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Soil contamination by petroleum in Tabasco, Mexico, and its environmental repercussions

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Abstract - At the beginning of the 1960's, there were 44 oil fields in 13 from the 17 municipalities in Tabasco, Mexico. Currently, new oil deposits are still being discovered, supporting the national economy. However, this benefit has also severe consequences for both the environment and Tabasco's society. Therefore, the main goal of this research is to analyzer the environmental repercussion of contamination of the soil due to oil spills in this state of México, as well as the use of the input-output analysis to assess the economic impact of the contamination produced by such oil spills. It is important to emphasize that Tabasco's territory is the main oil supplier in the country, but it is still necessary to think of it in terms of its environmental protection, and to carry out the fight against pollution to protect the soil and have a good management and exploitation through the creation of special programs with a multidisciplinary research team for a proper evaluation of the most sensitive biological communities and apply it to production costs. The one who contaminates pays. In other words, they will have to take full responsibility for the damages caused, and this according to the international law for nature care and social benefit.

Key words: Environmental conflicts. PEMEX. Social problems and politicization.

Contaminação do solo com óleo em Tabasco, México, e suas repercussões ambientais

Resumo - Em Tabasco, México, no início dos anos 60, existiam 44 campos petrolíferos, localizados em treze dos dezessete municípios da localidade. Atualmente, continuam a ser descobertas jazidas de petróleo, fomentando a economia a nível nacional. No entanto, esse benefício também tem graves consequências para o meio ambiente natural e a sociedade em Tabasco. Portanto, o objetivo desta pesquisa é analisar o impacto ambiental da crescente contaminação dos solos por vazamentos de petróleo em Tabasco, México. Além disso, é proposto o uso da análise de insumo-produto para avaliar economicamente a poluição produzida por vazamentos de óleo. É importante ressaltar que, no território de Tabasco, que é o principal fornecedor de petróleo do país, ainda assim é necessário pensar a situação junto com a proteção ambiental e o combate à poluição para conservar o solo. Devem ainda ser criados programas especiais com equipe de pesquisa multidisciplinar, para o manejo adequado e utilização do solo, de forma a possibilitar uma avaliação adequada das comunidades biológicas mais sensíveis e assim aplicar o custo de produção, pagos pelo poluidor. Em outras palavras, precisarão responder com a responsabilidade absoluta pelos danos causados, em cumprimento a leis internacionais relativas ao cuidado com a natureza e benefício da sociedade.

Palavras-chave: Conflitos ambientais. PEMEX. Problemas sociais e politização.

Contaminación del suelo con petróleo en Tabasco, México, y sus repercusiones ambientales

Resumen - En Tabasco, en los albores de la década de los 60, existían 44 campos petroleros, ubicados en trece de los diecisiete municipios de la entidad. Actualmente siguen descubriendo yacimientos del crudo, logrando un apoyo a la economía a nivel nacional. Sin embargo, este beneficio también trae consecuencias severas para el ambiente natural y la sociedad tabasqueña. Por lo tanto, el objetivo de esta investigación es analizar la repercusión ambiental de la creciente contaminación de los suelos por los derrames de petróleo en Tabasco, México. Además, se propone la utilización del análisis de insumos y productos para valorar económicamente la contaminación que se produce por los derrames de petróleo. Es importante destacar que en el territorio tabasqueño es el principal aportador de petróleo en el país, sin embargo, aún es necesario relacionarlo con el cuidado del ambiente y se debe establecer una lucha contra la contaminación y por la conservación de los suelos para un buen manejo y aprovechamiento a través de la creación de programas especiales con un equipo multidisciplinario de investigación para una adecuada evaluación de las comunidades biológicas más sensibles y con ello aplicar en los costos de producción, que paga el contaminador. Es decir, se tendrá que responder y cumplir con la responsabilidad absoluta por los daños causados cumpliendo los derechos internacionales sobre el cuidado y beneficio de la naturaleza y la sociedad.

Palabras clave: Conflictos ambientales. PEMEX. Problemas sociales y politización.

Introduction

On March 18, 1938, Oil Expropriation was decreed in Mexico. Three months later, on June 10, the oil and natural gas producer, shipper, refining, and trading company known as Mexican Petroleum Company (PEMEX) was created. It managed to position Mexico among the top oil-producing countries in the world. According to the Organization of the Petroleum Exporting Countries (OPEC), Mexico produces 1,813 oil barrels every day. With this production, it is in the tenth place worldwide (OPEC 2019) and has generated a huge economic power and an unprecedented and fast process of oligopoly in the economic history of oil-producing countries. Unfortunately, it has also exacerbated socio-environmental risks as well as the physical, natural, and cultural transformations generated by oil extraction (Priego-Hernández 2005).

