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IMPACT OF THE OIL SPILL, CONTINGENCY STRATEGIES AND REMEDIATION IN THE PERUVIAN SEA

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ABSTRACT: The absorption of the xenobiotic (oil/crude oil) occurs through ingestion, inhalation and skin absorption, and the toxicological effects become acute and even chronic, thus generating problems in the organisms of living beings exposed for a certain time and concentration to a spill. which cannot be controlled due to inefficiency in its contingency, therefore the objective of this article is to determine the effects and develop an action plan for the impacts generated by oil spills from ships on marine ecosystems and surrounding populations. By searching for articles in reliable databases through keywords and using the PRISMA method, results were obtained regarding mitigation measures in the countries of Spain, Honduras, Panama, Mexico and Peru, which show response methods. that involve a series of procedures and coordination between different levels of authorities to effectively manage spills and minimize their environmental and socioeconomic effects. Comparing these national plans, the conclusion is reached that a series of steps must be included in every contingency plan so that it is developed more efficiently, these range from preparation and prevention to immediate response and post-incident evaluation, considering into account ISO 14001: 2015.

Keywords: *Oil spill, coastal marine ecosystem, contingency plan, health impact, remediation.*

INTRODUCTION

Petroleum is a natural oil formed by a homogeneous and heterogeneous mixture of hydrocarbons, which originate from fossilized organic remains accumulated over billions of years beneath bodies of water and continental spaces subjected to chemical processes, and pressure and temperature conditions. These are deposited in geological formations, consisting of porous and permeable underground rocks that make up the oil reservoirs. Often, petroleum is also associated with natural gas reserves.

There are various types of petroleum, distinguished by their density, viscosity, color, and calorific capacity, which are suitable to produce multiple derivatives. In the utilization of this resource, the oil industry undertakes several steps: exploration, exploitation, refining, transportation, storage, and support services for petroleum [1]. When crude oil or its refined products are accidentally released into the environment, they lead to spills, particularly in bodies of water, resulting in severe ecological and economic consequences. These spills can occur in several ways, with common causes including tanker accidents, structural failures, explosions and fires, and defects in valves and pipelines.

When such a spill occurs, numerous and varied processes begin to take place that mitigate the impact on the environment. Some factors and phenomena have a greater influence than others, but likely the most critical, especially those related to the hydrocarbon itself, is the type of product spilled. This aspect largely determines the toxicity level of the hydrocarbon.
Exposure to hydrocarbons occurs through ingestion, absorption through intact skin, and inhalation of its vapours. The toxicological risks are severe, both acute and chronic, with particular concern for the toxic fractions of petroleum that can lead to death from poisoning, especially those associated with Polycyclic Aromatic Hydrocarbons (PAHs) [2].
In the case of oil spills, the negative health effects can be observed not only from the petroleum products themselves but also from the measures used for mitigation, such as the use of dispersants or the practice of in-situ burning of oil to limit its spread [3]. The general objective of the research is to analyse the literature on existing

contingency plans, compare them, and provide recommendations on aspects to consider for improving the contingency plan for bodies of water in Peru in response to impacts on marine ecosystems and nearby populations. The specific objectives were to identify the sources of pollution and their characteristics, determine the effects on the population and marine ecosystems, and formulate an action plan for future spills. The research question was: What are the main elements and recommendations derived from the comparative analysis of the existing literature on contingency plans in bodies of water, and how can these elements be applied to improve contingency plans in bodies of water in Peru?.

THEORETICAL FRAMEWORK

A xenobiotic is a substance foreign to an organism, usually synthetic or not naturally produced, which can have toxic effects [4]. Petroleum is considered a xenobiotic due to its chemical characteristics and the impact it generates on living organisms and the environment [5]. It does not degrade easily and can remain in soil and water for extended periods, accumulating and causing long-term or immediate toxic effects.

XB.	ORIGIN	APPLICATION	INTRINSIC ACTION	NATURE	METABOLIC REACTIVITY	BIOLOGICAL ACTION
Petroleum	Geological beds	Industry	Local Toxic Action	Organic chemistry	Persistent, bioaccumulative and biomagnifying	Carcinogenic and biosidic

Table 1. Characteristics of the xenobiotic (Cambria 10 pt) – align left.

Xenobiotic Pathway. The pathway of a xenobiotic such as crude oil in a marine ecosystem involves a series of processes that determine its fate and impacts on the environment. These processes include dispersion, biodegradation, bioaccumulation, and other mechanisms of chemical and physical transformation [6]. Each of these processes is detailed as follows:

Exposure. This can occur naturally through seepage or through human-originated events, such as explosions at drilling wells and oil spills [6]. In the initial hours of an oil spill, volatile compounds are released into the air, affecting atmospheric quality. Emulsification, which increases the water content in the oil to up to 90%, exacerbates marine pollution [7].

