

## Impacts and recovery techniques of degraded areas by petroleum spills - case study in southern Brazil

Impactos e técnicas de recuperação de áreas degradadas por derramamentos de petróleo - estudo de caso no sul do Brasil

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### ABSTRACT

Oil spills can threaten the environmental quality of coastal ecosystems. The environmental impact of accidents of this type is significant and it is important to understand them in order to assess the magnitude of such accidents. In this way, the present work aimed to discuss some of the main environmental impacts that can be caused by accidents of oil spill in marine and terrestrial environments, besides presenting a review of cleaning processes for the recovery of these degraded areas. In addition, this study aimed to elaborate a Program for the Recovery of Degraded Areas (PRAD) aiming a work plan for a case study: oil leakage in the coastal region of the municipality of Tramandaí (RS). Thus, a description of the study area was carried out aiming the correct elaboration of a work plan for the recovery of the area. The plan was based on preliminary assessment, containment and removal of oil in the aquatic environment, cleaning of the coastal environment, waste management, destination of the recovered area, along with schedule and budgets. The information presented in this paper serves as a support for the elaboration of recovery programs for areas degraded by oil accidents.

**Keywords:** Oil accident; Environmental pollution; Remediation. Protection

### RESUMO

Derramamentos de óleo podem ameaçar a qualidade ambiental dos ecossistemas costeiros. O impacto ambiental de acidentes desse tipo é significativo e é importante entendê-los para avaliar a magnitude desses acidentes. Dessa forma, o presente trabalho teve como objetivo discutir alguns dos principais impactos ambientais que podem ser causados por acidentes de derramamento de óleo em ambientes marinho e terrestre, além de apresentar uma revisão dos processos de limpeza para a recuperação dessas áreas degradadas. Além disso, este estudo teve como objetivo elaborar um Programa de Recuperação de Áreas Degradadas (PRAD), visando um plano de trabalho para um estudo de caso: vazamento de óleo na região costeira do município de Tramandaí (RS). Assim, foi realizada uma descrição da área de estudo visando a correta elaboração de um plano de trabalho para a recuperação

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da área. O plano baseou-se na avaliação preliminar, contenção e remoção de óleo no ambiente aquático, limpeza do ambiente costeiro, gerenciamento de resíduos, destino da área recuperada, juntamente com cronograma e orçamentos. As informações apresentadas neste artigo servem de apoio à elaboração de programas de recuperação de áreas degradadas por acidentes com petróleo.

**Palavras-chave:** Acidente de petróleo; Poluição ambiental; Remediação; Proteção

## 1 INTRODUCTION

Petroleum is an organic compound, formed by biogeochemical processes, consisting mostly of a complex mixture of hydrocarbons. The problem of contamination by oil and its derivatives is of great concern today, and in this way, several remediation techniques have been studied (WETLER-TONINI et al., 2010).

The oil has characteristics like oiliness, flammability, density lower than water and color variation between black and dark brown, and has a characteristic odor. Its composition presents variations directly related to the geographical location and the physical, chemical and biological conditions of origin (VAN HAMME et al., 2003).

The scenario of the oil exploration on the coast and the Brazilian continental shelf is in a moment of accelerated expansion, being the handling of equipment of extraction and transport of oil of offshore and coastal facilities causes a demand for instruments of planning, prevention and mitigating measures (SAO, 2015). Although statistics show a decline in the number of accidents involving oil spills at sea, they continue to occur, and most often threaten the environmental quality of coastal ecosystems such as beaches, rocky shores and mangroves, among others (LOPES et al., 2007).

The effects of an oil spill on coastal and marine environments are determined by the interaction of several factors, such as the chemical composition of the oil and spilled quantity, meteorological and oceanographic conditions, geographic location and dimensions of the affected area. The impact must also be assessed from different points of view, and the environment must be constantly monitored after contamination (BRASIL, 2001). These changes have important consequences for

ecosystems through their impact on soil and water quality, biodiversity and global climate systems (CHENG; LEI, 2001).

