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Guandu River Sediment Plume Space-Time Variability Characterization on Sepetiba Bay – Rio de Janeiro, SE Brazil

Caracterização da Variabilidade Espaço-Temporal da Pluma de Sedimentos do Rio Guandu na Baía de Sepetiba – Rio de Janeiro, SE Brasil

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Abstract

The Sepetiba Bay (Rio de Janeiro, SE Brazil) is an important coastal environment due to its ecological characteristics, extensive biodiversity, vast green area and connection to the sea, and vast socio-economic impact due to its importance to the surrounding communities and for the country. The bay receives a considerable amount of sediments through several small rivers and artificial channels along its coast, creating a "river plume" dynamic that influences its biogeochemical processes within the bay. This study analyzes a 20-year remote sensing temporal series from MODIS-Terra, combined with a semi-analytical algorithm based on well-established literature, to retrieve surface sediment concentration. The results reveal an inhomogeneous spatio-temporal pattern of the plume, which varies with climatological seasons. Summer and Spring present higher sediment concentrations and range, compared to Autumn and Winter. The observed patterns in the plume suggests a heterogeneous specialization that depends on the riverine inflow, which agrees with previous literature studies. Future studies should tackle both, the increase of remote sensing algorithms' accuracy to retrieve sediment concentration and focus on plume change detection events to better understand the impact of land cover changes within the drainage basins surrounding Sepetiba Bay.

Keywords: Remote sensing; River plume; Surface sediments

Resumo

A Baía de Sepetiba (Rio de Janeiro, SE Brasil) é um importante ambiente costeiro devido às suas características ecológicas, vasta biodiversidade, grande área verde e conexão com o mar, além de seu significativo impacto socioeconômico para as comunidades ao redor e para o país. A baía recebe uma quantidade considerável de sedimentos através de vários pequenos rios e canais artificiais ao longo de sua costa, criando uma dinâmica de "pluma fluvial" que influencia seus processos biogeoquímicos. Este estudo analisa uma série temporal de 20 anos de sensoriamento remoto do MODIS-Terra, combinada com um algoritmo semianalítico baseado em literatura bem estabelecida, para recuperar a concentração de sedimentos na superfície. Os resultados revelam um padrão espaço-temporal heterogêneo da pluma, que varia com as estações climatológicas. Verificou-se que o Verão e a Primavera apresentam maiores concentrações e alcance de sedimentos, comparados ao Outono e Inverno. Os padrões observados na pluma sugerem uma especialização heterogênea que depende do influxo fluvial, o que está de acordo com estudos anteriores na literatura. Estudos futuros devem abordar tanto o aumento da precisão dos algoritmos de sensoriamento remoto para recuperar a concentração de sedimentos quanto focar em eventos de detecção de mudanças na pluma para melhor entender o impacto das mudanças na cobertura do solo dentro das bacias de drenagem ao redor da Baía de Sepetiba.

Palavras-chave: Sensoriamento remoto; Pluma de rio; Sedimentos superficiais

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1 Introduction

Bays and estuaries are singular coastal environments due to their ecological and biogeochemical nature and their role in human-related economic activities (Costa & Souza-Conceição 2009; Silva Filho & Magrini 2017). Constant monitoring is fundamental to mitigating environmental impacts, mainly those induced by anthropogenic sources (Martins & Stevaux 2005). In particular, monitoring intrusive plumes from estuarine rivers can suggest significant changes in the region's hydrological and biogeochemical dynamics and reveal potential trends in constituent concentrations harmful to human health (Silva Andrade et al. 2013). Another important problem to look after is the change of turbidity in the waters of the bay, caused by the intrusive estuarine plume, that changes the light and radiation availability to support photosynthesizers organisms (Cussioli M et al. 2019; Teng W et al. 2007) that plays a big role in the balance of nutrients in the water column, affecting its composition and being a trend for fish deaths by eutrophication (Glibert et al. 2002).

The Sepetiba Bay (SB) is located in the Rio de Janeiro State (RJS) coastal region, between the largest urbanized area of RJS, the Metropolitan Region of Rio de Janeiro City (RMCRJ), and the Costa Verde region (RCV), one of the most preserved areas of the RJS (CEPERJ 2014). SB is economically important to RJS, mainly as the access and exit route of cargo ships from Itaguaí Port, Brazil's most significant public port for iron ore transportation (ANTAQ 2023; Chagas 2020). Also, SB is a focal point for local ecotourism (Palhares 2021). The bay has a notable biodiversity (Araújo et al. 1998; Azevedo et al. 1999) alongside a particular Geomorphology and Hydrography, which has been affected by landscape-altering mechanisms (Kjerfve et al. 2021). The Guandu River (GR), the region's main tributary, represents 86% of the entire fluvial discharge reaching SB (Tonhá et al. 2021). The Plume formed by GR discharge is the primary source of sediments and heavy metals that reaches the SB (Araújo et al. 2017; Ferreira, Horta & Cunha 2010; Molisani et al. 2006), which has been significantly modified, mainly due to the anthropogenic-induced land cover change in its drainage basin (Molisani et al. 2004).

Therefore, space-time characterization of GR Plume is urgent to predict sedimentation levels and the extent of possible heavy metal contamination impacts throughout SB. Although other studies have investigated the GR plume, this study tackles the characterization of the temporal and spatial dynamics of the GR sediment Plume from a set of long time-series remote sensing data, amplifying the methods and its spatio-temporal characterization. The study aims to understand the Plume's extent, spatiotemporal variability, and behavior under different climatic seasonal conditions.

2 Study Area – General Characteristics

The Sepetiba Bay (Figure 1) is 60 km west of Rio de Janeiro City and has nearly 130 km of perimeter. SB is in a transition region between important estuarine rivers of the RJS, such as the Itabapoana and the Guandu Rivers, and the Atlantic Ocean (Rocha et al. 2010).

The region is characterized by a microclimate typical for tropical coastal environments, being influenced by the proximity to the sea, topography, terrestrial and sea breezes, among other factors. Average rainfall is about 1500 to 2500 mm/year, reaching the maximum values from September to March (summer wet season) and minimum values from may to september (winter dry season) (Villena et al. 2012; WFL. Castelo et al. 2021). Wind predominant direction is NE/SW influenced by the proximity to the sea, generating a local circulation of terrestrial and sea breezes (Villena et al. 2012). Wind with SE direction spreads the sediments carried to GR, SW direction causes a phenomenon described as meteorological tide, forcing the water to the Barra de Guaratiba channel (Villena et al. 2012; Castelo et al. 2021). Water circulation in Sepetiba Bay occurs clockwise and can be considered slow, induced by different water density gradients (Alves Martins et al. 2019). Sea water is added in the western part of the bay, carrying fresh water and fluvial sediments to the south of the bay (Carvalho et al. 2021).

The anthropogenic-induced land cover change and structural modifications on the tributaries drainages basins discharging on SB are drivers of significant impact like heavy metals accumulation, both on suspended and bottom sediments and intense sedimentation processes (Araújo et al. 2017; Ferreira, Horta & Cunha 2010; Molisani et al. 2004). Concurrently, mangrove areas south of the bay, such as the Marambaia's Barrier Island, have experienced intense degradation (Castelo et al. 2021).

