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GEOSCIENCES

Multispectral Remote Sensing for mapping the areas affected by the techno-industrial disaster of the oil spill on Brazilian beaches

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Abstract: Since the emergence in August 2019 of portions of varying sizes of crude oil on several beaches in the Northeast region of Brazil, various studies have been conducted to identify the source of the disaster and estimate the damage caused. This article aims to contribute to this scientific effort in order to describe an extensive mapping that used Remote Sensing data of the impacted areas and its correlation with socioeconomic typology of the municipalities directly affected. The research was based on the list of 201 oiled beaches published on October 28th, 2019 in Technical Note from the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA, 2019). Applying the Supervised Classification to images from the MSI/Sentinel-2 sensor, a methodology for beach cartography was defined, then geographical sections were subsequently classified and quantified by thematic classes. This thematic mapping fostered to obtain a proxy of the possible impacted areas up to that date, generating an "Atlas of Beaches Affected by Oil" with 402 maps of the affected beaches, which is available on the Joaquim Nabuco Foundation website. This mapping is unprecedented and it becomes important for the environmental monitoring of these areas. This article was prepared from a request for the special edition of the AABC journal.

Key words: disaster, oil spill, Remote Sensing, social vulnerability, Brazil.

INTRODUCTION

Humankind is interacting in a complex way in the biosphere, modifying natural habitats and setting news challenges to current and future generations. The notion of risk in our daily life is increasingly more present and the more we know it, "better we appreciate the great extension of our ignorance". And, paradoxically, the more we try to control it, the greater are the risks generated in other parts of the system. However, we have to bear in mind that universalization of risk does not lead to the fact that all are equal regarding risk, since, as pointed by López Cerezo & Luján (2000), "being equals, some people are more equal than others".

This notion of risk urgency is part of contemporary societies and, therefore, of many academic discussions, particularly in social sciences, taking a central stand in political and governmental agenda. Risk is a topic that is present in many scientific researches in several areas of knowledge due to great potential for understanding disasters. But, due perhaps to its magnitude, environmental characteristics, spatial and cultural diversities, experts have not yet reached a unanimous definition related to a measurement unit for a social theory of risk.

Castro (2003) considers that human disasters are those generated by human actions or omissions. Natural or techno-industrial disasters are caused by the impact of natural phenomena or collapse of an industrial apparatus of great intensity over one populated or protected environmental areas, and they may or may not be aggravated by anthropic activities.

In fact, the social equation of losses caused by natural or tecno-industrial disasters is inversely proportional to reconstruction and adaptation. That is, the lower the income and wealth of a certain social group are, the greater will be the damages caused and the difficulty to return to daily life "normality". Even though now there is more wealth than before, social inequalities, poverty, and consumption of environmental assets continue, particularly in less developed regions of the planet, as still is the case in the Northeast region of Brazil.

Wilches-Chaux (1993) proposes that disaster is the outcome of the convergence of risk and vulnerability. As risk, he understands any phenomenon with natural or human origin that causes changes in the environment. Vulnerability means the incapacity of a given society in adapting to a special change in its environment. However, the notion of disaster has multiple meanings and the same happens with risk, danger and vulnerability.

The growth of global economic activities has been demanding greater energy consumption. In order to meet this growing demand, the exploration of oil reserves has intensified, making it necessary to transport the raw material to countries that do not have these natural resources or are not sufficient for their domestic consumption. According to the National Petroleum Agency of Brazil (ANP, 2021), "the volume of oil produced in the world in 2018 increased by 2.2 million barrels / day (2.4%) compared to 2017, from 92.5 million barrels/day to 94.7 million barrels/day" (ANP 2021). In fact, the data shows a steady growth in oil consumption from the mid-1960s until the beginning of the Covid-19 pandemic in December 2020. The monthly average, which was around 102 million barrels per day (bpd), decreased by around 18 million/bpd in April 2020 (Gauto 2019).

Therefore, there is an intensification of both the extraction of oil, as well as its commercialization and transport in large ships that follow long transoceanic routes. It was probably from this intense traffic of tankships loaded with oil that the spill in the Atlantic Ocean originated. After interacting with the marine environment (salinity, insolation, winds, ocean drift, etc.), the mass of crude oil at some point was divided into portions of varying sizes and submerged in shallow depth, due to changes in its biophysical-chemicals characteristics under these conditions.

Some time after the collapse of the industrial apparatus (rupture of tanks? transfer ducts between ships? offshore drilling?), the oil portions reached Brazilian beaches, in consequence of the tides and characteristics of coastal environments. This little depth of the portions after interacting with the marine environment may be the cause of the impossibility of recording the disaster by the earth's surface monitoring satellites, both the optical and radar orbital sensors. However, if it had not been possible to identify the source of the disaster, satellite images could have certainly mapped the impacted areas on the beaches affected by the spill.

At the end of August 2019, several beaches in the Northeast of Brazil were affected by large portions of crude oil, whose origins are still unknown. The phenomenon lasted for months and, on October 28th, 2019, the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA 2019) - national authority for the environment in the country, published a technical note in which it revealed the georeferenced survey of the 201 affected beaches by the oil in 92 municipalities, distributed in the nine states of the Northeast region, with some beaches being hit more than once. The entire research being limited by the data collected and published by IBAMA on this note.

Among these affected areas, which involve all the Northeastern states, large urban centers, important tourist hubs, and several environmental conservation units are listed.

Figure 1 presents the population of the municipalities affected by the oil slicks, according to the listing in IBAMA's technical note, already referenced. It can be seen that since the three main metropolitan regions in the region were affected, the total population surpasses 15 million people. The intensity of the impacts on each person depends on their interaction with the sea and the beach. The use of beaches, sea waters, and mangroves involve tourism, recreation, industrial fishing, artisanal fishing, and shellfish and crab gathering. Besides the obvious chains of tourism and fishing, the impacts are listed with the peddlers and people who live of leisure on the beaches, restaurants whose differential are the seafood and typical foods of the Northeastern coast, and the population itself, that was partially deprived of its free leisure.

In addition to economic issues, there are the consequences on ecosystems, which often suffer strong pressures from population growth, poorly planned urban densification, and the existence of urban settlements in risk areas.