In this context, the present work aimed to carry out a survey and to discuss some of the main environmental impacts that can be caused by accidents in which oil spills occur in marine and terrestrial environments. In addition, it is aimed to make a review of cleaning processes to recover these degraded areas, serving as a subsidy for the elaboration of recovery programs for areas degraded by oil spills.

Then, through a case study, a situation of a real accident was used to propose a Program of Recovery of Degraded Areas (PRAD) with the aim of recovering the area affected by the incident. The case study chosen was the oil spill that occur in 2012 in the coastal region of the municipality of Tramandaí (RS), north coast of Rio Grande do Sul, Brazil.

## **2 MATERIAL AND METHODS**

### **2.1 Description of the study area**

Tramandaí municipality is located on the North Coast of the State of Rio Grande do Sul, Brazil, with a stretch of beach of 12 km and a total area of 143.57 km<sup>2</sup>. It is located in the longitude 50°07'50 "W and in the latitude 29°56'30" S and its altitude is of 1.80 m. The regional climate is controlled by tropical air masses. The temperature ranges from 22-35°C in the summer season and between 3-18°C in winter.

The Tramandaí River establishes a communication between the lagoon and the sea. The lagoons of Armazém and Tramandaí form the estuary of Tramandaí. The Tramandaí Lagoon has sandy beaches (to the south), flooded areas (eastern margin) and restinga vegetation (to the southwest).

The topography is plain with dunes near the sea shore, saltwater lagoons, fresh or brackish, with streams and channels and high water table (TRAMANDAÍ, 2015).

### **2.2 Environmental Impacts and Remediation Techniques**

A literature search was carried out in order to raise some of the main impacts caused by episodes of oil spill, considering the importance and magnitude of accidents of this type. In addition, it was presented some cleaning techniques for affected environments, both terrestrial and aquatic.

## 2.3 Case Study

The methodology of the study case was based on the characterization of the problem and preparation of a work plan proposal for a Degraded Areas Recovery Program. The following steps were taken (Table 1):

Table 1 – Aspects to be included in the work plan proposal

	<b>Description</b>
Preliminary assessment	Based on the identification of the source of degradation; description of the accident; description of the type and characteristics of the spilled product; public agencies activated or present on site; Identification of the informant as well as the resources needed for the recovery of the area.
Containment and removal in the aquatic environment	Presenting the most appropriate methods for containment and removal, as well as the resources required to carry out this step.
Clean coastal environments	Description of the methodology proposed to solve the problem; manual or automatic cleaning.
Waste management	Description of classification, packaging, sorting, segregation, identification and weighing, storage, transportation and final destination.
Treatment and disposal of waste	Describe the most suitable technique for the study case.
Final destination of the reclaimed area	Describe the better alternative for the area use.
Timetable and budgets	Time and economic efficient alternatives.

Source: authors

## 3 RESULTS AND DISCUSSION

### 3.1 Environmental impacts

#### 3.1.1 Biological

The impacts of an oil spill on the marine environment will depend of a variety of parameters, such as the oil type, the volume that was spilled, the ecosystem that was reached and also the environmental conditions that were in place at the moment of the spill, such as wind speed and direction, currents and tides. Therefore, it can be

state that each spill will produce a different type of impact depending on those circumstances (LEE et al., 2015).

Considering the considerable quantity of leaked oil, the impacts on water quality and in the aquatic ecosystem are of great magnitude (LEE et al., 2015). Toxic and physical effects provoked by the oil spill on the biota, and its resistance to them, may vary and depends mostly of the involved species and which way they were reached (LOUVADO et al., 2019). The firsts and direct effects of the oil spill emerge from the contact of the organisms with the oil, varying with the type of organism. Given these points, for the fauna, the oil will act on its epithelial surface, inhibiting the respiratory processes which can induce suffocation. Moreover, suspended oil is highly toxic to larvae and fish eggs (DALY et al., 2016).

Usually, younger species are susceptible to impacts than adult forms; therefore, these more sensitive species may be exterminated (DALY et al., 2016). Even if not killed immediately by the spill, the long-term toxicity affects marine life, making it unsuitable for human consumption. Oil can interfere with vital reproduction processes even at low concentrations. Changing the reproductive cycle affects the whole food chain, consequently causing irreparable damage to the ecosystem (DALY et al., 2016). In seabirds, even small oil stains create several problems, such as loss of waterproofing of the plumage area, damaging its thermal insulation and buoyancy (TROISI et al., 2016).

