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Environmental vulnerability assessment for pre-selecting areas for waterway terminals implementation using AHP

Avaliação da vulnerabilidade ambiental na pré-seleção de áreas para implantação de terminais hidroviários utilizando AHP

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ABSTRACT

The aim of this article is to present an expedited methodology for assessing the environmental vulnerability of areas designated for the implementation of waterway terminals. Environmental studies involve numerous variables, and their relative weighting is highly complex. Existing methodologies often require extensive data collection, resulting in significant costs and time commitments. To address this, we propose a hierarchical environmental assessment procedure based on public and easily accessible data, facilitating the pre-selection of locations for more detailed subsequent studies. The motivation for this study was to balance development with environmental preservation through an expedited model, given that economic and logistical criteria are commonly prioritized based on regional market expectations. To achieve this, we employed the Analytic Hierarchy Process (AHP) method with expert judgment. The proposed procedure was applied to points suggested by the National Waterway Integration Plan (PNIH), published by the National Agency for Waterway Transportation (ANTAQ), for the implementation of waterway terminals on the Tietê River in the state of São Paulo. Our research revealed that near some points chosen by the PNIH (2013), there were areas classified as having very high environmental vulnerability and others with very low environmental vulnerability.

RESUMO

O objetivo deste artigo é apresentar uma metodologia expedita para a avaliação da vulnerabilidade ambiental de áreas designadas para a implantação de terminais hidroviários. Estudos ambientais envolvem numerosas variáveis, e sua ponderação relativa é altamente complexa. As metodologias existentes frequentemente requerem uma coleta extensiva de dados, resultando em custos significativos e compromissos de tempo consideráveis. Para resolver isso, propomos um procedimento de avaliação ambiental hierárquica baseado em dados públicos e de fácil acesso, facilitando a pré-seleção de locais para estudos subsequentes mais detalhados. A motivação para este estudo foi equilibrar o desenvolvimento com a preservação ambiental através de um modelo expedito, dado que critérios econômicos e logísticos são comumente priorizados com base nas expectativas do mercado regional. Para alcançar isso, utilizamos o método Analytic Hierarchy Process (AHP) com julgamento de especialistas. O procedimento proposto foi aplicado a pontos sugeridos pelo Plano Nacional de Integração Hidroviária (PNIH), publicado pela Agência Nacional de Transportes Aquaviários (ANTAQ), para a implantação de terminais hidroviários na Hidrovia Tietê, no estado de São Paulo. Nossa pesquisa revelou que, próximo a alguns pontos escolhidos pelo PNIH (2013), havia áreas classificadas como de muito alta vulnerabilidade ambiental e outras como de muito baixa vulnerabilidade ambiental.

1. INTRODUCTION

The transportation of cargo plays an increasingly important role in economic activities due to globalization, which demands the movement of both raw materials and manufactured goods. However, it is one of the main sources of congestion, greenhouse gas emissions, and fossil fuel consumption. Compared to road and rail transport, waterway transport is the most economical and efficient option. (Kelle et al., 2019). For long distances, waterway freight is more competitive and environmentally friendly, emitting the least carbon dioxide (CO_2) according to the National Confederation of Transport, CNT (2014a, 2014b). Roso et al. (2020) emphasize the environmental benefits of inland navigation, such as reduced congestion and lower environmental impact. Consequently, some companies choose waterway transport for product distribution or supply acquisition to achieve lower costs and increased competitiveness. Additionally, river transport causes less air, soil, and noise pollution and has lower rates of fatal accidents (Santana and Tachibana, 2008).

Waterways are crucial for decentralizing and balancing Brazil's freight transport matrix, as they help reduce the use of trucks for long distances, thereby alleviating road congestion. Navigable rivers, commonly referred to as waterways, are essential in this context. According to the National Agency for Waterway Transportation, ANTAQ (2014) and Simões (1999), Brazil has several waterways with increasing transport flow. Various government initiatives, such as the Ministry of Infrastructure's Program 2086, aim to improve system productivity and promote environmental sustainability in waterway areas (Brasil, 2017).

The main cargo transported on Brazilian waterways includes soybeans, soybean meal, corn, sand, and sugarcane (Brasil, 2018). In 2014, during a severe water crisis that affected the Southeast region of Brazil and halted navigation on the Tietê River, 4.4 million tons of cargo were transported on the Tietê-Paraná waterway. By 2017, this figure had increased to 8.9 million tons, and in 2018, a 9% growth was observed, amounting to 9.7 million tons, equivalent to 277 thousand bi-train trucks (Portogente, 2019). This growth underscores the importance of the Tietê-Paraná waterway for cargo transport logistics.

Despite the advantages of waterway transport, it relies on interconnections with other transport modes. This interconnection is facilitated through port infrastructure and cargo transshipment terminals, known as waterway terminals. A waterway terminal serves as a link between waterway transport and land transport modes (road, rail, and pipeline), comprising a dock and hinterland structure that allows cargo transfer between vessels, trucks, trains, and pipelines (Departamento Hidroviário, 2022). However, installing a waterway terminal can potentially cause significant environmental damage (Santana and Tachibana, 2004). Therefore, environmental analysis of port and terminal areas is mandated by Brazilian legislation (Law 6.938/81).

Environmental studies are complex, involving numerous variables and their relative weighting. Current techniques, such as Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA), require extensive data collection (Brasil, 2002).

According to Almeida et al. (2017), the United States was the pioneer in adopting Environmental Impact Assessment (EIA) back in 1969. Since then, driven by pressures from environmental groups, the practice of Environmental Studies has spread globally, all in pursuit of sustainable development. The authors assert that EIA processes delve into modifications in the physical and biological environment, as well as anthropogenic activities in the socioeconomic sphere.

Almeida, Alvarenga and Cespedes (2014) highlight the prevalent issue of poor-quality environmental studies as a significant obstacle in the application of EIA. They propose a checklist and agreement indices to evaluate the quality of Environmental Control Reports (ECR), consisting of 8 legal variables and their respective sub-items. The analysis of these variables relies on a binary assessment of presence or absence.

