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Editorial note / *Nota editorial*

COMPREHENSIVE APPROACHES TO CLIMATE ADAPTATION AND COASTAL MANAGEMENT: INSIGHTS FROM THE BRAZILIAN COAST AND A SOUTHEAST ASIAN PORT

F. Taveira-Pinto[@ 1, 2], A. R. Carrasco[2], P. Rosa-Santos[1, 3], A. M. Bento[1, 2], T. Fazeres-Ferradosa[1, 2]

Urban coastal areas are highly vulnerable to climate change due to their proximity to the sea and dense infrastructure, making resilience-building essential as threats such as sea-level rise, pollution, and intensified storms worsen. Environmental and climate planning are crucial for adapting these regions to potential climate-related disasters. The research presented in this issue provides practical evaluations of planning and monitoring in coastal regions, offering valuable insights for enhancing local management.

Environmental planning combines data from the natural environment with socio-economic information to preserve the integrity of both natural and human-made elements. In this issue, the work of Bonilha *et al*. (2024) presents a geoenvironmental zoning of the municipality of Rio Grande, which establishes guidelines for sustainable land use by balancing the physical characteristics of the environment with socio-economic needs. This zoning not only provides historical, environmental, and legislative knowledge, but also evaluates the land's usability in light of changes in landscape structure and function (Bonilha *et al*., 2024).

An essential part of climate planning is monitoring how coastal environments change over time, which informs the development of climate-resilient strategies. In this issue, Neto *et al*. (2024) conducted a seasonal monitoring study of physical and chemical water variables in the estuary of the Goiana and Megaó rivers, a protected area for artisanal fisheries. The authors identified seasonal variations in temperature, salinity, and transparency between the dry and rainy seasons, revealing that the estuary is experiencing hypoxia, which threatens local biodiversity. The area's status as a conservation unit for artisanal fishing is particularly important due to the economic reliance of local communities on biodiversity (Neto *et al*., 2024). Also, building on insights gained from monitoring data, the study by Coelho *et al*. (2024) provides a comprehensive understanding of how changes in tide nodal modulation affect tidal constituents and regimes worldwide. These results are crucial for precisely quantifying the impacts of climate change on tidal patterns (Coelho *et al*., 2024).

The study by Prabawardani *et al*. (2024), examines the climate resilience of Tanjung Emas Port in Semarang, Indonesia, which faces threats from land subsidence and rising sea levels. Through qualitative analysis, the authors evaluated the port's preparedness strategies and responses to climate change, aiming to provide insights for port managers and decision-makers in developing effective adaptation measures. The study enhances the understanding of climate resilience in ports and offers practical recommendations for more robust climate adaptation strategies and policies (Prabawardani *et al*., 2024).

Lastly, and at the governance level, the article by Araújo *et al*. (2024) evaluates national climate adaptation documents from

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countries bordering the Atlantic Ocean, including those in Europe, South America, Central America, Africa, and North America. The focus is on government documents related to climate adaptation management and planning, such as national adaptation plans, strategies, climate risk assessments, vulnerability assessments, and adaptation reports. To enhance climate change and disaster preparedness and response, the study suggests incorporating new indicators and contextual variables to better assess the quality of these planning documents (Araújo *et al.*, 2024).

ABORDAGENS ABRANGENTES À ADAPTAÇÃO CLIMÁTICA E GESTÃO COSTEIRA: PERSPETIVAS DA COSTA BRASILEIRA E DE UM PORTO NO SUDESTE ASIÁTICO

As zonas costeiras urbanas são altamente vulneráveis às alterações climáticas devido à sua proximidade ao mar e à densa ocupação. Fortalecer a resiliência dessas áreas é essencial, especialmente com o agravamento de ameaças como a subida do nível médio do mar, a poluição e a intensificação das tempestades. O planeamento ambiental e climático é crucial para adaptar estas regiões a potenciais desastres relacionados com o clima. A investigação apresentada nesta edição oferece avaliações práticas do planeamento e monitorização em regiões costeiras, proporcionando valiosas perspetivas para melhorar a gestão local.

O planeamento ambiental combina dados do meio natural com informações socioeconómicas para preservar a integridade tanto dos elementos naturais como dos construídos pelo homem. Neste número, o trabalho de Bonilha et al. (2024) apresenta uma zonação geoambiental para o município do Rio Grande, que estabelece diretrizes para o uso sustentável do solo, equilibrando as características físicas do ambiente com as necessidades socioeconómicas. Esta zonação não apenas fornece conhecimentos históricos, ambientais e legislativos, mas também avalia a utilidade do terreno face a mudanças na estrutura e função da paisagem (Bonilha et al., 2024).

Uma parte essencial do planeamento climático é a monitorização da mudança dos ambientes costeiros ao longo do tempo, suportando o desenvolvimento de estratégias resilientes ao clima. Neste número, Neto et al. (2024) realizaram um estudo de monitorização sazonal de variáveis físicas e químicas da água no estuário dos rios Goiana e Megaó, uma área protegida para a pesca artesanal. Os autores identificaram variações sazonais na temperatura, salinidade e transparência entre as estações seca e chuvosa, revelando que o estuário está a experienciar hipoxia, o que ameaça a biodiversidade local. O estatuto legal da área como unidade de conservação para a pesca artesanal é particularmente relevante devido à dependência económica das comunidades locais em relação à biodiversidade (Neto et al., 2024). Além disso, baseando-se nas perceções obtidas a partir dos dados de monitorização, o estudo de Coelho et al. (2024) fornece uma compreensão abrangente de como as alterações na modulação nodal das marés afetam os constituintes e regimes de maré a nível mundial. Estes resultados são cruciais para quantificar, de forma específica, os impactos das mudanças climáticas nos padrões de maré (Coelho et al., 2024).

O estudo de Prabawardani et al. (2024) examina a resiliência climática do Porto de Tanjung Emas em Semarang, Indonésia, que enfrenta ameaças devido à subsidência terrestre e à subida do nível do médio do mar. Através de uma análise qualitativa, os autores avaliaram as estratégias de preparação do porto e as respostas às mudanças climáticas, com o objetivo de fornecer aprendizagens para os gestores portuários e decisores locais envolvidos na elaboração de medidas de adaptação eficazes. O estudo aprimora a compreensão da resiliência climática nos portos e oferece recomendações práticas para estratégias e políticas mais robustas de adaptação climática (Prabawardani et al., 2024).

Por último, no âmbito da governança, o artigo de Araújo et al. (2024) avalia documentos nacionais de adaptação climática de países fronteira com Oceano Atlântico, incluindo países da Europa, América do Sul, América Central, África e América do Norte. O foco da análise reside em documentos do governo relacionados com a gestão e planeamento da adaptação climática, como planos nacionais de adaptação, estratégias, avaliações de risco climático, avaliações de vulnerabilidade e relatórios de adaptação. Para melhorar a preparação e a resposta a desastres relacionados com as mudanças climáticas, o estudo sugere a incorporação de novos indicadores e variáveis contextuais para uma melhor avaliação da qualidade destes documentos de planeamento (Araújo et al., 2024).

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ASSESSMENT OF CLIMATE ADAPTATION DOCUMENTS IN ATLANTIC COUNTRIES FOR THE MANAGEMENT OF COASTAL AND EXTREME CLIMATE RISKS

Luiggia Girardi Bastos Reis de Araujo[@ 1], Cesar Augusto Marques da Silva[2]

ABSTRACT: Populations in coastal zones are more susceptible to risks caused by extreme climate events. Therefore, climate planning is becoming an important tool to adapt these areas to the consequences of climate disasters. This article proposes an assessment of coastal risks and climate adaptation instruments developed by thirty countries in the Atlantic Area region. Climate adaptation strategies, plans and related documents were analyzed in order to understand whether the national planning framework can lead to an efficient management of extreme climate events. The contents of the documents were evaluated by thirty-two indicators within the awareness, analysis, and actions dimensions. Correlation and regression analyses were conducted to verify the influence of independent variables on their content. Results indicate that the documents resulted in medium overall quality to manage the risks of extreme events. Most indicators presented a good performance with a medium to high grade of breadth and depth scores. Based on Cronbach's alpha, this study reliability reached a high level. The regression analysis demonstrated that 20% of variance in content of documents could be explained by independent variables, suggesting a weak relationship. In order to improve the climate change and disaster preparedness and response managements, we recommend an inclusion of new indicators and contextual variables to investigate the quality of planning documents.

Keywords: Climate change; Adaptation; Disaster Risk Management; Public policy; Planning.

Resumo: *As populações das zonas costeiras são mais suscetíveis aos riscos causados por eventos climáticos extremos. Nesse sentido, o planejamento climático vem a ser uma ferramenta importante para adaptar essas áreas às consequências dos desastres climáticos. Este artigo propõe uma avaliação dos riscos costeiros e dos instrumentos de adaptação climática desenvolvidos por trinta países banhados pelo Oceano Atlântico. Estratégias, planos e outros documentos relacionados à adaptação climática foram avaliados a fim de compreender como a estrutura de planejamento nacional pode levar a uma gestão eficiente de eventos climáticos extremos. O conteúdo dos documentos foi avaliado por trinta e dois indicadores dentro das dimensões de conhecimento, análise e ações. Foram realizadas análises de correlação e regressão para verificar a influência das variáveis independentes em seu conteúdo. Os resultados indicam que a qualidade geral dos documentos foi média com relação ao gerenciamento dos riscos de eventos extremos. A maioria dos indicadores apresentou um bom desempenho apresentando média a alta pontuação na profundidade e amplitude. A análise de regressão demonstrou que 20% da variação no conteúdo dos documentos poderia ser explicada pelas variáveis independentes, sugerindo uma relação fraca. Para melhorar a gestão das mudanças climáticas e da preparação e resposta a desastres, é recomendável a inclusão de novos indicadores e variáveis independentes para investigar a qualidade dos documentos de planejamento.*

Palavras-chave: *Mudanças Climáticas; Adaptação; Gestão de Risco de Desastres; Políticas públicas; Planejamento.*

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1. INTRODUCTION

The climatic system has been unequivocally affected by human activities, causing irreversible, widespread, and rapid changes in climate components (IPCC, 2021; Rocha, 2021). Land-use changes and fossil fuel emissions are key drivers of climate change (Hong *et al.*, 2021; IPCC, 2021). A warmer climate has intensified surface temperature increase, sea level rise and very wet and very dry weather events (IPCC, 2021). Over the last 50 years, the number of disasters has increased fivefold, mainly in developing countries (WMO, 2021). The 2023 Aon Reporting demonstrated that there were 421 notable disaster events in 2022, resulting in economic losses of $313 billion. Nearly 31,300 people have lost their lives, of which 19,200 were linked to the heatwave in the European summer (Lörinc *et al.*, 2023). However, recent data estimated that the heatwave in the last European summer resulted in 61,672 deaths (Ballester *et al.*, 2023). Among the top 10 disaster events in 2022, five events were floods, leading to 4,091 deaths and $42.2 billion dollars of economic losses (Lörinc *et al.*, 2023). Without concrete adaptation interventions, the 136 largest coastal cities can lose 1 trillion USD per year in 2050 due the future floods (Magnan *et al.*, 2019).

Coastal zones exhibit high rates of urbanization and are the most densely populated in the World. At the same time, these areas are exposed to a range of climate risks, mainly in low-elevation zones (Batista, 2018; Neumann *et al.*, 2015). Estimates suggest that the global population living in low elevation coastal zones is between 750 million and approximately 1.1 billion persons (Macmanus *et al.*, 2021). Coastal areas have high diversity of marine and terrestrial ecosystems that support complex food-chains and are home for many species, including endemic and threatened species (Bijlsma, 1997; Figueiredo & Nicolodi, 2022; Veron *et al.*, 2019). They can support a variety of activities, such as fishery, aquaculture, ocean shipping, housing, tourism, mining, agriculture, and waste disposal. For this reason, coastal zones tend to have higher population and strong economic growth (Bijlsma, 1997; Blackburn *et al.*, 2019). The heavy urbanization is a driving force for ecosystem fragmentation and degradation (Blackburn *et al.*, 2019).

The Intergovernmental Panel on Climate Change and the United Nations Framework Convention on Climate Change have emphasized that Integrated Coastal Zone Management is a key tool for adapting to climate change and improving current conditions in coastal zones (Nicholls *et al.*, 2007). Climate Adaptation is defined "in human systems, as the process of adjustment to actual or expected climate and its effects in order to moderate harm or take advantage of beneficial opportunities" (IPCC, 2022). Adaptation is essential for reducing exposure and vulnerability to climate change and involves activities of an anticipatory, reactive, incremental and/or transformational nature. Adaptation can play a key role to build resilience, that is defined "as the capacity of social, economic and ecosystems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure as well as biodiversity in case of ecosystems while also maintaining the capacity for adaptation, learning and transformation" (IPCC, 2022). There are a set of adaptation options that include transition systems in land and ocean ecosystems management, urban and infrastructure, energy, and cross-sectoral options (IPCC, 2022). In coastal areas, three types of adaptations can be incorporated into their planning and management. Planned retreat options are related to abandonment of highly vulnerable areas and population resettlement. Accommodate options comprise ecosystem conservation and resilience actions to be harmonized with socioeconomic development. Protect options can involve hard structural measures, such as dikes, barriers, sea walls, and soft structural options, like beach nourishment and dune restoration (Bijlsma, 1997). Effectiveness, efficiency, equity, and legitimacy are important elements to be considered for the judgment of adaptation success (Adger *et al.*, 2005). The mitigation potential of land use activities related to forest conservation and sustainable agriculture has been recognized as fundamental to achieve the Paris Climate Agreement goals (Winkler *et al.*, 2021). Adaptation and mitigation actions must be included and integrated to limit warming and reduce damages and losses (Hurlimann *et al.*, 2021; Morecroft *et al.*, 2019).

For disaster risk management, it is fundamental that prospective or proactive integrated actions are priority in relation to corrective responses (Lavell, 2009). As a result, the development and integration of climate and coastal plans represent good devices to disaster preparedness in coastal areas, mainly in context of the extreme weather events (UNDP, 2010). Climate adaptation documents, like adaptation strategies and plans are relevant measures to reduce natural hazard and prevent disasters (UNDP, 2010). Disaster Preparedness Programs have intensified since the International Decade for Natural Disaster Reduction (IDNDR) was launched in 1989 (ISDR, 2022). From then on, there have been three events known as the World Conference on Disaster Risk Reduction in the cities of Yokohama (1994), Kobe (2005) and Sendai (2015). These conferences published three important disaster management frameworks: Yokohama Strategy and Plan of Action for a Safer World, Hyogo Framework for Action 2005 - 2015 and Sendai Framework for Disaster Risk Reduction 2015-2030 (Rodrigues, 2010; Coppola, 2015). The Sendai Framework aims to the substantial reduction of disaster risk and losses in lives, livelihoods, and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries, over the next 15 years (UNISDR, 2015). Each member state must propose national targets to implement concrete actions to minimize disaster risks, in accordance with their national priorities (UNISDR, 2015). The Sendai Framework also is aligned to other agreements, including the Sustainable Development Goals, The Paris Agreement on Climate Change, The Addis Ababa Action Agenda on Financing for Development, and the New Urban Agenda (UNDRR, 2023).

Considering that the development of public policies is essential for climate adaptation in coastal areas, the aim of this study was to assess the content of national climate adaptation documents from countries bordering the Atlantic Ocean.

2. METHODS

2. 1. Study area

To include the largest number of Atlantic coastal countries from different continents of the World, we selected the 30 longest Atlantic coastline countries. Coastline data was collected from "The World Factbook 2020" (CIA, 2021). We selected 16 countries from Europe (Croatia, Denmark, Estonia, France, Germany, Greece, Iceland, Italy, Norway, Portugal, Spain, Russia, Sweden, Turkey, Ukraine and the United Kingdom), 4 countries from South America (Argentina, Brazil, Chile and Venezuela), 4 countries from Central America (Bahamas, Cuba, Haiti and Panama), 3 countries from Africa (South Africa, Angola and Morocco) and 3 countries from North America (Canada, United States and Mexico).

2.2. Data Collection and Measurement

2.2.1. Selection of National Climate Adaptation Documents

This study source comprises federal government documents regarding climate adaptation management and planning, such as national adaptation plans, national adaptation strategies, climate risk assessments, climate vulnerability assessments and adaptation reports. Most of the plans and strategies were collected from the "Climate Change Laws of the World and Climate Change Litigation of the World" website (https://climate-laws.org/) developed by the Grantham Research Institute at the London School of Economics and Political Science. Additional climate-related documents were also obtained from government entities of each country. Table 1 lists all selected documents.

2.2.2. Dependent Variable

The content of national climate adaptation documents for disaster risk management is measured by thirty-two indicators, according to Tang (2008) and Tang *et al*. (2010; 2013). Each indicator is scored on a 0-2 scale. The score "0" means that the indicator is not identified and recognized. The score "1" means that the indicator has been identified or mentioned without details. The score "2" means that the indicator has been thoroughly identified in full, with details.

Table 1. List of National Climate Adaptation Documents.

Countries	Coastline (Km)	Document Titles	Publication Year
Canada	202080,00	1.Policies for In-Water and Shoreline Works and Related Activities 2.Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity 3. Land use planning tools for local adaptation to climate change 4. Federal Adaptation Policy Framework 5. Canada's marine coasts in a changing climate 6. An Emergency Management Framework for Canada 7. Measuring Progress on Adaptation and Climate Resilience: Recommendations to the Government of Canada 8. Canada's Top Climate Change Risks	2007, 2008, 2012, 2016, 2017, 2018, 2019

Table 1. (cont.) List of National Climate Adaptation Documents.

Countries	Coastline (Km)	Document Titles	Publication Year
Norway	83281,00	1. Climate Change Adaptation in Norway 2. Norway's First Adaptation Communication 3. Norway's Climate Action Plan 4. Norway's Seventh National Communication: Under the Framework Convention on Climate Change 5. Adapting to a Changing Climate Norway's vulnerability and the need to adapt to the impacts of climate change.	2008, 2012, 2013, 2020, 2021
Russia	37653,00	1. National Action Plan for the First Phase of Adaptation to Climate Change	2019
United States	19924,00	1. U.S. Environmental Protection Agency Climate Change Adaptation Plan - 2012 2. U.S. Environmental Protection Agency Climate Change Adaptation Plan - 2013 3. U.S. Environmental Protection Agency Climate Change Adaptation Plan - 2014 4. U.S. Environmental Protection Agency Climate Change Adaptation Plan – 2021	2012, 2013, 2014, 2021
Greece	13676,00	1. The Environmental, Economic and Social Impacts of Climate Change in Greece 2. Climate Change Adaptation Strategy 3. Greece's Recovery and Resilience Plan	2011, 2016, 2021
United Kingdom	12429,00	1. The National Adaptation Program: Making the Country Resilient to a Changing Climate 2. The National Adaptation Program and the Third Strategy for Climate Adaptation Reporting 3. Climate Adaptation Risk Assessment Progress Update – 2016 4. UK Climate Change Risk Assessment 2022	2013, 2016, 2018, 2022
Mexico	9330,00	1. National Climate Change Strategy 2. Decree Approving the Special Climate Change Program 3. Adaptation to Climate Change in Mexico: Vision, Elements and Criteria for Decision-Making 4. National Strategy for REDD+ 2017-2030	2012, 2014, 2017, 2018
Italy	7600,00	1. Climate Adaptation Strategy for Climate Change 2. Seventh National Communication under the UN Framework Convention on Climate Change 3. Italy's Integrated National and Energy Climate Plan 4. Italy's National Plan for Resilience and Recover	2015, 2017, 2019, 2021
Brazil	7491,00	1. Adaptation Climate Change Guide for Federal Entities 2. National Plan for Adaptation Climate Change	2013, 2016
Denmark	7314,00	1. Danish Strategy for Adaptation to a Changing climate 2. The Action Plan for a Climate-proof Denmark 3. The Danish Climate Policy Plan 4. Denmark's Integrated National Energy and Climate Plan 5. Denmark's Recovery and Resilience Plan	2008, 2012, 2013, 2019, 2021
Turkey	7200,00	1.Turkey's National Climate Change Adaptation Strategy and Action Plan 2. Climate Change Action Plan 2011-2023	2011, 2012
Chile	6435,00	1. National Climate Change Action Plan 2008-2012 2. National Climate Change Action Plan 2017-2022 3. Climate Change Adaptation Plan for the Agricultural and Fishery sectors 4. Climate Change Adaptation Plan for Biodiversity 5. National Climate Change Adaptation Plan 6. Climate Change Adaptation Plan for the Health Sector 7. National Strategy on Forests and Climate Change 2017-2025	2008, 2013, 2014, 2014, 2016, 2017, 2020
Croatia	5835,00	1. Integrated National Energy and Climate Plan for the Republic of Croatia 2. Climate Change Adaptation Strategy in the Republic of Croatia for the period to 2040 with a view to 2070 3. Regulation on the Adoption of the Plan for the Air Protection, Protection of the Ozone Layer and Climate Change Mitigation in the Republic of Croatia for the period 2013-2017	2017, 2019, 2020
Argentina	4989,00	1. National Action Plan for Energy and Climate Change 2. National Plan for Adaptation and Mitigation to Climate Change 3. Law 27520 on Minimum Budgets for Adaptation and Mitigation to Global Climate Change	2017, 2019

Table 1. (cont.) List of National Climate Adaptation Documents.

Countries	Coastline (Km)	Document Titles	Publication Year
Iceland	4970,00	1. Iceland's Climate Action Plan for 2018-2030 and 2020 Update 2. Iceland's 2020 Climate Action Plan	2018, 2020
Spain	4964,00	1. National Climate Change Adaptation Plan 2006-2020 2. National Climate Change Adaptation Plan 2021-2030 3. Spain's integrated National Energy and Climate Plan for 2021-2030 4. Spain's Recovery and Resilience Plan	2006, 2020, 2021
France	4853,00	1. National Climate Change Adaptation Plan 2018-2022 2. France's Integrated Energy and Climate Plan 3. France's Recovery and Resilience Plan	2018, 2020, 2021
Estonia	3974,00	1. Climate Change Adaptation Development Plan until 2030 (2017) 2. Estonia's 2030 National Energy and Climate Plan (NECP 2030) 2019 Estonia's Recovery and Resilience Plan	2017, 2019, 2021
Cuba	3735,00	1. Cuba's State Plan to Confront Climate Change	2017
Bahamas	3542,00	2. National Policy for the Adaptation to Climate Change	2005
Sweden	3218,00	1. National Strategy for Climate Change Adaptation (Government Proposition 2017/18:163) 2. The Swedish Climate Policy Framework 3. Sweden's Integrated National Energy and Climate Plan	2017, 2018, 2020
Morocco	2945,00	1. National Plan Against Climate Change 2. The National Climate Plan: Horizon 2030	2019, 2020
Venezuela	2800,00	1. Venezuela (Bolivarian Republic of) First Nationally Determined Contribution 2. Venezuela (Bolivarian Republic of) First Nationally Determined Contribution (Updated submission) 3. Venezuela National Communication 2	2017, 2021
South Africa	2798,00	1. National Climate Change Response Policy White Paper 2. National Climate Change and Health Adaptation Plan 2014-2019 3. RSA's National Climate Change Adaptation Strategy	2011, 2014, 2020
Ukraine	2782,00	1. Concept of State Climate Change Policy Implementation until 2030	2016
Panama	2490,00	1. National Strategy for Climate Change 2050 (Executive Decree 34/2019)	2019
Germany	2389,00	1. Climate Action Plan 2050 (2016) 2. Germany's Integrated National Energy and Climate Plan 2019 3. Germany's Recovery and Resilience Plan 2021 4. German Strategy for Adaptation to Climate Change (DAS) 2008	2008, 2016, 2019, 2021
Portugal	1793,00	1. National Adaptation Strategy to Climate Change 2. Portugal's National Energy and Climate Plan for 2021-2030 3. Portugal's Recovery and Resilience Plan	2015, 2021
Haiti	1771,00	1. National Policy to Fight Climate Change	2019
Angola	1600,00	1. National Strategy for Climate Change (ENAC) 2. Climate Change Adaptation Plan for Angola's Coastal Zone	2017; 2019

Each set of documents has received a final score ranging from 0 to 10, after normalizing the sum of the indicators evaluated using Equation 1.

$$QDj = \frac{10}{2m_j} \cdot \sum_{j=1}^{m} I_j \quad (1)$$

where QD_j is the quality of the j_{th} set of documents, m_j is the number of indicators and I_j represents the score of the i_{th} indicator (ranging from 0 to 2).

The performance of the indicators was measured using two indices: breadth and depth scores. These two indices measure each indicator's quality. Breadth score (Equation 2) assesses the extent to which each of the indicators is addressed across the set of documents, measuring their coverage. The depth score (Equation 3) of an indicator measures its level of importance and analyzes how much importance is stated in the documents where it is addressed.

$$BS_j = \frac{P_j}{N} \cdot 100 \quad (2)$$

where BS_j is the j_{th} indicator breadth score (ranging 0-100%), P_j is the number of countries with documents that address the j_{th} indicator and N is the total number of countries whose documents have been assessed.

$$DS_j = \frac{\sum_{j=1}^{P_j} I_j}{2P_j} \cdot 100 \quad (3)$$

where DS_j is the j_{th} indicator depth score (ranging 0-100%); I_j is the rating on the j_{th} indicator (ranging 0–2); and P_j is the number of countries with documents that address the j_{th} indicator.

2.2.3. Dependent variables: awareness, analysis, and action components

The "Awareness" component indicates the degree to which every set of documents understand climate change concepts and the relevance of extreme climate events, including evidences from IPCC reports (Tang *et al.*, 2010). The set of documents should recognize the role of climate variability and uncertainty. Climate resilience goals must be presented (Tang *et al.*, 2010).

The "Analysis" component assesses the hazards, vulnerabilities, risks, and costs of climate adaptation. This component is also divided into four indicators. The first indicator is related to the identification of coastal hazards from climate change. The vulnerability analysis considers whether there has been a characterization of the exposed populations and properties to a hazardous event in coastal areas. The physical and social vulnerabilities need to be identified. Risk assessment must be a description of the risks from possible hazard events in coastal areas. The analysis of adaptation costs estimates the mitigation and adaptation costs from the potential strategies (Tang *et al.*, 2010).

The "Action" component examines policies, tools, and strategies to adapt to climate change and reduce the risk of extreme events in coastal areas. Disaster risk management must develop resilience to potential climate impacts (Tang *et al.*, 2010). This component has 24 indicators, with six subcomponents. The first set of subcomponents shows important tools for reducing exposure. These tools are land use and development regulations, property acquisition programs, shoreline regulations and requirements, and defensive infrastructure and critical facilities policies (Tang *et al.*, 2013). The second set involves indicators to verify actions that increase resilience to changing risks, such as public awareness and education activities, the incorporation of risk management into decision-making processes, structure to enhance inter-organizational and inter-jurisdictional coordination and the establishment of a data platform. The third set of subcomponents includes actions to achieve a climate change transformation. Transformation is the deepest form of adaptation, where the development structures are reconfigured, the political-economy regime is reformed and individual values are reconstituted (Pelling *et al.*, 2010). The process of transformation should identify roles and responsibilities between sectors and stakeholders, measures of adaptive learning, continuous monitoring, evaluation and updating for successful adaptation; identification of financing sources and advances in scientific data and its analysis focused on climate change (Tang *et al.*, 2013). The fourth set of subcomponents is composed of action to reduce vulnerability, such as building codes, protection of natural resources, programs for local incentive and public-private initiatives. The fifth set comprises effective actions for countries to be able to prepare, respond and recover extreme weather events. The promotion of early warning systems, emergency preparedness and response procedures, local hazard mitigation plans and integration of climate change into coastal zone management plans are the indicators of this subcomponent. Finally, the sixth subcomponent consists of actions to pool, transfer and share climate risks, such as reserve funds and incentive loans, financial insurance, tax credits and the development of impact fees.

2.2.4. Independent Variables

Nine independent variables are measured and analyzed to explain the variation in the quality of national climate adaptation documents scores. These measurements and resources are listed in Table 2.

To select the independent variables for the regression model, we initially evaluated the correlation between the score of quality of documents (dependent variables) and each independent variable. A two-tailed hypothesis t-test was designed to measure the uncertainty associated with the correlation coefficients. The critical t-value (r=2.048) with n-2 degrees of freedom was used as a reference. If the t-test statistic value is greater than the critical value, then there is significant linear correlation, and we reject the null hypothesis. The variables with significant and highest correlation coefficients were elected for the multiple regression model.

2.2.5. Data treatment

Cronbach's Alpha (Equation 4) was calculated to examine the reliability of indicators:

$$\alpha = \frac{K}{K-1}[1-(\frac{\sum S_i^2}{S_T^2})] \tag{4}$$

where K is the number of component indicators, or the total number of indicators evaluated. $\sum S_i^2$ the sum of the variance of the component or all indicators (variance of each column) and S_T^2 is the variance of the total scores.

Cronbach's alpha above 0.75 to 0.8 suggests a high reliability level. The Cronbach's alpha scores can indicate an internal consistency of the indicators. The Table 3 lists qualitative descriptors used for value ranges to interpret alpha values calculated.

