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Socio-environmental assessment of the Santos and São Vicente municipalities on the coast of São Paulo/Brazil: application of social network analysis to the DPSIR conceptual framework

Avaliação socioambiental dos municípios de Santos e São Vicente no litoral de São Paulo/Brasil: aplicação da análise de redes sociais ao arcabouço conceitual do DPSIR

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ABSTRACT

Considering the social, economic, and ecological complexity of coastal regions and the difficulty of public and private environmental management in these highly populated areas with multiple sources of pollution, this study used the driver, pressure, state, impact, and response model to socio-environmentally assess the coastal municipalities of Santos and São Vicente in the Baixada Santista metropolitan region, SP-Brazil. Data were evaluated by social network analysis. Results indicated the most relevant drivers (i.e., those that most affected sustainability and environmental governance) within the municipalities of Santos and São Vicente, such as port activities (represented by the pressure due to the emission of contaminants in the air and water and dredging). Poor air quality due to pollution and its impacts on human health stand out as an element in the state factor. The most forceful responses refer to the increase in the inspection and control of atmospheric emissions, liquid effluents, dredging, and solid waste. Our approach will support decision-makers to focus on the most critical aspects in this study to implement corrective and preventive actions and develop environmental and sectoral public policies.

KEY-WORDS: DPSIR; Baixada Santista; Port of Santos; social networl analysis.

RESUMO

Considerando a complexidade social, econômica e ecológica das regiões costeiras e a dificuldade de gestão ambiental pública e privada nessas áreas altamente povoadas e com múltiplas fontes de poluição, este estudo utilizou o modelo driver, pressão, estado, impacto e resposta para avaliar socioambientalmente os municípios costeiros de Santos e São Vicente na região metropolitana da Baixada Santista, SP-Brasil. Os dados foram avaliados por análise de redes sociais. Os resultados indicaram os drivers mais relevantes (ou seja, aqueles que mais afetaram a sustentabilidade e a governança ambiental) dentro dos municípios de Santos e São Vicente, como as atividades portuárias (representadas pela pressão devido à emissão de contaminantes no ar e na água e dragagem). A má qualidade do ar devido à poluição e seus impactos na saúde humana se destacam como um elemento no fator estado. As respostas mais contundentes referem-se ao aumento da fiscalização e controle de emissões atmosféricas, efluentes líquidos, dragagem e resíduos sólidos. Nossa abordagem apoiará os tomadores de decisão a se concentrarem nos aspectos mais críticos deste estudo para implementar ações corretivas e preventivas e desenvolver políticas públicas ambientais e setoriais.

PALAVRAS-CHAVE: *DPSIR; Baixada Santista; Porto de Santos; análise de redes sociais.*

INTRODUCTION

The Baixada Santista metropolitan region in São Paulo State, Brazil, encompasses nine municipalities and houses the largest port in South America - the Port of Santos. This region produced 2.78% of the economic revenue of the State in 2020 (IBGE, 2020). The São Vicente island, home to the insular portion of the Santos and São Vicente municipalities, houses a high proportion of the population of this metropolitan region (Martins; Menegon; Lamparelli, 2020).

Of the two, Santos constitutes the most socially, economically, and demographically developed municipality, resulting in the highest gross domestic product in the Baixada Santista metropolitan region. Such economic development is mostly due to the construction of the Organized Port of Santos in 1892, which leveraged population expansion and, in turn, intensified the urban and social development of this section of the island (Pereira et al., 2015). From the 1960s onward, the region underwent an intense process of densification and conurbation that disregarded urban planning and socio-environmental needs (Carriço, 2015; Marguti; Costa; Favarão, 2018; Ramos, 2022). Of the consequences of this phenomenon, we highlight the verticalization of dwellings, the alteration of the original landscape, the modification of natural drainage mechanisms, the emergence of subnormal dwellings in hills and mangroves, among other problems inherent to large urban centers (Cunha; Oliveira, 2015; Ramos, 2022).

Around the 2000s, the exploitation of what is known as "pre-salt" oil largely increased real estate in the region. Thus, urbanization, industrialization, population density, urban and maritime transport, and tourism coexist in the municipalities that (alone or interacting with each other) impact the environment and human health and well-being (Siqueira, 2007).

Beginning in the 21st century, the Port of Santos underwent a new phase of investments after the new Port Terminal concessions that expanded its area. According to the Annual Report of the Port of Santos (2022), its Port Complex encompasses 16 kilometers of quays, 25 kilometers of navigable channel, 100 kilometers of railway lines, 60 berths for ship moorings, and 55 kilometers of pipelines (Relatório Anual do Porto de Santos, 2022).

