Revista ARACÊ
ISSN: 2358-2472

CONTINGENCY AND REMEDIATION OF OIL SPILLS IN THE COASTAL ZONE OF BRAZIL: CHARACTERIZATION AND ANALYSIS OF EMERGENCY ACTIONS AND TECHNOLOGIES

https://doi.org/10.56238/arev7n4-071

Submitted on: 08/03/2025 **Publication date:** 08/04/2025

Érica Machado da Silva Guerreiro[1], Elisabete de Santis Braga[2] and André Felipe Simões[3]

ABSTRACT

The challenges associated with oil spills at sea have been many, especially in a country characterized by an extensive coastal strip, as is the case of Brazil, whose Coastal Zone extends, in its terrestrial portion, for more than 8,500 km, covering 17 states and more than four hundred municipalities, distributed from the equatorial North to the temperate South of the country. In this context, it is urgent to have a well-planned action, in which all agencies cooperate with each other in order to allow an immediate and coordinated response action. Under the aegis of such considerations, the present work aims to characterize and analyze the main actions and technologies of contingency and remediation based on the best practices acquired after the last oil spill in the country, which occurred on the Brazilian coast, in 2019. The methodological route for this was based on a bibliographic review based on high-impact scientific publications and also on documentary research to obtain primary and secondary data on accidents that generate oil spills. From the development of this study, it was possible to infer that, in general, there is a notorious lack of preparation of the authorities regarding prevention and mitigation actions, making it urgent to train technical staff specialized in emergency management, and this in favor of greater efficiency of the offshore and coastal contingency structure. Conclusively, this study points to the need to implement a much more articulated communication between the spheres of public power and civil society for the purpose of coordination and integration in case of major oil accidents causing oil spills.

Keywords: Oil spills. Coastal Zone of Brazil. Contingency. Remediation. Emergency environmental measures.

[1]Master
Av. Prof. Luciano Gualberto 1289, São Paulo, 05508-900.
Lattes: http://lattes.cnpq.br/5711902192159730
Email: ericaguerreiro@usp.br
[2]Doctor
Praça do Oceanográfico, 191, Cidade Universitária, Butantã, São Paulo, SP, 05508-120
Lattes: http://lattes.cnpq.br/9298544294588050
Email: edsbraga@usp.br
[3]Associate Professor and Doctor
Av. Prof. Luciano Gualberto 1289, São Paulo, 05508-900.
Lattes: http://lattes.cnpq.br/1503283535579534
E-mail: afsimoes@usp.br

INTRODUCTION

In August 2019, one of the largest environmental disasters in Brazil occurred as a result of a crude oil spill from an oil tanker, which, due to its length (2,890 km) and impacts, is considered the most serious catastrophe ever recorded in tropical coastal regions (BRUM *et al*., 2020). The spills began to appear on the coast of Paraíba and extended for about 1,000 km from the coast (IBAMA, 2020a), in the northeast and southeast regions, between the states of Maranhão and Rio de Janeiro. From August 2019 to March 2020, 11 states, 130 municipalities, and 1,009 localities were affected by the oil spill (IBAMA, 2020b).

The reasons that made this environmental disaster so particular were not only the absence of measures taken by the Federal Government at the time, but also the characteristics of the accident itself, since it was not possible to identify crude oil easily on the surface, causing several negative impacts on marine biodiversity, affecting 10 ecosystems, more than 57 protected areas and 34 species (SOARES *et al*., 2020). Due to the difficulties of detection, it is likely that the oil traveled below the sea surface, even so, most of the containment and remediation techniques adopted were based on the principle of oil flotation, although this does not always happen and the oil can float, remain in suspension and/or sink according to the sea current and the occurrence of turbulence (LOBÃO *et al*., 2022).

Despite the extreme circumstances, the disaster still did not receive the attention required in a short period of time by the federal government at that time, whose inaction led to more significant long-term consequences, such as the compromise of preservation areas and the temporary suspension of artisanal fishing, harming the livelihoods of thousands of residents of the affected localities. The scenario of disorganization, inefficient communication and the absence of a health crisis office led to the mobilization of thousands of volunteers unprotected by safety equipment and vulnerable to exposure to the environment contaminated by petroleum derivatives (such as benzene and aromatics), thus exposing the lack of financial resources and the fragility of emergency health actions in the country (PENA *et al*., 2020). The oil was collected mostly by volunteer citizens, even with the participation of municipal public agencies (city halls and respective environmental departments, in particular) and Petrobras.

At the time, great attention was devoted by the authorities to the identification of the vessel responsible for the origin of the oil spill, and in a way, the focus was diverted from

Revista ARACÊ
ISSN: 2358-2472

the rapid emergency actions to contain the accident. As a result, the government's inaction in dealing quickly with the control of the spread of the oil slick was seen as harmful, leading to greater damage and impacts on ecosystems and local communities.

The National Contingency Plan (PNC) was activated for the first time after the oil spill accident off the Brazilian coast in 2019, whose characteristics were persistent oil, in which, according to internal data from the Brazilian Navy, responsible for the investigation, 5,379.76 tons of waste were collected – 30% of which is equivalent to oil. In most of the affected states, the oil collected was mostly treated and mixed with other waste with high calorific value and reused energetically as an alternative fuel in cement kilns through co-processing activity; while the part not applied in cement plants was disposed of in landfills.

At an initial moment, much of the oil was collected by volunteers from the coastal communities themselves, who were devoid of PPE (personal protective equipment). Such an environmental disaster, although of large territorial extension, is not technically considered of large volume when compared to others such as, according to ITOPF (2022), the Atlantic Empress (Caribbean), in 1979, with 287,000 tons, and the Torrey Canyon (United Kingdom), in 1967, with 119,000 tons, for example.