The human health aspect should also not be set aside, both due to the short-term risk of direct contact of the people (often voluntary) with oil, and the long-term risk due to the ingestion of contaminated food or even by populations living in stilt houses in large urban centers.

In order to estimate the response power of municipalities to this type of event, an index of their economic dependence on public administration was generated. This index is the ratio of the aggregate value of the public sector in the total aggregate value of the municipality, according to data from the 2017 GDPs of municipalities, published by IBGE. It is understood that the higher the indicator, the more dependent the municipal economy is and, consequently, the lower its ability to respond to problems of the type. This is because high indices indicate municipalities that are dependent on

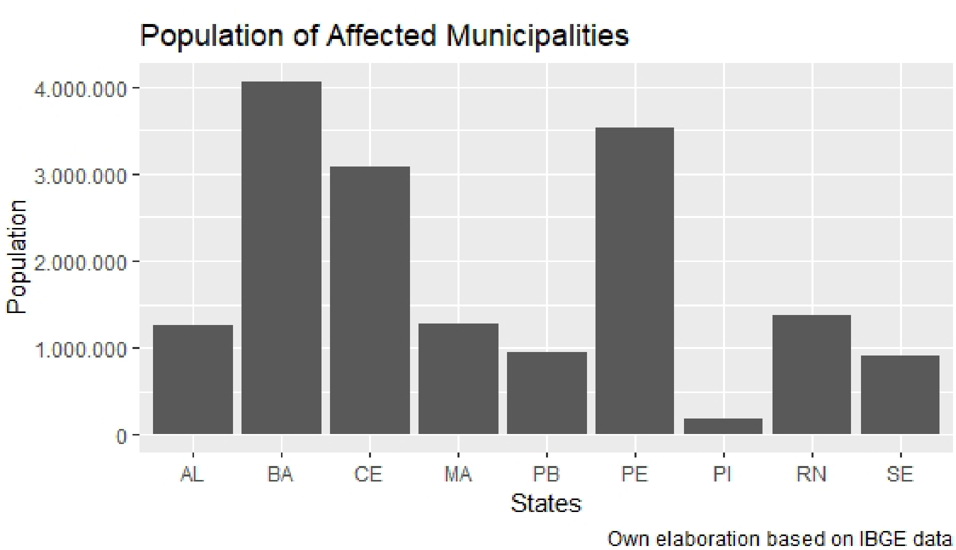

Figure 1. Population of Affected Municipalities.

resource transfers from the state and federal government. Figure 2 shows the box-plot of this indicator for the municipalities affected up to 10/28/2019.

The dependency is given by the ratio between the added value of the public sector to the municipality's GDP; the X coordinates represent the states of the Northeast, while the Y coordinates represent the percentage of dependence of the municipalities on the public sector. The data are from IBGE (2018).

At least three states reach high levels of dependence showing that their economies are fragile and probably the municipalities have little possibility of acting on their own to mitigate the environmental and socioeconomic effects of this disaster.

In order to measure the potential impact on the tourism trade, figure 3 was drawn up, which shows the total formal employment in hotels, restaurants and similar establishments for the affected municipalities, according to RAIS data from 2017. Note that there is a large contingent of workers who may have been affected. However, it should be noted that much of the tourism in Bahia, Ceará, and Pernambuco is also based on the so-called "event tourism" which causes the impacts to be different among the municipalities. The persistence of oil spill events on beaches, often with considerable impacts on tourism, caused a strong repercussion in the media and social networks.

Figure 4 shows the number of fishermen registered in the General Fishing Register (RGP), conducted in 2013 and made available by the Ministry of Agriculture. It is noted that there is a large volume of fishermen in Bahia and Maranhão. This stems from high contingents registered in the municipalities of Salvador and São Luiz. The contingent of fishermen reported for these municipalities by the RGP differs from the estimate of the number of fishermen made by IBGE based on data from the 2010 Census. Artisanal fishing, in general, is a family activity, which means that the number registered is a low estimate of the actual number of people who support themselves by fishing.

For a better understanding of the complexity of the impacts caused by this disaster, the research integrated socioeconomic data with multispectral data obtained by remote sensing. In that sense, the remote sensing data obtained from satellites have the potential to provide detailed information about the properties of

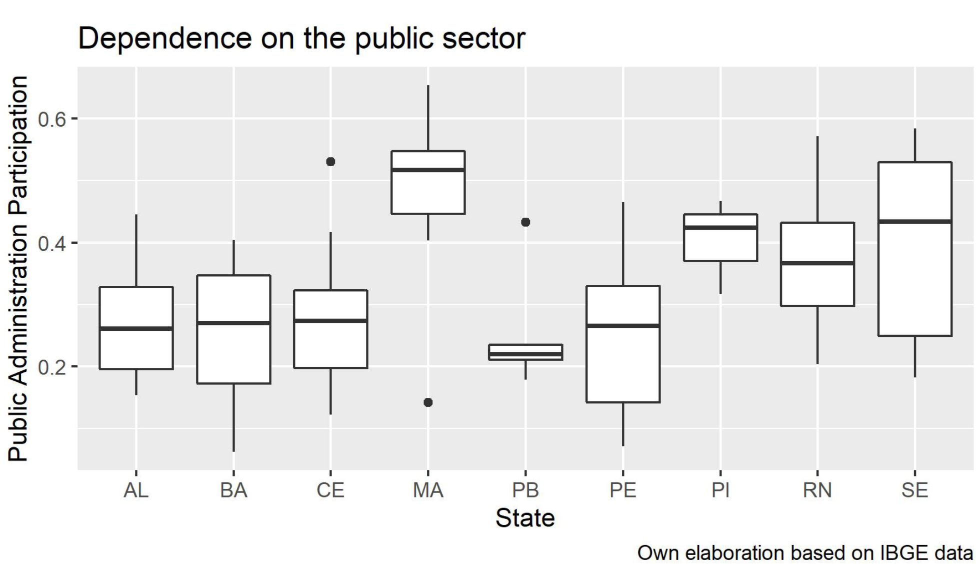

Figure 2. Dependence on the public sector.

land surface and the parameters at a local level or on a regional scale. Constant evolution in remote sensing has enabled, more recently, the detection of increasingly smaller targets due to spatial resolutions (geometric) and radiometric enhancements. Orbital sensing systems, with several spatial, spectral, and temporal resolutions, are thus the ideal solution for determining the spatial-temporal distribution of a specific target on the Earth's surface. Using remote sensing can help and make feasible the application of new urban or environmental policy instruments, in order to enforce the social function of property and the right to the city through data generation and identification of these irregular areas.