### 3.1.2 Socioeconomic

An oil spill can have significant consequences for the socio-economic activities carried out in the region in which they occur, among which tourism can be highlighted. The spilled oil may have negative consequences for tourism and trade in the region hit by the incident. Newspaper articles and images about water contamination can be widely publicized in the media. Thus, the accident, as well as oil combat and cleaning operations, impacts directly in the tourism. Another important negative impact is the loss of many different jobs in the area, along with payment and

compensation issues, affecting directly the local community, as reported by Albert, Amaratunga and Haigh, (2018).

### 3.2 Cleaning techniques

There are a significant number of techniques to clean an environment affected by an oil spill. In one way, some methods are efficient in removing the oil from the environment, restoring the affected areas and, in this way, satisfying the socioeconomic demands. However, in some cases these methods may be more harmful than the oil action itself (LOPES et al., 2007). A cleaning procedure is considered efficient when it allows the removal of the contaminant with the least possible additional effects to the affected ecosystem, as well as cooperates to the recovery of the environment as fast as it is possible. Cleaning techniques should be evaluated on a case-by-case basis, since each oil spill has particular characteristics and demands to consider. Zhang et al. (2019) stated that several methods are being investigated in order to remediate areas affected by oil spills, including chemical methods for oil-water separation, in situ burning and mechanical recovery.

One of the first ecosystems that is directly affected by the oil spills in the sea is the coastal, requiring actions to minimize the effects caused by the contamination. The determination of the cleaning techniques that best apply to the given environment must be defined before the accident occurs (LOPES et al., 2007). Another important aspect to consider is the concept of "sacrifice zones" and "priority areas of protection" (LOPES et al., 2007). It is important to identify areas of protection and immediate intervention immediately after the accident, in order to avoid the arrival of oil in more sensitive environments. The priority is the containment and the removal in sea that prevents the coast of the contamination and necessity of cleaning.

To provide an efficient response to oil containment and removal actions it is requested: (i) fastness activation of the teams and triggering the necessary actions; (ii) availability of equipment and resources that are appropriate in quantity and type to be able attend the particularity of the accidental scenario; and (iii) the availability of trained staff (MILANELLI, 1994).

### 3.2.1 Cleaning of aquatic environments

Crude oil, and its various by-products, have a high potential for environmental contamination. Physical and chemical characteristics of the oil determine its behaviour in the environment and its effects on the health and safety of the environment, as well as of human and fauna and flora (DALY et al., 2016).

The understanding of these characteristics is important to the decision-making during emergencies, such as accidents. This knowledge is essential when choosing the procedures and equipment that are compatible with the type of oil spilled and have to be used in an accident.

Characteristics that should be observed are related to the density, persistence, viscosity, solubility and surface tension of the oil (LOPES et al., 2007). The solubility of petroleum in water is classified as extremely low, since only a small part of the soluble hydrocarbons and the various mineral salts present in the oil dissolve in the aquatic environment (POFFO 2000). Another important characteristic is the density of the oil, to determine it, is adopted the API (American Petroleum Institute) grade unit. It is the density that will determine if an oil tends to sink or float in the water column after a leak (IBAMA, 2012).

Some processes may occur with the contact from the oil and the sea water, some of them are (LOPES et al., 2007):

**Natural dispersion:** starts in the first hour from the accident, and occurs more intensely in the next 48 hours and can last up to one month. Consists in the fragmentation of the oil slick into droplets, mainly due to the agitation of the sea, wind and waves. It can be chemically accelerated by the application of dispersants, or by mechanical action;

**Spread:** is more intense within the first 24 hours and lasts for more than a week. The oil spill spreads horizontally from the source of the leak on the surface of the water. It can be influenced by the action of winds, tides, waves and currents, the volume and type of oil leaked and the responsiveness also influence this process, moving to distant areas of origin, reaching sensitive areas;

Dissolution: more intense in the first hour and can last up to 24 hours. Aromatic hydrocarbons and other compounds of the oil can dissolve by the action of waves and currents and pass to the water column;

