº 357/2005.

- Classification of the quality of a source as "good" was statistically associated with the low occurrence of areas destined for agriculture.
- Surface water sources with a higher risk of fecal contamination must be subjected to low-cost treatment technologies in order to guarantee the supply of safe water to rural populations living in conditions of socio-environmental vulnerability.
- Considering the diversity of pesticides identified in this study and the greater danger of some of the compounds, there is a need to implement actions aimed at raising awareness among rural producers, with a focus on the compound carbofuran, banned by Anvisa since 2017.

It is recommended that studies be carried out that aim at quantifying pesticide concentrations, especially in water sources that can be used for public supply, in order to assess the health risk for individuals exposed on a temporal scale.

AUTHORS' CONTRIBUTIONS

Morais, L.: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Projetct Administration, Validation, Writing — First Draft, Writing — Review and Edition. Chagas, I.C.G.C.: Conceptualization, Formal Analysis, Investigation, Writing — First Draft. Silva, D.P.: Data Curation, Methodology, Projetct Administration, Supervision, Validation, Writing — Review and Edition. Scalize, P.S.: Data Curation, Projetct Administration, Supervision, Validation, Writing — Review and Edition.

REFERENCES

ABRAHÃO, R.; CARVALHO, M.; SILVA JUNIOR, W.R.; MACHADO, T.; GADELHA, C.; HERNANDEZ, M. Use of index analysis to evaluate the water quality of a stream receiving industrial effluents. *Water SA*, v. 33, n. 4, p. 459-565, 2007. https://doi.org/10.4314/wsa.v33i4.52940

AGÊNCIA NACIONAL DE VIGILÂNCIA SANITÁRIA (ANVISA). *Termina prazo de descontinuação do uso de Carbofurano*. ANVISA, 2018. Available at: www.gov.br/anvisa/pt-br/assuntos/noticias-anvisa/2018/termina-prazo-de-descontinuacao-do-uso-de-carbofurano. Accessed on: Oct. 8, 2021.

ALVES, T.C.; GIRARDI, R.; PINHEIRO, A. Micropoluentes orgânicos: ocorrência, remoção e regulamentação. *Rega*, v. 14, p. 1-20, 2017. https://doi.org/10.21168/rega.v14e1

AMERICAN PUBLIC HEALTH ASSOCIATION (APHA); AMERICAN WATER WORKS ASSOCIATION (AWWA); WATER ENVIRONMENT FEDERATION (WEF). *Standard Methods for examination of water and wastewater*. 22. ed. Washington, D.C.: American Public Health Association, 2017.

ANDRIETTI, G.; FREIRE, R.; AMARAL, A.G.D.; ALMEIDA, F.T.D.; BONGIOVANI, M.C.; SCHNEIDEER, R.M. Índices de qualidade da água e de estado trófico do rio Caiabi, MT. *Ambiente & Água*, v. 11, n. 1, p. 162-175, 2016. https://doi.org/10.4136/ambi-agua.1769

AGÊNCIA NACIONAL DE VIGILÂNCIA SANITÁRIA (ANVISA). *Resolução da Diretoria Colegiada (RDC) n. 294, de 29 de julho de 2019*. Dispõe sobre os critérios para avaliação e classificação toxicológica, priorização da análise e comparação da ação toxicológica de agrotóxicos, componentes, afins e preservativos de madeira, e dá outras providências. Anvisa, 2019.

ARYAL, M. An analysis of drinking water quality parameters to achieve sustainable development goals in rural and urban areas of Besisahar, Lamjung, Nepal. *World Water Policy,* 2022. https://doi.org/10.1002/wwp2.12073

BARROS, A.; GUIMARÃES, V.; SANTANA, W.S.C. Aplicação de um índice de qualidade de água em dois trechos (urbano e rural) da bacia do córrego Guanandy, Aquidauana, MS. *Caderno de Geografia*, v. 28, n. 54, p. 630-649, 2018. https://doi.org/10.5752/P.2318-2962.2018v28n54p630-649

BASCARÁN, G.M. Establecimiento de una metodología para conocer la calidad del agua. *Boletín Informativo del Medio Ambiente*, v. 1, n. 1, p. 30-49, 1979.

BAUMGARTEN, M.G.Z.; POZZA, S.A. *Qualidade de águas:* descrição de parâmetros químicos referidos na legislação ambiental. Rio Grande: Ed. FURG, 2001. 166 p.