Absorption. Petroleum components can be absorbed by marine organisms through their gills, water intake, and contaminated phytoplankton [5]. In humans, following an oil spill, they may be affected by contaminated seafood and inhalation of toxic vapors [8], as well as by contact with the xenobiotic on the skin.

Distribution. Upon entering the human body, petroleum components move into the bloodstream and are widely distributed throughout the body, often lodging in and remaining in organs such as the liver, kidneys, and lungs due to exposure to toxic vapors, the spleen, and even reaching the fetal bloodstream in pregnant women [4].

Metabolism. Once inside the organism, it cannot be biotransformed, thus characterized as persistent and bioaccumulating in various organs, becoming toxic [5]. The level of toxicity depends on the body's exposure to the xenobiotic, in terms of time and concentration. These issues include headaches, nausea, vomiting, dizziness, chromosomal damage, as well as causing chronic stress and high levels of psychological distress in local residents [9]. In cases of chronic exposure, cancer (skin, lungs, and leukemia) may develop [4]. Marine fauna also suffers consequences; it often damages cell membranes, inhibits photosynthesis in plants and algae, and affects the functioning of essential enzymatic systems [8].

Elimination. For the elimination of hydrocarbons, breaks are taken after a certain time in contact with some gases released from the xenobiotic; if the hydrocarbon enters the body through ingestion, the affected person must be taken to an emergency health center for gastric lavage and administration of activated charcoal pills to absorb the toxic substance [4] and thus prevent harm, in cases where they have been exposed to large volumes of gases, nebulization of the affected individual is necessary to cleanse the affected lungs [4].

Table 2. Description of the xenobiotic route

ROUTE	DESCRIPTION
EXPOSURE	Exposure to crude oil can occur naturally or anthropogenically. SVOCs are released, affecting the atmosphere, while they emulsify in water increasing marine pollution.
ABSORPTION	In marine species, it occurs by gills, water intake and contaminated food. In humans, it is found by consumption of contaminated seafood, inhalation of toxic vapours and contact with the skin.
DISTRIBUTION	The components of petroleum are distributed through the bloodstream, affecting organs such as liver, kidneys, lungs, and in pregnant women, can reach the fetus.
METABOLISM	It is not easily biotransformed, which causes bioaccumulation in humans. This causes toxic effects in the body. In marine fauna, it damages cell membranes, inhibits photosynthesis and affects enzyme systems.
ELIMINATION	In humans involves treatments such as gastric lavage In case of inhalation, nebulization is used.

Cleaning up an oil spill. The reality is that oil spilled in the sea, known as an oil slick or "black tide," poses a serious risk due to the formation of a highly resistant emulsion driven by wave action. In the face of such a disaster, it is crucial to act swiftly to prevent significant environmental damage. Therefore, the cleanup of an oil spill at sea is a complex process that requires a combination of physical, chemical, and biological methods to minimize environmental impact. Here are some common methods used in marine oil spill cleanup:

Containment Booms. These are floating physical barriers with a height that includes a flotation area and a draft area, which function to contain, control, and protect the recovery in the aquatic environment [10].

Skimmers. High-efficiency marine cleaning equipment for such incidents, used both at sea and along the coast. Skimmers function to collect oil through their brushes, which separate the hydrocarbon from the water within a perimeter delimited by the professionals in charge of the cleanup. They can be equipment installed on ships or specialized vehicles that use absorption, adsorption, flotation, or centrifugation methods to collect the oil [19].

Chemical Dispersants. These are chemical agents that alter the physical behavior of hydrocarbons on the sea surface. They consist of a mixture of surfactants dissolved in a solvent that helps the mixture penetrate the hydrocarbons. The surfactants reduce the surface tension of the hydrocarbons, thus increasing the rate of formation of small droplets and inhibiting their coalescence [20].

In-situ Burning. In-situ burning is a technique used in some spill scenarios where the oil slick is contained by barriers and then burned in a controlled manner. Although this technique does not leave large amounts of residues in the sea, it emits a significant amount of harmful gases into the atmosphere from the burning [21].