There are many challenges, especially in a country with a long continental extension like Brazil. Therefore, in the event of an oil spill, it is very important to have a well-planned action, in which all agencies cooperate with each other and in synergy, in order to allow an immediate and coordinated response action. It is also of great importance that the local community is well trained and enlightened on how to proceed and what emergency actions should be taken in a short period of time in the event of an eventual oil accident.

The tragedy of 2019 evidenced at the time the authorities' lack of preparation and disagreement regarding decision-making and choice of responses, such as, according to Souto (2020), the delay in activating the National Contingency Plan and modification of the Monitoring and Evaluation Group (GAA), in addition to the inefficiency of the rules and mechanisms to contain the advance of oil to the beaches. The PNC, although of great relevance, is applicable only in occurrences of greater proportions in macro-regions, especially in *offshore* zones, showing the absence of a rapid mobilization and contingency plan to cope with oil accidents, especially to the most vulnerable communities and those with difficult access by land.

Thus, even with the instances and scalar aspects regarding emergency response strategies (such as the National Contingency Plan, Individual Emergency Plan and Area

Revista ARACÊ
ISSN: 2358-2472

Plan), there is a need for an action plan focused on coastal areas and special attention to small cities with fewer resources and infrastructure, such as hard-to-reach communities.

OBJECTIVE

The objective of this work is to characterize and analyze the main actions and technologies of contingency and remediation based on the best practices acquired after the last oil spill in the country, which occurred on the Brazilian coast, in 2019.

METHODOLOGY

First, a systematic literature review was undertaken on oil accidents causing oil spills at sea. Then, from documentary research, primary and secondary data were obtained regarding the actions adopted and responses observed in the fight against the 2019 oil spill. Subsequently, the main Brazilian measures regarding the structuring of resources and emergency actions to combat oil accidents on the coast were analyzed, in order to observe possible forms of implementation when confronted with measures established in international protocols. It is also emphasized that this research is exploratory and descriptive, with a qualitative approach.

RESULTS AND DISCUSSION

According to internal data from the Brazilian Navy, responsible for the investigation, 5,379.76 tons of waste were collected – 30% of which was equivalent to oil. Table 1 shows the reported amount of waste collected by State in areas affected by the oil spill. The states of Alagoas (2,564.58 tons) and Pernambuco (1,676.26 tons) were the ones with the highest amount of waste collected.

Table 1 – Amount of waste collected by state after the oil spill on the Brazilian coast in 2019. Source: Prepared from IBAMA data (2022).

UF	Waste Collected by Petrobras (ton)	Waste Collected by Local Bodies (ton)	Total Amount Collected (ton)
Alagoas	16,09	2548,49	2564,58
Bahia	95,03	364,46	459,49
Ceará	0,00	39,76	39,76
Espírito Santo	0,00	6,26	6,26
Maranhão	0,01	13,68	13,69
Paraíba	0,00	0,85	0,85
Pernambuco	29,84	1646,42	1676,26
Piauí	0,00	10,46	10,46
Rio de Janeiro	0,00	0,00	0,00
Rio Grande do Norte	12,16	33,83	35,18

Revista ARACÊ
ISSN: 2358-2472

Sergipe	356,19	213,16	569,35
Offshore	1,00	2,88	3,88
TOTAL	**510,32**	**4.880,25**	**5.379,76**

Public data provided by IBAMA from the Access to Information Law (BRASIL, 2011b). Accessed in: 05/16/2022.

Figure 1, below, shows the large amount of oil spilled in 2019 on the Brazilian coast. It is noteworthy, in this context, that the waste was collected mostly by volunteer citizens and then reused energetically as an alternative fuel in cement plants, while another part was disposed of in landfills.

Figure 1. Oil spill on the Brazilian coast in 2019. Source: IBAMA, 2020a.

From external access to public data from IBAMA (Brazilian Institute of the Environment and Renewable Natural Resources), it is possible to verify that most of the oil collected on beaches on the Northeast coast was reused as an alternative fuel in cement kilns licensed for co-processing, as observed in Table 2, at the Votorantim Cimentos units in Laranjeiras (located in Sergipe) and Sobral (located in Ceará), Mizu Cimentos (located in Baraúna, RN), InterCement (located in Bahia) and Cement APODI (located in Ceará) for the purpose of generating energy in the respective industries.

Table 2 – Quantity and destination of oil collected on the beaches of the Brazilian Northeast after the 2019 environmental disaster. Source: Prepared from IBAMA data (2022).

UF	Estimated Oil Collected by Petrobras (ton)	Estimated Oil Collected by Local Agencies (ton)	Total Amount of Oil Collected (ton)	Temporary Storage	Transport	Destination

