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SEASONAL VARIATION OF PHYSICAL AND CHEMICAL CONDITIONS IN THE GOIANA AND MEGAÓ ESTUARY, NORTHEASTERN BRAZIL

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ABSTRACT: Estuaries are coastal ecosystems of transition between continental and marine waters, among their characteristics, there is the salinity variation due to tidal cycles, being necessary environmental monitoring actions for the identification of possible anthropic influences. The aim was to characterize seasonally the physical and chemical variables of water in the estuary of the rivers Goiana and Megaó. The study area comprises the estuary of the Goiana and Megaó rivers, located in the Northeast of Brazil, and is a protected area of sustainable use for the development of artisanal fisheries. A total of 20 points along the estuary were sampled during the months of May, July, September and November 2021, January and March 2022, collecting temperature (°C), pH, salinity, dissolved oxygen (mg/L) and transparency (cm). Temperature, salinity and transparency varied significantly between the dry and rainy seasons. The dissolved oxygen registered was lower than that described in the Brazilian legislation, causing a state of hypoxia in the estuary. Mitigation measures are needed to improve the quality of the estuarine water, ensuring the maintenance of local biodiversity.

Keywords: Coastal Ecosystem; Tropical Estuary; Conservation; Water Quality.

RESUMO: *Os estuários são ecossistemas costeiros de transição entre águas continentais e marinhas, entre suas características, há a variação de salinidade devido aos ciclos das marés, sendo necessárias ações de monitoramento ambiental para a identificação de possíveis influências antrópicas. O objetivo foi caracterizar sazonalmente as variáveis físicas e químicas da água no estuário dos rios Goiana e Megaó. A área de estudo compreende o estuário dos rios Goiana e Megaó, localizado no Nordeste do Brasil, e é uma área protegida de uso sustentável para o desenvolvimento da pesca artesanal. Um total de 20 pontos ao longo do estuário foram amostrados durante os meses de maio, julho, setembro e novembro de 2021, janeiro e março de 2022, coletando temperatura (°C), pH, salinidade, oxigênio dissolvido (mg/L) e transparência (cm). Temperatura, salinidade e transparência variaram significativamente entre as estações seca e chuvosa. O oxigênio dissolvido registrado foi inferior ao descrito na legislação brasileira, causando um estado de hipóxia no estuário. Medidas de mitigação são necessárias para melhorar a qualidade da água estuarina, garantindo a manutenção da biodiversidade local.*

Palavras-chave: *Ecossistema Costeiro; Estuário Tropical; Conservação; Qualidade da Água.*

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1. INTRODUCTION

Estuaries represent transitional ecosystems situated between rivers and marine environments, exhibiting characteristics resulting from the mingling of continental and oceanic waters, this interaction yields a salinity gradient ranging typically from 0.5 to 34, contingent upon local factors such as river discharge, tidal amplitude, and evaporation rates (Hansen & Rattray, 1966; Mclusky & Elliott, 2004; Guha & Lawrence, 2013). The pronounced mixing of these water masses engenders significant variability in the physical and chemical attributes of the waters, encompassing temperature, dissolved oxygen, turbidity, organic compounds, and nutrients levels, thereby fostering a highly productive milieu (Kennish, 1986a).

The trophic structure of estuarine biota is intricately linked to the physical and chemical milieu, with seasonal fluctuations exerting a profound influence on estuarine food webs (Possamai *et al*. 2021). Human-induced alterations in estuarine and adjacent ecosystems can further perturb the physical and chemical parameters of estuarine water, potentially leading to diminished biodiversity (Kennish, 2002).

Estuarine ecosystems boast a rich biodiversity comprising planktonic, benthic, and nektonic species, each adapted to endure fluctuations in and other physical and chemical parameters (Whitfield *et al*. 2012; Lana & Bernardino, 2018; Kennish, 1986b). This biodiversity is integral to artisanal fisheries, serving as a cornerstone for subsistence and economic development in numerous regions globally (Pinto *et al*. 2014). Thereby underscoring the socio-biodiversity nexus within estuarine ecosystem (Cidreira-Neto & Rodrigues, 2021; Watson *et al*. 2021).

Anthropogenic impacts on estuaries can precipitate degraded water quality, characterized by phenomena such as acidification, reduced light penetration, and eutrophication, all of which can disrupt estuarine dynamics and imperil fishery resources (Freeman *et al*. 2019). Furthermore, anthropogenic activities can alter sediment profile, crucial for benthic habitat persistence, and facilitate the accumulation of contaminants (Eidan *et al*. 2020; Quintana *et al*. 2020). Hence, there is an imperative to develop robust water quality monitoring strategies to inform environmental management endeavors aimed at mitigating anthropogenic stressors (Karydis & Kitsiou, 2013).

