Journal of World Architecture, 2024, Volume 8, Issue 2
https://ojs.bbwpublisher.com/index.php/JWA
Online ISSN: 2208-3499
Print ISSN: 2208-3480

Risk Assessment of an Environmental Liability in the Commercialization of Hydrocarbons – A Secondary Publication

Yamila Navarro Sosa[1], José Carlos Rojas Acosta[2], Lester Rivas Trasancos[1], Carlos C. Cañete Pérez[1], Yuletsis Díaz Rodríguez[1]*

[1]Center for Petroleum Research (CEINPET), Havana, Cuba
[2]Technological University of Havana José Antonio Echeverría, Havana, Cuba

***Corresponding author:** Yuletsis Díaz Rodríguez, yuletsis@ceinpet.cupet.cu

Abstract: The risk analysis evaluates the probability of occurrence with the impact of said risks. In the hydrocarbon sector, an environmental liability is an improperly abandoned facility, soil contaminated by spills or others. The objective of this work is to define a risk management plan. The characterization of the residue and the area was carried out. Hazardous events were identified: overflow spill, soil contamination by infiltration, as well as radiant heat and suffocating and toxic fumes from a fire. The matrix method was applied considering the probability of occurrence against vulnerability. The danger of infiltration implied a high level of risk. The risk management plan was drawn up, its main action being the liquidation of the pool and the sanitation of the area.

Keywords: Hazardous events; Environmental liability; Waste; Risk; Vulnerability

Online publication: May 20, 2024

1. Introduction

The oil industry is a major contributor to environmental damage, as it serves to meet the growing demand for crude oil through greater exploitation of this natural resource. Fortunately, many of the companies involved in this activity have begun to take action to minimize the environmental damage caused by the emission of polluting gases, oil spills, and deforestation in productive areas [1].

Environmental liabilities are areas that, due to the development of some activity or project, were contaminated by hazardous substances that were dispersed. In the hydrocarbon sector, an environmental liability is an improperly abandoned well or duct installation, soil contaminated by effluents or spills, waste residue, or others. For it to be considered an environmental liability, it must cause damage or pose a risk of harm to the environment or people's health [1,2].

Identifying and evaluating environmental liabilities in the hydrocarbon sector is crucial because any contaminated site or area exposed to hydrocarbon substances or other hazardous waste poses both current and potential threats to the environment and human health [3-5]. Therefore, proper disposal of these residues is necessary to mitigate the risks they pose and minimize the damage they can cause after their generation [6].

The qualitative risk analysis prioritizes risks for analysis by evaluating and combining the probability of occurrence with the impact of these risks. This process helps reduce the level of uncertainty and focus on high-priority risks.

After identifying and quantifying the risks, it is essential to respond promptly. This involves devising a risk management plan based on cause-and-effect analysis. This plan entails implementing both preventive and corrective measures, allocating organizational resources like budget, and assigning responsible individuals for execution and implementation [1,5,7].

Hence, it is crucial to characterize the environmental liability and assess the associated risks to develop a risk management plan that reduces the hazards that may arise from it. Therefore, the main objective of this research is to define a risk management plan to handle the environmental liability of a hydrocarbon waste pool belonging to a fuel distributor.

2. Methods

2.1. Characterization of environmental liabilities

The oil waste pool is an environmental liability that was generated by the accumulation of waste from fuel tank drains and other oil waste (**Figure 1**).

Figure 1. Environmental liability, oily waste pool

The approximate dimensions of the pool are 100 m × 60 m × 0.4 m, with an estimated waste volume of 2400 m^3 located in a naturally depressed area of an unsealed terrain. In order to characterize the waste contained in the pool, a sample of it was analyzed. The oil-contaminated sample was dehydrated to determine the content of emulsified water and prepare it for physical-chemical tests. The methods used for the physical-chemical characterization of the dehydrated waste are described in **Table 1**.