Multi-spectral and multi-temporal satellite images along with local databases and maps have been used to analyze nature, trend, and quantification and qualification of the damage of the disasters processes in different places. The outlining and mapping of affected areas are carried out to establish a reliable basis for monitoring the impacted areas as well as suitable strategies to fight it. The emergence of new orbital sensor systems, like the MSI/Sentinel-2, sets expectations that their data provide a better understanding of the disaster process evolution.

It is, therefore, in the context of the complexity associated with natural and techno-industrial disasters that this research was carried out, taking as a backdrop the dimensions of social vulnerability, exposure, and dangerousness, and aiming to map, through satellite images, the beaches investigated by IBAMA. Performing thematic mapping can be useful for analysis to facilitate problem delineation, planning, and decision making (Ribeiro, 2019).

This mapping can be accomplished through digital image classification, which is a procedure that aims to separate the image into "themes", according to the guidelines used for this separation (Ribeiro, *Op. Cit.*). A supervised classification is a procedure for identifying spectrally similar areas (training samples) in an image, in which the user preliminarily recognizes known regions of interest on the Earth's surface, and it is up to the chosen algorithm to extrapolate these spectral characteristics chosen for the other regions of the image, thus performing the classification (Castillejo-González et al., 2009).

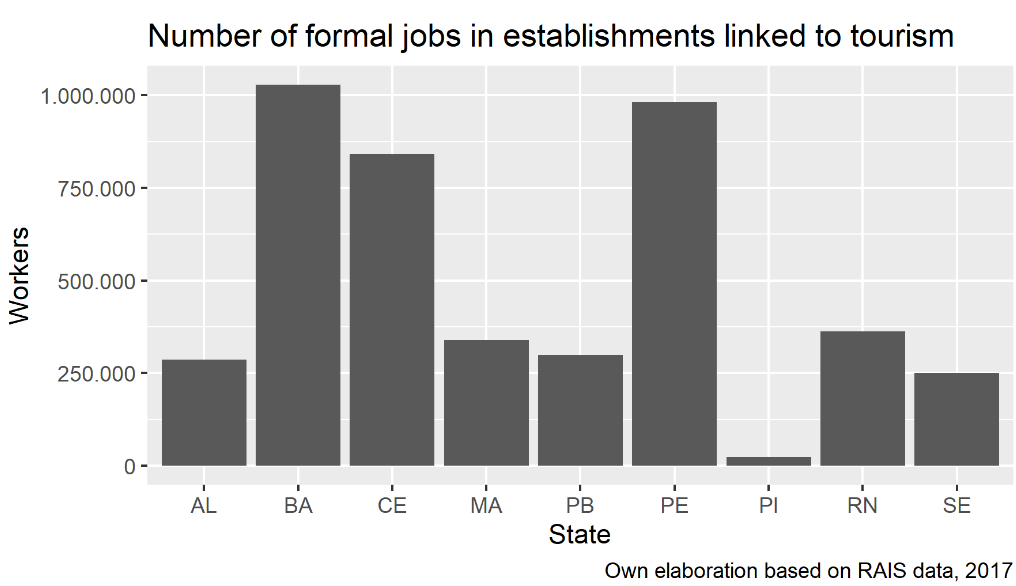

Figure 3. Number of formal jobs in establishments linked to tourism.

Therefore, this research was directed towards the mapping of the land cover of the impacted areas on the 201 beaches surveyed by IBAMA in October 2019, using a supervised classification of remote sensing images. This approach then complements the information in Figure 2 and used in conjunction with other social information, can reveal more of the impacts suffered by local populations.

MATERIALS AND METHODS

Study area

The study area comprised the 201 beaches affected by oil in the nine states in the Northeast region of Brazil (figure 5). A cartographic cut around each GPS point tracked by IBAMA in October 2019 was performed on the images, as will be detailed in the methodology and this being the study area mapping.

Materials

In order to map the existing land occupation in a significant regions where IBAMA field investigations have been carried out, the Sentinel-2 satellite was chosen for its temporal (5 days), spatial (10m, 20m and 60m) and spectral (13 bands) resolutions, in addition to the availability for free download on the Copernicus website. The satellite Sentinel-2 “is equipped with an opto-electronic multispectral sensor for surveying with a resolution of 10 to 60 m in the visible, near infrared (VNIR), and short-wave infrared (SWIR) spectral zones, including 13 spectral channels, which ensures the capture of differences in vegetation state, including temporal changes, and also minimizes impact on the quality of atmospheric photography” (EOS 2020). Its high temporal resolution is possible because the presence of two satellites in the mission allow repeated surveys every 5 days at the equator and every 2-3 days at middle latitudes.

The images for this study were selected using atmospheric conditions as criteria, specifically the cloud cover for each orbital scene since the objective was to map the ground occupation of the surveyed areas in every municipality. Additionally, images with a 2A processing level