The study hypothesizes seasonal variations in water variables across different reaches of the estuary. Accordingly, the present investigation aims to delineate the seasonal fluctuations in physical and chemical water parameters within the estuary of Goiana and Megaó rivers estuaries.

2. METHODOLOGICAL PROCEDURES

2.1 Study area

The research was conducted within the estuarine region of the Goiana and Megaó rivers, situated within the Acaú-Goiana Extractive Reserve, designated as a Marine Protected Area (AMP) located between the states Pernambuco and Paraíba in the Northeastern of Brazil (Figure 1). This reserve, owing to its extractive nature, encompasses six communities engaged in artisanal fishing within the estuarine environment, targeting various fishery resources including fish, crustaceans, and mollusks (Cidreira-Neto & Rodrigues, 2021). The conservation efforts directed towards the estuarine ecosystem, along with its associated biodiversity, play a pivotal role in ensuring the economic sustenance of numerous artisanal fishing families within the region.

The estuary is encircled by industrial activities spanning various sectors including sugar and ethanol production, automotive manufacturing, and pharmaceutical industries. Additionally. its proximity to urban centers, exemplified by the municipality of Goiana in Pernambuco, further exacerbates anthropogenic pressures on the ecosystem. The utilization of estuarine waters by industrial entities and discharge of effluents have led to documented occurrences of hypoxia and eutrophication within the area (Costa *et al*. 2017; Costa *et al*. 2018; Cidreira-Neto *et al*. 2022), as well as the presence of Polycyclic Aromatic Hydrocarbons (PAH) (Arruda-Santos *et al*. 2018) and substantial quantities of microplastics (Lima *et al*. 2014; Lima *et al*. 2015).

The land use and occupation patterns in the vicinity of the reserve encompass a spectrum of industrial and urban activities (Figure 2), directly impacting the water quality within the estuary of the Goiana and Megaó rivers. These activities either directly os indirectly consume estuarine water resource or modify the surrounding vegetation. The depth of the primary channel of the Goiana River varies from 1.0 to 11.6 m (Costa *et al*. 2018).

Based on the rainfall data provided by the Pernambuco's Water and Climate Agency (*Agência Pernambucana de Águas e Clima - APAC*), a historical analysis spanning the past twelve years reveals the distinct delineation of two seasons at the site, the rainy season, encompassing the months from March to August, and the dry season, spanning from September to February (Figure 3). This characterization is based on data collected from rainfall station 28 situated within the municipality of Goiana.

