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Socioeconomic vulnerability of communities on the Brazilian coast to the largest oil spill (2019–2020) in tropical oceans

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A R T I C L E   I N F O

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A B S T R A C T

This article aims to identify the socioeconomic vulnerability of establishments located on the Northeast coast of Brazil, affected by the most extensive oil spill (2019/2020) ever recorded in tropical oceans. To this end, we used secondary data to map locations soiled with oil and search for a concentration of commercial establishments and other institutions located close to these territories. From this information, we built a vulnerability indicator, with three segments: enterprises or institutions related or not to the Ocean Economy, their levels of proximity to oil stains, and persistence, in days, of pollution on the coast. In all, we mapped 53,472 establishments. As for the main research findings, mapping showed the two most vulnerable sectors - accommodation services and the food sector, which are essential for the functioning of the tourism production chain and the food security. Yet, the measurement of the vulnerability index disclosed a wide variation in the indices among states in the same region, related to coastal extension, ineffective strategic actions to fight stains, dependence on an economy strongly focused on the exploitation of coastal resources, or by social factors deficiencies.

1. Introduction

In September 2019, an oil spill on Brazil's coast spread over more than 3000 km, reaching ~1000 locations (The Brazilian Institute of the Environment and of Renewable Natural Resources) [Ibama], 2020). Altogether, it affected 11 states, of which nine in the Northeast region, thus representing the majority of affected sites (>80%) (Soares et al., 2020a, b). The spill challenged government authorities and society to look for specific and unconventional short and long-term solutions, to restrain the calamity and mitigate its negative impacts (Albert et al., 2018), especially in regions of high socioeconomic vulnerability (Osin et al., 2017; Soares et al., 2020a). Oil spills of great magnitude are considered wicked problems, since these comprise cataclysmic events that require a great collective effort to solve them (Rittel and Webber, 1973).

Precursors of wicked problems, Rittel and Webber (1973) detail the essential characteristics of these events, and one of the main issues regards the definition of their nature. Churchman (1967) explains that these problems belong to a class where information available is confusing and its stressors involve a series of conflicting players. Therefore, large-scale disasters such as this oil spill, which occurred at the end of August 2019 in Brazil's Northeast, are part of this class, since it is clear the agent that caused it (Soares et al., 2020a, b), but there is a distortion as to the problem itself, as well as its ramifications.

Fourteen months after the disaster, the responsible agent is the oil, but its causes are still under confidential investigation and remain unknown to the population and the vast majority of researchers (Soares et al., 2020a, b). Several hypotheses were raised regarding the origin of the oil sources, and there is a suspicion that oil came from Venezuela, since it has characteristics similar to Venezuelan oil (Lourenço et al., 2020; Oliveira et al., 2020). However, oil tankers in the marine region did not identify any accidents (e.g., vessels) that could confirm this hypothesis.

Since the climate and socioeconomic conditions of a community determine the extent of the effects of oil spill, it is necessary to measure the vulnerability of these affected regions in order to assess the real

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impact, either in the short or long term, thus allowing the creation of response strategies to current and future events (Albert et al., 2018). Some studies have measured the vulnerability under different dimensions. There has been a great focus on measuring environmental vulnerability (He et al., 2018; Lins-de-Barros, 2017; Nguyen et al., 2016), as well as the social (Paveglio et al., 2016; Rakauskiene and Strunz, 2016) and economic dimensions (Kantamaneni et al., 2018; Briguglio et al., 2009). However, few studies have measured socioeconomic vulnerability, or sought to contribute with indices, from the perspective of specific wicked problems such as environmental and social calamities caused by largest oil spills.

Kantamaneni et al. (2019) stress the need to systematically assess the vulnerability of these regions, by building indices that can show the high susceptibility of certain locations, given that these tools, combined with statistical data, can boost coastal management and consider future development options for these areas. Thus, this study aims to identify the socioeconomic vulnerability of establishments located on the coast of Brazil's Northeast region, affected by the most extensive oil spill ever recorded in the tropical oceans (2019/2020). To do that, we defined the following specific objectives: to map establishments situated close to the locations where oil stains were seen; and to generate a vulnerability indicator, from socioeconomic information on the Northeast shore.

2. Methodology

To achieve our objective, we carried out a quantitative exploratory study, with data gathered from secondary sources available on Google. Thus, we carry out a mapping based on the Google Earth and My Maps platforms, both made available by Google. In the first platform, we draw a 25-km radius limited perimeter from the georeferenced points of each oil stain. This buffer zone was defined based on previous studies and methods in the study area (Câmara et al., 2020; Nelson et al., 2018) that defined the 25 km radius over the coastal zone as the area of influence for the impact of oil tar balls, considering all economic activities in that area impacted. It is emphasized that the location of each oil stain was made available by Ibama (2020). The My Maps platform was used to manually save all the economic activities concentrated within the 25 km radius. It is noteworthy that the data regarding the companies and their respective location are community-sourced, quality checked and available to all researchers using this free platform.

