RESEARCH PAPER

INFLUENCE OF WATERSHED LAND USE ON WATER QUALITY IN THE STATE OF SANTA CATARINA, BRAZIL

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ABSTRACT. The inappropriate use of water resources by human actions compromises the balance between natural and anthropogenic factors. In this study, exploratory and field research were conducted with a scope of quantifying, based on satellite imaging, the use and occupation of land on the banks of the Itajaí-Açu River, the largest watercourse in the Itajaí River Basin, located in the State of Santa Catarina, Brazil. Five sampling points were allocated along the river at different times of the year to analyze water quality using chemical and biological indicators. The characterization of land use and occupation was carried out with Sentinel-2B satellite images at 10m resolution and QGIS software. Version 3.6.3 of the R Software was used to consolidate the data. The land use was categorized into several classes, the most representative of which was vegetation, which presented coverage of 34.42%, followed by the pastures and open fields class, with 27.83%, agriculture, with 18.18%, and urban areas, with 16.59% coverage. Our study showed that 62.6% of the river's base was affected by anthropogenic influence, characterizing an environment severely altered from its normal state. The results obtained in the statistical analysis revealed a directional correlation between land use and water quality, thus indicating that cities on the banks of watercourses are major sources of potential contaminants. Among the classes of land use, the presence of vegetation along the riverside territory attenuated part of the load of pollutants launched into the Itajaí-Açu River. This finding highlights the importance of conserving the vegetation alongside the river to maintain water quality and, consequently, preserve the ecosystem's biota.

KEYWORDS: land use; water quality, watershed, thermotolerant coliform indicators

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INTRODUCTION

The inadequate use of water resources by anthropogenic processes endangers the ecosystem's biota and, consequently, damages collective health. According to Costa Santos et al. (2019), the expansion of agricultural areas, the increase in urban agglomeration, and the exploitation of natural resources are examples of anthropogenic actions that cause rapid changes in the land cover, generating environmental repercussions.

River basins are areas drained by a river or a river system that flows into a common location where rainwater flows superficially or seeps into the soil, forming springs and watercourses and recharging the groundwater (Furlan et al. 2016). Since the beginning, as human life settled on the banks of rivers and developed their urban and industrial agglomerations, the river basins began to serve as containers for pollutants derived from land and the atmosphere (Martins et al. 2015).

Water resources are indispensable for the growth of a territory's economy and the maintenance of essential activities for human survival. However, the human actions carried out in the water resources' surroundings modify the physical, chemical, and biological environment, which, in turn, causes a significant decrease in water quality and water body biodiversity (Okumura et al. 2020).

In 1997, Brazil created a water resources policy (Law No. 9.433/97) to ensure current and future generations' necessary water availability at quality standards appropriate for the respective uses (*Lei No 9.433. Institui a Política Nacional de Recursos Hídricos 1997*). The chemical, physical, and biological parameters measured in a water body can indicate the degree of contamination and provide a basis for managing this resource. Such indication helps to assist in decision-making, focusing on the maintenance, remeasurement, and protection of water bodies.

According to Susanti and Wahyuningrum (2020), watershed management is inseparable from land use and management. The inappropriate use of land, disregarding soil and water conservation, causes damage to the watershed ecosystems. The mapping of land use and land cover emerges as a tool to quantify biodiversity losses. It can also measure the environmental impacts caused by territory urbanization. The interpretation of satellite images associated with water quality parameters in a river enables researchers to diagnose the river's current condition, identify the most relevant water quality issues (Silva 2015), and establish correlations regarding the compromised use and occupation of the land (Vieira 2019).

Considering this overview, several studies have shown a direct relationship between land use, maintenance of the vegetation cover, and changes in the water quality of watercourses. According to the study carried out by Freire and Castro (2014) in a hydrographic basin in the state of Espírito Santo (Brazil), there was a strong positive correlation (0.87) between the Water Degradation Index (associated with low oxygen content and high nitrate levels) and the Soil Human Activity Index (associated with soil exposure and pastures). Pereira (2016), while conducting a study in the Alto Tietê Hydrographic Basin (São Paulo, Brazil), evidenced the importance of analyzing the influence of soil use and occupation on the quality of water bodies after obtaining a high correlation with the concentrations of nutrients in the water that derived from human occupation around the basin. Cornelli et al. (2016) found that the native forest located in the sub-basins of the city of Caxias do Sul (Rio Grande do Sul, Brazil) attenuated the release of pollutants into the watercourses, thereby improving water quality.