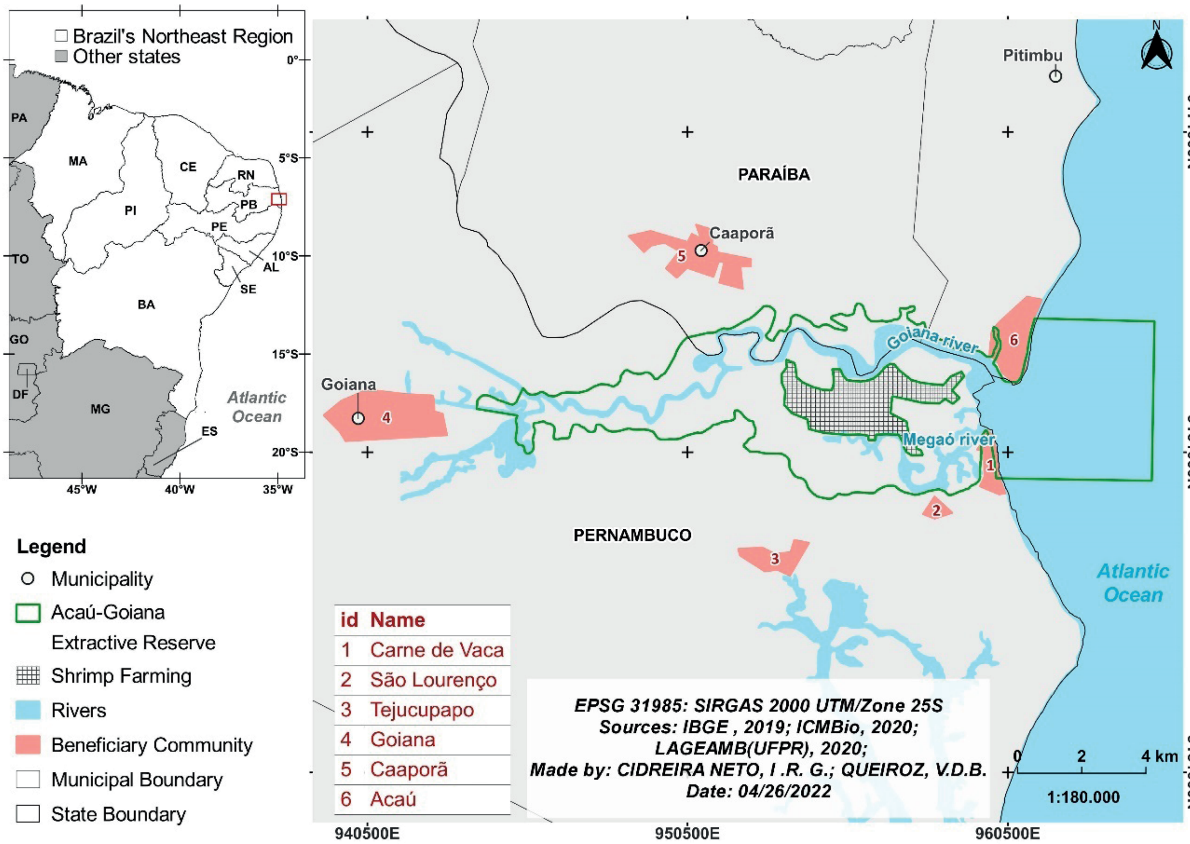

Figure 1. Location of the Goiana and Megaó estuary, which is part of the Conservation Unit of the Acaú-Goiana Extractive Reserve, in Northeastern Brazil, between the states of Pernambuco and Paraíba. Source: Authors own research (2022).

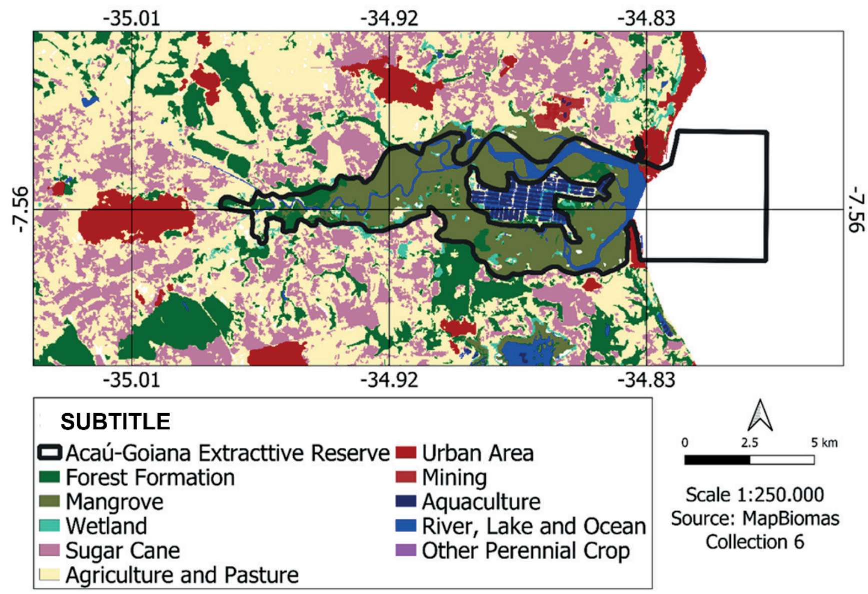

Figure 2. Land use and land cover in the Acaú-Goiana Extractive Reserve, and adjacent areas, for the year 2020. Source: Authors own research (2022).

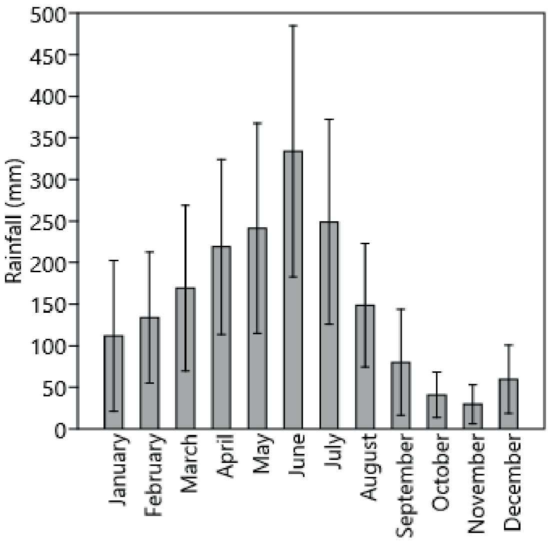

Figure 3. Rainfall regime for the municipality of Goiana (Pernambuco), using a twelve-year historical series (2010 - 2021). Source: Authors own research (2022).

