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Temporal evolution of suspended solids in the management of medium-sized watersheds in the Metropolitan Region of Paraíba Valley

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ABSTRACT

The demand for water to meet the needs of the population has increased with the rapid growth of urban centers. The urban expansion in Taubaté (23.03º S, 45.55º W) negatively impacts the Una River Basin, a significant tributary of the Paraíba do Sul River, resulting in issues of sedimentation, siltation, and flooding. Systematic monitoring of sediment characteristics in human-influenced areas allows for an understanding of water quality variations, watershed diagnosis, and analysis of impacts on aquatic ecosystems, with total suspended solids (TSS) being a widely used parameter in this context. This study investigated the temporal evolution of the TSS concentration in the Una River, highlighting the importance of sound management practices to reduce sedimentation in urban catchments, through the analysis of biochemical parameters obtained from the Cetesb/Infoaguas platform. From 2008 to 2022, lower TSS concentrations were observed in winter (86.2 ± 35.6 mg L^{-1}), while higher values were obtained in summer (779.7 ± 1024.8 mg L^{-1}). In general, statistically significant correlations were found at the 95% confidence level between TSS and turbidity (Pearson's r = 0.93), dissolved oxygen (Pearson's r = -0.46), and electrical conductivity (Pearson's r = -0.43), while other evaluated parameters (pH, dissolved solids, and precipitation) did not show significant correlations. Among the key findings, it is crucial to study the temporal evolution of TSS and to implement sustainable management strategies in urban catchments, including erosion control measures and stormwater management, to preserve water quality, aquatic ecosystems, and water supply in the urban communities of RMVale.

Keywords: basin, management strategies, sustainable, total suspended solids.

A evolução temporal de sólidos suspensos no manejo de bacias de médio porte na Região Metropolitana do Vale do Paraíba

RESUMO

O rápido crescimento dos centros urbanos tem dado origem a uma demanda crescente de água para suprir as necessidades da população. A expansão urbana em Taubaté (23,03º S, 45,55º W) afeta negativamente a bacia do Rio Una, um importante afluente do Rio Paraíba do Sul, causando problemas de sedimentação, assoreamento e inundações. O monitoramento sistemático das características dos sedimentos em áreas afetadas pelo ser humano permite compreender as variações da qualidade da água, diagnosticar a bacia hidrográfica e analisar o impacto nos ecossistemas aquáticos, sendo o TSS (Total de Sólidos em Suspensão) um parâmetro amplamente utilizado nesse contexto. Neste trabalho procurou-se investigar a evolução temporal da concentração de TSS no Rio Una, buscando ressaltar a relevância de boas práticas de gestão para a redução de sedimentos em bacias em urbanização, por meio da análise dos parâmetros bioquímicos obtidos na plataforma Cetesb/Infoaguas, no período de 2008 a 2022. Para o rio Una, no período de 2008 a 2022, valores de TSS mais reduzidos são observados no inverno (87,2 ±35,6 mg L^{-1}), enquanto valores mais altos são obtidos nos verões (779,7 ±1024,8 mg L^{-1}). De modo amplo, ao nível de 95% de confiabilidade, foram observadas correlações estatísticas significativas entre o TSS e a turbidez (r de Pearson = 0,93), oxigênio dissolvido (r de Pearson = -0,46) e condutividade elétrica (r de Pearson = -0,43), não se obtendo correlações expressivas para os demais parâmetros avaliados (pH, sólidos dissolvidos e precipitação). Dentre os aspectos observados, destaca-se a importância de investigar a evolução do TSS ao longo do tempo e sugerir estratégias de gestão sustentável em bacias em urbanização, incluindo medidas de controle de erosão e gerenciamento das águas pluviais, a fim de preservar a qualidade da água, os ecossistemas aquáticos e o abastecimento hídrico nas comunidades urbanas da RMVale (Região Metropolitana do Vale do Paraíba e Litoral Norte).

Palavras-chave: bacia hidrográfica, estratégia de gestão, sustentável, total de sólidos em suspensão.

1. INTRODUCTION

The accelerated expansion of urban centers has generated a greater demand for water to meet the needs of the population (dos Anjos Luís and Cabral, 2021). However, the disorderly growth of these areas, followed by the consequent alteration of natural runoff processes, modifies soil permeability, resulting in adverse consequences for the dynamics of the hydrological cycle (Pirolia and Levymanb, 2020; Ciupa *et al.*, 2021).

In Taubaté (23.03º S, 45.55º W, 621 m), the expansion of the urban area has had negative effects on the lower portion of the Una River Basin, a relevant tributary of the Paraíba do Sul River, whose waters are used for public and industrial supply, in addition to serving for irrigation of various properties and agricultural crops (Lobato and Targa, 2004; Alves and Cobo, 2013; Ribeiro *et al.*, 2015; Targa *et al.*, 2019). Some of these actions result in the environmental degradation of the Una Basin, leading to processes that increase the sedimentation and silting of the rivers, promoting flooding, mainly in its middle and lower reaches (Targa *et al.*, 2019; Santos *et al.*, 2012)

According to Targa *et al.* (2019), the increase in flood events on the Una River is directly related to the uncontrolled urban growth. Thus, the implementation of conservationist practices in the hydrographic basin is essential to combat the current scenario of environmental degradation, which is closely related to changes in the dominant land use and cover. Therefore, it is essential to carefully analyze how these changes occur to implement adequate management measures that protect and preserve both the soil and water resources of the basin.