Table 1. Test methods used in the analysis of the sample

Parameters	Method
Kinematic viscosity at 100º C (mm^2 /s)	ASTM D445-2019
Total ash (% mm)	ASTM D482-2013
Density at 15° C (kg/m)^3	ASTM D287-2012b
Density at 20° C (kg/m)^3	
API	
Total sulfur (% m/m)	ASTM D1552-2008
Carbon residue (Micro) (% m/m)	ASTM D4530-2015
Sediment in crude oil (% v)	ASTM D4807-2005 (re-approved 2015)
Net calorific value (kcal/kg)	ASTM D4809-2018
Pour point in crude oil (°C)	ASTM D5853-2017a
pH(25 °C)	NC 32:2009
Conductivity (25 °C) (µS/cm)	
Fats and Oils (G and A) (mg/kg)	APHA 5520:2017
Total Hydrocarbons (TCH) (mg/kg)	
Saturated HC (S) (mg/kg)	EPA 3540C:1996
HC Aromatics (A) (mg/kg)	
Resins (R) (mg/kg)	
Asphaltenes (A)(mg/kg)	
Metals	LSA-PT-29, Measurement by ICP-OES (internal method)

2.2. Geographical location and geological characterization of the area

Satellite images were used to locate the pool, which allowed for calculating the distance to vulnerable objects, confirmed through observation during a site visit. The geological characterization of the area comes from the Natural Risk Study of the entity [8]. The digital geological map of the Republic of Cuba at a scale of 1:100 000 was also used.

2.3. Risk assessment

Regarding an accident, risk is expressed in the magnitude of its consequences, which is directly proportional to the level of vulnerability of the physical components located in the affected area. Therefore, it is possible to determine the level of risk using the following equation [9].

$R = P_A V_T$

R: Risk of accident

P_A: Probability of accident

V_T: vulnerability of all potentially affected elements

2.3. Identification of potential hazards

To identify the risks associated with the environmental liability, a site visit was conducted to qualitatively determine the possible impacts in the surrounding area.

The hazardous events that could occur in this case would be spills and fires. These bring with them dangerous effects such as soil contamination, groundwater and surface water contamination due to infiltration, as well as overflow in the event of a meteorological phenomenon. Additionally, a fire can generate heat through radiation and produce toxic and suffocating fumes.

2.3.1. Overflow spillage

The waste pool was assumed to have a slope height of 0.7 m, and a radius of effect of 200 m was assumed, which is the approximate maximum distance that the overflowing waste can reach, taking into account that the slope is minimal.

2.3.2. Soil contamination by infiltration

Based on the geological and geomorphological characteristics of the area, which indicate a high infiltration coefficient and the presence of underground karstic processes leading to caverns and fissures, the risk associated with the environmental liability was estimated considering the duration of the residue's deposition.

2.3.3. Radiant heat from fire

To determine the risk posed by a fire and the magnitude of its consequences, the following expression defines the radiant heat flux received at a distance (d) from any flame [9]:

$$q_r = 0.0796 \frac{\varphi m \Delta H_C}{d^2} \qquad (2)$$

qr: Radiant heat flux received at distance *d* from the center of the flame (BTU/hpie2)

φ: Fraction of the emitted heat that is converted into radiation

ΔH_c: Heat of combustion of the burned gases or vapors (BTU/lb)

m: Mass flow rate of burned gases or vapors (lb/hr)

d: Distance from the central point of the flame to the point considered (feet)

To calculate the radiant heat flux, a fraction of heat emitted by radiation equal to 0.21 was considered, the calorific value of the residue was 9430 kcal/kg, the distance was 20 m, the density at 20°C was 1.0275 g/cm^3, the volume of residue in the pool was 2400 m^3, and the approximate burning time of the residue was 7 days.

The mass of the residue was determined based on the density and volume, which will be affected by 0.7 since it contains 30% water. The mass flow rate referred to the 7 days when the mass of residue was burned was calculated. The radiant heat flux (*qr*) was compared with the values exposed in the literature related to damage to people and structures [9]. The probability of the event occurring was established based on the damages and the distance.

2.4. Stifling and toxic fumes from the fire

For a mass flow rate equal to the one calculated previously, a global mass balance was performed in the pool, where the amount of residue was considered equal to the amount that was burned, disregarding the ashes produced during the process. Therefore, the load of contaminants present in the smoke was calculated, with which the magnitude of the consequences of this hazardous effect was estimated.

2.5. Method used to estimate risk levels

To estimate the current risk levels, we employed the risk matrix method, opting for a simple matrix that contrasts the probability of occurrence with the vulnerability of the physical environment. Both indicators were categorized as low, medium, and high, as depicted in **Figure 2**. Red cells denote high-risk levels, green indicates acceptable levels, and yellow signifies medium levels [9].

The probability of occurrence of a given accident depends on the existing safety level and is estimated according to the experience of past accidents or the influence of external agents. The magnitude of its consequences or impact on human life and health, economic and/or environmental impacts is determined both by the magnitude of the hazard and the vulnerability of the environment, determined by the presence of elements that can be affected by the hazardous effects of an accident.