3 Material and Methods

3.1 Material

The temporal series from 2002 to 2022 of the daily product MOD09GQ.061 (Vermote & Wolfe 2021) from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor aboard the TERRA platform was used in this study. The product has a spatial resolution of 250 m and a temporal resolution of one day. Image pre-processing, georeferencing,

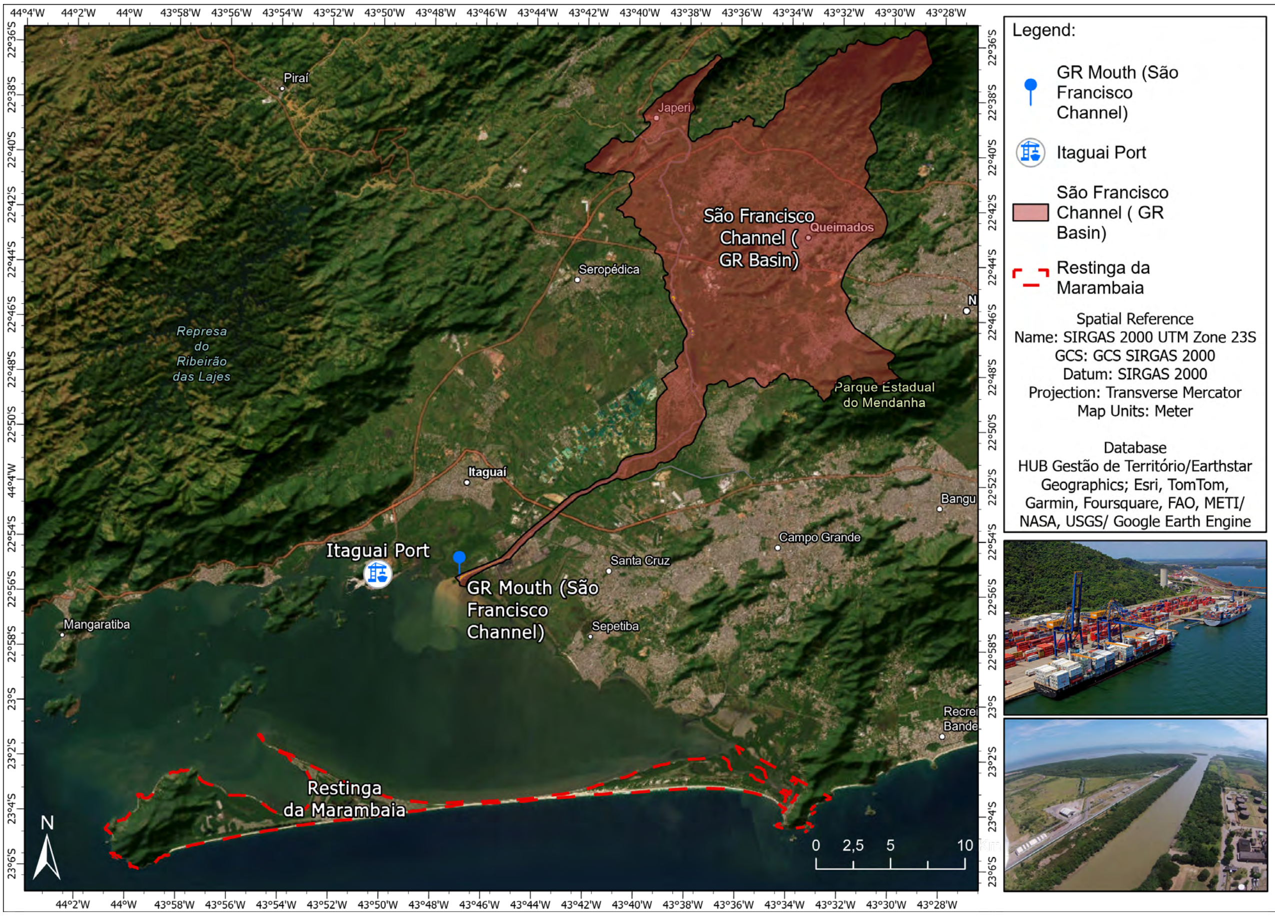

Figure 1 Presentation of Sepetiba Bay and places of interest.

and atmospheric correction were previously applied before product distribution. The temporal series analysis was built using the Google Earth Engine platform (GEE 2023) (https://earthengine.google.com/). This product has been extensively employed in characterizing suspended sediment dynamics in coastal regions worldwide (Nukapothula et al. 2022; Turner, Friedrichs & Friedrichs 2021; Yunus et al. 2022).

To estimate precipitation levels we used the temporal series of ERA5 Daily Aggregates Reanalysis by the ECMWF (European Center of Medium Weather Forecast) (Copernicus 2017) for the same period of time (2002 to 2022). This product has a spatial resolution of 2.7830 m and temporal resolution of one day, by aggregating hourly values per day (Hersbach et al. 2023). All the processing and the temporal series analysis was made using the Google Earth Engine platform (GEE 2024) (https://earthengine.google.com/). This product is well known in the literature and extensively used for estimating climate variables (Lavers et al. 2022; Jiao et al. 2021).

3.2 Methods

3.2.1. MODIS- TERRA Cloud Cover Masking

Two Cloud cover masking methods were used: (1) an algorithm using the *Surface Reflectance Band 1*, which collects reflectance values from the entire image and designates threshold value as cloud-free; (2) the second method involves collecting surface reflectance validation points within the image creating a threshold for visible and infrared bands, determining confidence levels for observing an unobstructed view of the Earth's surface. An indication of a shadow mask was also provided (Ackerman & Frey 2015).

The result was 3.600 cloud-free images centered in 43,79°W and 22,98°S available for analysis, reaching an average of fifteen monthly images for the entire temporal series. All procedures were carried out in GEE.

3.2.2. Quantifying Sediments Concentration

Total Suspended Sediments (TSS) concentration is retrieved by a global Nechad's algorithm (Equation 1) (Nechad, Ruddick & Park 2010). The Nechad's algorithm is extensively applied in studies that estimate TSS in coastal regions through Remote Sensing data (Ashphaq, Srivastava & Mitra 2023; Magrì et al. 2023; Yunus et al. 2022).

$$TSS = A^p \frac{\rho_w}{1-(\frac{\rho_w}{C^p})} + B^p \quad (1)$$

In this algorithm, *pw* represents the *Surface Reflectance Band 1* of the MOD09GQ.061, with a bandwidth of 620-670 nm. The constants ***ap***, ***bp***, and ***cp*** are calculated by Nechad, Ruddick & Park (2010), with values of 268.95, 2.17, and 16.61, respectively.

Due to the absence of TSS open-source data, we performed a comparative analysis to investigate the quality of the Nechad's algorithm for TSS retrieval. Two TSS maps (January and July 2003) from Rodrigues et al. (2009) were selected as reference. An Inverse Distance Weighting (IDW) (Bartier & Keller 1996; Watson & Philip 1984) method with a 1000-point mesh was applied to generate average isolines for comparison. The January/2003 maps from Rodrigues et al. (2009) are compared to the average Summer (January to March) TSS maps generated in this study, while the July/2003 maps are compared to the average Autumn (April to June) TSS maps.

3.2.3. Sediment Plume Extension Analyses

A temporal average of MOD09 within the 2002/2022 period is used to study the spatio-temporal variability of the GR plume. Data was separated into four seasonal time periods: Summer (January to March), Autumn (April to June), Winter (July to September), and Spring (October to December), to investigate the seasonal behavior of the GR plume. In order to identify the plume's range, 12 km length transects were constructed, tracking the concentration levels of TSS in three different directions. The first transect extends westward from the GR mouth,reaching the interior of the Bay's. The second transect points southwest, extending to a small portion of the Marambaia's Barrier Island. The third transect, aligned with the Sepetiba coastal areas, extends to the mangrove regions within the Marambaia's Barrier Island.

3.2.4. ERA 5 Precipitation Data

The precipitation levels were acquired with ERA5 data from the latest reanalysis of the ECMWF. We used the Daily Aggregate product to estimate precipitation for every month from 2002 to 2022. As a spatial distribution, we investigated the precipitation on the São Francisco Channel Basin (Figure 1), that comprehends the GR mouth, we used this basin understanding that spatially it would describe better the precipitation processes that reaches the GR and flows to the SB. The average precipitation per month was calculated to the whole basin.