After registering the establishments, we cataloged them with icons, according to their type. Finally, we separated them by sectors, namely: accommodation, food, services in general, shops, churches, as well as tourism and leisure. Then, after completing the maps, we edited the digital cartographic material on the geographic mapping platform Qgis.

In addition, we limited this study geographically to the 116 cities located in the states of Brazil's Northeast region, which had, at least, one

Fig. 1. Locations (beaches) and states reached by oil spill (2019/2020) in Brazil's Northeast and Southeast regions, until March 19, 2020.
Note. Source: adapted from The Brazilian Institute of the Environment and of Renewable Natural Resources [(Ibama 2020]).

among the 765 localities affected. It is emphasized again that these selected locations were based on the daily reports published by Ibama (2020), informing the georeferences of the oil stains. It was based on data published until December 3rd, 2019. We also highlight that the coastal area of this tropical region is the largest in the country, with an extension of about 3,300 km, comprising the states of Alagoas, Bahia, Ceará, Maranhão, Paraíba, Pernambuco, Piauí, Rio Grande do Norte and Sergipe (Fig. 1) (Instituto Brasileiro de Geografia e Estatística [IBGE], 2011).

For data analysis, we divided the collected enterprises in two groups, those whose activity has some relationship with the Ocean Economy, and those with no direct relationship. Carvalho (2018) divides this area in two scopes. One is the marine dimension, including activities directly or completely linked to the sea, which use sea inputs or provide products for using there; and activities adjacent to the sea, without a direct relationship with the ocean, but located in coastal areas, thus benefiting from this relationship, such as the accommodation and food sectors. Therefore, a survey by Carvalho (2018) classified these activities according to the classes established by the National Classification of Economic Activities (NCEA) 2.0.

In addition, in order to set different levels of economic impact within the 25 km radius limit, we drew three areas, based on the coordinates of the oil stains. This division of the 25 km area of influence into three strata was proposed by Câmara et al. (2020), who explain that this ecological disaster directly impacts the image of the Brazilian coast, consequently reducing its attractiveness. Therefore, the closer these companies are to the disaster region, the greater the economic impact felt, so the analysis area was divided into three strata, that is, 8 km, 16 km, and 25 km. Again, it is emphasized that these buffer zones were delimited using the Google Earth platform.

Hence, we measured the socioeconomic vulnerability of the coastal area of each state in the Northeast region of the country, considering the following equation adapted from Nelson and Grubesic (2018):

$$V_a = \sum_{i=1}^{n} E_j \qquad \text{(Equation 1)}$$

Where:

V_a = Vulnerability of a certain area of the respective state;
E_j = Vulnerability of the j-nth score in the calculated area

For E_j calculation, the first element considered was the level of establishments' exposure to the oil stain, taking into account those most susceptible of the Ocean Economy, that is, weight 2; for the others, weight 1. Regarding the division of the zone of influence in three areas, we assigned weights 3, 2, and 1, respectively, to establishments that are distant 8, 16 and 25 km from the spots. Finally, to analyze the relevance of the stain, we evaluated the persistence, in days, of the oil on the beaches, according to according to data provided by The Brazilian Institute of the Environment and of Renewable Natural Resources [(Ibama 2020]). This institute daily monitored the situation on the beaches and released reports of the status of oil stains in the respective areas. The affected locations were separated into classes, that is, separated into quartiles going from the beach with the least time in day (1 day) with exposure to oil stains to the one with the greatest exposure (95 days). Therefore, the locality classes were separated as follows: 1–10 days (weight 1), 11–21 days (weight 2), 22–33 days (weight 3), and 34–95 days (weight 4). Thus, we got:

$$E_i = \sum A \times (P_1 + P_2 + P_3) + M \times (P_1 + P_2 + P_3) + B \times (P_1 + P_2 + P_3) \qquad \text{(Equation 2)}$$

Where:

A = Number of establishments with high proximity to the stain;
M = Number of establishments with medium proximity to the stain;
B = Number of establishments with low proximity to the stain;
P_1 = Weight of exposure level (separation of economic activities by susceptibility, according to their level of relationship with the Ocean Economy);
P_2 = Weight of stain proximity (distance in kilometers from establishments to oil stains);
P_3 = Weight of vulnerability persistence (number of days on which beaches remained oiled).