Emulsification: occurs most intensely within the first ten hours after the spill and the first seven days, and can last for up to one year. Consists of the water molecules incorporating hydrocarbon molecules forming a water-oil emulsion;

Evaporation: considering the oil stain on the surface, the aromatic compounds of the hydrocarbons (the most toxic) pass into the atmosphere under direct interference with the ambient temperature and solar radiation;

Oxidation or photo-oxidation: process that starts in the first hour and can last up to a month. The incidence of ultraviolet light on the oil stain increases the presence of oxygen in its components. The compounds formed in this reaction become more toxic and soluble in water and move from the surface to the water column;

Sedimentation: a process that occurs most intensely from 24 hours to a month after the leak and can last for several years. Heavier components of the oil that do not dissolve in the water adhere to small inorganic particles and floating solids (debris, branches and debris) and sediment to the bottom of the ocean.

Cleaning methods for the water can be: (i) The removal of oil from the surface of the water using specific materials and/or equipment such as containment barriers, skimmers, absorbents, among others; or (ii) the transfer of the oil stains to the water column by the chemical dispersion of the product (LOPES et al., 2007). In addition, naturally occurring weathering processes can be understood as factors that help the removal of oil from the marine environment. Some of these methods are described below:

Natural cleaning: efficient in oceanic waters due to the fact that the oil is exposed to natural degradation processes (dispersion, dissolution, evaporation, biodegradation and photooxidation). It is not indicated to be applied in sheltered coastal waters and shallow non-intervention, since the risk of the oil reaching coastal

areas such as beaches, shores and mangroves are high, and the impact would be significantly higher;

**Barriers and collectors (containment and removal):** This equipment is responsible for containing the oil stain, in order not to allow the stain to disperse and accumulate the oil in a certain region to facilitate the work of the collector. There are several types and models of barriers and skimmer, which must be suitable for each type of scenario. This approach is characterized as a passive method for restrain the spread of oil, as reported by Bhardwaj and Bhaskarwar (2018).

**Absorbent barriers:** useful in the containment and especially in the collection of fainter spots (silver or iridescent) located in channels, bays and coves where conventional barriers would be inefficient. It is also possible to arrange in a combined manner the absorbent barriers coupled to containment barriers, ensuring the confinement and absorption of the stains;

**Pompons:** are absorbent formed of polypropylene fibers, which have a high rate of absorption (twenty to sixty times their own weight). They can be connected to cables, acquiring a linear conformation, or being used individually.

**Chemical dispersants:** chemical formulations of organic nature intended to reduce the surface tension between oil and water, contributing to the oil dispersion into droplets that are suspended in the aqueous medium. Consequently, the process of biodegradation promoted by organisms naturally present in water is favoured. They accelerate the process of dispersion and natural degradation of the oil, since the stains are broken in small particles with greater relation area/ volume, in a water column of several meters of depth, being able to be more easily degraded by microorganisms. The application of chemical dispersants is conditioned to the consent of the competent environmental agency and must comply with the Brazilian CONAMA Resolution No. 269 of September 14th, 2000.

**Granular absorbents:** useful for collecting less significant amounts. May cause additional damages when used in large quantities in restricted environments and are not collected after the remediation, especially if they are synthetic in nature (low rate

of degradability). It is preferable to use natural organic products such as peat, which have high efficiency and are biodegradable. In the literature, the absorbents are mentioned to exist in many forms and it is highly recommended the use of specific devices to enclose the product and avoid the dispersion, as reported by Bhardwaj and Bhaskarwar (2018).

#### Cleaning of terrestrial environments

When an oil spill occurs at sea, its consequences do occur only on the aquatic surface, petrochemical residues are often transported by the tides to the beaches, which can be classified basically by two types: thin sand and coarser sand, according to their characteristics.