After the expropriation in the states where new oil and natural gas deposits were discovered, such as Tabasco, there was an important increase in transport infrastructure, and spatial reorganization in job offers, assets, services and investment, as well as internal and external migration, mainly from Venezuela (Lajous 2014; Cabrera-Ballona and Díaz-Perera 2016). In these conditions, the territorial impact of hydrocarbon exploitation and extraction has devastated nature, mainly due to the abundance of oil, since Tabasco produces 1,388 barrels per day, being the state with the highest oil production in the country (Toledo 1983; Santiago 2016; SIE 2020).

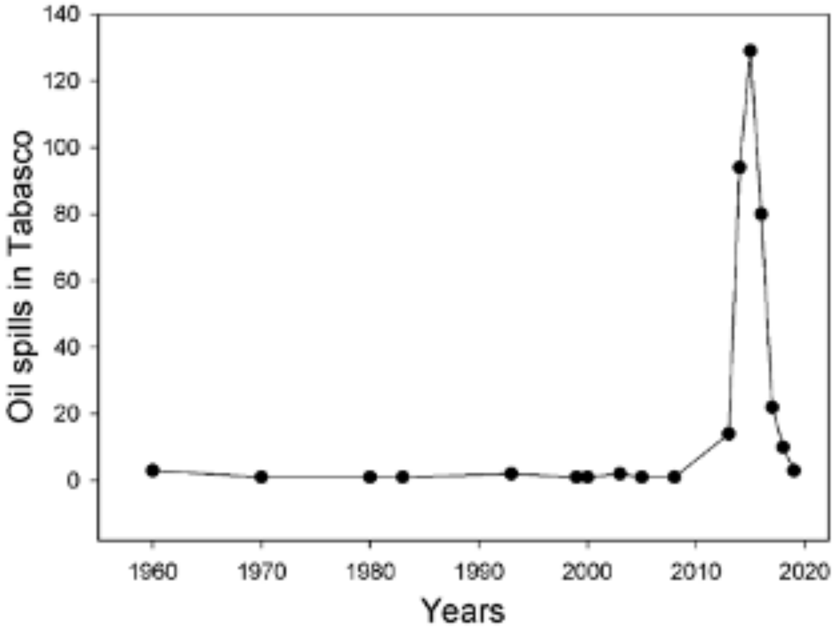
This high oil production causes many important accidents such as oil tank spills, pipe ruptures and incidents in oil extraction from wells (Pérez-Muñoz *et al.* 2019). These spills affect the soil, flora, fauna, and water directly and indirectly, and they represent a great concern for human health, since they cause chronic diseases which are potentially carcinogenic, mutagenic, and teratogenic (Dudai *et al.* 2018).

On the other hand, natural resources do not recognize nor obey borders or political limits and their deterioration is a serious, undeniable, and fast-growing problem (Aguilera-Gómez 2015). When new deposits are discovered, there is a logical economic benefit, but this also leads to ecosystem degradation, and the damage can be irreparable. (Lajous 2014). In Mexico, PEMEX declared in 2018 that there was a total of 1599.36 hectares (ha) contaminated with hydrocarbons from which only 61 ha have been remedied. That is why in Mexico there are laws which state that in matters of industrial, operational, and environmental protection, both assignees and contractors will be responsible for the waste, oil spills or other resulting damages. Again, the one who contaminates pays. Besides, the development of the country must be promoted with social responsibility and environmental protection (DOF 2012; 2013; Gobierno de la República 2013; 2014; Cossío *et al.* 2014; DOF 2016).

In this context, in Tabasco there are research that register several locations contaminated with petroleum hydrocarbons. Beltrán (1993) registered about 7,200 hectares affected (90% of them in swamps or flood zones). On the contrary, Adams-Schroeder *et al.* (1999), with the support of the Mexican Petroleum Institute (IMP), registered only around 300 ha of contaminated areas. Some years later, Rivera-Cruz *et al.* (2004) and Ferrera-Cerrato *et al.* (2006) pointed out that soil pollution by hydrocarbons in Tabasco had reached 0.07% of its total territorial extension, which is 24,731 km2 [15367.131 square miles]. From 2010 to 2016 there were 101 petroleum hydrocarbon spills among the states of Guanajuato, Puebla, and Tabasco, affecting 376, 299 m2 [233 square miles] (Pérez-Muñoz *et al.* 2019).

On the other hand, from 1960 to 2020 a high number of oil spills can be observed. As of 2013, the rise in the number of spill reports began and in 2015 the highest number of spills registered (129) was presented. Data from 2016 to 2020 are still being analyzed (Figure 1). However, from the numbers presented above, it can be concluded that it has been difficult to determine exactly the extent of contaminated soils, due to the fact that many of the spills were not recorded (Ochoa-Gaona *et al.* 2011), and the differences in terms the definition of contaminated areas and the criteria used to determine them. Nonetheless, in the context of the new financial demands that have come with globalization, PEMEX has been forced to make important changes regarding the definitions and statistics of hydrocarbon reserves.

Figure 1. Oil spills in Tabasco from 1960 to 2020. Note: the data from 2016 to 2020 are still being analyzed, since information on the spills reported to the different authorities continues to be compiled.



