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Analysis of anthropic interference in the quality of surface water in the Cotia River Basin (SP)

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Authors' notes'

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Abstract

Objective: To seasonally evaluate the water quality of the Cotia River Basin (CRB) by the Water Quality Index (WQI) between 2002 and 2018, correlating it with the classes of land use and occupation existing in this basin.

Methodology: Data from the Environmental Company of São Paulo State were used from 2002 to 2018 in five contribution areas (CAs) of the CRB (P1 to P5), calculating the WQI for the dry and rainy seasons. The Anthropic Transformation Index (ATI) was calculated and it was related to the WQI through Pearson's correlation.

Originality/Relevance: Take advantage of data from a monitored watershed to determine, from a historical series, the water quality as a function of quantifying the deleterious effects of human action.

Results: The average WQI of the CRB was classified as Regular for both analyzed periods, with distinction between the CAs, so that P5, corresponding to the Morro Grande Forest Reserve (MGFR), has Excellent quality, while those with anthropized areas presented WQI varying between Regular and Bad. The ATI classified the basin as having medium degradation and the MGFR as having weak degradation, however the anthropic CAs alternated between medium and strong degradation. The linear correlation between the ATI and the WQI confirmed that the anthropic classes of land use influence the opposite way in the water quality, being corroborated by the values of the parameters Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD) and Total Phosphorus (TF) that were outside the limits established by Resolution 357/2005 of the National Council for the Environment.

Contributions: The study showed that the behavior of water quality in the CAs acts in a heterogeneous way, revealing that the most anthropized areas of the basin are influencing the water quality, serving as support in the context of water resources management.

Keywords: indicator, water pollution, sanitation, geoprocessing

Análise da interferência antrópica na qualidade das águas superficiais da Bacia Hidrográfica do Rio Cotia (SP)

Resumo

Objetivo: Avaliar sazonalmente a qualidade da água da Bacia Hidrográfica do Rio Cotia (BHRC) pelo do Índice da Qualidade da Água (IQA) entre 2002 a 2018, correlacionando-a com as classes de uso e ocupação da terra existentes nesta bacia.

Metodologia: Foram utilizados os dados da Companhia Ambiental do Estado de São Paulo (CETESB), de 2002 a 2018 em cinco áreas de contribuição (ACs) da BHRC (P1 a P5), calculando-se o IQA para o período seco e chuvoso. Foi calculado o Índice de Transformação Antrópica (ITA) e este foi relacionado com o IQA por meio da correlação de Pearson.

Originalidade/Relevância: Utilizar os dados de uma bacia hidrográfica monitorada para determinar, a partir de uma série histórica, a qualidade da água em função da quantificação dos efeitos deletérios da ação antrópica.

Resultados: O IQA médio da BHRC foi classificado como Regular para ambos os períodos analisados, com distinção entre as ACs, de forma que o P5, correspondente à Reserva Florestal do Morro Grande (RFMG), possui qualidade Ótima, enquanto as que possuem áreas antropizadas apresentaram IQA variando entre Regular e Ruim. O ITA qualificou a bacia como de degradação média e a RFMG como de degradação fraca, contudo as ACs antropizadas alternaram entre degradação média e forte. A correlação linear entre o ITA e o IQA confirmou que as classes antropizadas de uso da terra influenciam de forma contrária na qualidade da água, sendo corroborada pelos valores dos parâmetros Oxigênio Dissolvido (OD), Demanda Bioquímica de Oxigênio (DBO) e Fósforo Total (FT) que ficaram fora dos limites estabelecidos pela Resolução 357/2005 do Conselho Nacional do Meio Ambiente (CONAMA).

Contribuições: O estudo evidenciou que o comportamento da qualidade da água na BHRC atua de forma heterogênea em função das ACs, revelando que as áreas mais antropizadas da bacia influenciaram negativamente na qualidade da água, servindo de suporte no âmbito da gestão dos recursos hídricos.

Palavras-chave: indicador, poluição hídrica, saneamento básico, geoprocessamento

Análisis de la interferencia antrópica en la calidad del agua superficial en la Cuenca del Río Cotia (SP)

Resumen

Objetivo: Evaluar estacionalmente la calidad del agua de la Cuenca del Río Cotia (CRC) mediante el Índice de Calidad del Agua (ICA) entre 2002 y 2018, correlacionándolo con las clases de uso y ocupación del suelo existentes en esta cuenca.

Metodología: Se utilizaron datos de la Empresa Ambiental del Estado de São Paulo (CETESB) de 2002 a 2018 en cinco áreas de contribución (AC) de la CRC (P1 a P5), calculándose el ICA para las estaciones seca y lluviosa. Se calculó el Índice de Transformación Antrópica (ITA) y se relacionó con el ICA mediante la correlación de Pearson.

Originalidad/Relevancia: Usar los datos de una cuenca monitoreada para determinar, a partir de una serie histórica, la calidad del agua en función de cuantificar los efectos deletéreos de la acción humana.

Resultados: El valor ICA promedio de la CRC se clasificó como Regular para ambos periodos analizados, con distinción entre las AC, de manera que P5, correspondiente a la Reserva Forestal Morro Grande (RFMG), tiene calidad Excelente, mientras que aquellas con áreas antrópicas presentaron ICA que van desde Regular a Malo. El ITA clasificó la cuenca como de degradación media y la RFMG como de degradación débil, sin embargo, las AC antrópicas alternaron entre degradación media y fuerte. La correlación lineal entre el ITA y el ICA confirmó que las clases antrópicas de uso del suelo influyen de manera opuesta en la calidad del agua, siendo corroborado por los valores de los parámetros Oxígeno Disuelto (OD), Demanda Bioquímica de Oxígeno (DBO) y Total Fósforo (FT) que se encontraban fuera de los límites establecidos por la Resolución 357/2005 del Consejo Nacional del Medio Ambiente (CONAMA).

Aportes: El estudio evidenció que el comportamiento de la calidad del agua en las AC actúa de forma heterogénea, revelando que las zonas más antrópicas de la cuenca están influyendo en la calidad del agua, sirviendo de apoyo en el ámbito de los recursos hídricos.

Palabras-clave: indicador, contaminación del agua, saneamiento, geoprocesamiento

Introduction

According to the projections of the United Nations report (UN, 2022), the world population will reach around 8.5 billion by 2030, a fact that intensifies pressure on natural resources, as the demand for urban expansion, arable land, raw materials, and industrial production considerably increases.

In this sense, natural resources and the physical system are constantly changing due to anthropogenic activities, and these changes can negatively impact society and the environment due to environmental degradation (Bezerra et al., 2022; Hasan et al., 2020; Silva et al., 2021). Environmental degradation occurs in various forms, requiring studies to quantify the effects of anthropogenic activities on the environment in order to support protection and management actions, especially regarding the impacts of land use on water quality (Simonetti et al., 2019; Bifano et al., 2020; Nong et al., 2020; Santos et al., 2020; Silva et al., 2022).

Consequently, the integrated analysis of spatial data can significantly contribute to identifying the different types of degradation resulting from these modifications (Melo et al., 2019). According to Silva et al. (2017), an important attribute in the integrated analysis of spatial data is the generation of indicators of environmental sustainability, especially in the degradation of water resources in hydrographic basins resulting mainly from human actions. Thus, water quality is essential to ensure water security, so that evaluative methods are constantly evolving to sustainably ensure public health (Nong et al., 2020; Valentini, Santos & Vieira, 2021; Machado et al., 2022).