BERNARDO, L.V.M.; FARINHA, M.J.U.S.; SANTOS CARDOSO, J.; RUVIARO, C.F. Uso de agrotóxicos e perfil de intoxicação humana na região Centro-Oeste do Brasil. *Multitemas*, v. 24, n. 57, p. 137-157, 2019. https://doi.org/10.20435/multi.v24i57.2285

BRASIL. Conselho Nacional do Meio Ambiente (CONAMA). *Resolução nº 357*, de 17 de março de 2005. Classificação de águas, doces, salobras e salinas do Território Nacional. Brasília: Conselho Nacional do Meio Ambiente, 2005.

BRASIL. Ministério da Saúde. *Portaria CM/MS nº 888*, de 4 de maio de 2021. Brasília, 2021.

CICILINSKI, A.D.; VIRGENS FILHO, J.S. A new water quality index elaborated under the brazilian legislation perspective. *International Journal of River Basin Management*, v. 20, n. 3, p. 323-334, 2022. https://doi.org/10.1080/15715124.2020.1803335

COELHO, E.R.C.; BERNARDO, L.D. Presença e remoção de atrazina, desetilatrazina, desisopropilatrazina e desetilhidroxiatrazina em instalação piloto de ozonização e filtração lenta. *Engenharia Sanitária e Ambiental*, v. 22, n. 4, p. 789-796, 2017. https://doi.org/10.1590/S1413-41522017147638

COMPANHIA AMBIENTAL DO ESTADO DE SÃO PAULO (CETESB). *Apêndice E:* significado ambiental e sanitário das variáveis de qualidade. São Paulo: CETESB, 2017.

COMPANHIA AMBIENTAL DO ESTADO DE SÃO PAULO (CETESB). *Guia nacional de coleta e preservação de amostras:* água, sedimento, comunidades aquáticas e efluentes líquidos. São Paulo: CETESB; Brasília: ANA, 2011.

COMPANHIA DE DESENVOLVIMENTO DOS VALES DO SÃO FRANCISCO E DO PARNAÍBA (CODEVASF). *Salinização do solo*. CODEVASF, 2017. Available at: www.codevasf.gov.br/linhas-de-negocio/irrigacao/impactos-ambientais/salinizacao-do-solo. Accessed on: Aug. 20, 2021.

DAMODHAR, U.; VIKRAM REDDY, M. Impact of pharmaceutical industry treated effluents on the water quality of river Uppanar, South east coast of India: A case study. *Applied Water Science*, v. 3, n. 2, p. 501-514, 2013. https://doi.org/10.1007/s13201-013-0098-x

ESTEVES, F.A. *Fundamentos de Limnologia*. 3ª ed. Rio de Janeiro: Interciência, 2011.

FATIMA, S.U.; KHAN, M.A.; SIDDIQUI, F.; MAHMOOD, N.; SALMAN, N.; ALAMGIR, A.; SHAUKAT, S.S. Geospatial assessment of water quality using principal components analysis (PCA) and water quality index (WQI) in Basho Valley, Gilgit Baltistan (Northern Areas of Pakistan). *Environmental Monitoring and Assessment*, v. 194, n. 3, p. 1-22, 2022. https://doi.org/10.1007/s10661-022-09845-5

FERREIRA, K.C.D.; LOPES, F.B.; ANDRADE, E.M.D.; MEIRELES, A.C.M.; SILVA, G.S.D. Adaptação do índice de qualidade de água da National Sanitation Foundation ao semiárido brasileiro. *Revista Ciência Agronômica*, v. 46, n. 2, p. 277-286, 2015. https://doi.org/10.5935/1806-6690.20150007

FONSECA, J.E.; ALCÂNTARA, R.; BARBOSA, J.E.D.C.; CAMPOS, P.K. Poluição da Água e solo por agrotóxicos. *Revista Científica e-Locução*, v. 1, n. 15, p. 90-99, 2019. https://doi.org/10.57209/e-locucao.v1i15.183

FUNDAÇÃO NACIONAL DE SAÚDE (FUNASA). *Manual de controle da qualidade da água para técnicos que trabalham em ETAS*. Brasília: FUNASA, 2014. 112 p.

GUPTA, S.; GUPTA, S.K. A critical review on water quality index tool: Genesis, evolution and future directions. *Ecological Informatics*, v. 63, 101299, 2021. https://doi.org/10.1016/j.ecoinf.2021.101299

HUSSIEN, A.K.; RASHWAN, I.M.H.; ELSHEMY, M. Surface water quality management for drinking use in El-Beheira Governorate, Egypt. *Water Environment Research*, v. 93, n. 8, p. 1428-1444, 2021. https://doi.org/10.1002/wer.1503

LOPES, C.V.A.; ALBUQUERQUE, G.S.C. Agrochemicals and their impacts on human and environmental health: a systematic review. *Saúde em Debate*, v. 42, n. 117, p. 518-534, 2018. https://doi.org/10.1590/0103-1104201811714

MAPBIOMAS. *Coleção 3.1 da Série Anual de Mapas de Cobertura e Uso de Solo do Brasil*. MAPBIOMAS. Available at: mapbiomas.org/colecoes-mapbiomas-1?cama_set_language=pt-br. Accessed on: Aug. 1, 2020.