Furthermore, Mexican laws and regulations have limitations and legislative gaps regarding soil care and recovery after oil spills. In fact, the figures on soils contaminated with hydrocarbons in the state of Tabasco have produced controversial environmental repercussions. The multiplicity of pollution sources and the scarcity of existing basic information about mechanisms of ecosystem functioning result in a large amount of mysteries regarding the impact of oil activities in the region (González-Osorio 2006; Cavazos-Arroyo *et al.* 2014).

Likewise, the brutality of economic, environmental, and social impact of oil activities has created the mindset of "the industry of complain" in people from Tabasco, mainly in rural areas (Beltrán 1988). In other words, peasant families fight for their well-being and that of the environment requesting financial compensation -at the expense of the environment- and "that the damage caused may be repaired" (Pinkus-Rendón and Contreras-Sánchez 2012).

Due to this, Adams-Schroeder *et al.* (1999), Azqueta and Delacámara (2008) and Rivera-Pineda *et al.* (2012) state that the topic of soil contamination has been politicized progressively, and the discourse on contamination has been reconceptualized as an undesirable change in the physical, chemical and biological characteristics of soil, air and water, which affects human life or the different species and can deplete or deteriorate the natural resources and the raw materials that are taken from the ecosystems.

For this reason, this work aims to analyze the environmental impact of soil contamination from oil spills in Tabasco, and the damage that these spills have caused to the ecosystem. Moreover, it is also analyzed and proposed the economic model input-output to assess the cost of soil loss by hydrocarbon contamination. Input-output analysis is an economic tool for the study of productive systems and has also been applied to environmental subjects. Its application is based in analyzing the economic reality of the systems in detail. In other words, it assesses the possibility of detecting the economic losses or costs of some productive activity (Tarancón-Morán 2003). In this case, it is applied to calculate the approximate cost of contaminating the soil due to oil spills.

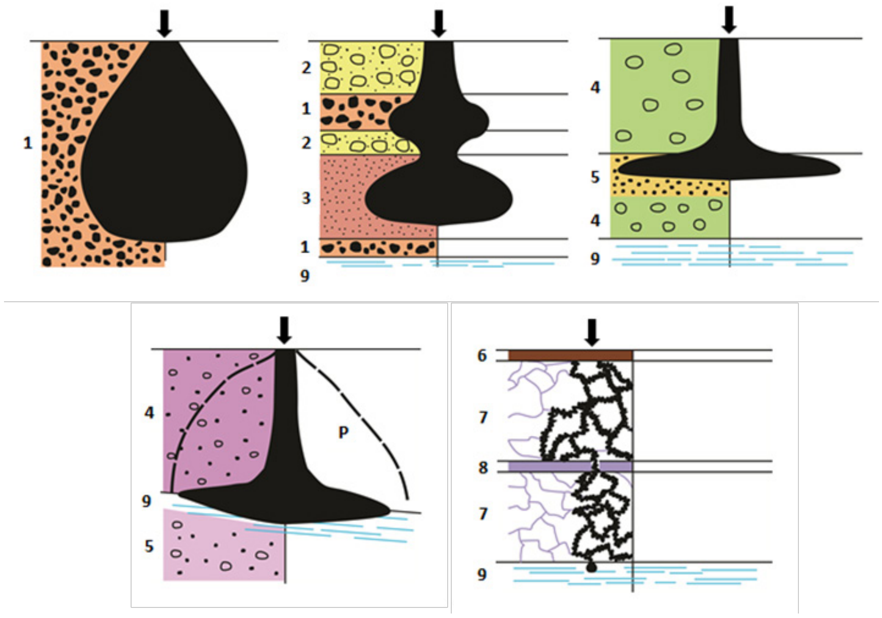
The proposal is to generate comprehensive databases to identify environmental damage and economic loss, so they can be used to generate alternatives to handle the natural resources that promote the restoration and remediation all of the affected areas for strategic regionalism as well as to support the establishment of public environmental politics according to the reality.

Effects of Crude Oil in the Soil

Among the innumerable negative effects of crude oil pollution on the ecosystem, the soil is the most affected one, since its pollution generates serious consequences and can lead to soil degradation due to the loss of nutrients because they can be directly or indirectly eliminated by the oil during its infiltration in the soil, or by erosion caused by runoff waters (Phillips 2000).

When crude oil falls over the ground, it flows vertically till the surface of groundwater. Heavier hydrocarbons leak slowly (oil, fuel oil, etc.), while the light ones (such as benzene) move much faster. According to Toledo-Ocampo (1982) and Rogner (1997), crude oil, during its filtration, advances mainly due to its specific weight and it is integrated into the subsoil as a body whose shape depends on the amount and composition of soil horizons. It penetrates rapidly and vertically into sand and seeps sideways. Very thin and poorly permeable layers can hold back or stop the infiltration. Thus, in soils such as the one of the Yucatan Peninsula, crude oil would infiltrate rapidly because it is calcareous soil (Figure 2).