According to Yang et al. (2018), analyzing and predicting spatiotemporal changes and exploring the corresponding impacts on water quality are essential for controlling and improving the ecological environment of water in watersheds. This monitoring can substantiate the importance of preserving natural resources and the consequent quality of life and health of the population living along the riverside or in nearby areas. In this context, the development of policies and guidelines aimed at territorial planning to improve the water quality in hydrographic basins is necessary, providing sustainable development and the identification of land use and occupation (Asciutti et al. 2019). It is crucial that studies like this be conducted since water quality can affect the health and welfare of the community in the long run (Ifabiyi et al. 2020).

Nunes et al. (2019) showed the advantages of using total and thermotolerant coliform indicators as bacteriological markers in aquatic environments; however, their study did not correlate with the satellite images. On the other hand, Costa Santos et al. (2019) demonstrated that Landsat images are reliable for assessing land use and occupation dynamics in areas protected by law regarding river preservation. Zhang et al. (2019) showed how the correlation between land use and chemical indicators proved vital for assessing water quality in the tributaries of a reservoir in China. In addition to the type of margin occupation and sample size analysis, the authors also drew attention to the seasonal variations that influenced the results; however, their study did not address the bacterial variables. Abdo and Prakash (2020) revealed that changes brought about by urbanization are highly correlated with several environmental problems that require attention, mainly concerning geotechnological resources.

There is a promising way of integrating data collected in the field with satellite images for environmental analysis. In this small review, it can be noted that, although there are countless technological instruments and geoprocessing methodologies available, it is encouraged that these methods be revised in order to contribute to this discussion. In addition, only a few systematic records show the correlation of chemical and biological indicators with land use and occupation.

The present study resulted from a research project aimed at quantifying, based on satellite imaging, the use and occupation of land on the banks of the Itajaí-Açu River, the largest watercourse in the Itajaí River Basin, located in the State of Santa Catarina, Brazil. Here, the land quantification was correlated with water quality, as determined by chemical and biological indicators at different selected points of the river.

MATERIALS AND METHODS

This section addresses the step-by-step approach used in this field and exploratory study and comprises the following subtopics: study area, characterization of land use and occupation, and chemical and biological monitoring of the water.

Study area

In Santa Catarina, the Itajaí River Basin has a total area of 15,000 km^2, which corresponds to 16.15% of the state territory. Approximately 20% of the population lives in the river territory. The Itajaí-Açu River is the longest watercourse in the basin, measuring 188.0 km in length and occupying an area of 2,780.0 km^2. It is formed by the confluence of the *Itajaí do Oeste and Itajaí do Sul* rivers, and originates in the municipality of Rio do Sul (*Fundação Agência de Água do Vale do Itajaí 2010*). The location of the Itajaí-Açu River is shown in Figure 1.

Five water sampling points were allocated along the Itajaí-Açu River; the first one was established at the source of the river, in the municipality of Rio do Sul, while the last one was located at the river's mouth, in the municipality of Navegantes. The choice of the other collection points took place in order from the first to the last point and consisted of vegetation area, urban areas, and open fields/areas (Fig. 1).