3. Results

Altogether, there were 765 localities affected, in at least 116 cities, as Table 1 shows.

Bahia was the state with the highest number of oil stain residues, with about 43% of the localities affected in all Northeast region (Table 1). The 328 coordinates resulted in 64 maps, since the closest georeferenced points were within the same area of 25 km radius. Bahia was also the region with more coordinate points removed (48 points), as there were no establishments found within a 25 km radius of these geographic references.

3.1. Mapping analysis

Along the entire coast of the Brazilian Northeast region, we demarcated 171 maps (Table 1) with 25 km radius each, resulting in 53,472 marked sites, including institutions, organizations, tourist attractions, and leisure points. Table 2 shows the division of these activities into sectors and their level of exposure.

Based on cartographic research, Table 2 shows the activities of high exposure, such as marine activities or those adjacent to the sea. These are: food, the most representative sector on the coast of the Northeast region (35.3%); accommodation (17.4%); activities related to tourism and leisure (3.8%); stores (0.7%), relating only to handicraft or embroidery, and food enterprises; and general services (0.7%), which include real estate, travel and tourism services, water transportation and aquaculture (Fig. 2). In addition, Table 2 shows a lower presence of activities outside the scope of the Ocean Economy, composed mainly of other low exposure stores (16.9%), and followed by general services of low exposure (15%), religious institutions (5.9%), esthetic services (2.2%), and automotive services (2.1%).

In the most representative sector of the coastal regions affected by oil stains, there were mainly restaurants, whose total was 5420 (28.7% of the food sector). In addition, there were snack bars and pizzerias (19.4%); meat and fish markets (16.5%), and bars (12%). Less expressive (each less than 5% of the total) were beach tents, ice cream or *açaí*

Table 1
Number of localities affected in each State (NE, Brazil).

State	Localities affected	% localities affected	Cities affected	Number of maps per area	Coordinates eliminated
Bahia (BA)	328	42.9	31	64	48
Alagoas (AL)	106	13.9	15	20	15
Sergipe (SE)	95	12.4	9	14	12
Rio Grande do Norte (RN)	75	9.8	14	20	1
Pernambuco (PE)	53	6.9	12	13	2
Ceará (CE)	37	4.8	17	25	3
Maranhão (MA)	32	4.2	9	6	26
Paraíba (PB)	20	2.6	7	6	2
Piauí (PI)	19	2.5	2	3	8
TOTAL	**765**	**100**	**116**	**171**	**117**

Note. Source: Ibama (2020).

Table 2
Division of establishments by sector and exposure level in the area of influence (25 km) of the places affected by oil spill (2019/2020) in Brazil's Northeast.

Level of Exposure	Sectors	Stains' Proximity			TOTAL	% TOTAL
		High Proximity (8 km)	Medium Proximity (16 km)	Low Proximity (25 km)		
High Exposure	Food	9578	4502	4776	18,856	35.3
	Accomodation	6669	1513	1112	9294	17.4
	Tourism and leisure	1122	424	479	2025	3.8
	General services of high exposure	192	82	89	363	0.7
	Stores of high exposure	182	68	130	380	0.7
Total High Exposure		**17,743**	**6589**	**6586**	**30,918**	**-**
Low Exposure	Automotive services	340	359	440	1139	2.1
	Esthetic services	438	320	425	1183	2.2
	General services of low exposure	3060	2390	2640	8009	15
	Stores of low exposure	3527	2415	3108	9050	16.9
	Religious institutions	1156	955	1062	3173	5.9
Total Low Exposure		**8521**	**6439**	**7675**	**22,554**	**-**
TOTAL					**53,472**	**100**

Note. Source: based on My Maps.

shops, steakhouses or spring chicken restaurants, candy or chocolate stores, coffee shops and bakeries. Accommodation facilities on the Northeast coast are mostly inns, which add up to more than 4.7 thousand establishments (50.7% of the total), followed by hotels (17.4%) and flats (13.1%). There are also beach houses (7.6%), hostels (5.6%), chalets (3.9%), resorts (1.1%), and ranches (0.6%), in a smaller number.

In the services sector, educational institutions (21%), including schools, daycare centers, universities and preparation courses, as well as private or public health units (13.1%), financial institutions (8.3%), logistics and transportation services (7.9%), and gas stations (7.7%) stood out. There were also NGOs, associations and foundations, with a lower percentage (<7% each); finance, accounting and insurance offices; advertising studios and agencies; nightclubs or buffets; post offices and notaries; engineering or technical assistance services; security; driving schools; laundries; telecommunication services; energy or water distributors; cleaning services; police stations and government headquarters or departments. In high-exposure services, there is a great expansion of the real estate market (58.1%), followed closely by travel and tourism (37.2%). We also mapped water transportation services (3%) and aquaculture-related services (1.7%).