Figure 2. Behaviour of an oil spill in soils. Graphical representation of oil infiltration in soils. 1. Thick sand, 2. Gravel or grit, 3. Fine sand 4. Grit-sand, 5. Clay, 6. Organic matter 7. Calcareous rocks 8. Flagstone, 9. Groundwater, P. Area of gaseous phase. Source: taken and modified from Toledo-Ocampo (1982).



The physical and chemical properties of soils are affected by spilled oil. Hydrocarbons affect soil particles bringing them together and generating thicker structures that cover the surface of the pore space, thus affecting soil aeration and making soil bases saturate and acidify. This acidification is caused by the blockage of water interface, oxygen and loss of proton biocycling in the soil, while protons absorption and mineral weathering decrease, generating an increase in the C/N ratio (Chaíneau *et al.* 2003; Sposito 2008).

Zavala-Cruz *et al.* (2002) mention that the interaction of crude oil with the soil reduces gas exchange in the atmosphere, as well as the modification of cation exchange capacity due to the increase in organic carbon content. The effect that oil causes in soils is the first planning step to integrate a new vision towards the restoration and recovery of soils contaminated by oil spills. Moreover, the limits of the cleaning of soils depend on the criteria or regulations in Mexico.

Nevertheless, oil spills have become a matter of concern for the environment, so much that there are researches in which different organisms, such as bacteria, fungi, earthworms, algae or plants are used to stabilize, remove and/or eliminate soil contamination by crude oil (Rodríguez-Campos *et al.* 2019).

The Role of Soil Microorganisms and the Roots of Plants in Bioremediation

When crude oil has contact with the soil, it is synthesized by hydrocarbonoclastic microorganisms, which manage to process pollutants thanks to their biogeochemical metabolizers and catalyzers (Varjani *et al.* 2017). In addition, plants and microorganisms interact beneficially to eliminate the existing pollutants in the soil. Their success depends primarily on the presence of nutrients such as Nitrogen (N), Phosphorus (P) (10:1), pH (5.5-8.8), optimum temperature (15-45 ºC; Vidali 2001; Shahi *et al.* 2016).

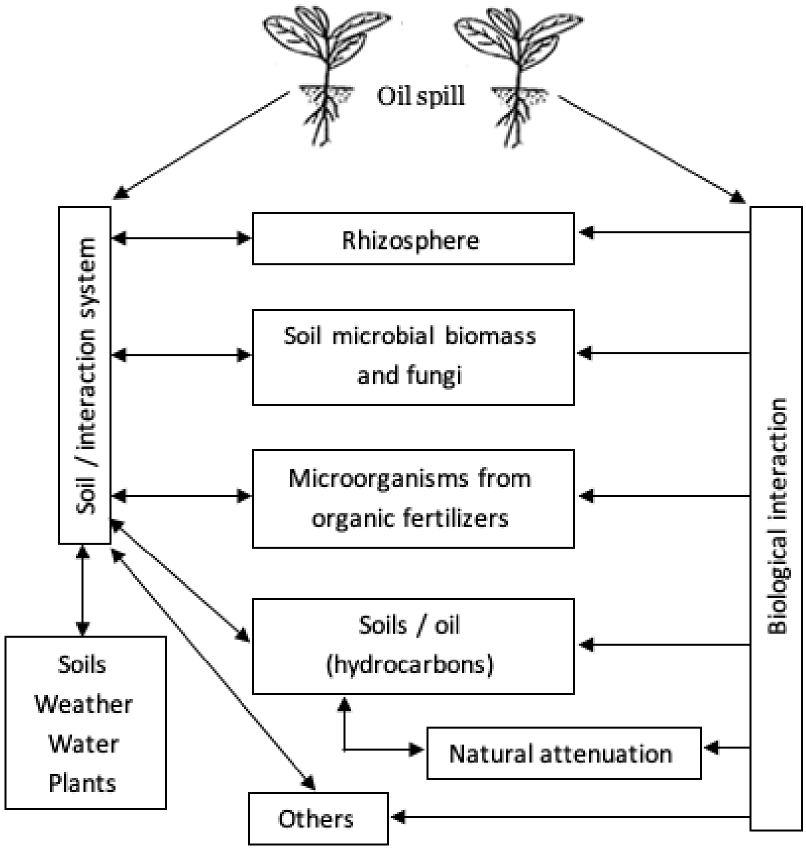
Bacteria excrete enzymes such as oxygenases, laccases, peroxidases, lipases, monooxygenases, and dioxygenases, which act as oxidants, solubilizers, hydrolyzers ant catalyzers for hydrocarbon degradation (Sharma *et al.* 2018). Many of the interactions that occur in the interface soil-microorganisms that are fostered by the same exudates, favor the establishment of bacteria capable of degrading/mineralizing hydrocarbons.