2.2 Methods and techniques

Sampling expeditions were conducted within the estuarine zones of the Goiana and Megaó rivers during low tide periods in May, July, September and November 2021, as well as in January and March 2022. A comprehensive sampling scheme was implemented, covering a total of 20 designated points distributed across the estuary (Figure 4), with the locations delineated in collaboration with local artisanal fishermen and fisherwomen.

To enhance the comprehension of the dataset, the sampling points have been categorized into four compartments, as in table 1 below:

Table 1. Estuary compartments of the rivers Goiana and Megaó from the collection points.

Compartments	Collection Points
C1	P1, P2, P3, P4, P5, P6, P7 e P8
C2	P9, P10, P11 e P12
C3	P13, P14, P15 e P16
C4	P17, P18, P19 e P20

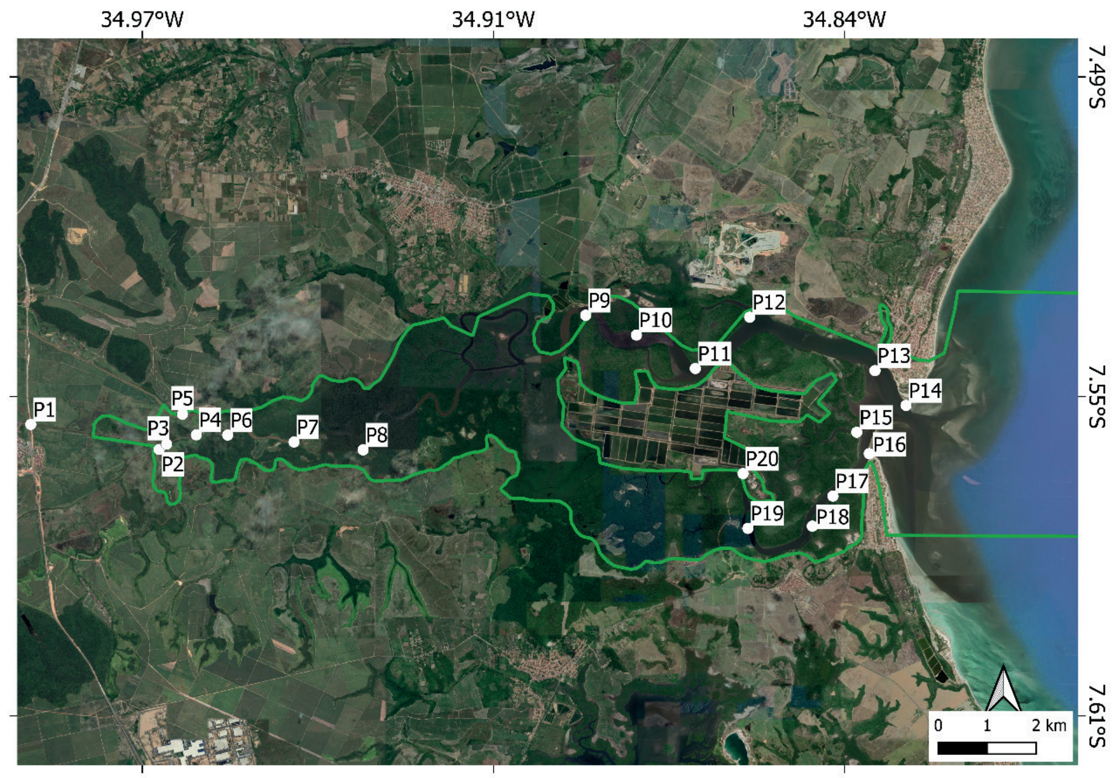

Figure 4. Location of the twenty sampling points in the estuary of the rivers Goiana and Megaó. Source: Authors own research (2022).

The following variables were measured during the sampling campaigns: (i) Temperature (ºC); (ii) pH; (iii) Salinity; (iv) Dissolved Oxygen (mg/L), using a multiparameter probe (Akso AK88), inserted into the surface layer of water (between 5 and 10 centimeters deep), and (v) Transparency (cm), from the Secchi disk. Additionally, cumulative rainfall data from the preceding ten days prior to each field collection were obtained from APAC records. This information was gathered to investigate the potential influence of rainfall events on the measured water variables.

2.3 Data Analysis

The means of the variables measured at each sampled point were plotted on graphs, with their respective standard deviation, enabling the visualization of the variations within each sample unit. To assess whether there was significant difference in the variables between the rainy season (May and July 2021; March 2022) and the dry season (September and November 2021; January 2022), the t-student test was employed.

ANOVA statistical test were conducted to examine variance among sampling points, between months, and across compartments.