On a similar note, Kaiser, Bezerra and Castro (2013) draw attention to the sluggishness associated with obtaining environmental licensing, a process that may span up to two decades. They examine this through the lens of Brazilian environmental legislation and policies governing navigation development and port management. The authors underscore the challenges inherent in securing environmental licensing, navigating the complexities involving multiple agencies in the licensing process.

These studies collectively underscore the intricate nature of environmental assessment processes, necessitating extensive data collection by multidisciplinary professionals across various sectors. This comprehensive approach aims to analyse both positive and negative environmental impacts, demanding substantial financial resources and time investment.

Interestingly, the literature review reveals a gap regarding a theoretical framework for pre-selecting potential sites preceding preliminary environmental studies. Current literature primarily focuses on environmental studies conducted after site selection and the subsequent procedures for environmental licensing. Notably, there's a tendency to prioritize economic and logistical criteria based on regional market expectations for terminal locations, often sidelining environmental concerns.

Thus, to address this gap, our research proposes an expedited and preliminary environmental analysis for waterway terminal implementation, leveraging readily available data. This approach aims to optimize the environmental impact assessment phase, enhancing the likelihood of prior licensing approval.

The proposed methodology involves mapping environmental vulnerability for waterway terminal implementation, emphasizing cost and time efficiency in analysis. We selected environmental sensitivity indicators based on existing literature and open databases. Through expert consultation, we assigned weights to these indicators, establishing a hierarchy of environmental sensitivity concerning site-specific physical characteristics. This procedure offers an expedited and cost-effective hierarchical environmental assessment for pre-selecting areas for river terminal implementation.

To illustrate the application of this methodology, we present a case study conducted on the Tietê waterway (ANTAQ, 2013a). Initially, we selected an area demarcated by ANTAQ, primarily chosen for logistical reasons. One notable advantage of this proposed approach is that it conducts environmental studies before determining the site, contrary to the prevalent practice where the site is chosen first, followed by the EIA/RIMA (Environmental Impact Assessment/Environmental Impact Report).

2. THEORETICAL BACKGROUND

The importance of environmental damage within a specific geographical area depends on various factors, including the nature of the enterprise and the anthropological and physical characteristics of its surroundings. Therefore, actions for control, prevention, monitoring of damages, as well as corrective and compensatory measures, must be developed as part of environmental programs to enable the execution of potentially polluting projects. The development of these environmental programs depends on governing bodies, which must comply with Brazilian environmental legislation outlined in the National Environmental Plan (PNMA), based on international conventions (Rezende, 2011).

A review of the literature reveals a lack of research addressing the evaluation of environmental vulnerability in the context of waterway terminal implementation. While case studies exist for operational terminals, such as those handling coal and iron ore transshipment, as cited by

Kuhlmann et al. (2014) and Debastiani Jr. et al. (2016), and Environmental Impact Studies with accompanying reports (EIA/RIMA) conducted in pre-selected terminal locations, there is a notable absence of environmental studies preceding site selection for terminal implementation.

Many of the identified environmental assessments primarily focus on risk mitigation, as noted by Zhao et al. (2018). These studies underscore the significance of establishing a sustainable environmental protection framework, contingent upon identifying areas of environmental vulnerability. However, assessing vulnerability proves to be a complex endeavour due to regional variations and multifaceted variables. Consequently, a tailored approach employing diverse assessment mechanisms and specific indicators is warranted for each location. For instance, different research objectives may necessitate varying sets of indicators, as evidenced by studies examining spatial recognition in highly urbanized regions versus those analysing long-term dynamic changes in environmental vulnerability.

In line with this, Villa and McLeod (2002) contend that vulnerability indicators based solely on economic factors oversimplify ecosystem complexities, while risk-based indicators entail substantial investment. To address this, they propose a nuanced quantification of environmental vulnerability, achievable with resources accessible to most countries. Their proposed parameters for environmental decision-making include vulnerability, conservation status, and recovery capacity, referencing stressor systems such as sea level rise, climate change, oil spills, and pesticide contamination of groundwater.

In the Brazilian context, CONAMA Resolution 398/2008 introduces Oil Environmental Vulnerability Maps, facilitating the visualization of areas most susceptible to spills. These maps account for the likelihood of oil reaching specific areas and consider scenarios involving accidental spills with worst-case volumes. Additionally, Romero et al. (2013) present a method for mapping oil environmental vulnerability, employing a vulnerability index and integrating oil spill modelling data with coastal sensitivity assessments. This approach generates georeferenced maps that indicate the vulnerability of specific areas, with vulnerability being determined by both sensitivity and the probability of oil spill impact.

2.1. Vulnerability and environmental sensitivity

Carmo and Guizardi (2018) traced the etymology of the term vulnerability back to the Latin words “vulnertare” and “bilis,” where the former denotes injury or harm, and the latter refers to susceptibility.

Initially, Cutter (1996) defined vulnerability as the potential for loss and emphasized its pivotal role in informing public policy formulation. He proposed the Social Vulnerability Index (SoVI) as a means of systematically assessing various social factors influencing vulnerability. This interdisciplinary approach integrates social sciences, natural sciences, and engineering to comprehend landscapes susceptible to risks. Cutter and Finch (2008) utilized SoVI to map temporal and spatial changes in social vulnerability in the United States, demonstrating its efficacy in prediction, response planning, and policy implementation.

Despite abundant literature, there exists no unified conceptualization of vulnerability. Scholars such as Saito (2011) perceive vulnerability as inherently negative, synonymous with loss. Romero (2009) regards vulnerability in the context of oil spills as the environment’s capacity to withstand harm, contrasting it with susceptibility, which pertains to the likelihood of an area being affected by oil. Gundlach and Hayers (1978), apud Romero et al. (2013), introduced the first method for classifying environments based on their sensitivity to oil spills, thereby conflating the terms sensitivity and vulnerability. However, Silva *et al.* (2012), apud Romero et al. (2013), argue that sensitivity and vulnerability are distinct concepts: vulnerability encompasses both susceptibility to environmental stressors and the local environment's response to these stressors.