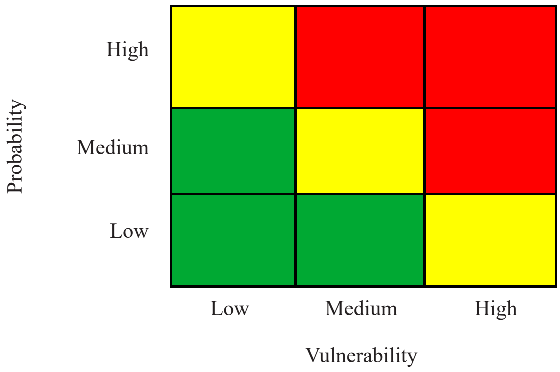

Figure 2. Simple probability vs vulnerability risk matrix

The components of the vulnerable elements were scored (**Table 2**) to determine the vulnerability factor (VF) for each hazardous effect using the following equation:

$$\boldsymbol{FV} = \sum \boldsymbol{Fi} \quad (3)$$

Fi: score for each indicator

Table 2. General model for environmental vulnerability assessment

No.	Description of vulnerable elements present in the area of effect	Existence in the area (X)	Approximatedistance (m)
1.	Facilities in the area of effect whose activity and users could be affected (1: 5 points, 2 or 3: 15 points, more than 3: 25 points)		
	Hospital or other healthcare facility		
	School or childcare center		
	Cultural, sports, or recreational area or center		
	Transportation terminal (bus, railway, air, etc.)		
	Commercial or service center or area		
	Administrative building (office or agency building)		
2.	Resident population in the area of effect (Less than 50: 10 points, 50 to 100: 15 points, more than 100: 25 points)		
3.	Other vulnerable elements and people in the area of effect. 1 or 2:10 points, 3 or more: 15 points.		
	LPG sales outlets		
	Petrol stations		
	Workshop or industrial installation		
	Electrical substation or high voltage network		
	Drinking water main or sewerage system		
	Workers		

Table 2 (Continued)

No.	Description of vulnerable elements present in the area of effect	Existence in the area (X)	Approximatedistance (m)
4.	Ecological vulnerability and heritage zones in the area of effect (1: 15 points, 2 or 3:25 points, more than 3: 35 points).		
	Protected area (nature or ecological reserve, other)		
	Wooded area		
	Water catchment area		
	River, stream, pond, or water reservoir		
	Bay or coastal area		
	Groundwater		
	Area for cultivation or animal husbandry		

The total vulnerability was classified as low, medium, or high according to the FV value [9].

$$FV < 15 \text{ Low vulnerability}$$
$$15 \geq PV < 25 \text{ Medium vulnerability}$$
$$FV \geq 25 \text{ High vulnerability}$$

2.6. Risk management plan

The outcome of the risk matrix and the availability of resources were taken into account in drawing up the risk management plan. Preventive and corrective actions were included to ensure that the risk was eliminated or mitigated.

3. Discussion

The oily waste contained in the pool is considered hazardous waste according to Annex VI General Classification of Hazardous Waste, CITMA Resolution 253/2021.

3.1. Physicochemical characterization of the dehydrated waste

The results (**Table 3**) showed that the oiled residue was similar to ultra-heavy oil according to density and API gravity. Besides, it could be classified as highly sulfurous according to its sulfur content [10]. Its calorific value was similar to that of crude oil, indicating a possibility of energy use.

Table 3. Results of physicochemical characterization

Parameters	Results
Kinematic viscosity at 100^{o} C (mm^2/s)	721.7
Total ash (% mm)	0.80
Density at 15 °C (kg/m^3)	1030.7
Density at 20 °C (kg/m^3)	1027.5
API	5.7
Total sulfur (% m/m)	8.3
Carbon residue (Micro) (% m/m)	15.7

Table 3 (Continued)

Parameters	Results
Sediments in crude oil (% v)	20.1
Net calorific value (kcal/kg)	9430
Pour point in crude oil (^{o} C)	26
Insoluble in n-heptane (asphaltenes) (% m/m)	17.8
pH(25^o C)	4.51
Conductivity (µS/cm)	1391
G and A (mg/kg)	970183 (97.0 %)
HCTP (mg/kg)	697337 (69.7 %)
S (mg/kg)	374508 (37.4 %)
A (mg/kg)	322829 (32.2 %)
R (mg/kg)	31570 (31.5 %)
A (mg/kg)	241276 (24.1 %)

When comparing the characterization results with NC 521: 2007 "Discharge of Wastewater into the Coastal Zone and Marine Waters - Specifications," the values obtained for petroleum hydrocarbons and related compounds were found to be very high. This suggests the presence of highly polluting waste.