In view of this, this study aims to socio-environmentally assess the municipalities of Santos and São Vicente using the driver-pressure-state-impact-response (DPSIR) structure proposed by the European Environment Agency (EEA, 1999) to understand the social, economic, and environmental consequences arising from the activities carried out in these municipalities. It used social network analysis (SNA) to raise the indicators of greater relevance and influence in this complex network of social and environmental elements and find the relationships between these indicators.

1. MATERIAL AND METHODS

1.1 STUDY AREA

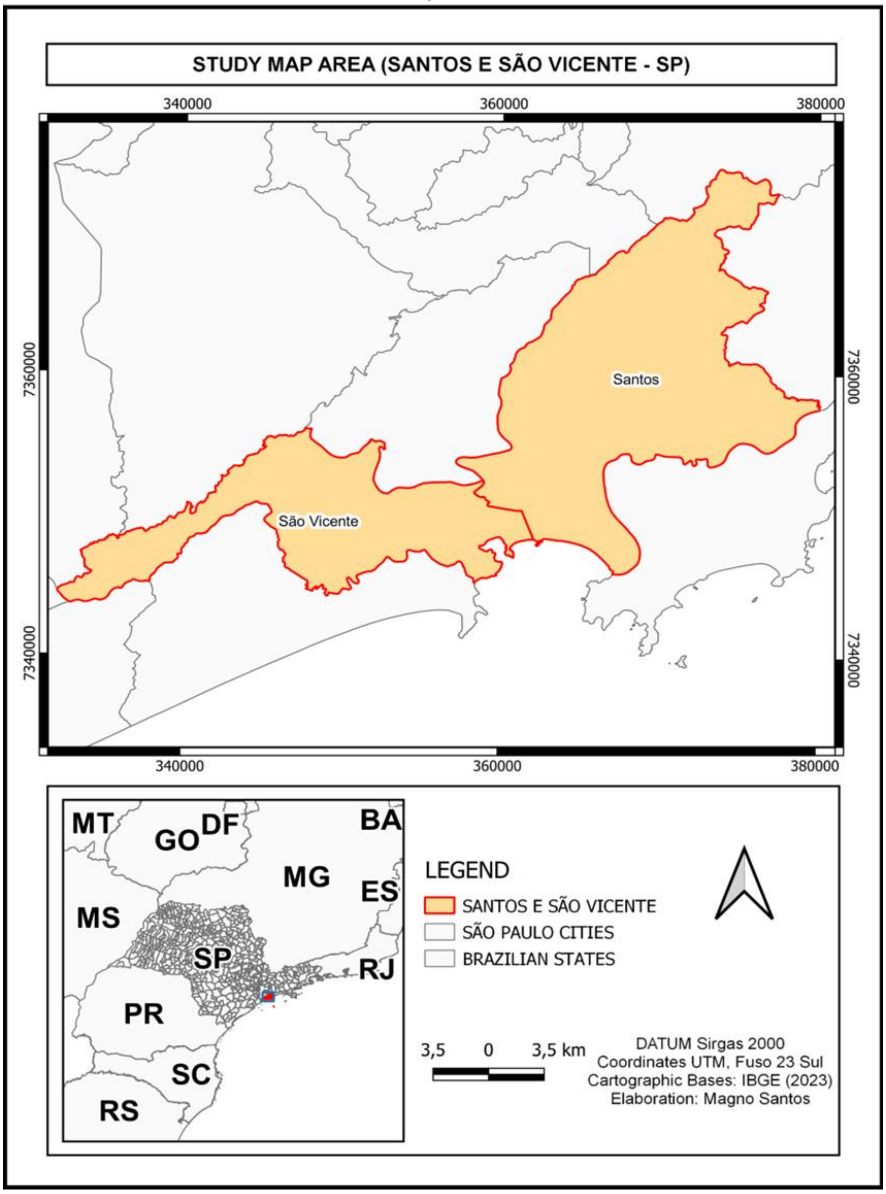
The island of São Vicente lies between latitudes 23° 91' S and 23° 99' S and longitudes 46° 30' W and 46° 42' W (Figure 1), being flanked to the south by the Bay of Santos; to the east, by the Santos Estuary; to the west, by Mar Pequeno; to the northwest, by Largo da Pompeba. and to the north, by the Casqueiro and Piaçaguera rivers (Martins; Menegon; Lamparelli, 2020). The region has a complex morphology, with many headwaters and extensive wetlands that form mangroves and mud banks in different connections with the adjacent ocean (Seiler et al., 2020). This predominantly flat island has isolated hills in its central part, the only place that still maintains small stretches of original vegetation (Bandeira, 2022).