In our study, we employ indicators of environmental sensitivity to elucidate the environmental impact of waterway terminal implementation. The term "environmental vulnerability" denotes the degree to which physical elements (soil, water, air, fauna, and flora) are affected. This distinction allows for a nuanced understanding of how terminals may impact their surroundings.

2.2. Determination of environmental sensitivity indicators

Each type of development generates specific environmental, social, and economic impacts. Evaluation studies for project implementation aim to identify and assess these impacts across all phases: construction, operation, and decommissioning. From these impacts, indicators are carefully selected for further analysis. Various methods exist for assessing environmental impacts, often applied in conjunction. The choice of method depends on various factors, including the nature of the development and the expertise of the executing team (Montaño and Ranieri, 2013).

However, the selection of indicators extends beyond the methodological choice. In this study, the identification of environmental indicators was driven by aspects that contribute significantly to environmental damage during both the implementation and operation phases of the terminal. These aspects include potential deforestation for terminal construction, if required, and for the construction of land transport routes, increased cargo flow, air and soil pollution, water contamination, and the risk of accidents during cargo handling and refuelling.

In proposing to integrate environmental criteria into the selection process for waterway terminal installation areas, the goal is to identify locations with the lowest environmental vulnerability using specific environmental sensitivity indicators. These indicators, drawn from the literature and tailored for this study, encompass factors such as susceptibility to erosion, soil permeability, noise pollution, air pollution, the impact of port activities on wildlife, competition for fertile land, water quality pollution, and the environmental impact of access construction, including deforestation (CPEA, 2009; Santana and Tachibana, 2008). Table 1 provides a concise overview of the selected indicators.

Table 1: Description of Environmental Sensitivity Indicators.

Indicator	Description
Susceptibility to Erosion	A parameter related to the properties of the soil that reflect on its erodibility, leaving it more vulnerable to the weathering processes of detachment and transport of solid particles.
Soil Permeability	Property related to the flow of water within it.
Pollution: Water Quality	The type of use that is made of the river can influence or be influenced by the activities of the terminal and navigation. The most common uses are fish farming, sports and recreation, fishing, water collection for domestic, rural and industrial use, effluent discharges. Cargo and oil spills interfere differently according to the uses of the river.
Impact of port activities on animal life	Noise, vibrations, atmospheric emissions, and nighttime light can disturb domestic animals and affect the life cycle of wild animals.
Air Pollution	Atmospheric emissions can disturb the population, flora and fauna.
Noise Pollution	Noise and vibrations can disturb the population, flora and fauna.
Dispute over fertile land	The occupation of the space for the implementation of a terminal will have different impacts if the area is an Environmental Protection Area, APA, or Permanent Preservation Area, APP, or even occupied by native forest or other types of activities such as agriculture, livestock, ranches or urbanized areas.
Construction of accesses/ deforestation	The presence of transport routes already in place eliminates the need for deforestation for construction.

Each of these indicators interacts with the site and, according to its characteristics, generates a differentiated degree of vulnerability, the combination of which results in the vulnerability of the site.

2.3. AHP hierarchical analysis for terminals location selection

The Analytic Hierarchy Process (AHP) is a multi-criteria analysis method developed by Saaty in the 1970s, which is associated with decision-making processes involving quantitative weights representing the degree of importance. It creates a hierarchy of criteria and weights defined by decision-makers based on pairwise comparisons of criteria. These weights are derived from a conversion of human preferences (Marchezetti, Kaviski and Braga, 2011; Ben, 2006; Saaty, 2008).

While AHP is highly useful for decision-making when there are multiple alternatives to be evaluated, encompassing various factors (Saaty, 2008), Quadros, Adamatti and Longaray (2021) discuss potential inconsistencies in judging certain attributes that may arise with AHP. However, Reis, Ladeira and Fernandes (2013) argue that despite these possible inconsistencies, the simplicity and extensive applicability of AHP serve as advantages. They blend intuition with rationality, potentially overcoming any shortcomings of the method.

In the literature, numerous studies have employed AHP for selecting transport terminals. For instance, Ka (2011) used the AHP method to locate the best alternative for the installation of dry ports, considering economic criteria and land use. Similarly, Nguyen et al. (2021) developed a model for choosing the location of a deep-water port using AHP and a geographic information system. They considered criteria such as topography with tide level, land use, and changes in the coastline, focusing on the Thi Vai River in Dong Nai Province, Vietnam.

3. METHOD

In this research, as previously mentioned, the concept of vulnerability was used as a set of conditions determined by physical, social, economic and environmental factors and processes that make the environment sensitive to an impact, which in this study is related to the operation and implementation of waterway terminals. The concept of sensitivity, in turn, is related to the conditions of soil, water, fauna and flora (susceptibility to erosion; permeability; water pollution; impact of port activities on animal life, construction of accesses/deforestation; air pollution; noise pollution and dispute over fertile land), which are maintained regardless of the implementation of the project. Thus, the estimated vulnerability is due to the existence of an impact, measured through environmental sensitivity indicators, calculated for each area according to its intrinsic characteristics.

The procedure for mapping environmental vulnerability was based on the following steps: determination of the study area; determination of environmental sensitivity indicators; data collection to characterize the area; determination of hierarchy between indicators and weights through consultation with specialists, assessment of the vulnerability of the area and its mapping.

3.1. Determination of the study area

The selection of the study area adhered to the directives outlined in the National Waterway Integration Plan (PNIH), released in 2013 by the National Agency for Waterway Transportation (ANTAQ, 2013b). This plan delineated suitable locations for the establishment of waterway terminals across various macro-regions. In this research, eight such macro-regions within the Tietê waterway were examined: Paulínia, Piracicaba, Ibitinga, Novo Horizonte, Sabino, Ubarana, Buritama, and Pereira Barreto, as illustrated in Figure 1.