In the automotive services group, workshops, auto parts and batteries were the majority (71.2% of the total). This group includes car wash (16.4%) and tire repair shops or tire stores (12.4%). In esthetic services, beauty and manicure salons (57%) prevailed, but there was also a great increase in the number of fitness centers (25.2%) and Spas or esthetic clinics (8.8%). There were also barber shops (6.9%) and tanning salons (2.1%). As for stores, clothing, cosmetics, jewelry or footwear accounted for 29.8%, as well as furniture, appliances or household articles (9.6%), building materials (9.5%), and pharmacies or food supplement stores (8.15%). In addition, a smaller percentage (<8% each) comprised children's stores; bicycles or quadricycles; electronics and games; stationery, printing, and bookstores; pet shops; florists; gas suppliers; liquor, ice or tobacco stores; swimming pool articles; fishing, hunting or sports articles; religious articles; optics; key chains; car dealers and varieties. Finally, in tourism and leisure activities, most of the sites saved were tourist spots (59.4%), followed by places for practicing sports (20.5%), parks and camps (11.9%), and museums and theaters (6.3%).

3.2. Vulnerability index (VI)

Table 3 shows the vulnerability index (VI) of the Northeast region states, and the three locations (beaches) of each, most susceptible to the damage by the oil spill (Fig. 3).

Regarding territorial extension, the state of Bahia was the most socioeconomically affected in the Northeast region, with an index 55.6% higher than the second placed. The stain reached at least 376 locations spread across 31 coastal cities, and until the last balance released by Ibama (March 19, 2020), it was still possible to see traces of sparse oil in 14.9% of these locations. This area had the highest index, due to the large concentration of activities close to the disaster, that is, 55.3% of the mapped establishments were within the 8 km radius around the spots; 6032 of them (71.7% of the establishments within 8 km), were activities related to the Ocean Economy, therefore considered of high exposure.

Among the areas that had the highest rates, we mention the coastline that extends from Praia de Piatã to Ondina, located in Salvador, whose index was 19,033 (Table 3). According to cartographic research, this region accumulates 2491 points of enterprises and institutions, about 16.4% of the total establishments mapped in the state, with 845 of them concentrated in the radius closest to the oil stains. These areas also have a strong presence of food establishments, with 872 units, mostly (36.6%) restaurants and similar. Data from the Annual List of Social Information [ALSI] (2018) confirm these data, since the highest incidence, among marine activities or those adjacent to the sea in Salvador, is of restaurants and alike, with 3162 formal establishments and 24,230 active employees, followed by hotels and related, with 5933 formal jobs in 286 establishments.

The second most affected state was Pernambuco, with an index of 68,751. Among the states with the largest number of affected places, the state is only the fifth (53 points of coordinates); however, among the seven most affected areas in the entire Northeast region, two are from Pernambuco, including Praia de Dell Chifre (Dell Chifre Beach), located in Olinda, which has a calculated index of 29,406. This beach concentrates most of the lodging establishments in the Northeast, with 471 businesses, mostly inns (27.2%) and hostels (19.5%).

Next, Ceará is the third most vulnerable economy in the Northeast, with an index of 58,770. The state is also the third with more activities related to the Ocean Economy within a radius of 8 km, and has a strong presence of accommodation establishments. Of the 1493 ventures of this type, 76.7% are located very close to the oil stains. In addition, of the three beaches with the highest indicators, two are in Fortaleza, the state capital. The first of them, Praia de Iracema, is the third place most socioeconomically susceptible in all Northeast region, with an index of 23,555.

As for the other states, it is worth mentioning Rio Grande do Norte, with an index of 47,511, and Paraíba, which appears as the fifth most vulnerable state. However, in this state the most susceptible areas range from Praia do Bessa to Praia do Cabo Branco, in João Pessoa, the state capital. The index is 29,582, with 3941 saved sites. The majority of these enterprises, unlike their states, were concentrated within a 25 km radius, and the main activities in the region comprise food and low-exposure services.