Among the indices used in monitoring the quality of surface waters, the Water Quality Index (WQI) stands out, which allows quantitative assessment of water quality (CETESB, 2017). The Water Quality Index was created by the National Sanitation Foundation in the United States and was adopted by CETESB in 1975 in the state of São Paulo; subsequently, the WQI was adopted by other Brazilian states, being the main water quality index currently used in Brazil (CETESB, 2017).

This way, WQI is considered efficient in representing the pollution conditions of water bodies, facilitating comparative analysis between different sampling sites and identifying changes in water quality trends (NSF, 2010; Valentini, Santos & Vieira, 2021; Silva et al., 2022). According to Valentini, Santos & Vieira (2021), the use of WQI proves to be a useful tool because this index has the advantage of resulting in a single number, easily communicated and understood.

Therefore, understanding the effects of land use related to environmental conditions that reflect on water quality is necessary to predict water resource pollution in watersheds, especially those that are not monitored and lack information (Silva et al., 2022). Hence, the use of geotechnologies assists in environmental analysis, evaluating how landscape anthropization behaves spatially and influences qualitative conditions in watersheds (Silva et al., 2017; Sonnenberg et al., 2020; Almeida et al., 2022).

Considerando a importância da associação correlata do uso múltiplo da terra com a qualidade da água e com a poluição difusa, diversos autores realizaram estudos nesse âmbito, tais como o de Steinke, Ferreira & Saito (2012) que calcularam a carga poluente nas áreas úmidas da Bacia Hidrográfica da Lagoa Mirim – fronteira entre Brasil e Uruguai, o de Silva et al. (2017) que propuseram indicadores de sustentabilidade na Bacia Hidrográfica do Rio Una (SP), enquanto Melo et al. (2019) utilizaram mapas auto-organizáveis utilizando redes neurais para buscar identificar possíveis padrões de uso da terra na qualidade da água de um importante reservatório de abastecimento público de água no município de Sorocaba (SP).

Considering the importance of the correlated association between multiple land use and water quality, as well as diffuse pollution, several authors have conducted studies in this area. For instance, Steinke, Ferreira & Saito (2012) conducted an analysis of pollutant loads in the wetland areas of the Mirim Lagoon Watershed, situated on the border between Brazil and Uruguay. Silva et al. (2017) introduced sustainability indicators in the Una River Watershed (SP). Additionally, Melo et al. (2019) utilized self-organizing maps and neurais networks to identify potential land use patterns impacting water quality in a pivotal public water supply reservoir within the municipality of Sorocaba (SP)."

In this context, the objective of this study is to assess water quality in five contributing areas of the Cotia River Watershed (SP) (CRW), by determining the Water Quality Index (WQI) from 2002 to 2018. This assessment takes into account the effects of seasonality and correlates them with the various land use and land cover classes present in the watershed.

Materials and Methods

Study Area

For the development of this research, the Cotia River Watershed (CRW) was selected, situated to the west of the Metropolitan Region of São Paulo (MRSP), encompassing the municipalities of Barueri (2.80%), Carapicuíba (6.92%), Cotia (79.32%), Embu das Artes (7.01%), Jandira (2.81%), and Vargem Grande Paulista (1.15%).

The study area covers 251.36 km² and is divided into two regions with specific characteristics regarding their physical differences and environmental preservation status: Lower Cotia and Upper Cotia (SABESP, 2019).

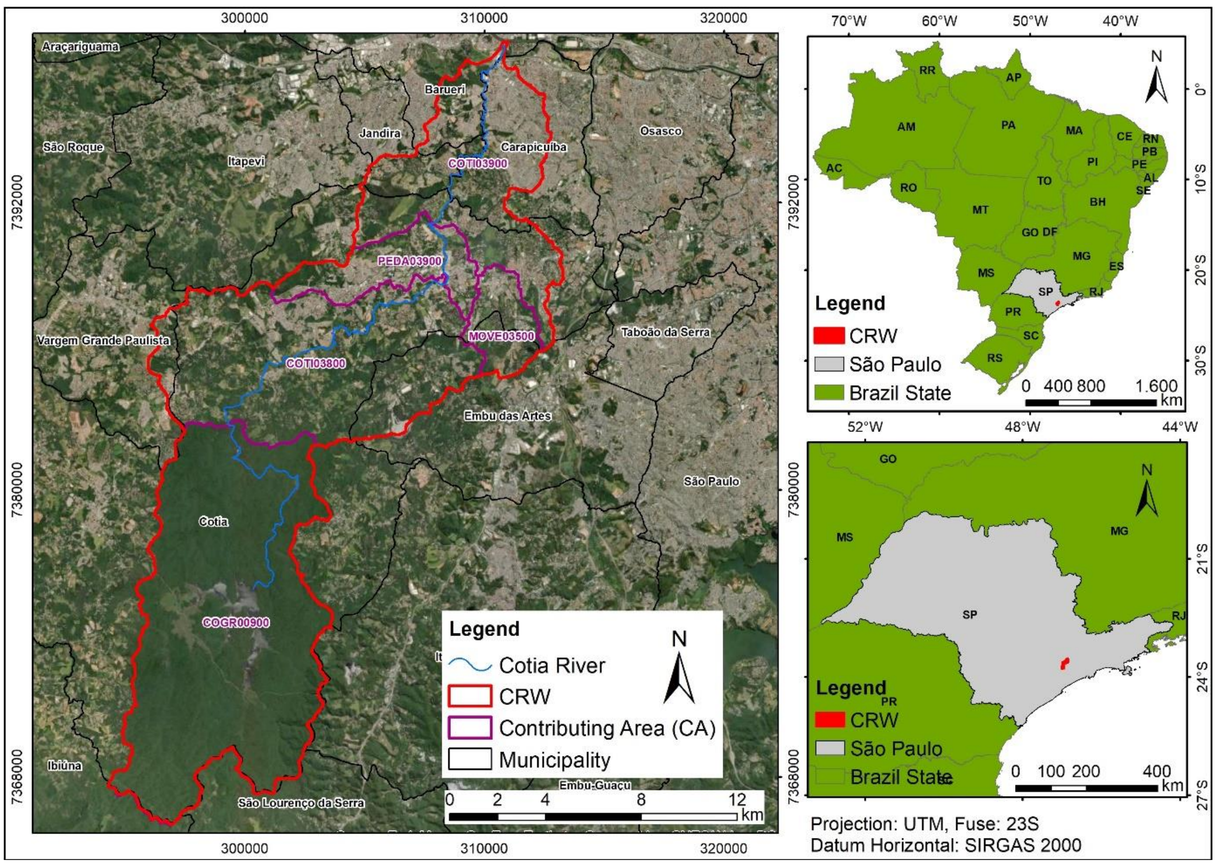
The study area lies in a humid subtropical climate designated as Cwa, with hot summers and dry winters, according to the Köppen-Geiger classification (EMBRAPA, 2018). The average temperature in winter is 16ºC, while in summer, it is 22ºC. The average annual rainfall ranges from 1380 to 1730 mm, with higher intensity upstream in the watershed (DAEE, 2020). The vegetation in the study area consists predominantly of dense ombrophilous forest and semi-deciduous mesophytic forest cover (São Paulo, 2007).