As per the findings of Batista *et al.* (2005), the Paraíba do Sul Hydrographic Basins Plan, which was implemented in 2003, establishes goals aimed at the management of water resources in the region, with the aim of minimizing silting, promoting the sustainability of springs, and restoring aquatic ecosystems. These targets cover several interventions, such as reducing the amount of sediment transported by rivers, improving water quality in specific stretches of the basin, preserving aquifer recharge areas, controlling pollution and sustainable water use, restoration of degraded areas, and strengthening the integrated management of natural resources in the basin (Targa *et al.*, 2019).

Regular monitoring of physical-chemical and behavioral properties of sediments in water bodies is essential in anthropized areas to understand temporal and spatial variations in water quality. This approach enables a comprehensive assessment of the hydrographic basin and analysis of aquatic ecosystems' response to human impacts. Guedes *et al.* (2012) emphasize its significance. As per Cremon *et al.* (2020), total suspended solids (TSS) emerges as a prominent indicator for evaluating water quality in river basins globally.

According to Esteves (2011), TSS refers to the measurement of all suspended particulate matter present in water bodies that cannot pass through a 0.45 μm filter. Brito *et al.* (2009) further elaborate that TSS typically consists of sediments, clay, sand, organic matter, and industrial waste. The characteristics of TSS are influenced by factors such as the average current velocity, source material, climate, and vegetation cover of the drainage basin. In the state of São Paulo, the Environmental Company of São Paulo State conducts regular sampling of rivers to monitor TSS levels, employing laboratory analysis to determine the concentration of suspended solids. This data is utilized to evaluate water quality and classify rivers based on the company's established criteria.

While sedimentological monitoring of rivers is recognized as crucial for comprehending environmental degradation processes (Ciupa *et al.*, 2021), it is essential to adopt a more comprehensive systemic perspective encompassing geomorphological studies and hydrology to analyze the interconnections among the various elements within the watershed (Xu *et al.*, 2021). Therefore, interest in studies involving the continuous monitoring of suspended solids in basins undergoing urbanization grows, an activity of extreme importance to the planning and management of water resources and the preservation of the environment, since these data allow the evaluation of possible variations in biochemical parameters associated with sediment transport in the river, providing essential information to understand sedimentation processes and water quality.

Given this purpose, this research investigated the temporal evolution of TSS concentration in the Una River, seeking to highlight the relevance of management practices for the reduction of sediments in basins undergoing urbanization in the Metropolitan Region of Paraíba Valley. Through the analysis of biochemical parameters obtained on the Cetesb/Infoaguas platform from 2008 to 2022, an attempt was made to identify seasonal patterns, peak events and long-term trends, with the aim of understanding the processes that impact the sediment load in the basin and obtain a comprehensive view on the dynamics and variation of sediment levels over time.

2. MATERIAL AND METHODS

2.1. Site description

The data collection for the analysis of the temporal evolution of the TSS in the Una River was carried out in Taubaté, SP (23.03º S, 45.55º W, 621 m), a medium-sized city located in the eastern part of the State of São Paulo, in the Metropolitan Region of Paraíba Valley and North Coast (RMVale), with a population of approximately 320,000 inhabitants (IBGE, 2022).

According to the Köppen-Geiger classification, Taubaté has a humid subtropical climate (Cfa), characterized by summers with heavy rains and dry winters. In general, the city experiences high temperatures, with an average annual temperature of 22°C. Taubaté has two distinct rainfall seasons: a rainy season in summer and a dry season in winter (Fisch and Valério, 2005). Fisch and Valério (2005) also note that there is interannual variability in precipitation, with an average annual rainfall of 1365.6 mm, which is close to the climatological normal (1352.2 mm). The wettest month is January, with an average rainfall of 223.5 mm, while the driest months are July (30.7 mm) and August (32.6 mm).

The Una River watershed, shown in Figure 1, is contained in a total area of 476 km², located between latitudes 23°15'6” S and 22°54'54” S and longitudes 45°14'58” W and 45°45'7” W, comprising part of the municipalities of Taubaté (83%), Tremembé (8%), Pindamonhangaba (8%) and Redenção da Serra (1%) (Dias *et al.*, 2010). The elevations of the basin vary between 500 and 1400 m, being limited by Serra do Quebra Cangalha to the northeast and Serra do Jambeiro to the southeast (Batista, 2006). The course of the Una River, from its mouth on the Paraíba do Sul River to the confluence of its tributaries and the longest stretch of its source, totals approximately 68 km in length (Batista *et al.*, 2005).

Batista (2006) emphasizes that the Una River Basin is representative of the topographical, geological and geomorphological characteristics found in the other basins of the Vale do Paraíba Paulista region, presenting land with flattened surfaces, interfluves without a specific orientation, limited mountain ranges and tops of rounded hills. According to the author, the slopes, for the most part, have convex and/or straight profiles, with slopes varying between 20 and 60%.