Beaches of coarse sand usually have larger slopes, berm presence and flat supralittoral terrace, usually have a relatively heterogeneous and unstable profile. The granulometry often differs along the beach profile, with thinner sediments in the forefoot. The granulometric characteristics can also vary throughout the year, as a reflection of the dynamics of the constructive/destructive cycle. At these beaches the degree of sediment compaction is very low, making it unstable and preventing the development of a rich biological community, especially under conditions of intense hydrodynamism (waves). Intertidal zone colonized mainly by crustaceans and molluscs. In this type of sand oil penetration can exceed 25 cm deep in the sediment, making the residence time higher. The degree of penetration also depends on the characteristics of the oil. The loose sediment of these beaches makes it difficult to operationally clean and remove the oil.

Regarding the fine sand beaches, the sediment is more stable and compact, with smaller interstitial space and greater capacity of accumulation of organic matter associated to finer particles. In these environments, the biota is considerably rich, complex, and sensitive to oil, represented by both the epifauna and the infauna/endofauna. Most of the biota is concentrated in the surface layer of the sediment. One route of oil penetration into the sediment is tubes and galleries created by organisms such as molluscs, crustaceans and polychaetes.

The methods for beach cleaning available are: absorption, manual removal, vacuum pumping, mechanical removal, induced biodegradation, chemical dispersion, burning, natural cleaning and blasting. Considering the work of Gundlach e Hayes (1978) and NOAA (2000) cleaning should focus on manually removing oil from the middle and supralittoral; in this way, the amount of sand removed is smaller, and should be minimal on sandy beaches. Low pressure blasting can be used to direct and accumulate oil to be collected by skimmers and absorbents.

High pressure sandblasting should be avoided as it can transport contaminated material to other locations, cause mechanical impact on wildlife, dislodge fauna and remove sediment (CETESB, 2015). Natural cleaning is plausible for exposed beaches where the action of the waves is enough to remove the oil (IPIECA, 2004). It is also recommended for sheltered beaches where other procedures may cause additional damage to the environment. When natural cleaning is not appropriate (for example, area with poor hydrodynamics, biota or major socioeconomic resources under threat), other options may be considered: low pressure blasting for firm sediments with low slope; manual and mechanical removal; absorbents; vacuum pumping; bioremediation.

Other methods for treatment of contaminated sand are: sand washing; coprocessing; and landfill processes. The sand washing can have its efficiency improved significantly, through the use of surfactants, used to break the surface tension of the oil, making it to be in solution in the colloidal form. This technique can be applied either on site (in situ) or in reactors. In situ form is less used because it introduces another contaminant in the environment, and also has difficulties in establishing safe operating conditions.

Applying this technique in reactors to clean the sand removed from the contaminated beaches has presented satisfactory results in tests performed in the attendance to some occurrences. In these tests, the residue was mixed with a solution containing 0.5% surfactant and then stirred. One type of reactor can be a concrete mixer, for instance. The technique minimizes pollution and, in some cases, has

achieved more than 90% oil removal. It also has the bonus of allowing the control of the full process. Nonetheless, has the disadvantage of generating an effluent that will require additional treatment, preferably in specially designed treatment plants (CETESB, 2015).

The coprocessing method is the use of a waste from an industrial process in order to substitute one of the raw materials of the process or to allow the reduction of the fuel consumption of the process through the energetic use of the waste. This technique is applicable to oily substances, sand or earth contaminated with oil, chemical packages, resins, rubber, photographic products among other types of waste that can be used as auxiliary fuel, having compatible thermal input to be used as alternative fuel. Metal packaging, household waste, glass, batteries and radioactive material cannot be coprocessed (CETESB, 2015). It is highlighted the great importance of recovering these areas since sand beaches serves as habitat for primary and secondary producers, along with widely diversified fauna (BEJARANO; MICHEL, 2016).

### **3.3 Case study**

#### 3.3.1 Characterization

The spill incident of the Marlim Sul type oil occurred in the monoboia MN-602, located in the coastal region of the municipality of Tramandaí (RS). According to the initial statement by Transpetro (responsible company), the incident occurred during the unloading operation of the ship "ELKA ARISTOTELE" for the MN-602, where there was a rupture of the safety valve called "breakway coupling", installed in MN-602 floating hoses, causing oil spills into the sea (IBAMA, 2012).

The distance from the MN-602 to the beach is 6 km, and the oil spill reached the beach area that is located between the Tramandaí Platform and the Barra de Imbé, forming an oil spot of 1 km<sup>2</sup>, equivalent to approximately 100 football fields.