Floating Storage. These systems are equipped with tanks or special compartments where the collected oil is safely stored until it can be transferred to onshore facilities for proper treatment and disposal [22]

Table 3. Description of cleaning techniques

CLEANING METHOD	DESCRIPTION
Containment barriers.	Floating devices that contain and control the dispersion of oil in the sea, facilitating its recovery.
Skimmers	Equipment that collects floating oil by absorption, flotation or centrifuging methods. These may be mounted on specialized boats or vehicles.
Chemical Dispersants	Surfactants that modify the physical properties of oil, facilitating its dispersion into small drops and preventing its coalescence.
Burned in situ	Technique consisting of burning the oil contained, releasing harmful gases but reducing the amount of waste in the sea.
Floating Storage	Systems equipped with tanks that store safely the oil collected, before transferring it to ground facilities for treatment and disposal.

METHODOLOGY

To conduct a comprehensive comparison of contingency plans for oil spills, a systematic review of scientific literature and governmental information was carried out, utilizing recognized scientific dissemination databases such as Scopus, Web of Science, and Google Scholar. The keywords used included "oil spills," "contingency plan," "emergency response," "remediation," "Ventanilla," "environmental emergency," and "beach."

Following a meticulous search using key terms, articles were obtained, which then underwent a selection process based on inclusion and exclusion criteria. The inclusion criteria considered studies published from 2014 to 2024, peer-reviewed articles, technical reports, and specific case studies that detailed the implementation and evaluation of contingency plans.

Articles that were not available in full text, documents that did not focus directly on oil spills, and those that did not provide empirical data or efficacy evaluations were excluded. Subsequently, the selected articles underwent a full-text review to confirm their relevance and quality. Relevant data from each study were extracted and synthesized, with special attention paid to the methodologies used, the results obtained, and the recommendations proposed

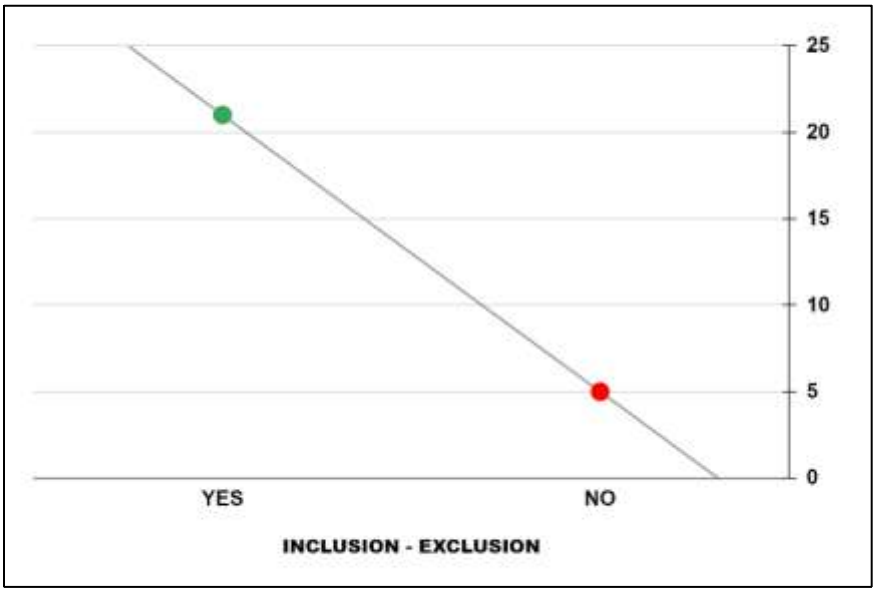

Fig. 1. Scattering table

Secondly, preliminary searches were conducted using combinations of keywords to identify an initial set of relevant articles. For instance, the combination "oil spill AND contingency plan AND emergency response" was used to refine the search. The titles and abstracts of the retrieved articles were reviewed to verify their relevance according to the established criteria.

Subsequently, the selected articles underwent a full-text review to confirm their pertinence and quality. Relevant data from each study were extracted and synthesized, with special attention paid to the methodologies used, the results obtained, and the recommendations proposed. Finally, a comparative analysis of the identified contingency plans was conducted, assessing their relative efficacy and highlighting best practices. This systematic and rigorous approach ensured that the review provided a comprehensive and substantiated insight into the different approaches and strategies in managing oil spills

RESULTS.

Contingency Plan. For MINAM (Ministry of Environment), a contingency plan is a management tool aimed at preventing or reducing potential damage to human life, health, property, and the environment. It consists of a set of specific pre-established operational procedures designed for coordination, alert, mobilization, and response to a likely emergency arising from a natural phenomenon or human action that can occur in any installation, building, and enclosure of any type, in any location, and during the development of an activity or operation, including transportation [11]. These plans include preventive measures, such as regular inspections and equipment maintenance, and immediate response actions, including the activation of cleanup teams, the use of barriers to contain the spill, and the recovery of oil using various techniques. Moreover, contingency plans involve close coordination with local, regional, and national authorities, as well as ongoing training for personnel responsible for emergency responses, thus ensuring effective and efficient management of such incidents.