Revista ARACÊ
ISSN: 2358-2472

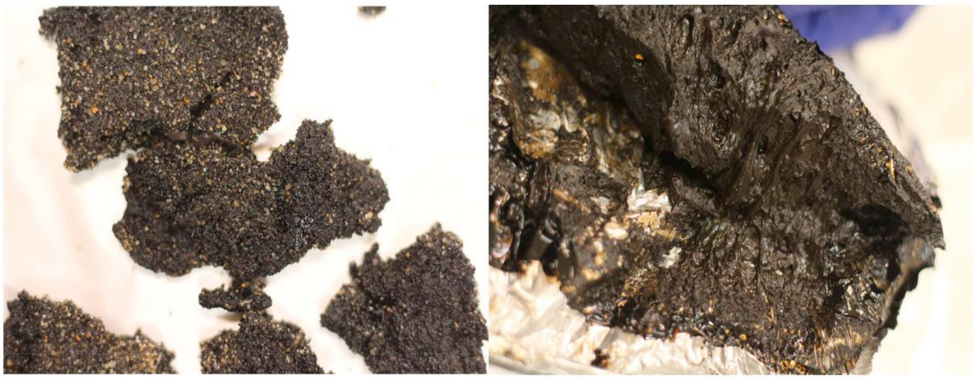
Alagoas	16,09	2.548,49	2.564,58	Petrobras Waste Management Center in Carmópolis (SE)	Petrobras	Votorantim Laranjeiras (SE) and Mizu Cimentos in Baraúna (RN)
Bahia	95,03	364,46	459,49	Petrobras Waste Management Center in Carmópolis (SE); CETREL (in Camaçari)	State	Cement company InterCement and CTR-Bahia
Ceará	0,00	39,76	39,76		State	APODI Cement Plant (CE)
Espiríto Santo	0,00	6,26	6,26	São Luiz da Barra, Linhares and São Mateus - ES	State	Class I Sanitary Landfill of the company Vitória Ambiental
Maranhao	0,01	13,68	13,69	IBAMA (MA), Tutóia, Port Captaincy in São Luiz and Parnaíba Waste Center (PI)	State and Petrobras	Class I Waste Management Center of Tiara and Votorantim Cimentos in Sobral (CE)
Paraiba	0,00	0,85	0,85	Cabedelo	State	Metropolitan Class I Sanitary Landfill of João Pessoa

Public data provided by IBAMA from the Access to Information Law (BRASIL, 2011b). Accessed in: 05/16/2022.

According to Lourenço *et al*. (2020), the oil collected from the Brazilian coast (Figure 2) presented a solid appearance, denser than seawater and visually similar to tar, whose chromatogram analyses indicated the pattern compatible with that of crude oil, while the chemical characterization suggested the presence of light hydrocarbons with high potential for long-term toxicity to the affected ecosystems, due to the possibility of gradual release of toxic compounds into the marine environment, with negative effects on coastal organisms and ecosystems after release into the water column, especially in case of inefficient cleaning.

Revista ARACÊ
ISSN: 2358-2472

Figure 2. Appearance of the oil collected after the oil spill off the Brazilian coast in 2019.



Source: LOURENÇO *et al*., 2020.

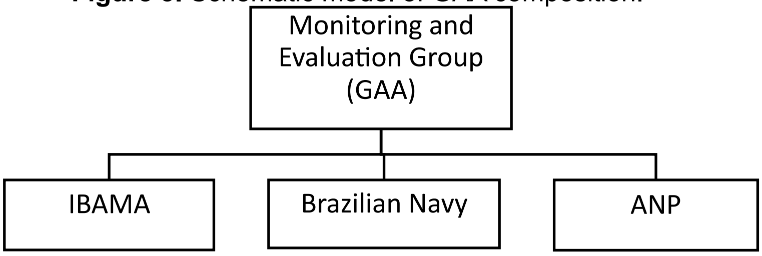
ACTIONS IN RESPONSE TO A SPILL

The Environmental Sensitivity Letters to Oil Spills, known as SAO Letters, are instruments of great importance for the elaboration of a contingency action plan and response to oil spills, as they identify the environments with the greatest need for protection and lead to the correct allocation of resources and mobilization of teams (BRASIL, 2004). According to Law No. 9,966 (BRASIL, 2000), known as the Oil Law and later updated in 2002 – which provides for the prevention, control and inspection of pollution caused by the discharge of oil and other harmful or dangerous substances into waters under national jurisdiction – the Ministry of the Environment (MMA) is responsible for identifying and delimiting ecologically sensitive areas.

In the case of the National Contingency Plan (PNC) for Oil Pollution Incidents in Waters under Jurisdiction, it was regulated by Decree No. 10,950 (BRASIL, 2022) and provides for additional measures under the responsibility of the government whenever the individual response capacity of an entrepreneur is exceeded in a scenario of high severity; establishing an organizational structure, guidelines, procedures, actions and assignment of responsibilities. According to Ibama (2024), the PNC also establishes the Monitoring and Evaluation Group (GAA), which is composed of representatives of the Brazilian Navy, Ibama (Brazilian Institute of the Environment and Resources) and the National Agency of Petroleum, Natural Gas and Biofuels (ANP), as shown in Figure 3, which explains that the activation of the PNC occurs only after all the resources of the Individual Emergency Plan (PEI) and the Area Plan (PA).

Revista ARACÊ
ISSN: 2358-2472

Figure 3. Schematic model of GAA composition.



Source: Prepared by the authors, 2024.

According to Ibama (2022), it is provided in the PNC that the Operational Coordinator of the response strategies to an accident is the responsibility of the respective public agency, obeying the following preference:

a) Brazilian Navy for incidents in maritime waters;
b) Ibama for incidents in inland waters;
c) ANP for incidents involving subsea oil drilling and/or production structures.

According to the National Secretariat for Urban Environment and Environmental Quality (SQA) and Petrobras, Ibama does not follow a specific official protocol for oil spills on the Brazilian coast caused by licensed entrepreneurs, and as a result, the emergency actions to be taken are described in the Individual Emergency Plan for oil pollution incidents in waters under national jurisdiction, regulated by CONAMA Resolution 398 (BRASIL, 2008), which must be submitted to Ibama by the offshore platforms.

In addition to the PEI, the Area Plan is used in regions of concentration of enterprises, which is regulated by Decree No. 4,871 (BRASIL, 2003) and provides for the fight against oil pollution in areas of concentration of organized ports, terminals, pipelines or platforms and their respective support facilities. Table 3 shows the Area Plans approved and under the coordination of Ibama, according to internal data updated in 2024, in which it is possible to verify that of the 26 Brazilian states, only 7 have area plans already approved.