1.2 DPSIR FRAMEWORK

Developed by the European Environment Agency, the DPSIR conceptual model was adjusted to the collected data to analyze the interactions between the studied human activities and environments. The components of the DPSIR consist of drivers (D), pressures (P), state (S), impacts (I), and responses (R). A structure prior to the DPSIR (which was developed by the Organisation for Economic Co-operation and Development and used from 1993 onward) only had pressure, state, and response. In 1999, the European Environment Agency improved this tool, giving rise to the DPSIR, which began to be adopted in environmental management studies around the world, especially on coastal zones (Sekovski; Newton; Dennison., 2012).

The DPSIR is initially elaborated by surveying the driving forces that originate from the basic and elementary needs of human beings, such as food, water, shelter, energy, among others, depending on the local geography and culture (Sekovski; Newton; Dennison, 2012). Drivers act as triggers and comprise essential human needs such as water, food, shelter, energy, and transportation due to the influence of population, industrial, and economic growth (Obubu et al., 2022; Suseno et al., 2023).

Figure 1 - Map of the study region, municipalities of Santos and São Vicente, São Paulo – Brazil



Source: prepared in QGIS, based on IBGE cartography (2023).

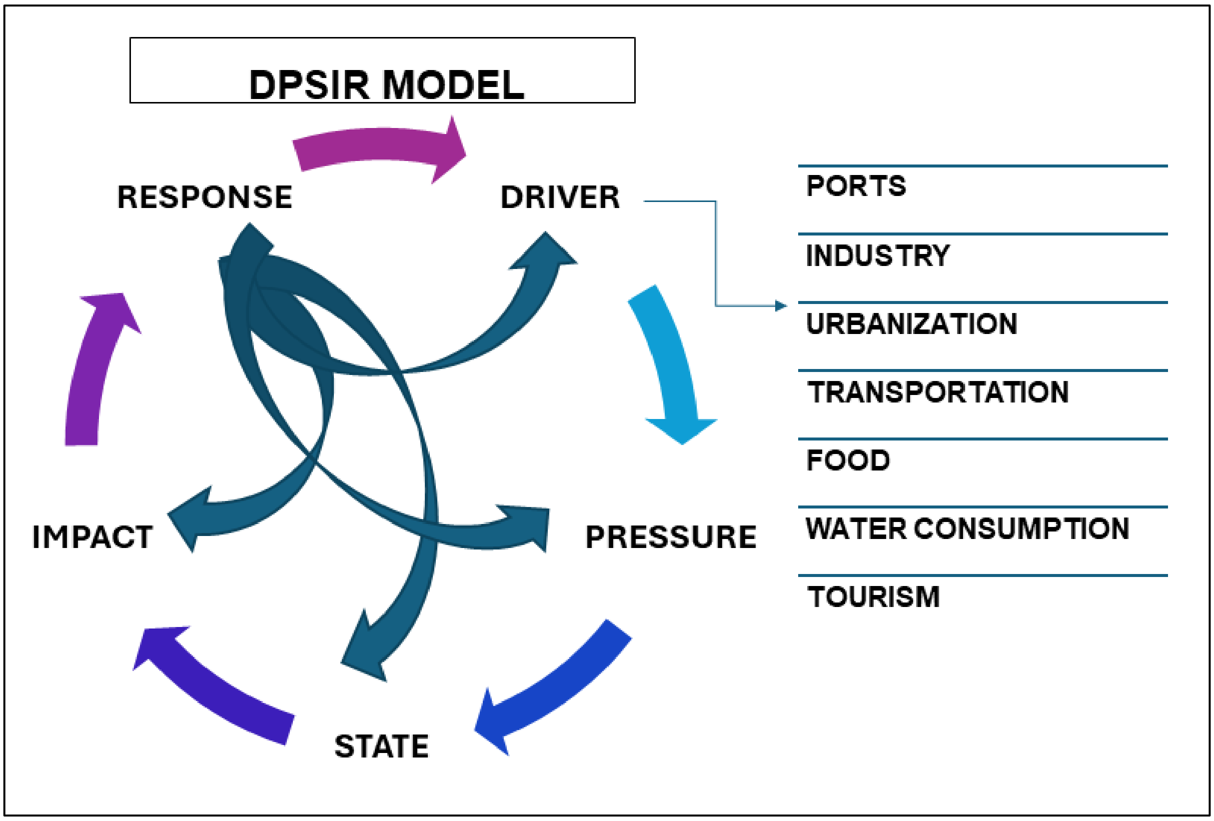
Pressures refer to the direct actions of drivers on the environment, such as waste production, pollutant emission, and natural resource overuse (Federigi et al., 2022). State refers to the physicochemical and biological changes to the environment resulting from pressures, which are shown as indicators (data) of these properties (Federigi et al., 2022). Impacts include the consequences of state changes on the functioning of the environment, ecosystem, social economy, and well-being (Tesfaldet; Ndeh, 2022). Finally, responses refer to possible measures to adjust drivers, minimize pressures, recover the initial state of a system, and reduce impacts (Malmir et al., 2021).