4 Results

Figure 2 displays the 20-year (2002 to 2022) spatio-temporal average of TSS concentration (mg/l) in Sepetiba Bay. High TSS concentrations are observed near the mouth of the GR, gradually decreasing at a rate of 0.0016 mg/l per meter in Transect 1, 0.0017 mg/l in Transect 2 and 0.0012 mg/l in Transect 3. This shows that from the GR mouth to central regions of the Bay, towards the central regions of the Bay, the decay is more accentuated (Transects 1 and 2) than in the direction of Sepetiba Coastline (Transect 3). Additionally, elevated TSS levels are evident in the Pedra de Guaratiba region, near Marambaia 's Barrier Island.

Figure 3A illustrates the spatio-temporal average TSS concentration during the Summer (January to March). The highest TSS concentration, reaching up to 30 mg/l, are observed near the mouth of the GR, decreasing to 4 mg/l in the interior regions of the bay. The decay in meters from point 1 to 7, is 0.0020 mg/l in Transect 1, 0.0018 mg/l in Transect 2 and 0.0012 mg/l in Transect 3, demonstrating that near to the Sepetiba coast the TSS decay is less accentuated, this informations starts to be clear when we notice that from Transect 1 to 2, we have a difference of 0.002 mg/l per meter of decay, and between Transect 1 to 3, 0.008 mg/l per meter. We can describe this scenario as a highly turbid scenario.

An opposite scenario of TSS values is presented for the Autumn (April to June) (Figure 3B), where lower TSS concentration appears, ranging from 20 mg/l up to 2 mg/l. Doing the same analyzes of Figures 2 and 3A, we found out that on Autumn, the decay of TSS values are, 0.0014 mg/l per meter, 0.0014 mg/l and 0.0012 mg/l from Transect 1 to 3 respectively, this shows a different pattern in the decay scenarios, principally in Transects 1 and 2, that stays with the same decay rate, another point to look after is the fact that in three scenarios (General Average, Summer and Autumn) the decay in Transect 3, stays the same, pointing a plumes dispersion preference. We can describe Autumn as a moderate turbid scenario.

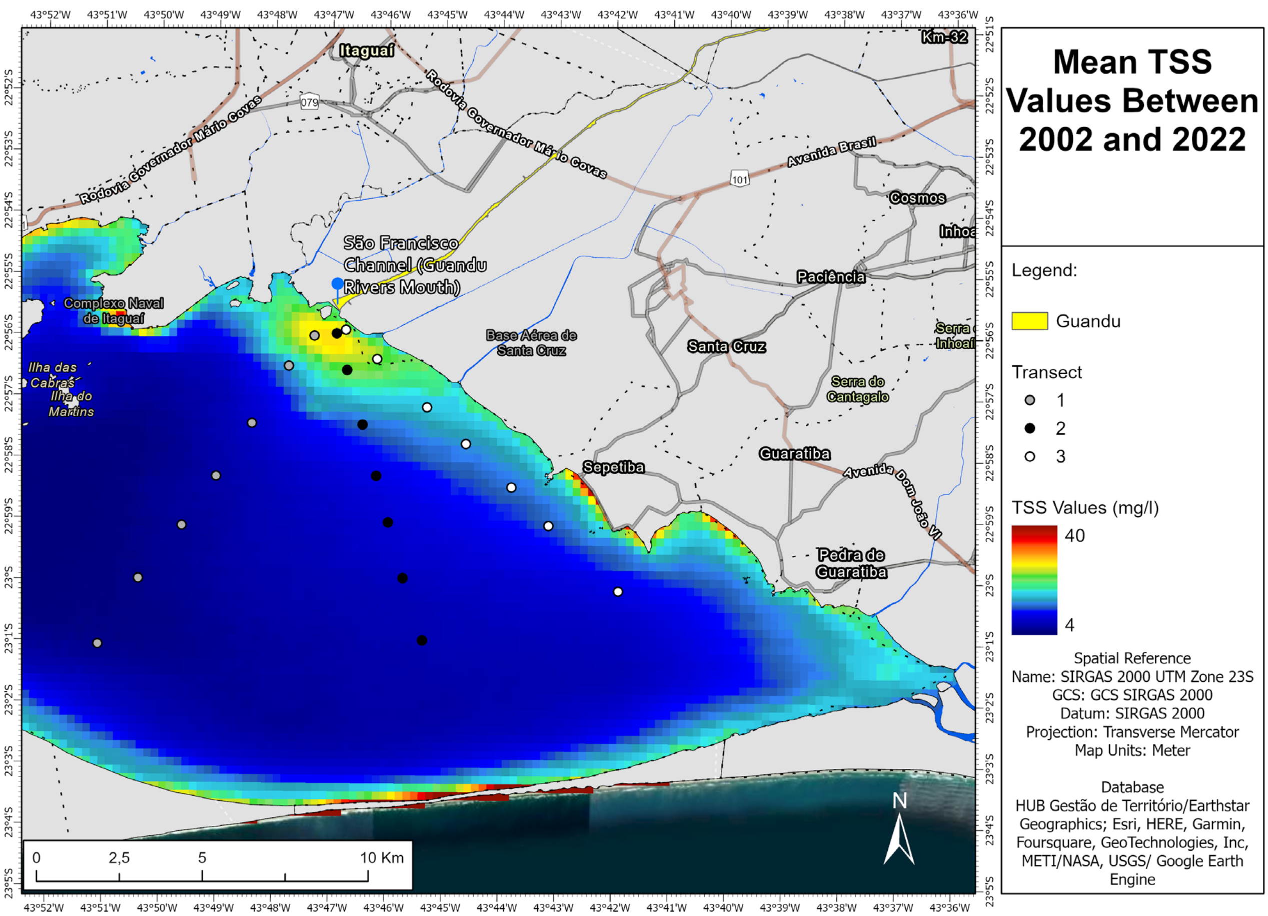

Figure 2 Average values of TSS (mg/l) for the hole series (2002 - 2022) and Transects used to measure the plume extension.

Figure 3C shows the Winter (July to September) series of TSS and it can also be identified as a moderately turbid scenario for having spatial characteristics similar to Autumn. Although it's similar spatial pattern, when we analyzed the decay values, 0.0012 mg/l per meter was found in Transect 1, 0.0011 mg/l in Transect 2 and 0.001 mg/l for Transect 3. This shows that the moderated turbid scenarios are not the highest in TSS concentrations, but when we study the conservation of TSS values as we move along the Transects, they appear as a trend to this particular characteristic of the plume.

Similar to Summer, Figure 3D shows Spring (October to December), the other highly turbid scenario in our temporal series. Spring is similar both in spatial distribution and decay of values, however it is interesting to point out that the decay value in meters found in Transect 3 is 0.001 mg/l.

Considering the analysis of Figure 2 and comparing it with the seasonal spatio-temporal analysis (Figure 3), it is possible to identify fluctuations in the extent and concentration of the plume, which reveal a dependency on the seasonality. During months with higher TSS concentration, the plume exhibits larger dimensions, reaching from the GR mouth up to the central regions of the Bay. In contrast, during Autumn and Winter seasons, the plume contracts, remaining closer to the GR mouth and the Sepetiba coastline.