In terms of multivariate statistics, Principal Component Analysis (ACP) was utilized to discern which variables exhibited the most pronounced response to estuary conditions, while cluster analysis (similarity) was employed to elucidate the proximity between collection points and compartments. All statistical analyses were performed using the PAST software (version 4.03).

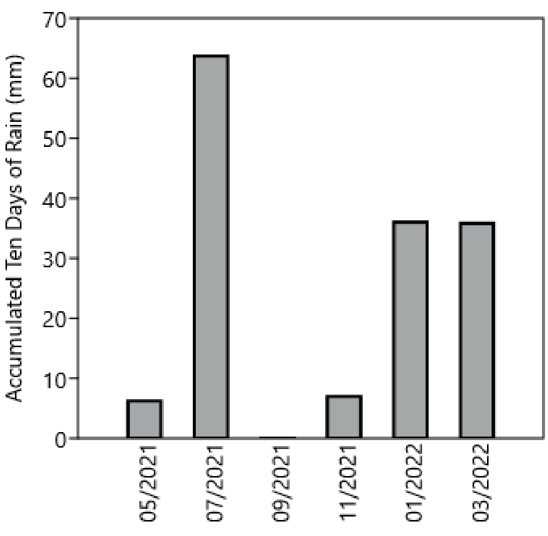

Figure 5. Accumulated rainfall during the ten days prior to the sampling (Station 28 - Goiana - Itapirema). Source: Authors own research (2022).

3. RESULTS

The cumulative rainfall over the preceding ten days (Figure 5) exhibited its peak concentration in July 2021, registering 63.7 mm, succeeded by January and March 2022, with 36 mm and 35.8 mm, respectively. Notably, no rainfall was recorded at the site in September.

The average temperature within the estuary exhibited a mean of 29.4°C (±2.41), ranging from 23.4°C (P1) in July 2021, to 39.7°C (P14) in November 2021 (Figure 6A). The pH displayed an overall mean of 7.53 (±0.47) across the estuarine environment, with a recorded minimum value of 6.67 (P6) in March 2022, and a maximum of 8.97 (P14) in September 2021 (Figure 6B).

Salinity demonstrated a mean 14.85 (±13.34) within the estuary, with a low of 0.14 (P5) in July 2021, indicative of brackish water, and a high of 39 (P14) in November, representing oceanic conditions ($p < 0.05$ / $f = 36.38$) (Figure 6C). Dissolved Oxygen exhibited an average fluctuation of 3.24 mg/L (±1.52), reaching a minimum of 0.5 mg/L (P1) in May 2021 and a maximum value of 10.3 mg/L (P14) in January 2022 (Figure 6D).

Average transparency measured at 30.75 cm (±13.29), with a minimum of 10 cm (P2, P3, P4, P5, P6, P7, P8, P11, P12 and P19) observed in May (2021), January and March (2022). The highest maximum transparency recorded was 80 cm (P14) for January 2022 (Figure 6E).

In terms of seasonality, notable variations were observed between the rainy and dry seasons concerning temperature, salinity, and transparency levels, attributable to their correlation with rainfall patterns a consequently, river flow (Table 2).

Dissolved oxygen and salinity exhibited significant variability across all tests, encompassing differences between sites, compartments, and months. Transparency demonstrated variation among sampling points and compartments, albeit without notable distinctions across months (Table 3).

Cluster analysis based on similarity yielded two primaries' groups: Group A, further subdivided into A1, primarily comprising the rainy seasons of C2. C2 and C4, and A2, containing the rainy season of C3 and C4. The second group, Group B, encompasses both the dry and rainy season of C1 (Figure 7).

In the multivariate PCA analysis, the two principal components (PC) collectively accounted for 66.92% of the sample variance (PC1 = 42.55% and PC = 24.37 (Figure 8).