Table 2. Measurement of independent variables

Variables	Variable Description	Scale	Data Sources
Federal risk management	Disaster preparedness and response plans and risk assessment updated over the last 5 years	0-1 0 for no documents 0.5 for documents up to 2017 1 for documents after 2017.	Climate Laws of the World https://climate-laws.org/ Platform Climate Adapt https://climate-adapt.eea.europa.eu/ Official websites from government entities
Wealth	Median income per capita (2022)	Dollars (natural logarithm)	World Population Review
Educational attainment	Percentage of population aged 25 years and over with a Bachelor's degree or higher	0-100%	World Bank Data World Population Review
Number of extreme climatic events	Number of severe weather events during 1980-2020	Number of disasters	Climate Knowledge Portal
Population Size	Number of people per country in 2022	Number of people (natural logarithm)	The World Bank Data
Number of deaths from disasters	Number of deaths from disasters during 1980-2020	Number of deaths (natural logarithm)	Our World In Data
Energy consumption	Total estimated energy per capita (2022)	GigaWatts	World Population Review
Transport emission	Amount of carbon dioxide emitted by transportation sector in 2019	Tonnes per capita	Our World In Data
Greenhouse gases emission	Percentage of emissions worldwide	0-100%	Climate Laws of the World https://climate-laws.org/

Table 3. Reliability classification from the Cronbach's Alpha.

Alpha Value	Reliability
$\alpha \leq 0,30$	Very low
$0.30 < \alpha \leq 0.60$	Low
$0.60 < \alpha \leq 0.75$	Moderate
$0.75 < \alpha \leq 0.90$	High
$\alpha > 0.90$	Very high

Source: Freitas & Rodrigues (2005).

In order to evaluate the multicollinearity between the predictors, the Variance Inflation Factor (Equation 5) was calculated, according to Thompson *et al*. (2017).

$$VIF = \frac{1}{(1 - R_{Ij}^2)} \quad (5)$$

where R_{Ij}^2 is the multiple correlation coefficient of the independent variables.

VIF greater than 10 indicates the presence of multicollinearity. If VIF is lower than 10, there is a weak collinearity. In addition, the Tolerance coefficient (Equation 6) was used to evaluate the multicollinearity better.

$$TOL = \frac{1}{VIF} \quad (6)$$

where VIF is the Variance Inflation Factor.

Smaller tolerance values increase the likelihood of multicollinearity. The closer the TOL is to 1, the likelihood of multicollinearity decreases. If TOL approaches zero, the greater the chance of multicollinearity (Thompson *et al*., 2017).

The regression model significance was determined through an analysis of variance (ANOVA). ANOVA uses the F-test to assess the equality of means in three or more groups of data. The null hypothesis is that all β parameters are equal to 1. The null hypothesis is rejected when at least one of the parameters is different from zero. The significance of the β parameters was checked using the p-value in ANOVA. When p-value is lower than 0.05, the regression model is considered significant (Bedeian & Mossholder, 1994). Correlation and Regression Analysis were performed using the tool "Data Analysis" in Excel®.

3. RESULTS AND DISCUSSION

3.1. Quality of Climate Adaptation Documents

The documents selected for this study showed a medium quality in managing the risks of extreme events, since the average score was $QD_{(MEAN)}$=6.55, at a scale of 0 to 100. The minimum score was $QD_{(MIN)}$ = 2.91, corresponding to Ukraine, while the maximum score was $QD_{(MAX)}$ = 8.91, corresponding to Norway, the United Kingdom, Croatia, and Spain. Ukraine is currently in an unfortunate period of war, but its documents were elaborated before this period. The low quality of its documents is due half of indicators assessed were scored zero. Only the first two indicators scored maximum points. The mean scores for the three indicator components and the final score per country can be seen in Figure 1 and Table 4.

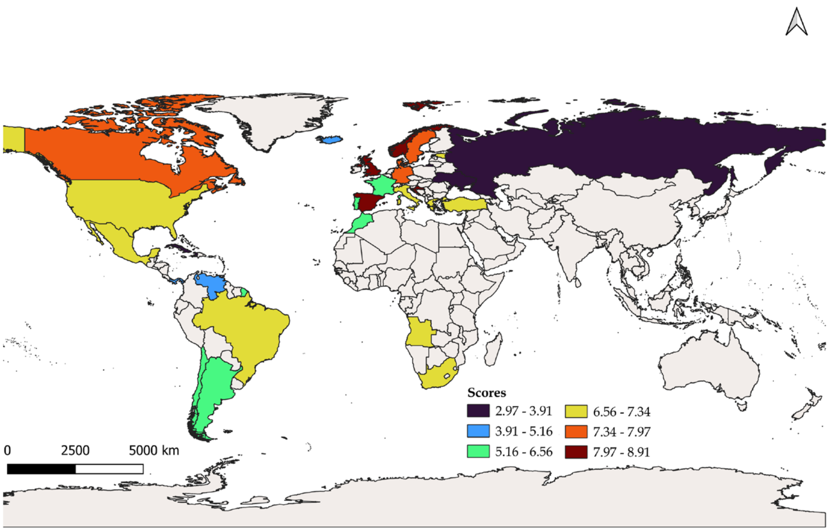

Figure 1. Map of climate adaptation document scores.

Table 4. Plan component scores and total scores (by percentage).

Country	Awareness	Analysis	Action	Whole documents
Canada	0.88	0.75	0.79	7.97
Norway	0.88	1.00	0.88	8.91
Russia	0.38	0.25	0.38	3.59
United States	1.00	0.63	0.67	7.03
Greece	100	0.88	0.63	7.03
United Kingdom	0.63	0.88	0.94	8.91
Mexico	0.88	0.63	0.71	7.19
Italy	1.00	0.63	0.65	6.88
Brazil	0.88	0.75	0.69	7.19
Denmark	1.00	0.75	0.75	7.81
Turkey	0.88	0.63	0.69	7.03
Chile	0.88	0.63	0.54	5.94
Croatia	1.00	1.00	0.85	8.91
Argentina	0.88	0.63	0.56	6.09
Iceland	0.25	0.25	0.60	5.16
Spain	1.00	1.00	0.85	8.91
France	0.88	0.38	0.54	5.63
Estonia	1.00	0.88	0.67	7.34
Cuba	0.50	0.63	0.33	3.91
Bahamas	0.63	0.38	0.35	3.91
Sweden	0.88	0.88	0.71	7.50
Morocco	0.63	0.75	0.65	6.56
Venezuela	0.88	0.38	0.46	5.00
South Africa	0.88	0.88	0.65	7.03
Ukraine	0.50	0.38	0.25	2.97
Panama	0.50	0.38	0.42	4.22
Germany	0.75	1.00	0.75	7.81
Portugal	1.00	0.75	0.54	6.25
Haiti	0.38	0.38	0.33	3.44
Angola	0.75	0.38	0.75	7.03

Large variations were found among the countries. Norway, the United Kingdom, Croatia, Spain, Canada, Denmark, Germany, Sweden, Estonia, Mexico, and Brazil are the 10 countries with the highest quality documents. All of these countries have developed documents detailing important measures for managing the risk of extreme weather events and disasters, such as continuous monitoring, use of scientific data in decision-making process, emergency preparedness and response planning and early warning system procedures, guidelines for local hazard mitigation plans, land use and building codes. However, Norway, the United Kingdom, Croatia and Spain have developed better other indicators, such as assessment of adaptation costs, adaptive learning, tax credits, impact fees, and therefore received the highest scores.

The ten worst performers were Chile, France, Iceland, Venezuela, Panama, Cuba, the Bahamas, Russia, Haiti and Ukraine, whose documents scored below 6. All these countries developed climate adaptation documents with gaps in indicators related to emergency response, land use, and taxation. Another common feature is that many documents were extremely short. The documents for Cuba, Russia, Ukraine, France and Iceland ranged from 7 to 26 pages.

3.2. Indicator performance

Table 2 lists the breadth and depth scores for each indicator. The mean breadth score is 83.3%, which means that all indicators were checked in 25 countries. The breadth scores ranged from 43.3% to 100%. Four indicators were developed by all countries. These included identification of coastal hazards from climate change, risk assessment, identification of potential financing sources, and contingency and emergency preparedness and response procedures for extreme events. Assessment of adaptation costs showed the lower breadth, verified in 13 of the 30 countries.

This depth score shows that, among the countries whose documents identified any of the indicators, 54.5% to 96.5% received the maximum possible score. This is the case for the first indicator "Extreme events from climate change", whose total score was 56 in 58 and achieved the maximum depth score. The indicator "Development of local all-hazard mitigation plans" was found in 22 national documents and received 24 out of 44 possible points.

In the "Awareness" component, more than 90% of the documents recognized extreme events from climate change. Seven countries did not cite climate change evidences from IPCC reports in their documents. Although 90% of the countries mentioned climate resilience as an objective in their documents, the depth was moderate (DS = 68.5%). 75% of the countries have achieved the highest level for this component and four countries did not reach 50% of the maximum score: Venezuela, Iceland, Haiti and Russia. Portugal, Estonia, Croatia, Denmark, Italy, the United States and Greece fully developed this component, scoring 100%. Despite the resilience goals not being consolidated in the documents analyzed, resilience plans have already been developed by the member states of the European Union. These plans follow the "NextGenerationEU" regulation, which aims to rebuild Europe after the pandemic crisis through green and digital transition (Pilati, 2021). The United States has also supported developing municipal resilience plans, with a total investment of $1 billion (Woodruff *et al.*, 2022). Resilience plans have presented a more integrated and participatory approach than adaptation plans, although local adaptation plans present a more robust assessment of local impacts (Woodruff *et al.*, 2022).

The mean depth and breadth scores for the "Analysis" component were around 80% for all countries. Russia, Iceland, France, Bahamas, Ukraine, Panama, Haiti and Angola also did not reach 50% of the score in this component. Most documents provide a good level of depth (DS = 66.7%) in identifying coastal hazards from climate change, but without contextualizing the geographical characteristics of the country. With regard to the assessment of vulnerability, 28 out of 30 countries carried it out with a high level of depth (DS = 83.3%). In contrast to the other indicators, the assessment of adaptation costs had a low breadth (BS = 43.3%), being developed by only thirteen countries. However, these countries reported a detailed analysis with significant depth (DS = 84.6%). Norway, Croatia, Spain, and Germany produced good assessment documents, addressing their hazards, risks, and vulnerabilities according to their geographical and socio-economic characteristics, and developing a detailed assessment of adaptation costs. Nonetheless, the assessment of adaptation costs is a difficult tool to implement. There are gaps in the scope and depth of the many analyses, such as the costing of measures, and the treatment of uncertainty. This reflects the difficulty of measuring costs, which tend to be underestimated (Fankhauser, 2010). There is also a lack of knowledge on how to measure and assess adaptive capacity and practical barriers to adaptation. Little is known about how to adequately evaluate the aggregate costs of adaptation, but implementation has become more difficult (Fankhauser, 2017).

The "Action" component was rated the lowest among the countries, which together reached 62% of the maximum score. The top 4 scoring countries were Norway, the United Kingdom, Croatia, Spain, and Germany, with scores ranging from 75% to 94%. The lowest scoring countries ranged from 25% for Ukraine, 33% for Cuba and Haiti, 35% for the Bahamas, 38% for Russia, 42% for Panama, and 46% for Venezuela. Given that this component includes proposals, guidance, and actions to achieve climate resilience, it is worrying that highly vulnerable countries have not sufficiently developed this part of the planning. Cuba, Haiti, Panama, and Venezuela are part of the climate-vulnerable Latin America that still has a deficit in implementing adaptation measures and disaster management strategies (Nagy *et al.*, 2019; Stennet-Brown *et al.*, 2019).

In the "exposure reduction" subcomponent, land acquisition programs (BS = 60%; DS = 61.1%) and shoreline regulations (BS = 56.7%; DS = 67.6%) received moderate attention. These two issues are sensitive because they may involve removing people from their homes. The intensification of hazard risks due to climate change has increased the need for resettlement policies, which can be a violation if it destroys the livelihood and network

Table 5. Indicator breadth and depth scores

Components and subcomponents		**Indicators**	**Breadth (%)**	**Depth (%)**
AWARENESS		A01. Extreme events from climate change	96.6	96.6
		A02. Uncertainty of climate change	86.7	94.2
		A03. Climate change evidence identified by IPCC assessment report	80	91.7
		A04. Goal for building coastal resilience	93.3	69.9
ANALYSIS		B01. Identification of coastal hazards from climate change	100	66.7
		B02. Vulnerability assessment	93.3	83.9
		B03. Risk assessment	100	80
		B04. Assessment of adaptation costs	43.3	84.6
ACTION	Reduce exposure	C01. Land use and development regulations	86.7	76.9
		C02. Property acquisition programs	60	61.1
		C03. Shoreline regulations and requirements	56.7	67.6
		C04. Defensive infrastructure and critical facilities policies	96.7	82.8
	Increase resilience to changing risks	C05. Public awareness, education to climate change and hazards	96.7	91.4
		C06. Incorporation of risk management into economic development decision-making processes	96.7	86.2
		C07. Enhancement inter-organizational, cross-jurisdictional coordination	83.3	62.0
		C08. Establishment of environmental stewardship and sustainability platform	86.7	80.8
	Transformation	C09. Identification of roles and responsibilities among sectors and stakeholders	93.3	62.5
		C10. Adaptive learning, continuous monitor, evaluate and update	100	83.3
		C11. Identification of potential financing sources	93.3	80.4
		C12. Advancing science data and analysis for climate change	83.3	80
	Reduce vulnerability	C13. Building codes and design standards	83.3	80
		C14. Natural resource protection	96.7	84.5
		C15. Local incentive programs	73.3	68.2
		C16. Public-private sector initiatives	96.7	74.1
	Prepare, respond, recover effectively	C17. Promotion of early warning and communication	83.3	78
		C018. Emergency preparedness and response procedures for extreme events	100	76.7
		C19. Development of local all-hazard mitigation plans	73.3	54.5
		C20. Integration of climate change into coastal zone management plans	63.3	68.4
	Pool, transfer, and share risks	C21. Mutual and reserve funds/incentive loans	90	90.7
		C22. Financial insurance	76.7	69.6
		C23. Tax credits	80	72.9
		C24. Development impact fees	50	66.7

of communities exposed to risks without replacing them. Many countries don't have the legislation, institutions, and qualified professionals to carry out this process in a humane and fair manner. There is no clear internationally accepted definition of uninhabitability and under what conditions resettlement may be the best option (Oliver-Smith, 2021).

In the subcomponent "Increase resilience to changing risks", the enhancement of inter-organizational and cross-jurisdictional coordination had great breadth but moderate depth (BS = 83.3%; DS = 62.5%). The role of regional international organizations in the implementation of disaster-related adaptation measures was weakly mentioned in the documents. Regional organizations are important sources of technical and financial assistance in areas such as food security, water resources management, and coastal management. Increased coordination tends to reduce rivalries and competition for access to international funding sources (Gilfillan *et al.*, 2020).

In the transformation subcomponent, most countries identified the roles and responsibilities between sectors and stakeholders but did not provide a more detailed description (BS = 93.3%; DS = 62.5%), especially with regard to climate disasters. The documents were limited to mentioning coordination and relationships between different spheres of government (local, state and federal), but the responsibilities of each level for managing extreme weather events were poorly developed. Half of the countries have described procedures for adaptive learning, continuous learning, evaluation and updating in relation to extreme climate events, with medium to high depth (BS = 50%; PPI = 63.3%). Adaptive capacity is a fundamental requirement for the success of adaptation measures. Lack of knowledge has been identified as one of the constraints in the adaptation process. The production and sharing of knowledge are a strong determinant in this process (Williams *et al.*, 2015). The low breadth and moderate depth of this indicator may indicate that this key condition has not been prioritized in planning processes. Multi-stakeholder integration is essential for the development of a knowledge culture, which leads to the civil society participation in decision-making processes related to planning and implementation of disaster preparedness and response (Butler *et al.*, 2015).

Considering that extreme weather events can cause irreparable material and human damage, investing in early warning systems (EWS) is one of the main ways to prepare for and respond to emergencies (Zommers & Singh, 2014). In this regard, 24 out of 30 countries presented and described procedures for these systems (BS = 83.3%; DS = 78%). Since the Indian Ocean tsunami in 2004, the number of publications on EWS and disaster management has increased, although there are still limitations in their performance, which ignores power relations and the need for a pluralistic knowledge approach (Hermans *et al*. 2022). Within the "prepare, response and recovery effectively" subcomponent, the development of local hazard mitigation plans also had a high breadth but low depth (BS = 73.3%; DS = 54,5%). Planning at the local level is essential to identify and manage hazards, risks, and vulnerabilities with spatial specificity. In this sense, it is necessary for all national jurisdictions to require local hazard mitigation plans, integrated into local climate plans, in order to access national funds and to prepare for and respond to climate change-related disasters (Stults, 2017; Wickham *et al.*, 2019). Still regarding disaster preparedness and response, coastal countries need to have integrated coastal management and climate adaptation plans, mainly due to the greater vulnerability of these areas to extreme weather events (Frazão Santos *et al.*, 2020). However, only 18 countries have developed documents indicating this integration and only 7 have detailed it (BS = 63.3%; DS = 68.4%). The low level of operationalization of this integration has been identified as a major challenge (Frazão Santos *et al.*, 2020).

In the subcomponent "pool, transfer and share risks", the development of impact fees was presented by half of the countries and detailed by only 5 (BS = 50%; DS = 66.7%). The development of emission impact fees is an important tool for internalizing the costs of climate change. It should be developed based on a cost analysis of greenhouse gas emissions by economic activities and households (Jepson, 2011). The formulation of these taxes, especially in households, needs to be done with public participation and support (Jepson, 2011). Another important application is the taxation of emissions through Pigouvian taxes. For example, in Sweden and Uruguay, economic activities must pay a tax of $130 and $137 per ton of carbon emitted, respectively (World Bank, 2022).

3.3. Cronbach's alpha Coefficient

The components ranged from low to high reliability, indicating differences in the internal consistency of each component separately. "Awareness" component coefficient was the lowest (α = 0.59) and with the smallest variance, resulting in low consistency. The "Analysis" component obtained moderate reliability (α = 0.72). The "Actions" component (α = 0.89) and the total of the indicators (α = 0.92) were considered to have high and very high reliability, respectively (Table 6). Overall, the reliability of the indicators is very good, but the low variances for the “Awareness” and “Analysis” components suggest the need for the selection of indicators for these components.

3.4. Correlation and Regression

Two independent variables were statistically significant with the document scores, and they were selected for the regression model, as seen in Table 7.

Among the nine independent variables, “Wealth” and “Educational attainment” were statistically significant and had the highest correlation values for selection in the regression model. The results of the VIF and TOL multicollinearity tests are shown in Table 8.

The variables selected for the regression model had VIF values less than 10, indicating weak collinearity. However, the TOL estimator had a value of 0.49, slightly closer to 0 than to 1. Based on the above tests, we decided to perform a multiple regression with the tested variables that were significant (Wealth and Educational attainment).

In the multiple regression analysis, the coefficient of determination (r2) was 0.20, which means that the selected variables explain about 20% of the variation in the document scores. The F-test in one-way ANOVA was less than 0.05, which shows that the linear regression model is significant. However, the parameters $\beta 1$ and $\beta 2$, both parameters showed a p-value above 0.05 and therefore not significant. The low value of the coefficient of determination suggests that new explanatory variables should be selected and tested to explain the variation in document quality. Residuals are randomly scattered and are normally distributed. Tables 9 and 10 show the values of the regression model developed for this study.

Table 6. Cronbach’s alpha Coefficient for the indicators

Components	Number of indicators	$\sum S_i^2$	S_T^2	Cronbach’s alpha index	Reliability
Awareness	4	1.73	3.10	0.59	Low
Analysis	4	1.69	3.63	0.71	Moderate
Action	24	10.32	74.15	0.89	High
All indicators	32	13.75	123.13	0.92	Very high

Table 7. Correlation between document scores and independent variables

Independent variable	Coefficient of correlation (r)	Student’s t-test (Critical Value = 2,048)	p-value
Federal risk management	0.27	1.48	0.45
Wealth	0.39	2.26	0.03
Educational attainment	0.42	2.43	0.02
Number of extreme climatic events	0.17	0.92	0.34
Population Size	-0.20	1.10	0.28
Number of deaths from disasters	-0.22	1.21	0.24
Energy consumption	0.12	0.62	0.54
Transport emission	0.33	1.86	0.09
Greenhouse gases emission	0.02	0.13	0.90

Table 8. Multicollinearity test for the selected variables for regression model

Isolated variable	VIF	TOL
Wealth	2.05	0.49
Educational attainment	2.05	0.49

Table 9. Regression Model Parameters

Parameters	Value
Coefficient of determination	0.1924
F-test (ANOVA)	0.0544

Table 10. P-value of the parameters β in the Regression Models

Predictor Variable	P-value
Wealth (β1)	0.445
Educational attainment (β2)	0.267

4. CONCLUSIONS

Climate adaptation documents include strategies, plans, reports, and risk analyses designed to reduce climate vulnerability and to integrate with other related national programs, activities, and policies. In coastal areas, the impact of extreme weather events tends to be greater due to their geographical vulnerability and ability to affect large numbers of people and economic activities.

The climate adaptation documents in this study presented good contents, as the average obtained was M=6.44 (above 6). Twelve of the thirty countries evaluated scored below the average (Russia, Chile, Argentina, Iceland, France, Cuba, Bahamas, Venezuela, Ukraine, Panama, and Haiti).

In the “Awareness” component, which consists of four indicators, the inclusion of IPCC data and climate resilience targets is fundamental to contextualize climate adaptation strategies and plans. These indicators have been reasonably developed by most countries. The definition of climate resilience targets was not developed in detail in the adaptation documents. In most countries, the issue was briefly mentioned.

Similarly, an assessment of the country’s risks, hazards, and vulnerabilities, as well as a study of the costs of adaptation, are key factors for a successful adaptation process. Within the “Analysis” component, the identification of coastal hazards was carried out in little depth by most of the countries in the study, without detail and contextualization with their geographical, meteorological, and climatic peculiarities. The analysis of adaptation costs is a difficult process and was performed by less than half of the countries.

The “Action” component, with 24 indicators, was the least developed in this study. 19 out of 30 countries developed the subcomponents “reduce exposure and vulnerability”, “increase resilience”, “ transformation”, “prepare, respond and recover effectively” and “pool, transfer and share risks” above average. This result indicates the need to review the documents for improvements. The indicator “local hazard mitigation plan” was poorly developed by 16 countries. Adaptive learning policies were also underdeveloped and represent barriers to climate adaptation. Many of the worst performing countries in this component are part of the Caribbean, an area highly vulnerable to climate change. It is imperative that these countries improve their planning and, above all, implement the measures necessary for good climate adaptation.

The quality of the selected indicators developed by Tang *et al*. (2010; 2013) showed low to very high reliability based on Cronbach’s alpha coefficient. A revision of the “Awareness” component could increase the internal consistency of the indicators. In addition, the selection of new indicators could enhance the consistency of the method. Indicators that could potentially be tested include an achievement of goals from disaster risk management frameworks and document release dates.

Finally, the regression model is significant, and the residuals are randomly scattered and normally distributed. However, the coefficient of determination is low, indicating that wealth and education attainment explain 20% of the variation in the document scores. Some additional independent variables should be selected and tested to further identify the relationship between planning content and influencing factors.

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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.

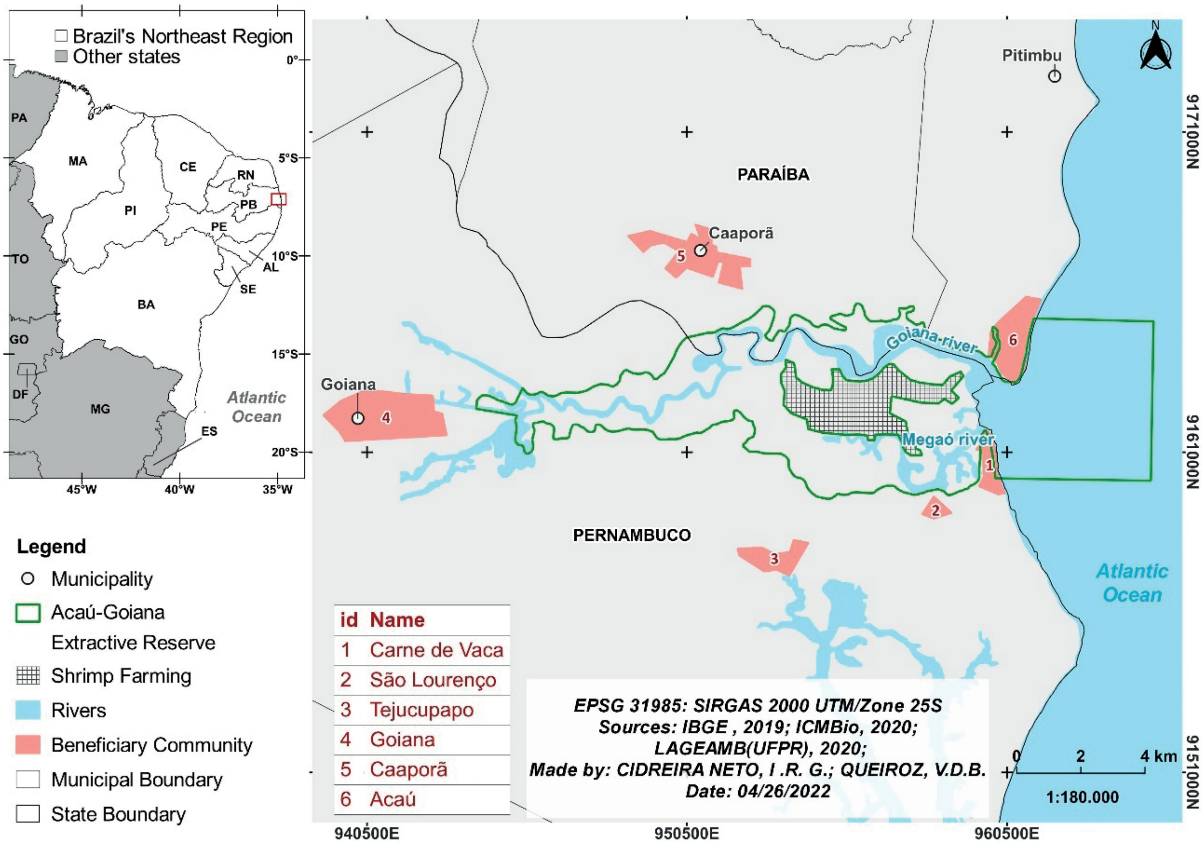

Figure 1. Location of the Goiana and Megaó estuary, which is part of the Conservation Unit of the Acaú-Goiana Extractive Reserve, in Northeastern Brazil, between the states of Pernambuco and Paraíba. Source: Authors own research (2022).

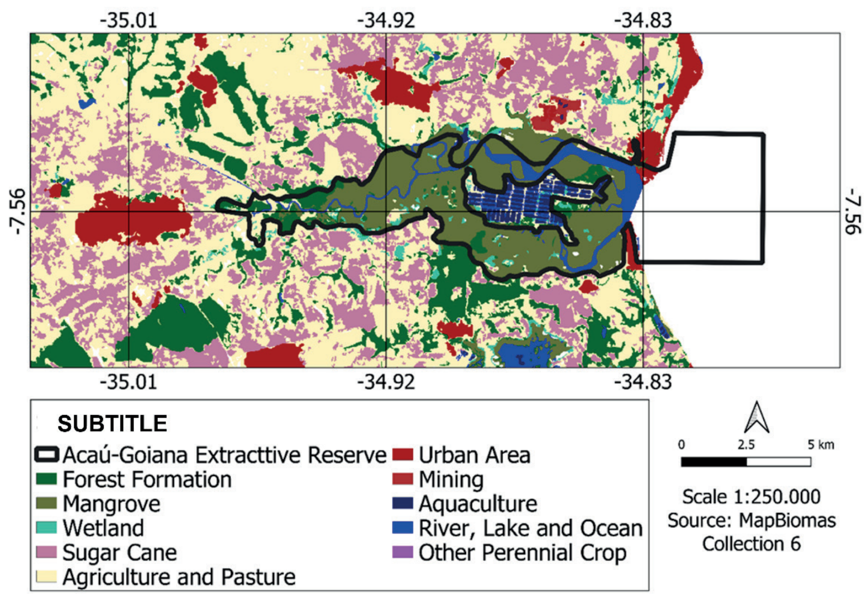

Figure 2. Land use and land cover in the Acaú-Goiana Extractive Reserve, and adjacent areas, for the year 2020. Source: Authors own research (2022).