Through research and analysis, contingency plans at the national level from four countries were obtained, which provide detailed steps to be followed in the event of an oil spill in their maritime areas. These include:

Manual for the Management of Hydrocarbon Pollution Incidents on the Coast (Spain)
The National Response System (SNR) includes two subsystems, whose areas of operation are maritime waters and the coast, respectively. These subsystems consist of a series of contingency plans. The National Response System comprises two subsystems, the Maritime Subsystem and the Coastal Subsystem; the Maritime Subsystem is divided into the National Maritime Plan (PMN) and the Internal Maritime Plan (PIM). Whereas the Coastal Subsystem is divided into the RIBERA Plan, Territorial Plans, and Local Plans.
National Maritime Plan (PMN). The event affects waters over which Spain exercises sovereignty. Emergency 2 or 3. In situation 2, the RIBERA Plan is activated in alert phase.

Internal Maritime Plan (PIM). The event affects maritime facilities (ports, maritime cargo handling terminals, among others). Emergency 0 or 1.
RIBERA Plan. The event affects the coast and requires the intervention of the General Administration of the State (AGE) through the Ministry for Ecological Transition (MITECO). Emergency 3. It can mobilize resources at the request of the autonomous communities in emergency 2. It is activated in alert situation if the PMN or the territorial plan is in situation 2.
Territorial Plans: The event affects the coast of an autonomous community. Emergency 2. The RIBERA Plan is activated in alert phase. Drafted by the respective coastal autonomous community.
Local Plans: The event affects the scope of a local coastal entity. Emergency 0 or 1. Prepared by the competent local administration.

National Contingency Plan (Honduras)
Regarding Honduras, if a spill is observed, whether in sensitive areas or not, a notification is issued to the competent authorities for the activation of the National Contingency Plan, in which the response prioritizes human life and health, minimizing environmental and socio-economic impacts. Information about the spill (characteristics of the hydrocarbon and its behaviour), location, and prediction of movement is gathered, and if an impact on the coast is expected, protection of it is implemented. The spill may be addressed through an in-situ burning operation, chemical dispersion, or mechanical containment and recovery; if there are risks to wildlife, techniques and strategies to disperse birds from the area are included, and if these are found coated in oil, they are rescued for rehabilitation. Finally, the recovered hydrocarbon is transferred and stored

National Contingency Plan for Oil Spills (Panama)
This plan establishes guidelines for preparation and organization at the national level for oil spills, allowing for a tiered response to different levels of events: Tier I, Tier II, and Tier III (Table 1). Its objective is to provide the competent authorities with the necessary tools to implement best practices in preparedness, emergency response, and incident management at the national level. In addition to establishing local contingency plans and area plans, the National Plan will develop the capacity to respond to oil spills, promoting continuous improvement to protect life, the environment, and the economic resources of the country.

Tier I: Developed with local contingency plans, this is the first level of response activated in the event of an incident. Human resources and equipment should be on-site for a prompt response time.

Tier II: Developed with area contingency plans and supporting the response at Tier I. The competent authorities will be able to define mechanisms for the acquisition of additional human resources and equipment.

Tier III: Developed with the National Plan and manages resources through the activation of local and area contingency plans. It will also serve to coordinate and facilitate the support of international resources.

Table 4. Graphic relationship of the step response system

Major Spill	**Tier 3**	**Tier 3**	**Tier 3**
Medium Spill	**Tier 2**	**Tier 2**	**Tier 3**
Minor Spill	**Tier 1**	**Tier 2**	**Tier 2**
	Local Plan	Area Plan	National Plan

National Contingency Plan Against Oil Spills and Potentially Hazardous Substances in Mexican Marine Zones (Mexico)

This plan is activated when it is determined that a spill cannot be controlled, contained, recovered, and stored; it is detected through remote or in situ sensors, and the captain in charge must immediately notify local authorities or organizations via radio, phone, message, etc., detailing the characteristics of the hydrocarbon (date, time, location, origin, spilled product, cause, trajectory, extent, and impacts). After confirming the incident through an official record, the use of chemical dispersants and in-situ burning will be considered, decisions based on international practices, technical knowledge, and specific circumstances. The plan is deactivated when most of the hydrocarbon is on the surface, and the pollution source has been controlled, followed by monitoring the incident to ensure compliance with terms by those responsible, species recovery, compensations, or legal processes.