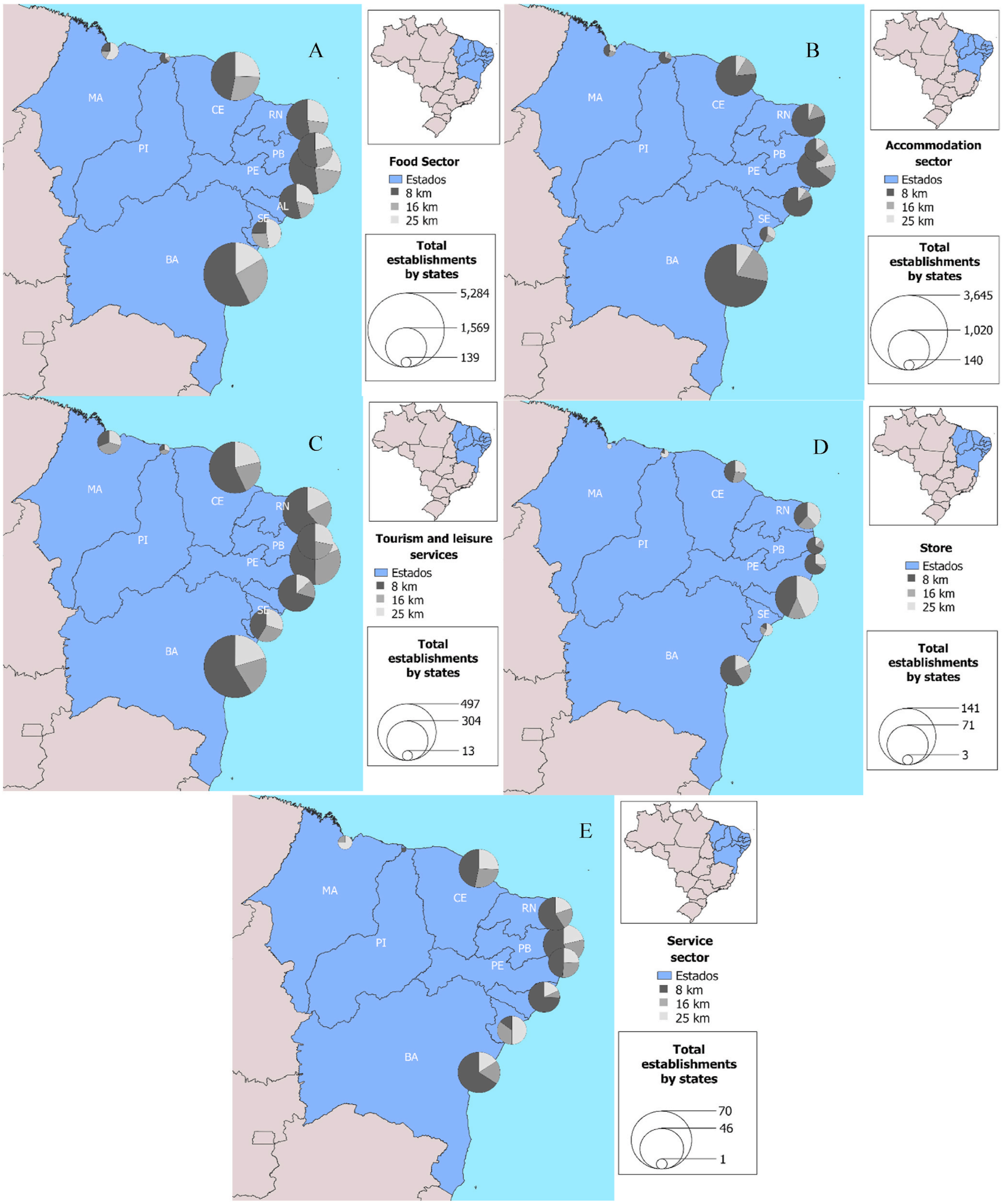

Fig. 2. Total economic activities of high exposure, by state, affected by oil stains (Brazil). A. Food sector; B. Accommodation sector; C. Tourism and leisure; D. Stores; E. General services. AL = Alagoas; BA = Bahia; CE = Ceará; MA = Maranhão; PB = Paraíba; PE = Pernambuco; PI = Piauí; RN = Rio Grande do Norte; SE = Sergipe. **Fonte:** elaboration with Qgis.

Table 3
Vulnerability index (VI) by area of influence (25 km) of the localities affected by the oil spill (2019/2020) in Brazilian Northeast coast. AL = Alagoas; BA = Bahia; CE = Ceará; MA = Maranhão; PB = Paraíba; PE = Pernambuco; PI = Piauí; RN = Rio Grande do Norte; SE = Sergipe.