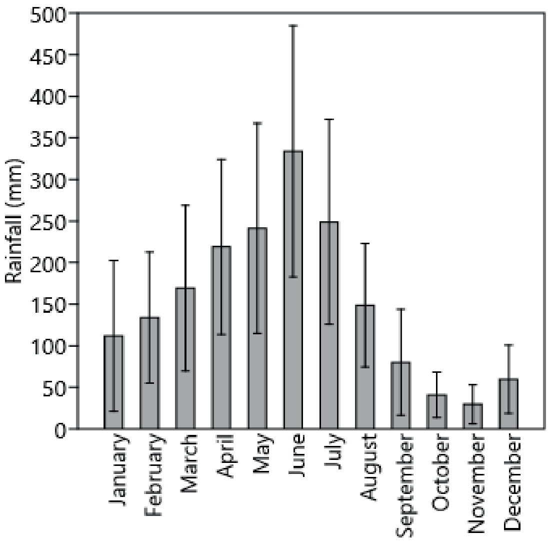

Figure 3. Rainfall regime for the municipality of Goiana (Pernambuco), using a twelve-year historical series (2010 - 2021). Source: Authors own research (2022).

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

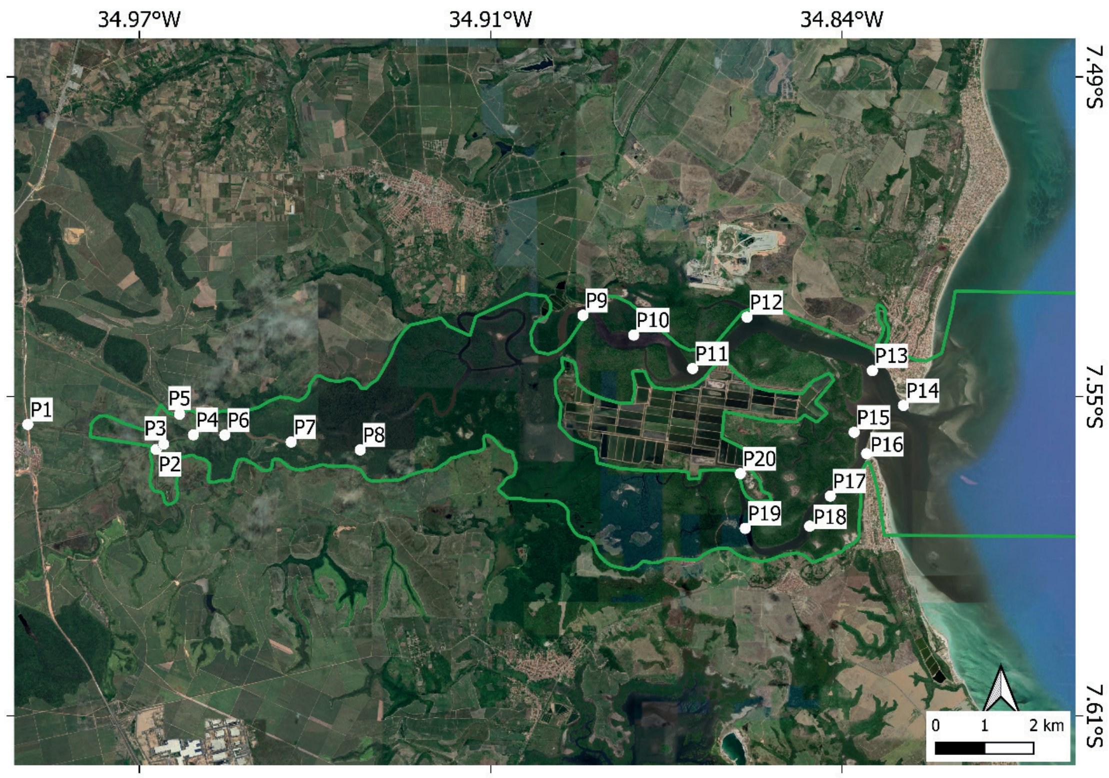

Figure 4. Location of the twenty sampling points in the estuary of the rivers Goiana and Megaó. Source: Authors own research (2022).

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).

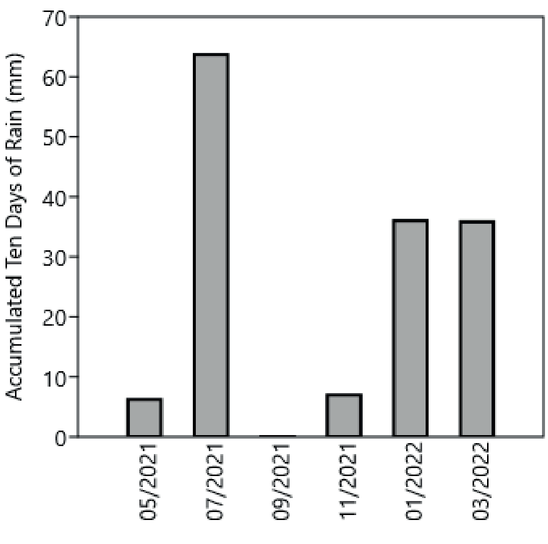

Figure 5. Accumulated rainfall during the ten days prior to the sampling (Station 28 - Goiana - Itapirema). Source: Authors own research (2022).

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).

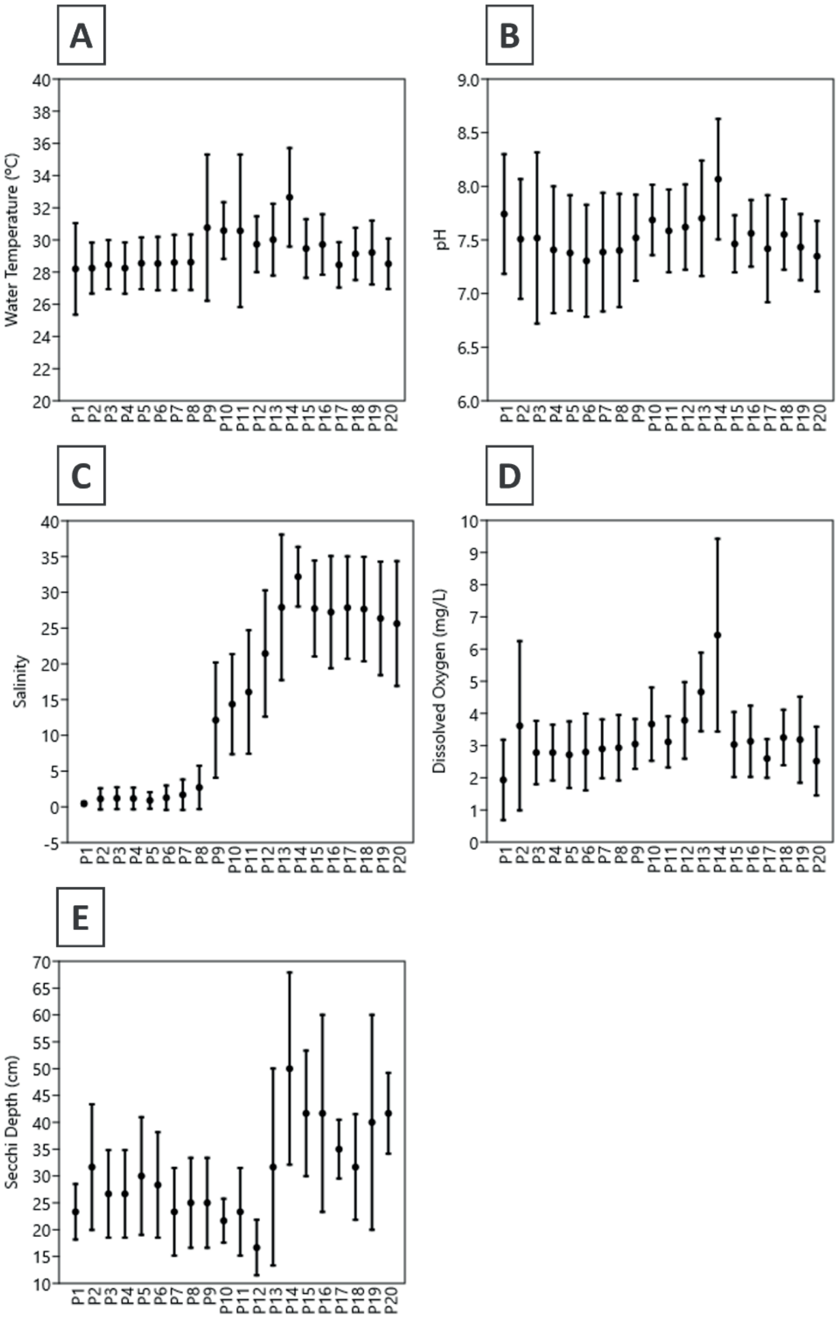

Figure 6. Physical and chemical parameters of water in the estuary of the rivers Goiana and Megaó, Northeast Brazil. A. Average variation of water temperature (ºC). B. Average variation of pH. C. Average variation in salinity. D. Average variation in Dissolved Oxygen (mg/L). E. Average variation in transparency (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 (GL = 19)	Between the Compartments (GL = 3)	Between months (GL = 5)
Temperature	NS	*	*
pH	NS	NS	*
Salinity	*	*	*
Dissolved Oxygen	*	*	*
Transparency	*	*	NS

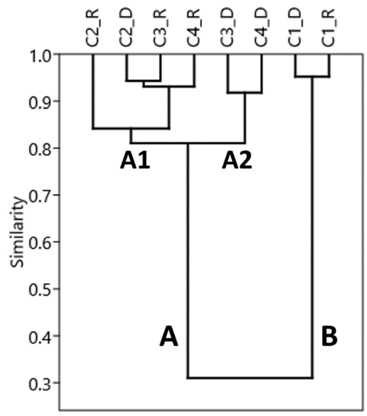

Figure 7. Cluster analysis by similarity among the sampling points in the estuary of Goiana and Megaó rivers. Source: Authors (2022).

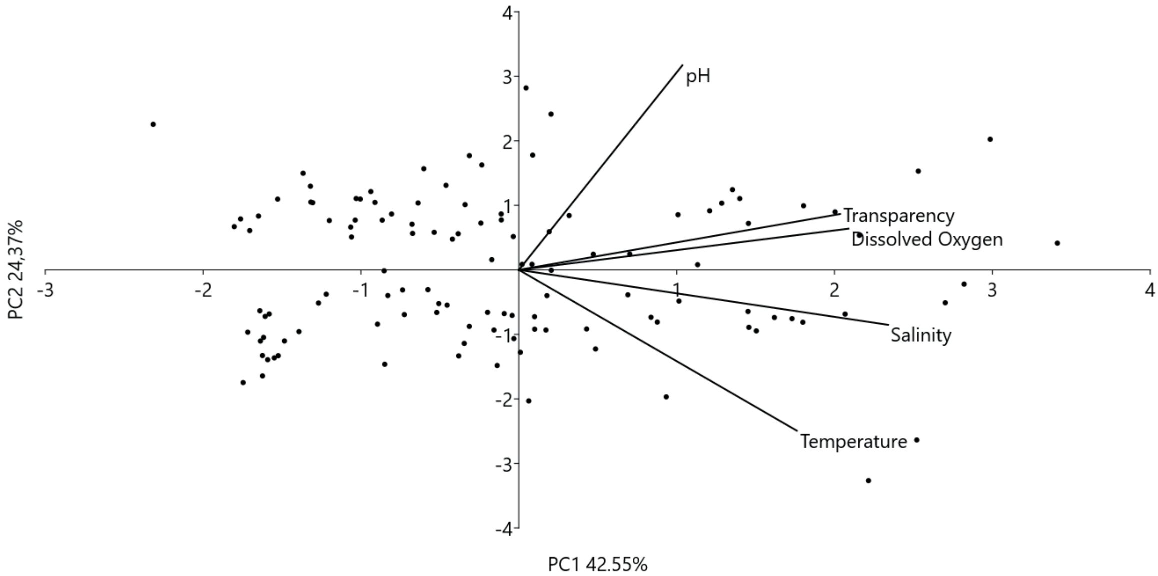

Figure 8. Principal Component Analysis (ACP) with the water variables of the sampling points in the estuary of Goiana and Megaó rivers. Source: Authors own research (2022).

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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EXPLORING TIDAL CONSTITUENT TRENDS: UNVEILING THE IMPACT OF THE 18.6-YEAR LUNAR NODAL CYCLE THROUGH HARMONIC ANALYSIS AND LONG-TERM TIDE GAUGE RECORDS

André de Lima Coelho[@ 1], Tiago Zenker Gireli[1], Kelly Kawai Venancio[2], Patrícia Dalsoglio Garcia[2]

ABSTRACT: Understanding tidal constituent trends is becoming increasingly important in a world where climate change puts pressure on the tidal regime across the globe. Tidal constituents change constantly, but there is strong evidence that nodal modulation interferes with constituent amplitude values, thus hindering efforts to accurately measure their trends. Therefore, this paper proposes a practical approach to remove the influence of nodal modulation in constituent trend analysis. We collected multiple 18.6-year series of sea level data from tide gauges in Brest (France), Cananeia (Brazil), and Eastport (USA) and performed a harmonic analysis. Our main focus is to assess the interference of the nodal cycle on M2 tidal constituents. Although 19-year series are optimal to minimize this interference, they drastically reduce the number of data sets analyzed. To mitigate this problem, we employed a sliding window approach where each 19-year series starts one year after the previous one. The results of all three surveyed sites show that by employing this approach, the trends of the tidal constituents change significantly compared to what was previously seen with nodal interference. For instance, in Eastport, the analysis indicates that nodal modulation is partially responsible for the apparent reduction of the M2 amplitude tendency slope after 1980, a change that is softened when the effects of this modulation are removed. The reliability of the trends identified in this study suggests that this practical approach can also help future research predict the slope tendency of main tidal constituents.

Keywords: Tides; Nodal cycle; Harmonic analysis; Tidal Constituents; Tide gauge records.

RESUMO: *A compreensão das tendências das componentes de maré está se tornando uma pauta relevante, principalmente ao considerar que as mudanças climáticas podem afetar o comportamento das marés ao redor do mundo. As componentes de maré mudam constantemente, mas há fortes evidências de que a modulação nodal interfere nos valores de amplitude das componentes, dificultando assim os esforços para medir com precisão suas tendências. Portanto, o presente estudo propõe uma abordagem prática para remover a influência da modulação nodal na análise de tendências das componentes. Diversas séries de dados de nível do mar de longo período, ou seja, de 18.6 anos, foram coletadas de marégrafos em Brest (França), Cananéia (Brasil) e Eastport (EUA). Com base em tais dados, foram conduzidas diversas análises harmônicas. O principal foco deste estudo é avaliar a interferência do ciclo nodal nas componentes de maré M2. Embora as séries de 19 anos sejam ideais para minimizar essa interferência, elas reduzem drasticamente a quantidade de conjuntos de dados analisados. Para atenuar tal problema, foi empregada uma abordagem de janela móvel na qual cada série de 19 anos começa um ano após o início da série anterior. Os resultados dos três locais estudados mostram que, ao adotar essa abordagem, as tendências das componentes de maré mudam significativamente em comparação ao que foi visto anteriormente com a interferência nodal. Por exemplo, em Eastport, a análise indica que a modulação nodal é parcialmente responsável pela aparente redução da inclinação da tendência de amplitude da componente M2 após 1980, uma mudança que é suavizada quando os efeitos dessa modulação são removidos. A confiabilidade das tendências identificadas neste estudo sugere que essa abordagem prática também poderá ajudar pesquisas futuras na previsão de tendências das principais componentes de maré.*

Palavras-chave: *Marés; Ciclo nodal; Análise Harmônica; Componentes de Maré; Registros maregráficos.*

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1. INTRODUCTION

Global climate change has become one of the major global concerns of the 21st century because of the countless impacts it exerts on the environment. For instance, the change in sea level has been described as one of these major impacts (Nicholls, 2010) due to its far-reaching consequences. Presumably, the sea level rise (SLR) process is going to be accelerated throughout the 21st century (Meehl *et al*., 2007). Several studies show a trend toward a higher global relative SLR, which may pose a threat to coastal communities. Seaside areas host roughly 40% of the world's population and represent one of the most developed areas in the world (Vousdoukas *et al*., 2018).

Changes in the mean sea level (MSL) stand as the main factor in the evaluation of coastal vulnerability (IPCC, 2013). However, the natural variations in the sea level due to tidal phenomena combined with storm surges may cause extreme changes in sea level, leading to significant hazards to coastal zones, such as floods. Thus, according to Arns *et al*. (2017), the high tide period appears as the critical moment for coastal flooding, creating a demand to consider changes at both mean sea level and tidal range.

One of the traditional calculation methods for tidal variation is the classical harmonic analysis (HA), which divides the tide into several sinusoidal constituents. Each harmonic constituent, which is also called a harmonic constant, comprises a fixed frequency, usually associated with astronomical cycles, as well as a variable phase lag and a variable amplitude, depending on location (Godin, 1972). These constituents are usually used to predict the tidal variation, obtaining the predicted heights and time instants of high and low tides. Several studies showed that tidal constituents change over time (Haigh *et al*., 2020; Jay, 2009; Ray, 2009; Woodworth, 2010). These changes in the tidal constituents might affect the resulting tide, especially if they significantly alter the most energetic tidal components, such as the M_2 (principal semidiurnal lunar) and the S2 (principal semidiurnal solar). For example, Ray (2006) demonstrated an upward trend in M_2 amplitude in the Gulf of Maine, and concluded that part of the variations seemed to be related to local resonance and water depth changes. Nonetheless, the exact underlying mechanisms of these changes are not yet fully understood.

Moreover, annual samples of the harmonic constituents present a periodic variation when plotted together. The variation of harmonic constituents over 18.6 years is known as nodal modulation. This modulation usually equals the gravitational potential, and its estimation relies on lunar astronomical parameters. The nodal modulation occurs because the lunar plane of motion is inclined at a mean angle of 5°09' relative to the ecliptic. The lunar plane rotates over a period of 18.61 years, and this motion affects approximately 3.7% of the constituent amplitude (Pugh, 1996). However, studies suggest that some nodal modulations differ from their corresponding nodal equilibrium tidal constituents (Shaw & Tsimplis, 2010).

Gravitational forcing is commonly thought to be stationary on non-geological time scales and since humankind started instrumental measurements of the tides. In recent years, the most dramatic changes in tidal features have happened in estuaries and tidal rivers. Modifications in tides can be caused by a variety of motives, including turbulent mixing, channel and flat depth, surface area, width, convergence, resonance and reflection, river flow, and instrumentation modifications (Haigh *et al*., 2020). Consequently, the tidal constituents in these regions also suffer variations.

The long-term effects of the tidal constituents variation are still debated, especially regarding predicting extreme sea levels (Arns *et al*., 2017; Haigh *et al*., 2020). In tidal prediction, the values for short-term predictions should be updated to the forecast date (Guo *et al*., 2018). However, for long-term predictions, even updated values could generate misleading results due to the unstable attributes of the tidal constituents, especially in strong tidal regimes (Byun & Cho, 2009), and shallow-water environments. Notwithstanding, further research is still needed to fully understand the consequences of the variation in tidal constituent values (Church *et al*., 2011).

Tidal constituent changes are usually caused by local unknown phenomena, which may affect the amplitude of tidal constituents. The usual method to verify the trend of the tidal constituents in tide gauges consists of segmenting the data into 12-month periods (Pawlowicz *et al*., 2002). Despite this segmentation providing one set of tidal constituents per year, these constituents become affected by nodal modulation.

The nodal corrections are the common approach, although the 12-month period segmentation undergoes nodal modulation effect compared to the HA approach with more than 18.6 years of data (Foreman *et al*. 2009). Hence, one method to increase the precision of tidal constituents is to use a larger dataset. This method allows for the identification and isolation of "satellite" constituents, characterized by slight frequency deviations from the main tidal constituents. Such precision, as demonstrated by

Zetler *et al*. (2015), leads to enhanced accuracy in tidal trend analysis.

We can extract the nodal modulation signal from the main astronomical constituents by increasing the segmentation period to 19 years, once the series size exceeds the nodal cycle period (Cherniawsky *et al*., 2010). However, the number of constituent sets is severely reduced (i.e., one constituent set for every 19 years of data). Tide gauges that have been recently installed often lack a database extensive enough to adequately address nodal effects in the analysis, a limitation also observed in tide gauges with data gaps or collection failures. In these cases, nodal corrections are the most typical approach employed for trend analysis. Nonetheless, the Global Sea Level Observing System - GLOSS (IOC, 2012) database presents several tide gauge records with lengths that exceed the need for nodal corrections.

The harmonic analysis method on annual series is a widely used method for evaluating the constituents of a tide gauge (Foreman,1977; Godin, 1986). In these methods, nodal corrections are made to adjust the constituent values. However, even considering these corrections, changes in trend may be masked by remnants of the nodal effect. Therefore, our study proposed a method that uses long-period series, i.e. sets longer than 18.6 years, to conduct harmonic analysis to suppress nodal period modulation from the primary tidal constituent. The selected tide gauges to validate this approach were Brest (France), Cananeia (Brazil), and Eastport (USA). The proposed method eliminates nodal influence and facilitates seeing the trends of the tidal constituents. Hence, the identified changes provide relevant insights for future tide-dependent planning. Comprehending the potential coastal impacts resulting from tidal variations empowers us to implement optimal strategic planning measures.

2. DATA AND METHODOLOGY

2.1 Tide Gauge Data

This study used real tide gauge elevation data to evaluate the proposed approach. The tide gauge selection criteria included the following items: location across the globe, record length, data availability and discontinuities, and knowledge of local changes that might affect the tidal pattern.

We considered only tide gauges with more than 50 years of data. The selected tide gauges (Figure 1) comprised i) Brest, Bretagne, France (BRE) (Pouvreau *et al*., 2006; Wöppelmann *et al*., 2008); ii) Cananeia, São Paulo, Brazil (CAN) (Harari & Camargo, 2003; Prado *et al*., 2019); and iii) Eastport, Maine, United States (EAS) (Pan *et al*., 2019; Ray, 2006). The data from these tide gauges were provided by the University of Hawaii Sea Level Center (Caldwell *et al*., 2015). The following tide gauge records have met the length criterion: i) Brest from 1846 to 2021 (176 years); ii) Cananeia from 1954 to 2006 (53 years), and iii) Eastport from 1929 to 2019 (91 years).

We looked for errors and discontinuity in each selected tide gauge record. BRE retained several discontinuities before 1860, and in the stretch between 1938 and 1951; hence the data from these periods were disregarded in this study. We failed to find any discontinuity in CAN, such as missing or outlier values. The full dataset of EAS remained usable regardless of a minor discontinuity in 1976.

The BRE tide gauge datum remained stable over the 1890-1996 period, despite the bombing of Brest during the Second World War. After this event, a 19 mm offset in MSL was found in comparison with the nearby station of Newlyn (Wöppelmann *et al*., 2008).

The CAN tide gauge region underwent changes that impacted the tide data. The most important one was in the Valo Grande channel: the channel was closed in 1979 for the construction of a dyke in 1979 and then reopened in 1983. A significant geomorphological change also occurred in the same period, with a 1-kilometer dislocation of the Icapara inlet between 1962 and 2000 (Prado *et al*., 2019). Relatively large subsidence has been found in the location (Almeida *et al*., 2015) since the 1960s. Furthermore, Harari & Camargo (2003) observed that the sea level trends in Cananeia did not align with the patterns typically seen in Southeastern Brazil. In light of this discrepancy, Bouin & Woppelmann (2010) suggested the need for a comprehensive investigation into tide gauge motion, utilizing GNSS recording to gain a deeper understanding of the situation.

The EAS tide gauge presented a slightly negative vertical movement relative to the mean sea level (-0.21 ± 0.07 mm/yr) (Bouin and Woppelmann, 2010). However, GPS-derived vertical velocity data indicated a positive vertical movement (2.07 ± 0,89mm/yr), contrasting with those presented by the local tide gauge (Bouin & Woppelmann, 2010).

After the previous verifications about the data consistency, we conducted the Harmonic Analysis (HA) using the T_Tide package (Pawlowicz *et al*., 2002) for each tide gauge dataset.

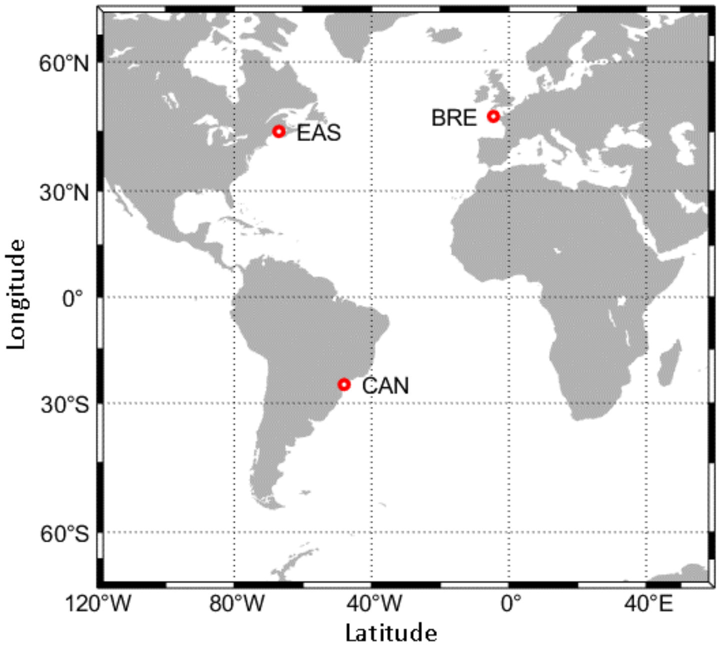

Figure 1. Tide gauge locations.

2.2 Harmonic Analysis

The tidal analysis method used in the T_Tide (Pawlowicz *et al*., 2002) assumes one-dimensional time series, expressed by Equation 1 (Foreman *et al*., 2009):

$$h(t_j) = Z_0 + \sum_{k=1}^{n} f_k(t_0) A_k \; COS \left[\omega_k \, (t_j - t_0) + V_k(t_0) + u_k(t_0) - g_k\right] + R(t_j) \quad (1)$$

where $h(t_j)$ is the measurement at time t_j; Z_0 is a constant background value (mean sea level); $f_k(t_0)$ and $u_k(t_0)$ are the nodal corrections to amplitude and phase lag, respectively, at some reference time t_0 for major constituent k with frequency v_k; A_k and g_k are the amplitude and the phase lag of constituent k, respectively; $V_k(t_0)$ is the astronomical argument for constituent k at time t_0; $R(t_j)$ is the non-tidal residual; n is the number of tidal constituents.

The approach of Godin (1986) for nodal corrections (applied in the T_Tide package) successfully stabilizes the amplitude and the phase lag variations with 18.6 years for most constituents. Nevertheless, the effectiveness of the nodal correction is subject to multiple factors, such as the location of the tidal record and the existence of nonlinear effects (Godin & Gutiérrez, 1986). Equation 1 also assumes that the amplitude and the phase of each constituent may remain stationary throughout the time series. This assumption might lead to an incorrect estimation of the amplitudes and phases of the tidal constituents (Codiga, 2011). Therefore, temporal changes in harmonic constituents should be evaluated using timely sequential tables of harmonic constituents. Thus, we checked only the M_2 constituent for this study, although the method may be applied to verify any major constituent stability and pattern changes.

2.3 Tendency analysis

During the analysis of the yearly HA constituents of the selected tide gauges, we identified the necessity for a method to suppress nodal modulation. All the significant components of the tide could be separated from 19 years of observations (Godin, 1986). The frequencies present in the diurnal and semidiurnal bands cluster in groups separated by a gap in frequency. Usually, in each group, one constituent dominates and is surrounded by others of lesser magnitude, which are called satellite constituents. Therefore, an analysis with more than 19 years of observations successfully separates these constituents and generates M_2 constituents with less variation.

Thus, we adopted a sliding window approach, in which each window has 19 years of data because HA suppresses the nodal variability when performed in datasets longer than 18.6 years. The central year of the 19-year series was presented as the reference year, for comparison purposes. We highlight that erroneous or missing values over long data series affect the HA results. Hence, we compared the yearly HA constituents and the 19-year HA constituents, which became a valuable source of information (Figure 2).

Additionally, in time-series analysis, the stability of a variable may be evaluated by performing statistical tests or verifying its adjustment to a previously fitted model. These evaluations consider mathematical approaches that identify pattern changes and structural breakpoints, although they fail to explain the cause of the change. However, the detection of tidal constituent changes in graphs depicting amplitude versus time was relatively straightforward. Thus, although a mathematical approach could be taken to confirm the quantitative changes (*e.g.*, a test with known break dates), the visual identification and historical study of local changes became a better approach.

In this study, breakpoint identification (Figure 2) took two steps: i) the detection of changes that may affect the tidal regime considering the local history; ii) the visual identification of pattern changes on generated graphs by the researcher.

Moreover, the tide gauge history knowledge facilitated the identification of vertical movements, changes in tide gauge location, or local changes near the tide gauge installation site. The M_2 amplitudes from tide gauges were compared with previously known pattern breaks presented in other studies.

We identified and considered a breakpoint for each tide gauge, which was used for the tendency analysis. We applied linear fitting to the values of M_2 amplitude. We also used the errors found in each HA to elaborate graphs and calculate tendencies. In summary, we followed the methodology described in Figure 2 to analyze the three tide gauges selected for this study.