Therefore, as deep as the roots get, as greater the process of bioremediation will be. This process is directed to the elimination of soil pollutants and it is based on two principles: the elimination through convective heat transfer (the transfer of heat by real movement of the molecules of a substance) and biological degradation (Otten *et al.* 1997). This occurs because a complex dynamic microenvironment is created in the soil and it is there where the rhizosphere performs important biogeochemical processes related to plants and soil interaction (Ferrera-Cerrato and Alarcón 2013). This process occurs about 1 and 2 mm thick between the root and the soil that surrounds it, which is where bacteria and fungi can grow and eliminate some hydrocarbon from the soil (Ferrera-Cerrato 1995; Gregory 2006).

Plant growth promoting bacteria can act positively on plants through direct or indirect mechanisms. Direct mechanisms are shown through the capacity of producing phytohormones, or indirectly, by changing the rhizosphere balance favoring beneficial microorganisms and stimulating plant-specific resistance mechanisms and degrading pollutants (Carvalhais *et al.* 2013; Ferrera-Cerrato and Alarcón 2013).

The microorganisms that inhabit the rhizosphere have a positive effect associated with organic fertilizers, because there is interaction inside the soil system (Figure 3) to perform the degradation or complete mineralization of hydrocarbons in less than a year (Ferrera-Cerrato and Alarcón 2013), or natural attenuation is allowed, i.e., without human intervention, through biogeochemical cycles that are performed by soil native microorganisms which manage to degrade the pollutants. However, the time that nature needs to recover may vary from a few days to more than ten years (Fernández-Linares 2013).

Figure 3. Interaction in the soil system affected by hydrocarbons derived from crude oil.



These organisms associated to plant roots provide a complex and dynamic microenvironment with detoxifying potential to degrade harmful organic compounds through the synthesis of amino acids that help plants to supply themselves with water and, at the same time, assimilate growing substances and antibiotics from the soil for their development in polluted soils.

The presence of certain bacterial groups and fungi help plants to face different adverse conditions for growing in contaminated soils (Chan-Quijano *et al.* 2020). In addition, these bacterial groups and fungi have interaction with biochemical signals and biosynthetic reactions with plants, which supply the latter with energy (Parés and Juárez 2002; Pathak and Nallapeta 2014), and thus photosynthesis, oxidation of organic compounds and degradative metabolism of organic substrates are carried on, making microorganisms fix nitrogen (Kim *et al.* 2012). This is the reason why using indigenous plants as strategic elements in the bioremediation of contaminated soils by oil spills is an important alternative in the process of remediation of affected areas.

State of the Art on Soil Contamination Monitoring in Tabasco

In Tabasco, there are studies on oil spills (Sánchez-Pérez 2003), plant toxicity (Rivera-Cruz and Trujillo-Narcia 2004), decontamination of soils polluted by crude oil using indigenous microorganisms (Rivera-Cruz *et al.* 2004), bioremediation processes (Ferrera-Cerrato *et al.* 2006), restoration technologies (Zavala-Cruz *et al.* 2002) and soil fertility (Domínguez-Rodríguez *et al.* 2020).

There are also studies on infrastructure, regional integration and the environment (Uribe-Iniesta 2009), potential species for phytoremediation of hydrocarbon contaminated soils (Ochoa-Gaona *et al.* 2011), application of pre-germination techniques for seeds of tree species (Chan-Quijano *et al.* 2012; 2015), tree species tolerant to different concentrations of hydrocarbons, as well as its development and growth in contaminated soils (Pérez-Hernández *et al.* 2016), socio-environmental impacts (Pinkus-Rendón and Contreras-Sánchez 2012), energy reform, strategies, government, finance and oil (Priego-Hernández 2005; Lajous 2014), and guidelines for the remediation of soils contaminated by hydrocarbons (Chan-Quijano *et al.* 2015).

Likewise, attention has been called to scientific evidence on acclimatization of plants in soils polluted by oil (Chan-Quijano *et al.* 2020). However, this acclimatization is due to the ecophysiological performance of the plants that manage to respond to the type of environment where they get established (Lüttge 2008; Sanesi *et al.* 2011). Through this acclimatization, plants react by slowing down or stopping their basic physiological functions due to the stress they suffer in this environment.

Even though, it is still needed some research on degradation routes, plant physiology of species that acclimatize to contaminated soil by hydrocarbons and its phyllosphere, the synergic or antagonic behaviour of hydrocarbons in ecosystems, remediation techniques, carcinogenic particles in the environment, genetic analysis, and socio-environmental, healthy, and social conflict studies.

Toledo and Vázquez-Botello (1988) proposed a series of measures to monitor the damage of the effects of hydrocarbons. Some of these measures are: evaluating the role of oil hydrocarbons in the environment to monitor and stop the dissemination of harmful particles; evaluating the short, mid and long term effects of pollution on the ecosystems due to oil spills in order to see if there could be any genetic and reproductive changes in the flora and fauna on the affected areas; and analyze if the oil acts cinegetically, independently or antagonically with other toxic substances.