State	VI – State	Area	Localities	City	VI – Localities
BA	106,951	1st	From Praia do Piatã to Ondina	Salvador	19,033
		2nd	From Praia do Taipe to Paraíso dos Pataxós	Porto Seguro	9146
		3rd	From São Domingos to Praia dos Milionários	Ilhéus	8035
PE	68,751	1st	Praia de Dell Chifre	Olinda	29,406
		2nd	From Boa Viagem to Praia da Barra da Jangada	Recife/Jaboatão dos Guararapes	13,016
		3rd	From Praia do Pontal de Maracaípe to Praia de Gamboa	Ipojuca	7668
CE	58,770	1st	Praia de Iracema	Fortaleza	23,555
		2nd	Praia do Futuro	Fortaleza	9312
		3rd	Praia da Prainha	Aquiraz	3425
RN	47,511	1st	From Ponta Negra to Barreira do Inferno	Natal/ Parnamirim	13,500
		2nd	From Praia do Forte to Praia da Via Costeira	Natal	12,662
		3rd	From Praia do Madeiro to Sibaúma	Tibau do Sul	4073
PB	38,515	1st	From Praia do Bessa to Praia do Cabo Branco	João Pessoa	29,582
		2nd	From Praia Formosa to Praia de Intermares	Cabedelo	6259
		3rd	From Praia de Tabatinga to Praia de Gramame	Conde	1973
AL	33,179	1st	From Assis Chateaubriand to Pajuçara	Maceió	13,220
		2nd	From Ponta do Mangue to Praia de São Bento	Maragogi	3917
		3rd	From Praia do Francês to Allot. Encontro do Mar	Marechal Deodoro/Barra de São Miguel	3277
SE	21,074	1st	From Praia do Mosqueiro to Praia Atalaia Nova	Aracaju	12,852
		2nd	Praia dos Náufragos	Aracaju	3018
		3rd	From Atalaia Nova to Santo Amaro das Brotas	Santo Amaro das Brotas/Nossa Senhora do Socorro	1436
MA	4724	1st	Av. Litorânea	São Luís	2711
		2nd	Tutóia	Tutóia	841
		3rd	Atins	Barreirinhas	575
PI	2403	1st	From Praia Peito de Moça to Luís Correia	Luís Correia	1780
		2nd	From Praia do Arrombado to Praia do Coqueiro	Luís Correia	519
		3rd	From Praia do Pontal to Parnaíba 's South Delta	Parnaíba	104

4. Discussion

One of the essential characteristics of wicked problems is their singular nature; as much as this problem resembles another previous one, their attributes are not part of the same system that triggered them (Rittel and Webber, 1973). In Brazil, there was a leak of 1.3 million liters of oil in January 2000, with a stain of 5 km extension on the Guanabara Bay, in Rio de Janeiro (Maciel-Souza et al., 2006). However, the country's political, economic, social and environmental context was different, and the disaster's exposure (2019/2020) was more significant.

Regarding the solutions to wicked problems, according to Rittel and Webber (1973) there is no perfect solution, but a more beneficial (or less harmful) one; as these events are imminent, they do not allow finding the solution by trial and error. It is not possible to choose among a set of solutions for these phenomena, since each solution developed to fight the problem changes the understanding and the consequences; therefore, we cannot make a final test of the solution in order to know if we adopted the best measure.

In a disaster such as oil spill, it is important to act quickly and, initially, build floating barriers to prevent the dissipation of crude oil (Grubesic et al., 2017). In Brazil, there is a National Contingency Plan for Oil Pollution Incidents (PNC), which the Ministry of the Environment should activate in such situations, which would allow an immediate response and coordinated actions based on measures that could predict the stains' location (Soares et al., 2020a, b). However, the federal government's actions were ineffective because they took too long. Ibama's first notification of the incident was on August 30, 2019, but only almost a month later, on September 26, the Navy began to mobilize. In the absence of answers from the Federal Government, the Federal Prosecution Service filed an action for omission, establishing a fine of R$ 1 million per day, for non-compliance with PNC (Soares et al., 2020a). Some Brazilian states acted, in view of the demobilization of the federal government (Soares et al., 2020 a,b). However, states do not have regional contingency plans. For this reason, most of them used containment barriers guided by SAO letters (Letters of Environmental Sensitivity to Oil Spills), made available by the Ministry of the Environment (MMA, 2004). Moreover, local stakeholders in the states (e.g., NGOs, universities, public agencies) play a key role in the mitigation measures during the disaster (Magalhães et al., 2020; Soares et al., 2020b).