Lower Cotia presents a highly urbanized scenario, with streams constantly contaminated and silted due to unplanned occupation, lack of basic sanitation infrastructure, and the presence of industrial activities, which ultimately compromise the quality of treated water (São Paulo, 2007).

Figure 1 shows the spatial position of the CRW.

Figure 1

Map showing the location of the Cotia River Watershed (CRW)



Source: the Author.

According to Metzger et al. (2006), the Upper Cotia experiences minimal anthropogenic pressure due to the presence of the Morro Grande Forest Reserve (RFMG), one of the largest forest remnants in the São Paulo Atlantic Plateau. However, the area has faced significant deforestation in the past for urban expansion, agriculture, and historically for charcoal and firewood extraction. The Morro Grande Reserve is located at the headwaters of the Cotia River, housing the Pedro Beicht and Cachoeira da Graça reservoirs. Since 1916, the Upper Cotia Production System, operated by the São Paulo State Basic Sanitation Company (SABESP), has supplied water to over 500,000 residents of the Metropolitan Region of São Paulo.

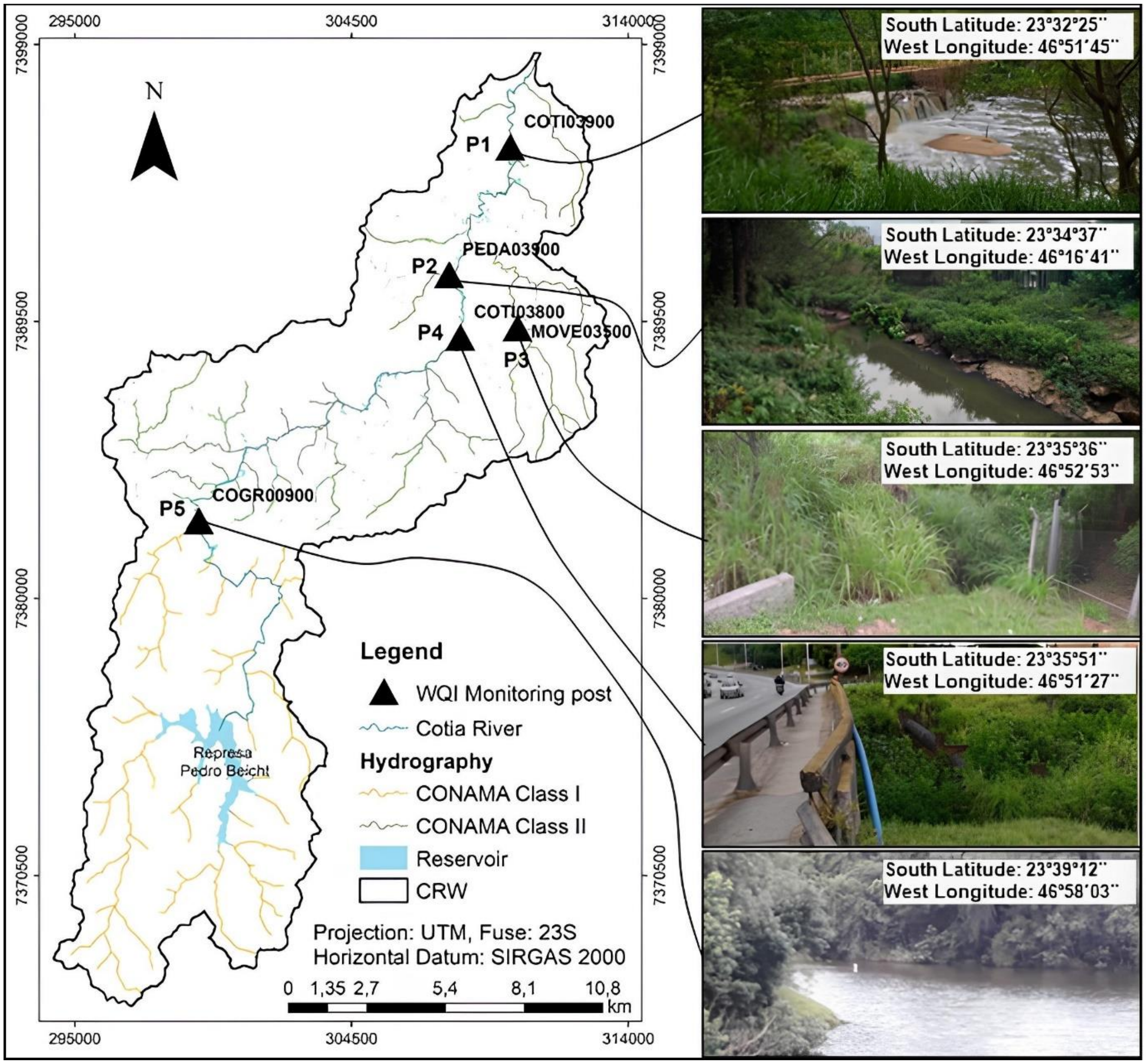
According to the São Paulo State Data Analysis System Foundation (SEADE, 2020), the resident population of the CRW was approximately 495,000 in 2019, 445,000 in 2011, and 390,000 in 2002, indicating an approximate population growth rate of 12% for both periods.

Methodological Procedures

For the development of the Water Quality Index (WQI), data from the Infoáguas Portal of the Environmental Company of the State of São Paulo (CETESB, 2019) were used. Five monitoring stations within the Cotia River Watershed (CRW) were selected, as shown in Figure 2.

Figure 2

Map showing the locations of monitoring stations



Source: the Author

Field visits for landscape analysis at the water quality monitoring sites were conducted between October and November 2019. Observations were made along a circuit from downstream to upstream of the Cotia River and divided into the contributing areas.

According to CONAMA Resolution No. 357 (Brazil, 2005), and as depicted in Figure 2, Class I encompasses the Cotia River and all its tributaries up to the Graças Dam. Class III extends from the Graças Dam in Cotia to the Isolina Dam, located at the border between the municipalities of Barueri and Carapicuíba (São Paulo, 1977). Thus, only monitoring station COGR00900 (P5) falls under Class I, while the other four stations fall under Class III (P1 to P4).

The WQI was analyzed according to the methodology proposed by CETESB (2019), calculated by the weighted product (Equation 1) of the values of the nine parameters that compose the WQI with their respective weights (wi) indicated in parentheses: Dissolved Oxygen (DO - 0.17); Thermotolerant Coliforms (TC - 0.15); Hydrogenionic Potential (pH - 0.12); Biochemical Oxygen Demand (BOD - 0.10); Total Nitrogen (TN - 0.10); Total Phosphorus (TP - 0.10); Turbidity (0.08), Temperature (0.10), and Total Solids (TS - 0.08). Therefore, each variable is weighted by a wi value between 0 and 1, and the sum of all weights equals 1. The result of the WQI is a number expressed between 0 and 100, based on normalizing curves (CETESB, 2019).

$$\text{WQI} = \prod_{i=1}^{9} qi^{wi} \qquad (1)$$

Given: qi is the quality of parameter i, obtained through the qualitative mean curve (graph parameter) as a function of its measurement; wi is the weight given to the parameter based on its priority in quality.