Table 3. Area Plans approved in Brazil under the coordination of Ibama. Source: IBAMA internal data, 2024.

UF	Approved Area Plans
BA	Area Plan of the Port of Aratu and Region
ES	Espírito Santo Area Plan
MA	Area Plan of the Port Complex of Itaqui
MS	Area Plan of the Port of Corumbá/Ladário
SC	Babitonga Bay Area Plan

SP	Area Plan of the Port of Santos and Region
SP	Area Plan of the Organized Port of São Sebastião
AL	Maceió Port Area Plan

The low number of states with an Area Plan in operation shows the absence of actions to prevent oil spills in the country. Although extremely relevant, the National Contingency Plan, however, is used only in occurrences of greater proportions, that is, of national significance. Coastal cities/communities that are difficult to access by land are the most vulnerable, because in the event of an oil accident, the arrival of teams and equipment becomes more complex because it is not immediate and there is no contingency plan with specific emergency actions for more remote locations.

There are many challenges to be overcome since the lack of emergency plans located in areas of greater vulnerability and difficult access was verified. Thus, actions such as contact and training of the local population is essential, as well as the implementation of basic equipment and protection technologies, as well as the use of *drones* and helicopters, for example, since they allow a quick visual dimension about the proportions of an oil accident, in addition to being relatively easy to access from small to large cities.

The physical modeling of marine currents is a very important auxiliary tool in supporting decisions. Petrobras is known as the largest reference in the country in technological tools, such as orbital and airborne remote sensing, use of slick drift models and development of protocols for laboratory and ad-hoc field tests.

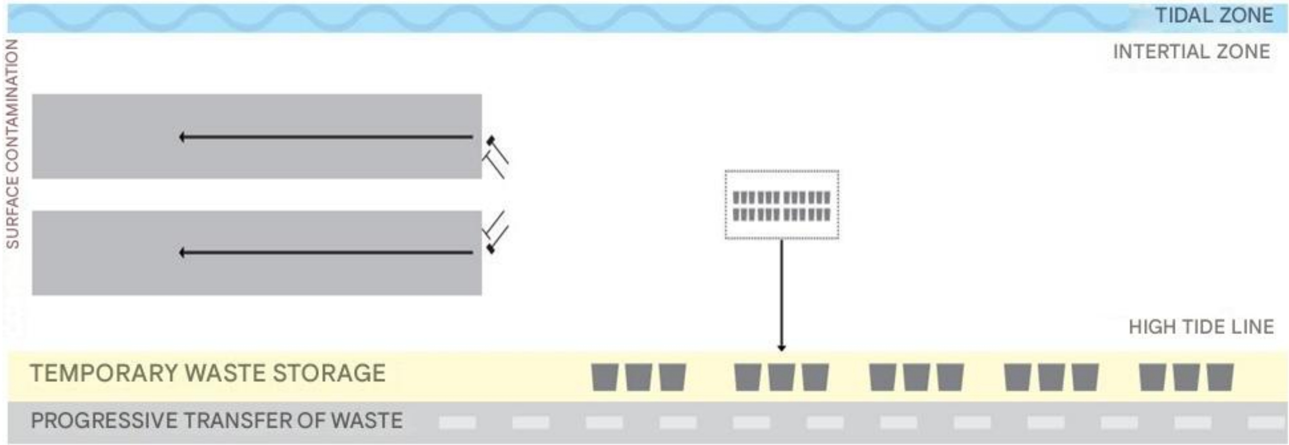
Then, after the aerial reconnaissance, the location detection is carried out with the aid of GPS and the dimensioning estimation, and then it is necessary to define the regions of highest priority and the evaluation of the thickness of the slick, in order to determine the amount of oil on the sea surface (FERREIRA, 2006). After detecting the areas affected by the oil, the *end points* are delimited , which demarcate the regions that will be demobilized and will have access to the population after the completion of the cleaning phase.

It should be noted that, due to the large amount of oil collected, oil accidents, in addition to environmental issues, also end up encompassing waste management, which, according to the recommendations of ITOPF and Ibama (2022a), when well carried out, avoids the generation of new waste and secondary contamination, in which the oil is collected on the coastline in order to minimize the removal of sand, it is later stored in

Revista ARACÊ
ISSN: 2358-2472

appropriate containers (such as *big bags*), which must be relocated to temporary/intermediate storage areas, as illustrated in Figure 4.

Figure 4. Technical guidance for temporary storage of waste. Source: ITOPF and IBAMA, 2022a.



The inspection and cleaning actions of environments affected by the oil spill, according to technical guidelines from ITOPF and Ibama (2022b), are divided into three phases according to each type of environment, namely:

- 1st Phase: Reactive cleaning action in newly affected locations;
- 2nd Phase: Systematization of the monitoring and cleaning inspection of beaches;
- 3rd Phase: Follow-up inspection and cleaning of residual oil.

In Brazil, there is still no continuous monitoring plan. For an effective repair of the damage caused by an oil spill, it is necessary to have monitoring, because, in many cases, only the compensation awarded by the judiciary is not enough to meet all the emergency needs of the affected environments, due to its complexity (SILVA, 2019).

OIL IDENTIFICATION

In terms of oil identification, the following aspects are of great importance for visual classification: oil evaluations on the coastline, delimitation of tidal zones and distribution of oil layers.

a) Oil Ratings in Linha de Costa

The mapping of coastlines allows a better understanding of the types of vegetation and species, and accessibility by land and sea, contributing to the planning of strategy and transit of people and equipment according to the characteristics of each environment.