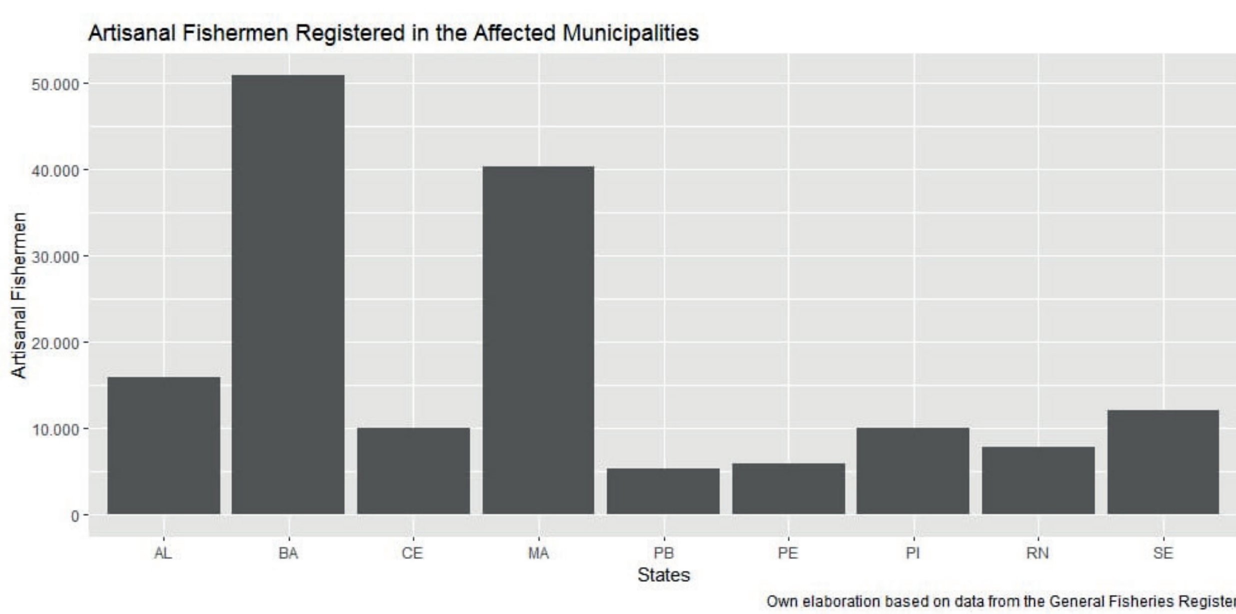

Figure 4. Artisanal Fishermen Registered in the Affected Municipalities.

were chosen, which are calibrated to Bottom Of Atmosphere (BOA) reflectance.

Besides that, vector information made available by IBAMA, referring to the beaches investigated due to the oil spill, and the IBGE digital cartographic base were used.

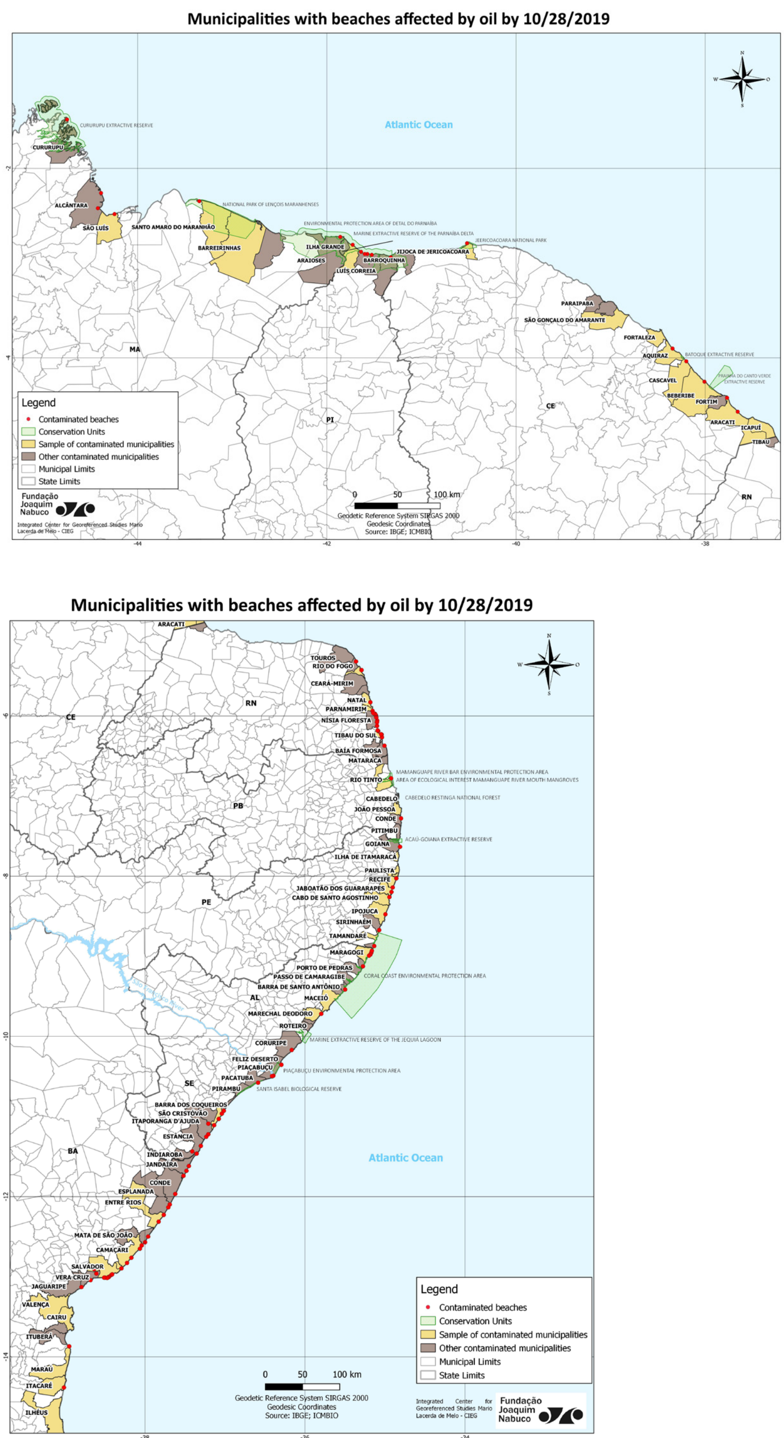

Figure 5. Map of beaches and municipalities affected by the disaster on the east coast of northeastern Brazil (top) and map of beaches affected by the disaster on the north coast (bottom). Source: Authors' elaboration based on IBGE (2018) and IBAMA (2019) data.

Geoprocessing

For the definition of the thematic mapping limits of each beach studied, the GPS data were plotted on IBGE municipal digital cartographic base and, after that, buffers were created around the points and the existing municipal limits. This generated, through geoprocessing, vectors of 1x4km that were used as a reference for the clipping of the images.

The dimensions of these vectors were defined considering the fact that they would spatially cover the stretch of land and, still allowing the analysis of land use and occupation of the area around the studied point (figure 6). However, due to the proximity of some points, these dimensions were reduced to the intersection of their buffers.

After all the thematic mapping boundaries of each beach were generated, the images were cropped for their subsequent supervised classification (Figure 7).