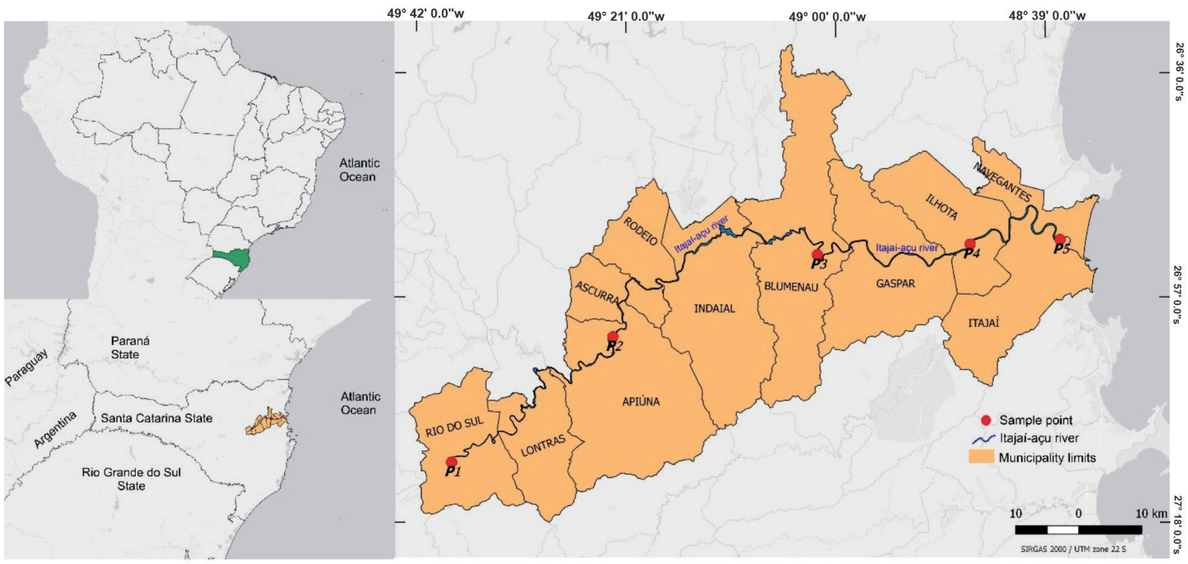

Fig. 1. Location and position of the sampling points along the Itajaí-Açu River

Characterization of soil use and occupation

In order to obtain images of the banks of the Itajaí-Açu River, files were freely downloaded from the Copernicus Open Access Hub website, which is managed by the European Space Agency (ESA). Images were taken by the Sentinel-2 satellite, at 10m resolution (Bottom of Atmosphere), with pictures obtained from the orbit areas T22JGR, T22JFQ, and T22JFR, dated August 2019. With the QGIS software - version 2.18, it was possible to determine the composition of the false-color bands using B08, B03, B04, and subsequent mosaic with B04, B03, B02, thus delimiting an area of 300 meters parallel to the margins of the buffer.

Land use/occupation was classified according to the *Dzetsaka* automatic classification tool into five classes: urban areas, pastures and open fields, agriculture, lakes and bodies of water, and vegetation, as shown in Table 1.

With the *Dzetsaka* plugin, a method of supervised classification developed by Nicolas Karasiak that uses a GMM (Gaussian Mixture Model) classifier, the automatic raster classification process in false color was carried out for the sample areas (Karasiak 2021). Using the classified raster image, the features identified by the algorithm were validated with true image color. Subsequently, the classified image was transformed into *shapefile* format, generating polygons for the specified classes, in which the area of each class was quantified.

Chemical and biological monitoring of the water

The parameters used as variables to correlate the use and occupation of the soil with water quality were selected according to Resolution No. 357/2005 of the Brazilian National Environment Council (CONAMA), according to their use classes, classified as fresh water. Nitrite and nitrate were used as chemical indicators, whereas thermotolerant coliforms and total coliforms were used as biological markers (Resolução CONAMA No 357 2005); the analyzed periods were the spring and summer seasons, with a water sample being collected per point/per station, totaling 40 analyzes throughout the territory. All samples were analyzed at the Central Laboratory of Analytical Tests, UNIVALI – CLEAn, in the municipality of Itajaí - SC, which followed the normative references of the Standard Methods for the Examination of Water and Wastewater, considering the following potability limits: nitrite, up to 1 mg/L; nitrate up to 10 mg/L for all water use classes; thermotolerant coliforms, class 1 up to 200 thermotolerant coliforms per 100 ml, class 2 up to 1000 thermotolerant coliforms per 100 ml, classes 3 and 4 without exceeding 4000 thermotolerant coliforms per 100 ml; total coliforms, unspecified, just an indicator of biological contamination.

In order to consolidate the objective proposed in this partial research, i.e., to correlate the use and occupation of land and water quality, the R Software, version 3.6.3, was used. For the Pearson correlation analysis, descriptive statistics were applied to extract the average variation coefficients.

RESULTS AND DISCUSSION

From sampling station 1 (P1) to sampling station 5 (P5), a total of 109.16 km^2 of land use were classified. The values obtained by coverage area has been shown in table 2.

This land-use classification had a buffer of 300 meters from the river bank to both sides, as shown in the map in Fig. 2. Among all the classes, the most representative of land use was the vegetation class, which presented coverage of 34.42%. Next came the pastures and open fields class, with 27.83%, agriculture with 18.18%, and urban areas with 16.59% coverage. When the sampling points on the map were analyzed individually (table 2), point 2 (P2) was the region that presented the highest vegetation occupancy. In contrast, point 1 (P1) stood out as being occupied mainly by agriculture, point 4 (P4) by pastures and open fields, and, finally, points 3 (P3) and 5 (P5) showed to be highly occupied by urban areas.