Thus, the DPSIR is configured as a circular model in which each item is engendered with the next. It should be noted that responses can be found for any step in the process, i.e., actions that prevent the triggering of negative impacts by directly interfering with drivers or their corresponding pressures (Sekovski; Newton; Dennison, 2012).

1.3 DATA COLLECTION

In an initial stage, studies published in scientific journals were search for data regarding the DPSIR items related to the Santos and São Vicente municipalities in São Paulo State, Brazil, from November 2020 to January 2021. Considering information for the Santos and São Vicente municipalities, seven drivers were listed (Figure 2), namely (1) ports, (2) industry, (3) urbanization, (4) transportation, (5) food, (6) water consumption, and (7) tourism. Evaluators described the pressures imposed by each driver, the observed states, resulting impacts, and the responses needed to minimize or eliminate negative consequences.

Figure 2 - European Environment Agency DPSIR model



Source: prepared by the authors.

1.4 DATA SYSTEMATIZATION AND ANALYSIS

The collected information was standardized and listed in an electronic spreadsheet to respect the association of the data obtained for each DPSIR item. To facilitate cataloging and avoid duplicating such information, each datum was represented by an acronym. As a result of the survey, a spreadsheet with two columns titled "Input" and "Output" was set up to facilitate the description of cause-consequence relationships inherent to the DPSIR.

Social network analysis (SNA) was used to detect and highlight the most influential elements in the complex network of DPSIR connections. Cluster networking analysis was employed to detect the clusters of these elements (Charrad, 2016). SNA is a commonly used method in social sciences as it can identify dependencies between social entities, connection densities, clusters, and centrality measures in a complex network of interconnected entities (Mester et al., 2021; Tabassum, 2018). Collected indicators were represented by nodes in the structure, which were interconnected according to their relationship in the DPSIR model.

The data obtained by applying the DPSIR framework were processed in R Studio (version R 4.2.0), following Charrad (2016) and Jacob (2022). The method uses the igraph package (an open-source tool that can create, manipulate, and visualize graphs) to design a diagram that represents a network and an algorithm (cluster_edge_betweenness) to detect communities within the network.

To find the importance of each node in the graph, their centrality measures were highlighted by calculating algorithms according to Graph Theory. The betweenness, closeness, diameter, and transitivity centrality measures were estimated for the DPSIR network. However, data analysis focused on betweenness and closeness measures. Betweennes measures the number of times a node lies on the shortest path to other nodes, whereas closeness is related to the number of steps to access all other vertices from a given vertex, i.e., a high index of this measure may indicate greater relevance of a node in a given network.