Figure 4 shows the comparative analysis based on Rodrigues et al. (2009). Figures 4A and 4b exhibit a similar pattern of plume dispersion, with higher TSS concentration nearer to the GR mouth, extending to central areas of the Bay and along the Sepetiba coastline.TSS concentrations for the January-Summer comparison (Figure 4A) show an epicenter near to the GR mouth for Rodrigues et al. (2009), with values ranging from 20 to 30 mg/l. A similar scenario in Figure 4B shows lower values, ranging from 10 to 18 mg/l. The agreement between both maps suggests that the Nechad's algorithm produces reliable

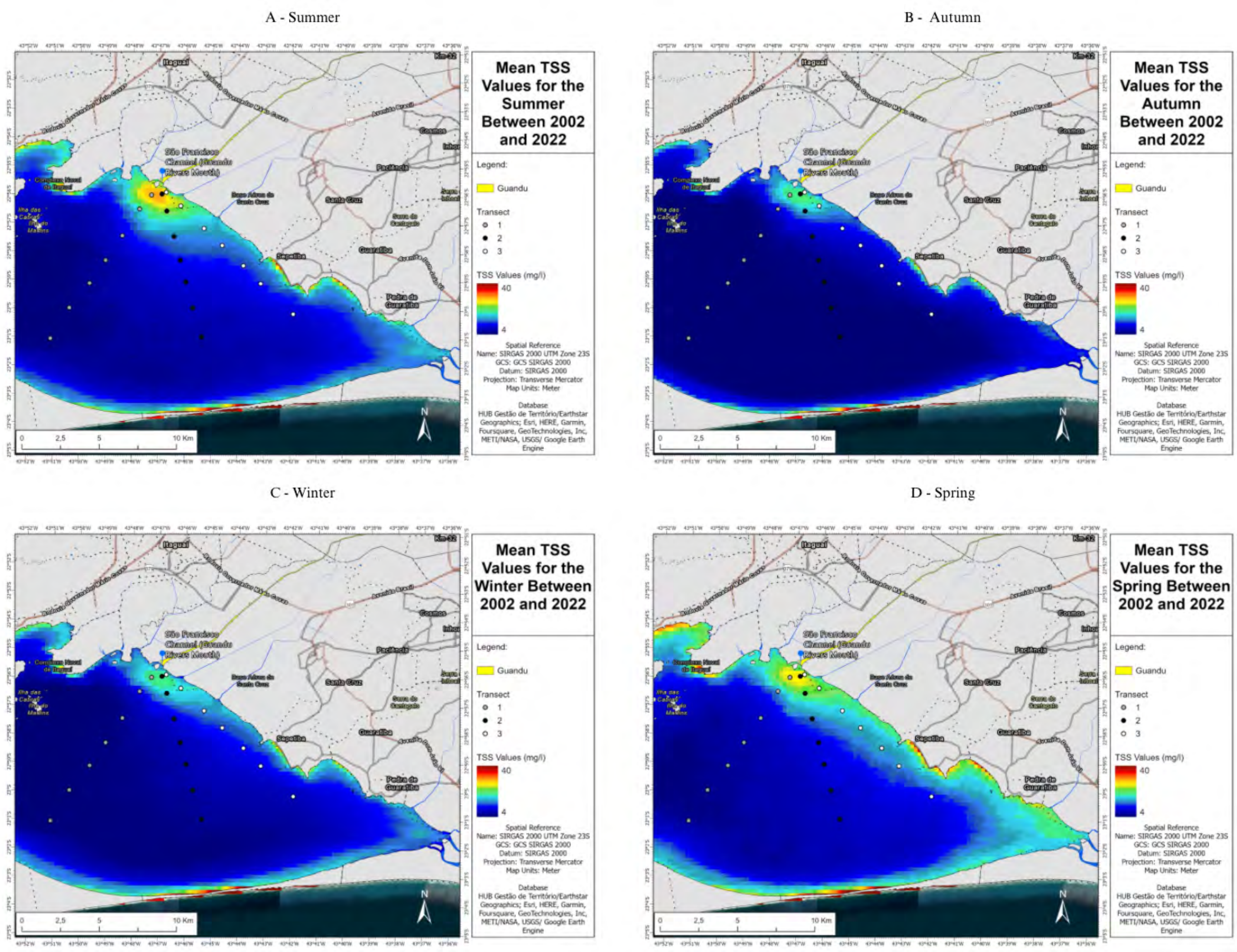

Figure 3 Seasonal average TSS (mg/l): A. Summer mean for 20 years; B. Autumn mean for 20 years; C. Winter mean for 20 years; D. Spring mean for 20 years.

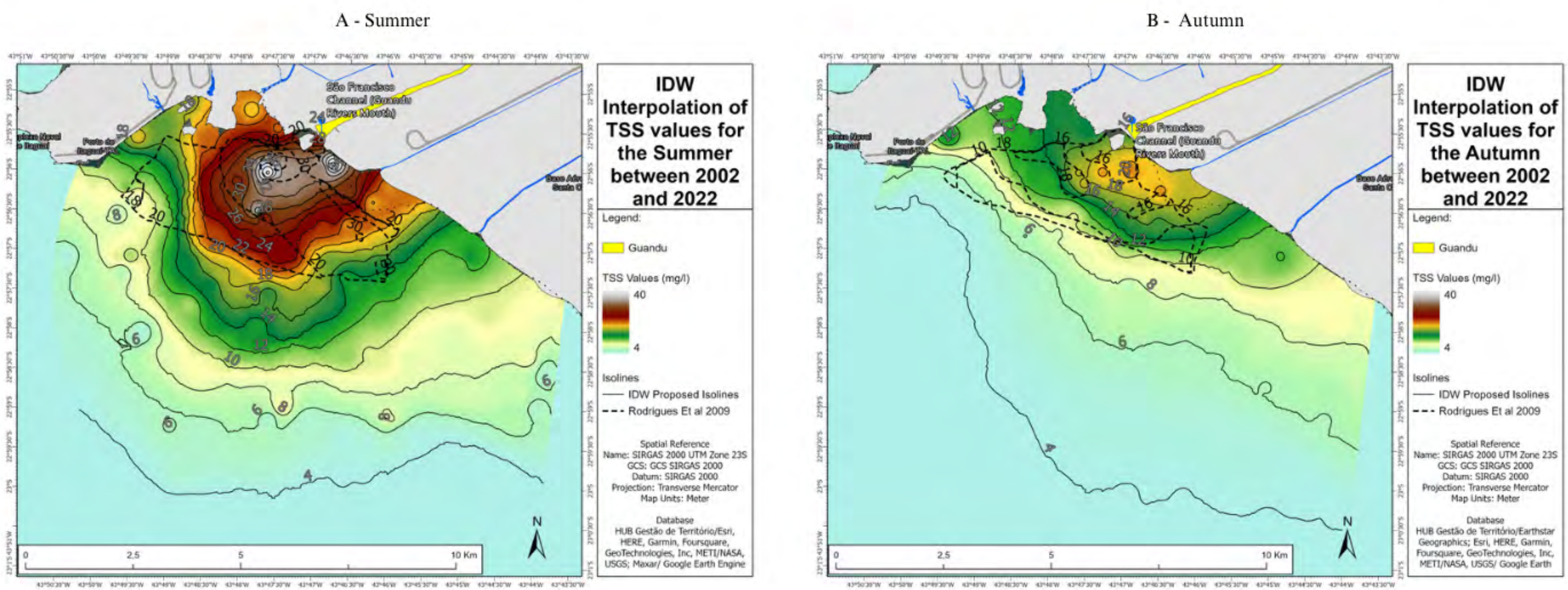

Figure 4 Isolines depicting sediment concentration in Sepetiba Bay were generated by the author and adapted from Rodrigues et al. (2009), illustrating the horizontal distribution of suspended particulate matter (SPM). Panel A represents the summer season, while panel B represents autumn.

results, not only for tracking the plume's range but also for TSS concentration. Although it is the author's knowledge that further sampling efforts need to be carried out to fully characterize the robustness of a Remote Sensing algorithm to retrieve optical active components (OAC) (Augusto-Silva et al. 2014; Carvalho et al. 2015; Maciel et al. 2019), we believe that this comparison exercise gives a solid ground on the evaluation of the plume's spatiotemporal variability.