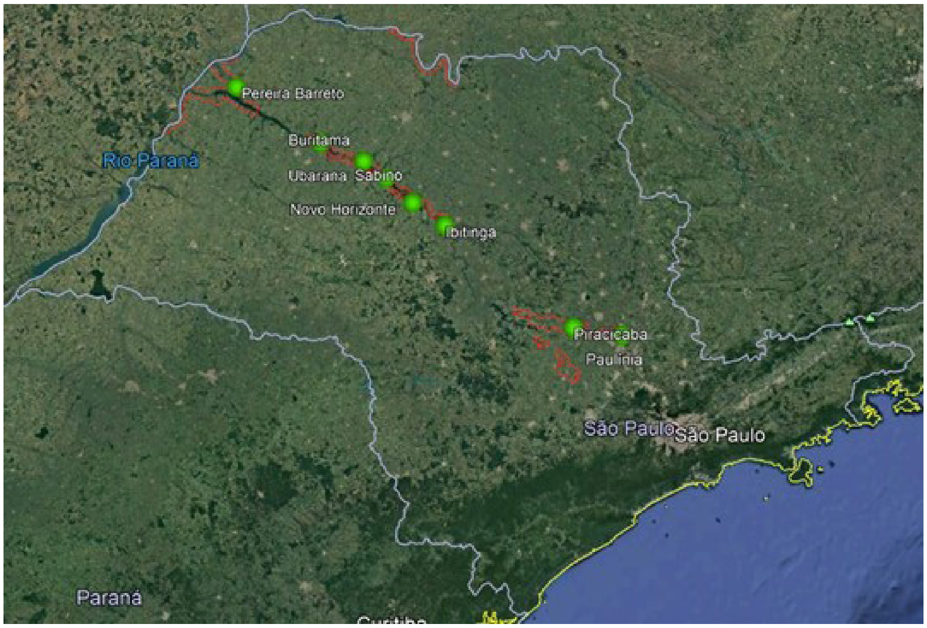

Figure 1. Location of the macro-regions under study. Source: Google Earth.

In the ANTAQ study, a favourable point was identified for each macro-region, representing the optimal location based solely on logistical considerations. To characterize the area, 8 polygons (each covering approximately 2 km^2) were delineated around these favourable points within each macro-region. These polygons were uniformly distributed both upstream and downstream of the favourable point, as well as along both the left and right riverbanks. Each polygon's characteristics were assessed according to the selected sensitivity indicators outlined in Table 1. Data sources utilized for this assessment are detailed in Table 2. Consensus among researchers determined the disturbance distances for air and noise pollution indicators: within 0.5 km, disturbances were considered more intense; from 0.5 to 1 km, less intense; from 1 to 5 km, milder; and beyond 5 km, disturbances tended to be negligible.

Table 2: Environmental sensitivity indicators and data sources.

Environmental sensitivity indicators	Data Source
Susceptibility to Erosion	Thematic maps of the Institute of Technological Research: Geotechnical Map of the State of São Paulo at the scale of 1:500:000 (IPT, 1994) and IPT (2012).
Soil Permeability	Pedological map of the State of São Paulo at a scale of 1:250000 (ROSSI, 2017).
Pollution: Water Quality	Framing of water bodies. CONAMA 357/2005, CETESB (2015; 2020) and DAAE (2015).
Impact of port activities on animal life	It was observed in *Google Earth and Google Maps* the existence of residences for domestic animals, the existence of pastures for animals for consumption and the existence of forests for wild animals. The calculation was performed using the occupied area.
Air Pollution	The distance observed in *Google Earth* between the occupancy of houses and the possible location of the terminal was calculated. The distances were separated by up to 0.5 km; from 0.5 to 1 km; from 1 to 5 km and above 5 km. The closer it is, the greater the disturbance.
Noise Pollution	The distance observed in *Google Earth* between the occupancy of houses and the possible location of the terminal was calculated. The distances were separated by up to 0.5 km; from 0.5 to 1 km; from 1 to 5 km and above 5 km. The closer it is, the greater the disturbance.
Dispute over fertile land	SP Cidades (2022); *Google Earth* e *Google Maps*
Construction of accesses/ deforestation	Data from IBGE (2016), observation on *Google Earth* and *Google Maps* on the existence of road accesses.

Therefore, for each polygon, the following considerations were made:

a) **Soil Characteristics Regarding Permeability and Susceptibility to Erosion:** Parameters such as erodibility and permeability were determined based on official thematic maps outlined in Table 2. To assess areas' susceptibility to erosion, IPT (Institute for Technological Research) defined 5 susceptibility classes (I - very high, II - high, III - medium, IV - low, and V - very low), which were synthesized into 3 classes for this research: I - high (for IPT's very high and high classifications), II - medium (for IPT's medium classification), and III - low (for IPT's low and very low classifications). Soil permeability was inferred from the predominant soil texture identified for each delimited polygon, where clayey textures indicated low permeability soils, and medium to sandy textures were classified as high permeability.

b) **Land Use and Occupancy and Distance between the Chosen Location and the Community:** The impact of space occupation for terminal implementation varies depending on whether the area is designated as an Environmental Protection Area (APA), Permanent Preservation Area (APP), or occupied by native forests or other activities such as agriculture, livestock, ranches, and urbanized zones. These land uses were identified through research on municipal websites and Google Earth images. Additionally, the distance between the center of the chosen location and the nearest urbanized area was measured using Google Earth. The presence of domestic or wild animals was determined based on the area's characterization regarding land use and occupancy, supplemented by information from Google Maps and municipal websites, as listed in Table 2. The methodology for identifying areas of sugarcane and food production followed similar procedures.

c) **Water Quality - River Use:** The classification of water bodies, as detailed in Table 2, was used to assess the influence of river use on terminal activities and navigation.

d) **Existence of Roads/Railways:** The presence of transportation routes eliminates the need for deforestation for their construction. Proximity to land transport accesses, one of the criteria outlined in the National Waterway Integration Plan (PNIH), was assessed using data from the IBGE (Brazilian Institute of Geography and Statistics) database (2016) and Google Earth.