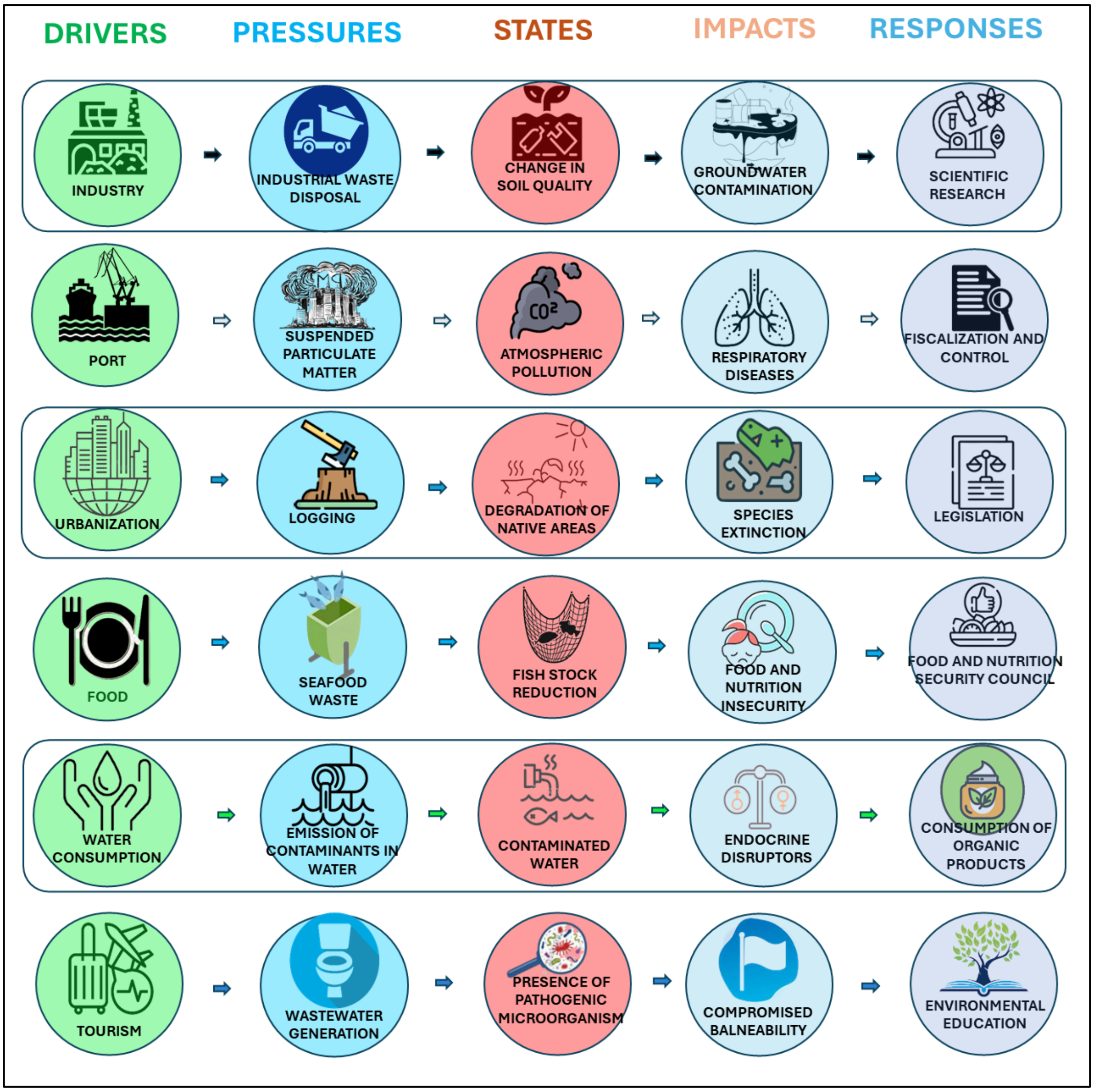
The used clustering method, Cluster Edge Betweenness algorithm, consists of a hierarchical clustering algorithm based on edge betweenness, which refers to the measure of the number of times an edge is used to connect pairs of vertices in shorter paths within the graph. Cluster edge betweenness configures an unsupervised algorithm that dispenses with labels or prior information about vertex classes (Jacob, 2022). Thus, it can be applied in areas with no previous information about vertex classes.

2. RESULTS AND DISCUSSION

2.1 DPSIR IN SANTOS AND SÃO VICENTE

Data collection and the DPSIR treatment found and included 114 indicators. The connections between them generated 388 links. The indicators and their interactions after the application of the model to the study area are shown below in a simplified manner (Figure 3).

Figure 3 - Representation network of the DPSIR indicators applied to the Santos and São Vicente municipalities, São Paulo – Brazil.



Note: Drivers - Basic and elementary needs of human beings; Pressures - Human activities that excessively use natural resources, degrading ecosystems; States - Physical, chemical, and biological alterations the compromise of good environmental quality; Impacts - Result of the alterations to the States; Responses - Set of actions to reduce, alter, and/or prevent impacts, states, pressures, and drivers.

Source: prepared by the authors.

The most important economic activity in the region (the Port driver) was related to several pressures, states, impacts, and responses that arose from its construction and activity. Important pressures due to this driver in the study area include dredging, the introduction of exotic species (especially in local estuarine and marine ecosystems), and the emission of polluting gases.

Dredging removes material and sediments from the bed of water bodies for specific purposes. It is classified according to the following concepts: implantation dredging (to implement, expand, or deepen navigation channels, docks, and other engineering works or services in liquid masses), maintenance dredging (to fully or partially restore the originally licensed conditions and landslides by disaggregating and removing submerged materials that impair navigation and whose hardness makes removal by traditional dredging unfeasible), mining dredging (to economically exploit and use mineral resources), and environmental recovery dredging (to improve environmental or sanitary conditions) (Marinha do Brasil, 2022).

Another problem related to port activity includes the introduction of exotic species brought by the ballast waters of ships arriving at the Port of Santos. Data from the NGO Água de Lastro Brasil (2009) indicated the presence of Salmonella subspecies I in 20% (18/90) of bivalve water samples collected in natural proliferation banks near the port regions of Santos.