Supervised classification

The supervised classification was performed on the thematic clippings of each beach studied, using the Maximum Likelihood classifier with an acceptance threshold of 100%. The maximum likelihood classifier (MaxVer) considers the weighting of the distances between the mean pixel values of the classes, using statistical parameters. It assumes that all bands have normal distribution and calculates the probability that a given pixel belongs to a specific class (INPE, 2008). It is a more efficient classifier because the training classes are utilized to estimate the shape of the distribution of pixels contained in each class in the space of "n" bands, as well as the location of the center of each class. (Meneses & Almeida 2012). More information about this classifier and its mathematical basis can be found in Richards & Jia (2006).

In the supervised classifications, 10 bands out of the 13 available were used, namely: B2, B3, B4, B5, B6, B7, B8, B8A, B10 and B11. The processing

Figure 6. Buffer in multi-spectral Sentinel-2B image for later supervised classification and generation of beach cartography. The red lines are buffers of 2km radius around the GPS point tracked by IBAMA, and the yellow lines are buffers of 500m along the coastline. Source: Authors' elaboration based on MSI / Sentinel-2 data (EOS 2020).

was carried out using the ENVI 5.5 software available in the Social Cartography Laboratory of the Integrated Center for Georeferenced Studies (CIEG). For this processing, the bands with 20m spatial resolution were resampled to 10m, thus homogenizing the stack to be classified.

Hence, we have as products, thematic maps, multispectral image maps, and the calculation of the areas of each class, providing, besides the spatial visualization of its occurrence, the quantitative analysis of the data.

Cross-referencing land use and occupation with economic and social data

With the land use and land cover information for each beach, it is possible to aggregate by municipality. This is important in order to have a land use profile of the directly affected areas at an aggregation level where statistical information from society is available. From this aggregation, crossings were made with information from IBGE's Municipal Information Survey. In this survey, IBGE collects data from each Brazilian municipality and makes them available on a web platform. Throughout the year of 2018, there were questions about the municipalities' risk response system, such as the existence or not of a Municipal Risk Reduction Plan, a Fire Department, a Civil Defense Council, or a Civil Defense Center. It was also crossed with variables such as the GDP per capita in 2016 and two proxies to measure the importance of the tourism and fishing sectors in the municipality. For the tourism sector, we used the percentage

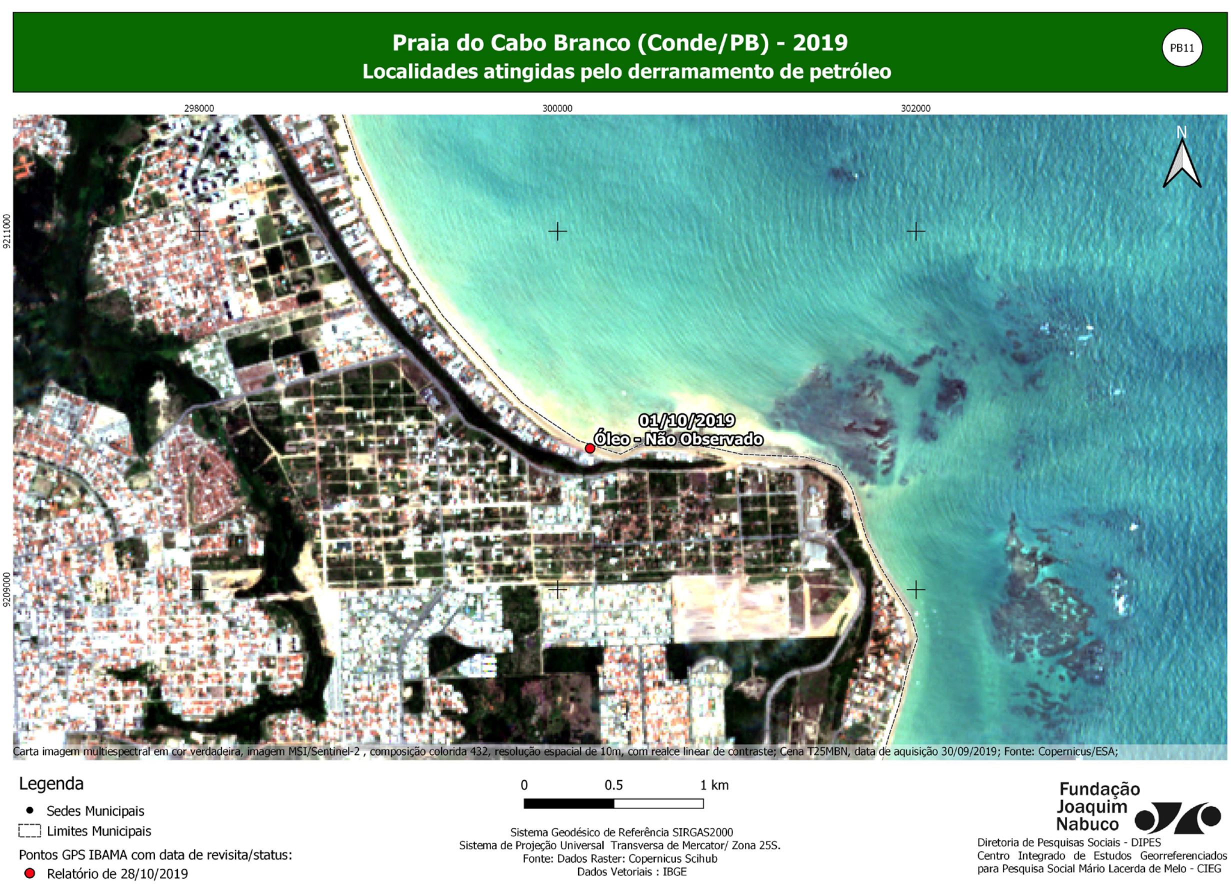

Figure 7. Multispectral image map of the beach affected by the disaSter. Source: Authors' elaboration from the digital image processing of the sensor / satellite MSI / Sentinel-2.

of formal workers employed in establishments linked to tourism according to RAIS (Annual Record of Social Information) of 2017. For the fishing sector, the ratio of artisanal fishermen registered in the General Fishing Registry by the number of inhabitants was used.

RESULTS AND DISCUSSIONS

The digital processing of satellite images using the Supervised Classification method resulted in thematic maps with the location and distribution of the classes.