To further investigate the relationship between plume's extension and TSS concentration in Sepetiba Bay. Figure 5 show a detailed representation of transects 1, 2, and 3 for each season and for the overall mean of the 2002-2022 temporal series. It is noteworthy that the plumes have a non-linear dispersion behavior.

In Figure 5A, a significant (almost exponential) decay in TSS concentration values is observed as we move toward the interior of Sepetiba Bay. A pronounced decay between points 1 and 3, approximately 4.5 km from the GR mouth, where TSS concentrations decrease from 30 mg/l to 10 mg/l in Summer, representing a reduction of around 66%. In the Autumn, a decrease in TSS concentration values from 20 mg/l to 5 mg/l increases the reduction to approximately 76% when compared to the Summer. From points 4 to 7, there is a trend of stability in the TSS concentration values, indicating that beyond this point, values considered to be influenced by the sediment plume are not observed.

In Figure 5B, we analyze Transect 2, closer to the Sepetiba's shore than Transect 1. It exhibits similar characteristics to Transect 1, with a more intense decay between points 1 and 3, approximately 4 km from the GR mouth, but in a different direction (closer to Sepetiba and towards Marambaia's Barrier Island). However, TSS concentration values in Transect 2 are higher than in Transect 1. While Transect 1 presents a 66% reduction in Summer, going from 30 mg/l to 10 mg/l, Transect 2 goes from 30 mg/l to 15 mg/l, representing a reduction of 50%, and in Autumn, from 20 mg/l to 8 mg/l, representing a reduction of 60%. Points 4 and 5 in this transect show the Plume's impact during Summer and Spring, while points 6 and 7 tend to stabilize. This trend towards stability can already be observed from point 4 in Autumn and Winter, delineating the sediment plume.

Figure 5C shows Transect 3. As it is the closest transect to Sepetiba's bay shore, exhibiting characteristics that distinguish it from the other two. The first notable feature is that the values do not decay as sharply as in the other two transects as we move further away from the river mouth. Compared to Transect 1, which decreases from 30 mg/l to 10 mg/l (66%) over 4 km from the river mouth, Transect 3 shows a decay from 25 mg/l to 8 mg/l (68%) over 12 km from the river mouth, demonstrating the significant impact of the direction taken by the last transect, which is perpendicular to Sepetiba coastline and towards Marambaia's Barrier Island and Pedra de Guaratiba. Also, the difference, particularly at point 1, in TSS concentration, indicates an apparent plume centroid during Spring and Summer, which can also be observed in Transects 1 and 2. Based on this analysis, it can be observed that the plume, in general, moves towards Pedra de Guaratiba and does not extend towards the interior of Sepetiba Bay. TSS concentration values are higher near the GR mouth and the coastal regions of the bay (Marambaia's Barrier Island, Sepetiba e Pedra de Guaratiba), reaching its peak in extent and concentration during Summer.

5 Discussion

One of the significant findings of this study is the identification of a pattern of surface sediment concentration, being higher near the GR inlet for all seasons and decreasing with distance in all directions from the GR mouth. However, there is a variability of the sediment plume and its concentration across different climatological seasons which is crucial for the understanding of the environmental dynamics of the region. Summer and Spring present higher sediment concentrations and range, followed by Autumn and Winter. Figure 6 describes climatologically the precipitation levels in the area, we can observe that in the months with higher TSS levels, we also found the higher precipitation values, and in the months with lower TSS levels, the observed was low precipitation values. This might corroborate the idea of an increased flow rate of the riverine inputs when we have more precipitation, leading to an increase of TSS reaching the Bay, giving the plume the spatio characteristics observed in this study, having an inhomogeneous spatial distribution which may impact some biogeochemical processes, such as the plants photosynthesis, since this organisms are receiving less energy (Davies Colley & Smith 2001) along the bay which endorse previous studies and expands the sediment plume dynamics characterization in Sepetiba Bay, both temporally and spatially.

The spatio-temporal analysis reinforces Lacerda et al. (2007), which shows that TSS transport to Sepetiba Bay mainly occurs through the riverine inputs, particularly the GR mouth, which accounts for 73% of TSS that reaches the Bay. Also, it indicates higher surface concentration in regions pointed out by Lacerda et al. (2007) as the most significant for sediment accumulations, in the northern and southeastern coastlines of the Bay (Port Region and Sepetiba City, respectively) decreasing by up to 5 times in

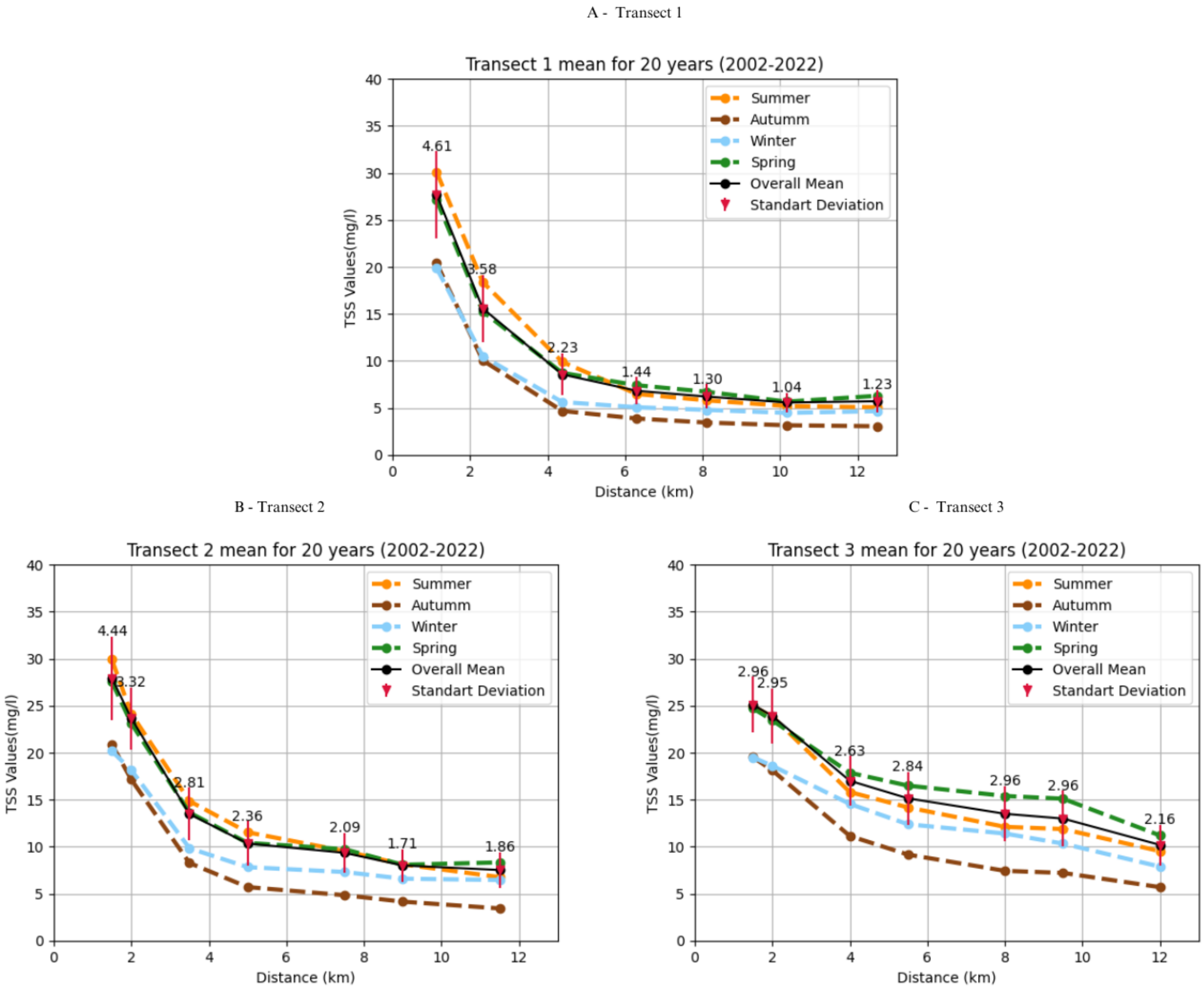

Figure 5 Average TSS (mg/l) dispersion for 20 years in the Created Transects: A. Transect 1; B. Transect 2; C. Transect 3.