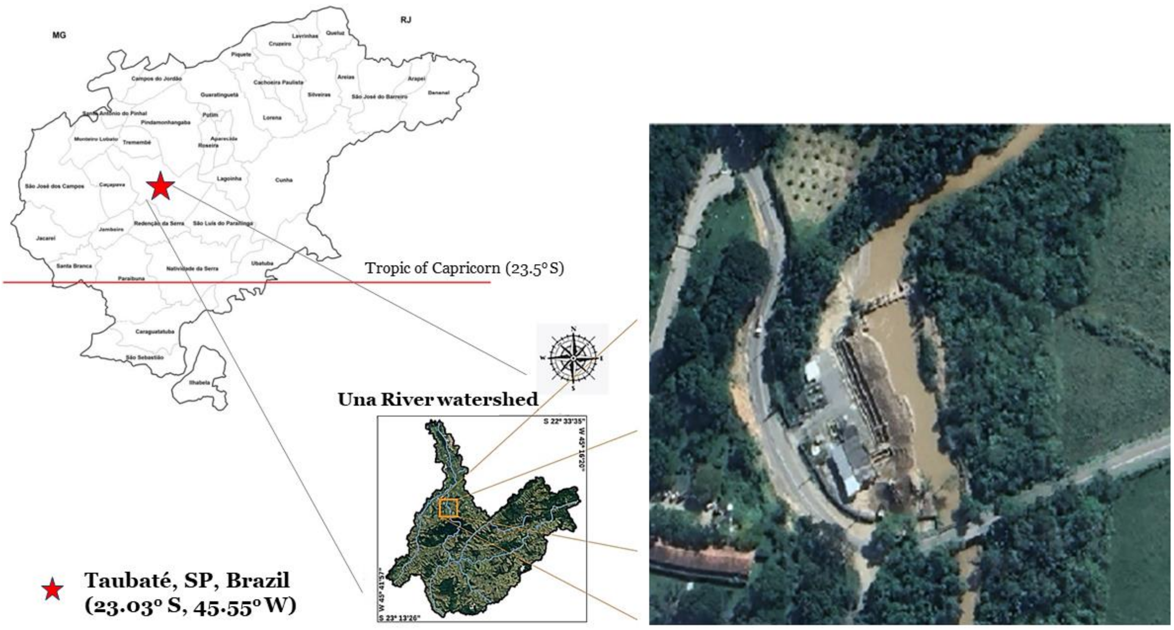

Figure 1. The location of the Una River Basin and geographic position of Sabesp water collection.

As shown in Figure 2, the thalweg of the Una River has a steep slope of 300 m km^{-1} for the first 1.7 km and then changes to 12.7 m km^{-1} for the next 4.7 km, returning to a steep slope of 196 m km^{-1} in the next 0.5 km, and finally a gentle slope of approximately 4.2 m km^{-1} for 44 km until reaching the Sabesp water collection station that supplies the municipality.

In relation to the various soils encountered in the basin, Dias *et al.* (2010) emphasize the presence of three main types: 1) areas where tertiary sediments are present, characterized by the occurrence of red-yellow, thick, porous, and permeable oxisols; 2) regions dominated by Precambrian crystalline rocks, where podzolic soils are prevalent, exhibiting limited development and thickness; 3) in certain instances, deep, porous, and well-drained soils can be found on these crystalline rocks, typically classified as yellow latosols.

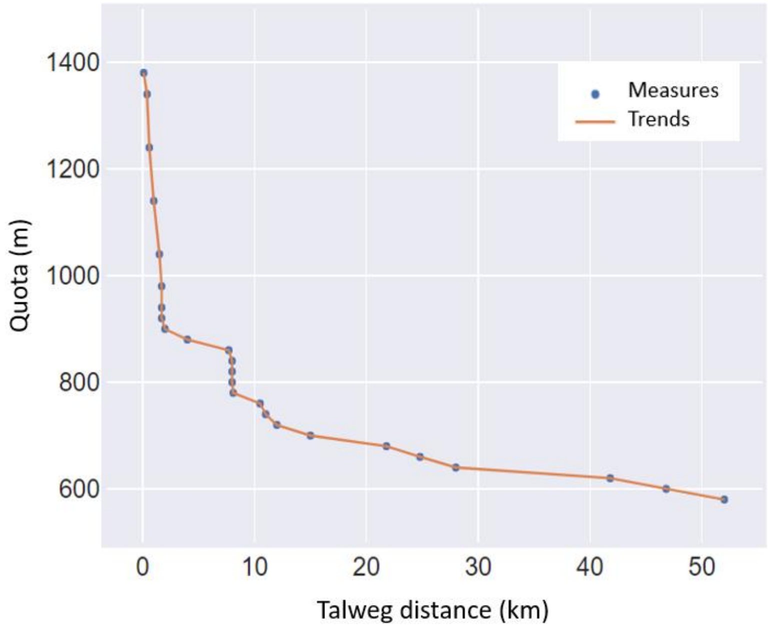

Figure 2. Talweg of the Una River, tracing its course from the source to the water collection point for the municipality.
Source: Adapted from Unitau (2021).

2.2. Sampling description and data analysis

CETESB has been monitoring the quality of water in the Una River only at the point of collection for supplying the Basic Sanitation Company of the State of São Paulo (SABESP), located at coordinates 23º01'49" S, 45º30'26" W (Figure 1). According to Ribeiro *et al.* (2015), there is no news of sampling or regular monitoring of biochemical parameters in other locations within the basin.

From the compilation of data available on the Infoaguas platform (https://servicos.cetesb.sp.gov.br/infoaguas/) for the Una River (Water Resources Management Units, UGRHI 02) the following parameters were evaluated: pH, TSS, dissolved solids, turbidity, dissolved oxygen and electrical conductivity. The analytical methods used for the Infoaguas system are detailed in Cetesb (2009).