There is a recognized complexity in the debate on repair and estimation of the socioeconomic damage caused by wicked problems, such as oil spills in the sea. This goes far beyond the civil liability of those involved and the financial compensations resulting from lawsuits filed by the State or injured citizens (Lewis, 1993). Such an environmental harm cannot rely only on monetary compensation, since the consequent damages will have long-term effects, difficult to measure, which include quality of life, health, and coastal ecosystem dynamics (Silva, 2019; Nelson and Grubesic, 2018; Araújo et al., 2020; Magalhães et al., 2020).

In terms of socioeconomic factors, the main findings of the research show a set of activities that mostly comprise accommodation and food services. The three states more economically susceptible to the disaster are also those that showed the highest concentration of activities in these sectors. The Brazilian tourism sector had revenues of R$ 20.3 billion until October 2019, with the Northeast being responsible for 13% of this amount (Confederação Nacional do Comércio de Bens, Serviços e Turismo [CNC], 2019). Furthermore, of the 10 national destinations, in the second half of 2019, six were coastal cities in the Northeast region, including Fortaleza as the main destination (Ministério do Turismo [MTur], 2019). In Pernambuco, Dell Chifre Beach has the largest number of accommodation facilities (471 establishments), 31% within the 8 km radius from where the spots were found. It is important to mention that tourism is a major source of income for that tropical region, which is one of the main tourist destinations in the country.

In addition, of the three most vulnerable regions in each Northeastern state (Table 3), at least one of them is located in the capital,

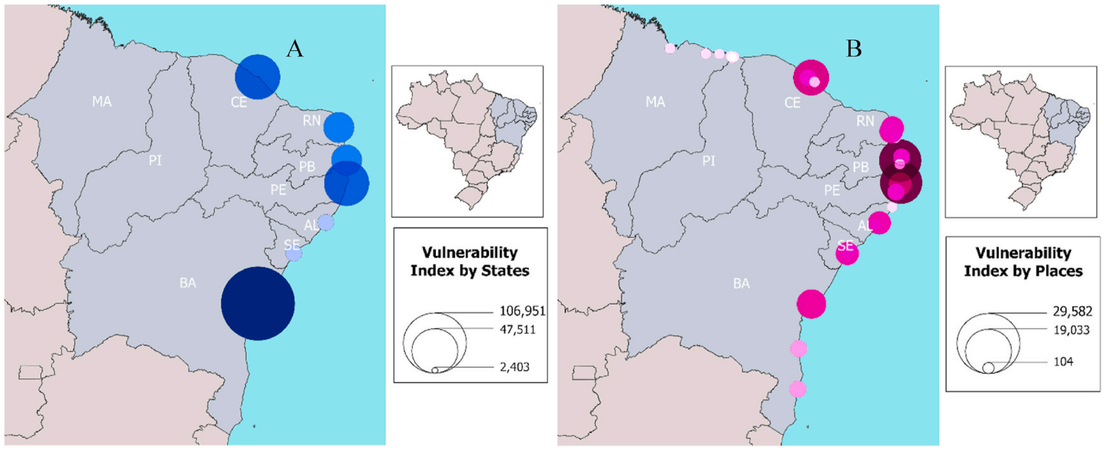

Fig. 3. Vulnerability Index (VI). A. States; B. Places most affected, by state. AL = Alagoas; BA = Bahia; CE = Ceará; MA = Maranhão; PB = Paraíba; PE = Pernambuco; PI = Piauí; RN = Rio Grande do Norte; SE = Sergipe.
Fonte: elaboration with Qgis.

except for Piauí, whose capital, Teresina, is inland. However, Parnaíba, a city with the second largest Gross Domestic Product (GDP), is among the most susceptible areas of that state. Maranhão was the least socioeconomically affected state, when analyzing the list of coordinates eliminated and the number of localities harmed (Table 1). In total, nine cities were affected, among the 35 located on the coast, which possibly makes it a quite vulnerable area in environmental terms.

In the Northeast, a series of demographic, social, geomorphological and economic determinants can worsen economic and social impacts. Eight capitals of the nine states in the region are coastal cities, and by concentrating the economy's strength, they have a strong influence over the whole territory of their states, leading to economic dependency by other cities. Thus, although this environmental disaster did not affect some non-coastal cities, the dependency creates chain effects and brings serious social and economic effects.

In the same way, it is pertinent to emphasize that the socioeconomic consequences of the oil spill can further exacerbate regional inequalities in this region (Araújo et al., 2020; Magalhães et al., 2020; Ribeiro et al., 2020). In view of the greater vulnerability of sectors such as tourism, accommodation and food stores, the economic impacts of oil leakage can hinder the development of these economic chains, which are highly interrelated (Araújo et al., 2020). This is of particular concern for the Northeastern region of Brazil - which has a poorly diversified economic matrix and, consequently, more dependent on tourism (Câmara et al., 2020; Ribeiro et al., 2020) -, as these economic sectors have been highlighted for their role in reducing regional inequalities in Brazil (Haddad et al., 2013; Ribeiro et al., 2017).