We performed the yearly HA method and the 19-year HA method in BRE, CAN, and EAS tide gauges. In each tide gauge, we identified a breakpoint in the M_2 amplitude, by combining visual analysis of the amplitudes for both types of HA methods and considering local history. We disregarded the nodal correction method due to its higher variance. After removing the periods affected by the lack of information, we applied the 19-year sliding window approach. The obtained M_2 amplitudes before and after the breakpoints were submitted to linear fitting, considering the uncertainties in the amplitude values.

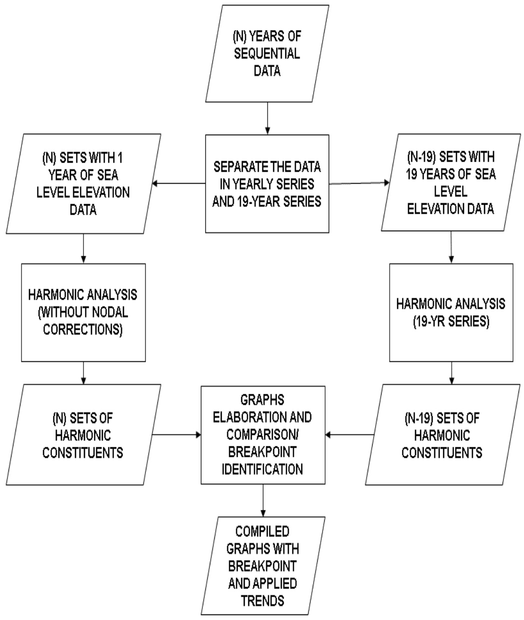

Figure 2. Flowchart for the methodology steps.

3. RESULTS AND DISCUSSION

Breakpoints were identified in different periods: 1945 to 1951 in BRE, 1983 in CAN, and 1980 in EAS. Table 1 provides a summary of the slopes, intercepts (with their respective standard deviations), and root mean square errors (RMSE) of the fitted lines.

The root-mean-square error was considerably smaller in the 19-year HA than its yearly counterpart, as expected by the smoothing characteristics of the 19-year analysis. The standard deviation was also smaller in the 19-year analysis, accounting for the suppression of the nodal effect. Usually, the slopes and intersections found were maintained, except in BRE general slope, CAN 1983-2007 intersect, and EAS 1929-1979 intersect. The specific results for each tide gauge are presented in the following sections.

3.1 Local Analysis

3.1.1 Brest

In the BRE case, the missing data near the 1940s is well known (Wöppelmann *et al.*, 2008). The lack of tidal constituents between 1945 and 1952 highlighted a slight upward change in the previous downward trend. However, this change became de-emphasized by the clear nodal modulation in the M_2 constituent.

Table 1. Linear fit of tide gauge M2 amplitude data for yearly HA, and 19-year HA

		YEARLY HA			19-YR HA		
		SLOPE (mm/yr)	INTERSECT (mm/yr)	RMSE (mm)	SLOPE (mm/yr)	INTERSECT (mm/yr)	RMSE (mm)
BREST	1860-2020	0.02±0.01	2019.76±25.41	55.3	0.12±0.01	2276.28±12.20	7.8
	1860-1937	0.39±0.03	2789.85±65.67	53.9	0.46±0.02	2928.96±35.10	2.7
	1953-2020	0.60±0.05	867.44±106.34	54.0	0.22±0.04	1619.86±78.43	2.4
CANANEIA	1954-2007	0.27±0.04	164.51±82.45	11.6	0.40±0.03	436.52±56.16	1.1
	1954-1982	0.45±0.09	515.30±186.03	10.9	0.56±0.07	735.20±130.05	0.2
	1983-2007	0.38±0.16	389.72±325.38	12.1	0.19±0.09	117.94±187.66	0.4
EASTPORT	1929-2019	1.00±0.04	676.63±88.65	65.8	0.80±0.02	1064.44±49.66	8.6
	1929-1979	1.80±0.18	882.42±344.81	47.9	0.83±0.08	1000.11±147.93	10.9
	1980-2019	1.04±0.15	584.71±303.53	52.6	0.98±0.10	689.59±203.51	3.0

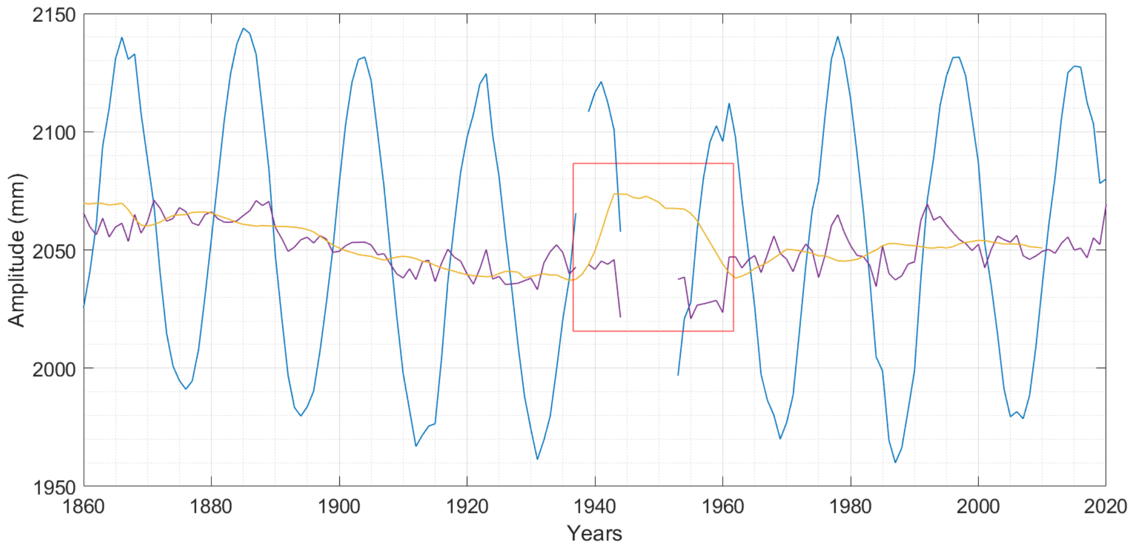

Figure 3. (BRE) M2 amplitudes (mm): without nodal corrections in blue; with nodal corrections in purple; the 19-year analysis in yellow. The red box highlights the large discrepancies found where the 19-year analysis was affected by the missing data.

The data gap (1945-1952) affected the 19-year HA results, masking the amplitude of unidentified constituents in the M_2 amplitude. The lack of information created a seemingly larger M_2 amplitude, with no physical causes (Figure 3). Therefore, this extra value in the amplitude of the M_2 constituent must come from the adjacent constituents, misidentified as M_2 due to the smaller volume of data available for HA.

Notwithstanding the identified minimum vertical motion of the tide gauge, there was no apparent correlation with the amplitude fluctuations in the M_2 tidal constituent. The BRE yearly HA presented an apparent nodal modulation effect in the M_2 amplitudes (Figure 4), as expected by the absence of nodal corrections. The remaining modulation effect was still identifiable in the 19-year M_2 amplitudes (Figure 5). The small oscillatory pattern noticed in Figure 5 and the original nodal oscillation noticed in Figure 4 present differences between phases. This result suggests that some long-period amplitude could be misidentified as a nodal influence. Thus, other long-period effects, such as the 8.85-year perigean cycle, still affect the M_2 amplitude in the 19-year HA. The change in the slope found in the yearly HA (-0.39±0.03 mm to 0.60±0.05 mm) also exists in the 19-year HA (-0.46±0.02 mm to 0.22±0.04 mm).

Our results align with the findings of Pouvreau *et al*. (2006), which suggested a long-period oscillation in the M_2 amplitudes, but no tidal constituent or combination of constituents could cause this oscillation tendency. However, the downward trend in the amplitude of the M_2 constituent noted in Brest between 1880 and 1920 might be attributed to harbor development or dredging activities as pointed out by Pouvreau *et al*. (2006)

Furthermore, Pineau-Guillou *et al*. (2021) found that several tide gauges in the North-East Atlantic exhibit a consistent break pattern, indicating that the observed change was unlikely to be attributed to local factors such as dredging or instrumentation errors.

The upward trend found post-break was expressively smaller in the 19-yr HA (0.60±0.05 mm vs 0.22±0.04 mm). On the other hand, a general downward trend (-0.12 ±0.01 mm) would not be adequate to represent the current pattern of these tide gauge constituents, due to the change near the 1940s. This downward trend was also questioned by Pouvreau *et al*. (2006), since their results, from 1960 on, pointed to an increase in the M_2 amplitude tendency.

3.1.2 Cananeia

The CAN analysis remained unaffected by the presence of identified missing values. The apparent sea level rise at a high rate, combined with a negative vertical movement in the region still needs a careful investigation, as stated by Bouin & Woppelman (2010). In CAN, both subsidence reported by Almeida *et al*. (2015) and the estuary changes pointed out by Prado *et al*. (2019) could potentially exert some influence on the upward trend observed after 1983.

For CAN, both the yearly HA (Figure 6) and the 19-year HA (Figure 7) exhibit an upward trend in the M_2 amplitude. However, the breakpoint observed in 1983, which appeared as a vertical offset in the yearly HA, was not evident in the 19-year HA. In the 19-year HA, a potential oscillatory pattern becomes visible in the later years (1983-1998) of the analysis. Interestingly, this pattern also existed in the early years (1963-1983) of the analysis, but it was obscured by the steep slope of the amplitude tendency.

The yearly HA revealed an upward trend in the amplitude of the M_2 constituent (0.45±0.09 mm to 0.38±0.16 mm). In the

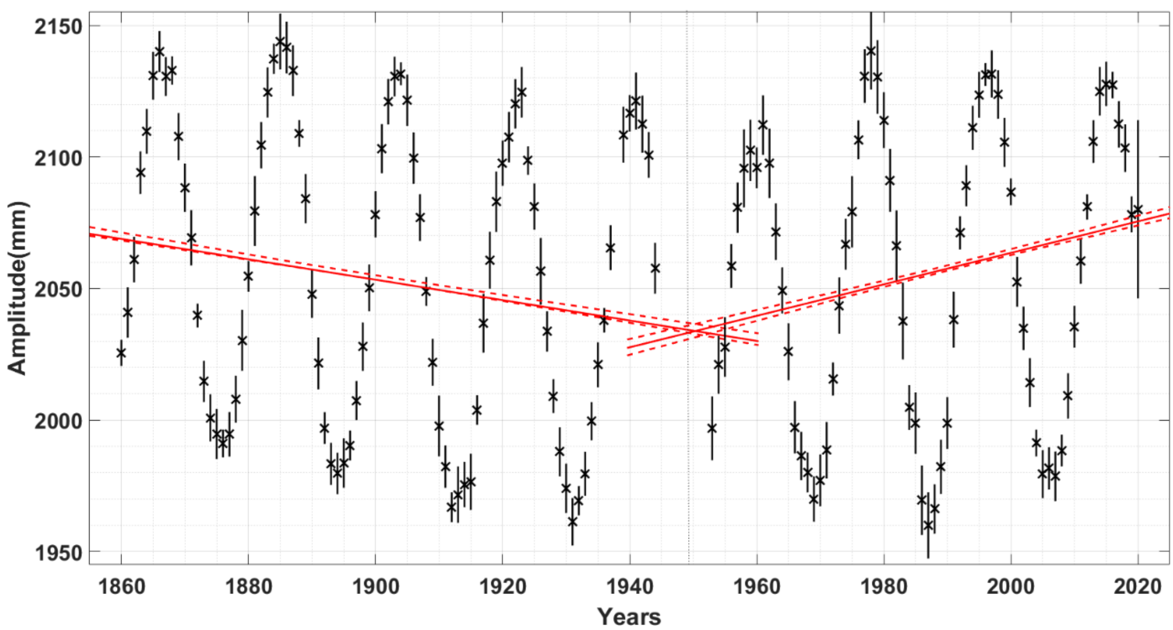

Figure 4. (BRE) Yearly HA M_2 amplitudes in mm, M_2 amplitude standard deviation in mm, and linear fits pre-1940s and post-1950s (red lines) considering the imprecision of the data (red dashed).

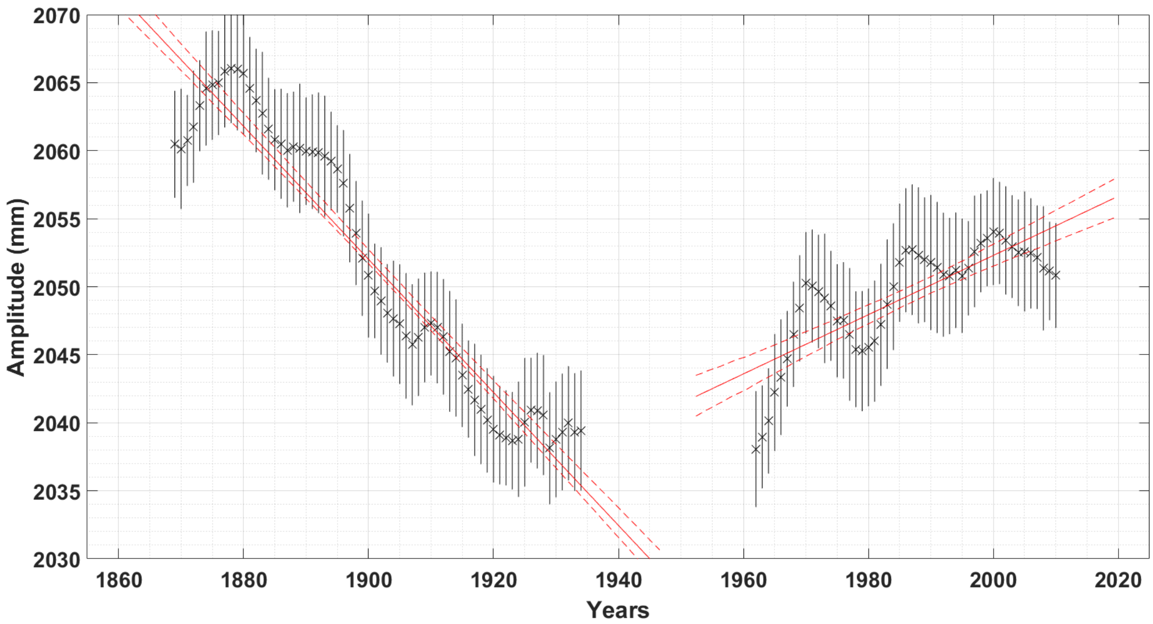

Figure 5. (BRE) 19-year HA M_2 amplitude in mm, amplitude standard deviation in mm, and linear fits pre-1940s and post-1950s (red lines) considering the imprecision of the data (red dashed).

19-year HA, the M_2 amplitude also presents an upward trend, but the trend found post-break was not as significant (0.56±0.07 mm to 0.13±0.09 mm) as the yearly trend. The milder slope observed in the 19-year HA suggests that a portion of the M_2 amplitude calculated in the yearly HA may have been influenced by nodal effects, indicating a significant nodal modulation in the yearly HA analysis values.

3.1.3 Eastport

The data unavailability affected the EAS results, which could explain some of the high deviation observed in the yearly HA (Figure 8). The 19-year HA (Figure 9) solved the deviation effect. However, even in the 19-year analysis, a smaller period modulation was still noticeable, suggesting that a portion of the effect initially attributed to nodal modulation comprised modulations with other periods. The yearly HA of EAS was consistent with the results of Ray (2006) and Pan *et al*. (2019). The inconclusive 1972 M_2 yearly amplitude (Figure 8) also correlates with the observation made by Pineau-Guillou *et al*. (2021). In both yearly and 19-year HA, the M_2 amplitude trend continued to show an upward direction, albeit with a minor vertical offset. The reduction in the trend slope is more visible in the yearly HA (1.80±0.18 mm to 1.04±0.15 mm). Conversely, the slope of the 19-year HA trend increased after 1980, suggesting that the drop in the M_2 amplitude during the 1980s could be attributed to changes in nodal modulation. Figure 9 depicts that the M_2 amplitude without nodal modulation maintains a relatively consistent slope as before (0.83 ±0.08 mm to 0.98 ±0.1 mm)

The upward trend identified here contradicts the results of Greenberg *et al*., (2012), which suggested that trends in M_2 amplitude after 1982 at Portland, Eastport, and Saint John were approximately half of those observed earlier due to an apparent regime shift, evident in both M_2 amplitude and MSL trend changes. Moreover, according to Pan *et al*. (2019), the North Atlantic Oscillation might also be a contributing factor to this effect, and the apparent reduction in M_2 amplitude could be attributed to nodal modulation. The 19-year HA effectively filters the interference caused by the nodal modulation. As a result, the residual modulation becomes minimal in comparison to the yearly HA. In the case of EAS, the 19-year HA does not exhibit a decrease (0.83 ±0.08 mm to 0.98 ±0.10 mm) in slope following the breakpoint. Therefore, the decrease reported by Greenberg *et al*. (2012) and also observed in our yearly HA analysis (1.8±0.18 mm to 1.04±0.15 mm) is closely associated with the nodal modulation effect on the M_2 constituent. The 19-year HA results in EAS showed that the trend slope increased after 1980. This outcome implies a potential correlation between the reduction in M_2 slope noted in other studies and the influence of nodal modulation.

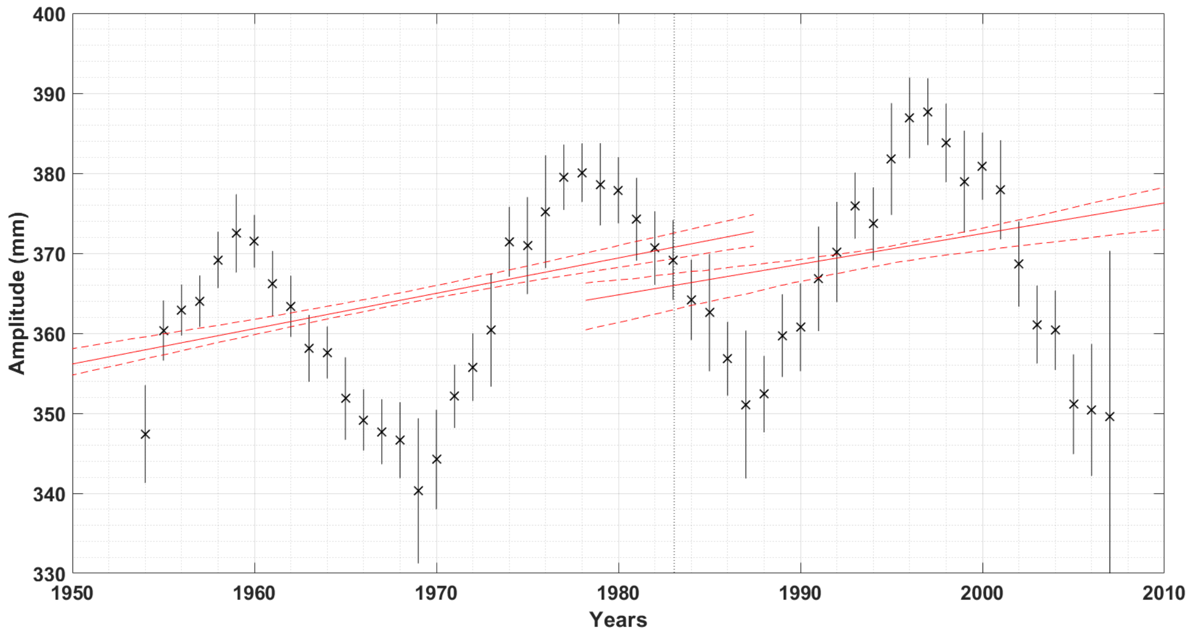

Figure 6. (CAN) Yearly HA M2 amplitude in mm, amplitude standard deviation in mm, and linear fits pre-1983 and post-1983 (red lines) considering the imprecision of the data (red dashed).

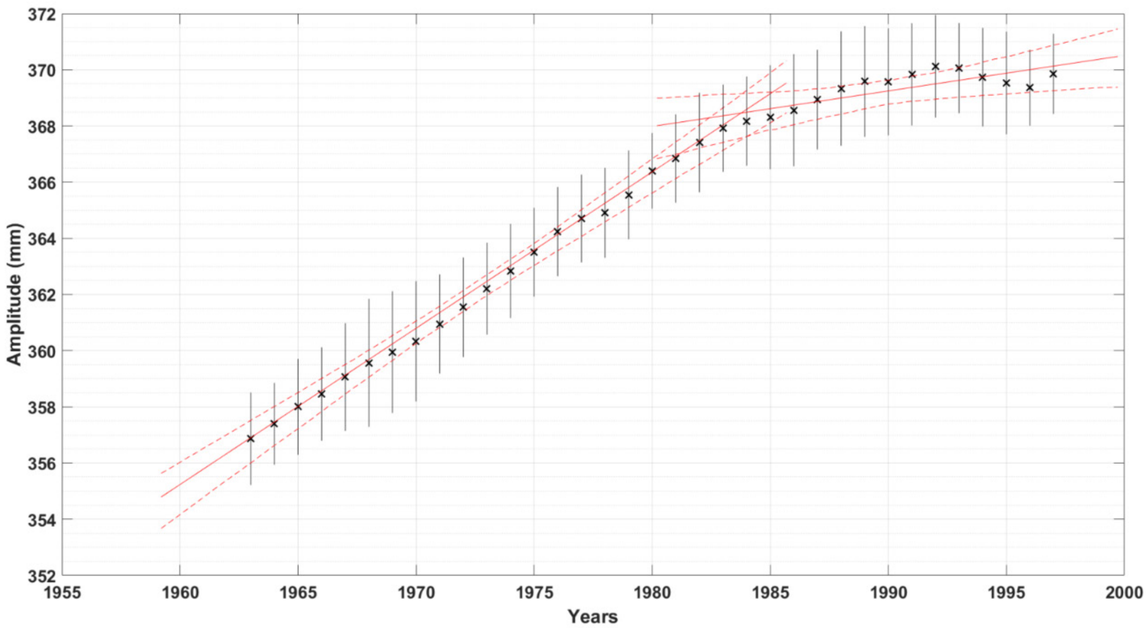

Figure 7. (CAN) 19-year HA M2 amplitude in mm, amplitude standard deviation in mm, and linear fits pre-1983 and post-1983 (red lines) considering the imprecision of the data (red dashed).

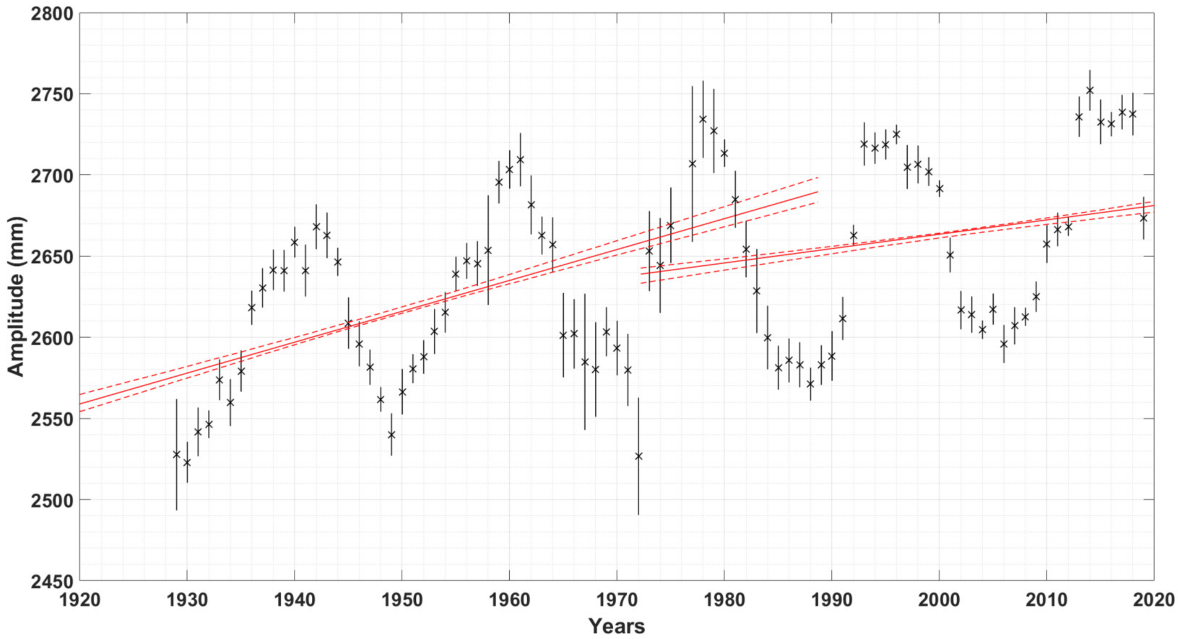

Figure 8: (EAS) Yearly HA M2 amplitude in mm, amplitude standard deviation in mm, and linear fits pre-1980s and post-1980s (red lines), considering the imprecision of the data (red dashed).

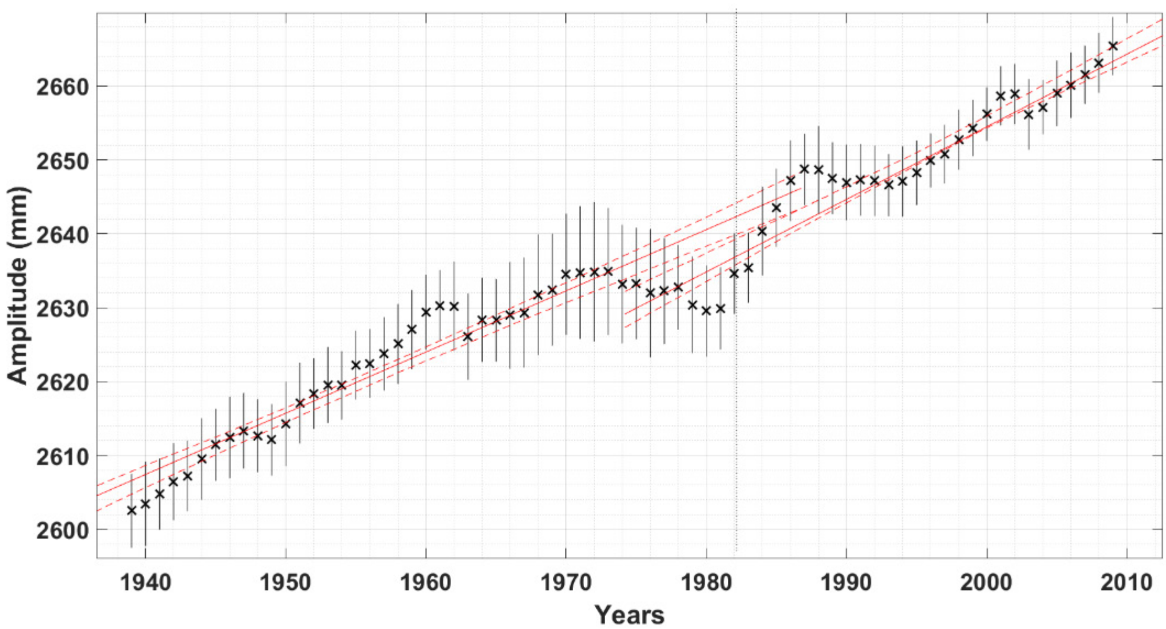

Figure 9: (EAS) 19-year HA M2 amplitude in mm, amplitude standard deviation in mm, and linear fits pre-1980 and post-1980 (red lines), considering the imprecision of the data (red dashed).

3.2 General Analysis

The results of each tide gauge reinforced the significance of conducting local research prior to data interpretation. During this phase, researchers play a crucial role, as they are required to engage in visual analysis with a discerning perspective. For instance, the observed shift in trend at the CAN tide gauge is linked to alterations in the estuary. Lacking awareness of the local context, the cause of this trend shift might erroneously be attributed to tide gauge movement. Likewise, a similar misinterpretation could arise at BRE if the researcher overlooks the 8-year data gap (indicated by the red square in Figure 3). In the case of EAS, we observed a high deviation in the yearly HA, which was solved by using the 19-year HA approach.

Nonetheless, local factors present challenges to breakpoint identification. Without a deeper understanding of local tidal circulation and hydrodynamics, the researcher might find multiple incorrect breakpoints without a physical basis. Each location must be thoroughly studied to gather information on potential causes of tidal trend changes. The availability of data can also invalidate the proposed approach, as it needs multiple consecutive 19-year series.

The 19-year HA results in EAS showed that the trend slope increased after 1980. This outcome implies a potential correlation between the reduction in M_2 slope noted in other studies Greenberg *et al*. (2012), Pan *et al*. (2019) and the influence of nodal modulation. Furthermore, the relationship between vertical movement and the 19-year HA results was opposite in EAS compared to CAN. EAS showed an upward slope, while CAN exhibited a downward slope. Despite this dissimilarity, there is no apparent direct association between vertical movement and fluctuations in M_2 amplitude tendencies.

Our proposed approach of 19-year HA method effectively eliminated the nodal impact on the M_2 amplitudes. The smoothing of variations led to diminished errors and improved the clarity of linear trend visualization. The comparison of yearly and 19-year HA allowed the identification of nodal influence in the M_2 amplitudes for each tide gauge.

Moreover, the variations observed in the three examined sites may potentially stem from shifts in mean sea level (MSL), alterations in coastal structures, and occurrences linked to climatic events.