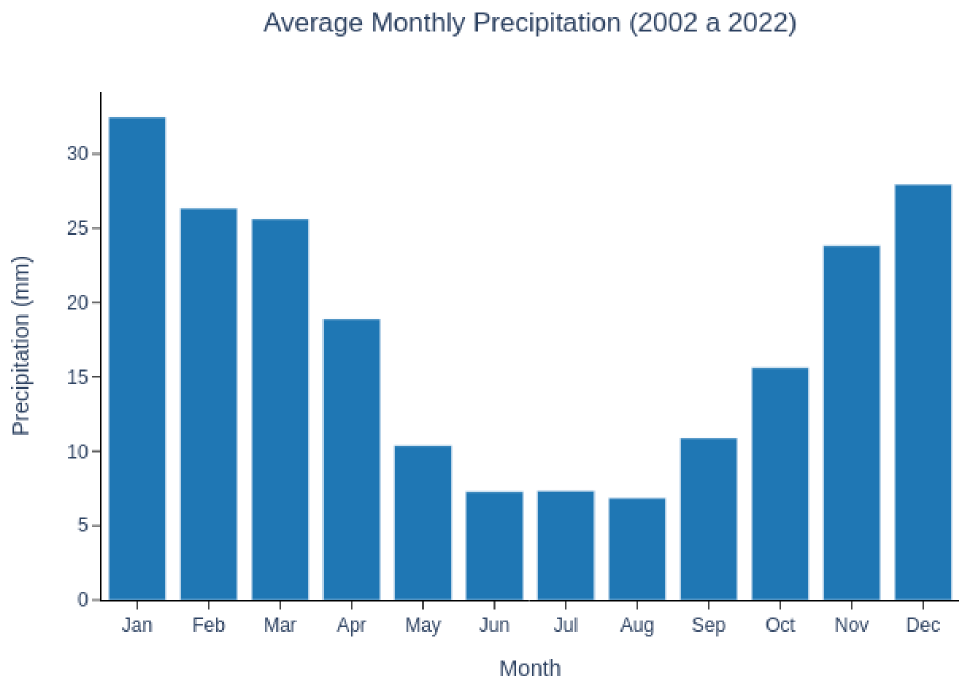

Figure 6 Average Monthly precipitation (mm), with ERA5 Reanalysis from 2002 to 2022 in the São Francisco Channel (GR Basin).

more interior regions of Sepetiba Bay. The spatiotemporal analysis also agrees with Montezuma (2007), who points out that sediment plumes originating from the channel's mouth have an area of influence that extends from the beaches of Sepetiba City to regions closer to the open ocean. However, quantitatively, the TSS concentration remains higher between the channel mouth and the Sepetiba coastline, extending to the Restinga de Marambaia beaches. The retention of the sediment plume in regions closer to the GR mouth is attributed, among other factors, to tidal currents that circulate and trap sediments along the Sepetiba coastline, as shown by Rocha et al. (2010).

There has been a significant rise in potentially toxic element concentrations in the last 50 to 70 years, mainly due to anthropogenic sources (Silva et al. 2022). Several studies have pointed out the presence of Heavy Metals and trace elements in the surface and subsurface sediments exposing the ecological risks for the Sepetiba Bay and normally the biggest amount of this concentrations, can be found in the areas shown by this paper (Veeck et al. 2007; Silva et al. 2022). According to Araújo et al. (2017), the drainage basins of channels reaching the Sepetiba Bay have undergone significant land cover changes for the past 30 years. Particularly, sand extraction areas have increased almost 100-fol, from 15.12 ha to 1,531.08 ha, and urban coverage areas have an increase of 9,000 ha. Vegetation, agriculture, and mangrove areas have decreased, being the mangrove areas the most impacted with a 26 % reduction. Sand extraction and the urban regions increase are only responsible for 12.61% of the total land cover usage within the drainage basins but are in regions close to the rivers and channels, which might impact the sediment transport caused runoff, increasing sediment concentration. A deviation from the Sepetiba Bay plume spatiotemporal distribution found for each season in this study can be a proxy for understanding future land cover change impacts.

6 Conclusion

The remote sensing-based analyses presented in this study reveal that Sepetiba`s Bay plume presents an inhomogeneous spatial pattern that varies with the climatological seasons. Analyzing the decay and the spatial distribution of the TSS values, we could comprehend more about the plume characteristics and its behavior. The Transects charts addressed some important information of plumes range and the particularities of the scenarios evaluated in our temporal series. The comparison to an in situ study brings reliability to the methodology used in this study, although is important to further improve the validations methods. Future perspectives include the need to better understand the relation between the sediment plume and some forcing factors in the region, for example, how the GR discharge can be determinant for the plumes extension or how important is the study of winds regional physics to the monitoring of the plume dynamics. Another focus on future works is to collect in situ remote sensing data, in order to better validate and parameterize mathematical models to retrieve TSS concentration with higher accuracy, allowing a complete understanding of the plume dynamics and its determinants. Change detection strategies can also enable the understanding of, not only, deviations from the spatiotemporal pattern of the Sepetiba`s Bay plume but also how it connects to natural biogeochemical processes and anthropogenic environmental impacts.

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8 References

Ackerman, S. & Frey, R. 2015, *MODIS atmosphere L2 cloud mask product*, viewed 10 october 2023, <https://modis.gsfc.nasa.gov/data/dataprod/mod35.php>.

ANTAQ - Agência Nacional de Transportes Aquaviários 2023, *Assuntos, Instalações Portuárias, Portos, Desempenho Portuário*, viewed 10 october 2023, <https://web3.antaq.gov.br/ea/sense/index.html#pt>.

Araújo, D. F., Peres, L. G., Yepez, S., Mulholland, D. S., Machado, W., Tonhá, M. & Garnier, J. 2017, 'Assessing man-induced environmental changes in the Sepetiba Bay (Southeastern Brazil) with geochemical and satellite data', *Comptes Rendus Geoscience*, vol. 349, no. 6-7, pp. 290-98.

Araújo, F.G., Cruz-Filho, A.G.D., Azevêdo, M.C.C.D. & Santos, A.C.D.A. 1998, 'Estrutura da comunidade de peixes demersais da Baía de Sepetiba, RJ', *Revista Brasileira de Biologia*, vol. 58, pp. 417-30.

Ashphaq, M., Srivastava, P. K. & Mitra, D. 2023, 'Preliminary examination of influence of Chlorophyll, Total Suspended Material, and Turbidity on Satellite Derived-Bathymetry estimation in coastal turbid water', *Regional Studies in Marine Science*, vol. 62, 102920.

Augusto-Silva, P.B., Ogashawara, I., Barbosa, C.C., De Carvalho, L.A., Jorge, D.S., Fornari, C.I. & Stech, J.L. 2014, 'Analysis of MERIS reflectance algorithms for estimating chlorophyll-a concentration in a Brazilian reservoir', *Remote Sensing*, vol. 6, no. 12, pp. 11689-707.

Azevedo, M.C.C., Araújo, F.G., Cruz-Filho, A.G., Gomes, I.D. & Pessanha, A.L.M. 1999, 'Variação espacial e temporal de bagres marinhos (Siluriformes, Ariidae) na Baía de Sepetiba, Rio de Janeiro', *Revista Brasileira de Biologia*, vol. 59, pp. 443-54.