Therefore, we highlight the relevance of mapping coastal regions, since offshore oil activity increases the risk of similar disasters happening again, not only in Brazil, but worldwide. Hence, it is essential to understand the phenomenon of oil spills and how their displacement can affect coastal areas, in order to mitigate and prevent losses for all sectors and economic activities along the coast (Nelson et al., 2018). That is why building vulnerability indices and mapping regions susceptible to these risks have been used in other studies (Nelson et al., 2018; Andrade et al., 2010; Nelson and Grubesic, 2018), which intended to predict where new oil strandings could occur and anticipate mitigation actions.

The results presented here help in the elaboration of impact compensation mechanisms. For example, currently fishers living in these affected regions have been receiving government aid, a recent achievement through a judicial decision and made effective through Provisional Measure n. 908, of November 28, 2019 (Brasil, 2019). However, little has been done by other economic sectors that continue without financial support. In addition, the findings also help in the management of risks and environmental disasters, since new accidents (e.g., oil spills) may occur, as well as in the elaboration of contingency plans, as the research shows the heterogeneity of the socioeconomic vulnerability of the Brazilian tropical coast, which has different levels of urbanization, tropical ecosystems, social inequality, and economic activities (Magalhães et al., 2020; Magris & Giarrizzo, 2020; Soares et al., 2020 a,b).

In addition, Ibama's last report regarding the location and situation of the affected areas, due to the disaster here addressed, was on March 19, 2020. It still mentioned sparse traces of oil in at least 135 places, 129 of them in the Northeast region. The problem with these oil residues is that, by the weathering process, which is the physical-chemical and biological action exerted on pollutants, they pass through the process of sedimentation and sinking, accumulating on the seabed (Marinha, 2019; Oliveira et al., 2020). This can affect important marine ecosystems (e.g., coral reefs, mangroves, seagrass and rhodolith beds) that are the basis of fishing and tourism, and relevant for keeping environmental quality (Magris & Tommaso 2020; Sissini et al., 2020). Therefore, besides this social and environmental impact that will persist on its beaches, the economic recovery of the region will take a long time, since the impact of such extensive stains directly affects the image of the tourist destination and, consequently, brings a lesser flow of tourists, spreading to other sectors not directly affected (Nelson et al., 2018; Andrade et al., 2010).

5. Conclusion

The presence of large oil stains was relieved, but the consequences and impacts will extend over the long term. Therefore, it is necessary to monitor and assess the susceptibility of the affected areas in the coming years. The results of this study show that the three largest economies in the Northeast region (Bahia, Pernambuco, and Ceará) have tourism as one of their major sources of income, and that accommodation and food are the two most affected activities among those related to the sea and adjacent areas reached by oil spill.

The use of digital mapping, together with building vulnerability indices, is a step forward in the development of measures to fight the increase in coastal susceptibility associated with wicked problems. Its use allows comparing regions and checking how much the same cause agent (Lourenço et al., 2020; Oliveira et al., 2020) can disproportionately affect areas so close together, but with very different socioeconomic configurations. Our findings reveal a wide variation in the indices between states in the same region, ranging from 2403 (Piauí) to 106,951 (Bahia), either caused by coastal extension, ineffective strategic actions to fight the oil stains, the economy's dependency on the exploitation of coastal resources, or by other factors, such as deficiencies in social factors.

Building these vulnerability indicators might not only show susceptible regions, but also allow the development of policies to strengthen the resilience of these communities regarding future impacts. Although of a different nature, but affecting the same activities, Covid-19, a pandemic caused by the Coronavirus (Sars-CoV-2), has strongly affected local tourism, which was recovering from the ecological disaster caused by oil stains less than fourteen months ago (Magalhães et al., 2020). In addition, as management implications, this cartographic research allows envisioning the concentration of certain socioeconomic activities in these areas, serving as a tool to support decision-making.

Given the extension of Brazil's Northeast coast (3.3 km) and the scale of the environmental disaster, we used in this research free digital cartographic material, with recent information. However, another option would be a field research, with a high cost, without the financial support from Brazilian scientific funding agencies due to budget cuts in recent years (Andrade, 2019). Finally, we emphasize the need for research that replicates the methods used in this study in other coastal regions also affected, such as Brazil's Southeast, not only to assess these regions' vulnerability, but to support policies for developing social and economic resilience in these coastal areas.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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