Actual research has demonstrated that we have not even reached half of the measures proposed by Toledo and Vázquez-Botello (1988) three decades ago. According to Silva-Arroyave and Correa-Restrepo (2009), a strategy to regulate the costs of pollution and environmental passives is to generate economic instruments that may incentive the protection and conservation of natural resources. Likewise, the implementation of these economic mechanisms will allow to show the value of the resource "soil" as a provider of goods and environmental services, so that it might be integrated in the income statements of companies.

Analysis of Input-output Charts for Oil Spills[5]

Loyola-Díaz and Torres-Bernardino (2018) mention that the relationship between society and environment and the interactions of the global system are important considering the impact to natural resources caused by the oil industry. Given these impacts, Hernández-Franyuti (2016) affirms that a claim syndrome was generated and, with this, there was an increase in abusive lawyers and corruption, landholders became millionaires (wasting and misusing the money) and, without thinking about the future, they ran out of money. This caused the claim industry to increase, but with more violence.

In this sense, the socio-environmental conflicts that were gradually generated due to oil spills also produced concern for the social and environmental situation. Far from assuming that environmental defense can only be carried out by great government actions, it is necessary to understand that it is not this way (Cossío *et al.* 2014). In fact, many alternatives have been proposed by other people from civil society organizations, research institutes and universities, as well as environmental defenders.

This is how economic-mathematical models have been proposed as action science against oil spills (Gil-Valdivia and Chacón-Domínguez 2008). These tools can help to economically measure the levels of contamination of the oil industry during its processing, thus being able to evaluate the damage caused to society and the environment. In addition, it allows to calculate environmental passives of non-compensated impacts and the infinite price to pay if the damage is irreversible.

Input-output analysis is an economic model to assess the existing relations between the variables that determine the production and consumption functions of a country. It was proposed by Wassily Leontief in the 1930s (Martínez-Alier and Roca-Jusment 2013) and it consists in disaggregating the economy into different sectors, computing periodic monetary flows and making contributions to try to uncover the environmental impacts caused by petroleum industry activities. It also describes the flow of goods and services of different sectors of the economy over a period to calculate the contamination by hydrocarbon spills (Fontela and Pulido 2005; Martínez-Alier and Roca-Jusmet 2013). For this it is necessary to carry out the following actions: a) To observe and monitor the contaminated soil of the affected municipality in different periods of time, and b) To observe and monitor the cost of the activities that the affected municipality carries over time. After these observations, the next steps would be:

1) To estimate the value of what was produced by the municipality every month; this must be multiplied by the cost of the activities. For example, on October 27, 2013, there was an oil spill caused by the explosion of oil well Terra 123 in Oxiacaque, municipality of Nacajuca, Tabasco. In this village, productive activities are small-scale livestock production, farm animal raising and agriculture (Sanchéz-Munguía 2009; Robles-Moreno 2015). In animal production they earned $ 21.60 mexican pesos a day and $324.00 a month for 15 chickens; as there was little livestock production, they sold $ 350.00 per head and $ 3,500.00 a month for 10 heads of cattle, so the value of what they produced in a month was 15 (21.60) + 10 (3500) = 35,324.00 pesos.

2) Therefore, and according to Riera *et al.* (2005), the economic system in the affected area must denote the production of goods as:

$$Q=F\ (Z, K, L)$$

5 It is recommended to check Leontief (1936); Riera *et al.* (2005) and Martínez-Alier and Roca-Jusmet (2013) for a better review of the input-output formulae, and to deepen this analysis.

Q is equal to the production of goods;
Z is equal to the set of inputs that represent the natural and environmental resources, or, if it is required, the natural capital;
L is equal to the input of production;
K is equal to real capital;
F is equal to the relationship of production factors and Q output.

3) Then the damage cost (per period) of the municipality affected by the oil spill is estimated. That is, if there is an oil spill, production value units decrease. For example, due to the explosion, the community was affected by about 20 thousand barrels of oil, that is, 3, 180,000 liters of spilled crude oil (Hernández-Román 2014). Therefore, within environmental economy it is important to determine the amount of natural and environmental resources that are being affected by oil spill pollution.

So, who should pay for the damage? The one who polluted or the victim of the contamination? And who will pay for the external environmental damage produced? These are some of the questions that Riera *et al.* (2005) and Meixueiro-Nájerapues (2007) have asked, since they argue that not only the polluter is guilty and that is why *the principle of victim pays* is created, i.e., that citizens also have the responsibility to accept and support the care and recovery of the affected areas. However, this is scarcely accepted by the society.

In addition, Martínez-Alier and Roca-Jusment (2013) mention that if the environmental impact affects directly the production of goods and the damage is small, it is important to address it, since the total impact will be very big due to the fact that the sector is supplied with a significant amount of inputs and production is purely environmental, so the problem will be serious, as it is the case of soils contaminated by oil spills.