Revista ARACÊ
ISSN: 2358-2472

Possible impacts on local habitats are assessed , considering nature's own resilience capacity, as well as environmental characteristics and access to regions. All these aspects, added to the properties of the oil and spill pattern, are important items in the identification of the most appropriate response actions to the observed accident scenario.

According to the Leopoldo Américo Miguez de Mello Research, Development and Innovation Center (Cenpes, 2006), oil assessments on the coast line were carried out for the first time in Brazil in 2000 by Petrobras with the objective of mapping the areas affected by an oil spill in that same year and are decisive in making decisions regarding response strategies. as it allows a better visualization as to the extent and severity of a spill. The Basic Manual for the Elaboration of Environmental Sensitivity Maps to Oil Spills (Petrobras, 2002), is known as an important guide reference regarding the oil characterization codes and delimitation of the areas affected by the spill, whose main types of coastline in Brazil are segmented according to the sensitivity index, ranging from 1 to 10, depending on the impacts and response action.

However, it is observed that the manual prepared by Petrobras on Maps of Environmental Sensitivity to Oil Spills is extremely technical and more directly focused on the classification of oil slicks and affected areas, not being didactic and simplified as to the emergency responses to be taken by the local community. In other words, there is no focus on society or environmental health.

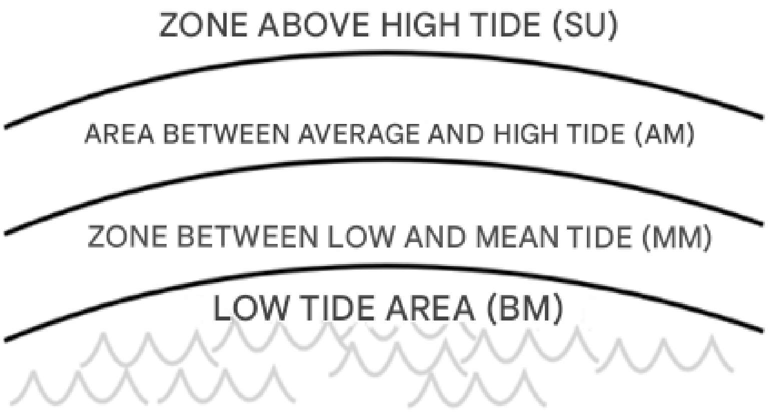
Thus, in the event of an oil spill accident, the populations of coastal regions will not be informed about how to proceed in case of rapid contingency actions, and the environment will be more vulnerable to toxicological effects.

b) Tidal Zones and Oil Layer

According to the Petrobras Manual prepared by Cenpes (2006), a standardization is proposed regarding the classification codes of tidal zones and oil layer (regarding distribution, thickness and characteristics), in order to enable a quick identification of the spill conditions and contribute to the choice of cleaning actions. The delimitation of the tide height, as shown in Figure 5, is important to identify the occurrence and location of oil on the coast.

Revista ARACÊ
ISSN: 2358-2472

Figure 5. Classification of tidal zones.



Source: CENPES, 2006.

Where:

BM: low tide zone;

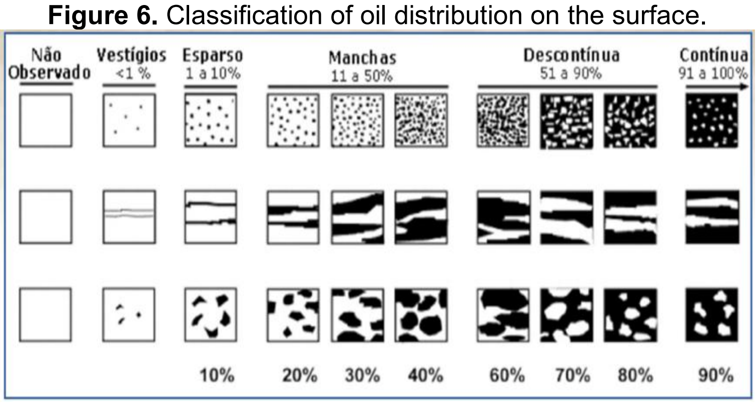
MM: zone at mean tide level;

AM: zone at high tide level;

SU: zone above high tide level.

The distribution of the Oil Layer (Figure 6) serves to estimate the quantitative percentage of oil on the surface from the establishment of a scale.

Figure 6. Classification of oil distribution on the surface.



Source: CENPES, 2006.

Where:

NO = not observed (no trace of oil);

V = traces of oil (<1%);

E = sparse oil (1% to 10%);

M = oil stains (11% to 50%);

D = discontinuous coverage (51% to 90%);

C = continuous coverage (91% to 100%).

Finally, layer classification codes are also called for thickness and characteristic parameters.

a) Oil Layer Thickness Codes:

EO = puddled oil (fresh oil or mousse with a thickness of more than 1cm);

GC = oil in a thick layer (oil or mousse greater than 1mm and less than 1cm on any surface);

CF = thin layer oil (<1mm, which can be removed with scraping);

MA = visible oil stain, but which cannot be removed with scraping;

FI = film (transparent glossy layer);

NO = no evidence of oil found.

b) Oil Layer Characteristics Codes:

FR = fresh and liquid oil; MS = mousse (emulsified oil covering large areas); PO = oil pellets (small accumulations of oil less than 10cm in diameter); PI = pitch (layer of highly weathered oil, of thick, almost solid consistency); RS = oil residues on the surface (non-cohesive oil residues on the surface of the sediment); PA = asphalt pavement (oil associated with the sediment, making it cohesive)

NO = no evidence of oil.

It should be noted that the subsurface characterization can be carried out from the drilling technique in order to identify the possible presence of oil in the sediment pores.

c) Oil Spill Response Strategies

The choice of the most appropriate techniques for dealing with an oil accident is made according to the evaluations of mapping, coastline and environmental characteristics, in addition to the classifications of tidal zones and oil layer.