Table 1. Classes used for training the algorithm in supervised classification

Feature Code	Class Name	Interpretation Example
1	Urban areas	residential areas, infrastructure, highways, isolated buildings, and industrial areas.
2	Pastures and Open Fields	animal grazing, open fields without animals, soccer fields, and vacant lots.
3	Agriculture	rice, banana, and other identified crops.
4	Lakes and Bodies of Water	artificial weirs, wetlands, and river entry.
5	Vegetation	remnants of Ombrophilous Dense Forest, capoeirão forests, shrubs, and reforestation.

Source: Primary data, 2020

Table 2. Classification of the use and occupation of soil and their respective areas and percentages of coverage

Class Name	Area [km^2]	% of coverage
Urban areas	18,11	16,59
Pastures and Open Fields	30,38	27,83
Agriculture	19,85	18,18
Lakes and Bodies of Water	3,25	2,98
Vegetation	37,57	34,42
Total	109,16	100

Source: Primary data, 2020

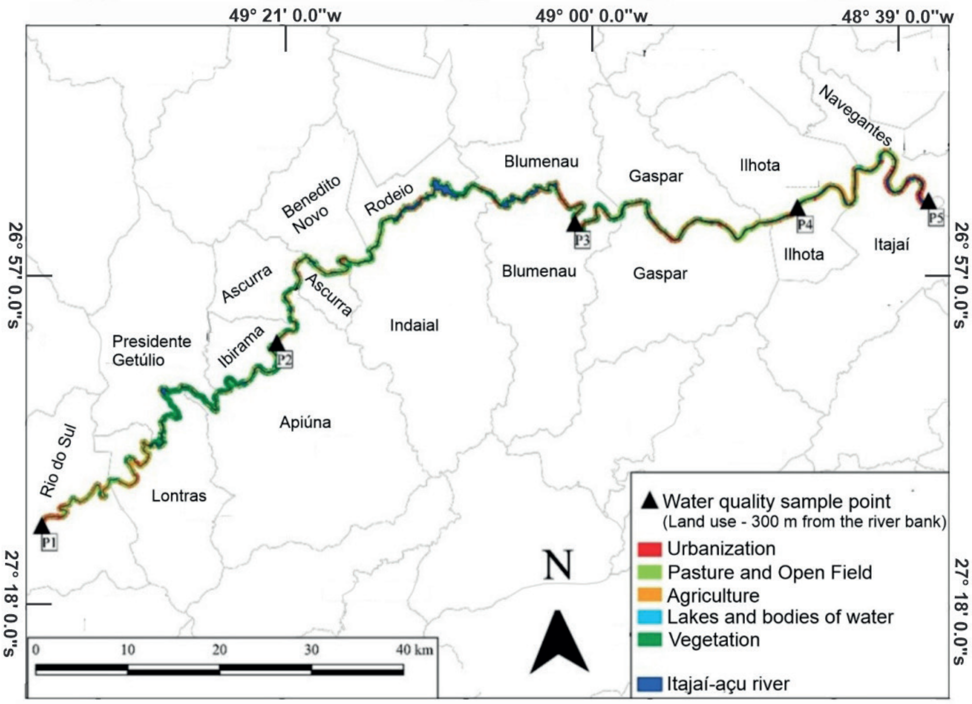

Fig. 2. Classification of the use and occupation of soil on the banks of the Itajaí-Açu River

According to the obtained results, it was possible to note that 62.6% of the analyzed territory was under anthropogenic influence, thus characterizing a severely altered environment. Experts claim that urbanization is one of the main changes in land cover that is highly correlated with many environmental problems, with constant effects on the atmosphere, water and soil (Abdo and Prakash 2020). Similar results were reported by Almeida et al. (2016) while studying a watershed in Tocantins, Brazil. Also, Sulistyo et al. (2020), who explored the Air Bengkulu River watershed in Indonesia, showed that land erosion can be caused by several factors, such as the loss of vegetation cover due to deforestation, agricultural practices, and the construction of residential areas. These alleged attacks are related to the hydrographic basin under study, because it has 62.6% of its territory under anthropogenic influence.