According to the WQI classification, the quality of raw surface waters can vary on a scale of 0 to 100, as follows: from 0 to 19 classified as "Very Poor"; 20 to 36, "Poor"; 37 to 51, "Average"; 52 to 79, "Good"; and 80 to 100, "Excellent" (CETESB, 2019).

Thus, to better represent the seasonality of water quality data in the CRW, the WQI was divided into dry season (DS) and rainy season (RS) over the period from 2002 to 2018, with WQIDS designated for the dry season and WQIRS for the rainy season.

The Contributing Areas (CAs) were delimited as proposed by Toniolo (2021), which are equivalent to watersheds based on the five monitoring stations, with the aid of geoprocessing techniques (Figure 2), to assist in the spatial analysis of the WQI.

The WQI values were calculated using the free software IQAData 2010 Version (Posselt & Costa, 2010) and then transferred to Excel. With the assistance of BioEstat 5.3 software (Ayres et al., 2007), the WQIRS and WQIDS values were statistically analyzed, applied per CA.

The Anthropogenic Transformation Index (ATI), proposed by Lémechev (1982) (Equation 2), was used to quantify anthropogenic pressure on various types of landscape occupation, whether natural or artificial, i.e., land use and land cover classes, with a range from 0 to 10. A value of 0 is assigned to minimum or no pressure, while a value of 10 indicates maximum anthropogenic pressure.

$$\text{ATI} = \sum \frac{(\%\text{USE x WEIGHT})}{100} \quad (2)$$

Given: USE is the area in percentage values of a specific land use class; and WEIGHT is the value assigned to different types of land use regarding the degree of anthropogenic modification.

For the USE variable, the land use and land cover map prepared by Toniolo (2020) was utilized as a reference for the years 2002, 2011, and 2019. This map was derived from the manual updating of polygons from the "Atlas of Land Use and Land Cover of the Municipalities of the RMSP" (EMPLASA, 2006) for the year 2002, and from the photointerpretation of orthorectified images (Novo, 2010) for the years 2011 and 2019, provided by the São Paulo State Basic Sanitation Company (SABESP).

For the WEIGHT variable, the arithmetic average of weights used in other studies by researchers Karnaukhova (2000); Ortega (2011); Gouveia, Galvanin & Neves (2013); Rodrigues et al. (2014); and Lopes et al. (2017) was applied. These weights are as follows: 8.3 for subnormal agglomerate; 6.9 for agriculture; 8.8 for urban area; 9.2 for landfill; 2.9 for hydrography; 9.1 for industry; 10.0 for mining; 5.8 for pasture; 3.2 for reforestation; 7.5 for exposed soil; and 0.8 for tree vegetation.

In order to assess the potential influence of land use and land cover on water quality, the Pearson correlation coefficient (r) was applied to the WQI and ATI for each land use class. The association verification was conducted using the Student's t-test, which is suitable for a set of up to 30 samples, with a significance level of 5% and with n – 2 degrees of freedom, as indicated by Bruce & Bruce (2019). BioEstat 5.3 software (Ayres et al., 2007) was also utilized for calculating this correlation.

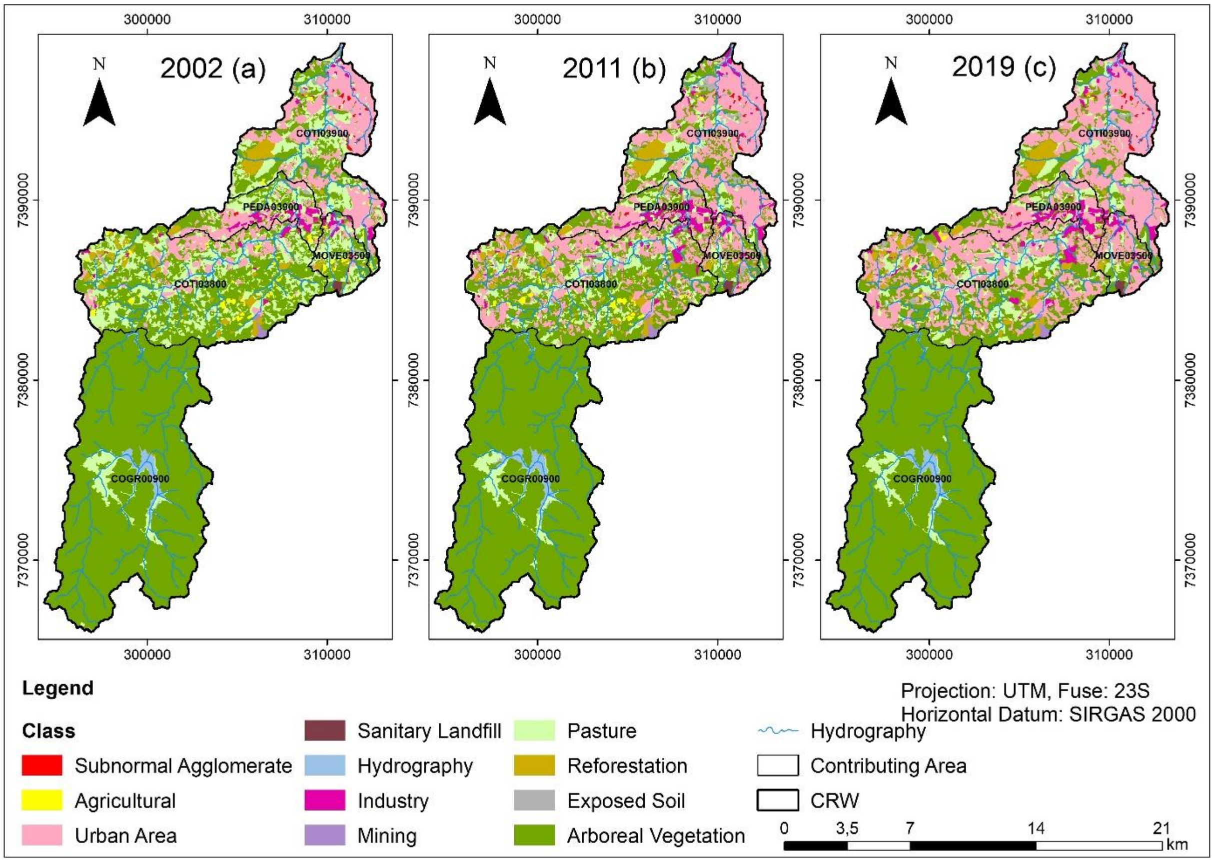
The classification of correlation was adapted from Santos et al. (2019) as follows: $r = 1$, perfect positive correlation; $0.8 \le r < 1$, strong positive correlation; $0.5 \le r < 0.8$, moderate positive correlation; $0.1 \le r < 0.5$, weak positive correlation; $0 \le r < 0.1$, negligible positive correlation; $r = 0$, no correlation; $0 < r < -0.1$, negligible negative correlation; $-0.1 \le r < -0.5$, weak negative correlation; $-0.5 \le r < -0.8$, moderate negative correlation; $-0.8 \le r < -1$, strong negative correlation; and $r = -1$, perfect negative correlation.

Results and Discussion

Regarding land use and occupancy, according to Figure 3 (a - c), it is noted that in 2002, BHRC had a proportion of 81.13% natural areas about its total area, while anthropized areas corresponded to 18.87%. However, by 2011, the percentage of natural areas reduced to 71.61%, while anthropized areas increased to 28.39%. Finally, in 2019, BHRC presented an even lower proportion of natural areas, corresponding to 66.40% of the total area, while anthropized areas grew to 33.60%.