The evaluation considered data for the period between 2008 and 2022, with monthly monitoring frequency. The average monthly precipitation for the same period was obtained from data provided by Inmet (National Institute of Meteorology), from the Station Data Table (https://tempo.inmet.gov.br/TabelaEstacoes/A728).

The data were compiled into a single spreadsheet, using an algorithm structured in Python, an interpreted and object-oriented programming language that supports and offers a multiplatform interface (Sebesta, 2003). The routine was developed in Colab (Google Collaboratory), a research project aimed at generating machine learning models, which provides serverless notebook environments for interactive web development (Bisong, 2019) and all statistical processing was developed from of a subroutine with Scipy, a tool developed for statistical calculations and applied mathematics in Python (Virtanen *et al.*, 2020).

3. RESULTS AND DISCUSSION

Figure 3 illustrates the seasonal temporal evolution of the TSS parameter measured in the Una River from 2008 to 2022. The graph reveals lower concentrations during the winter season, characterized by minimal or no precipitation in the region, with an average variation of 86.2 ± 35.6 mg L^{-1} in June. Conversely, higher values are observed during the summer season, particularly in February, exhibiting an average variation of 779.7 ± 1024.8 mg L^{-1}.

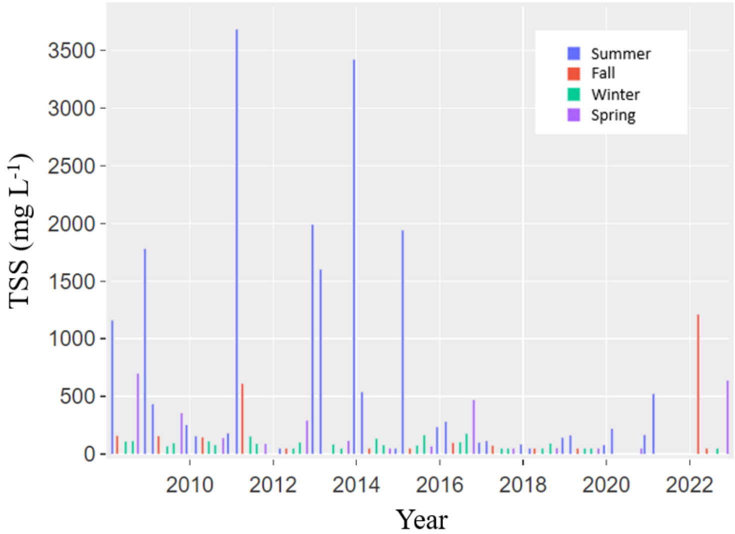

Figure 3. Evolution of the TSS measured on the Una River by season from 2008 to 2022.

The Cetesb Legislation (2016) establishes the following reference values for the classification of surface water quality in relation to the TSS parameter: Special Class (TSS ≤ 20 mg L^{-1}), Class 1 (TSS ≤ 50 mg L^{-1}), Class 2 (TSS ≤ 100 mg L^{-1}), Class 3 (TSS ≤ 200 mg L^{-1}) and Class 4 (TSS > 200 mg L^{-1}). According to the document, in relation to water quality in rivers in the state of São Paulo, "Class 2" allows the use of water for: a) human supply after conventional treatment; b) protection of aquatic communities; c) primary contact recreation, such as swimming, water skiing and diving, in accordance with CONAMA Resolution No. 274/2000 (CONAMA, 2000); d) irrigation of vegetables, fruit plants, parks, gardens, sports and leisure fields, with which the public may have direct contact; and e) aquaculture and fishing activity.

As you move to higher classes such as "Class 3" and "Class 4", contamination levels may increase, indicating higher concentrations of pollutants that compromise water quality and consequently increase the risks associated with its various uses. Therefore, Figure 4 shows the temporal evolution of the biochemical parameters recorded under TSS conditions above “Class 2” when TSS > 100 mg L^{-1}. They are illustrated by season of the year: TSS (Figure 4a), total dissolved solid (Figure 4b), turbidity (Figure 4c), dissolved oxygen (Figure 4e), and electrical conductivity (Figure 4f). The monthly rainfall in the period is illustrated in Figure 4d. For better visualization of the data, the graph scales involving TSS (Figure 4a), total dissolved solid (Figure 4b) and turbidity (Figure 4c) are presented in logarithmic mode.

Figure 5, which complements the analysis of the temporal evolution of the biochemical parameters shown in Figure 4, presents the Pearson correlation matrix between the TSS parameters, total dissolved solid, turbidity, dissolved oxygen, electrical conductivity, pH and rainfall.

Analyzing Figure 4a, which portrays TSS levels surpassing the "Class 2" threshold during the assessed period, it becomes evident that the limit of 100 mg L^{-1} was exceeded on 42 occasions (equivalent to 42 months), heightening the risks associated with water usage and sediment accumulation in the Una River. A significant portion of these instances of limit exceedance transpires during the summer season, where TSS concentrations peak at 912.6 ± 1088.5 mg L^{-1}. Nonetheless, even during the winter season, albeit to a lesser extent compared to summer, such occurrences persist, amounting to 8 and 20 situations, respectively. Noteworthy episodic increases in TSS are also observed during autumn and spring, with concentrations in 2022 reaching 1210 mg L^{-1} and 638 mg L^{-1} for each respective season.