This method made it possible to identify and quantify important areas of beach morphodynamics (Calliari et al. 2003), especially in swash zones and prairie zones: mangrove/native vegetation, rocky outcrops, beach faces, submerged corals (up to 1.5m deep), ocean and surface water bodies and urbanized areas. The results were presented by state and, later, compared with the interviews carried out among the social groups affected by the disaster. The main results point out that the beaches with more significant areas of mangrove/native vegetation, therefore close to river estuaries, are those where traditional populations of artisanal fishermen were most impacted, while in beaches with more urbanized areas the tourism sector suffered more impacts.

The mapping also showed the beaches with the largest areas of rocky outcrops and submerged corals that require more attention from the authorities in the recovery of the damages caused, as well as the monitoring of these areas due to the possibility of future detachments of portions deposited in these coastal environments, especially in the syzygy tides.

Thus, the Supervised Classification and quantification of land use and occupation was carried out for each of the 201 beaches in the 9 states and 81 municipalities affected and, finally, the generation of 201 image maps, their respective 201 thematic maps of use and occupation (figure 8), as well as the graphics of the areas that make up the “Atlas of the beaches hit by the environmental disaster from the oil spill” that will be published and made available in e-book format. The thematic classes defined were: rocky outcrop, inland water body, ocean, sand strip, submerged corals, native vegetation and urbanized area.

Since the method of extracting information by Supervised Classification allows the quantification of the thematic areas, it became feasible to calculate the possible areas impacted by the disaster on these beaches from the satellite images used. The graphs with these areas were prepared by state, allowing to establish some conclusions about the relationship between these thematic classes and the field research carried out among approximately 4 thousand people, who were impacted by the disaster. This research revealed a socioeconomic profile of these groups, showing their correlation with the data obtained by Remote Sensing.

Figure 9 contain the data referring to the sum, in each state, of the thematic areas obtained in these clippings of the beach cartography.

Once the supervised classification of each beach is done, it is possible to aggregate this information by municipality in order to verify the profile of land use and occupation of each one. Table I shows the crossing of the average occupation by type, crossing with information that the municipalities provide to IBGE on their risk response structure. IBGE informs whether or not the municipality has certain types of action that establish a proxy for its capacity to respond to risk. The PMRR column represents the average percentage of land occupation for the municipalities that declared to IBGE that they have a Municipal Risk Response Plan. The

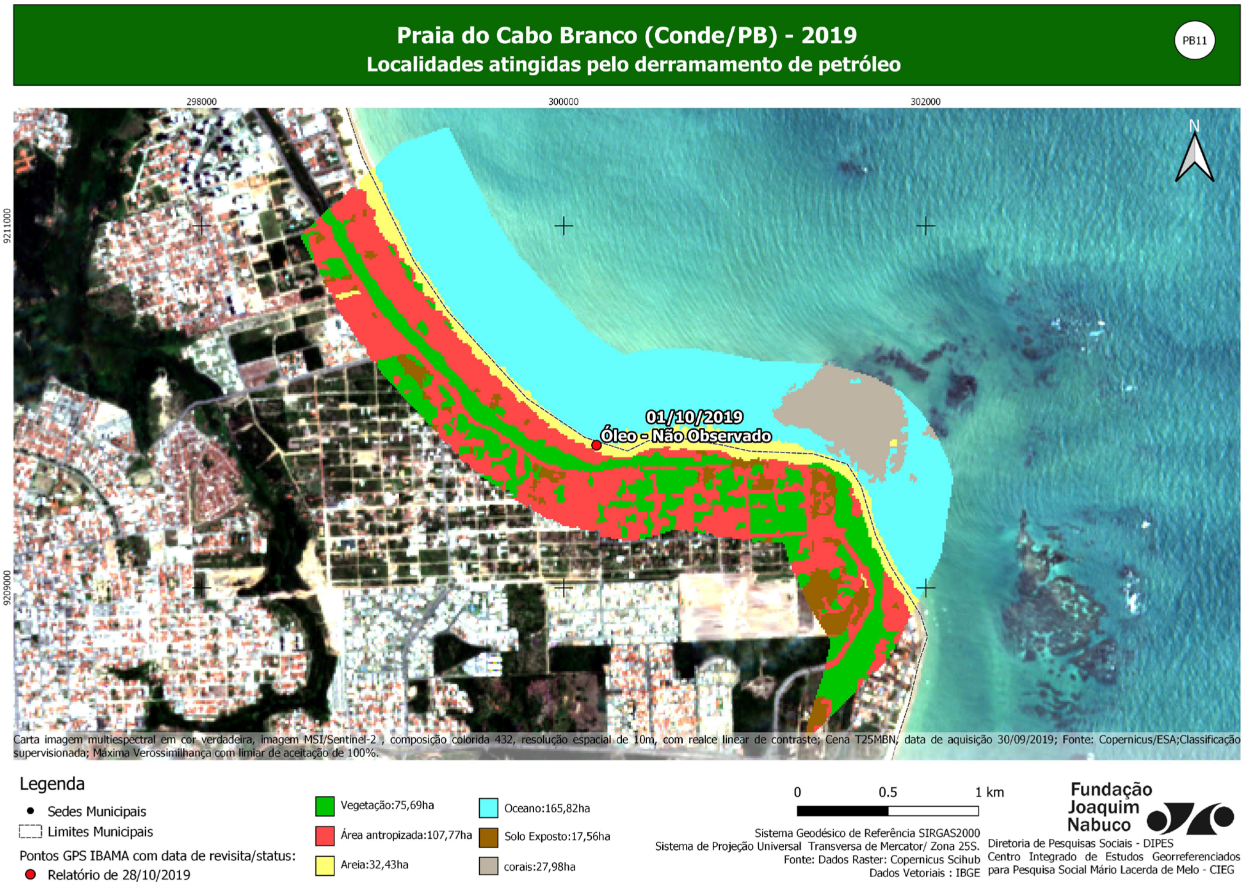

Figure 8. Thematic map obtained from the Supervisioned Classification in multispectral image of the MSI / Sentinel-2 satellite. Source: Authors' elaboration based on Sentinel-2 images.