Corroborating with the aforementioned authors, the present study, which analyzed land use and occupation activities, confirmed that several environmental weaknesses may enhance some natural processes, with the intensification of soil loss through erosion and consequent silting, leading to reduced water quality. Barbosa and da Silva Filho (2018), signaled the occupation of the land, promoted by intense urbanization and agricultural activities from the 1980s and 1990s, as an aggravating factor of soil sealing, generating the increase of sediments for the rivers, impairing the quality of the waters. Irregular human actions are also pointed out by Paula et al.(2021), inferring the processes of the physical environment such as erosion and silting as the destruction of waterways.

The primary data gathered in the water quality assessment during the two analyzed seasons and at the five sampling points are shown in Table 3. In addition, the reports can be ratified by accessing the following link: encurtador.com.br/fnuER.

Based on the results, it can be noted that the nitrite indicator showed consistency in value during the spring season, which influenced the subsequent correlation with the data on land use and occupation. At sampling points P1, P2, P3 and P4, nitrate levels are within the standard established by CONAMA resolution No. 357/05, being less than 10 mg/L of nitrate (-NO3), in both stations. However, in the spring, point P5 exceeded that allowed by the same resolution, presenting 24.61 mg/L (Table 3). It is necessary to note that nitrates are toxic to humans, causing a disease called infantile methemoglobinemia, which is lethal for children (Xavier et al. 2018) . If this water is ingested, the nitrate is reduced to nitrite in the bloodstream and competes with free oxygen, leading to asphyxia. Therefore, nitrate is the standard for water potability, with its maximum value allowed at 10 mg/L also by Ordinance No. 518 of the Ministry of Health (BRASIL, 2004).

The nitrite indicator was found within the established parameters of water potability, at all sampling points in both stations, according to CONAMA Resolution No. 357/05, which establishes the maximum value of 1 mg/L of nitrite (–NO2). Betio et al. (2016), point out that one of the hypotheses for not detecting high values of this indicator in the water can be explained by the rapid transformation of nitrite to nitrate by bacteria of the genus Nitrobacter, present in the soil of the river, causing it to move quickly for groundwater.

Regarding biological indicators (Table 3), when categorized according to water use classes by CONAMA Resolution No. 357/05, point 1 showed 16,000 (MPN - most likely number) thermotolerant coliforms per milliliter (ml) of water, in both seasons , fitting as fresh water class 4, having its use only for navigation and landscape harmony. Point 2, for the same indicator, presented 330 and 790 MPN/ml in the spring and summer seasons respectively, fitting as class 2 fresh water, which allows up to 1000 thermotolerant coliforms/100ml, where its use is intended for human consumption after conventional treatment, primary contact recreation and vegetable irrigation. The Point 3 was classified as freshwater class 4 in spring and class 3 in summer. This class establishes up to 2500 thermotolerant coliforms/100ml, intended for human consumption only after advanced treatment and for secondary contact recreation (sporadic or accidental). Point 4 showed 2200 MPN/ml; 330 MPN/ml of thermotolerant coliforms respectively in the spring and summer seasons, attributing themselves as classes 3 and 2. Finally, the point 5, with results that attributed the classes of water use, the point 3 in spring and class 4 in summer. The abovementioned values, when compared to the Brazilian legislation, point to biological contamination throughout the sampled territorial extension. According to Lima et al. (2018), the presence of thermotolerant coliforms in water samples may indicate contamination by intestinal pathogens, harmful to health, arising exclusively from human fecal origin.

Table 3. Primary water collection data results

Primary Laboratory Data										
	P1		P2		P3		P4		P5	
Parameter (Unite)	Spring	Summer	Spring	Summer	Spring	Summer	Spring	Summer	Spring	Summer
Nitrite (mg/mL)	0.01	0.12	0.01	0.12	0.01	0.13	0.01	0.44	0.01	0.25
Nitrate (mg/mL)	3.81	0.58	5.66	0.31	5.29	0.92	5.29	1.06	24.61	1.44
Thermo. Coliforms (MPN/100mL)	16000	9200	330	790	16000	2200	2200	330	1700	16000
Total Coliforms (MPN/100mL)	16000	16000	2200	1300	16000	5400	16000	3500	16000	16000