Figure 3

Land use and occupancy maps for 2002 (a), 2011 (b), and 2019 (c)

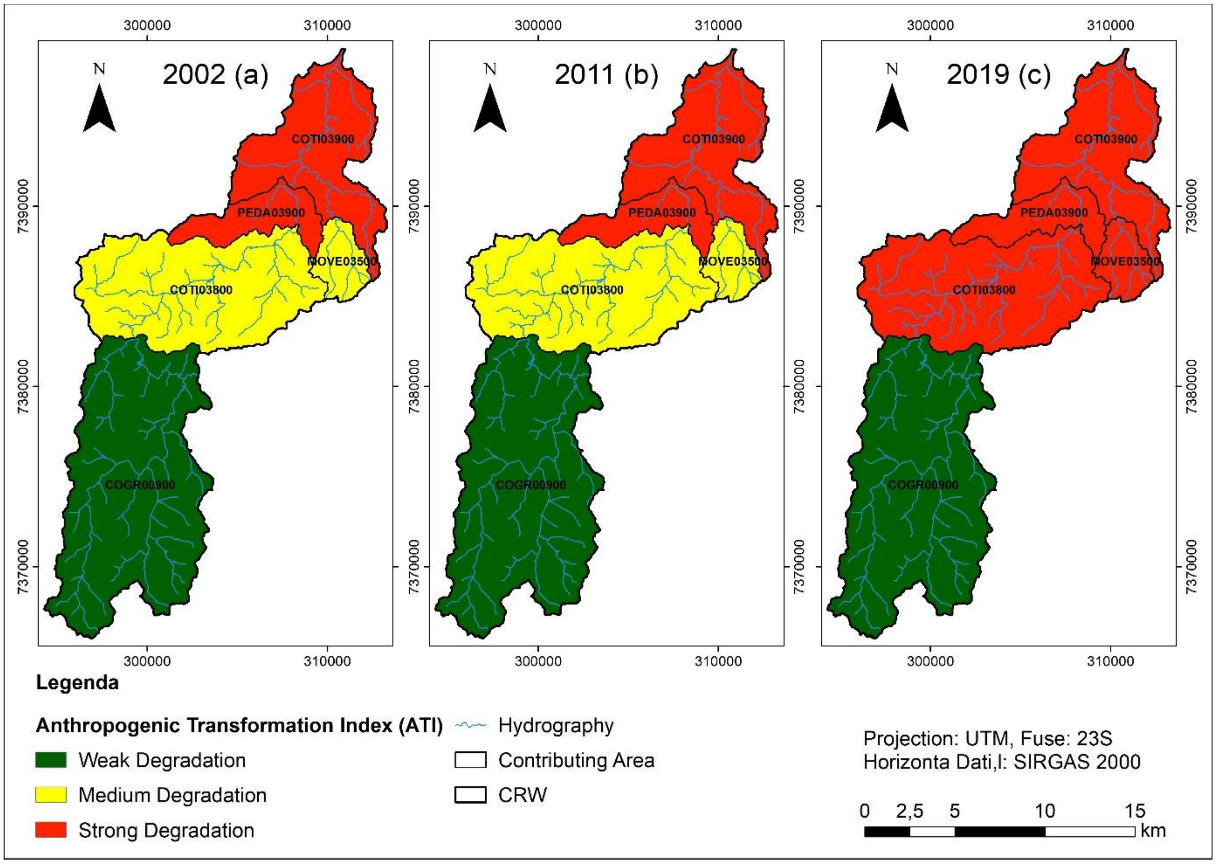


Source: Toniolo (2020).

Furthermore, according to Figure 3 (a - c), it is possible to highlight a constant reduction of natural areas in BHRC, making room for anthropized classes, such as urbanized and industrial areas. Thus, to better demonstrate the evolution of the anthropization of the watershed, the Anthropogenic Transformation Index (ATI) is presented for each CA in the periods of 2002, 2011, and 2019 in Figure 4 (a - c).

Figure 4

Maps of the ATI for 2002 (a), 2011 (b), and 2019 (c)



Source: the Author.

The results obtained through the calculations of the ATI applied to land use classes allowed the general classification of BHRC as having medium degradation for the three years analyzed, with the following scores: 3.10 for 2002, 3.50 for 2011, and 3.84 for 2019.

In Figure 4(a - c), it is possible to observe that the CA with the least degradation is P5 (COGR00900), mainly because this region is environmentally protected, inhibiting anthropogenic pressure. The other CAs, located in the Lower Cotia region, showed increasing anthropization during the analyzed period, ranging from Medium Degradation to Strong Degradation.

From the analysis of the classes comprising the ATI, urban areas and pasture exhibited the largest occupied areas concerning land use for BHRC. For the year 2002, the ATI value was 2.17, corresponding to 31.11%, while the ATI for the year 2011 was 2.45 (31.82%), and 2.90 (36.36%) for the year 2019. However, it is worth noting that the urban area showed continuous growth (ATI was 1.1 in 2002; 1.81 in 2011, and 2.35 in 2019), while pasture experienced continuous decline (ATI was 1.07 in 2002; 0.64 in 2011, and 0.55 in 2019).

The industrial class in BHRC showed significant growth from 2002 to 2011, with an ATI value of 0.13 (1.48%) and 0.22 (2.42%) respectively. However, from 2011 to 2019, it remained stagnant. This occurred due to the low expansion of factories in this second interval: in 2011, there were 607.04 hectares of this class in BHRC, and in 2019, it increased to 607.48 hectares, representing an increase of only 0.40%.

The mining and landfill classes in BHRC remained stable during the period, with an average ATI of 0.02 (0.18%) and 0.01 (0.13%), respectively. The areas of subnormal agglomeration and reforestation also showed consistent behavior during the period, with an average ATI of 0.02 (0.24%) and 0.09 (2.74%), respectively. The hydrography class, corresponding to the ponds and reservoirs in the study area, also remained relatively constant during the three years of the study, with an average ATI value of 0.03 (1.21%).

The exposed soil class in BHRC showed an increase in ATI from 2002 to 2011, with values of 0.05 (0.73%) and 0.12 (1.55%), respectively. However, for the year 2019, it exhibited a decrease, with an ATI value of 0.07 (0.89%). Agricultural activities decreased significantly, with an ATI of 0.06 (0.86%) in 2002, 0.03 (0.47%) in 2011, and 0.01 (0.11%) in 2019.