On the other side, with this analysis an important government investment could be carried on not only to stimulate the development of the economy, but also to reduce both the direct and indirect environmental consequences of such a development (Shmelev 2012). In addition, it would also be an opportunity to reorient decision making about environmental responsibility and sustainability towards the oil industry. Martínez-Alier and Roca-Jusment (2013) mention that in order to create a kind of politics that allows to get the impact of oil spill contamination and hydrocarbon concentrations [mg kg-1], it is necessary to take into consideration the level of economic growth, a change in the productive structure derived from the demand and the relation between contamination and production unit of different sectors (measured in constant prices).

Therefore, when integrated into environmental problems, input-output analysis in economy allows to estimate physical and structural flows, i.e., it provides a fundamental requirement in the integration related to the economic activity, valued in monetary terms, and the one corresponding to the environment, estimated in physical terms (kilograms, tonnes of oil equivalent, emissions of pollutants; Shmelev 2012; Martínez-Alier and Roca-Jusmet 2013). Labour, material and or equipment costs must also be considered, as well as the direct and indirect costs of contaminated soil remediation (Wan *et al.* 2016).

Shmelev (2012) mentions that input-output analysis has been linked to the environment through multi-criteria decisions to identify direct and indirect impacts on the different economic sectors to make them more sustainable. For this reason, Fontela and Pulido (2005) made a synthesis of the input-output analysis as a technical instrument to build both descriptive and planning economic models that, in this case, can be adapted to an action context for the economic evaluation of contaminated soils by oil hydrocarbons (Figures 4 and 5).

Figure 4. Descriptive model for economic evaluation of soils affected by oil pollution. Source: taken and modified from Fontela and Pulido (2005).

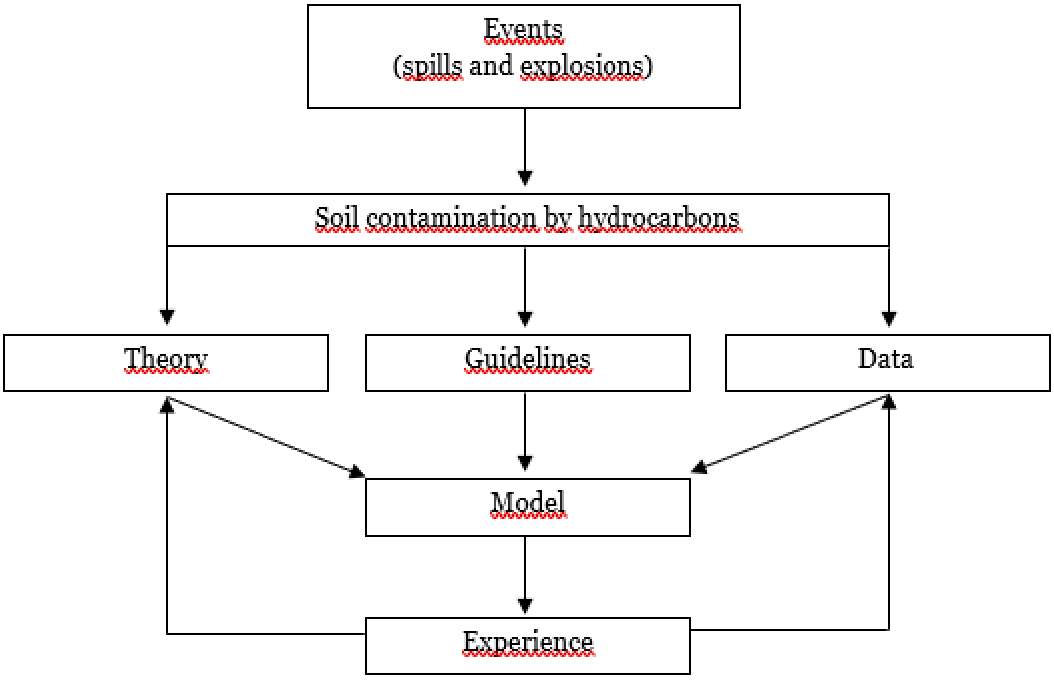
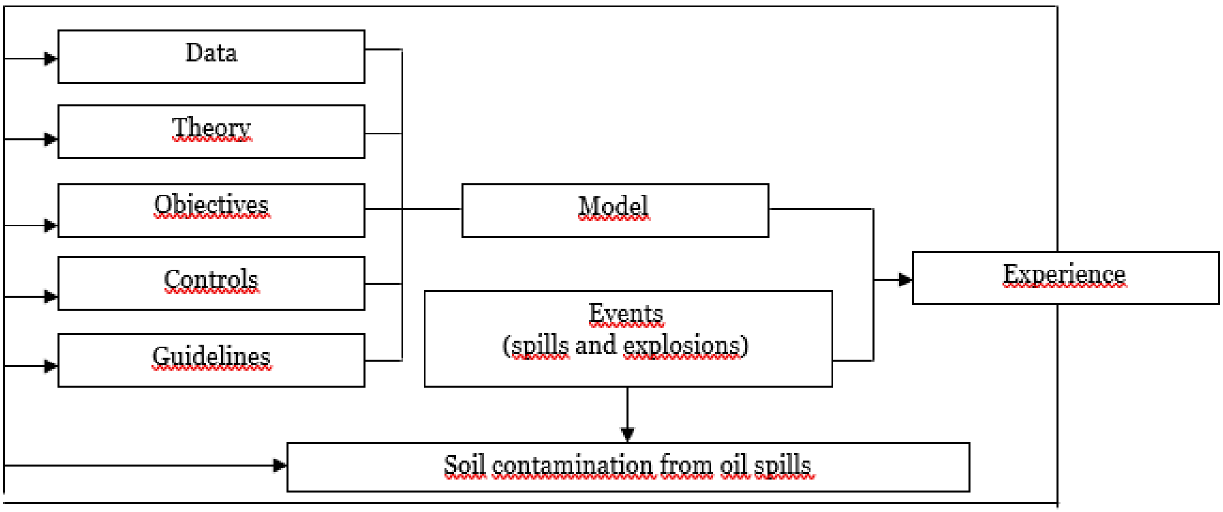