Source: Primary data, 2020

After correlating the classes of land use and occupation with the chemical and biological indexes found in the water sample analysis, conducted in the spring and summer, using the R Statistical Software, for Sperman correlation, we obtained the data shown in Fig. 3. According to Freire and Castro (2014), correlations equal to or greater than 0.7 ($r = 0.7$) are considered strong correlations, which become even stronger when the value approaches 1.0 ($r = 1.0$). Positive values indicate that the two variables move together in the same direction; similarly, negative values were obtained when the two variables move in opposite directions in the hypothesis. Based on Table 3, it is noted that, during the spring, the urbanization class showed a negative correlation with the chemical indicator nitrate ($r = -0.95$) and a positive correlation with thermotolerant coliforms ($r = 0.8$), the agriculture class showed a positive correlation with nitrate and a negative correlation with total and thermotolerant coliforms ($r = 0.74$; -0.77; -0.88, respectively). In summer, the classes pasture and vegetation showed a negative correlation with nitrate ($r = -0.8$; 1, respectively) and the classes agriculture and vegetation showed a negative correlation with the chemical indicator nitrite (both, $r = -0.8$). In this season there was no strong positive correlations for the land use classes.

During the spring season, the thermotolerant coliform content in the water increased due to the impact of urbanization on water quality, as shown in Figure 3. This can be explained by the influence of climatic factors. However, the same indicator decreased significantly during the summer season, owing to the increase in precipitation, which led to its dilution in the river. Our data corroborate with the study conducted by Cheng et al. (2018) on the Haihe River Basin in China, where the authors stated that dilution by precipitation became a dominant factor that affected water quality and resulted in relatively better indexes than in the pre-rainy season. Centeno et al. (2016), in the state of Rio Grande do Sul, also observed that increases in precipitation led to an improvement in water quality. Additionaly, Nunes et al. (2019) reported that the presence of thermotolerant coliforms in the aquatic environment of the Salgadinho River (Ceará, Brazil) was indicative of contamination by human feces, which resulted from the lack of basic sanitation in the region. In this sense, Amorim et al. (2020), in their study of a hydrographic basin in the state of Alagoas, found that the impaired quality of surface water in water bodies, resulting from the negative influence of anthropogenic actions, mainly arises from the inadequate disposal of effluents.

Considering the agriculture class, a positive correlation of nitrate in the spring and a negative correlation of nitrite in the summer were identified. The decrease in the indicator's presence in the river was due to nitrification (a process that follows fertilization in the panicle stage of rice cultivation from September to October). Nitrification is the term used to describe the first step of the biological nitrogen removal process, in which ammonia (chemical fertilizer) is oxidized into nitrite, which, in turn, is oxidized into nitrate (Streck et al. 2006). When plants reach a certain degree of development, they reduce nitrate content in their roots and transport the compound to different parts of the plant in the form of amino acids. This result was pointed out in the study by Cristina et al. (2013) on nitrate reductase in rice cultivars. During the spring, the indicator nitrite showed constant values (due to the nitrification process mentioned previously) in all five sampling locations, making it impossible to calculate the correlation.

Fernandes et al. (2017), in their study on the impact of nitrogen fertilization on pastures, also reported a reduction

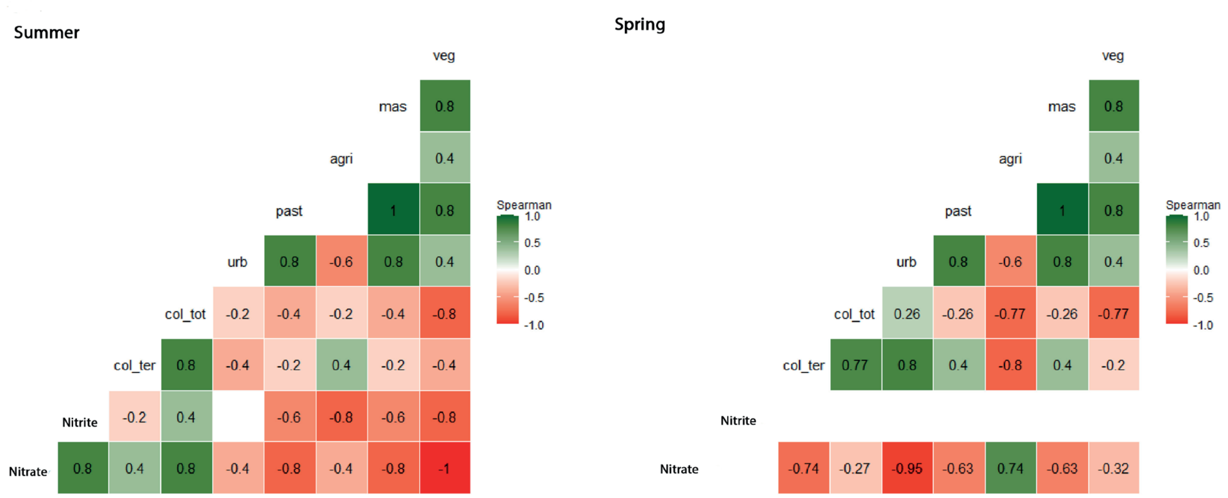

Fig. 3. Correlations between chemical and biological indicators and the classes of land use and occupation