3.2. Vulnerability assessment

After identifying the indicators of environmental sensitivity, the expert judgment method was used for their quantitative classification. Thus, the vulnerability assessment was carried out in 3 stages. In the first stage, a consultation with experts was carried out to obtain the order of importance of the selected indicators (hierarchy) and the weights of the dimensions of the environmental sensitivity indicators. In the second stage, the weighting and application of these weights in the regions studied was carried out, and the third stage corresponds to the elaboration of vulnerability maps.

3.2.1. Step 1

The analysis model chosen was the AHP method, because it is indicated to perform a multicriteria evaluation by capturing different perspectives from experts (Rodrigues, 2019). Thus, a survey was carried out with specialists, through the submission of an online questionnaire. In all, 23 experts were invited, 10 of whom responded, among them 3 are from the environmental areas, 3 from the navigation area, 2 from the transportation area, 1 from the biosciences area, and 1 from the civil engineering area. The answers were given during the year 2020. The specialists are undergraduate and/or graduate professors. The questionnaire was divided into two parts and is presented in the Table A1 of the Appendix of this article.

Part I of the questionnaire aimed to verify the importance of the indicator for the sensitivity of a site, creating a hierarchy of relevance called the domains studied. This first part was important in determining the level of detail that each domain should have. The hierarchy of indicators was given by the experts in a descending manner, with 1 being the most important and 10 the lowest. Part II was carried out concomitantly with Part I and aimed to assign weights to the dimensions of the sensitivity indicators of each of the domains of Part I.

3.2.2. Step 2

The experts' answers in Part I and Part II of the questionnaire were summed and normalized in an interval between 0 and 1, to define a hierarchy of importance and the respective index, Table 3.

The weights obtained were used to calculate the vulnerability of each of the eight areas selected for the pre-analysis of each macro-region. Each of the 8 areas was made up of 8 polygons. Table 4 provides an example of the vulnerability calculation. The first column identifies the polygon of each macro-region studied, followed by the area of each polygon in km^2, in the third column is the identification of the domain (Part I of the research), followed by its characteristics contained in Part II (determination of weights), in the fourth column are the respective indices of the third column, the result of the research consultation of experts. The fifth column is the product of the normalized sum of the domain and the normalized sum of the domain criterion. From the sixth column onwards, the same structure is repeated for another domain, and so on. In the last column is the sum of all the results, polygon by polygon.

These indices have also been normalized and classified into 5 categories of vulnerability: very high, high, medium, low, and very low.

3.3.3. Step 3

Based on the results of Stage 2, vulnerability maps were created for each possible region for the operation of river terminals. The data were georeferenced in *Google Earth* to facilitate the identification of the most sensitive locations.

4. RESULTS

According to the experts, the order of importance of the environmental sensitivity indicators and their respective indexes, from the most important to the least important, are susceptibility to erosion and water pollution (tied); impact of port activities on animal life; soil permeability; construction of accesses/deforestation; air pollution and noise pollution.

Table 3 shows the normalized values of the weights of the dimensions and the indicators determined by the experts and the order of importance of the environmental sensitivity domains and indicators, from the most important to the least important.

As an example, to illustrate the method, the calculation for the macro-region of Paulínia is presented, the result of which is summarized in Table 4.

Polygon 1 has an area of 1.68 km^2. When analysing domain, A (erosion susceptibility indicator), which has a weight of 0.149, it was found that the soil characteristic in relation to this indicator is low throughout the area of the polygon and, therefore, has a weight of 0.233. Therefore, the result for susceptibility to erosion in Paulínia in polygon 1 is 0.149 × 0.233 = 0.035.

For domain B (water pollution indicator) which has a weight of 0.149, the water use characteristic is class 2. Class 2 encompasses all the uses indicated in table 3 (Supply, Human Consumption, Fish Farming, Animal Thirst and Leisure) and, therefore, its weight corresponds to the sum of all the weights of the indicators, totalling 1, and thus, the result of the water quality indicator is 0.149.

Domain C (indicator impact of port activities on animal life) had a weight of 0.134 and the presence of three types of animals: animals for consumption weighing 0.326 occupying 11% of the polygon area, partial result 0.134 × 0.326 × 0.11 = 0.0048; wild animals with a weight of 0.415 occupying 16% of the polygon area, partial result 0.134 × 0.415 × 0.16 = 0.0089 and domestic animals with a weight of 0.259 occupying 14% of the total area of the polygon, partial result 0.0049, therefore, the result of the indicator impact of port activities on animal life is the sum of the plots: 0.0048 + 0.0089 + 0.0049.

Domain D (permeability indicator) had a weight of 0.129 and the least permeable soil characteristic had a weight of 0.391; Similarly, the result of this indicator is 0.050, and so on. The final score (NF) of this polygon was obtained by adding up all the results of all indicators, NF = 0.0347 + 0.149 + (0.0047 + 0.0090 + 0.0050) + 0.050 + 0.0 + 0.0336 + 0.0343 + (0.0056 + 0.001) = 0.326. Table 4 presents also the calculation of polygon 1. This procedure was repeated for all polygons of the 8 macro-regions analysed.

The vulnerability ranges were defined by dividing the amplitude of the final grades into 5 classes, as shown in Figure 2. The vulnerability values were normalized to receive relative values and classified using Table 5.

Table 3: Normalized weights of each of the sensitivity indicators.

Domain	Sensitivity indicator	Indicator Weight
A - Susceptibility to erosion	**Erosion**	
Weight (0.149)	Low	0.233
	Average	0.318
	Discharge	0.449
B - Water pollution	**Water quality**	
	Supply Human Consumption	0.298
Weight (0.149)	Fish farming	0.252
	Animal thirst	0.239
	Leisure	0.211
C - Impact of port activities on animal life	**Animals**	
Weight (0.134)	Raising animals for food	0.326
	Wild animals	0.415
	Pets	0.259
D - Permeability	**Soil permeability**	
Weight (0.129)	More permeable soil	0.609
	Less permeable soil	0.391
E - Construction of accesses/deforestation	**Construction of accesses**	
	Deforestation native vegetation	0.405

Table 3: Continued...