The coastal region close to the accident is formed by intermediate sandy beaches and can be classified as a region of environmental sensitivity equal to four (ISL4), with medium permeability substrates, moderate penetration/burial of oil,

according to the specifications and Technical Standards of Environmental Sensitivity for Oil Spills (BRASIL, 2002).

### 3.3.2 Work plan

Considering the incident in Tramandaí in 2012 and the characterization of the area, the proposed actions plan for the recovery of the degraded area in the different environments (aquatic and terrestrial) is described in Table 2.

Table 2 – Work plan for the case study

<b>Work plan for the case study</b>	
<b>Preliminary assessment</b>	
Communication of the occurrence	Communicate to the authorities: the Port Authority of Tramandaí Agency (AGTRAMANDAÍ), the National Agency of Petroleum, Natural Gas and Biofuel (ANP), the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) and State Foundation for Environmental Protection Henrique Luiz Roessler - RS (FEPAM), of the incident.
Identification of the leakage source	MN-602, located in the coastal region of the municipality of Tramandaí (RS).
Date and time of occurrence	January 26th, 2012 around 12 a.m.
Type and characteristics of the leaked product	Type Marlin Sul, with oil 23.1 ° API. Spilled volume: about 1.2 million liters of oil in the sea.
Identification of the informant	Transpetro Company
Necessary resources	For the effective evaluation, it is indispensable to use topographic and nautical charts and tide tables that will serve to guide the aerial, maritime and terrestrial surveys in the areas under the influence of the leak.
<b>Containment and removal in aquatic environment</b>	
Oil containment	Use of containment barriers that concentrate the oil for later collection (Fig. 1).
Oil removal	Use of skimmers. In the case under study the skimmers were coupled to monoboia to collect the oil.
Required resources	Human resources trained to carry out containment and removal operations, equipment and materials for containment, removal and storage, personal protective equipment.
<b>Cleaning of coastal environments</b>	
Manual removal	Manually removing the oil from the environment with utensils such as cans, buckets, etc. (Fig 2).
<b>Waste Management</b>	
Classification	For waste disposal, it is necessary to characterize and classify it, and for this purpose, samples must be collected for analysis.
Packaging	The most used materials are plastic bags (Fig. 3).

Screening	The process of sorting the waste at the workplace (beach).
Segregation	Among the residues are: contaminated solid waste brought by the tide consisting of household waste, vegetation and dead animals among other materials; sand slightly contaminated by oil; sand heavily contaminated by oil; absorbent and adsorbent products impregnated with oil; rags and cloths used in cleaning.
Identification and weighing	Use of pre-prepared standardized labels containing the following data: date, name of the company responsible, name of the emergency operation, origin: name of the beach or location from which the waste was removed and municipality (optional), type of residue and estimated weight.
Storage	The company must have an oily waste management plan that includes the destination, ensuring the storage period does not exceed 90 days and that conditions of environmental protection and industrial safety are guaranteed for it.
Transport	For the transportation of oily wastes in Brazil, it is necessary to observe the ABNT Standard NBR 13.221 and for those classified as hazardous, observing the Federal Decree no. 96,044 of May 5, 1988, the CONAMA Resolution no. 001-A of January 23, 1986 and Federal Decree no. 204 of 5/20/1997. Using a truck for transportation.
Final destination	Use of the landfarming process.

Source: authors

Figure 1 - Containment barriers. CLICRBS (2012)



Source: authors

Figure 2 - Manual removal of oil from sand. CLICRBS (2012)



Source: authors

Figure 3 - Bags used for packaging. CLICRBS (2012)



Source: authors

Regarding the *treatment and disposal of waste*, the landfarming was the selected treatment, which is a technique where the oily residue is incorporated into the soil under controlled conditions to promote the degradation and immobilization of the hazardous contaminants present. Typically, the residue is applied to the surface of an area and mixed with the soil by conventional equipment, such as tractors equipped with plows or crates. For the design and operation of this of treatment, it is necessary to observe the established in the regulatory standard of each country, which in Brazil is the norm ABNT NBR 13.894 - Treatment in the soil (landfarming). This technique is suitable for disposing of non-recoverable oil as impregnated absorbent materials (straw, sawdust and peat), and water-in-oil emulsions.