The State of São Paulo legislation (specifically Law 898/1976 and Decree 8468/1976) and the federal CONAMA Resolution 237/1997 consider port and industry activities as effectively or potentially polluting drivers. Thus, the legislation requires responses such as environmental licensing and in-depth studies from these activities, contributing to the greater relevance of the port and industry drivers in the network analysis of the DPSIR in the studied municipalities. It is possible to evince that the atmospheric emissions from the Port of Santos and the industries supporting this driver contribute to the local "atmospheric pollution" state. On the other hand, dredging, a support activity for the functionality of the Port of Santos directly contributed to the "sediment flow alteration" state.

The industry driver pressured the environment by generating waste and emitting liquid and gaseous effluents (Cetesb, 2020). The inadequate dumping of industrial waste in the Santos and São Vicente municipalities changed the state of some areas that later became inhabited by households, impacting the environment and the local population's health (CETESB, 2021). Braga et al. (2009) studied 4,000 families in four contaminated areas in the region, showing the prevalence of skin diseases in São Vicente and a higher rate of respiratory diseases than in other municipalities in the Baixada Santista and São Paulo metropolitan regions. They also found mercury above the biological tolerance limit, low white blood cell indices (leukopenia), and other problems within the investigated families, showing the impact to these individuals' health.

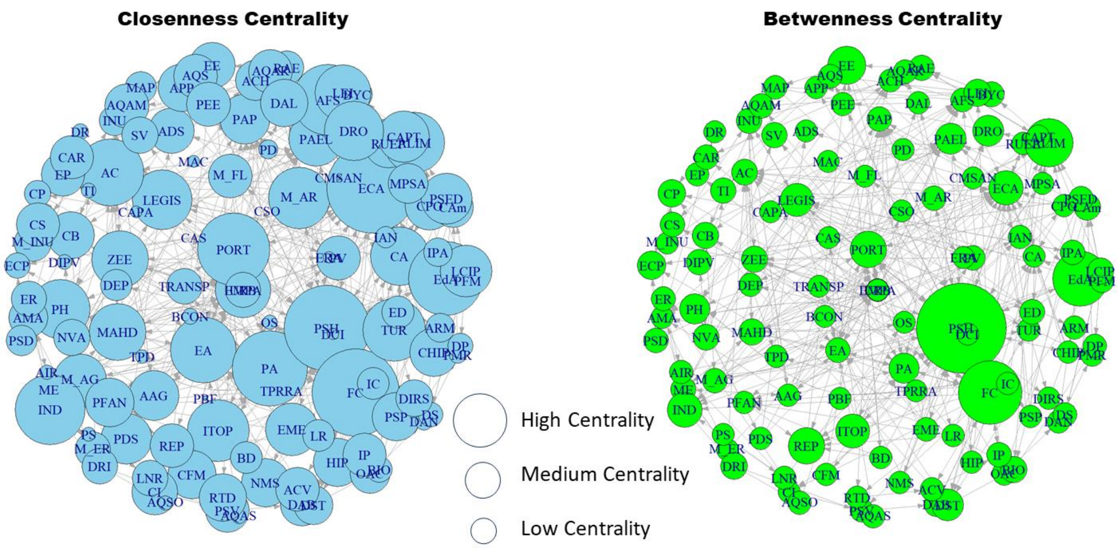
The following urbanization pressures stand out: atmospheric contamination, hydrological flow changes, water and sediment contamination, sediment flow alteration, climate change, and deforestation (Carmo; Abessa; Machado Neto, 2011; Prefeitura Municipal de Santos, 2016; Rodrigues; Victor; Pires, 2006; Silva; Quiñones, 2012).

Activities related to the need for food generate a series of environmental, social, and economic pressures. The following stand out in the studied region: overfishing, disorderly exploitation of fish stocks, bycatch, ghost fishing, suppression of native vegetation for agriculture, disposal of toxic substances, and waste of fish. These activities alter states, generate impacts, and require responses from the government and civil society. Moreover, activities such as artisanal and subsistence fishing; crab, mussel, and shrimp catching; and fish trade stand out as means of obtaining food in the region (Conepe, 2014; Henriques et al., 2018; Paiva-Filho; Schmiegelow, 1986; Soykan et al., 2008).

2.2 SOCIAL NETWORK ANALYSIS AND DPSIR

SNA served to determine the centrality measures of each DPSIR indicator that emerged in the first stage of this study. Thus, it was possible to identify the most relevant elements in the network, i.e., those with greater centrality, which this research considers by their betwenness value in the DPSIR structure for Santos and São Vicente (Figure 4). Nodes with higher betweenness indicate the greater relevance of an element within the network, i.e., they more greatly influence the other elements, making them key elements for environmental management strategies. Figure 5 shows our cluster analysis.