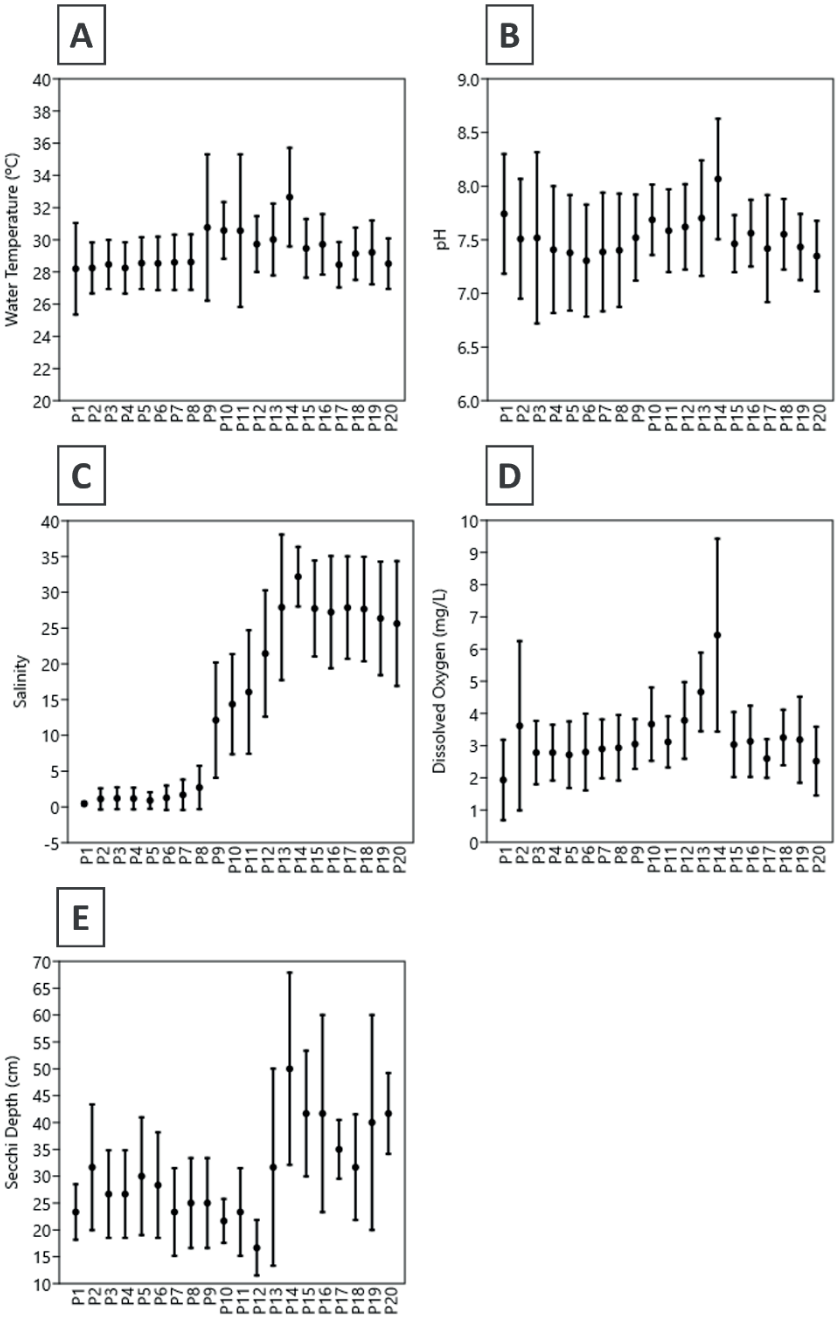

Figure 6. Physical and chemical parameters of water in the estuary of the rivers Goiana and Megaó, Northeast Brazil. A. Average variation of water temperature (ºC). B. Average variation of pH. C. Average variation in salinity. D. Average variation in Dissolved Oxygen (mg/L). E. Average variation in transparency (cm). Source: Authors own research (2022).

Table 2. Seasonal variation of the mean and standard deviation, from the compartments of the Goiana and Megaó rivers estuary, containing the t-test p-value (* < 0.05), NS = non-significant.

Variables	Seasonality	C1	C2	C3	C4
Temperature	Rainy	27.7±1.9	28.9±1.9	29.2±2.2	28±1.7
	Dry	29.2±0.9	31.9±3.7	31.7±2.2	29.6±1
	t	*	*	*	*
pH	Rainy	7.4±0.5	7.6±0.2	7.5±0.4	7.3±0.2
	Dry	7.5±0.6	7.6±0.5	7.8±0.5	7.5±0.5
	t	NS	NS	NS	NS
Salinity	Rainy	0.3±0.1	10.7±7.4	23.6±6.7	21.4±6.2
	Dry	2.4±1.9	21.2±5.7	33.9±3	32.3±3.1
	t	*	*	*	*
Dissolved Oxygen	Rainy	1.9±0.6	3.1±1	3.7±1.9	2.6±0.9
	Dry	3.7±1.2	3.7±0.9	4.9±2.4	3.1±1
	t	*	NS	NS	NS
Transparency	Rainy	30.4±5.5	18.4±5.8	30±9.5	29.2±9
	Dry	23.4±10	25±6.7	52.5±15.4	45±9
	t	*	*	*	*

Table 3. ANOVA summary of the variables among the points, compartment, and months. p-value (* < 0.05), NS = non-significant.