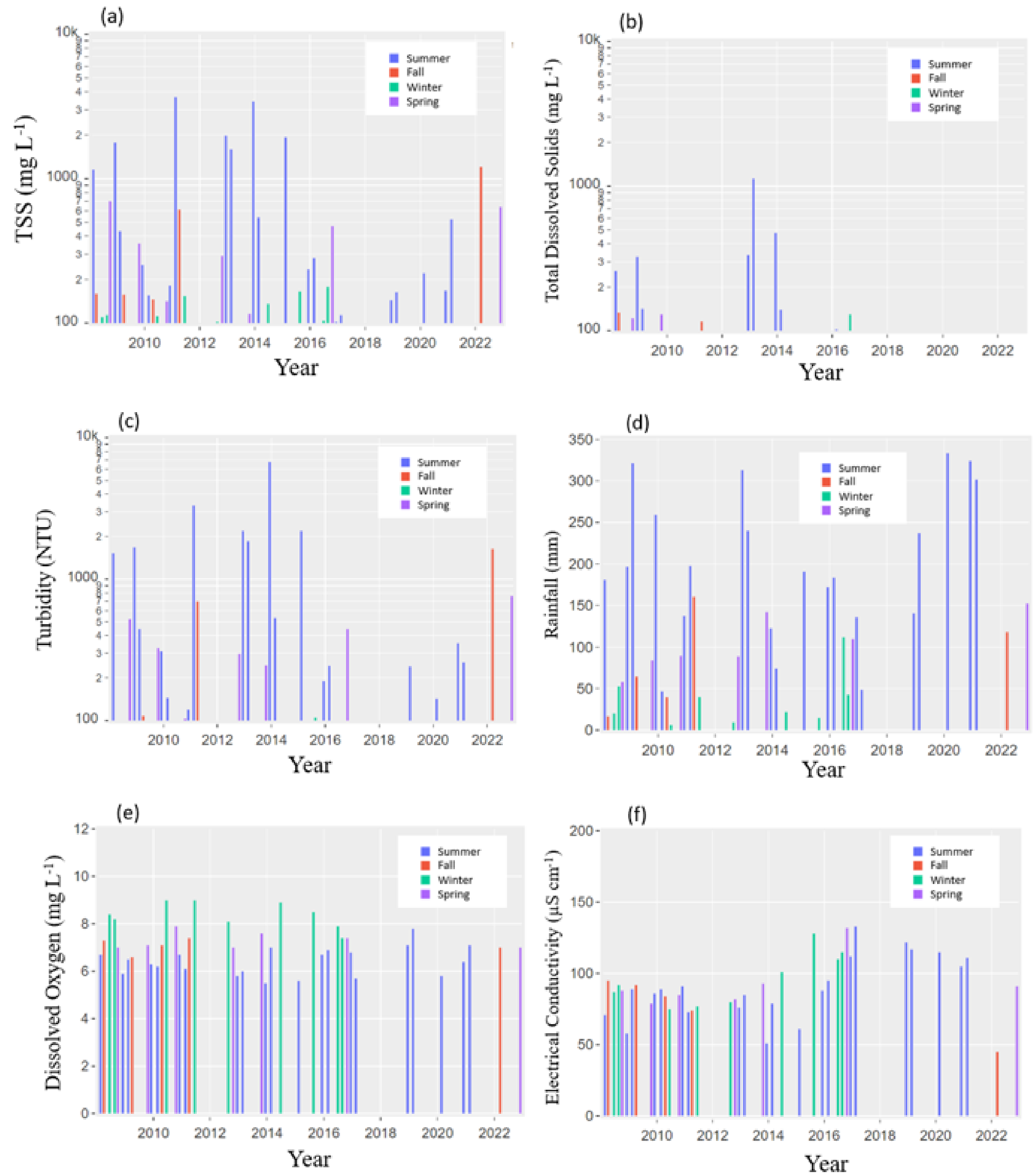

Figure 4. Seasonality of parameters evaluated when TSS > 100 mg L^{-1}: TSS (a), total dissolved solid (b), turbidity (c), precipitation (d), dissolved oxygen (e) and electrical conductivity (f).

Based on Figure 5, it was observed that the concentration of dissolved solids did not exhibit the same temporal variation pattern as the TSS concentration (as depicted in Figure 4b). However, there was a positive statistical correlation between these two parameters (Figure 5, Pearson's r = 0.53, p-value ≪ 0.05). This dissociation could be attributed to the presence of different pollution sources that contribute differently to each type of solid, or to complex chemical and biological interactions that impact the levels of dissolved solids independently of the TSS. Additionally, as noted by Permana *et al.* (2022), other specific characteristics of water bodies can also influence the dissolution and concentration of dissolved solids, acting independently of the TSS.