of the indicator in the soil during the development cycle of grasses; this can be explained since they absorb differentiated amounts of nitrogen in the form of nitrate (NO3-) and ammonium (NH4+). Also, Zhang et al. (2019) revealed that farmland and urban areas promoted unfavorable impacts on water quality; in contrast, forest and grasslands presented a favorable influence on water quality. These findings are consistent with the correlations obtained from both the chemical and biological indicators in the present study.

Santos et al. (2020) stated that agriculture is the form of land use that most contributes to the generation of surface runoff into sub-basins. The mineral and organic fertilizers applied to crops for enhanced agricultural production can be carried out to watercourses through surface runoff, compromising water quality. According to Mello et al. (2018), agricultural and urban areas are responsible for water quality degradation. The sewage derived from residential areas, sediments, and nutrients from short-cycle crops lead to nonpoint source pollution into rivers.

Finally, it can be noted that vegetation plays a crucial role in the reduction of nitrite and nitrate indicators in water, as well as total and thermotolerant coliforms. It acts as a natural filter in the ecosystem by minimizing the leaching of these indicators from the soil to the water, contributing to the maintenance of the natural biota. Shang et al. (2018) demonstrated the importance of soil-stream hydrological connectivity, primarily because there is a phase that can be frequently mobilized through water leaching and flushing, evidencing the need for more empirical studies to incorporate a science-based management framework. These studies highlight the relevance of water quality assessments since contaminated or polluted water bodies can become vectors of water-borne diseases, generating serious public health problems, affecting future demand for good quality water (Santos 2020). According to Pessoa et al. (2018), collecting and treating all generated sewage and the supervision of irregular sewer connections could improve the quality of river waters since the release of sewage is one of the leading causes of water body degradation.

Satellite imaging is vital for monitoring land use and occupation (Gonçalves and Ribeiro 2021). The integration of field research with geospatial data provides knowledge to understand new information regarding the impact of humans on nature. Therefore, in the era of information and technology, technological knowledge is essential for environmental management.

CONCLUSION

The way human beings use and occupy the soil is directly associated with water quality in watercourses. Therefore, a directional correlation analysis was performed in the present study, dividing land use into different classes. Depending on the climatic season, each class of land use and occupation positively or negatively influenced water quality.

According to the obtained results, we can conclude that the waters of the Itajaí-Açu River are potentially contaminated by total and thermotolerant coliforms. Anthropogenic influence and inadequate land use regarding the discharge of urban and industrial effluents without suitable treatment into the watercourse were verified.

The values obtained for the biological indicator thermotolerant coliforms at the confluence of the river, in the municipality of Rio do Sul, disqualify the suitability of its waters for consumption and bathing on account of human fecal contamination. The minimum coliform density established in CONAMA Resolution No. 357/2005, used to assess water quality, is 1,000 MPN per 100 mL of water. Our results on water quality transcended the minimum value. Thus, the water of the respective river was classified as class 4, which could only be reserved for purposes of navigation and landscape harmony. Hence, the results indicate that the biological contamination of the Itajaí-Açu River confluence occurs upstream, with subsequent contamination along its course.

Our results also showed that even with the impacts generated by anthropogenic influence on the banks of the Itajaí-Açu River, the vegetation present on the riverside was capable of attenuating part of the pollutant load released through agricultural, industrial, and domestic effluents. Therefore, it can be inferred that cities on the banks of watercourses serve as potential water contaminants.

Based on our findings, it is noteworthy that public actions are essential for developing policies and guidelines aimed at territorial planning to improve water quality in hydrographic basins and their occupation. Access to clean water and adequate sanitary sewage systems constitute an effort that should be continued in order to carry out concrete actions that contribute to the environmental health of the territory of water bodies and their inhabitants.

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