Bartier, P.M., & Keller, C.P. 1996, 'Multivariate interpolation to incorporate thematic surface data using inverse distance weighting (IDW)', *Computers & Geosciences*, vol. 22, no. 7, pp. 795-99.

Carvalho, A.C., Moreira, V.D.A., Vicente, M.D.C., Bernardes, M.C., Bidone, E.D. & Sabadini-Santos, E. 2021, 'Evolution of the sources contribution of aliphatic hydrocarbons and their fate in Sepetiba Bay, Rio De Janeiro, Brazil', *Estuarine, Coastal and Shelf Science*, vol. 261, 107548.

Carvalho, L.A.S., Barbosa, C.C.F., de Moraes Novo, E.M.L. & Moraes Rudorff, C. 2015, 'Implications of scatter corrections for absorption measurements on optical closure of Amazon floodplain lakes using the Spectral Absorption and Attenuation Meter (AC-S-WETLabs)', *Remote Sensing of Environment*, vol. 157, pp. 123-37.

Castelo, W.F.L., Martins, M.V.A., Martínez-Colón, M., Guerra, J.V., Dadalto, T.P., Terroso, D., Soares, M.F., Frontalini, F., Duleba, W., Socorro, O.A.A., Geraldes, M.C., Rocha, F. & Bergamaschi, S. 2021, 'Disentangling natural vs. anthropogenic induced environmental variability during the Holocene: Marambaia Cove, SW sector of the Sepetiba Bay (SE Brazil)', *Environmental Science and Pollution* Research, vol. 28, pp. 22612-40.

Castelo, W.F.L., Martins, M.V.A., Lima Ferreira, P.A., Figueira, R., Costa, C.F., Fonseca, L.B., Bergamashi, S., Pereira, E., Terroso, D., Pinto, A.F.S., Simon, M.B., Socorro, O.A.A.S., Frontalini, F., Silva, L.C., Rocha, F., Geraldes, M. & Guerra, J.V. 2021, 'Long-term eutrophication and contamination of the central area of Sepetiba Bay (SW Brazil)', *Environmental Monitoring and Assessment*, vol. 193, pp. 1-27.

CEPERJ - Centro Estadual de Estatísticas, Pesquisas e Formação de Servidores Públicos do Rio de Janeiro 2014, *Geociências, Publicações, Regionalização do Rio de Janeiro*, viewed 12 october 2023, <https://gis-portal.westeurope.cloudapp.azure.com/portal/apps/MapSeries/index.html?appid=a3ee8884e811426ba3ef022b1b2f4167>.

Copernicus Climate Change Service (C3S) 2017, *ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global* *climate*, viewed 12 October 2023, <https://cds.climate.copernicus.eu/cdsapp#!/home>.

Chagas, G.M. 2020, ‘Porto de Itaguaí: Indutor de um polo logístico-produtivo’, *Espaço e Economia: Revista Brasileira de Geografia Econômica*, vol. 19.

Costa, M.D. & Souza-Conceição, J.M. 2009, ‘Composição e abundância de ovos e larvas de peixes na baía da Babitonga, Santa Catarina, Brasil’, *Pan-American Journal of Aquatic Sciences*, vol. 4, no. 3, pp. 372-82.

Cussioli, M.C., Bryan, K.R., Pilditch, C.A., Lange, W.P. & Bischof, K. 2019, ‘Light penetration in a temperate meso-tidal lagoon: Implications for seagrass growth and dredging in Tauranga Harbour, New Zealand’, *Ocean & Coastal Management*, vol. 174, pp. 25-37.

Davies-Colley, R.J. & Smith, D.G. 2001, ‘Turbidity suspeni)ed sediment, and water clarity: A review’, *JAWRA Journal of the American Water Resources Association*, vol. 37, no. 5, pp. 1085-101.

Ferreira, A.P., Horta, M.A.P. & Cunha, C.D.L.N. 2010, ‘Avaliação das concentrações de metais pesados no sedimento, na água e nos órgãos de Nycticorax nycticorax (Garçada-noite) na Baía de Sepetiba, RJ, Brasil’, *Revista de Gestão Costeira Integrada-Journal of Integrated Coastal Zone Management*, vol. 10, no. 2, pp. 229-41.

Ferreira, A.P., Horta, M.A.P. & Cunha, C.D.L.N. 2010, ‘Avaliação das concentrações de metais pesados no sedimento, na água e nos órgãos de Nycticorax nycticorax (Garçada-noite) na Baía de Sepetiba, RJ, Brasil’, *Revista de Gestão Costeira Integrada-Journal of Integrated Coastal Zone Management*, vol. 10, no. 2, pp. 229-41.

GEE - Google Earth Engine 2023, *MOD09GQ.061 Terra Surface Reflectance Daily Global 250m*, viewed 10 october 2023, <https://developers.google.com/earth-engine/datasets/catalog/MODIS_061_MOD09GQ>.

GEE - Google Earth Engine 2024, *ERA5 Daily Aggregates, Latest Climate Reanalysis Produced by ECMWF/ Copernicus Climate Change Service*, viewed 10 october 2023, <https://developers.google.com/earth-engine/datasets/catalog/ECMWF_ERA5_DAILY>.

Glibert, P.M., Landsberg, J.H., Evans, J.J., Al-Sarawi, M.A., Faraj, M., Al-Jarallah, M.A., Haywood, A., Ibrahem, S., Klesius, P., Powell, C. & Shoemaker, C. 2002, ‘A fish kill of massive proportion in Kuwait Bay, Arabian Gulf, 2001: The roles of bacterial disease, harmful algae, and eutrophication’, *Harmful Algae*, vol. 1, no. 2, pp. 215-31.

Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Horányi, A., Muñoz Sabater, J., Nicolas, J., Peubey, C., Radu, R., Rozum, I., Schepers, D., Simmons, A., Soci, C., Dee, D. & Thépaut, J-N. 2023, *ERA5 hourly data on single levels from 1940 to present*, viewed 4 september 2024, <https://doi.org/10.24381/cds.adbb2d47>.

Jiao, D., Xu, N., Yang, F., & Xu, K. 2021, ‘Evaluation of spatial-temporal variation performance of ERA5 precipitation data in China’, *Scientific Reports*, vol. 11, no. 1, 17956.

Kjerfve, B., Dias, G.T., Filippo, A. & Geraldes, M.C. 2021, ‘Oceanographic and environmental characteristics of a coupled coastal bay system: Baía de Ilha Grande-Baía de Sepetiba, Rio de Janeiro, Brazil’, *Regional Studies in Marine Science*, vol. 41, 101594.

Lacerda, L.D., Paraquetii, H.H.M., Molisani, M.M. & Bernardes, M.C. 2007, ‘Transporte de materiais na interface continente-mar na baía de Sepetiba, Rio de Janeiro’, Congresso Latino-Americano de Ciências do Mar, vol. 12, pp. 1-3.

Lavers, D.A., Simmons, A., Vamborg, F. & Rodwell, M.J. 2022, ‘An evaluation of ERA5 precipitation for climate monitoring’, *Quarterly Journal of the Royal Meteorological Society*, vol. 148, no. 748, pp. 3152-65.

Maciel, D., Novo, E., Sander de Carvalho, L., Barbosa, C., Flores Júnior, R. & Lucia Lobo, F. 2019, ‘Retrieving total and inorganic suspended sediments in Amazon floodplain lakes: A multisensor approach’, *Remote Sensing*, vol. 11, no. 15, 1744.

Magrì, S., Ottaviani, E., Prampolini, E., Federici, B., Besio, G. & Fabiano, B. 2023, ‘Application of machine learning techniques to derive sea water turbidity from Sentinel-2 imagery’, *Remote Sensing Applications: Society and Environment*, vol. 30, 100951.