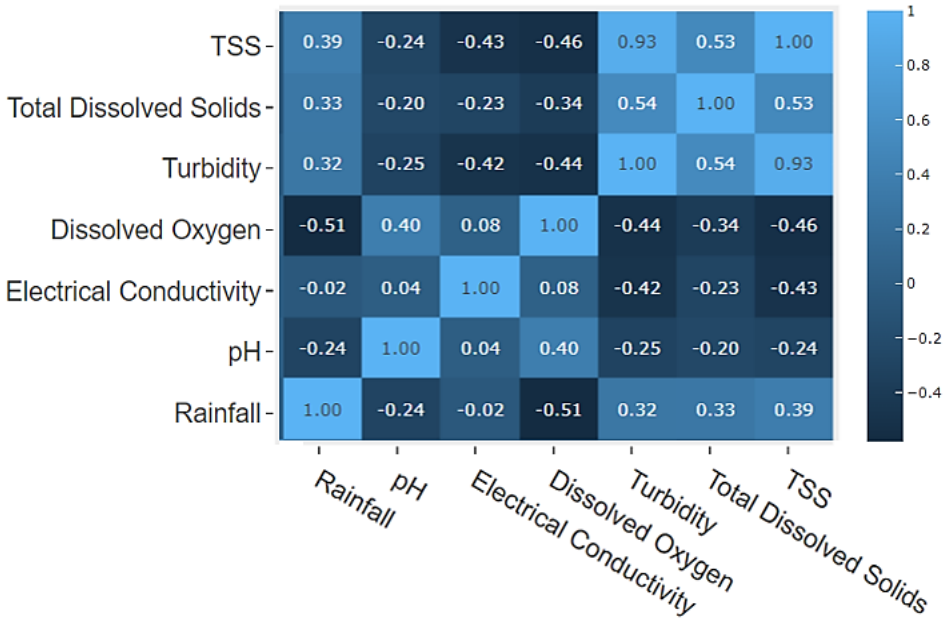

Figure 5. Pearson correlation matrix involving TSS, Total Dissolved Solids, Turbidity, Dissolved Oxygen, Electrical Conductivity, pH, and Rainfall. P-values displayed at the 95% significance level.

Unlike dissolved solids, water turbidity was strongly influenced by TSS (Figure 3c) (Figure 5, Pearson's r = 0.93, p-value ≪ 0.05). In Brazil, the Jackson Scale is widely used to measure water quality in rivers, being based on the visual comparison of water clarity about a standard silicate suspension of known turbidity (Cetesb, 2016). This scale ranges from 0 to 100 nephelometric turbidity units (NTU), where low values (0 to 10 NTU) indicate very clear water with high transparency, medium values (10 to 40 NTU) represent moderately clear water, and higher values (above 40 NTU) indicate turbid water, with low transparency due to the presence of sediments, suspended particles or suspended organic matter.

The high turbidity observed under TSS conditions greater than 100 mg L^{-1} reflects the very etymology of the word "Una", a word of Tupi-Guarani origin with multiple meanings, contextually distinct, which, about rivers, is usually associated with a small, narrow, or fast-flowing river. According to Dias *et al.* (2010), the high infiltration capacity of the oxisols present in the basin favors the formation of a shallow water table aquifer. Due to the seasonality of rainfall, there is a significant variation in the water level of the aquifer, which, combined with the presence of the porous soil that surrounds it, facilitates the transport of a considerable number of solutes toward rivers and streams, resulting in its characteristic turbidity.

There was no statistically significant correlation between the TSS and the accumulated precipitation in the month (Figure 5, Pearson's r = 0.39, p-value ≪ 0.05). The amount of accumulated precipitation was significantly higher in the summer (Figure 4d), but this precipitation pattern did not directly affect most of the analyzed parameters, showing a moderate and negative statistical correlation only with dissolved oxygen (Pearson's r = -0, 51, p-value ≪ 0.05, Figure 5). Likewise, no statistically significant correlation was found between TSS, dissolved oxygen, and electrical conductivity, with Pearson correlation coefficients of -0.43 (p-value ≪ 0.05) and -0.46 (p-value ≪ 0.05), respectively (Figure 4e, 4f and Figure 5).

In a previous study, when investigating the physical-chemical and microbiological characteristics of the waters of the Una River Basin, Dias *et al.* (2010) found that the water from the Itaim Stream, one of its main tributaries, presents a different pattern from the other areas of the basin, showing a significantly greater variation in the electrical conductivity parameter during periods of lower river flow. According to the authors, this occurrence would be related to high concentrations of phosphorus and nitrogen in the water, resulting from the excessive application of nitrogen fertilizers in agricultural areas, livestock activity, and the release of domestic effluents, treated or not, into the water body. In this same study, Dias *et al.* (2010) did not find total phosphorus concentrations above the established limits in any of the sub-basins.

Although the main objective of this research was not to obtain total nitrogen and total phosphorus data for the Una River, this information was collected for the analyzed period using the Infoaguas platform. Based on these data, it was found that the limit of 3.7 mg L^{-1} established by Conama Resolution nº 375/05 (CONAMA, 2005) for total nitrogen was exceeded on only two occasions: October 2016 (5.8 mg L^{-1}) and October 2018 (6.3 mg L^{-1}). Regarding the total phosphorus content, Machado *et al.* (2009) mentions that in rivers with low currents, the critical levels of phosphorus to start the eutrophication process are in the range of 0.1 to 0.2 mg L^{-1}, while in rivers of high current, it should not exceed the limit of 0.3 mg L^{-1}. Data collected for the Una River reveal that this limit was also exceeded on only two occasions: in October 2010 (0.5 mg L^{-1}) and December 2013 (1.2 mg L^{-1}).