4. CONCLUSIONS

The investigation of tidal nodal modulation has become a prominent subject of numerous studies in the present day. Researchers have been actively discussing the nodal modulation local influence and proposing several approaches to either eliminate or assess its impact. The nodal modulation might interfere with the value of the harmonic constituents, causing changes in the results of trend analyses. We recommend additional localized studies to gain a deeper understanding of how regional changes exert influence over M_2 amplitude and the overall tidal fluctuation. Our approach has demonstrated that nodal modulation can affect the tendencies in constituent amplitudes. Moreover, our approach facilitates the pinpointing of potential breakpoints. Therefore, our proposed approach of 19-year HA poses a relevant approach to verify these tidal constituent trends in locations affected by the nodal modulation variability. Subsequent research will be dedicated to investigating how these alterations impact tidal predictions and relative sea levels. Understanding the behavior of tides enables us to differentiate expected patterns from an astronomical tide perspective and identify potential effects attributed to climate change. Additionally, this comprehension empowers us to develop more effective coastal management plans tailored to tide-related factors.

CONTRIBUTIONS

André de Lima Coelho: Study conception, data collection, analysis and interpretation of results, manuscript writing and revision. Tiago Zenker Gireli: Study conception, analysis and interpretation of results, manuscript revision. Kelly Kawai Venancio: Analysis and interpretation of results, manuscript writing and revision. Patrícia Dalsoglio Garcia: Study conception, manuscript revision.

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PORT AND COASTAL MANAGEMENT AGAINST CLIMATE CHANGE: A CASE STUDY OF TANJUNG EMAS PORT SEMARANG, CENTRAL JAVA, INDONESIA

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ABSTRACT: This study investigates the climate resilience of Tanjung Emas Port, Semarang, Indonesia, a major port facing significant land subsidence and sea-level rise. Through a descriptive qualitative analysis, we examine the port's preparedness strategies and actions in response to climate change impacts. The research aims to provide valuable insights for port managers and decision-makers in developing effective climate adaptation measures. Key findings include the existence of a disaster contingency plan by the port authority, although further identification of disaster-prone port infrastructure is necessary. Based on PIANC standards, Tanjung Emas Port demonstrates a level of climate resilience, but additional research on the resilience of port infrastructure is warranted. Moreover, enhanced synergy among port users, operators, and stakeholders is crucial for building a robust resilience system. This research contributes to the understanding of climate resilience in ports and offers practical recommendations for port managers and policymakers. The findings and insights from this study can inform the development of effective climate adaptation strategies and policies, ultimately promoting the creation of resilient ports in the face of climate change challenges.

Keywords: Climate change, Port resilience, Tanjung Emas Port, Sea-level rise, Land subsidence, Disaster contingency plan, Port infrastructure, Climate adaptation, Stakeholder engagement, PIANC standards.

RESUMO: *Este estudo investiga a resiliência climática do porto de Tanjung Emas, em Semarang, na Indonésia, um importante porto que enfrenta uma significativa subsidência de terras e a subida do nível do mar. Através de uma análise qualitativa descritiva, examinamos as estratégias e acções de preparação do porto em resposta aos impactos das alterações climáticas. A investigação tem como objetivo fornecer informações valiosas aos gestores portuários e aos decisores no desenvolvimento de medidas eficazes de adaptação ao clima. As principais conclusões incluem a existência de um plano de contingência para catástrofes por parte da autoridade portuária, embora seja necessária uma maior identificação das infra-estruturas portuárias propensas a catástrofes. Com base nas normas PIANC, o porto de Tanjung Emas demonstra um nível de resiliência climática, mas é necessária investigação adicional sobre a resiliência das infra-estruturas portuárias. Além disso, uma maior sinergia entre os utilizadores, operadores e partes interessadas do porto é crucial para a construção de um sistema de resiliência robusto. Esta investigação contribui para a compreensão da resiliência climática nos portos e oferece recomendações práticas para os gestores portuários e decisores políticos. As conclusões e os conhecimentos deste estudo podem servir de base ao desenvolvimento de estratégias e políticas de adaptação climática eficazes, promovendo, em última análise, a criação de portos resilientes face aos desafios das alterações climáticas.*

Palavra-chave: *Alterações climáticas, Resiliência portuária, Porto de Tanjung Emas, Subida do nível do mar, Subsidência de terrenos, Plano de contingência para catástrofes, Infra-estruturas portuárias, Adaptação às alterações climáticas, Envolvimento das partes interessadas, Normas PIANC.*

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1. INTRODUCTION

Climate change is the biggest threat facing the planet now, as a consequence of the ever-increasing use of fossil fuels. Melting ice sheets result in rising sea levels (Boukarta & Berezowska-Azzag, 2022). The global hydrological cycle has been altered as a result of the warming of the planet (Oza *et al*., 2022). Extreme weather and other disasters are possible results of climate change. Climate change can cause various kinds of impacts, one of the biggest impacts is the hydrological consequences. The water balance in an area becomes unbalanced, especially due to increased evaporation (Marsz *et al*., 2022).

Additionally, ports are crucial nodes in both regional and international supply chains (León-Mateos *et al*., 2021). Because of its closeness to the ocean, the port is a crucial economic sector at risk from climate-related disasters (Poo *et al*., 2021). Climate change also results in social risks, social risk is one of the impacts that occur from social vulnerability, resilience and adaptive capacity (Lupu, 2019). Rising sea levels, storms, floods, tidal waves, strong winds, heavy rain, and higher average water temperatures are only some of the natural disasters that the changing climate is causing. According to previous studies that confirm this, port flooding due to rising sea levels, violent storms, strong winds, and erosion of coastal areas is the most significant hazard to ports. The devastating effects of climate change necessitate port adaptations. Port authorities and stakeholders can utilize an adaptation framework to assess the impact of climate change on their operations and develop effective responses (da Veiga Lima & de Souza, 2022a; Yang *et al*., 2018).

The melting of ice sheets and thermal expansion of warming seawater contribute to an overall increase in sea levels due to global warming. Half of the sea level rise from 1971 to 2018 was due to thermal expansion, the rest was due to melting ice sheets, and 8% was due to surface water storage. From 2006 to 2018, rising sea levels had a significant contributor in the form of melting ice from the Earth's surface. The present-day sea level rise is as much as 20 centimeters. Depending on future emissions, it will continue to go up (Arias, *et al*., 2022). When sea levels rise, piers, storage areas, and breakwater piers may become inaccessible, rendering port facilities useless and raising expenses for relocation and repairing flooded facilities (da Veiga Lima & de Souza, 2022b).

Subsidence is a common issue in large coastal cities like Semarang. It wreaks havoc on urban infrastructure, such as roads and buildings, and other infrastructure, such as ports (Yastika *et al*., 2019). Semarang City's ports and coastal areas are frequently flooded due to soil subsidence and other factors. Geodetic monitoring, groundwater extraction, and engineering geology are just a few monitoring methods applied to study land subsidence in Semarang.

The rate of land subsidence in Semarang varied spatially between 1 and 10 cm per year between 1980 and 2010, according to geodetic measurements (Sarah & Soebowo, 2018). Overpopulation, Industrialization, and excessive groundwater consumption are to blame (Bott *et al*., 2021). The Tanjung Emas Port is located nearby, and land subsidence has been observed in the surrounding waterways and alluvium sediments (Yastika *et al*., 2019). Coastal areas, including the port area in Semarang, face a severe threat from the combined effects of sea level rise and ground subsidence (Nurhidayah & McIlgorm, 2019). Approximately 6.51 centimeters per year is the average rate of sea level rise in Semarang waters (Salsabila *et al*., 2022).

The effects of climate change have been the subject of extensive study. Despite the issue's urgency, studies of climate change's impact on ports are still scarce (Panahi *et al*., 2020). Therefore, studying ports' preparedness for climate change's effects is appealing. This research looks at how well-prepared ports are to deal with the effects of climate change, using the example of Tanjung Emas Port in Semarang, Indonesia. This study will shed new and vital light on how ports may adapt to climate change. When it comes to sustaining and enhancing port performance in the face of the problems posed by climate change, this study can also help decision-makers and connected parties design effective strategic strategies.

This study exclusively investigates the impacts of climate change on Tanjung Emas Port in Semarang, Indonesia. The hypothesis is that the port is not fully prepared to withstand the growing climate risks, particularly considering the potential for future intensification. By focusing on Tanjung Emas, this research aims to provide valuable insights into the vulnerabilities of ports to climate change and identify necessary adaptation measures. The findings may highlight the urgent need for comprehensive strategies to enhance port resilience and ensure long-term sustainability in the face of climate challenges.

First, a literature review of various literatures is presented, including previous research related to climate change, climate change and its effects on ports, and how resilient ports should be to climate change. Then the second is presented regarding the explanation of the research location. the third is presented regarding the methodology used in this study. The fourth, this study presents the results of research analysis and field observations as well as the results of FGDs, then also presents on how the actions and potential actions taken by the port of Tanjung Emas in the face of climate change. Finally, a summary and discussion of what the port should do in the face of climate change and what findings are generated from this study are presented. The conclusion drawn from the study is presented at the end of this paper.

2. LITERATURE REVIEW

The maritime sector, essential for global trade and the world economy, is encountering unparalleled difficulties as a consequence of climate change (A. Becker, 2020; Lau *et al*., 2024)

As a reference in dealing with the impact of climate change on ports, this study uses illustrations from the PIANC (Permanent International Association of Navigation Congresses) Guidelines regarding the relationship between climate factors and their effects on port infrastructure from PIANC. It is similarly centered on the port work sector. This study relates to PIANC because Indonesia is a member (Indonesia formally joined PIANC in January 2016).

The World Association for Waterborne Transport Infrastructure, or PIANC, is an international professional organization created in 1885. PIANC is a global organization that provides guidance and technical support to ports, marinas, and waterways on sustainable aquatic transportation infrastructure. PIANC is deeply concerned about sustainable development, climate change, working with nature, and digitization (https://www.pianc.org/about). PIANC is the only global organization involved in maritime affairs. Providing recommendations on sustainable water transportation infrastructure for ports and waterways is one of PIANC's responsibilities Table 1 depicts the link between climate conditions and port infrastructure impacts.

The PIANC paper categorizes ports into eight sections: navigation zone, protective infrastructure, maneuver, and berthing area, loading/unloading area, storage/offices, processing/manufacturing area, and hinterland connection. This study refers to these eight kinds of port areas/port activities. For example, air temperature, water temperature, precipitation intensity, mean

Table 1. Relationship between climate parameters and impacts on port operations/infrastructure.

Work Area in Port	Climate Parameters	Impacts
Navigation Zone	Air Temperature, Water temperature, Precipitation Intensity/distribution, Mean sea level/astronomical tide, Wind conditions/stoThriness, water chemistry	Ice or Icing, Snow or hail, Fog or visibility, Water depth, Currents, Sediments characteristics, Wind load, Biological change
Protective infrastructure		Ice or icing, Overtopping, Scouring Wave load, Biological change, Corrosion
Manoeuvre and berthing area		Ice or Icing, Fog or visibility, Water depth, Currents, Scouring/accretion, Wave characteristics, Wind Load, Biological change, Corrosion
Loading/Unloading Area	Air temperature, Precipitation intensity/distribution, Mean sea level/astronomical tide, Wind conditions/storminess, Water chemistry	Excess heat/humidity, Ice or icing, Snow or hail, Fog or visibility, Surface water flooding, Overtopping, Water depth, Wave load, Wind load, Biological change, Corrosion,
Port equipment,	Air temperature, Precipitation Intensity/distribution, Wind conditions/storminess	Excess heat/humidity, ice or icing, Snow or hail, Fog or visibility, Surface water flooding, Overtopping, Water depth, Wave load, Wind load, Biological change, Corrosion,
Storage/office		
Processing/ manufacturing		
Hinterland connections	Air temperature, Water temperature, Precipitation intensity/distribution, Mean Sea Level/Astronomical Tide, Water chemistry	Excess heat/humidity, Ice or icing, Snow or hail, Fog or visibility, Surface water flooding, Overtopping, Water depth, Currents, Sediment dynamics, Wave characteristics, Groundwater flooding, Legacy contamination, Wind load, Biological change, Corrosion

(Source : (Brooke *et al.*, 2020))

sea level, wind conditions, and water chemical conditions can all be affected by climate characteristics in the navigation area zone. Visibility or fog that interferes with navigation, water depth, changes in currents and sediment dynamics, wave features that interfere with navigation, wind loads, and changes in biological conditions can all have an impact (Brooke *et al.*, 2020)

So far, we only have a general idea of how climate change will affect ports. However, several studies have looked at individual ports. Several studies in Asia have concluded that port cities in several Asian countries are at risk from climate change. Adaptation tends to have a negative impact on other ports compared to mitigation. However, in general, adaptation can also improve community welfare more quickly. Mitigation efforts remain essential as a long-term solution to climate change. This research provides insight into how the world's port cities are working together to address the global challenges of climate change while rebuilding their identities as progressive and ecologically responsible urban centers (Blok & Tschötschel, 2016; Jiang *et al.*, 2020). Another research about a hybrid statistical-dynamic hybrid framework combining weather generators and meta models can be used to probabilistically evaluate port operations considering climate change influences such as sea level rise (Camus *et al.*, 2019). Research conducted on 18 port organizations in China shows that port organizations are generally aware of climate change and agree that more advanced measures must be taken. However, policy support is key to implementing climate change adaptation plans (Lin *et al.*, 2020).

A study was done in 2,013 ports worldwide (Toimil *et al.*, 2020), analyzing the global risks and effects of high-level warming by looking at atmospheric and ocean materials, setting operational limits for industries, and assessing vulnerabilities. In the year 2100, places in the Pacific Islands, the Caribbean Sea, and the Indian Ocean were found to be in a perilous situation. Ports in the African Mediterranean and the Arabian Peninsula (the Persian Gulf and the Red Sea) are at very high risk. Much research has also been done on how ready and strong the ports in South America and the Caribbean Islands are. The results show that ports need better information and knowledge about setting up a local database of important climatological parameters, permanent scale projections, and temporary risks for port operations. And infrastructure in different climate situations (Mariano & Cascajo, 2020). With case studies of several ports in the United Kingdom, the Climate Change Risks Indicator Framework was made to help lawmakers evaluate ports. This study used Evidence Reasoning (E.R.) to fill in missing data to evaluate climate risk at ports (Poo *et al.*, 2021). Still, more research is needed, especially case studies of specific ports in different parts of the world, such as Indonesia, to learn more about the effects of climate change on ports and what can be done to fix them.

Several studies have shown that sea level rise caused by climate change is the leading cause of problems with port facilities. The research was done at Morocco's Tangier Med-Port Port, whose operations will be affected if the High-End Scenario happens in 2090 (Jebbad *et al.*, 2022). Another study done at the Port of Mobile, Alabama, showed that if a hurricane like Hurricane Katrina hit in the late 21st century, the damage to the port would be nearly seven times worse than what Hurricane Katrina did on its own (Abdelhafez *et al.*, 2021). Researchers who looked at case studies in Indonesia and Japan found that when people face the problem of relative SLRs, they tend to move closer to the sea instead of moving away. This adaptation to face the SLR is an example of maladaptation (Esteban *et al.*, 2020). Then, another study that talks about the future effects of SLR is research that looked at how well ports and low-lying areas in Tohoku, Japan (which was hit by the 2011 Tsunami Earthquake) and Jakarta, Indonesia, were able to adjust. The results of this study show that one way to figure out how SLRs will affect transportation systems in the future is to look at how ports in Japan and Indonesia deal with sinking land. At the same time, adaptation will not cost more if a stricter plan for preventing climate change is implemented (Esteban *et al.*, 2020). Another research says that one way to adapt to SLRs is to change how harbors and other coastal defense buildings are built ahead of time and the study will look at changes in international maritime trade that align with world temperature rises of 2°C and 4°C, as well as the effects of sea level rise that would come with those temperature rises (Hanson & Nicholls, 2020).

Climate change impacts global shipping networks, requiring the development of a methodology combining climate risk indicators, centrality analysis, and ship routing optimization to identify alternative routes and reduce vulnerabilities (Poo & Yang, 2024). Another research indicates that global ports will increasingly be exposed to significant risks due to climate change, including extreme sea level rise (ESLs), waves, and extreme heat events. By 2050, between 55% and 59% of the 3,630 ports considered may face ESLs exceeding 2 meters above baseline average sea level. By 2100, this figure is projected to rise to between 71% and 83%. Although international and regional policies and legal instruments have been established to support climate change adaptation, resilience building, and disaster risk reduction in ports, further action is required to accelerate the implementation of effective adaptation measures across regions (Asariotis *et al.*, 2024).

Another study was done on how ports can adapt to climate change and its effects in Australia. This research found that effective adaptation solutions are not just about the physical layout and engineering projects. However, it must also change how ports are managed and planned (Ng *et al*., 2013). Other studies (Yang *et al*. 2018) say that taking the steps suggested in the literature to adapt to climate change can lower the chance that significant climate change will affect how a port works.

A resilient port can bounce back quickly after natural disasters without suffering severe losses, damage, or a drop in productivity or quality of life, and does so with little to no outside aid. Ports can prepare for climate change in some ways, some of which are: 1. involving the entire network of stakeholders in resilience planning; 2. increasing local climate projections and improving conditions for risk assessment; 3. choosing adaptation strategies, such as renewing storm defenses, elevating buildings based on projected sea level rise, or relocating the harbor as a whole (A. Becker, 2013); and 4. developing an environment that is beneficial to coping with the effects of climate change. The concept of resilience ports system shown in Figure 1.

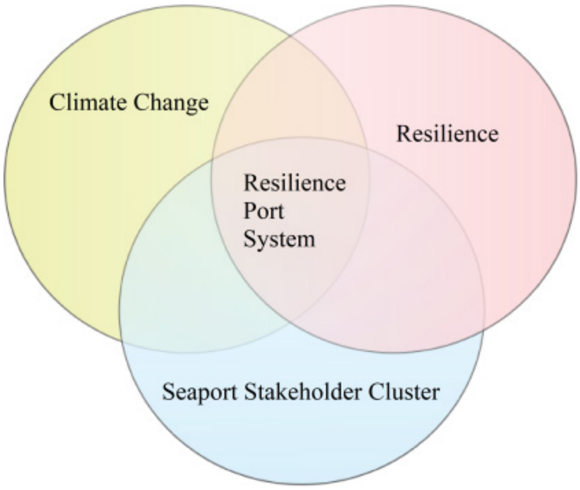

Figure 1. Sea Port Resilience System (Source: (A. H. Becker *et al.*, 2013))

3. MATERIAL

The location of this research is being conducted in Semarang, Central Java, Indonesia. Tanjung Emas is Semarang City's only harbor for both people and freight. Geographically it is located at -6.94S and 110.423E or roughly 5 km from Tugu Muda City Center Semarang.

The port is run by the state-owned company P.T. (Persero) Pelabuhan Indonesia III Tanjung Emas Branch, which is overseen by Kantor Syahbandar dan Otoritas Pelabuhan (KSOP) Class I Tanjung Emas, a Technical Implementation (UPT) under the Ministry of Transportation's Directorate General of Sea Transportation. This port is a class I port on an international scale and is a strategic port supporting sea transportation in Semarang (Ariyono *et al*., 2017). Tanjung Emas Port is an efficient port in western Indonesia (Sutomo & Soemardjito, 2012) based on the criteria of (1) density of transportation infrastructure, (2) port capacity, and (3) speed of commodities flows to the port. Tanjung Emas Port in Semarang serves as a liaison (supply chain logistics), commercial gateway, and a link between sea, land, and rail transit via railroad reactivation. Semarang Tanjung Emas Port offers Roro Terminal, Passenger Terminal (both International and Domestic), Container Terminal (both International and Domestic), Liquid Bulk Terminal, and Dry Bulk Terminal services. Fuel, LNG, LPG, CPO, and asphalt are among the commodities handled at the Liquid Bulk Terminal. Tanjung Emas Port is also expected to be able to support businesses such as textile, food, energy, gas shipping, and other manufacturing. The Location of Tanjung Emas Port in Semarang is seen in Figure 2.

4. METHOD

The method used in this research is descriptive analysis to explain the readiness of Tanjung Emas Port to face climate change. The research flow chart is shown in Figure 3. The primary and secondary sources of data were used for this review. The data used is secondary data obtained from Kantor Syahbandar dan Otoraritas Pelabuhan (KSOP) Class I Tanjung Emas and PT Pelindo Regional III. The data include Tanjung Emas Port Semarang port facilities in 2022.

A group discussion was conducted once among scientists and stakeholders on September 27, 2022. This focus group discussion (FGD) took place to collect information from stakeholder and scientists about how the Tanjung Emas Port is handling the effects of climate change. The discussion aimed to identify strategies that the port can adopt to enhance its resilience. Stakeholders involved in this discussion are BMKG (Badan Meteorologi, Klimatologi, dan Geofisika) or Meteorological, Climatological, and Geophysical Agency; KSOP, PT Pelindo Regional III, and BRIN (Badan Riset dan Inovasi Nasional) or National Research and Inovation Agency.

The selection of FGD participants was based on the significance of their role in managing ports concerning climate change. KSOP

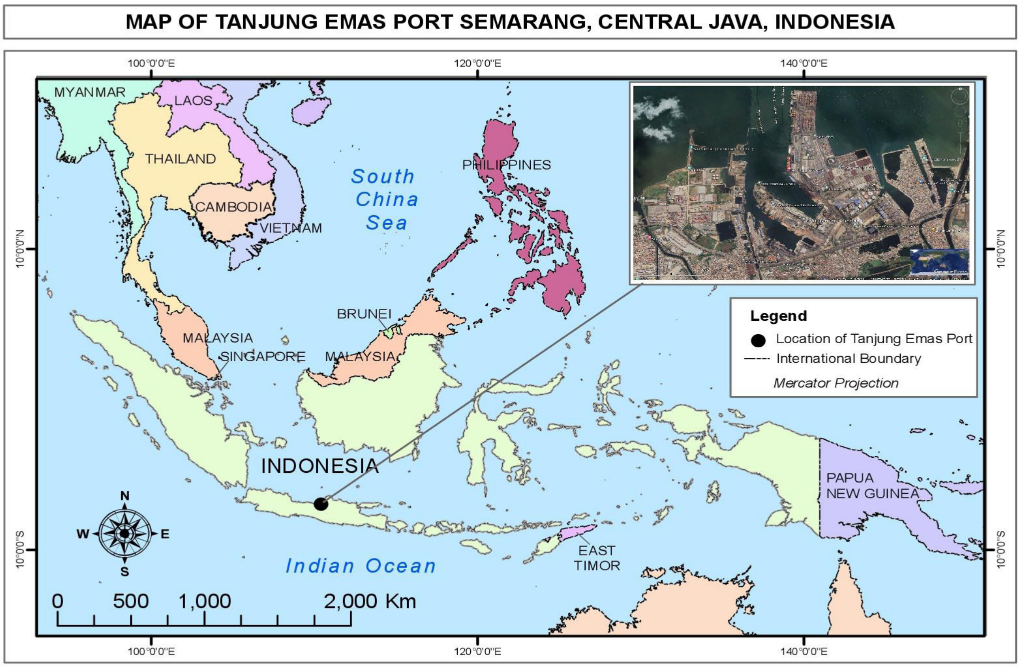

Figure 2. Location of Tanjung Emas Port Semarang (Source: Processed Secondary Data, 2024).

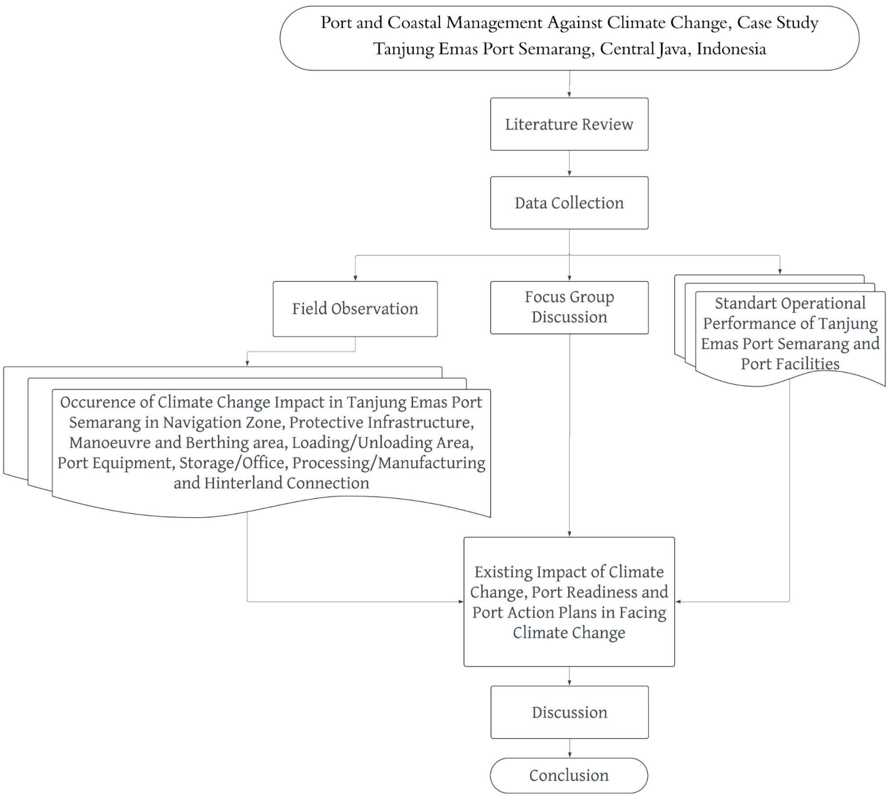

Figure 3. Flow chart of the research.

is active in policymaking and regulation, BMKG is a climate information agency, PT Pelindo Regional III is a port operator or user, and BRIN is also a scientists for hydrometeorological disasters. FGD participants were agency executives, port managers, hydrometeorological disaster professionals and disaster practitioners. In particular, those present in the FGD are senior officers from each institution with the appropriate knowledge, power and skill necessary to design and build climate resilient ports. Figure 4 shows FGD activity.

Researchers also made direct observations in the field to see the impact of climate change occurring at Tanjung Emas Port and to validate the data obtained from the agency. Direct field observations were carried out in each port area as classified according to the PIANC document. The area is divided into eight areas: a navigation zone, protection zone, maneuvering and berthing area, loading and unloading area, port equipment, storage/office area, processing/manufacturing area, and hinterland connection.

Direct observations were carried out to determine the impact of climate change on regional navigation zones, especially the influence of climate parameters such as air temperature, water temperature, rainfall intensity, average sea level/astronomical tides, wind/storm conditions, and water chemistry. Observations are made by observing whether there is ice or ice, snow or hail, fog or visibility, water depth, current sediment dynamics, wave characteristics, wind loads, and biological changes that can disrupt the smooth navigation of ships and other air transport.

Like observations in the navigation area, observations are carried out by observing whether there are impacts arising from climate change, such as ice cover, water overflow, scouring, wave loads, biological changes, and corrosion on the area's protective infrastructure.

Observations in maneuvering and anchoring areas are carried out by observing whether icing occurs, fog or visibility occurs and disrupts the port process, water depth that can interfere with the ship's berthing, currents, scour/accretion, wave characteristics, wind loads, biological changes, and corrosion that occurs in that area. Observations in the loading/unloading area are carried out by observing the processes of excess heat/humidity, ice or layers of ice, snow or hail, visibility of fog that can disturb the area, surface water flooding, runoff, water depth, wave load, wind load, biological changes, and corrosion that occur in that area.

Observations of the port equipment, storage/office, and processing/manufacturing areas are carried out to see if there is excess heat/humidity, ice or layers of ice, snow or sleet, fog or visibility, surface water flooding, water overflow, groundwater flooding, legacy contamination, wind loads, and corrosion. Meanwhile, observations for hinterland area connections

Figure 4. Focus Group Discussion to identify strategies that the Tanjung Emas Port Semarang can adopt to enhance its resilience (Source: Primary Data, 2022).

are carried out by observing whether there is excess heat/ humidity, ice or layers of ice, snow or hail, fog or visibility, surface water flooding, water overflow, water depth, currents, sediment dynamics, wave characteristics, water flooding, legacy contamination, wind loads, biological changes, corrosion occurring, or not.

A systematic search was also conducted to find all articles published in English and other languages related to the subject of the current review from 2012 to 2022 Science Direct and Google Scholar databases. The keywords used for the search are "Port Tanjung Emas, Port Resilience, Climate Change in Port Tanjung Emas, Sea Level Rise, Climate Change in Port, Land Subsidence in Port Tanjung Emas Semarang, Land Subsidence in Semarang." The articles found were then selected according to the scope of the subject of this current review.

Based on the potential application of specific methods or approaches, case studies were selected to explore and estimate the impacts of climate change in a specific context. The search using the keywords yielded the following results: 1 article on a specific topic, 77 articles on another topic, no articles on a third topic, an estimated impact value of 33.046, 41 articles on a fourth topic, no articles on a fifth topic, and seven articles on a sixth topic. The study also placed significant emphasis on research articles related to policies for climate change adaptation in ports. After that, each of the papers main findings was noted along with their research scale, adopted methods, the illustration of concepts, and their limitations.