Firefighters column is the average occupation of the soil for those who declared to have a group of the fire brigade. The COMDEC column shows the average land occupation for the municipalities that declared to have a Civil Defense Council. The NUDEC column shows the average land occupation of the municipalities that declared they had Civil Defense Centers. The stilt columns and subnormal subdivisions indicate the average land occupation of the municipalities that declared they had this type of human agglomeration. This is an alternative to check the geographical characteristics of the municipalities with their specific organization to face adversity.

This table can be understood as describing the profile of land use and occupation in the municipalities that have some type of social structure that enables them to respond to adversity. It may happen that the municipality appears in more than one aggregation, since they may have more than one structure. For example, municipalities that have PMRR present 21.1% of their anthropized area, 10.3% of native vegetation, and 4.5% of exposed soil.

The municipalities that declared having a Municipal Risk Reduction Plan present a lower participation of surface water bodies; native vegetation/mangroves; sand and exposed soil than the average of all the municipalities analyzed. On the other hand, these municipalities present a higher participation of coral and, mainly, urban areas. When the answer is whether there is a fire department in the municipality,

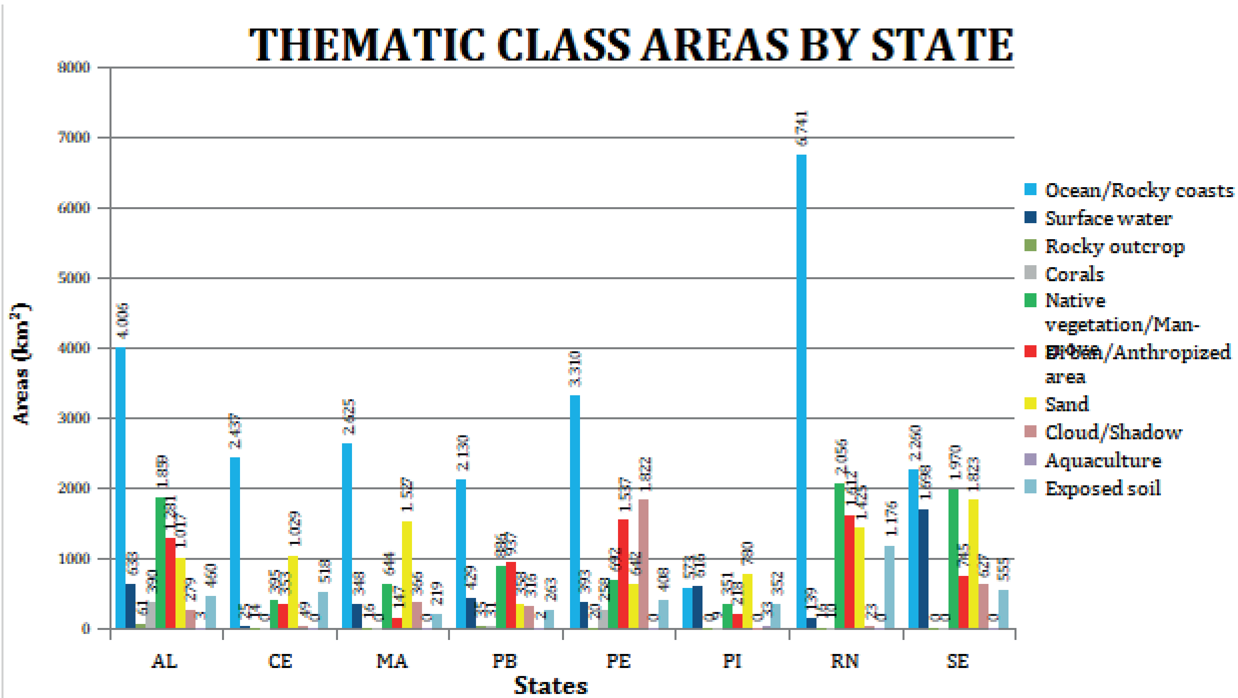

Figure 9. Totals of thematic areas by state on the beaches affected by the disaster. Source: Authors' elaboration based on digital image processing from the Sentinel-2B satellite (2020).

the lowest participation of native vegetation/mangroves and the highest participation of urban areas stand out.

The municipalities that declared to have Municipal Defense Councils (COMDEC) have a land use and occupation profile closer to the average of all the municipalities analyzed. The municipalities that declared to have Municipal Defense Nuclei (NUDEC) have an urban area percentage above the average, but lower than those that have PMRR and Fire Department. The stilt houses and subnormal settlements seem to be more connected to municipalities with a higher percentage of area with native vegetation/mangroves and urban area.

Table II presents the correlation between socioeconomic variables and the shares of each land cover type. In bold are the correlations that draw more attention for their magnitude. It is noteworthy that municipalities with higher GDP per capita are inversely correlated with the presence of surface water bodies and sand in the affected areas. On the other hand, there is a direct relationship between GDP per capita and urban area. The information about GDP per capita then confirms that the affected beaches in richer regions are more populated to the point that part of the sand strip is occupied for construction.

The participation of workers in tourism among the total formal employment is directly related to the presence of coral reefs, native vegetation, and also aquaculture. Here the direct relationship is explained by the natural beauties that tend to specialize the locality in tourism reception. The presence of aquaculture is probably due more to an indirect effect of the presence of mangroves.

On one hand, artisanal fishing is directly related to surface water bodies, native vegetation, sand, and aquaculture. On the other hand, it is inversely related to the urban area.

Table I. **Crossing of the average occupation by type of municipalities.**

Type of Ocupation	PMRR	Fire Department	COMDEC	NUDEC	Stilt Houses	Irregular allotments	Average of all municipalities
Ocean/Rocky Coasts	39,5	35,3	36,8	37,9	39,3	37,6	37,9
Surface water	3,6	5,2	6,6	3,6	3,8	6,4	6,9
Rockyoutcrop	0,1	0,0	0,1	0,0	0,4	0,3	0,3
Corals	2,9	1,1	1,5	2,5	2,0	1,7	1,5
Native vegetation /mangrove	10,3	10,7	11,0	12,0	13,1	13,0	12,4
Urban/Anthropized area	21,1	18,2	14,7	17,8	14,5	12,4	11,4
Sand	8,8	15,0	14,9	12,3	11,3	15,0	16,6
Cloud/Shadow	9,1	10,0	8,5	9,7	9,8	8,0	6,9
Aquaculture	0,0	0,0	0,0	0,0	0,0	0,0	0,1
Exposedsoil	4,6	4,5	5,9	4,0	5,8	5,5	6,1

Source: Authors' elaboration.