Figure 4. Spherical graph highlighting the elements of greater relevance in the social network of the DPSIR for the Santos and São Vicente Region, SP – Brazil.



CLOSENNESS	
Fiscalization e Control (FC)	0.003472222
Environmental Education(EdA)	0.003174603
Emission of Contaminants (ECA)	0.0035335
Atmosferic Polution (PA)	0.003205128
Problems in Human Heath (PSH	0.003436426

BETWENNESS	
Problems in Human Heath (PSH)	1458.4476947
Fiscalization & Control (FC)	2327.235160
Environmental Education (EdA)	1533.5356071
Food (Alim)	1480.4422179
Ports (PORT)	951.3370890

Note: Measure of individual centrality of the most prominent elements in the network.
Source: prepared by the authors

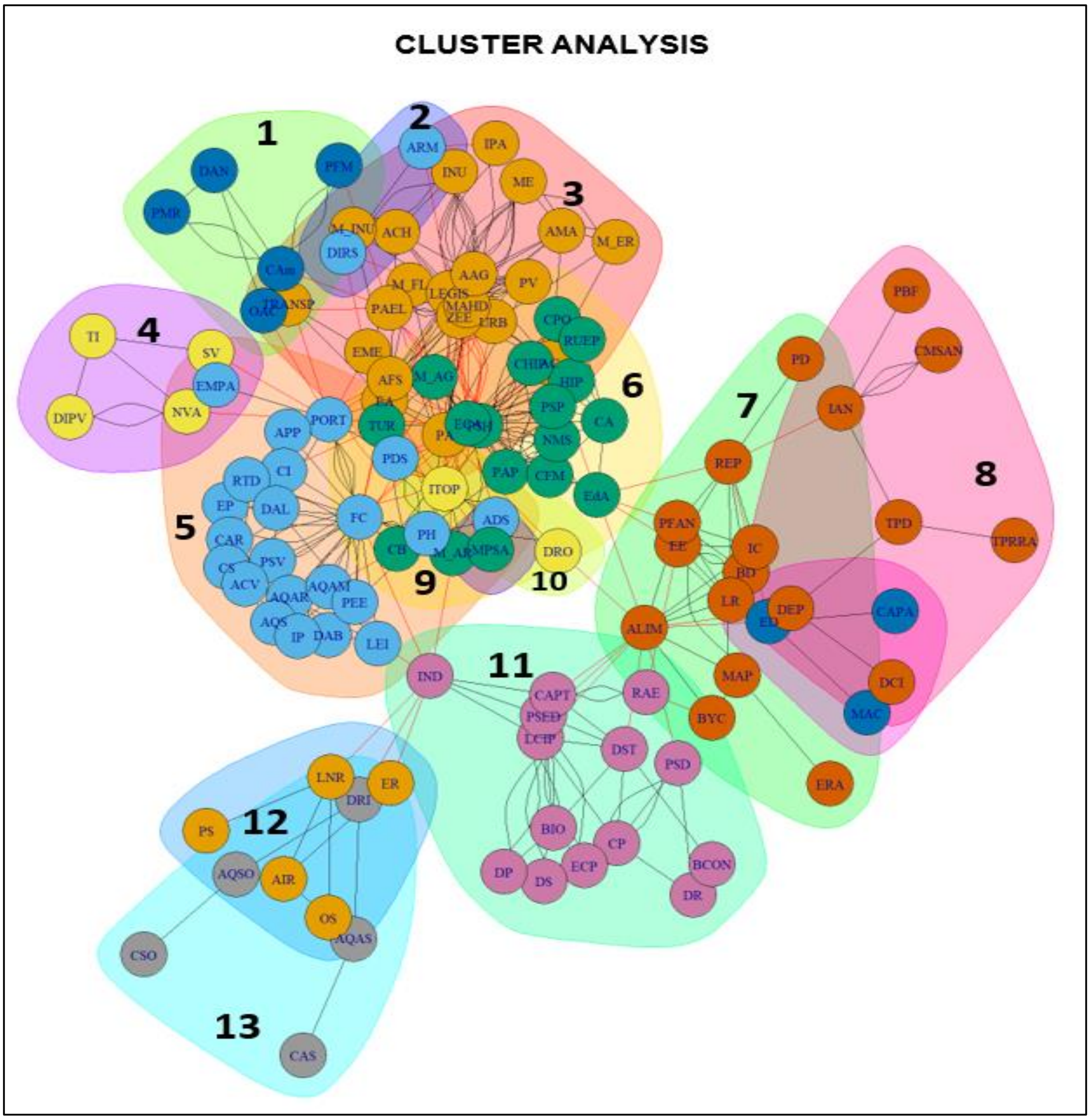
The "water contaminant emission" pressure showed the highest measure of betweenness (0.003533569) of all indicators, thus evincing its very high relevance in the structure. Several authors and studies on different classes of waste, hazardous chemicals, and toxic elements due to the aforementioned activities evince the presence of contaminants from the port/industrial activities in the Santos estuary region and its surroundings (Abreu et al., 2020; Begliomini et al., 2017; Gouveia et al., 2022; Kim; Kabir; Jahan, 2017; Pusceddu et al., 2019; Ribeiro et al., 2021; Ribeiro-Brasil et al., 2020). This directly alters the quality of the water and the life of the local biota, impacting human health in the region. The prominence of this indicator in the SNA agrees with the literature and reinforces the need of prioritizing socio-environmental management efforts focused on responses to this pressure.