5. EXISTING IMPACT OF CLIMATE CHANGE IN THE TANJUNG EMAS PORT SEMARANG

Researchers conducted field observations to validate the data and explore the extent to which climate change is affecting the port area. The results of these observations are explained in the points below.

a. Navigation zone
Because in a tropical country, the ice and snow phenomenon does not occur. For the navigation area, based on observations, it shows that the phenomenon of fog or visibility of water depth, currents, wave characteristics, and wind load occurs. The navigation area is not affected by sediment dynamics and biological change phenomena. Because of this, the conditions in the navigation zone environment of the Semarang Emas Port are relatively safe to carry out work operations by the density of ship traffic that has existed so far. Table 2 shows existing impact of climate change in the Tanjung Emas Port Semarang at the navigation zone.

b. Protective Infrastructre Zone
At present, the existing condition of the breakwater of Port Tanjung Emas is below sea level, and this is due to sufficient scour at the breakwater and a pretty intense wave loading along the breakwater. Table 3 shows existing impact of climate change at protective infrastructure zone in the Tanjung Emas Port Semarang.

c. Maneuver and Berthing Area
In the maneuver and berthing port work area, the process of ice or icing does not occur because the Tanjung Emas Port

Table 2. The Curent Impact of Climate Change in the Tanjung Emas Port Semarang at Navigation Zone.

Impact of Climate Change	Explanation	Yes	No
Ice or Icing (N/A)	There is a layer of ice around the navigation zone		√
Snow or hail (N/A)	The occurrence of snow or hail in the navigation area		√
Fog or visibility	There is fog which causes a decrease in visibility in the navigation area	√	
Water depth	The occurrence of silting which disrupts the navigation flow	√	
Currents	The strength and direction of the currents that occur in the navigation channel	√	
Sediments dynamics	The dynamics of sedimentation that occurs in the navigation area		√
Wave characteristic	Wave characteristics in the navigation area	√	
Wind load	The occurrence of strong winds can affect the navigation process	√	

(Source: Processed Primary Data, 2022)

Table 3. The Curent Impact of Climate Change at Protective Infrastructure Zone in the Tanjung Emas Port Semarang

Impact of Climate Change	Explanation	Yes	No
Ice or Icing (N/A)	There is a layer of ice around the protective infrastructure zone		√
Overtopping	Occurrence of overtopping/overflow of seawater in massive breakwater structure		√
Scouring	The occurrence of scouring on the concrete structure of breakwater buildings	√	
Wave load	Intense wave loading on breakwater structures due to big waves	√	
Biological change	Biological changes (marine biota) around the breakwater area		√
Corrosion	Corrosion occurs in breakwater structures		√

(Source: Processed Primary Data, 2022)

in Semarang is located in a tropical country. Ships must maneuver when they are about to sail or arrive at the port and when crossing canals and traffic zones. Maneuver and berthing areas are crucial port work areas because they involve the safety of shipping ships. Therefore, climate change impacts in this area are very influential, such as wave load, overtopping, scouring, and changes in biological conditions. Overtopping, scouring, wave loads, and biological changes in the maneuver and berthing area did not occur at Tanjung Emas Port, Semarang. Table 4 shows existing impact of climate change at protective maneuver and berthing area in the Tanjung Emas Port Semarang.

d. Loading/Unloading Area
Based on the actual conditions, the results of observations in the dock area/loading and unloading area have increased heat/humidity, which is relatively high. Under certain conditions, massive seawater runoff and tidal floods often occur. There was no siltation in this area but quite an intense wave loading in the dock/loading area due to big waves. For wind conditions that do not affect the loading and unloading process, the occurrence of quite massive corrosion on the dock/loading and unloading facilities and infrastructure needs special handling so as not to disturb the loading and unloading process. Table 5 shows existing impact of climate change at loading/unloading area in the Tanjung Emas Port Semarang.

e. Port Equipment Area
In the work area for Port Equipment, the process of ice or icing and snow or hail does not occurs because Tanjung Emas Semarang Port is located in a tropical country. Based on the actual conditions observed in the port equipment work area, climate change impacts such as excess heat/humidity, fog or visibility, surface water flooding, overtopping, groundwater flooding, and legacy contamination do not occur at Tanjung Emas Port. However, corrosion can happen in this port work area. Table 6 shows existing impact of climate change at port equipment area in the Tanjung Emas Port Semarang.

f. Storage Office Area
In the storage office work area, climate change impact that do not occur are ice or icing and snow or hail because Tanjung Emas Port is in a tropical country. Meanwhile, other climate change impacts that occur in the port work area are the occurrence of excess heat/humidity and corrosion. While fog or visibility, surface flooding, overtopping, groundwater flooding, and legacy contamination. Table 7 shows existing impact of climate change impacts at strorage office area in the Tanjung Emas Port Semarang.

g. Procession Manufacturing Area
In the procession manufacturing work area, the climate change impact such as ice or icing and snow or hail do not occur because Tanjung Emas Port is located in the tropics. The climate change impacts such as fog or visibility disturbance, surface water flooding, overtopping, groundwater flooding, and legacy contamination do not appear in the work area of the procession manufacturing port. However, excess heat/humidity affect the procession manufacturing area. Table 8 shows existing impact of climate change change impact at procession manufacturing area in the Tanjung Emas Port Semarang.

h. Hinterland Connection Area
In general, the hinterland connection does not have much impact on climate change. Still, several aspects of field conditions need attention, namely high heat/humidity, seawater runoff under certain conditions, and massive corrosion of infrastructure in the hinterland connection area. Table 9 shows existing impact of climate change impacts at hinterland connection area in the Tanjung Emas Port Semarang.

Table 4. The Curent Impact of Climate Change at the Maneuver and Berthing Area in the Tanjung Emas Port Semarang.

Impact of Climate Change	Explanation	Yes	No
Ice or Icing (N/A)	Icing process or the presence of ice in the maneuver and berthing area		√
Overtopping	Overtopping of seawater in the maneuver and berthing area		√
Scouring	Scouring occurred in the maneuver and berthing area		√
Wave load	Intensive wave load in the maneuver and berthing area		√
Biological change	Biological changes around the maneuver and berthing area		√
Corrosion	Corrosion occurs in the maneuver and berthing area		√

(Source: Processed Primary Data, 2022)

Table 5. The Curent Impact of Climate Change at Loading/Unloading Area in the Tanjung Emas Port Semarang.

Impact of Climate Change	Explanation	Yes	No
Excess heat/humidity	High heat/humidity in the loading and unloading area	√	
Fog or visibility	The occurrence of fog/decreased visibility ability in the loading and unloading area		√
Surface water flooding	Surface Flooding in the loading and unloading area	√	
Overtopping	Massive overtopping occurs in the loading and unloading area	√	
Water depth	The occurrence of silting, which resulted in obstacles during the loading and unloading process		√
Wave load	Intense wave loading on the wharf/loading or unloading area due to big waves	√	
Wind load	The occurrence of a strong wind is quite intense, which affects the process of loading and unloading/port activities at the dock/loading and unloading area		√
Biological change	Biological changes around the loading and unloading area		√
Corrosion	The occurrence of corrosion on the facilities and infrastructure of the loading and unloading area	√	

(Source: Processed Primary Data, 2022)

Table 6. The Curent Impact of Climate Change at Port Equipment Area in the Tanjung Emas Port Semarang

Impact of Climate Change	Explanation	Yes	No
Excess heat/humidity	Excess heat/humidity, which may affect port equipment		√
Ice or icing (N/A)	The occurrence of icing that can interfere with the port performance		√
Snow or hail (N/A)	The occurrence of snow or hail that can interfere with the port performance		√
Fog or visibility	There is fog which causes a decrease in visibility when operating equipment at the port		√
Surface water flooding	Surface flooding can affect the operation of port equipment		√
Overtopping	Harbor equipment such as protective walls, dikes, sluice gates, drainage systems, and surge gauges can help reduce the risk of seawater runoff into the port area		√
Groundwater flooding	Flooding in the port area affects the performance of port equipment		√
Legacy contamination	The occurrence of continuous pollution can affect the operation of the equipment at the port		√
Corrosion	The occurrence of corrosion that can affect the use of port equipment	√	

(Source: Processed Primary Data, 2022)

Table 7. The Curent Impact of Climate Change at Storage Office Area in the Tanjung Emas Port Semarang

Impact of Climate Change	Explanation	Yes	No
Excess heat/humidity	There is excess heat/humidity that can affect the storage office area	√	
Ice or icing (N/A)	The icing process occurs in the storage office		√
Snow or hail (N/A)	Snow or hail occurs in the storage office		√
Fog or visibility	Fog or limited visibility occurs, which disrupts visibility in the storage offices area		√
Surface water flooding	Surface flooding occurs in the storage area		√
Overtopping	Massive overtopping occurs in the storage area		√
Groundwater flooding	Flooding in the port area affects the storage office		√
Legacy contamination	The occurrence of continuous pollution can affect the operation of the storage office		√
Corrosion	The occurrence of corrosion that can affect the use of port equipment	√	

(Source: Processed Primary Data, 2022)

Table 8. The Curent Impact of Climate Change at Procession Manufacturing Area in the Tanjung Emas Port Semarang.

Impact of Climate Change	Explanation	Yes	No
Excess heat/humidity	Excess heat/humidity that can affect the procession manufacturing area	√	
Ice or icing (N/A)	The icing process occurs in the storage office		√
Snow or hail (N/A)	Snow or hail occurs in the procession manufacturing area		√
Fog or visibility	Fog or limited visibility occurs, which disrupts visibility in the procession manufacturing area		√
Surface water flooding	Surface flooding occurs in the procession manufacturing area		√
Overtopping	Massive overtopping occurs in the procession manufacturing area		√
Groundwater flooding	Flooding in the port area affects the operation of the procession manufacturing area		√
Legacy contamination	The occurrence of continuous pollution can affect the operation of the procession manufacturing area		√
Corrosion	The occurrence of corrosion that can affect the use of the procession manufacturing area		√

(Source: Processed Primary Data, 2022)

Table 9. The Current Impact of Climate Change at Hinterland Connection Area in the Tanjung Emas Port Semarang.

Impact of Climate Change	Explanation	Yes	No
Excess heat/humidity	There is high heat/humidity in the hinterland connection area	√	
Fog or visibility	The occurrence of fog or decreased visibility in the hinterland connection area		√
Surface water flooding	Surface water flooding occurs in the hinterland connection area	√	
Overtopping	Massive overtopping occurs in the hinterland connection area	√	
Water depth	Siltation occurs in the hinterland connection area		√
Currents	Strong currents that occur in the hinterland connection area		√
Sediment dynamics	There has been pretty massive sedimentation in the hinterland connection area		√
Wave characteristics	Changes in wave characteristics that disrupt activities in the hinterland connections area		√
Groundwater flooding	Groundwater flooding occurred, which disrupted activities in the hinterland connection		√
Legacy contamination	Legacy contamination occurred, which disrupted activities in the hinterland connection area		√
Wind load	The occurrence of strong winds that are pretty intense and disturbing occurs in the hinterland connection area		√
Biological change	Biological changes occur in the hinterland connection area		√
Corrosion	Corrosion in the hinterland connection area	√	

(Source: Processed Primary Data, 2022)

6. TANJUNG EMAS PORT ACTION AGAINST CLIMATE CHANGE

Information gathering regarding mitigating hydrometeorological disasters caused by climate change was carried out on September 27, 2022. Focus Group Discussions (Figure 4) involved stakeholders in the Tanjung Emas Port area, Semarang. Stakeholders involved include PT Pelindo III, Tanjung Emas Port and Class I Port Authority, BMKG, and BRIN. Some of the discussion points include:

a. Port Authority and Class I Tanjung Emas Port :
   - have software to handle hydrometeorological disasters
   - have regulations related to port activities when hydrometeorological and land subsidence disasters occur
   - The port area needs to anticipate tidal disasters and land subsidence
   - The Port of Tanjung Emas Semarang has a Port Master Plan, which contains one concerning the Repair and development of port infrastructure. Improvement and construction of Tanjung Emas Port infrastructure in Semarang as part of the port's adaptation and mitigation of disasters caused by climate change. The Port Master Plan I (2012-2016) of Tanjung Emas Port has been implemented with various infrastructure developments. Meanwhile, the implementation of Port Master Plan II (2017-2021) was constrained by the pandemic, and construction continued on Port Master Plan III (2022-2031). In this Port Master Plan III, several activities have been carried out, such as those carried out in stages in improving the facilities and management of Tanjung Emas Port.
   - Efforts that have been made in addition to the construction and improvement of infrastructure include: calculation of the tides, construction of breakwaters, and use of pumps (when a disaster occurs)
   - KSOP issues a sailing permit
   - Collaborate with BMKG to update data from BMKG in real-time

b. PT Pelindo III as Port Operator at Tanjung Emas Port in Semarang
   - Pelindo III has taken several strategic steps, including dredging shipping lanes and the Tanjung Emas port pool, extending the TPKS Pier, procuring container cranes and RTG
   - The main problems that often occur are tidal flooding and land subsidence
   - Pelindo III has invested in equipment that is planned to come in 2024
   - Have built an embankment as high as 1 meter and always add height periodically (30-40cm)
   - Use of sluice gates to accommodate small vessels
   - Pumps have been installed in the Tanjung Emas port area, Semarang
   - Implementation of a polder system
   - build 3 pump houses, where all the water will be brought to the retention pond and then disposed of to cope with overflow from the sea with a capacity of 800 m3/s
   - Pelindo III already has an emergency response procedure for handling tidal floods at Tanjung Emas Port (Predictive Response Procedure and Emergency Response Procedure).
   - Coordination and communication have been carried out between port operators and Port Authority and Class I Tanjung Emas Port and stakeholders in the Tanjung Emas port area

c. BMKG
   - Submission of weather and climate information is carried out periodically to stakeholders who need weather and climate data at the port
   - BMKG already has a mobile BMKG for early warning
   - Disaster mitigation due to climate change that BMKG has carried out includes outreach to the community, education, field schools, and visits to schools and campuses
   - Release an early warning 1 hour before based on monitoring data 3-6 hours before an early warning is released.
   - determination of limits in managing disasters must be based on impact case.
   - BMKG often gets information from captains who are already docked at the harbor

From the results of the FGD, it was also found that Tanjung Emas Port has several challenges that must be faced, including the implementation of disaster mitigation and anticipation is carried out separately for each stakeholder (due to constraints on their respective duties and functions), requires a high asset and infrastructure maintenance costs, often missing checks and mitigation and monitoring facilities, there is no massively integrated early warning system in the port area, increased investment for research and application of appropriate technology to deal with the impacts of climate change. From these challenges, various potentials can be developed for the Tanjung Emas Port area, such as creating a comprehensive and integrated early warning system. Apart from that, SOPs can also be set, which involve all parties (stakeholders) in an integrated manner.

In a number of situations, ports must figure out the number of indirect effects on the economy and change to them. As a result of how climate change affects the economic sector, some ports and waterways may see a change in the type, amount, or time of goods and people moving through them. Because of this, the port must also be able to handle different risks linked to weather, water, and ocean processes and parameters. Climate change will affect these factors and make existing risks worse, such as flooding, runoff, and flooding due to high river flow rates, high tides or storm surges, changes in sea conditions (agitation, extreme waves), changes in bathymetry or sediment transport, sedimentation, erosion of river bed or river banks, fog or reduced visibility, changes in wind speed/strength, direction, or duration, extreme heat or humidity (in terms of magnitude, duration, or frequency), and chemical spills.

In this case, the Class I Harbor Master and Port Authority (KSOP) Office of Tanjung Emas Port Authority has done a number of things to deal with the problems caused by climate change, such as the rising sea level and sinking land. Some of the things that can be done are fixing ponds and cleaning, putting in pumps, raising wharves, fixing infrastructure, and moving docks. Table 10 shows what Tanjung Emas Port in Semarang wants to do to deal with climate change.

7. DISCUSSION

This study look at port readiness in the face of climate change, focusing on Tanjung Emas Port in Semarang, Indonesia. Tanjung Emas Port in Semarang is one of Indonesia's ports and a significant port for economic and service activities. Furthermore, the findings of this study demonstrate that numerous efforts and predictions have been made to deal with climate change at the Port of Tanjung Emas.

Port infrastructure development and repair have been carried out by both the authorities and the port operator, including the construction of a breakwater, dredging, dam construction, pump installation, the addition of quay lining, the implementation of a polder system, and the use of sluice gates to accommodate small vessels. Efforts and anticipation of dealing with climate change in terms of Tanjung Emas Port management have been carried out in collaboration between authorities, port management operators, and other stakeholders (for example, BMKG), besides that, the efforts and mitigation of Tanjung Emas Port in Semarang in dealing with climate change are outlined in Port Master Plan I and II but are only limited to physical development and infrastructure. Tanjung Emas Port in Semarang likewise has protocols in place to deal with tidal floodings.

The findings of the study also suggest that numerous factors of climate change are occurring in each location of Tanjung Emas Port in Semarang. Climate aspects that arise and affect port performance, as in the navigation zone area, include fog/visibility, sea depth, currents, wave characteristics, and wind load. Scouring and wave loading occur in the protective infrastructure region, however in the manoeuvre and berthing zones, climate change impacts such as overtopping, scouring, wave load, biological change, and corrosion have no effect. Excess heat/humidity, surface water flooding, overtopping, wave load, and corrosion are climate characteristics in loading and unloading. Corrosion is one of the climate change impacts that happens in the port equipment area. Excess heat/humidity and corrosion occur in the port storage office work area, while excess heat/humidity occurs in the procession manufacturing work area, and extra heat/humidity, surface water flooding, overtopping, and corrosion occur in the hinterland connection work area. If applied to other ports, the climate parameters following the location of the port work area and port circumstances between one port work area and another will be different; the climate parameters in the port will be different.

Table 10 displays the measures and actions taken by the Tanjung Emas port in Semarang. Tanjung Emas Port has responded to climate change by adapting and mitigating its effects. The visible effort is to address climate change by improving and developing infrastructure. According to (A. H. Becker *et al*., 2013), a resilient port is one that can resist natural calamities that can result in large losses, damage, diminished output, or quality of life without much outside assistance. Public. Some of the strategies implemented by the Port of Tanjung Emas Semarang demonstrate that the port is attempting to increase its resilience to climate change, including increasing the resilience of infrastructure and infrastructure development, synergies between stakeholders despite various implementation challenges, increasing climate projections, and creating a

Table 10. Tanjung Emas Port Action Plans Against Climate Change.

<table>
<tr><th>No</th><th>Port operations as Repoerted by PIANC</th><th>Recent Actions of the Port Authority</th><th>Potential Actions from Literature</th><th>Detailed Potential Actions</th></tr>
<tr><td>1</td><td>Navigation zone</td><td>Dredging and pond revitalization</td><td rowspan="3">· hazard assessment for infrastructure
· modify infrastructures, design, operations, and maintenance activities to account for potential hazards.</td><td>· investigate climate past records, climatic tendencies, anticipated weather circumtances, start monitoring climate change
· Evaluate design parameters to detect threshold, fix maintenance concern, take corrective steps to reduce operational incidents and boost resilience</td></tr>
<tr><td>2</td><td>Protective infrastructure</td><td>· Pump installation
· Improve drainage to overcome rob</td><td rowspan="2">· construction of decks, drainholes, increasing aprons and breakwater and also wave bariers to raise vital assets; relocation or increasing elevation of the access road and storage facilities to protect against flooding and wave overtopping
· refine or replace outdated infrastructure</td></tr>
<tr><td>3</td><td>Maneuver and berthing area</td><td>· pier lining elevation
· increasing elevation of the pier floor
· Harboor and channels maintenance
· Pelabuhan Dalam 1 and Pelabuhan Dalam 2 construction and development
· Pelabuhan Rakyat Relocation</td></tr>
<tr><td>4</td><td>Loading and unloading</td><td>Elevation of the stacking field</td><td rowspan="5">· collecting, monitoring and modeling historical and climate data to local level
· Adjust infrastructure, design, operation, and maintenance activities in line with possible hazard
· Use electric yard tractors,
· Use high-tonnage electric forklifts,
· Use an electric top handler
· Digitization at port
· Elevate land</td><td rowspan="5">· investigate climate past records, possible climate conditions and climate tendencies
· Evaluate design parameters to detect threshold, fix maintenance concern, take corrective steps to reduce operational incidents and boost resilience;
· relocation and revitalization infrastructure</td></tr>
<tr><td>5</td><td>Port Equipment</td><td>Container Terminal Reactivation railroads</td></tr>
<tr><td>6</td><td>Storage/
offices</td><td>Storage office relocation</td></tr>
<tr><td>7</td><td>Processing/
Manufacturing</td><td>Construction of The Port Associated Industry Zone (planned 2022-2031)</td></tr>
<tr><td>8</td><td>Hinterland Connection</td><td>Intermodal development of Tanjung Emas Port and Kendal Terminal I</td></tr>
</table>

Source : Analysis researcher based on data from PIANC; (Margarita Pery *et al.*, 2021), Kantor Syahbandar dan Otoritas (KSOP) Class I Tanjung Emas in 2022; (A. Becker, 2014).; with adjustments made by the researchers.

favourable environment for adaptation investment. According to PIANC (Brooke *et al.*, 2020), improving port resilience and adaptation requires more than just reinforcing current physical infrastructure. Depending on the type of risk detected, management or maintenance, operational modifications, or cost savings may be implemented. Institutional reforms, such as finance policies, can be a long-term solution for improving port resilience and climate change resilience.

The findings of this study can be utilized to evaluate and consider managers when making decisions about managing the port area in the face of climate change consequences. This research is crucial because it requires the correct tactics, findings, and policies to assist in the realization of a port that is resilient to climate change disasters.

Climate change adaptation is a continuous process. As a result, conversations with stakeholders and a flexible approach to absorbing new sources of information are critical. As the adaptation planning process proceeds, the objectives are likely to change. Monitoring results or other additional information, for example, will become available; other organisations may become engaged in the planning and delivery process; or awareness of the potential consequences of climate change will improve. At this stage, first priorities are established to clarify and focus on the climate change adaptation choice. Port and airway operators, as well as other stakeholders, must clarify their roles and duties and take decisive action.

This study contains limitations in terms of source data, information, and references regarding assessing port readiness in Indonesia to face climate change. As a result, more research on establishing port readiness in dealing with the effects of climate change is required. In terms of infrastructure, management, and the environment. Limitations in this research include the limited availability of primary data and previous research so that it can influence the expected results. The data collection method using an FGD scheme could cause personal bias, and a small sample of respondents will influence the formulation of port adaptation strategy recommendations for facing climate change.

Another limitation of this study is the lack of long-term data. Climate change is a long and ongoing process. Therefore, this study is limited if it only uses data over a short period of time. This can lead to a lack of precision and accuracy in predicting long-term trends or in formulating effective strategies for the future in the long term. The lack of social and economic data related to the port in the face of change is also a limitation in this study, so that the resulting analysis cannot be in-depth and does not consider the needs and welfare of the community around the port.

In addition, the difficulty encountered in this research is that there is not much research on port adaptation in the face of climate change both technically and economically in Indonesia, so the references for this research are very limited.

8. CONCLUSIONS

Based on the PIANC standards and the findings of this research, Tanjung Emas Port demonstrates a level of preparedness to address climate change challenges. However, further investigation into the resilience of port infrastructure is necessary to ensure its long-term sustainability. Additionally, fostering synergy among port users, operators, and stakeholders is crucial for building a robust resilience system.

This research offers valuable insights for port managers and decision-makers in developing effective climate adaptation strategies. The findings and recommendations can inform the creation of appropriate policies and actions to promote the realization of resilient ports. A multi-faceted approach, combining various methods and perspectives, is essential for achieving this goal. While port authorities have disaster contingency plans, identifying specific port infrastructure vulnerable to disasters remains a priority for future research. By addressing these gaps, we can enhance the overall resilience of Tanjung Emas Port and serve as a model for other ports facing similar climate challenges.

CONTRIBUTIONS

Destianingrum Ratna Prabawardani : Conceptualization, Formal Analysis, Investigation, Methodology, Resources, Visualisation, Writing (Original Draft), Writing (Reviewing & Editing), Aprijanto: Conceptualization, Supervision, Writing (Review &Editing), Tjahjono Prijambodo:, Resources, Investigation, Ibnu Fauzi: Data Curation, Formal Analysis, Resources, Writing (Review & Editing), Maria Nooza Airawati: Data Curation, Resources, Buddin Al Hakim: Data Curation, Investigation, Danang Ariyanto: Investigation, Validation, Resources, Writing (Review & Editing), Muhammad Alfan Santosa: Supervision, Muhammad Irfani: Supervision , Ridwan Budi Prasetyo: Supervision, Fajar Yulianto: Supervision (Writing), Nofika Cahyani Putri: Visualization, Catur Indra Sukmana: Project Administration, Eny Cholishoh: Project Administration, Cahyarsi Murti Aji:Validation, Eko Kustiyanto: Investigation, Bakti Wibawa: Supervision, Nurkhalis Rahili: Visualization, Joko Sutopo: Funding Acquisition

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GEOENVIRONMENTAL ZONING OF THE MUNICIPALITY OF RIO GRANDE, SOUTHEAST BRAZIL

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ABSTRACT: Zoning has the function of making the development of urban and rural areas compatible, defining restrictions and adjustments to the use of the soil. A subdivision of environmental zoning is geoenvironmental zoning, which considers the landscape as a physical and conceptual tool/contribution to the planning actions. The municipality of Rio Grande (Rio Grande do Sul-South Brazil), which is situated in a lagunar area, with sectors far away from the beach, allowed different uses of the urban and rural spaces, which drastically affected the operation and organization of the landscape. Therefore, there has been a need for studies on environmental planning, being the objective of this research to present the geoenvironmental planning for Rio Grande municipality. The geoecology of landscapes will be used as a theoretical and methodological approach, as it allows the establishment of geoenvironmental units. The geoenvironmental zoning defined six areas, which are: preservation, conservation, damping, rehabilitation, improvement, and use. The geoenvironmental zoning allowed the proposition of rules to the adequate use of the environment, conciliating the characteristics of the physical environment with the needs of socioeconomic dynamics.

Keywords: Planning, Landscape, Geoenvironmental Units, Zoning.

RESUMO: *O zoneamento tem a função de compatibilizar o desenvolvimento das áreas urbanas e rurais, definindo restrições e adequações ao uso do solo. Uma subdivisão do zoneamento ambiental é o zoneamento geoambiental, que considera a paisagem como instrumento/contribuição física e conceitual para as ações de planejamento. O município de Rio Grande (RS), situado em uma área lagunar, com setores distantes da praia, permitiu usos diferenciados dos espaços urbano e rural, o que afetou drasticamente o funcionamento e a organização da paisagem. Portanto, houve a necessidade de estudos sobre planejamento ambiental, sendo o objetivo desta pesquisa apresentar o planejamento geoambiental para o município de Rio Grande. A geoecologia de paisagens será utilizada como abordagem teórica e metodológica, pois permite o estabelecimento de unidades geoambientais. O zoneamento geoambiental definiu seis áreas, sendo elas: preservação, conservação, amortecimento, reabilitação, melhoria e uso. O zoneamento geoambiental permitiu a proposição de regras para o uso adequado do meio ambiente, conciliando as características do meio físico com as necessidades da dinâmica socioeconômica.*

Palavras-chave: *Planejamento, Paisagem, Unidades Geoambientais, Zoneamento.*

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1. INTRODUCTION

Environmental planning is based on integrating information gathered from the natural environment with information from the social-economic dynamic of places. Its objective is to keep the integrity of the elements, both natural and anthropic, with propositions aiming at adjusting the use of the land to its natural vocation. It seeks harmonic development and the maintenance of the natural characteristics of the environment aligned with sustainable development (Santos, 2004; Rodriguez *et al.*, 2013).

Environmental planning establishes goals and guidelines to be reached within a temporal scenario, and zoning is one of its guiding principles. Zoning is both a methodology and a planning instrument, as it spatially organizes the area in question (Santos, 2004; Zacharias, 2010).

Zoning is the division of a certain territory into smaller areas according to their most relevant attributes and dynamics (Santos, 2004). Each delimited area is considered a homogeneous one, with similar characteristics, and highly differentiated from the other sectors. The areas are constituted as expressions of the vocations, susceptibilities, good actions, and conflicts inherent to each spatial segment. Therefore, a specific set of rules is attributed to each area, which are used to guide the land uses and the protection of nature.

Environmental zoning is one of the instruments of the Brazilian national environmental policy (Brasil, 1981) and has the function of integrating the development of urban and rural areas, defining the restrictions or the suitability of the uses of the areas. Besides, it also defines that environmental zoning has a subdivision called geoenvironmental zoning (Zacharias, 2010).

According to Oliveira (2012), geoenvironmental zoning is a territorial planning instrument strongly guided by environmental issues and seeks support from a systemic approach. It provides insight into the possibilities and limitations of the landscape and also addresses land use and the pressures caused by such uses. Benini (2009) states that geoenvironmental zoning is a prevention strategy when choosing areas, in which it is possible to carry out specific planning. The main objective is to individualize areas with similar characteristics based on a diagnosis integrated with ordered surveys for better interpretation of the results.