Variables	Variance Analysis		
	Between the Points	Between the Compartments	Between months
	(GL = 19)	(GL = 3)	(GL = 5)
Temperature	NS	*	*
pH	NS	NS	*
Salinity	*	*	*
Dissolved Oxygen	*	*	*
Transparency	*	*	NS

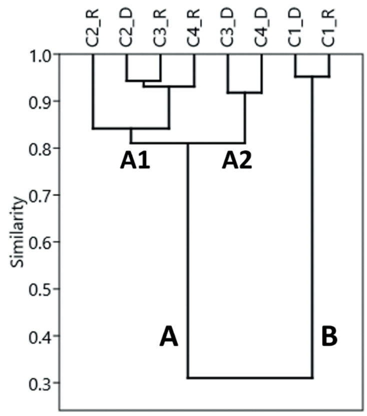

Figure 7. Cluster analysis by similarity among the sampling points in the estuary of Goiana and Megaó rivers. Source: Authors (2022).

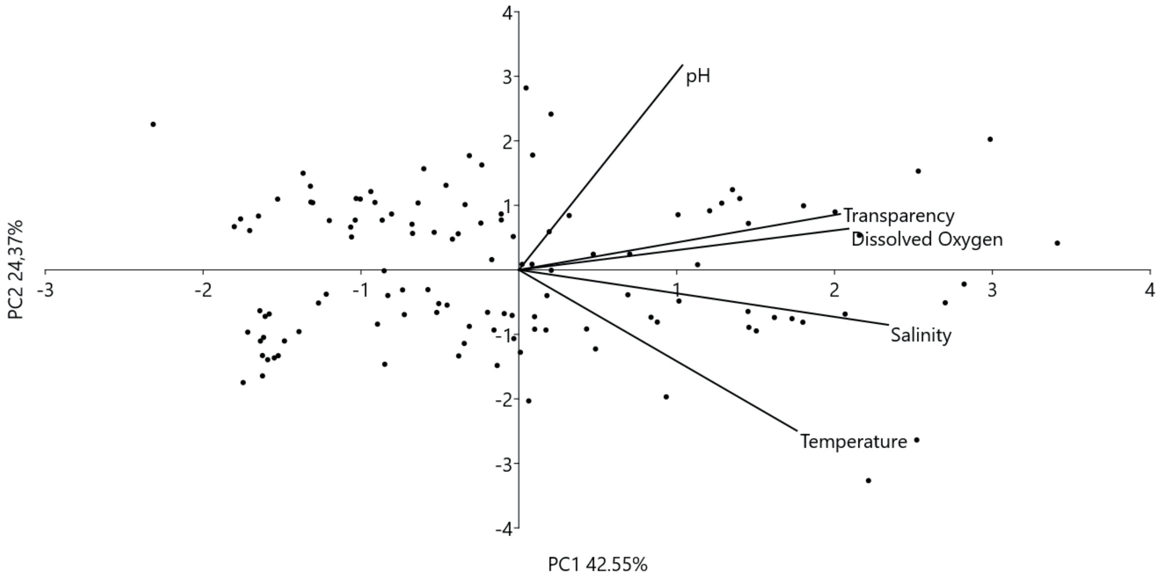

Figure 8. Principal Component Analysis (ACP) with the water variables of the sampling points in the estuary of Goiana and Megaó rivers. Source: Authors own research (2022).

In PC1, temperature, salinity, dissolved oxygen, and transparency emerged as the primary components defining the sampling, whereas in PC2, temperature and pH were identified as the most influential variables (Table 4).

Table 4. Principal Component Analysis (ACP) emphasizing its correlations of PC1 and PC2.

Variables	PC1	PC2
Temperature	**0.41335**	**-0.58499**
pH	0.24324	**0.74438**
Salinity	**0.54906**	-0.19988
Dissolved Oxygen	**0.49019**	-0.14979
Transparency	**0.47772**	-0.20319

4. DISCUSSION

Precipitation constitutes a critical variable in the examination and monitoring of ecosystem dynamics. Continuous data are imperative due to precipitation's influences on various water quality parameters, including augmentation of river flow, reduction of salinity and temperature, and increase in domestic effluent discharge (Ferguson *et al*. 1996; Coulliette & Noble, 2008; Powers *et al*. 2021). These alterations carry repercussions for ecosystem maintenance.

In the northeastern Brazil, seasons are determined by alternating dry and rainy periods depending on the year. The months with the heaviest rainfall are concentrated between March and August, while the driest months span from September and February. However, monthly variations are observable on larger scale. July exhibited the highest accumulated average precipitation, followed by January and March. Consequently, the elevated rainfall values observed in the ten days prior to collection in January (considered as dry season), may have influenced the variables.