MATTHIENSEN, A. Poluição e eutrofização de águas interiores. *In*: SIQUEIRA, G.; SILVA, J.D. (eds.). *12 feridas ambientais do planeta*. Florianópolis: HB, 2017. p. 50-51.

MEDEIROS, A.C.; LIMA, M.O.; GUIMARÃES, R.M. Assessment of the quality of water for consumption by river-bank communities in areas exposed to urban and industrial pollutants in the municipalities of Abaetetuba and Barcarena in the state of Pará, Brazil. *Ciência e Saúde Coletiva*, v. 21, n. 3, p. 695-708, 2016. https://doi.org/10.1590/1413-81232015213.26572015

MELLER, F.; REOLON-COSTA, A.; CEOLIN, S. Uso de agrotóxicos e os riscos à saúde humana: panorama da área rural do município de Independência-RS. *Research, Society and Development*, v. 10, n. 13, e454101321161, 2021. https://doi.org/10.33448/rsd-v10i13.21161

MENBERU, Z.; MOGESSE, B.; REDDYTHOTA, D. Avaliação da qualidade da água e status de eutrofização do Lago Hawassa com base em diferentes índices de qualidade da água. *Applied Water Science*, v. 11, p. 61, 2021. https://doi.org/10.1007/s13201-021-01385-6

MUNIZ, G.L. Qualidade da água do ribeirão São Bartolomeu avaliada pelo índice de qualidade da água em ponto de captação para abastecimento no período seco. *Holos*, v. 7, e5579, 2019. https://doi.org/10.15628/holos.2019.5579

NICODEMO, M.L.F.; MATTHIENSEN, A.; OLIVEIRA FILHO, E.C.; PEREIRA, L.A.; BRITO, L.T.L.; OTENIO, M.H.; OLIVEIRA, M.D. Qualidade da água e redução da poluição. *In*: SILVA, M.S.L.; MATTHIENSEN, A.; BRITO, L.T.L.; LIMA, J.E.F.W.; CARVALHO, C.J.R. (Eds.). *Água e saneamento:* contribuições da Embrapa. Brasília: Embrapa, 2018. chapter 3.

PAIVA, R.F.P.S.; SOUZA, M.F.P. Associação entre condições socioeconômicas, sanitárias e de atenção básica e a morbidade hospitalar por doenças de veiculação hídrica no Brasil. *Cadernos de Saúde Pública*, v. 34, n. 1, e00017316, 2018. https://doi.org/10.1590/0102-311X00017316

PEDROSO, L.B.; COLESANTI, M.T.M. Determinação do Índice de Qualidade de Água da bacia hidrográfica do Ribeirão da Areia – Goiás, em período de estiagem. *Caminhos de Geografia*, v. 18, n. 61, p. 219-230, 2017. https://doi.org/10.14393/RCG186114

PELLIZZARO, P.; HARDT, L.; BOLLMANN, H.; HARDT, C. Urbanização em áreas de mananciais hídricos: estudo de caso em Piraquara, Paraná. *Cadernos Metrópole*, n. 19, p. 221-243, 2008.

PEREIRA, M.A.B.; ALVEZ, W.S.; OLIVEIRA, L.D.; MORAIS, W.A.; LIMA, L.O. Qualidade Hídrica da Cachoeira do Rio São Tomás, no Município de Rio Verde, Goiás, Brasil. *Revista Brasileira de Geografia Física*, v. 13, n. 1, p. 377-390, 2020. https://doi.org/10.26848/rbgf.v13.1.p377-390

PIGNATI, W.A.; LIMA, F.A.N.D.S.; LARA, S.S.D.; CORREA, M.L.M.; BARBOSA, J.R.; LEÃO, L.H.D.C.; PIGNATTI, M.G. Distribuição espacial do uso de agrotóxicos no Brasil: uma ferramenta para a Vigilância em Saúde. *Ciência & Saúde Coletiva*, v. 22, n. 10, p. 3281-3293, 2017. https://doi.org/10.1590/1413-812320172210.17742017

POLHEIM, T.S.; CARDOSO, J.T.; SCHEIN, V.A.S. Characterization of the surface water of a municipal natural park by quality indexes. *Acta Brasiliensis*, v. 3, n. 2, p. 40-48, 2019.