Sato (2008) mentions that geoenvironmental zoning allows the identification of areas whose environmental characteristics provide the individualization of zones, in which socioeconomic issues are incorporated, promoting integrated analysis.

It means, geoenvironmental zoning results from the integrated diagnosis of the landscape, which identifies its capabilities and use restrictions, where the analysis of the physical environment constitutes the basis for initial knowledge of the landscape.

Hence, the objective of this study is to perform the geoenvironmental zoning of a municipality in South Brazil (Rio Grande – RS – Brazil), using the geoecology of landscape as the theoretical-methodological approach that surveys the landscape based on a systemic approach. Such an approach dates from the end of the 19th century, when it was necessary to integrate the geographic approach (spatial) with the ecological one (functional) to analyzes landscapes, considering them as a global system (Rodriguez *et al.*, 2013).

The notion of landscape is the basic concept of Landscape Geoecology, which offers an essential contribution to the knowledge of the natural base and also provides solid foundations in the elaboration of theoretical and methodological bases for planning, focusing attention on the interaction between the physical environment and the socioeconomic dynamics (Rodríguez *et al.*, 2017).

The geoecology of a landscape can be used in environmental planning as it allows the systematization of the multiple elements of the landscape that is the object of the research. Crossing information, in a synthetic way, allows the identification of similarities and differences that promote the delimitation of the geoenvironmental units, the homogeneous areas of the landscape, acquired through the integration of natural and anthropic elements (Santos, 2004; Rodríguez *et al.*, 2017).

There have been various studies in Brazil lately using this approach, namely Farias (2012), related with a geoecological zoning of the municipality of Novas Russas (Semi-arid - CE-Brazil); Farias (2015), who describes the use of geoecology of landscape in hydrographic basin of Palmeira River (CE-Brazil); Alencar (2018), who attests that geoenvironmental zoning of the municipality of Camocin (Costal area – CE-Brazil); Lima and Oliveira (2018), who analyzes the geoenvironmental zoning of the municipality of Caraguatatuba municipality (SP-Brazil); and Teixeira (2018), who focus on the geoecological analysis of the municipality of Tejuçuoca (CE-Brazil) as support to environmental planning.

Thus, the present study identifies the areas that present a balance between the physical environment and socioeconomic dynamic;

the areas with limitations to endure anthropic interventions; and the areas that are in an advanced stage of degradation. Therefore, as an example, it is presented the geoenvironmental zoning of the municipality of Rio Grande (RS-Brazil), situated in a lagunar area, with sectors far away from the shoreline, but with elements of coastal dynamics controlling its evolution.

2. STUDIED AREA

The municipality of Rio Grande (Figure 1) is located in the south of Rio Grande do Sul State (Brazil). It has a total area of 3,338.3 km^2 divided into five districts (Rio Grande, 2008), having more than 191,900 inhabitants (IBGE, 2022).

The origins of the municipality, in an area originally inhabited by *Tupi-Guarani* and *Chaná* indigenous nations, date from the geopolitical context of the conflicts between Portugal and Spain in the XVII and XVIII centuries, when both European nations were engaged in expanding their territory. Ever since its foundation, on 19th February 1737, by Brigadier José de Silva Paes, extensive sandy plains, severe weather, and the existence of salty areas imposed difficulties on the settlement of the Europeans. However, its strategic location on the Atlantic coast allowed the town to develop as one of the main Brazilian seaports, which was vital to promote the urban and commercial development of the area during the XIX century, attracting immigrants and investors from different countries, and fomenting the textile industry (Vieira, 1983; Queiróz, 1987; Wilwock and Tomazelli, 1995; Martins, 2007; Torres, 2008; Telles, 2011).

At the beginning of the XX century fishing industries became important due to the biological diversity of the Patos Lagoon (which lasted until the 1980s) and, later, in the 1970s, the town received oil refining and fertilizing industries. In the XXI century, the town witnessed the emergence of naval industries and offshore, with the construction and/or repair of ships and oil and gas platforms, however, such investments have been stagnated lately (Martins, 2007; Carvalho, 2011; Torres, 2011).

The municipality of Rio Grande is located on a coastal plain, a recent geological formation characterized by the accumulation of thick sedimentary packages due to sea-level oscillations. These events culminated in an area of sedimentation, formed by extensive sandy ridges and a complex hydrographic system comprised of the Atlantic Ocean, Patos Lagoon, Mirin Lagoon, and São Gonçalo Channel, a natural channel that communicates between the waters of Lagoa Mirim and Patos Lagoon (Delaney, 1962; Wilvock and Tomazelli, 1995).

The local climates considered humid subtropical (Krusche *et al*, 2002) whose main characteristics are regular rainfall distribution along the year and moderate temperatures, without abrupt transitions (Castelão and Möller Jr, 2003; Rossato, 2011).

Climate and geological conditions, associated with a plain topography without great elevations, have allowed a constant water table supply, allowing the existence of shallow water depths and wetlands. The low energy of the geographic relay allows a longer period of water runoff and its consequent infiltration (Rio Grande, 2013b).

The conjugation between the aspects of the climate (well-distributed rainfall and moderate temperatures) and the geological ones (sandy permeable deposits) determined a peculiar vegetation formation that allows the development of small to medium-sized cover (Vieira, 1983). The vegetal cover is comprised predominantly of herbaceous grass, which is characterized by thick underbrush vegetation that covers the soil entirely (Bonilha, 2013), and tree species of heterogeneous aspect, known as Restinga forest (coastal plain forests), are also found in this area. Physiognomy of the Restinga forest shows variations due to the peculiar conditions of origin, as they migrate from different coastal areas (Tagliani, 2002; Scherer *et al*., 2005).

Various aspects regarding climate, hydrography, biogeography, geology and geomorphology condition the different pedogenetic processes of the soil and determine the type of soil found in this area (Bastos *et al*, 2005), predominantly of sandy texture, with exception for the areas near to the Patos Lagoon and São Gonçalo Channel, where the soil is hydromorphic (Klant *et al*., 1985; Cunha *et al*., 1996).

3. METHODOLOGY

The methodology used in this study was based on the one proposed by Rodriguez *et al*. (2017) regarding the Geoecology of Landscape and it is comprised of 5 stages: organization, inventory, analysis, diagnosis and propositions.

In the organization stage, a bibliographic review was conducted and the scale of the work was established (1:250.000). The inventory stage was used to evaluate the physical environment related to geology (IBGE, 2017a), geomorphology (IBGE, 2017b), pedology (IBGE, 2017c), vegetation (IBGE, 2017d), climate and hydrography. Despite the importance of climatic and hydrographic conditions in the configuration of the landscape of the study

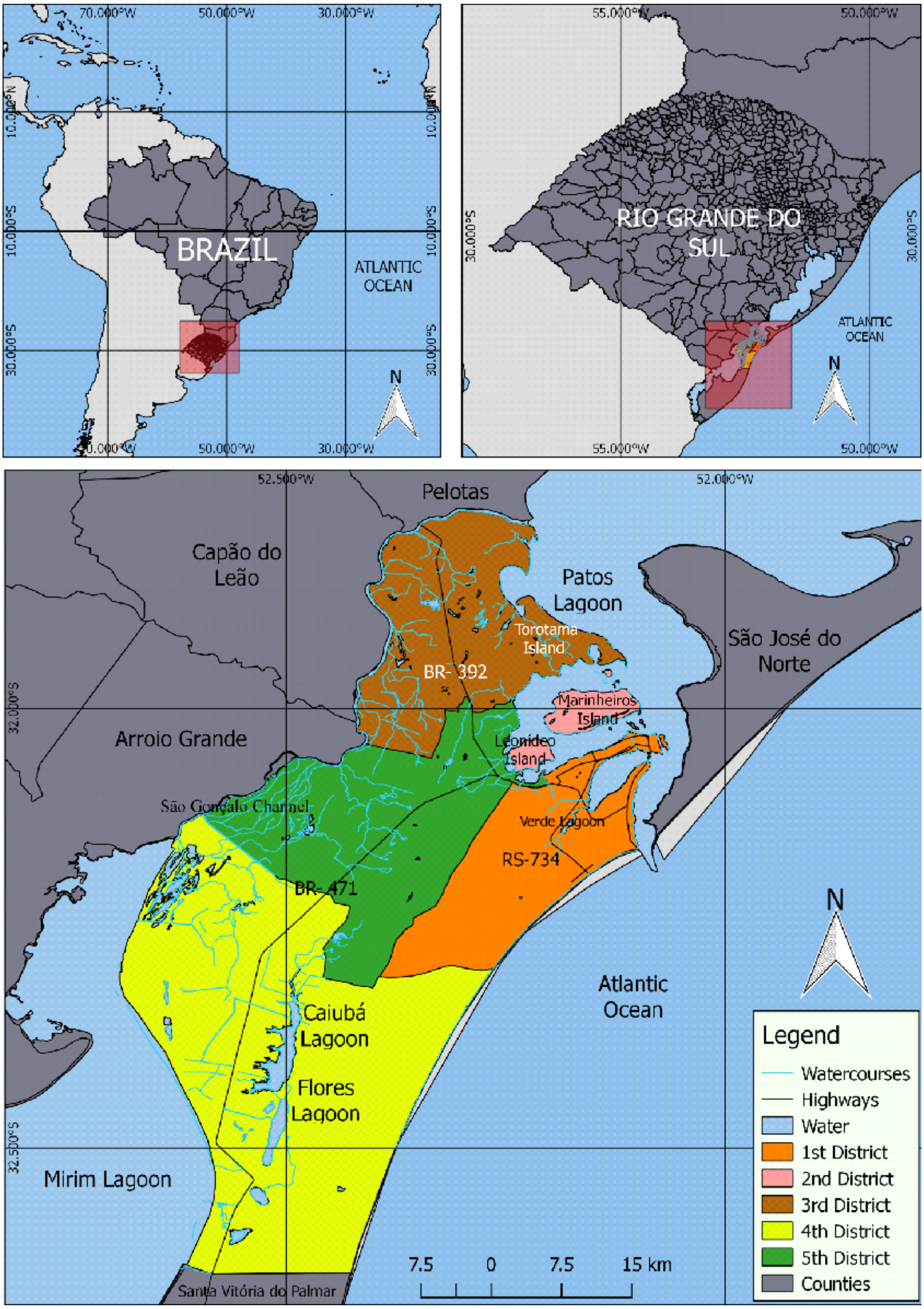

Figure 1. Location of the municipality of Rio Grande (RS-Brazil) and its district division. (Bonilha, 2019; Modified by Bonilha, GO)

area, as modelling agents, it is not possible to characterize homogeneous zones using these quantities, considering that they are vector quantities, such as winds. Thus, priority is given to the physical-natural aspects in which there is the availability of cartographic products, whose aspects become more latent in the research in question. It was also carried out the socioeconomic characterization of the area using land cover and land uses maps (Bonilha, 2019) that were elaborated with Landsat images dated from 11/05/1990, 04/05/2005 and 10/12/2015.

The treatment and interpretation of data obtained by the inventory was done in the stage of the analysis when the geoenvironmental units (Figure 2) were identified. As the recent landscape is conditioned by various natural and anthropic elements over time (Rodriguez *et al*., 2017), geoenvironmental units of the studied area represent the areas of the territory where there is a greater interaction between the natural elements (geology, geomorphology, soil, vegetation and the anthropic ones (land uses) allowing their spatial delimitation. It is important to highlight that the geomorphological criteria were preponderant.

Regarding the compatibility between the land uses (urban area, agriculture, livestock, rice cultivation and forestry) and the physical characteristics of the coastal plain, the land use was considered as:

- Compatible when its use has not spoiled nor affected the physical characteristics of the geoenvironmental unit;
- Incompatible when its use has spoiled and negatively affected the physical characteristics of the geoenvironmental unit.

Regarding the environmental legislation, the uses of the land were considered as:

- Adequate: when the land use has not violated the environmental legislation;
- Inadequate: when the land use has violated the environmental legislation.

The objective of identifying geoenvironmental units is to allow the understanding of the structure and the behavior of the landscape (Rodriguez *et al*., 2017). In the diagnosis stage, geoenvironmental units were evaluated according to the fulfilment of their geoecological functions, and their capacity to ensure the conservation of the structure and the functioning of the system through the exchange of matter and energy (Rodriguez *et al*., 2017). Therefore, the functional approach used here allowed the classification of the function of each geoenvironmental unit into three categories:

- Emitting areas: the ones that ensure the flow of matter and energy to the other areas, being positioned in higher altimetry levels;
- Transmitting areas: the ones that ensure the flow of matter and energy to lower altimetry levels;
- Accumulating areas: the ones that accumulate the flow of matter and energy and are situated in lower altimetry levels.

The identification of the functional role of each unit allowed the determination of their geoecological status (Figure 3), which is the result of the integration of physical and socioeconomic characteristics in each geoenvironmental unit, considering the changes in the structure and functioning of the landscape (Rodriguez *et al*., 2017).

It is important to highlight that the starting point to define the geoecological state is based on a landscape of reference, which are the earliest images available from the area under study. Thus, the modification on of the structure of the landscape was characterized by changes in the relief and the removal of native vegetation, as in the field structural changes are more perceptible in these elements.

The way the landscape has functioned in the studied area has been influenced by the rainfall, as it intensifies energy flows and matter transportation. Changes in watercourses and drainage patterns have modified how the landscape works, as drainage processes have acted to shape the landscape of the studied area (Vieira, 1983).

The classification done categorizes the geoecologcal stages as (Roodriguez *et al*, 2017):

- Stable: when the original structure is in a good state of conservation or presents few changes. There are no major problems affecting the way the landscape works. The anthropic influence is small and the land use is limited to the areas where the conservation of the natural elements is assured.
- Unstable: when there are considerable changes and partial loss of the original structure as a result of anthropic interference. However, the changes are reversible and it is possible to keep the landscape working. The uses of the land exceeded the capacity for renewal of the natural elements.
- Critical: when there are general, irreversible modifications and total loss of the original structure, being the functioning of the modified landscape. Those are areas where the land use does not allow the self-regulation of the natural elements.

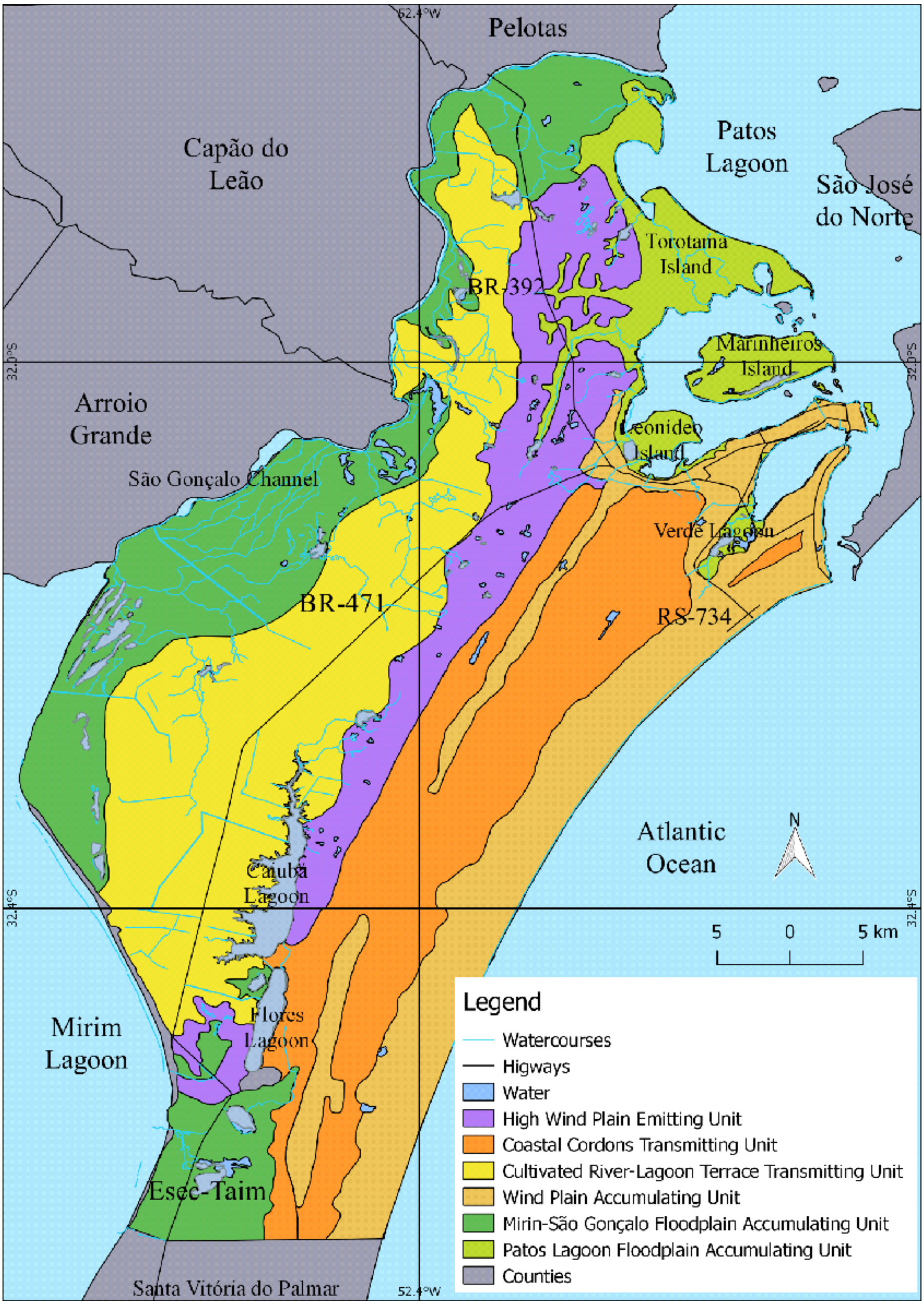

Figure 2. Geoenvironmental Units of Rio Grande (RS-Brazil) Municipality. (Bonilha, 2019; Bonilha, 2023).

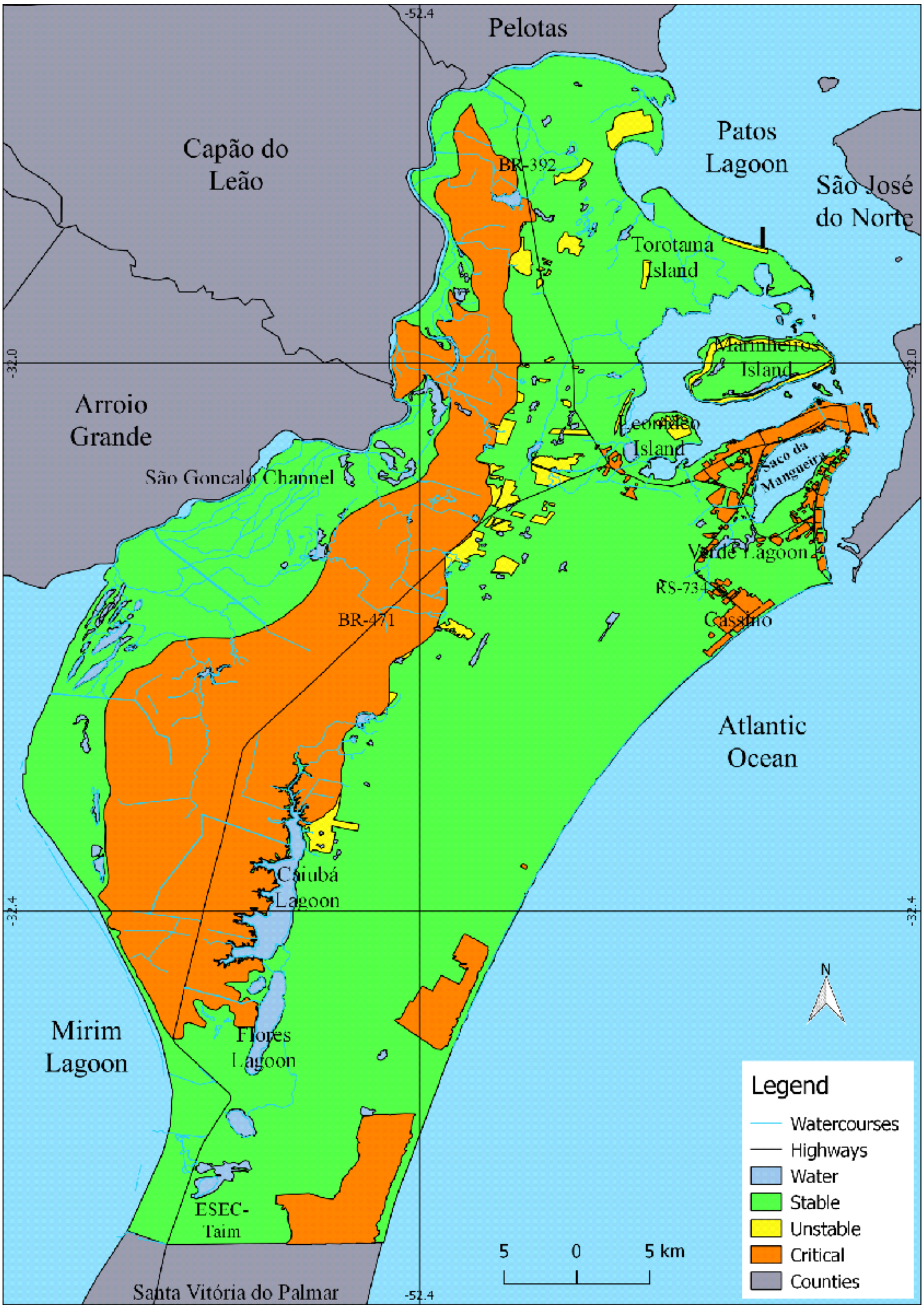

Figure 3. Geoecologica state. (Elaborated by Bonilha, 2023).

The classification of the geoecological states along with the identification of the compatibility and adequacy of the uses were considered to classify the current landscape (Figure 4), according to the geoecological degradation levels caused by the anthropic intervention. Rodriguez *et al*. (2017) classifies the landscape as

- Optimized: when the original structure is preserved, under regular protective measures, and the landscape does not present geoecological degradation.
- Compensate: when the original structure is preserved and the land uses are controlled or happen in small areas. The landscape may present some degree of geoecological degradation; however, it can be easily reverted
- Depleted: when the original structure was modified and its functions badly affected. The landscape reaches a degree of geological degradation that is difficult to revert, however possible.
- Modified: when the original structure was so modified that the functions were eliminated. The land is intensively used and the landscape presents a degree of irreversible geological degradation.

Finally, in the proposition stage, the geoenvironmental-zoning map (Figure 5), the main objective of the planning, is presented. The careful evaluation of the geoecological state and the classification of the current landscape allowed identify the areas that need urgent mitigating measures to ease the imbalance generated in the self-regulatory mechanisms of the landscape, and define preventive and/or corrective measures to guarantee the fulfilment of the functions of each geoenvironmental unit of the landscape.

The areas were identified by colours, following the principle of the intensity of the phenomenon. The areas that need simple measures are marked in light cool colours and the areas where urgent measures are required are in dark warm colours (Sato *et al*., 2015). Data collected from the diagnosis stage and the field trip were used to propose the necessary actions for each area.

The nomenclature of the areas was proposed based on the studies of Oliveira e Souza (2012) and Braz *et al*. (2015). Six categories were elected: preservation, conservation, prevention, use, regeneration and improvement. Some actions were recommended for delimited and defined areas (Table 1), which should be carried out by the local government and population of Rio Grande (RS-Brazil) municipality.

4. RESULTS

The geoenvironmental zoning of Rio Grande (RS-Brazil) municipality (Figure 5) aims to establish guidelines that will allow efficient maintenance of matter and energy flows in the area studied. Such actions will contribute to keeping the balance between the geoecological functions of the landscape and the current uses of the landscape.

The areas defined have the objective of guiding the land uses, considering the legal aspects and physical characteristics of the environment, or indicating the most adequate kind of land used for each area on the map. Six areas were defined: Preservation Area, Conservation Area, Prevention Area, Use Area, Regeneration Area, and Improvement Area.

Table 1. Type of action recommended for the categories of the geoenvironmental zoning (Oliveira and Souza, 2012; Bonilha, 2023).

CATEGORY	ACTIONS
Preservation	Prohibition
Conservation	Restriction and/or Limitation
Prevention	Prevention and/or Restraint
Use	Control and/or Improvement
Regeneration	Recovering
Improvement	Repair

4.1 Preservation Area

The main function of the preservation area is the protection of the natural conditions due to their high relevance to environmental dynamics, as they are essential to the structural and functional integrity of the landscape (Oliveira and Souza, 2012). Therefore, it is necessary to keep these areas protected from anthropic interventions to avoid possible environmental problems; excepting those actions aimed at conservation (Braz *et al*., 2015). The actions aim at keeping the geoecological state stable (Figure 3) and the landscape optimized or balanced (Figure 5).

The following geoenvironmental units comprise the preservation area: Mirin-São Gonçalo Floodplain Accumulating Unit, Patos Lagoon Floodplain Accumulating Unit and Coastal Cordons Transmitting Unit (Figure 2).

The preservation area of the Mirin-São Gonçalo Floodplain Accumulating Unit is characterized by wide surfaces that were originated from lagoon accumulation processes, permanent or periodically flooded, which lithology is composed of unconsolidated alluvial deposits originating from coastal lagoons silting up (RADAMBRASIL, 1986; IBGE, 2003). Lagoa Mirim and São Gonçalo Channel are subjected to periodical floods, which allow the accumulation of organic matter that gave origin to lowland soils, organic soils and gley soils (Embrapa, 2006), and a large extension of areas constantly wet.

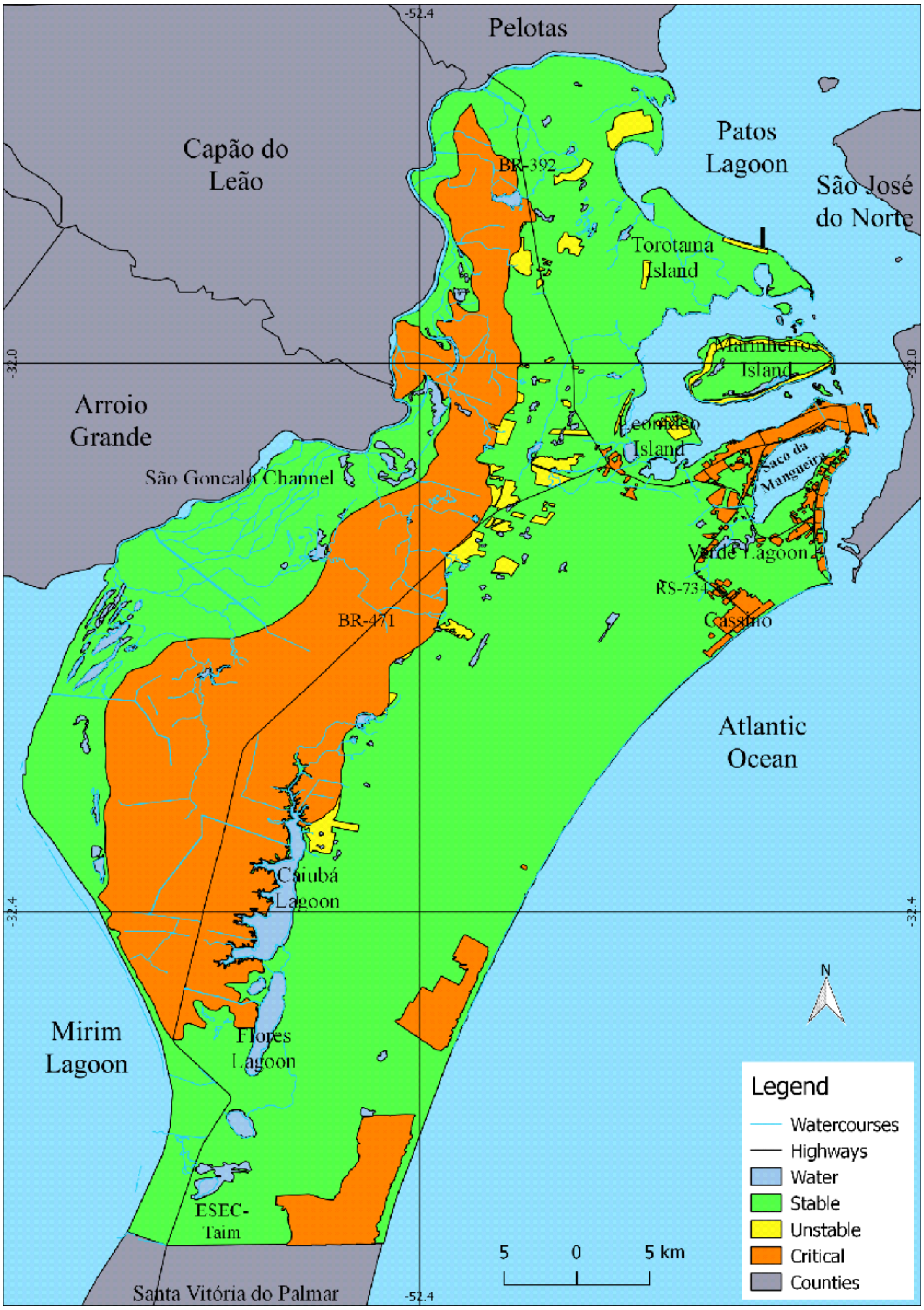

Figure 4. Current Landscape. (Elaborated by Bonilha, 2023).