National Contingency Plan for the Prevention, Control, and Combat of Oil Spills and Other Harmful Substances in the Aquatic Environment (Peru)

This plan is complemented by and related to Environmental Emergency Declarations, which are measures adopted when an event poses a significant risk to the environment. Issued by the Ministry of the Environment, these declarations aim to mobilize resources and take urgent actions to mitigate the effects of the emergency, in accordance with Law No. 28804 and its amendment by Law No. 29243. Both instruments are implemented as follows:

- Preparation and Prevention: Establishes the procedures, protocols, and resources necessary to prevent and combat oil spills and prepare for their eventuality.
- Response and Coordination: The NCP is activated and establishes the organizational structure for response when an oil spill or other harmful substances occur.
- Evaluation and Monitoring: The NCP and environmental emergency declarations require constant monitoring and assessment of the environmental impacts. The interaction between both allows for the collection of relevant data, assessing the effects of oil spills, and making informed decisions to manage the emergency and restore the affected environment.

Table 5. Comparative of national plans

Activities		P.N.España	P.N.Panamá	P.N.Honduras	P.N.México	P.N.Perú
Response time	Short	X		X		
	Broad		X		X	X
Priority response	Environment	X	X		X	X
	Health		X	X		
	Socio-economic	X	X	X	X	

DISCUSSIONS

The text analysis provides a comprehensive view of the issues surrounding oil spills, covering their origin and composition, environmental impacts, and mitigation strategies. The effectiveness of contingency plans is crucial for minimizing the damage caused by oil spills. Examples from national plans of Spain, Honduras, Panama, Mexico, and Peru illustrate various approaches and levels of preparedness for these incidents. Each country has developed a response framework that includes preventive measures, immediate response actions, and post-incident follow-up. Spain has implemented a national response system with specific plans for maritime and coastal areas, which facilitates a quick and coordinated reaction compared to others. Honduras prioritizes human life and health, minimizing environmental and socioeconomic impacts through operations such as in-situ burning, chemical dispersion, and mechanical containment.

Panama uses a tiered response for different levels of spills (Tier I, II, and III), allowing flexible adaptation to the magnitude of the incident. Mexico focuses on immediate notification and technical assessment to decide the use of chemical dispersants and in-situ burning, based on international practices. Peru combines its contingency plan with environmental emergency declarations to mobilize resources and mitigate effects, but these remain primarily documentary.

CONCLUSION AND RECOMMENDATION

The findings of the analysis underscore the importance of a detailed understanding of the composition of oil and the risks associated with spills. Preparation reduces response time in emergencies, increasing the effectiveness of recovery by allowing for rapid decisions and the selection of the most appropriate response methods [7]. The implementation of well-structured and coordinated contingency plans is crucial for mitigating negative impacts on human health and the environment. The systematic review of the literature provides a robust framework for

the formulation of effective and adaptive strategies, which should be continuously updated and improved based on new evidence and experiences.
As a recommendation, following the National Contingency Plan carried out by the Peruvian Navy, we urge companies to implement this NCP at their potential risk facilities; additionally, the ISO 14001: 2015 standard can be included, specifically under requirement 8.2, which indicates the Emergency Response Plan, where actions are planned to prevent or mitigate adverse environmental impacts in anticipation of how to respond to these situations by periodically testing these responses; including the conduct of exercises and drills to ensure that the response plans are effective. Moreover, the review should take into account lessons learned to continually improve the organization's response capacity and ensure that all employees and other relevant stakeholders are aware of their roles and responsibilities in case of an emergency.
The process includes remote and in-situ detection, rapid notifications, and the collection of information about the characteristics of the xenobiotic. An immediate response is carried out with techniques such as containment barriers, skimmers, chemical dispersers, and controlled burning, in addition to the rescue of affected birds and marine mammals. Finally, the collection and storage of hydrocarbons are conducted, and legalities are addressed through legal processes against those responsible.
In summary, managing oil spills requires a multidisciplinary and coordinated approach that includes prevention, immediate response, and long-term monitoring, thus ensuring the protection of human health and the preservation of marine ecosystems. This may involve regulatory bodies, emergency personnel, the local community, and others as appropriate in an emergency.
The implementation of stricter regulations to combat pollution generated by ships, along with the introduction of double-hulled tankers and significant improvements in the surveillance and monitoring of maritime traffic, have contributed to reducing the environmental impact of maritime activities [8].

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