Domain	Sensitivity indicator	Indicator Weight
Weight (0.118)	Interference with agricultural/livestock water	0.328
	Interference in anthropized area	0.267
F - Air pollution	**Air Pollution**	
	Up to 0.5 km	0.292
Weight (0.115)	Above 0.5 km up to 1 km	0.262
	Above 1 km up to 5 km	0.200
	Above 5 km up to 10 km	0.151
	Above 10 km	0.095
G - Noise pollution	**Noise pollution**	
	Up to 0.5 km	0.306
Weight (0.112)	Above 0.5 km up to 1 km	0.253
	Above 1 km up to 5 km	0.203
	Above 5 km up to 10 km	0.149
	Above 10 km	0.089
H - Dispute over fertile land	**Dispute over land**	
	Reforestation	0.376
Weight (0.094)	Sugarcane production	0.282
	Food production	0.342

Table 4: Example of Calculation Polygon 1 in Paulínia.

Location: Paulínia		**Polygon 1**		**Area in km^2: 1.68 -4**	
Domain (1)	**Sensitivity indicator**	**Indicator Weight (2)**	**Area in km^2 (3)**	**(3)÷(4) (5)**	**Result (1)×(2)×(5)**
A - Susceptibility to erosion	Erosion				
Weight (0.149)	Low	0.233	1.68	1.000	0.0347
	Medium	0.318	0.00	0.000	0.0000
	High	0.449	0.00	0.000	0.0000
B - Water pollution	Water quality				
Weight (0.149)	Human Consumption	0.298	1.68	1.000	0.0445
	Fish farming	0.252	1.68	1.000	0.0375
	Animal thirst	0.239	1.68	1.000	0.0356
	Leisure	0.211	1.68	1.000	0.0314
C - Impact of port activities on animal life	Animals				
Weight (0.134)	Raising animals for food	0.326	0.18	0.107	0.0047
	Wild animals	0.415	0.27	0.161	0.0090
	Pets	0.259	0.24	0.143	0.0050
D - Permeability	Soil permeability				
Weight (0.129)	More permeable soil	0.609	0.00	0.000	0.0000
	Less permeable soil	0.391	1.68	1.000	0.0500

Table 4: Continued...

Location: Paulínia		**Polygon 1**		**Area in km²: 1.68 -4**	
Domain (1)	**Sensitivity indicator**	**Indicator Weight (2)**	**Area in km² (3)**	**(3)÷(4) (5)**	**Result (1)×(2)×(5)**
E - Construction of accesses/ deforestation	Construction of accesses				
Weight (0.118)	Deforestation native vegetation	0.405	0.00	0.000	0.0000
	Interference agricultural/ livestock water	0.328	0.00	0.000	0.0000
	Interference in anthropized area	0.267	0.00	0.000	0.0000
F - Air pollution	Air Pollution				
Weight (0.115)	Up to 0.5 km	0.292	1.68	1.000	0.0336
	Above 0.5 km up to 1 km	0.262	0.00	0.000	0.0000
	Above 1 km up to 5 km	0.200	0.00	0.000	0.0000
	Above 5 km up to 10 km	0.151	0.00	0.000	0.0000
	Above 10 km	0.095	0.00	0.000	0.0000
G - Noise pollution	Noise pollution				
Weight (0.112)	Up to 0.5 km	0.306	1.68	1.000	0.0343
	Above 0.5 km up to 1 km	0.253	0.00	0.000	0.0000
	Above 1 km up to 5 km	0.203	0.00	0.000	0.0000
	Above 5 km up to 10 km	0.149	0.00	0.000	0.0000
	Above 10 km	0.089	0.00	0.000	0.0000
H - Dispute over fertile land	Dispute over land				
Weight (0.094)	Reforestation	0.376	0.270	0.160	0.0056
	Sugarcane production	0.282	0.000	0.000	0.0000
	Food production	0.342	0.050	0.030	0.0001
Total					0.3260

Table 5: Relative Environmental Vulnerability Ranking.

Relative Vulnerability Ranking	**Interval**		**Relative value**
Very high vulnerability	0.4126	0.3944	5
High vulnerability	0.3945	0.3762	4
Medium vulnerability	0.3763	0.3580	3
Low vulnerability	0.3581	0.3398	2
Very low vulnerability	0.3399	0.3217	1

4.1. Vulnerability maps

Vulnerability maps were then constructed based on the final scores obtained for each polygon of the macro-regions studied, according to the data presented in table 4. The maps make it easier to identify the most vulnerable places for the installation of river terminals, as shown in Figure 2. Table 6 shows the distribution of the polygons of each proposed area in each degree of vulnerability.

Table 6. Distribution of polygons by vulnerability.

Environmental Vulnerability	Polygons by vulnerability				
	Very low	Low	Medium	High	Very high
Paulínia	1,2,4,5,7,8	6	3		
Piracicaba	5,6	1,2	3,7	4, 8	
Ibitinga	7	5,6,8	1,3	2,4	
Novo Horizonte	6	5	1,3,8	2,4,7	
Sabino		1	3,4	2,6,7	5,8
Ubarana	2,4,6	1,3,5			7,8
Buritama		1,2,6,7,8	3,4,5		
Pereira Barreto		4	1,2,3,5,7,8	6	

In general, Paulínia is the place that presents the least environmental vulnerability, as it has 6 polygons classified as very low vulnerability, followed by Buritama which, although it does not have a polygon classified as very low, has 5 polygons classified as low and no polygon as high or very high. Piracicaba comes next with 2 very low-rated polygons, 2 low, 2 medium, and 2 high-ranked polygons, and not very highly rated polygons. Ibitinga and Novo Horizonte are respectively in 4th and 5th place of least vulnerable, Ibitinga has 3 polygons with low vulnerability classification while Novo Horizonte has only 1. In order is Pereira Barreto with 7 polygons concentrated in the average classification, Ubarana and Sabino with 2 polygons classified in very high and Ubarana has 3 polygons in very low and Sabino none.