According to Ferreira (2006), the most common strategies for responding to an oil spill are:

1. **Non-Response/ Monitoring of the Slick –** used when there is no displacement of the oil slick to the most sensitive environmental areas and in which the evolution and behavior of the plume (displacement, spreading and physical and chemical characteristics) is monitored;
2. **Containment and retraction –** a technique preferable in situations of favorable weather and oceanographic conditions, in which the largest possible amount of oil is removed, through containment (*booming*) and recollection (*skimming*);

3. **Mechanical Dispersion –** mechanical agitation from propellants or agitation device on vessels, or even the use of water cannons to stimulate the dispersion of oil through the pumping of seawater, in order to overcome the mechanical resistance caused by the viscosity of the oil and the chemical resistance generated by the interfacial tension of the oil-water mixture;
4. **Chemical Dispersion –** a technique used preferably when there is a risk to life or danger of fire to the vessel, which involves the application of chemical dispersant either by helicopter, ship and/or plane, in order to reduce the oil-water interfacial tension and stimulate the appearance of oil droplets. This strategy is considered controversial by environmentalists because it does not extinguish the spill;
5. **Non-Dispersant Chemical Responses –** application of alternative products (such as solidifiers and demulsifiers) with the objective of changing the physical or chemical characteristics of the oil;
6. **Controlled burning of oil at sea –** strategy of eliminating a large volume of oil on the surface, however, accompanied by some limitations due to the emissions of atmospheric pollutants and control of flame combustion; in addition to not being used in Brazil;
7. **Protection and Cleanup of Shorelines –** use of floating barriers and absorbent materials to protect sensitive areas (such as mangroves) from the oil slick;
8. **Bioremediation –** process of accelerating the natural biodegradation of oil into simpler components (such as CO2, water and biomass) from the application of nutrients or microbes through biostimulation and/or bioaugmentation. The technique, although useful, is slow and restricted in use, since it cannot be applied when the oil is on the surface of the ocean.

It should be noted that, on the recommendation of ITOPF, both mechanical and manual collection has been shown to be the most appropriate techniques for collecting oil. While the application of chemical dispersants, such as detergents (surfactants), has not been well accepted by environmentalists, due to the impacts of toxicity, since after the breakup of the oil slick, most of the dispersed hydrocarbons remain in the water column, increasing the exposure and absorption of polycyclic aromatic hydrocarbons (PAHs) by some species, such as fish and crustaceans (SAADOUN, 2015) and, for other more sensitive ones, such as corals.

Revista ARACÊ
ISSN: 2358-2472

WEATHERING AND EFFECTS OF OIL ON THE MARINE ENVIRONMENT

Weathering processes are one of the decision-making criteria for the evaluation and selection of response techniques and equipment to be allocated in the field. The dimensions of the impacts of an oil spill on the environment depend on several factors, such as climatic characteristics and the area affected, the degree of efficiency of the response methods applied, as well as the amount and type of oil, which can be: a) non-persistent when there is rapid dissipation from evaporation; and b) persistent when dissipation occurs more slowly and poses a potential threat to natural resources (ANDERSON, 2001), this in relation to the apparent permanence in the environment.

For a better understanding of the behavior of the oil in the environment, it is necessary to take into account, according to Ferreira (2006), the characterization of the type of oil (density, viscosity and pour point), the classification (paraffinic, naphthenic, light and heavy) and the tests (laboratory analyses, weathering tests and experimental spills).

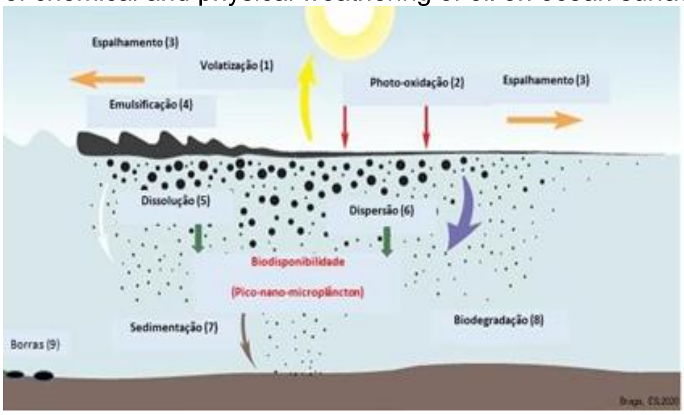
According to ITOPF (2014) and GESAMP (Group of Experts on the Scientific Aspects of Marine Environmental Protection), the weathering of an oil in the marine environment can suffer effects from the following processes:

a) Spreading – the spreading speed is related to the speed of the oil and the volume spilled, in which low-viscosity oils spread faster than high-viscosity ones;
b) Evaporation – the evaporation process depends on both the temperature and the wind speed of the place, in which the most volatile components of the oil evaporate into the atmosphere;
c) Dispersion – dispersion is influenced by the nature of the oil and the weather and ocean conditions (such as the presence of waves, currents and winds);
d) Emulsification – emulsions (water-in-oil) are formed when oils absorb water. More viscous oils tend to absorb water more slowly;
e) Dissolution – dissolution depends on the composition of the oil, spreading, water temperature, turbulence, and degree of dispersion;
f) Oxidation – sunlight promotes photo-oxidation of oil, in which hydrocarbons react with oxygen, leading to the formation of soluble products;
g) Sedimentation – dispersed oil droplets can interact with suspended solids in the water column, contributing to the sedimentation of oily particles;
h) Deposition – some oils have a specific gravity (density) higher than that of seawater and, consequently, end up suffering deposition.