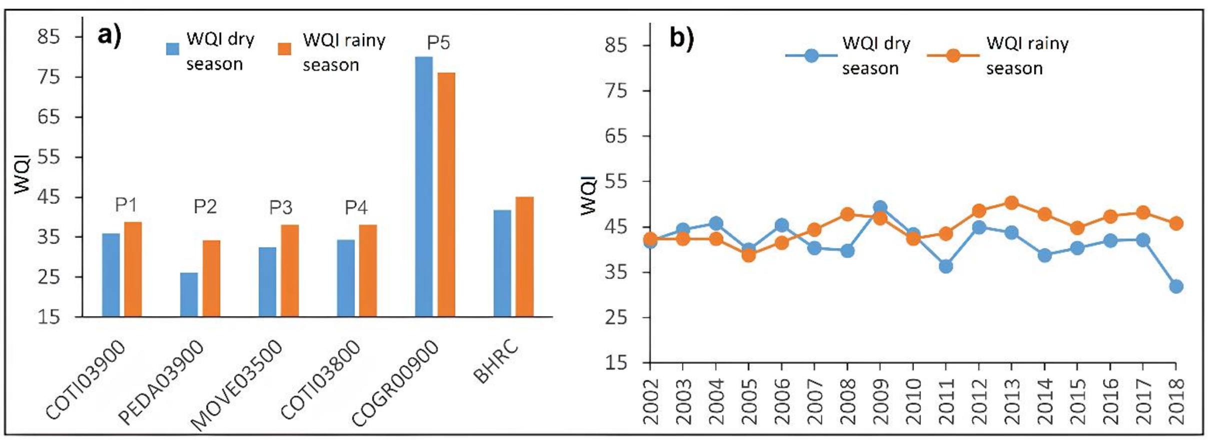
Moreover, the forests and forest fragments, corresponding to the arboreal vegetation class in BHRC, showed a decline during the period, also explained by soil sealing. For 2002, they had an ATI value of 0.52 (61.40%), for 2011 an ATI of 0.50 (59.11%), while for 2019 the ATI was 0.47 (55.77%). It is noteworthy that, although this class has the third highest contribution to the ATI, it has the lowest degradation intensity, with a weight of only 0.8.

The strong degradation of the CAs in the Lower Cotia region stems from urban, industrial, and subnormal agglomeration areas. The low agricultural activity in BHRC and the predominance of natural areas align with the presented ATI result. Unfortunately, the ATI value tends to increase in BHRC due to the expansion of urban occupation, making the regions of natural vegetation and water resources the most vulnerable points to this anthropogenic pressure (Silva et al., 2017).

Figure 5 (a - b) presents the spatial (left side) and temporal (right side) variability graphs of the Water Quality Index (WQI) for the Cotia River Basin (BHRC), considering the arithmetic mean of the WQI from the five monitoring stations.

Figure 5

Average variation of the WQI along space (a) and time (b) in the Cotia River Basin (BHRC) during dry and rainy seasons



Source: the Author.

Examining Figure 5(a), it is observed that the station with the highest water quality value was P5 (COGR00900), classified as Excellent for both periods. P4 (COTI3800) had a WQI value of 34 for the dry season and 38 for the rainy season, classifying it as Average. P3 (MOVE03500) had a WQI value of 32 (Poor) for the dry season and 38 for the rainy season

(Average). P2 (PEDA03900) exhibited poor water quality (WQI = 26 in the dry season and WQI = 34 in the rainy season), while P1 (COTI03900) showed average water quality for both periods.

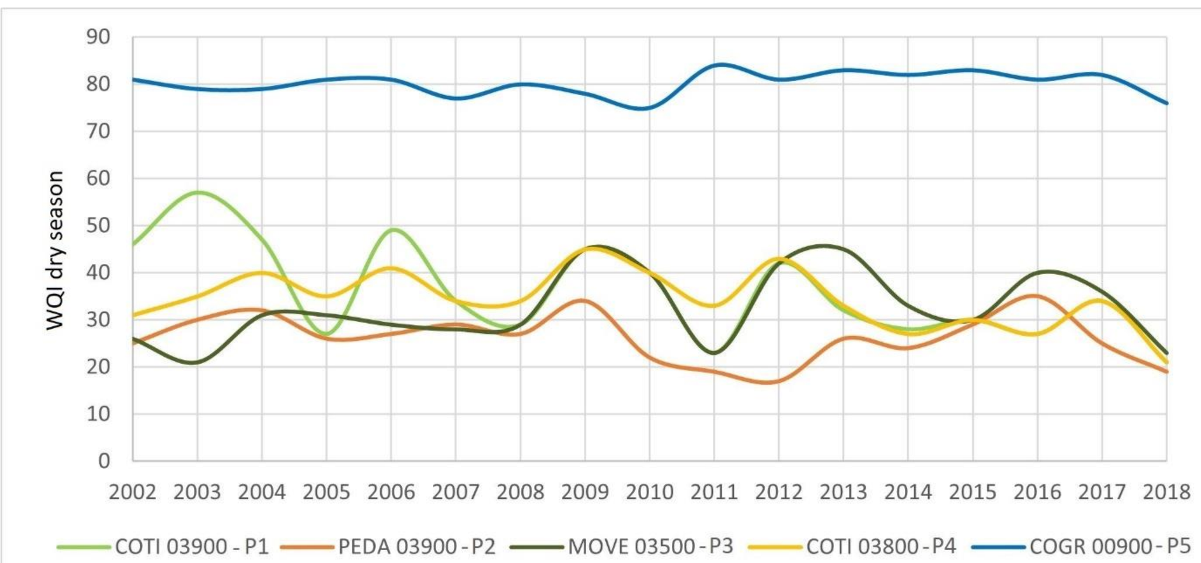
The average WQI of the BHRC falls into the "Average" category, that is, with a WQI of 42 for the dry season and 45 for the rainy season. It was also observed that water quality values are higher during the rainy season, corroborating the study by Araujo et al. (2018), who found that precipitation significantly influences the values of parameters such as turbidity, pH, total solids, temperature, and total phosphorus tested in the Billings Reservoir in the RMSP.

The temporal variation of the WQI in the BHRC (Figure 5b) shows that from 2002 until the second semester of 2006, the quality remained higher during the dry season, fluctuating until 2010, where the situation then reverses, meaning that the WQI has higher values during the rainy season.

In Figures 6 and 7, the average variations of the WQI for the monitored stations are presented.

Figure 6

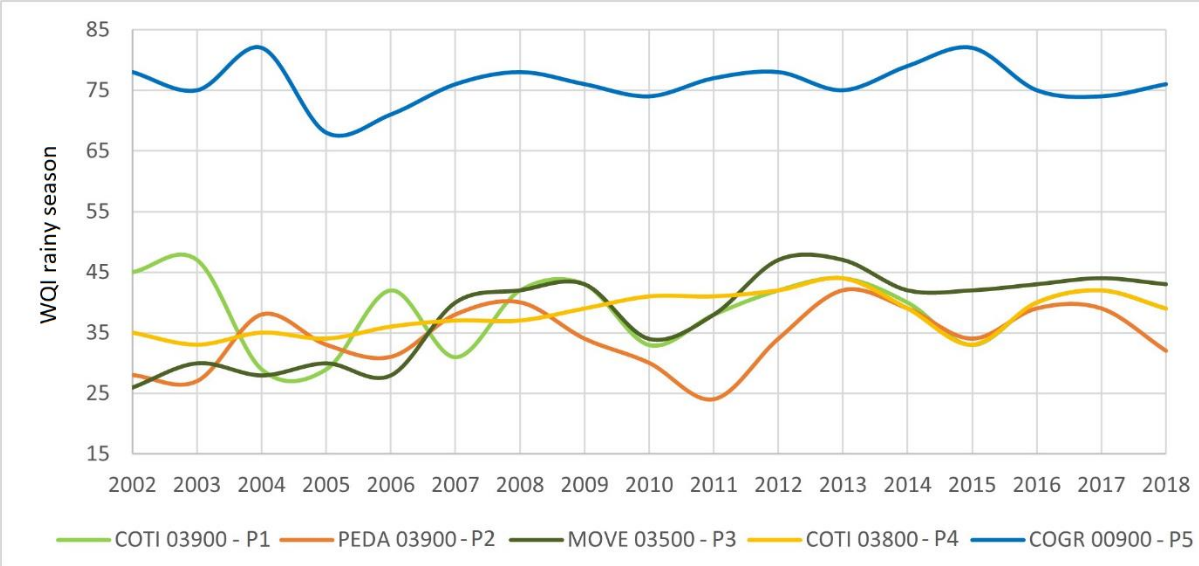
Average variation of the WQI over time at the sampled stations for the dry period



Source: the Author.