Based on the obtained results, it is crucial to acknowledge that monthly monitoring systems provide a comprehensive understanding of biochemical parameters over time, enabling the identification of trends and seasonal variations. However, these systems may overlook certain daily fluctuations due to the longer intervals between samplings. To address this limitation, it is recommended to supplement monthly monitoring with spot sampling conducted on a daily or weekly basis. The integration of monthly monitoring with spot sampling at more frequent intervals allows for a broader comprehension of variations in river biochemical parameters, encompassing both long-term trends and daily fluctuations. This approach facilitates the analysis of the dynamics of the river environment and assists in identifying potential impacts and significant changes in biochemical parameters.

As previously mentioned, the monitoring of TSS holds significant importance in evaluating the environmental and human health aspects within basins undergoing urbanization. Land use and cover alterations, such as urbanization and the expansion of built-up areas, can lead to soil waterproofing and the degradation of natural ecosystems. These changes contribute to increased surface runoff, soil erosion, and water body contamination. Consequently, monitoring TSS in the Una River Basin becomes indispensable for assessing the impacts of these transformations and implementing sustainable management strategies in the RMVale.

The changes in land use and land cover within the Una River Basin become increasingly concerning when considering the projected models of urban expansion and population growth in the municipality of Taubaté. Presently, the population is estimated to be 310,739 inhabitants. However, the population projection for the year 2050 anticipates a rise to 322,336 inhabitants, with an estimated urban population of 315,778 and a rural population of 6,658 (SEADE, 2020). These Figure highlight the potential intensification of urbanization, which further emphasizes the need for effective measures to manage the environmental impacts and ensure the sustainability of the Una River Basin.

Figure 6 illustrate images of the temporal evolution of land use and occupation in a stretch of the Una Basin, upstream of the water supply point, respectively, in 2008 (5a), when it was essentially rural, 2014 (5b), 2018 (5c) and 2020 (5d). When observing the images, it is evident that urban expansion in this specific area of the basin resulted in environmental imbalance and increased social risks, increasing floods, landslides, increased soil impermeability, and silting, all resulting from inappropriate use. or uneven soil.

The insights gained from the analysis of Figure 6 are complemented by Table 1, which presents the land use and occupation classes within the basin for 2003 (Batista *et al.*, 2006) and 2021(Unitau, 2021). The table shows both their percentage distribution and area coverage (in hectares), with negative variability indicated in blue and positive variability in red.

Figure 6. Example of the temporal evolution of land use and occupation upstream of the Una River water catchment point: a) 2008, b) 2014, c) 2018 and d) 2020.
Source: Google Earth (2023).

Table 1. Evolution of land use classes (2003 vs. 2021) in terms of area (ha) and percentage distribution. Positive changes are highlighted in red and negative changes are marked in blue.

Land Use Class	2003 (ha)	2003 (%)	2021 (ha)	2021 (%)	Variability (%)
Urban and Exposed Soil	992	2.1%	1625	3.4%	64%
Forest or Scrubland	10082	21.1%	11790	24.7%	17%
Pasture	32927	69.1%	30779	64.6%	-7%
Crops	604	1.3%	260	0.5%	-57%
Water Bodies	230	0.5%	90	0.2%	-61%
Reforestation	2713	5.7%	3168	6.6%	17%
Others	128	0.3%	35,6	0.1%	-72%
Total	**47676**	**100%**	**47676**	**100%**	

Based on these data, significant land use changes are evident, particularly in the context of urban expansion. In 2003, urban and exposed soil areas covered 992 hectares, or 2.1% of the total area, and grew to 1625 hectares (3.4%) by 2021, representing a substantial growth of 64%. Forested and scrubland areas increased by 17%, while pasture area decreased by 7%. Cultivated land saw a significant reduction of 57%. Water body coverage decreased by 61%, and reforested areas grew by 17%. The 'Others' category, which includes mining activities, experienced a substantial decline of 72%.

Despite the significant growth of the urbanization process in recent decades, previous studies indicate that the Una River Basin still maintains a high rate of vegetation cover compared to other delimited areas (Dias *et al.*, 2010; Unitau, 2021). The conservation of these areas is essential to avoid environmental problems resulting from physical processes, such as erosion, silting, floods, and flooding, which tend to get worse with increased exposure and soil impermeability. Nevertheless, during field visits, numerous anthropogenic activities can be observed, which contribute to the intensification of the degradation scenario in the vicinity of the watershed. Figure 7 showcase several current scenarios witnessed in the Una River Basin, ranging from its source (Figure 7.1a) to the Paraíba do Sul River outlet (Figure 7.2c).