Hence, based on the results, Paulínia is the macro region that presents the most alternatives of areas with very low vulnerability. Sabino is the area that has the fewest suitable polygons, as it has 2 polygons rated at very high impact and no polygon with very low vulnerability.

The studied polygons of each area surround the apt point indicated by the PNIH. For example, for a possible implementation of a terminal in Ubarana, the terminal should be in polygons 2, 4 or 6 that indicate lower environmental vulnerability. Additionally, the terminal should not be installed in polygons 7 and 8 because they have high environmental vulnerability.

In this analysis, the most significant parameter was soil permeability with the 2 indices, more and less permeable, followed by susceptibility to erosion with three indices, high, medium, and low. Only when these indicators are equal for the 8 polygons of a suitable area do the other indicators become significant. An example is the indicators "dispute over fertile land" and "impact of port activities on animal life" which were measured according to the area occupied, the first by reforestation, sugarcane production and food plantation and the second by pastures, poultry, and fish farming, which in this case are decisive for the classification of polygons in terms of environmental vulnerability.

Air pollution and noise pollution were measured according to the distance between the possible location of the terminal and the urbanized area, and the shorter the distance (up to 0.5 km), the greater the environmental vulnerability. The quality of the water was not relevant, because all the points correspond to the class II watercourses and, therefore, have the same score for all the polygons of all the suitable areas, but the method can be applied in areas whose stretches have different classifications. Similarly, the access construction/deforestation index had the same result, as the propitious points pointed out by the PNIH had as a requirement the proximity of highways.

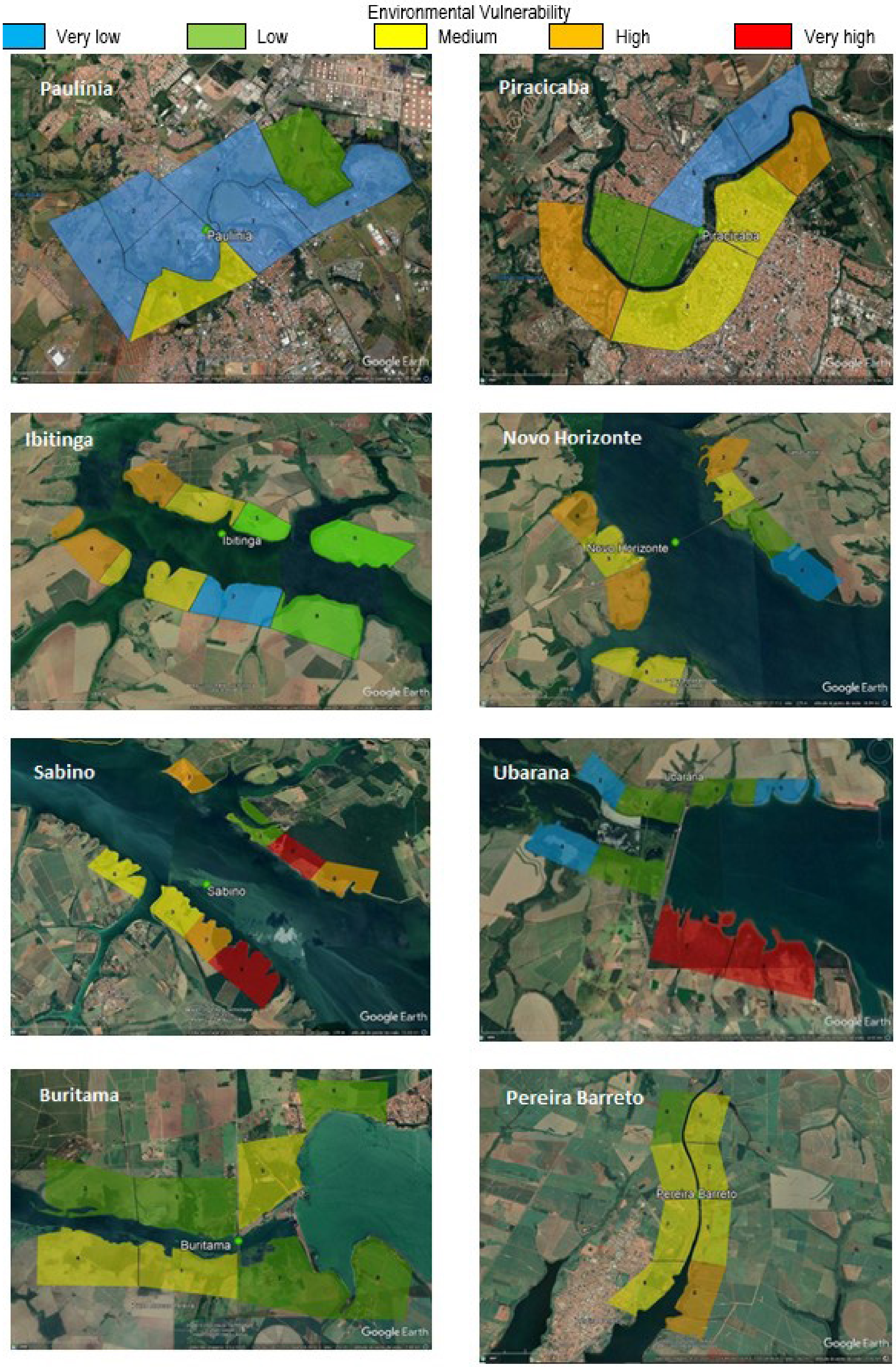

Figure 2. Vulnerability maps.

5. FINAL CONSIDERATIONS

The implementation of river terminals brings significant local and regional development. The insertion of the waterway mode of transport provides greater balance for the Brazilian transport matrix and in the supply/distribution channels, facilitates the competitiveness and expansion of the market, providing a drop in the prices of products and consequent increase in consumption and quality of life, greater specialization in production, in addition to the fact that cheaper transport allows production and consumption in increasingly distant places. Although waterway transport is considered the least polluting, the environmental cost of operating the terminals must be measured. The research evaluated the possible locations for the implementation of terminals to point out the least environmentally impactful location, through a methodology that indicates in a hierarchical way the environmental vulnerability of the region. The methodology presented can be applied as an initial stage of the environmental assessment, with a low cost, and which allows the identification of less vulnerable areas, so that the later stages can be done in a more focused and resource-saving way, as fewer areas would be evaluated.