Revista ARACÊ
ISSN: 2358-2472

Figure 7 shows an illustrative scheme of the main weathering processes after an oil spill in the ocean. According to Braga (2002), once in the marine environment, oil undergoes several processes that end up facilitating its integration into biological systems, whose pollution has disastrous impacts on most species of phytoplankton, benthic algae and zooplankton.

Figure 7. Illustration of chemical and physical weathering of oil on ocean surface and water column.



Source: Braga, ES (2020), adapted from ITOPF, 2008.

According to the United Nations Convention on the Law of the Sea (UN, 1982), "pollution of the marine environment" is the "introduction by man, directly or indirectly, of substances or energy into the marine environment... that has or may have deleterious effects, such as damage to living resources and marine life". Thus, marine pollution is that introduced by man, whose substances have concentrations above the natural level. Among the main characteristics of pollutants are persistence, toxicity and bioaccumulation (high concentration with harmful potential).

The bioaccumulation process can be found in marine species, such as fish, whose organisms have suffered physiological effects, since the greater the exposure to contamination, the greater the potential for bioaccumulation. In the case of pollution by oil and derivatives, the pollutants are persistent (slow degradation) and fat-soluble (dissolve in fats), whose effects of oil on the marine environment highlight species mortality, incorporation of hydrocarbons into the tissues of organisms, absorption of mutagenic and carcinogenic agents in the food chain. The heaviest compounds are, in general, the most toxic.

It should be noted that mangroves are extremely sensitive nurseries to exposure to oil, and therefore require emergency measures, since, in the event of an accident, they need to be immediately protected against the advance of the oil slick.

Oil pollution may not have visible effects in the short term, but it can cause long-term effects caused by bioaccumulation from the consumption of fish and/or other marine organisms contaminated by the introduction of persistent toxic substances that induce harm to individuals in the food chain (Braga, 2002). Thus, exposure to pollution poses serious risks of contamination to the health of the population, both through direct skin contact and indirect contact from the consumption of contaminated marine animals.

Local communities are the most affected in the event of an oil spill, as they depend directly on fishing and tourism, and after the loss of their main means of subsistence, many families end up suffering psychological shocks and illnesses caused as a result of contact with the oil. The populations of coastal regions need to be informed by the authorities about the rapid actions of contingency and recovery of the oil, as well as the protection of more fragile areas, so that they are not vulnerable to toxicological effects.

CONCLUSIONS

It was observed that, even with the instances and scalar aspects regarding emergency response strategies (such as the National Contingency Plan, Individual Emergency Plan and Area Plan), there is a need for an action plan focused on coastal areas and special attention to small cities and communities with fewer resources and infrastructure. Although extremely relevant, the PNC is only used in occurrences of greater national proportions, and in addition, Ibama still needs a specific official protocol for the defense of such vulnerable areas, being important socio-environmental contributions for improvement in actions.

It is also noteworthy that most of the manuals for dealing with spills are extremely technical and aimed at identifying and classifying oil slicks and affected areas, and are not prepared with didactic and simplified language regarding the emergency responses to be taken by the local community. Thus, there is a need for a greater focus, aimed at clarifying society, especially local communities, so that in the event of an accident due to an oil spill, the populations of coastal regions should be informed about how to proceed in case of rapid contingency actions.

ACKNOWLEDGMENT

The author Érica Machado da Silva Guerreiro thanks CAPES (Coordination for the Improvement of Higher Education Personnel) for the financial support through a Doctoral

Scholarship. The author André Felipe Simões thanks CNPq (National Council for Scientific and Technological Development) for the financial support via the PQ2 Productivity Grant.
To all who believe in science.

Revista ARACÊ
ISSN: 2358-2472

REFERENCES

1. Anderson, C. (2001). Persistent vs non-persistent oils: What you need to know. Beacon (Skuld Newsletter). The International Tanker Owners Pollution Federation Limited (ITOPF). https://www.itopf.org/fileadmin/uploads/itopf/data/Documents/Papers/persistent.pdf

2. Braga, E. S. (2002). Bioquímica marinha: Efeitos da poluição nos processos bioquímicos (2nd ed.). FUNDESPA.

3. Brasil. (2000). Lei nº 9.966, de 28 de abril de 2000. Dispõe sobre a prevenção, o controle e a fiscalização da poluição causada por lançamento de óleo e outras substâncias nocivas ou perigosas em águas sob jurisdição nacional e dá outras providências. Diário Oficial da União. https://www.planalto.gov.br/ccivil_03/leis/l9966.htm

4. Brasil. (2003). Decreto nº 4.871, de 06 de novembro de 2003. Dispõe sobre a instituição dos Planos de Áreas para o combate à poluição por óleo em águas sob jurisdição nacional e dá outras providências. Diário Oficial da União. https://www.planalto.gov.br/ccivil_03/decreto/2003/d4871.htm

5. Brasil. (2004). Atlas de sensibilidade ambiental ao óleo das bacias marítimas do Ceará e Potiguar. Ministério do Meio Ambiente.