PROGRAMA DE ANÁLISE DE RESÍDUOS DE AGROTÓXICOS EM ALIMENTOS (PARA). *Relatório das amostras analisadas no período 2017-2018*. Primeiro ciclo do Plano Plurianual 2017-2020. Gerência Geral de Toxicologia. PARA, 2019.

R CORE TEAM. *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing, 2020.

REPÓRTER BRASIL. *Íntegra das respostas sobre alimentos campeões de agrotóxicos acima do limite*. São Paulo, 2020.

RODRIGUES, E.A.M.; COUTINHO, A.P.; SOUZA, J.D.S.; COSTA, I.R.A.; NETO, S.M.S.; ANTONINO, A.C.D. Rural Sanitation: Scenarios and Public Policies for the Brazilian Semi-Arid Region. *Sustainability*, v. 14, n. 12, p. 7157, 2022. https://doi.org/10.3390/su14127157

ROSANOVA, C.; FARIA, V.A.; MATOS, F.T.; PINHO, E.S.; AKAMA, A.; MACEDO, D.B. Utilização do Índice de Estado Trófico para análise do grau de trofia do Parque Aquícola Sucupira (Lago de Palmas, TO) na estação seca. *Revista Ouricuri*, v. 8, n. 1, p. 23-36, 2018. https://doi.org/10.29327/ouricuri.v8.i1.a3

SABATIER, R.; MEYER, K.; WIEGAND, K.; CLOUGH, Y. Non-linear effects of pesticide application on biodiversity-driven ecosystem services and disservices in a cacao agroecosystem: a modelling study. *Basic* *and Applied Ecology*, v. 14, n. 2, p. 115-125, 2013. https://doi.org/10.1016/j.baae.2012.12.006

SILVA, A.M.C.; CUNHA, M.C.C.; LOPES, D.V. Qualidade da água como reflexo de atividades antrópicas em bacias hidrográficas do Nordeste, Brasil. *Geosul*, v. 34, n. 72, p. 102-123, 2019. https://doi.org/10.5007/1982-5153.2019v34n72p102

SILVA, E.; SÁ-OLIVEIRA, J. Avaliação da Qualidade da Água da Reserva Particular do Patrimônio Natural (RPPN) Seringal Triunfo, Rio Araguari, Ferreira Gomes-AP-Brasil. *Biota Amazônica*, v. 4, n. 2, p 28-42, 2014. https://doi.org/10.18561/2179-5746/biotaamazonia.v4n2p28-42

SUN, W.; XIA, C.; XU, M.; GUO, J.; SUN, G. Application of modified water quality indices as indicators to assess the spatial and temporal trends of water quality in the Dongjiang River, *Ecological Indicators*, v. 66, p. 306-312, 2016. https://doi.org/10.1016/j.ecolind.2016.01.054

SYBERG, K.; BACKHAUS, T.; BANTA, G.; BRUCE, P.; GUSTAVSSON, M.; MUNNS JR. W.R.; RÄMÖ, R.; SELCK, H.; GUNNARSSON, J. Toward a conceptual approach for assessing risks from chemical mixtures and other stressors to coastal ecosystem services. *Integrated Environmental Assessment and Management*, v. 13, n. 2, p. 376-386, 2017. https://doi.org/10.1002/ieam.1849

UDDIN, M.G.; NASH, S.; OLBERT, A.I. A review of water quality index models and their use for assessing surface water quality. *Ecological Indicators*, v. 122, 107218, 2021. https://doi.org/10.1016/j.ecolind.2020.107218

VALADARES, A.A. *Análise da dinâmica do uso e cobertura do solo sobre a vulnerabilidade ambiental em área do Distrito Federal*. 2017. 197f. Dissertation (Mestrado em Tecnologia Ambiental e Recursos Hídricos) – Universidade de Brasília, Brasília, 2017.

VASCO, A.N.; BRITTO, F.B.; PEREIRA, A.P.S.; MÉLLO JÚNIOR, A.V.M.; GARCIA, C.A.B.; NOGUEIRA, L.C. Avaliação espacial e temporal da qualidade da água na sub-bacia do Rio Poxim, Sergipe, Brasil. *Ambiente & Água*, v. 6, n. 1, p. 118-130, 2011. https://doi.org/10.4136/1980-993X

YAN, T.; SHEN, S.; ZHOU, A. Indices and models of surface water quality assessment: Review and perspectives. *Environmental Pollution*, v. 308, 119611, 2022. https://doi.org/10.1016/j.envpol.2022.119611

WU, Z.; LAI, X.; LI, K. Water quality assessment of rivers in Lake Chaohu Basin (China) using water quality index. *Ecological Indicators*, v. 121, 107021, 2021. https://doi.org/10.1016/j.ecolind.2020.107021