Temperature is closely linked to rainfall; increased precipitation leads to a reduction in water temperature and a decrease in salinity (Monteiro *et al*. 2016; Costa *et al*. 2018), serving as an indication for climate change (Scanes *et al*. 2020). The sampled points exhibited temperature variations exceeding 10 °C between different sites and collection months, which can impact the dynamics of local biodiversity, especially in organisms that are not eurythermal.

The National Council for the Environment (*Conselho Nacional de Meio Ambiente* - CONAMA), a regulatory body affiliated with the Ministry of the Environment (*Ministério do Meio Ambiente* - MMA) in Brazil, establishes physical and chemical water parameters to assess environmental water quality (Resolution No. 357 of 2005). For the comparative purposes, the parameters outlined for Class 1 brackish waters, which pertain to estuarine ecosystems supporting biodiversity protection, aquaculture, recreation, and water supply and irrigation, will be utilized.

Although exhibiting minor variations, estuarine pH remained circumneutral and within the range proposed by CONAMA 357 for 2005 (from 6.5 to 8.5). September registered highest pH values, reaching 8.97, possibly associated which the onset of sugar cane burning/cutting. Industrial sector land use and occupation, resulting in effluent discharge into the estuary, can influence pH reduction, leading to estuarine acidification (Nershey *et al*. 2020).

Salinity measurements revealed of the Goiana River into three sections: the upper stretch (P1 to P8) with low salinity, the middle stretch (P9 to P12) with intermediate salinity, and the Megaó River and beach areas (P13 to P20) with higher salinity. This variation, primarily due to spatial distance from the downstream, aids in compartmentalizing the estuary, enabling targeted actions for each location as proposed by Costa *et al*. (2018). Points from P1 to P12 receive a greater influx of river water and urban/industrial waste, resulting in lower salinity compared to other compartments. Compartment C3 (P13 to P16) receives a higher load of ocean water, while compartment C4 (P17 to P20) is primarily connected to the oceanic region rather than a larger river system.

Regarding the months of sampling, November exhibited the highest overall average salinity, coinciding with lower accumulated rainfall in the preceding ten days. Most estuarine organisms are euryhaline, capable of tolerating salinity variations (Telesh *et al*. 2013), which in this estuary ranged from nearly zero to nearly 40 (forty).

Transparency, measured by the disappearance of the secchi disk, still presents uncertainties due to low accuracy and interference from factors affecting disk reflection in water, but this is still one of the main methods used to verify the turbidity of the water (Bowers *et al*. 2020). In this study, transparency correlated with salinity sites influenced more by tides, as they are located downstream in the estuary. Transparency and dissolved oxygen levels appear correlated in the PCA, with areas of greater transparency exhibiting higher dissolved oxygen percentages due to greater phytoplankton primary production in estuarine surface waters (Fatema *et al*. 2015; Li *et al*. 2020). CONAMA specifies a dissolved oxygen range not to fall below 4mg/L.

Hypoxia warrants consideration in management plans due to its influence on water quality and local biodiversity maintenance. Comparing with the results, the estuary exhibited an oxygen deficit likely resulting from anthropogenic modifications such as discharge of domestic, industrial, and agricultural effluents (e.g. Costa *et al*. 2018). Land use and occupation, particularly by nearby industries, influence fertilizer runoff concentration in the estuary, modifying water quality (Barletta *et al*. 2019).

Cluster analysis revealed compartment 1 distinct separation, primarily due to the greater influence of Goiana river basin waters. The other cluster demonstrated division based on seasonality (dry/rainy), indicating the significant influence of rainfall regime on water variables in compartments 2, 3 and 4. All compartments are susceptible to impacts from adjacent human activities, such as unregulated of urban and industrial waste and sugar cane burning.

5. CONCLUSIONS

The estuary of Goiana and Megaó rivers is experiencing hypoxia, posing a threat to the preservation of local biodiversity. Investigation into anthropogenic and/or natural factors influencing this outcome is imperative. Given the status of the area as a conservation unit aimed at safeguarding artisanal fishing activities, this situation is particularly concerning, considering the economic importance significance of biodiversity to the communities dependent on it.

Environmental licensing mandates monitoring of water quality and effluent parameters, yet these conditions are not being met. The utilization of water for biodiversity protection within the protected area and for traditional fishing is jeopardized, disregarding legal priorities. Consequently, it's crucial for the environmental agency to enhance its monitoring and control capabilities to address the environmental impacts in accordance with CONAMA Resolutions 357 and 430, Law 9985 (SNUC), and the Unit Management Plan.

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