6. Brasil. (2008). Resolução CONAMA nº 398, de 11 de junho de 2008. Dispõe sobre o conteúdo mínimo do Plano de Emergência Individual para incidentes de poluição por óleo em águas sob jurisdição nacional. Diário Oficial da União. http://www2.mma.gov.br/port/conama/res/res08/res39808.pdf

7. Brasil. (2022). Plano Nacional de Contingência para Incidentes de Poluição por Óleo em Águas sob Jurisdição Nacional. Diário Oficial da União. https://www.gov.br/ibama/pt-br/assuntos/fiscalizacao-e-protecao-ambiental/emergencias-ambientais/petroleo-e-derivados/pnc

8. Brum, H. D., Campos Silva, J. V., & Oliveira, E. G. (2020). Brazil oil spill response: Government inaction. Science, 367(6474), 155-156. https://doi.org/10.1126/science.aba0369

9. CENPES. (2006). Manual de avaliação de óleo em linha de costa. Centro de Pesquisa Leopoldo A. Miguez de Mello – CENPES/PETROBRAS. https://saopelotas.furg.br/images/stories/documentosdereferencia/manuais%20de%20avaliao%20petrobras.pdf

10. Convenção das Nações Unidas sobre o Direito do Mar. (1982). Organização das Nações Unidas. https://www.un.org/depts/los/convention_agreements/texts/unclos/part1.htm

Revista ARACÊ
ISSN: 2358-2472

11. Ferreira, J. P. (2006). Análise de estratégias de resposta a derramamento de óleo pesado no litoral do Espírito Santo utilizando modelagem computacional [Dissertação de mestrado, Universidade Federal do Espírito Santo].

12. IBAMA. (2020a). Cartilha informativa sobre a trajetória do acidente. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. https://www.ibama.gov.br/phocadownload/emergenciasambientais/2020/cartilha_v2.pdf

13. IBAMA. (2020b). Localidades afetadas. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. https://www.ibama.gov.br/phocadownload/emergenciasambientais/2020/2020-03-19_LOCALIDADES_AFETADAS.pdf

14. IBAMA. (2022). Plano Nacional de Contingência para Incidentes de Poluição por Óleo em Águas sob Jurisdição Nacional (PNC). Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. https://www.gov.br/ibama/pt-br/assuntos/fiscalizacao-e-protecao-ambiental/emergencias-ambientais/petroleo-e-derivados/pnc

15. IBAMA. (2024). Ibama assume coordenação de grupo que avalia incidentes de poluição por óleo. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. https://www.gov.br/ibama/pt-br/assuntos/noticias/2024/ibama-assume-coordenacao-de-grupo-que-avalia-incidentes-de-poluicao-por-oleo

16. ITOPF. (2007). ITOPF handbook 2007/2008. The International Tanker Owners Pollution Federation Limited.

17. ITOPF. (2014). Fate of marine oil spills (Technical Information Papers, No. 2). The International Tanker Owners Pollution Federation Limited. https://www.itopf.org/fileadmin/uploads/itopf/data/Documents/TIPS_TAPS_new/TIP_2_Fate_of_Marine_Oil_Spills.pdf

18. ITOPF. (2022). Statistics. The International Tanker Owners Pollution Federation Limited. https://www.itopf.org/knowledge-resources/data-statistics/statistics/

19. ITOPF, & IBAMA. (2022a). Manchas de óleo – Litoral do Nordeste. Orientações técnicas: Gestão de resíduos. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. https://www.gov.br/ibama/pt-br/assuntos/fiscalizacao-e-protecao-ambiental/emergencias-ambientais/manchasdeoleo/arquivos/2022/20221216_OT_gestao_residuos_oleo.pdf

20. ITOPF, & IBAMA. (2022b). Orientação técnica: Vistoria de acompanhamento e limpeza do litoral. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. https://www.gov.br/ibama/pt-br/assuntos/fiscalizacao-e-protecao-ambiental/emergencias-ambientais/manchasdeoleo/arquivos/2019/10.pdf

Revista ARACÊ
ISSN: 2358-2472

21. Lobão, M. M., Thomazelli, F. F., Batista, E. P. M. P., Oliveira, R. F., Souza, M. D. C., & Matos, N. A. V. (2022). Chronic oil spills revealed by the most important set of samples from the incident in northeastern Brazil, 2019. Anais da Academia Brasileira de Ciências, 94(4), Article e20210492. https://doi.org/10.1590/0001-3765202220210492

22. Lourenço, R. A., Combi, T., Alexandre, M. R., Sasaki, S. T., Zanardi-Lamardo, E., & Yogui, G. T. (2020). Mysterious oil spill along Brazil's northeast and southeast seaboard (2019-2020): Trying to find answers and filling data gaps. Marine Pollution Bulletin, 156, Article 111219. https://doi.org/10.1016/j.marpolbul.2020.111219

23. Pena, P. G. L., Northcross, A. L., Lima, M. A. G., & Rêgo, R. C. F. (2020). Derramamento de óleo bruto na costa brasileira em 2019: Emergência em saúde pública em questão. Cadernos de Saúde Pública, 36(2), Article e00231019. https://doi.org/10.1590/0102-311XER231019

24. Saadoun, I. M. K. (2015). Impact of oil spills on marine life. In Emerging pollutants in the environment: Current and further implications (pp. 1-20). IntechOpen. https://doi.org/10.5772/60455

25. Silva, A. C. C. F. A. (2019). Dano por derramamento de óleo no mar: Responsabilidade e reparação [Tese de doutorado, Universidade de São Paulo].

26. Soares, M. O., Teixeira, C. E. P., Bezerra, L. E. A., Paiva, S. V., Tavares, T. C. L., Garcia, T. M., & Carneiro, P. B. M. (2020). Oil spill in South Atlantic (Brazil): Environmental and governmental disaster. Marine Policy, 115, Article 103879. https://doi.org/10.1016/j.marpol.2020.103879

27. Souto, R. D. (2020). Estudo de caso: Governança ambiental participativa e justiça social: Uso do mapeamento participativo como ferramenta para análise do derrame de petróleo na costa brasileira em 2019-2020. In L. C. Gerhardinger & A. B. Guarda (Eds.), I Volume Horizonte Oceânico Brasileiro: Ampliando o horizonte da governança inclusiva para o desenvolvimento sustentável do oceano brasileiro (pp. 201-233). Instituto Costa Brasilis - Desenvolvimento Socioambiental.