3.2. Location of vulnerable elements

Table 4 records the vulnerable elements close to the waste pool and their distance from it.

Table 4. Distance of vulnerable elements from the pool

Elements	Boilers	Tanks							Bay
		13	22	23	27	28	29	43	
Distance (m)	19	59	51	32	63	179	72	34	285

3.3. Geological-geomorphological characterization of the area

Geomorphologically, the area has four levels of emerged marine terraces. The coastline is karst-regular and abrasive with the presence of a cliff that reaches heights of up to 2 m above mean sea level. The area is also characterized by crevasse systems, both perpendicular and parallel to the coastline, the latter being the most developed. The perpendicular cracks close to the interior of the area and open towards the sea [8].

The infiltration coefficient is very high, which justifies the abundance of subterranean karst processes of dissolution originating caverns and cracks. These features define a young relief on a surface of marine origin, on a carbonate base, with the development of karst processes whose evidence can be seen in the forms of superficial karst relief, located in the terrain such as dolines, lapiaz, caverns, and cracks of the same origin. Lithologically, the formations are made up of sediments with high porosity and permeability, so that the infiltration of any fluid would be relatively fast based on its viscosity.

The current relief in the study area is characterized by a high level of modification due to the construction processes, both of roads, installations, and port infrastructure, in the latter case, including the rectification of sections of the coastline and the filling of marine surfaces with borrow material. Part of the industrial area is located on a karstic-denudation surface.

The hydrogeological characteristics of the formations present are those of a coastal aquifer, partially or totally affected by marine instruction. It should be noted that the dip of the geological layers towards the southeast coincides with the slope of the relief, indicating that this is the preferential direction of runoff both at the surface and underneath [11].

3.4. Risk assessment

The models for the hazards overflow spillage, seepage pollution, radiation heat from the fire, and suffocating and toxic fumes from the fire were modeled and the probability of occurrence was determined, the results of which are shown in **Table 5**. The schematic representation of the results in the matrix is shown in **Figure 3**.

Table 5. Results of the risk assessment

No.	Danger	Factor of vulnerability	Vulnerability	Probability	Level ofrisk
1	Overflow spillage	10	Low	Medium	Low
2	Soil contamination byinfiltration	15	Medium	High	High
3	Radiated heat from fires	15	Media	Low	Low
4	Stifling and toxic fumesof fires	30	High	Low	Medium

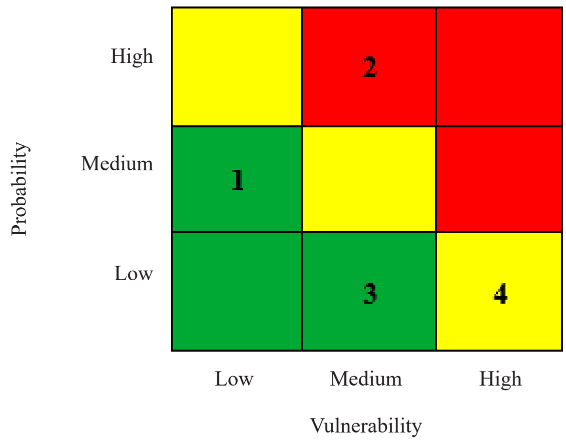

Figure 3. Risk matrix

The spill overflow hazard (1) and fire radiation heat (3) was at an acceptable risk level. However, it is necessary to act systematically to maintain this level, particularly by developing and adhering to the required inspection and maintenance programs for both technological equipment and existing protection systems and means (prevention and mitigation) to preserve their initial technical conditions.

The stifling and toxic fire fumes hazard (4) was classified as a medium risk level and should be reduced to an acceptable level economically.

The infiltration soil contamination hazard (2) was classified as high-risk, so immediate action is required to decrease it to acceptable levels (green grids). This includes decreasing the probability of occurrence and the magnitude of the consequences.

3.5. Risk management plan

Taking into account the above results, two hazards deserve attention with higher priority (suffocating and toxic fire fumes and soil contamination by infiltration), although the risk management plan includes actions to maintain an acceptable risk level for the remaining hazards analyzed. The risk management measures are listed below.