For future research, it is suggested the analysis of other items, such as social impact, which corresponds to a gap identified in the bibliometric research. The navigability of the river and the impact of river works when necessary are also relevant aspects, but they did not interfere in the hierarchical order of the polygons studied in each municipality, due to their geographical proximity. However, they may add differences in the hierarchy of polygon vulnerability between municipalities, for example, Paulínia and Buritama, since the navigability characteristics are different in these stretches of the Waterway. In addition, it is also suggested to use other methods in conjunction with AHP one to analyse the possible inconsistency of the judgment of certain attributes.

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Appendix

Table A1 - Contextualization for expert judgment

RESEARCH SUMMARY

The implementation of river terminals, as well as their activities, cause significant environmental impact. To prioritize sustainable economic development, this research aims to evaluate less environmentally sensitive locations for the implementation of terminals. The locations studied followed the proposal of the National Waterway Integration Plan – PNIH, published by the National Waterway Transport Agency – ANTAQ, which developed logistical scenarios for the insertion of waterway terminals on the Tietê River, based on the expectations of the regional market. The hierarchy of sensitivity of the sites studied, the result of this research, is important because it allows the lowest environmental cost, therefore, only after the analysis of the results and based on them should the site be chosen and subsequently carry out the environmental impact study.

1. The environmental impacts, which were considered in the implementation phase of a river terminal, are:
- Deforestation for the implementation of the terminal;
- Deforestation for the construction of land transport routes, if necessary and;
- River works for the adequacy of the road.

2. The environmental impacts that may occur in the operation phase of the river terminal are:
- Increased charge flux;
- Pollution, soil and water resources;
- Risk of accidents: with the cargo (solid bulk – grains) or during the refueling of the vessel.

EXPERT CONSULTATION

The consultation of experts aims to determine the weights to be given to the indicators of environmental sensitivity. The analysis and calculation of these weights will classify the studied localities to build a hierarchy based on the vulnerability of each region.

Considerations:

1. Soil - soil types offer susceptibility to erosion, influencing the environmental vulnerability of the site to be chosen.
2. Land use and occupation – The occupation of the space for the implementation of a terminal will have different impacts if the area is an Environmental Protection Area, APA, or Permanent Preservation Area, APP, or even occupied by native forest or other types of activities such as agriculture, livestock or ranches.

● River uses in the region – The type of use that is made of the river can influence or be influenced by the activities of the terminal and navigation, such as fish farming, sports and recreation, fishing, water collection or effluent discharges, cargo and oil spills interfere differently according to the types of use of the river.

● Distance between the chosen location and the community – noise, vibrations and atmospheric emissions can bother the population.

● Existence of roads/railways – the presence of transport routes eliminates the need for deforestation for their construction. The quality of the roads also interferes with the risk of congestion arising from the increase in traffic that the terminal will cause.

● Need for river works, depending on the size of the work, this can make the existence of the terminal unfeasible in both the environmental and economic sectors.

PART I

Classify the environmental sensitivity indicators, **WITH 1 BEING THE INDICATOR THAT CAUSES THE LEAST INTERFERENCE AND 10 BEING THE INDICATOR THAT CAUSES THE MOST ENVIRONMENTAL INTERFERENCE.**

Note: The numbers can be repeated in case the indicators cause the same degree of interference and can be skipped in case the interference of one indicator is much higher than another.

Establishment of a hierarchy of indicators Interference order (from 1 to 10)

SOIL Susceptibility to erosion

Permeability

ANTHROPIC FACTOR REFERRING TO THE SURROUNDING COMMUNITY Noise pollution

Air Pollution

FAUNA Impact of port activities on animal life

AGRICULTURE Dispute over fertile land

USE OF THE RIVER Pollution: Importance of maintaining water quality

CONSTRUCTION OF THE ROAD SYSTEM Construction of accesses/ deforestation

Table A1 - Contextualization for expert judgment
PART II
Determine the **weights of the factors that make up each of the sensitivity indicators. THE VALUATION OF THE FACTORS THAT MAKE UP THE INDICATORS: 1 corresponds to nothing important, and 10 to very important.** **Each indicator is evaluated independently of the others** **SOLO:** EROSION OF THE BANKS (ERODIBLE) Factors that make up the indicators Weight (1 to 10) Low Medium High **SOIL:**PERMEABILITY Factors that make up the indicators Weight (1 to 10) More permeable soil (sandy soil) Less permeable soil (clay soil) **ANTHROPIC FACTOR RELATED TO THE SURROUNDING COMMUNITY**: NOISE POLLUTION Factors that make up the indicators Weight (1 to 10) Up to 0.5 km Above 0.5Km up to 1 km Above 1Km up to 5 km Above 5 km up to 10 km Above 10 km **ANTHROPIC FACTOR RELATED TO THE SURROUNDING COMMUNITY**: AIR POLLUTION Factors that make up the indicators Weight (1 to 10) Up to 0.5 km Above 0.5Km up to 1 km Above 1Km up to 5 km Above 5 km up to 10 km Above 10 km **FAUNA**: IMPACT OF PORT ACTIVITIES ON ANIMAL LIFE Factors that make up the indicators Weight (1 to 10) Raising animals for food Wild animals Pets **AGRICULTURE:** DISPUTE OVER FERTILE LAND Factors that make up the indicators Peso (1 a 10) Reforestation Sugarcane Production Food Production **USE OF THE RIVER:** importance of maintaining water quality Factors that make up the indicators Weight (1 to 10) Water supply for human consumption Fish farming Animal thirst Leisure **CONSTRUCTION OF THE ROAD SYSTEM** Factors that make up the indicators Weight (1 to 10) Deforestation of native vegetation Interference in agricultural/animal husbandry Interference in anthropized area