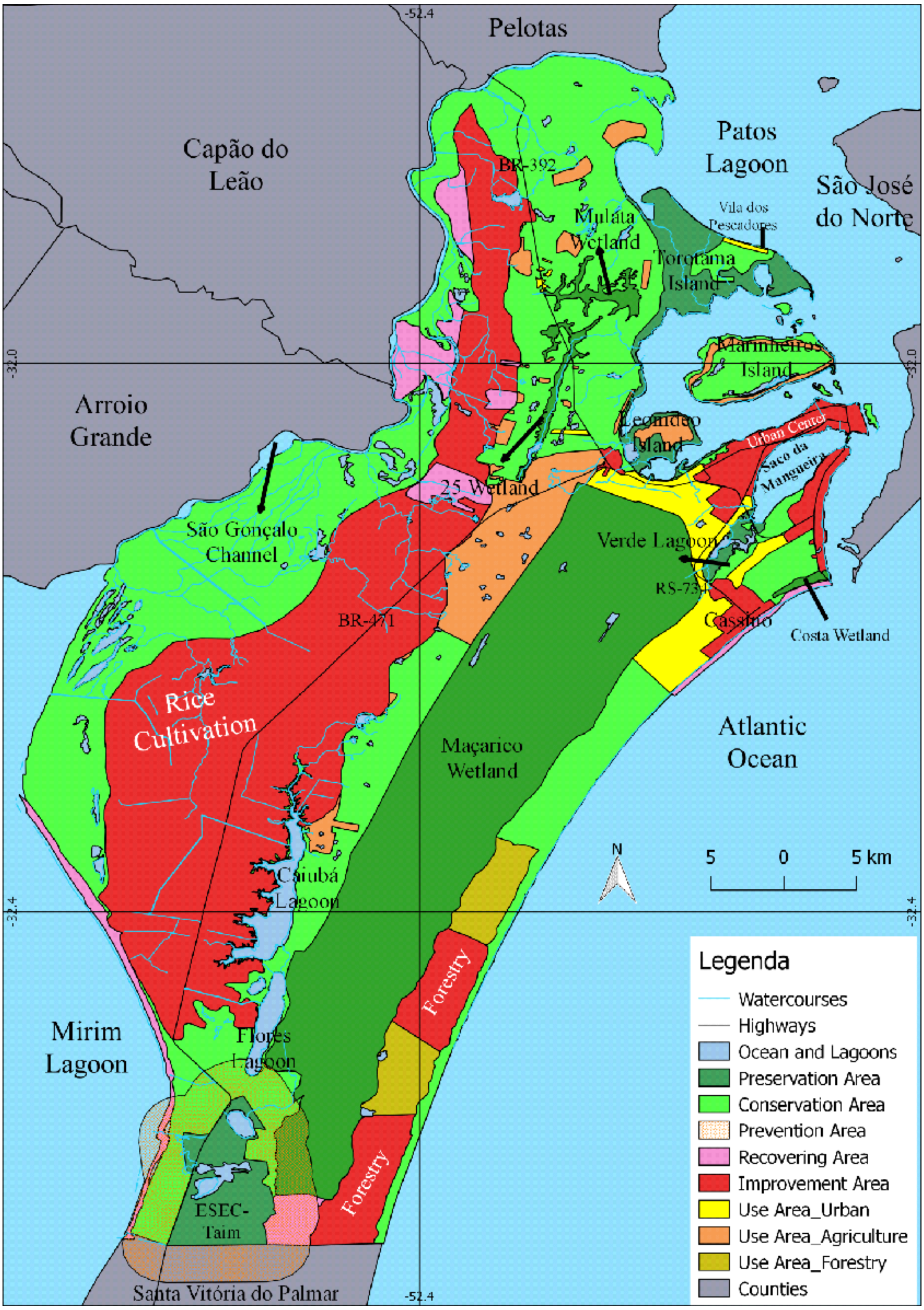

Figure 5. Geoenvironmental Zoning of Rio Grande (RS-Brazil) municipality. (Bonilha, 2019; Bonilha, 2023).

Taim Ecological Park (Figure 6) is an example of such wetlands, being characterized as vital to the maintenance of hydrological regulation. The land use in this geoenvironmental unit is restricted to livestock due to the soil conditions and frequent flooding. However, our proposition is for this activity to be forbidden in the area of ESEC-Taim, as the ecologic park is protected by a law that forbids anthropic interventions in this area (Brasil, 2000).

The conservation zone where Patos Lagoon Floodplain Accumulating Unit (Figure 2) is located is an area originated by fluvial and lagoon accumulating processes that are subject to periodical flooding. Unconsolidated alluvial deposits originated from coastal lagoons silting up compose the lithology of the area (IBGE, 2003). Planosoils are predominant in this area, however organic soils and plinth soils may also be found. As for their proximity to the estuary, the planosoils may present high concentrations of sodium and high natural fertility (Embrapa, 2006). The land use in this area is associated with rural activities, livestock and agriculture.

Salt marshes are frequent in this geoenvironmental unit, as they are herbaceous grasses (Figure 6) that bear periodic flooding, salinity variation, and low temperatures, both air and water (Schaeffer-Novelli, 2000; Marangoni and Costa, 2010). Salt marshes are considered areas of permanent conservation - APP (Brasil, 2000; Rio Grande, 2008), and they have the function of mitigating erosive processes caused by the water flow of the Patos Lagoon (Schaeffer-Novelli, 2000; Marangoni and Costa, 2010). Therefore, the salt marshes should continue to be categorized as an area of permanent conservation and protected from anthropic interventions, being the livestock activity removed from this area.

There are also wet areas in the Patos Lagoon Floodplain Accumulating Unit (Figure 2) that require attention, which are "Banhados do 25 and Mulata" (wetlands) and Verde Lagoon Environmental Protection Unit (Figure 5). The late one is a conservation unit (Brasil, 2000) recognised by the municipal law (Rio Grande RS-Brazil) 6.084/2005, which has the objective of protecting the natural resources and biodiversity and performing educational and research activities (Rio Grande, 2005).

Verde Lagoon Environmental Protection Unit (EPU), which has been considered as an area of sustainable use, should be considered as a Permanent Protection Unit (PPU). Such change in category has been suggested in an attempt to prevent the urban expansion that has been observed in this area and its implications, such as the disposal of illegal waste.

"Wetlands of the 25 and Mulata" (Figure 5) should be classified as PPU due to their systemic functions as hydrological regulators and refuge for biodiversity, as both areas shelter animal and vegetal species.

The area of preservation comprised by the Coastal Cordons Transmitting Unit (Figure 2) is an area of marine terrace slightly declined towards the Atlantic Ocean (IBGE, 2003). The area is characterized by a series of beaded bundles, with crests and pits, parallel to the shoreline (Godolphin, 1976). Lithology is composed of thin sand deposits, rich in organic matter (RADAMBRASIL, 1986), however, the spodosol present in the unit should not be used for agriculture (Embrapa, 2006).

Native vegetation composed of herbaceous grasses and paleoxerophytes is still preserved (Tagliani and Vicens, 2003), and the land is used mainly for livestock. Coastal cords (Figure 6) are comprised of a large area of wetlands used as shelter and reproduction areas for many species. Therefore, in 2014 Maçarico Wetland Biological Reservation was created (Sema, 2017).

It is understood that Maçarico Wetland Biological Reservation should be categorized as a PPU, as it is located on coastal cordons that should be preserved, as they are part of the geological formation of the coastal plain (Brasil, 2012), and livestock should also be removed from these areas. Furthermore, the coastal cordons connect the Mirim Lagoon (through Taim Wetland) to the Patos Lagoon (through Verde Lagoon and da Costa Wetland) establishing a balanced system. Da Costa Wetland (Figure 5) shelters numerous species of birds and it is closely related to the coastal cordons, being relevant to the flow of matter and energy, and in the hydrological regulation. Therefore, it should be categorized as PPU.

The suggestions for the waterways, based on municipal, state and federal legislation (Rio Grande do Sul, 2000; Rio Grande, 2008; Brasil, 2012) take into consideration the water oscillation in periods of flood and drought. It is proposed a propose a range of 200 m for São Gonçalo Channel, aiming at protecting riparian vegetation and possible erosion events; 100 m for Caiubá and Flores Lagoons, aiming at the restraint of rice cultivation; and, at least 30 m for the other waterways in an attempt to restrain urban expansion.

4.2 Conservation Area

The conservation area has the function of keeping the natural characteristics, being different from the preservation area as its function is the restriction (or limitation), and not the prohibition. The land can be used within limitations that will guarantee the

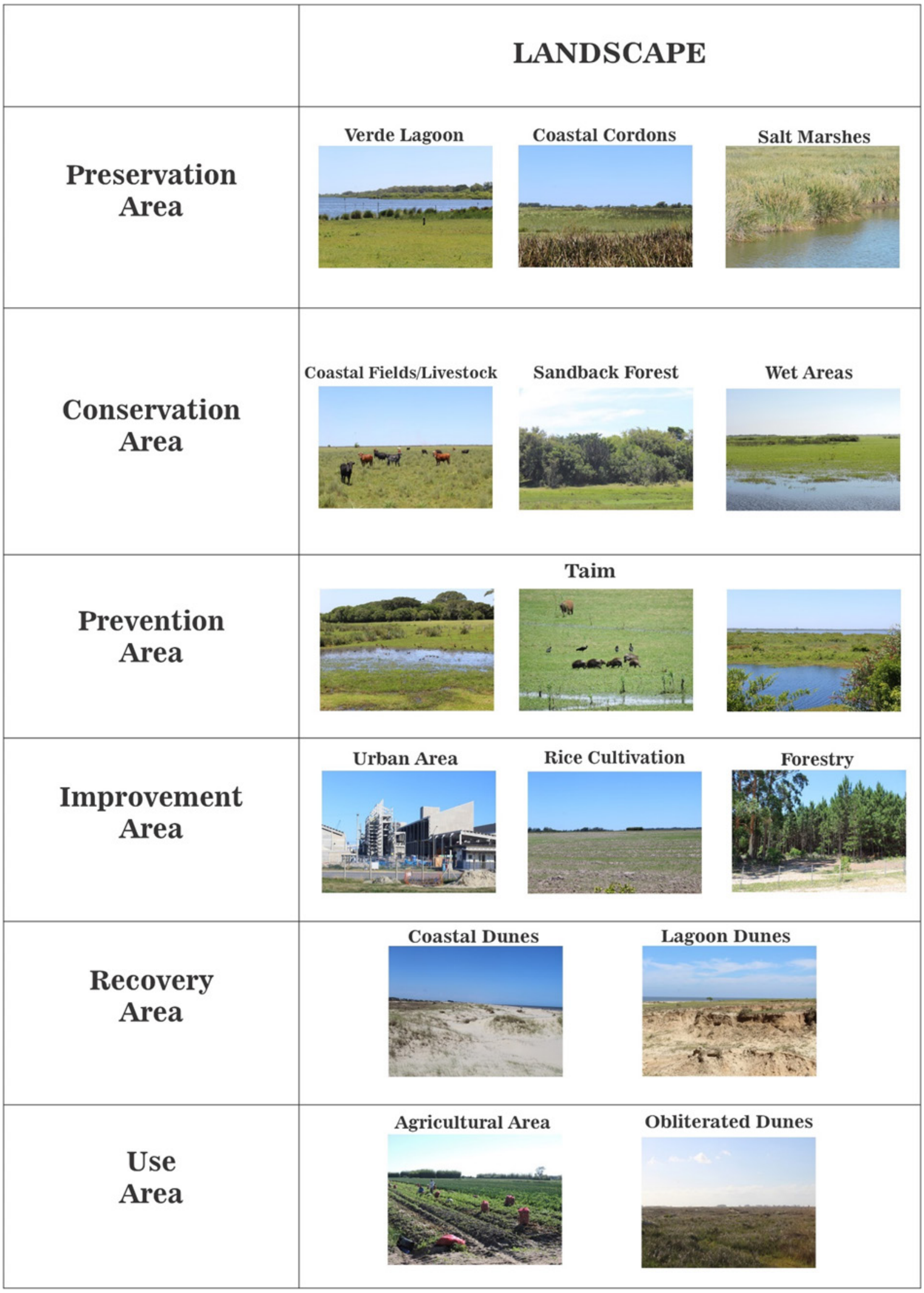

Figure 6. Characteristic landscape of the defined areas. (Bonilha, 2023).

integrity of the physical environment, conciliating the uses of the land with the characteristics of the landscape, and respecting its capacity (Oliveira and Souza, 2012; Claudino-Sales and Peulvast, 2002). The functions of this area should be kept as they are (Braz *et al*., 2015), as long as the geoecological state is stable (Figure 3), and the landscape optimized or balanced (Figure 4).

The conservation area is composed of the following geoenvironmental units: High Wind Plain Emitting Unit, Wind Plain Accumulating Unit, Mirim São Gonçalo Flood Plain Accumulating Unit, Patos Lagoon Flood Plain Accumulating Unit (Figure 2).

The High Wind Plain Emitting Unit is characterized as a slightly waved plain, formed by Pleistocene-aged wind deposits, from different origins, which are impregnated by iron oxides (RADAMBRASIL, 1986; IBGE, 2003). Therefore, clay accumulation gives origin to well-developed soils, argisols; and soils developed under restricted water percolation, plintosols, which present iron segregation (Embrapa, 2006).

The area of the Wind Plain Accumulating Unit (Figure 2) is comprised of plain areas of sandy deposits reshaped by the wind, being mainly formed by obliterated dunes (IBGE, 2003), which is a type of dune pre-fixed by Psammophilus vegetation (Tagliani and Vicens, 2003). The lithology in this area is composed of Holocene quartz sand wind deposits (RADAMBRASIL, 1986). The soil is poorly developed, neosols, due to the low intensity of pedogenetic processes, or other formation factors. Neosols have a sandy texture, are susceptible to erosion, and are poor in nutrients; however, they do not present resistance to the growth of roots (Embrapa, 2006).

In both geoenvironmental units Eolic Plain and High Eolian Plain, native vegetation is represented by coastal fields, which according to Bonilha (2013) is a grassy-herbaceous vegetation characterized by thick creeping species that cover the entire soil and sandbank forests, represented by tree species originated from other environments that migrated to coastal areas. They have physiognomy variations due to the different conditions of the environment where they come from (Tagliani, 2002; Scherer *et al*., 2005).

Coastal fields (Figure 6) are largely used for livestock and should be used in an extensive way to avoid the risks of geoecological degradation. The way this land has been used has not posed a risk to the landscape.

Regarding the sandbank forests (Figure 6), the exploitation of native vegetation is legislated by Law No 11.248 (Brasil, 2006) Decree No 5.975 (Brasil, 2006b). The conservation of the vegetation in these areas is important as the vegetation interferes with the drainage maintenance and in the stability of the sandy substrate, protecting the soil from the wind which is a relevant agent in the modification of the landscape (Scherer *et al*., 2005). The native vegetation is also relevant to be used as shelter for a variety of native and/or migratory species.

The conservation area is also comprised of the wide wet areas of the Mirim São Gonçalo Flood Plain Accumulating Unit (Figure 2), which are used mainly for livestock due to their characteristics. Livestock can continue in the area if it is done extensively. Wetlands should be conserved as they guarantee the survival of adjacent areas, working as “natural sponges”, supplying water in times of drought, and retaining water in floods (Simon, 2007). The way livestock activity has been conducted does not seem to pose a risk to the landscape in these areas.

Finally, the Patos Lagoon Flood Plain Accumulating Unit (Figure 2) is considered a tourist area due to its characteristics such as visiting areas and as visiting and leisure areas. Public authorities should supervise these areas as, according to Michelin (2006), most tourists have no idea of the impact of their acts on the environment. They believe they do not need to follow the rules and exploit the environment without worrying about the consequences of their actions. Tourists throw away used packaging, food, bottles and other kinds of waste, causing an accumulation of garbage that generates not only pollution but also a negative visual impact on the environment.

4.3 Prevention Area

The prevention area has the function of minimizing or even avoiding the negative environmental impacts produced by urban and rural activities that may affect the natural elements within a conservation unit. Therefore, anthropic activities are regulated in the prevention area in an attempt to keep the maintenance of the geoecological processes (Ganem, 2015).

ESEC-Taim (Figure 6) should have its prevention area, within an area of coverage with a radius of 3 km (Conama, 2010), and the elaboration of a management plan, as ESEC-Taim does not have an official one.

ESEC-Taim was created in 1986 by the decree No 92.963, aiming at the preservation of its fauna and flora. It should also protect the area that is used for resting, nesting and resting by migratory species, mainly birds. This area is also used as a shelter for migratory species, reproduction and/or habitat area for endemic species (Backes, 2012; Burger, 2000). The problems spotted in this area are the ones related to livestock, which is migrating into ESEC-Taim, poaching and the fact that many species are run over on the road that crosses this area (BR-471). The activities in the prevention area should aim at conserving the vegetation, the hydric resources and the species, both in transit and inhabitants of the ESEC-Taim.

4.4. Improvement Area

The improvement area has the objective of diminishing the environmental impact (Conama, 1986) caused by the uses of the land, as anthropic interventions have resulted in irreversible changes, giving the landscape a different dynamic. The suggestions given for this area aim at adjusting the uses of the land to allow the landscape to find its functional flow (Braz *et al.*, 2015). Here, it is not proposed changes in the use of the land, as the geoecological state of the areas is critical (Figure 3), and the current landscape has been altered (Figure 5), being the natural conditions of the area unlikely to be restored.

In the area under study, the improvement area has the following geoenvironmental units: Cultivated River-Lagoon Terrace Transmitting Unit and Wind Plain Accumulating Unit.

In the area of the Cultivated River-Lagoon Terrace Transmitting Unit (Figure 2), the improvement area is comprised of lagoon and river-lagoon terraces. These are flat areas slightly sloped towards the lagoon plain that was sculpted by changes in the flow conditions and water blade, or even by erosive processes (IBGE, 2003).

Lithology is comprised of quartz sand lagoon deposits (RADAMBRASIL, 1986), with gleysols, a type of soil originating in sloped areas under the influence of groundwater outcrop, where the water is either internally stagnant or the saturation is achieved by lateral flow, and in both circumstances, the water in the soil can emerge into the surface (Embrapa, 2006). Native vegetation can only be found on the side of the road (BR-471) (Figure 1), as the whole environment was changed by the activity of rice cultivation.

Inside this geoenvironmental unit, where rice cultivation (Figure 6) is consolidated, the water for irrigation comes from São Gonçalo Channel and Mirim, Caiubá e *das* Flores Lagoons (Figures 6). As the water returns later for these water bodies and waterways, the authorities should control the use of fertilizers and pesticides, as they cause eutrophication processes.

In the surroundings of Caiubá and *das* Flores Lagoons (Figure 5), after the recommended range of 100 m (PPU) and within the limits among Mirim-São Gonçalo Flood Plain, Cultivated Lagoon terrace, and High Wind Plain Geoenvironmental Units (Figure 2) the cultivation of organic rice is proposed. Such cultivation uses a process that does not harm the natural resources, helping plant fertilization by replacing nutrients in the soil instead of using artificial fertilizers. Therefore, there will be an offer of free toxic substances in food that are obtained from balanced and fertile systems (Mattos and Martins, 2009).

In the Wind Plain Accumulating Unit (Figure 2), the improvement area was consolidated into an urbanized area used for swine farming. The improvements in the urban areas (Figure 6) should focus on the improvement of matter and energy flow, and housing conditions, being sanitation the main action required. The propositions for the swine farming area aim at managing the use of the water resources and avoiding the dispersion of exotic species.

Rio Grande municipality has a flat relief, which means that rainwater takes a long time to runoff (Rio Grande, 2013). Such a situation requires the use of drain pumps in the urban draining system, which should be regularly revised and, in the future, this system should be replaced by a more efficient one, as in extreme situations flooding has been observed in these areas.

Furthermore, soil sealing should also be present, as it influences the infiltration of the water in the soil (Guerra and Cunha, 2005). It is here proposed the opening of spaces for urban afforestation (Figure 5) and paving the streets using *Uni Stein* blocks instead of asphalt.

Finally, the other land use consolidated in this geoenvironmental unit is Forestry activity that uses *pinus* and *eucalyptus* as the main species (Treflor, 2010), whose main characteristic is the high intake of water in the early stages of plant development (Tagliani, 2000). The forestry area is located on an area of obliterated dunes, where water table recharge is difficult, and the vegetation can retain the rainfall at the treetops, where the water is lost into the atmosphere by evapotranspiration (Guerra and Cunha, 2005).

There is not enough space among the trees in the production area (Bonilha, 2019). Therefore, the opening of corridors will allow rainfall to reach the soil. Here, it is still recommended We still recommend further studies to be conducted regarding the growth and direction of the roots towards wetter areas (coastal cordons or ESEC-Taim). Corridors of *eucalyptus* should be used as windbreaks (Ziller and Galvão, 2002) to prevent the dispersion of the seeds of *pinus*[4].

4.5 Recovering Area

The main function of the recovering area is to recover the structure and function of the landscape (Oliveira and Souza, 2012). The propositions for this area aim at a great change in the way the land has been used, so the physical environment can have its environmental functions restored. However, due to anthropic changes, the restoration of this area is not possible; therefore, recovery measures are closer to the reality of the place (Braz *et al*., 2015).

The following geoenvironmental units comprise the recovering area: Cultivated River-Lagoon Terrace Transmitting Unit, Coastal Cordons Transmitting Unit, Mirim São Gonçalo Flood Plain Accumulating Unit and Wind Plain Accumulating Unit (Figure 2).

In the recovering area of the Cultivated River-Lagoon Terrace Transmitting Unit (Figure 2), we can observe forestry on lagoon terraces (IBGE, 2003), and rice cultivation on the river-lagoon terraces (IBGE, 2003) that reach São Gonçalo Channel bank (Bonilha, 2019).

It would be advisable to remove forestry activity from the lagoon terraces, as forestry should not be located in these areas due to the geomorphological relevance of these features to local and regional hydrological regulation (Tagliani, 2000). Furthermore, the area defined for rice cultivation should be reduced over the river-lagoon terraces, being the lagoon terrace the limit to its activity, as it would avoid economic losses related to the floods in this area (Rio Grande, 2013).

In the recovering area in the Coastal Cordons Transmitting Unit (Figure 2), the area of forestry has advanced into the prevention area of ESEC-Taim (Bonilha, 2019). Such activity should be removed from this area, as it is very difficult to control the pine dispersion, and in the prevention area, the intention is to control anthropic activities. Furthermore, forestry should also be avoided over coastal cordons (Tagliani, 2000).

The recovering area within the Wind Plain Accumulating Unit (Figure 2) is comprised of the coastal dunes (Figure 6). These features, due to their proximity to urban areas, have suffered the interference of anthropic actions that have compromised their natural dynamic and their migratory process. The actions have tried to stop the advance of the dunes over adjacent houses, and wood barriers, and the dunes have had their dynamic affected by access to the beach (Nema, 2008).

Periodic supervision by the authorities and cleaning actions in these areas should be performed due to the great amount of waste disposal. Signs with alerts regarding the relevance of the dunes, and how to protect them should be distributed along the main accesses to the beach.

Coastal dunes, despite their beauty, have the role of protecting adjacent areas, such as fields, wetlands and urban areas, from the effect of the high tides. The dunes also serve as a barrier against the penetration of salty water into the water table due to the pressure of the freshwater they retain (Nema, 2008). It is important to develop a project that would adequate the traffic of vehicles on Cassino Beach (RS-Brazil).

In the area of Mirim São Gonçalo Flood Plain Accumulating Unit, there are lagoon dunes (Figure 6) near Mirim Lagoon, a tourist area known as “Capilha”. Anthropic interventions in this area range from the illegal disposal of waste to livestock in Mirim Lagoon. Periodic actions for cleaning this area and control over the touristic activities should be monitored by the government in an attempt to avoid the degradation of the landscape. Livestock should also be removed from inside Mirim Lagoon.

4.6 Use area

The main function of the use area is the improvement of the land uses, aiming at using the available resources more efficiently, and having as a reference the basic levels of environmental sustainability (Oliveira and Souza, 2012). Improving the way the land has been used is the main proposition for the use area, as the area is geologically unstable (Figure 3) and the landscape depleted (Figure 4) due to the space occupation of the area. The measures aim to guide the urban, agricultural and forestry expansion. The following geoenvironmental units comprise the use area: High Wind Plain Emitting Unit, Wind Plain Accumulating Unit, Patos Lagoon Flood Plain Accumulating Unit.

In the agricultural areas (Figure 6) in the High Wind Plain Emitting Unit, agriculture and forestry should be managed with the addition of organic matter to help in soil cohesion. Furthermore, there is an area recommended to be used for agriculture expansion (Figure 5), as a way of avoiding the expansion of this activity into preservation areas.

In the agricultural areas in Patos Lagoon Flood Plain Accumulating Unit, the propositions aim at a more efficient and coherent use of the land with the dynamics of the physical environment, as these areas are essential to provide food sold in street markets in the town of Rio Grande (RS-Brazil). Therefore, a better use of irrigation water and the use of natural pest control should be encouraged in these areas.

In addition to encouraging family agriculture and organic cultivation, the method of drip irrigation should also be encouraged, as it is a more efficient and beneficial method than the sprinkling traditional one, taking the water to the plant at the right moment. Drip irrigation may also be associated with the use of fertilizers through the irrigation system, as the fertilizers are applied closer to the roots and the doses can be fractioned, which improves their efficiency (Deus and Bakonyi, 2012).

Pest control can be approached with neem oil instead of traditional pesticides. Neem oil is a natural compost that repels insects and pests, it does not exterminate them, has low toxicity for natural predators and pollinators, and degrades fast in the environment (Deus and Bakonyi, 2012).

The urban expansion should be stimulated in the areas of the Wind Plain Accumulating Unit, which has already been taking place towards Cassino Beach RS-Brazil (along RS-734 road), and Pelotas RS-Brazil (along BR-392 road) in an attempt to keep them away from the preservation areas. According to Martins (2007) the urban expansion that was driven by the industrial sector, has now been driven by the expansion of the real estate sector by the sale of plots of land.

The expansion of forestry should be considered along the coast over obliterated dunes (Figure 6). Northeast is the predominant wind direction in this area (Gomez *et al.*, 1987) and a great amount of sand from the dunes is transported and deposited near the area of forestry, forming a barrier. Forestry would have a "beneficial" effect, which is the maintenance of the landscape. If the trees are taken from the area, environmental dynamics could be changed, which could affect the landscape by clogging the wetlands, lagoons and coastal cordons. Therefore, forestry could be developed along the coast over the obliterated dunes as a way of protecting and keeping the landscape.

5. FINAL CONSIDERATIONS

Geoenvironmental zoning in the municipality of Rio Grande (RS-Brazil), done using Geoecology of Landscape, a theoretic-methodological proposition that investigates the landscape based on a systemic approach, has proved to be satisfactory, as single characterization, analysis and delimitation of geoenvironmental units system was established. The analysis of the geoenvironmental units has allowed understanding of the flows of matter and energy. Evaluating the land uses and the pressure over the landscape, it was possible to define the geoecological states and the classification of the actual landscape, and then propose the necessary actions that characterize the zoning.

The land uses in the municipality of Rio Grande have been in expansion and it means a disarticulation between natural and anthropic elements. Results showed that the irrational land use has resulted in significant changes in the landscape, directly affecting its functioning, as Rio Grande municipality has been sensitive to the use and occupation processes. Furthermore, the land has been the main influencer of the landscape dynamic, as it causes an imbalance in the natural systems, interfering in the matter and energy flows due to its capacity to modify the characteristics of the physical environment.

Aiming at reaching a balance in the relation of the natural and socioeconomic elements, the environmental dynamics should be understood, elaborating norms and guidelines that consider this dynamic to the proposition of actions that have the objective of conciliating the proper anthropic intervention with the physical environment. In this perspective, the proposed zoning has not only aimed at the restrictions or interruptions of the use of the land but also that such uses should take into consideration the environmental conditions. It is important to highlight that restricting or ceasing the current uses of the land would demand a complete change in the social-historical-cultural patterns, as the current uses of the land are related to the survival of the population.

The geoenvironmental zoning proposed in this study, beyond offering historical, environmental and legislative knowledge regarding the natural elements, has also evaluated the capacity of use of the land taking into consideration the changes in the landscape structure and functioning. Due to its systemic character, the geoenvironmental zoning was used to recognize the limitations and possibilities of the area under study, proposing actions to mitigate punctual problems, and to guide the conciliation between the physical environment and socioeconomic dynamic. Therefore, the cartographic products generated may help the managers to make decisions aimed at the social and environmental development of Rio Grande municipality, which is situated in an important lagunar area of South America continent, what makes it a very singular region and landscape.

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