Moreover, cluster analysis (Figure 5) found that the "water contaminant emission" indicator configured the main element of Cluster 6. Understanding the characteristics that unite the indicators in a given requires considering the context of the DPSIR and the characteristics of the used algorithm. The presence of water contaminant emission pressure as a hub indicates that a strategic route to minimize human interference in the environment should target this indicator as a priority.

As the DPSIR model establishes a greater number of connections for response indicators, this study expected that they would have high centralities. The “increased inspection and control” response showed the second highest measure of betwenness in the network (0.003472222). This indicator stands out and appears as the main node of Cluster 5 (Figure 5). Its prevalence in the network shows that this response affects several indicators and evinces the need to focus and increase the quantity and quality of these actions. Thus, as the response that most influences the network, it is to be expected that efficient management will prioritize efforts regarding it.

The “human health problems” impact had the third highest measure of betwenness (0.003436426). As this type of impact constitutes a central node in our network, it samples how human activities harmfully affect humans. The literature exemplifies how this impact has greater relevance in Santos and São Vicente than in adjacent areas. This impact and the “water contaminant emission” pressure configure the main nodes of the relevant Cluster 6 (Figure 5).

Figure 5 - Social network cluster detection by the Cluster_Edge_betwenness algorithm applied to the DPSIR framework for the Santos and São Vicente Region, SP – Brazil.



Source: prepared by the authors.

The “atmospheric pollution” state in Cluster 3 showed the fourth highest measure of betwenness in the network (0.003205128). This result reflects the characteristics of the studied region, which concentrates high rates of atmospheric emissions from activities related to the Port of Santos (Cetesb, 2020). The relevant presence of “atmospheric pollution” in the region impacts the local community with high rates of respiratory diseases (a form of the “human health problems” impact), configuring another relevant indicator of the network and linking Clusters 3 and 6.

The most relevant drivers in the structure refer to industry (IND in Figures 4 and 5 — Cluster 11) and Port (PORT in Figures 4 and 5 — Cluster 5). The "port" driver configured the main and central element in Cluster 5 (Figure 5) and had the highest betwenness among drivers (0.003134796). This result was expected since this is the main economic activity in the region, causing pressures, impacts, and responses. The "industry" driver (0.003076923 betwenness) also stood out in the network due to its importance for the studied region—justifying the a priori theoretical choice to treat it separately from port activities since they have different importance and activities in the region, despite the industrial characteristics of the latter.

Thus, it is concluded that the actors that most affect sustainability and environmental governance in Santos and São Vicente refer to, in descending order of SNA centrality: the "water contaminant emission" pressure, the "increased inspection and control" response, the "human health problems" impact, the "port" driver, and the "atmospheric pollution" state.

3. FINAL CONSIDERATIONS

The approach in this study more efficiently allocated the resources available for socio-environmental assessment and monitoring, focusing on its most relevant and critical aspects and aiming at decision-making based on information and the implementation of effective actions.

Applying SNA to the DPSIR framework satisfactorily detected important features and phenomena within the complex DPSIR link structure, as evinced by the central elements of the generated network and clusters. However, more advanced studies are needed to understand some of these phenomena, such as: what socio-environmental characteristics unite the elements in a cluster? What do the most important elements of a network (i.e., those with greater centrality measures) represent for environmental management?

It is understood that the data obtained in this study fails to exhaust the entire universe of DPSIR variables in the municipalities of Santos and São Vicente, but they have successfully framed the local reality based on the analyzed material. Thus, even if only initially, it is believed that this research may contribute to the state of the literature on DPSIR in the studied region. It should also be noted that the application of the DPSIR using only peer-reviewed publications and gray literature may disregard the scarcely studied indicators in the region, which may impair this evaluation.

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