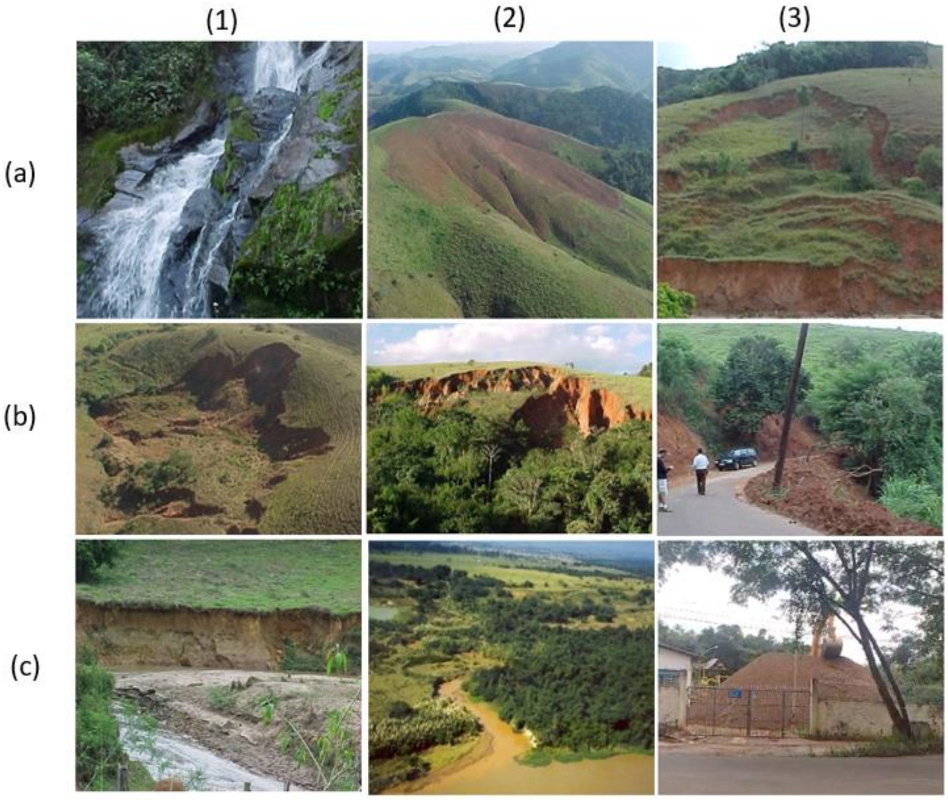

Figure 7. Scenarios observed in the Una River Basin, from the source (7.1a) to the outlet (7.2c). Figure 7.3c shows the removal of sediment near the point of intake of water for public supply.

Comparing Figure 7.1a, which shows the water at the source of the Una River during a specific period of the year, with Figure 7.2c, which shows the water at the outlet of the basin during the same period, it is clear that the basin is experiencing advanced stages of human-induced impacts. Throughout its course from source to estuary, several signs of human-induced degradation can be observed. These include downhill plowing (Figure 7.2a), block erosion caused by roads and paths used by livestock (Figure 7.3a, as shown in Figure 7.1b), mass landslides (Figure 7.2b), and erosion of unprotected secondary roads (Figure 7.3b). In addition, instability and erosion of unprotected banks (Figure 7.1c) contribute to increased sediment transport and subsequent deposition in the riverbed, as shown in Figure 7.2c.

Figure 7.3c shows a significant amount of sediment being removed from the Una River at the water collection point for the community of Taubaté. Examining Figure 7, it is clear that the unregulated urban expansion and land use changes in the Una River Basin have led to remarkable consequences. These results underscore the urgency of implementing recommendations to address soil degradation and depletion.

According to Unitau (2021), these recommendations should prioritize three main strategies: increasing vegetation cover to mitigate soil erosion, improving water infiltration to minimize surface runoff, and implementing runoff control measures to mitigate erosion and pollution of water sources. These measures are intended to protect water quality, wildlife, and the environment while regulating the watershed's hydrologic regime. However, to achieve these goals, it is essential to increase the vegetative cover of the soil to reduce the impact of raindrops and soil breakdown. It is also necessary to improve water infiltration into the soil, reducing surface runoff and increasing storage capacity.

Finally, it is essential to implement measures to control surface runoff to reduce soil erosion and prevent contamination of water sources and to regulate the water regime of the basin. These actions play a critical role in protecting water quality, preserving wildlife, and ensuring the long-term environmental sustainability of the region. To effectively address these challenges, cooperation is needed among rural producers, residents, and government agencies. It is imperative to join forces and seek solutions together to promote environmental stewardship and sustainable development in the region.

It is important to emphasize that suspended sediment monitoring plays a critical role in guiding the implementation of effective sedimentation reduction practices in urbanizing watersheds. In addition to maintaining native vegetation cover and preserving or restoring riparian forests along rivers, streams, springs, and steep slopes, monitoring suspended solids helps prevent erosion and protect biodiversity. In addition, it is recommended that water runoff from roads be directed to drainage channels or infiltration basins as a method of controlling water flow and facilitating proper soil infiltration. Suspended solids monitoring thus becomes a valuable tool for evaluating the effectiveness of the measures implemented and for ensuring the success of actions aimed at reducing sediments and preserving water resources in these basins.

4. CONCLUSION

Changes in land use and land cover in the Una River Basin, located in the Metropolitan Region of Vale do Paraíba and the North Coast (RMVale), were studied using advanced geoprocessing techniques. The results of this analysis essentially show a significant increase in urbanization of 64%, as perceived visually. In addition, increases were also identified in the categories of "native forest" and "natural regeneration", both of which experienced a growth of 17%, as well as in the class of "reforestation".

The evaluation of the biochemical parameters over a 14-year period (2008-2022) collected as part of the monitoring of the Una River reveals noticeable seasonal patterns. Total Suspended Solids (TSS) levels fluctuated throughout the seasons, being lower in winter and higher in summer. These levels only showed statistically significant correlations with parameters such as turbidity, dissolved oxygen and electrical conductivity.

In this context, it is recommended that a monthly monitoring approach be adopted, accompanied by intermittent sampling at shorter intervals. This strategy will allow daily variations to be captured, contributing to a more comprehensive analysis of biochemical parameters. This more intensive approach will provide a deeper understanding of the processes and temporal variations in the Una River Basin.

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