(1) Eliminating the wastewater entering the swimming pool
(2) Raising slopes
(3) Establishing a monitoring system for the timely detection of incidents
(4) Conducting fire drills frequently
(5) Maintaining fire extinguishers
(6) Maintaining water levels of hydrants
(7) Taking protective measures
(8) Signposting areas with potential hazards
(9) Removing the waste pool and sanitizing the impacted area

The elimination of environmental liability is the measure that allows the cancellation of the identified risks and is the solution to avoid the infiltration of pollutants into the soil. However, its execution depends on the technical and economic conditions for its implementation, so it is necessary to apply the rest of the actions to reduce the levels of risk until it is possible to eliminate the pool.

4. Conclusion

The characterization of the residue revealed high levels of contamination in the pool. The risk assessment demonstrated that the hazard of soil contamination by infiltration presents a high level of risk, with potential negative impact on areas of the bay. A risk management plan proposal is presented to minimize and/or eliminate the identified risks.

Disclosure statement

The authors declare no conflict of interest.

References

[1] Díaz Y, Baujín P, 2020, Procedimiento Para la Identificación, Cuantificación y Registro Contable de los Pasivos Ambientales en la Industria Petrolera Cubana [Procedure for the Identification, Quantification, and Accounting Recording of Environmental Liabilities in the Cuban Oil Industry]. Cuban Journal of Finance and Pricing, 4(1): 63–72.

[2] Nilles V, Goenaga A, 2019, Pasivos Ambientales e Información Socioambiental en Empresas Petroleras Argentinas [Environmental Liabilities and Socio-Environmental Information in Argentinean Oil Companies]. CEA Journal, 3(1): 49–70.

[3] Oblasser Á, Chaparro E, 2008, Comparative Study of the Management of Mining Environmental Liabilities in Bolivia, Chile, Peru and the United States [Estudio Comparativo de la Gestión de Pasivos Ambientales Mineros en Bolivia, Chile, Perú y Estados Unidos], CEPAL - Serie Recursos Naturales e Infraestructira, Santiago de Chile.

[4] Posada YY, 2017, Formulación del Plan de Gestión Ambiental de la Compañía Drillsite Fluid Treatment bajo lineamientos de la Norma ISO 14001, Trabajo de grado Para Optar el Título de Ingeniera Ambiental y Sanitaria [Formulation of the Environmental Management Plan of the Drillsite Fluid Treatment Company Under the Guidelines of the ISO 14001 Standard], thesis, Corporación Universitaria Autónoma del Cauca, Popayan

[5] Valdés W, 2011, Tratamiento Físico Químico de Residuos Oleosos [Physical Chemical Treatment of Oily Waste],

thesis, Universidad Nacional de Ingeniería, Lima.

[6] Cárdenas EA, Piñeros CA, 2019, Diseño de Una Metodología que Permita la Identificación y la Valorización de los Pasivos Ambientales Huérfanos Petroleros Mediante el Uso de Una Plataforma Digital [Designing a Methodology that Allows the Identification and Valuation of Oil Orphan Environmental Liabilities Through the Use of a Digital Platform], thesis, Fundación Universidad de América.

[7] Díaz JM, 2021, Construcción del Plan de Gestión de Riesgos Asociados a Las Actividades del Proceso de Gestión Inmobiliaria de Servidumbres Petroleras Aplicado a la Empresa Codeinsu S.A.S] Construction of the Risk Management Plan Associated with the Activities of the Real Estate Management Process of Oil Easements Applied to the Company Codeinsu S.A.S, thesis, Universidad Nacional Abierta y a Distancia

[8] Rubio M, Hernández K, Olivera W, et al., 2019, Estudio de Riesgos Naturales ECC Matanzas [ECC Matanzas Natural Risk Study], Matanzas.

[9] Camejo JJ, Alfonso M, 2016, Seguridad Industrial: Aspectos Básicos [Industrial Safety: Basic Aspects], Instituto Superior Politecnico "José A. Echeverría" (CUJAE), Havana.

[10] Linares E, García D, Delgado O, et al., 2011, Yacimientos y Manifestaciones de Hidrocarburos de la República de Cuba [Hydrocarbon Deposits and Manifestations of the Republic of Cuba], Centro de Investigaciones del Petróleo, Havana.

[11] Molerio LF, Escalera V, Balado EJ, 2014, Desarrollo Gasopetrolífero y Gestión de Los Recursos Hidráulicos Subterráneos en el Área Cársica Protegida de Punta Guanos, Matanzas, Cuba [Gas-Oil Development and Management of Groundwater Resources in the Punta Guanos Karst Protected Area], Gota a Gota, 6: 10–20.

Publisher's note

Bio-Byword Scientific Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.