Figure 7

Average variation in WQI over time in the sampled stations for the rainy season



Source: the Author.

Analyzing the results presented in Figures 6 and 7, it is possible to observe that the best WQI values correspond to P5 (P5 - AC COGR00900) for both periods, with values much higher than the other sampled stations.

P1 experienced significant fluctuations over time, achieving the best results in both periods in 2003 and declining in 2018.

P2 (PEDA03900) also showed variation over time, with the worst WQI values found from 2010 to 2012 for the dry season, while 2011 had the lowest value during the rainy season.

P3 (MOVE03500) presented the worst values in 2002 and 2003, in both the rainy and dry periods, and over time showed an increase in the WQI value, with the year 2009 having the highest value obtained during the dry period, while the years 2012 and 2013 had the highest values during the rainy period. However, for the year 2018, P3 showed a decrease in quality, especially during the dry period.

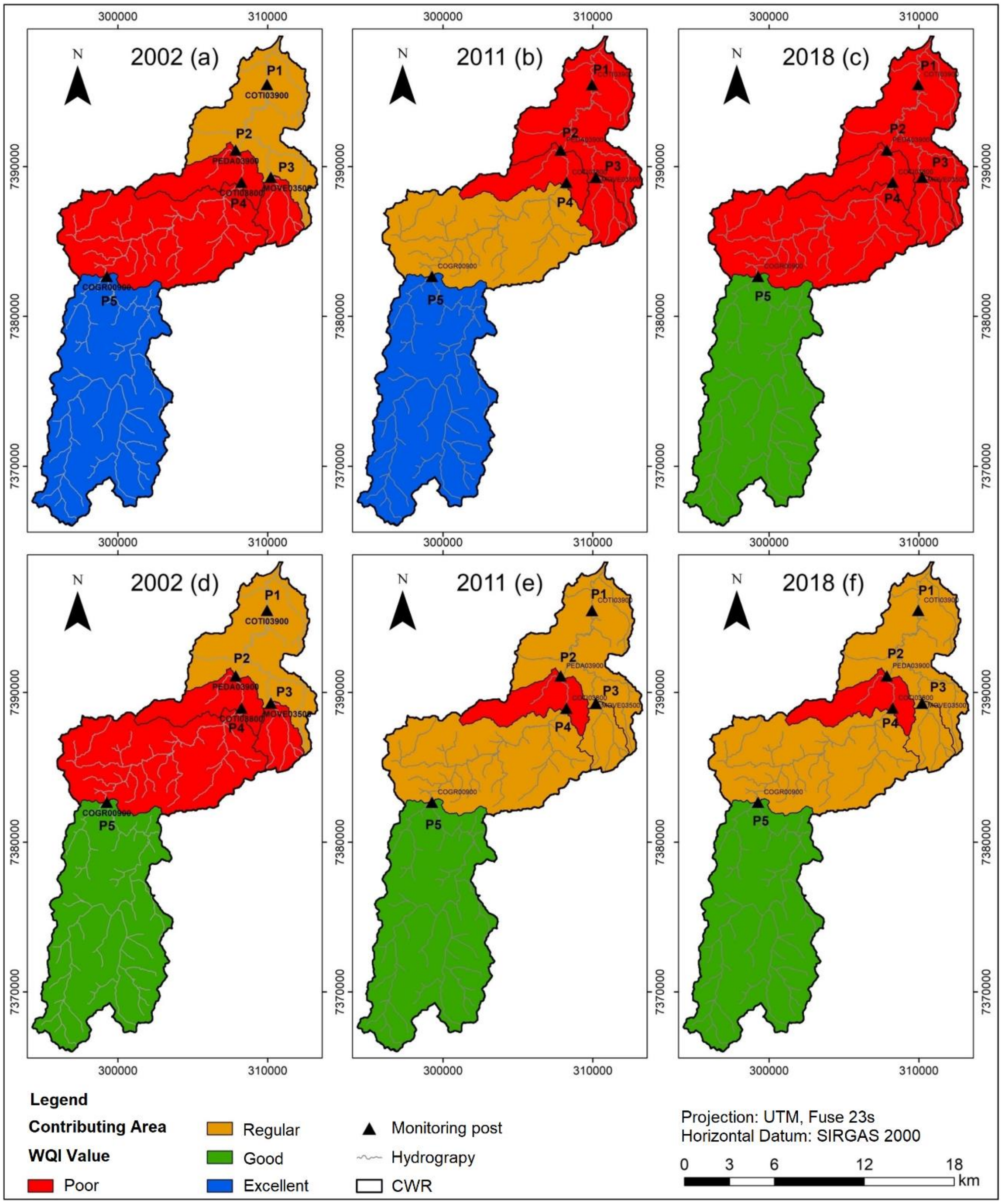
P4 (COTI03800) presented the highest WQI value during the dry period in 2009 and in 2013 during the rainy period, while the worst values were obtained in 2003 during the rainy period and in 2018 during the dry period.

In general, it is observed that the WQI maintains higher values during the rainy season in anthropized areas and maintains higher values during the dry season in natural areas (P5 - AC COGR00900). This can be explained by the dilution of pollutant loads during precipitation periods, where the water body's flow is higher, even though the discharge of untreated sewage tends to reduce the intensity of dilution (Silva et al., 2017; SABESP, 2019).

The natural areas, on the other hand, tend not to be as influenced by precipitation due to their natural conservation state, which favors the self-purification of water bodies (CETESB, 2019; Simonetti et al., 2019). Figure 8 (a – f) presents the average WQI values for the years 2002, 2011, and 2018, respectively.

Figure 8

(a – f). Maps of the WQI during the dry period (a – c) and during the rainy period (d – f) by contributing area



Source: the Author.

Analyzing Figure 8 (a – f), it is observed that all five CA's showed fluctuation in WQI values during the analyzed periods. The CA of P1 (COTI03900) exhibited a deterioration in its quality, transitioning from Average to Poor from 2011 to 2018 during the dry period, while maintaining its Average quality in all years during the rainy period.

The CA of P2 (PEDA03900) maintained its WQI as Poor in all years and in both periods, being the worst contributing area of the Cotia River Watershed. The CA of P3 (MOVE03500) kept its WQI as Poor in all analyzed years during the dry period. However, during the rainy period, it improved its class from Poor to Average between 2002 and 2011, and it remained so until 2018 in the same period.

Regarding the contributing area of P4 (COTI03800), it showed an improvement in its quality, transitioning from the Poor class in 2002 to Average in 2011 during the dry period, and experiencing a new decrease in its quality in 2018. During the rainy period, it went from Poor in 2002 to Average in 2011, and it remained so until 2018.