Martins, D.P. & Stevaux, J.C. 2005, ‘Formas de leito e transporte de carga de fundo do alto rio Paraná’, *Revista Brasileira de Geomorfologia*, vol. 6, no. 2.

Martins, M.V.A., Pereira, E., Figueira, R.C.L., Oliveira, T., Simon, A.F.S.P., Terroso, D., Ramalho, J.C.M., Silva, L., Ferreira, C., Geraldes, M.C., Duleba, W., Rocha, F. & Rodrigues, M.A. 2019, ‘Impact of eutrophication on benthic foraminifera in Sepetiba Bay (Rio de Janeiro State, SE Brazil)’, *Journal of Sedimentary Environments*, pp. 480-500.

Molisani, M.M., Kjerfve, B., Silva, A.P., & Lacerda, L.D.D. 2006, ‘Water discharge and sediment load to Sepetiba Bay from an anthropogenically-altered drainage basin, SE Brazil’, *Journal of Hydrology*, vol. 331, no. 3-4, pp. 425-33.

Molisani, M.M., Marins, R.V., Machado, W., Paraquetti, H.H.M., Bidone, E.D. & Lacerda, L.D.D. 2004, ‘Environmental changes in Sepetiba bay, SE Brazil’, *Regional Environmental Change*, vol. 4, pp. 17-27.

Montezuma, P.D. 2007, ‘Impactos nos processos de assoreamento na Baía de Sepetiba-RJ, de sedimentos oriundos da bacia contribuinte e de dragagens portuárias’, MsD thesis, Universidade Federal do Rio de Janeiro, Rio de Janeiro.

Nechad, B., Ruddick, K.G. & Park, Y. 2010, ‘Calibration and validation of a generic multisensor algorithm for mapping of total suspended matter in turbid waters’, *Remote Sensing of Environment*, vol. 114, no. 4, pp. 854-66.

Nukapothula, S., Chen, C. & Yunus, A.P. 2022, ‘Seasonal sediment plumes in the Krishna-Godavari basin using satellite observations’, *Deep Sea Research Part I: Oceanographic Research Papers*, vol. 188, 103850.

Palhares, P.R. 2021, ‘Panorama Da Apa Guandu: Reflexões Acerca Do Ecoturismo E Alternativas À Preservação Dos Recursos Hídricos-RMRJ’, *XIV Encontro Nacional de Pós Graduação e Pesquisa em Geografia*, Brazill, viewed 8 august 2023. <https://editorarealize.com.br/editora/anais/enanpege/2021/TRABALHO_COMPLETO_EV154_MD1_SA161_ID225430092021164133.pdf>.

Rocha, D.S., Cunha, B.C., Geraldes, M.C., Pereira, S.D. & Almeida, A.C. 2010, 'Metais pesados em sedimentos da baía de Sepetiba, RJ: implicações sobre fontes e dinâmica da distribuição pelas correntes de maré', *Geochimica Brasiliensis*, vol. 24, no. 1, 63.

Rodrigues, R.P., Knoppers, B.A., Souza, W.F.L.D. & Santos, E.S. 2009, 'Suspended matter and nutrient gradients of a small-scale river plume in Sepetiba Bay, SE-Brazil', *Brazilian Archives of Biology and Technology*, vol. 52, pp. 503-12.

Silva Andrade, L.N.P., Santos Leandro, G.R. & Souza, C.A. 2013, 'Geoformas deposicionais e sedimentos de fundo na foz da baía Salobra confluência com o rio Paraguai Pantanal de Cáceres-Mato Grosso', *Revista Brasileira de Geografia Física*, vol. 6, no. 2, pp. 253-70.

Silva Filho, L.C.R. & Magrini, A. 2017, 'Desenvolvimento econômico-industrial e o impacto sobre a zona costeira: o caso Baía de Sepetiba, Rio de Janeiro/Brasil', *Revista Augustus*, vol. 21, no. 42, pp. 93-105.

Silva, L.C., Martins, M.V.A., Castelo, W.F.L., Saibro, M.B., Rangel, D., Pereira, E., Bergamaschi, S., Mello e Sousa, S.H., Varela, J., Laut, L., Frontalini, F., Chaves, H., Reis, A.T., Aguilera, O., Zaaboub, N., Cheriyan, E. & Geraldes, M.C. 2022, 'Trace metals enrichment and potential ecological risk in sediments of the Sepetiba Bay (Rio de Janeiro, SE Brazil)', *Marine Pollution Bulletin*, vol. 177, 113485.

Teng, W., Guoxiang, W. & Qiang, L. 2007, 'Effects of water turbidity on the photosynthetic characteristics of Myriophyllum spicatum L', *Asian Journal of Plant Sciences*, vol. 6, no. 5, pp. 773-80.

Tonhá, M.S., Araújo, D.F., Araújo, R., Cunha, B.C., Machado, W., Portela, J.F., Souza, J.P.R., Carvalho, H.K., Dantas, E.L., Roig, H.L., Seyler, P. & Garnier, J. 2021, 'Trace metal dynamics in an industrialized Brazilian river: A combined application of Zn isotopes, geochemical partitioning, and multivariate statistics', *Journal of Environmental Sciences*, vol. 101, pp. 313-25.

Turner, J.S., Friedrichs, C.T. & Friedrichs, M.A. 2021, 'Long-Term Trends in Chesapeake Bay Remote Sensing Reflectance: Implications for Water Clarity', *Journal of Geophysical Research: Oceans*, vol. 126, no. 12, e2021JC017959.

Veeck, L., Silva-Filho, E.V., Wasserman, J.C., Sella, S.M., Santos, I.R. & Lacerda, L.D.D. 2007, 'Mercury distribution in sediments of a sub-tropical coastal lagoon, Sepetiba Bay, SE Brazil', *Geochimica Brasiliensis*, vol. 21, no. 1.

Vermote, E. & Wolfe, R. 2021, *MODIS/Terra Surface Reflectance Daily L2G Global 250m SIN Grid V061*, viewed 10 october 2023, <https://doi.org/10.5067/MODIS/MOD09GQ.061>.

Villena, H.H., Pereira, S.D., Chaves, H.A., Dias, M.S. & Guerra, J.V. 2012, 'Indícios da variação do nível do mar na Baía de Sepetiba', in M.A.C. Rodrigues, S.D. Pereira & S.B. Santos (eds) *Baía de Sepetiba: Estado da Arte*, Editora Corbã, Rio de Janeiro.

Watson, D.F. & Philip, G.M. 1984, 'Triangle based interpolation', *Journal of the International Association for Mathematical Geology*, vol. 16, pp. 779-95.

Yunus, A.P., Masago, Y., Boulange, J. & Hijioka, Y. 2022, 'Natural and anthropogenic forces on suspended sediment dynamics in Asian estuaries', *Science of The Total Environment*, vol. 836, 155569.

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Caio Eduardo Barbosa dos Santos Ferreira: conceptualization; data curation; formal analysis; investigation; methodology; writing-original draft. **Lino Augusto Sander de Carvalho:** conceptualization; formal analysis; investigation; methodology; supervision; writing-original draft; writing-review and editing. **Beatriz Nunes Ramalho da Rocha:** precipitation methodology; analysis; writing-review and editing. **Wilson Thadeu Valle Machado:** conceptualization; writing-review and editing. **Vincent Vantrepotte:** writing-review and editing.

Conflict of interest

The authors declare no potential conflict of interest.

Data availability statement

All data presented are freely available in the literature and cited in references. Reference datasets can be downloaded from:

https://developers.google.com/earth-engine/datasets/catalog/MODIS_061_MOD09GQ

https://developers.google.com/earth-engine/datasets/catalog/ECMWF_ERA5_DAILY

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