Regarding the *monitoring* the effects of an oil spill on coastal and marine environments are determined by the interaction of several factors, such as: chemical composition of the oil and spilled quantity, meteorological and oceanographic conditions, geographic location and dimensions of the affected area. The impact must also be assessed from different points of view, and the environment must be constantly monitored after contamination (BRASIL, 2001). These changes have important consequences for ecosystems through their impact on soil and water quality, biodiversity and global climate systems (CHENG; LEI, 2001). When incidents such as the one in Tramandai occur, it is essential to carry out frequent surveys by air, sea and land in order to guide the actions to combat an oil spill.

The recovery actions of the degraded area aim to return, through economically viable techniques, the environment closer to the original and, if it is not possible, to

<b>Time</b>	<b>Land operations</b>	<b>Sea operations</b>
6 h	Rental of trucks	Preparation of vessels
7 h	Prepare of the extra workers	Prepare of the extra workers
8 h	Removal of sand	Addition of containment barriers
12 h	Removal of sand	Addition of containment

return to the closest conditions to those existing prior to the oil spill. Thus, in relation to the sea, considering

that it is a water resource, the purpose of the recovery is to preserve it, in order to protect the entire marine ecosystem and consequently to preserve all the species and habitats it depends on. The ultimate goal is to return the area to its original uses of fishing, tourism and leisure.

In order to prepare the schedule (Table 3), it was assumed that the company in charge had an emergency plan for incidents of oil leakage, as required by the legislation. It was considered hypothetically that the leak occurred on Tramandaí beach on January 26, 2012; and that this was found at 05:00 and controlled in a period of 12 hours.

Table 3 - Schedule of activities

		barriers
14 h	Removal of sand	Removal of oil
17 h	Removal of sand	Removal of oil
18 h	Finalization of work	Finalization of work

Source: authors

To mitigate the impact caused by the oil spill, 280 men were needed, divided into two groups: 20 to act in the offshore leakage and 260 to act on land in the collection of contaminated sand and corpses of animals affected by the disaster. Each worker received a value of \$ 40.00 for the work, totalling \$ 11,050.00 for labour. It can be highlighted that these workers were outsourced and the methods adopted were the most efficient, fast and lowest cost.

Table 4 shows some additional expenses with individual protection equipment. These products may change due to quantity purchased and negotiation with suppliers. The expenses with the treatment of the material collected with the use of landfarming must also be considered, according to Jerônimo and Kitzinger (2014) the cost is approximately of \$ 37.00 per cubic meter. In addition, the costs of containment barriers and the vessel used to remove the oil from the water should also be considered.

Table 4 - Budget of the material used to clean the beach

<b>Product</b>	<b>Value (\$)</b>	<b>Quantity</b>	<b>Total (\$)</b>
Safety boots	6.31	290	1830.72
Gloves	7.31	300	2194.50
Shovels	3.93	200	762.80
Truck rental	526.07	08	4208.56
		<b>Total</b>	<b>8996.59</b>

Source: authors

## CONCLUSION

The present work is important for understanding the dynamics of petroleum in the environment, given its highly toxic and polluting character. Understanding the main impacts of an oil accident is an important tool to first seek to avoid accidents of this type and, if they occur, to know the priority of recovery actions. In addition, a review of the main oil cleaning processes was presented, both in the aquatic and terrestrial environments. The information presented in this paper serves as a subsidy for the elaboration of recovery programs for areas degraded by oil accidents.

The work carried out showed the importance of the application of the proposed Degraded Area Recovery Plan, aiming to minimize the impacts caused by the incident in Tramandaí (RS), with possible application in other locations. The elaborated PRAD aimed the environmental recovery of the degraded area, so that the biotic and abiotic resources are sufficient to continue its development without additional subsidies and the place could return to its previous conditions.

This study serves as a basis for future studies and application in locations affected by oil contamination, and modifications or adaptations of the proposed plan are necessary to better adapt to the recovery interests of the area in question.

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