On the other hand, P5 (COGR00900) exhibited a decrease in quality, transitioning from Excellent to Good in the dry period from 2011 to 2018, while maintaining a Good quality during the rainy period. Overall, the quality of the analyzed water bodies tends to be better during the rainy season.

The results of the Pearson correlation between the Anthropogenic Transformation Index (ATI) and the Water Quality Index (WQI) are presented in Table 1 for the dry period (dp), as well as the significance level (p-value).

Pearson correlation between ATI and WQI in the dry period (dp)

Soil Class	Pearson coefficient (R)			P-value		
	2002	2011	2019	2002	2011	2019
Subnormal Agglomerate	-0,279	-0,658	-0,517	0,215	0,016*	0,049*
Agricultural	-0,718	-0,120	-0,364	0,025*	0,370	0,147
Urban Area	-0,355	-0,913	-0,934	0,154	0,000	0,000
Sanitary Landfill	-0,376	-0,276	-0,204	0,139	0,217	0,284
Hydrography	0,939	1,000	0,984	1,000	1,000	1,000
Industry	-0,627	-0,612	-0,551	0,023*	0,027*	0,046*
Mining	-0,257	-0,070	-0,250	0,234	0,423	0,241
Pasture	-0,908	-0,876	-0,901	0,001*	0,002*	0,001*
Reforestation	-0,414	-0,557	-0,665	0,113	0,044*	0,015*
Exposed soil	-0,320	-0,592	-0,520	0,181	0,032*	0,048*
Arboreal Vegetation	0,832	0,908	0,886	0,999	1,000	1,000

Subtitle: * is statistically significant when the p-value is ≤ 0.05.

Source: the Author.

Analyzing Table 1, it is possible to notice that out of 33 correlations, only 13 showed statistical significance, with the industrial and pasture classes showing significance for the entire evaluated period; subnormal agglomeration, exposed soil, and reforestation for 2011 and 2019, and agriculture only for 2002. This result suggests that such land uses were determinant in causing changes in water quality, with industrial areas standing out as a moderate negative correlation and pasture with a strong negative correlation.

This way, anthropized classes showed a negative correlation, meaning their higher frequency may be related to lower WQI values. These values confirm anthropogenic pressure on the physical environment, especially the strong correlation of the urban area. The moderate correlation of industrial use and the weak correlation of the subnormal agglomeration also reinforce the occurrence of clandestine discharge of untreated sewage, reducing dissolved oxygen in the water and increasing pollution of water bodies (Von Sperling, 2005; Simonetti et al., 2019; Mendonça, Gonçalves & Rigue, 2020).

The mining and sanitary landfill classes also showed moderate negative correlations, whereas the agriculture class presented a moderate negative correlation with significance only in the first period. This could be attributed to the small size of these categories in relation to the study area, despite having a high degree of anthropogenic transformation and the potential to cause serious environmental problems such as soil contamination, pollution of watercourses, and erosion (Schnack et al., 2018; Nery et al., 2020).

The natural classes, which include arboreal vegetation and hydrography, showed positive correlations as strong, meaning their greater spatial contribution may be associated with an improvement in water quality, given that the input of nutrients generated by vegetation is low, contributing to the reduction of biochemical oxygen demand (BOD) and thermotolerant coliforms, favoring the preservation of water resources (CETESB, 2019; Poersch et al., 2022).

Table 2 presents the correlation results of ATI versus WQI for the rainy period (pc).

Table 2

Pearson correlation between ATI and WQI in the rainy period (pc)

Soil Class	Pearson coefficient (R)			P-value		
	2002	2011	2019	2002	2011	2019
Subnormal Agglomerate	-0,333	-0,538	-0,495	0,171	0,051	0,049*
Agricultural	-0,737	-0,093	-0,345	0,006*	0,398	0,161
Urban Area	-0,370	-0,854	-0,913	0,143	0,000	0,000
Sanitary Landfill	-0,432	-0,158	-0,090	0,103	0,330	0,401
Hydrography	0,952	0,972	0,960	1,000	1,000	1,000
Industry	-0,626	-0,760	-0,665	0,023*	0,004*	0,015*
Mining	-0,195	-0,073	-0,219	0,293	0,420	0,270
Pasture	-0,928	-0,828	-0,879	0,002*	0,001*	0,001*
Reforestation	-0,387	-0,499	-0,642	0,131	0,037*	0,020*
Exposed soil	-0,312	-0,670	-0,511	0,187	0,014*	0,042*
Arboreal Vegetation	0,873	0,821	0,830	1,000	0,999	0,999

Subtitle: * is statistically significant when the p-value is ≤ 0.05.

Source: the Author.

According to Table 2, it is noticeable that the correlations between ATI and WQI during the rainy period were similar to those during the dry period (Table 1). Out of 33 correlations, 12 showed statistical significance, with the industrial (moderate negative) and pasture (strong negative) classes standing out for all three years analyzed.

The reforestation class proved to be significant in altering WQI values and showed a moderate correlation in the years 2011 and 2019. This supports the premise that initially forest plantations can cause environmental damage such as the decrease of native species and soil impoverishment, as they facilitate sediment runoff into water bodies. However, after growth, they tend to reach balance (São Paulo, 2007; Rodrigues et al., 2014).

Similar results were obtained by Araujo et al. (2018) in micro-watersheds of the Billings Reservoir in the Metropolitan Region of São Paulo (RMSP). The anthropized areas showed a decrease in water quality, with parameters such as turbidity, total solids, electrical conductivity, and phosphorus showing negative correlation and statistical significance. On the other hand, Bariani et al. (2013) concluded that the urban area and the native field can influence the contamination of water bodies in the municipality of Itaqui – RS, Since both classes showed significant Spearman correlations with the mesophilic bacteria variable, being 0.71 and 0.65, respectively.

In order to improve the quality of water used for public supply and preserve biodiversity against human intervention, it is essential for public policies to be adopted to promote the management of environmental programs in river basins. This may include measures such as the restoration and maintenance of native vegetation and the protection of watercourses and their surroundings, reducing the pollutant load reaching the rivers, and consequently improving the Water Quality Index (WQI), as well as water treatment for human consumption (Metzger et al., 2006; SABESP, 2019; Cosso & Mariosa, 2022; Rizzo et al., 2022).

Conclusion

The WQI obtained for both the dry and rainy periods, between the years 2002 and 2018, was classified as "Average", with values of 42 and 45, respectively. The other contributing areas (CAs) were classified as "Poor" WQI for the dry period and "Average" WQI for the rainy period, data that confirms the high level of environmental fragility in which the Lower Cotia is inserted.

Even though the Anthropogenic Transformation Index (ATI) of the Cotia River Basin for the analyzed period was classified as having a moderate level of environmental degradation, there is an intensification of anthropogenic action in the contributing areas (CAs) located in the Lower Cotia, mostly characterized as heavily degraded. This observation sheds light on the potential risks to the biodiversity of the Morro Grande Reserve and raises environmental concerns due to the observed urban growth in the area.

Although most integrated analyses lack statistical significance, the linear correlation confirmed that anthropized land use classes are inversely proportional to the WQI. This may be attributed to the negative values found in the Pearson correlation for these classes, which contributes to natural areas positively influencing water quality.

Finally, as a suggestion for future studies, it is recommended to associate this method with a more detailed study of the biotic and social aspects of the Cotia River Basin, as well as in similar river basins, contributing to the control of water pollution and the improvement of environmental program development.

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