Figure 5. Planning model for economic evaluation of soils affected by oil pollution. Source: taken and modified from Fontela and Pulido (2005).



Hydrocarbon toxicity in tropical soils is still to be studied but, regulatorily speaking, the way the final deposition should be treated is not taken into consideration, since oil dispersion routes can reach the coastal lagoons. For this reason, Larios-Nossif (1988) mentions that the recovery and remediation of the affected area is not only a government's obligation, but also a moral responsibility of the society.

However, the conjuncture of the oil boom in Tabasco caused an environmental impact such as salinization, water retention and contamination (Uribe-Iniesta 2009), as well as health problems in people living nearby the oil wells. This problem has not been taken in consideration into the public policies to protect the inhabitants' health. Regarding the environment, those areas should be remediated by performing preventive and corrective actions, as well as a permanent monitoring of recovery and remediation activities in order to be in harmony with the ecosystems of the place and with the society (Larios- Nossif 1988; Cossío *et al.* 2014).

In this context, laws and regulations do not mention what should be done when there are environmental passives, which are those contaminated spaces or places that were not timely remediated due to the release of hazardous materials or waste (including evident hydrocarbon stains, location of abandoned buried tanks, bodies of water with hydrocarbon stains, to name a few).

In addition, these laws do not mention what to do when potentially contaminated sites are located and have not been registered, nor consider the historical environmental information of the site and the geophysics, electrical tomography, and different depths of pollutant penetration. However, despite the fact that there are laws on the care and protection of the environment in Mexico, environmental damage still remains, and contamination by oil spills is still increasing and it even exceeds the maximum allowable standards that the regulations hold and this could short term affect the environment and human health.

Perspectives and Final Considerations

Although soil contamination in Tabasco has been approached from social, environmental, and economic perspectives, more specific studies are still needed, especially in ecological restoration, edaphology, ecology, soil chemistry, plant ecophysiology, phyllosphere and agronomy. To carry out a comprehensive work, it is necessary to assemble a multi-disciplinary team to come up with more viable, economical, and socially beneficial alternatives that allow us to guarantee next generations sustainability.

In Tabasco, research on health problems that may be developing on people leaving nearby areas affected by oil spills is still scanty. Consequently, there is a need to implement a municipal or regional state program to approach the health issues related to soil contamination by oil spills or to work with the SEMARNAT (Secretaría del Medio Ambiente y Recursos Naturales) [Mexican ministry of natural resources and environment], the SSA [(Secretaría de Salud) Mexican ministry of health] and the medical area of PEMEX.

It is necessary to relate environmental care, the fight against pollution and soil conservation to achieve good handling and exploitation through the development of special programs with a multidisciplinary research team for a proper evaluation of the most sensitive biological communities and thus apply to production costs the idea of the one who contaminates pays. It is also necessary to have support strategies for the society considering the recovery of contaminated areas through public policies in accordance with the contamination zones, since many times pollutant concentration in the soil exceeds the established regulations. In response to this, some guidelines oriented to the use of biotechnologies have been created for the recovery of contaminated soils. In addition, in the case of legislative absences for potentially contaminated sites that are not identified, satellite images and geographic Information system should be used, and field trips should be made to verify if the identified sites correspond to potential environmental passives.

The protection of the soil resource must be a national and international policy and with input-output analysis we can ensure the cost of contamination and thereby carry out the restoration of the affected ecosystem and, at the same time, manage it properly for its recovery. Simultaneously, socio-environmental, and socio-ecological indicators must be developed to assess the quality of the affected soil, as well as human health and the conflicts that may arise before and after an environmental contingency.

It is important to note that PEMEX is still discovering more oil in Tabasco's territory, but many people living in the so-called Mexican Eden have the next questions: is that good or bad? How many more oil spills do we need to be aware of and understand that our ecosystems are sensitive? The truth is that oil spills have been a problem, which has already been studied by many researchers from different branches of science, but they will still be investigated if the necessary attention is not paid to them and it will be a more serious problem every day. We must remember that the earth is only one and we must be aware of what it provides us, such as ecosystem services.

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