This shows that there is a clear profile of land occupation of localities specialized in fishing with larger areas of preservation, with respect for the natural range of the beach, and with the production of fish and crustaceans in areas contiguous to the mangroves.

Considering the total of beaches mapped in the research, the thematic class which presented the greatest exposure to the risk derived from the oil spill, was "Ocean/Rocky Coasts" with 24,081km², followed by the classes "Native vegetation/mangrove" with 8,852km², and "Sand" with 8,602km² (figure 10). However, despite not being among the classes with the largest territory, the class "Corals", with around 700km of risk exposure, is highlighted by its biological importance in coastal ecosystems and its social-economical impacts on traditional populations of high social vulnerability who live off artisanal fishing all over the northeastern coast. In total, 60,978.58 km², distributed in 201 satellite images and their respective thematic maps.

CONCLUSIONS

Although the biggest thematic classes mapped were the ocean areas, the classes made up of mangrove/native vegetation and submerged corals stood out because they are places of permanent preservation, according to the Brazilian environmental legislation. This has profoundly affected the traditional populations that live off fishing in these places, as well as the various economic chains that, in some way, depend on the attractions and natural resources of these environments.

Only on the contaminated beaches in Alagoas, for example, about 1,860 ha may have been affected by oil in the areas of mangrove and native vegetation, including near the mouth of the São Francisco River. In Pernambuco, there were 1,536 ha of urbanized area that may

Table II. Correlation between socioeconomic variables and the shares of each land cover type.

Type of Land Occupation	GDP Per Capita	Workers' particpation in the population	
		Turism	Fishing
Ocean/Rocky coasts	0,05	-0,05	-0,30
Surface water	-0,20	-0,09	0,31
Rocky outcrop	0,01	-0,02	0,05
Corals	-0,01	0,32	-0,07
Native vegetation	-0,08	0,15	0,17
Urban/Anthropized area	0,25	0,08	-0,25
Sand	-0,30	-0,08	0,24
Cloud/Shadow	0,32	-0,10	-0,03
Aquaculture	-0,08	0,25	0,56
Exposed soil	-0,10	0,12	-0,02

Source: Authors' elaboration.

have been affected by contamination in 11 municipalities within the state (Fundaj 2020), many of which have an important economic dependence on tourist activities.

The areas of submerged corals were significant in the mapping, as they are places of great biodiversity, in addition to serving as a refuge and breeding environment for various species of fish and crustaceans - important fishing resources for the numerous traditional populations inhabiting these locations, such as shellfish gatherers and artisanal fishermen.

In this sense, in Alagoas only, there were 390 ha of coral areas that were exposed to contamination. Such areas, as well as mangroves, require extensive work to remove contaminating material, which quickly fragments and deposits in lake environments and lagoons. The consequences for the environment, therefore, are not yet fully understood or mapped.

The cross-referencing of land occupation data with socioeconomic information from the municipalities allowed us to elucidate that three types of situations can be observed. The first involves large municipalities with high GDP per capita, high-risk response capacity, diversified economy, high population densification, and occupation of the beaches. Another type observed are municipalities with natural beauty and many tourist attractions, but low-risk response capacity. Finally, the fishing municipalities with a little occupation of beaches, large areas of mangroves and native vegetation, and also large areas dedicated to aquaculture. This last type, with lower capacity to respond to risk.

Among the conclusions, the research highlights that the local administrations of smaller municipalities do not have sufficient preparation to face calamities - part of the response to the oil spill must be the strengthening of local administrations, probably with the creation of consortia. The initial hypothesis was also confirmed, as the impact of

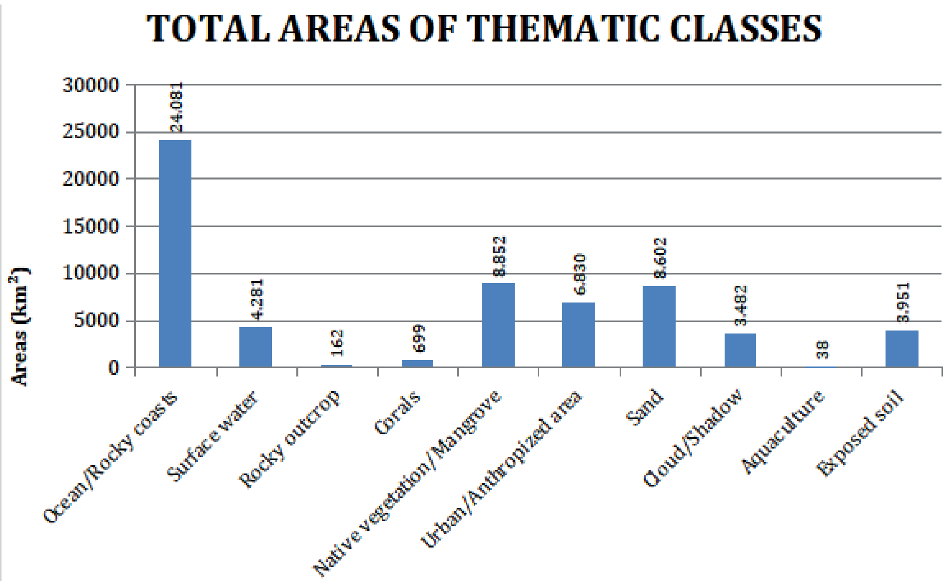

Figure 10. Totals areas of thematic classes on the beaches affected by the disaster. Source: Authors' elaboration based on digital image processing from the Sentinel-2B satellite (2020).

the oil spill is not homogeneous among all the municipalities. Therefore, policies to mitigate the effects of the oil spill should be designed by type of municipality. It is important that these actions have federal coordination, especially in disasters of a large territorial proportion such as the case in question. In cases of oil spills at sea, coordination is provided by law.

The National Contingency Plan for oil pollution incidents in waters under national jurisdiction is the risk management tool for oil pollution in waters under national jurisdiction, which is provided for in Law 8127/2013. The actions that involve tourism should be to create diversification of options, because, although the large municipalities have lesser impacts on society as a whole, the damage to the environment is always of great magnitude and intensity (Fundaj 2020).

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