Investigation note

# Methodological proposal for the analysis of environmental vulnerability to a possible spill of polyducts and oil pipelines

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## Abstract

The hydrocarbon industry in Colombia is one of the most dynamic, compared to other mining production fronts. Hydrocarbons have become fundamental elements for the development of society, in the economic, political, environmental and social fields. However, its exploitation, together with the topographic and climatological characteristics of Colombia, have become a threat to the environment, since the probability of a spill is high, which directly or indirectly has toxic effects on fauna, flora, bodies of water and the general population. These alterations cause interference in the reproduction, growth and behavior of animals. They affect root systems causing leaf fall and tree death. Additionally, it causes economic losses and migration of the affected population, due to the difficulty of quickly eliminating the pollutant, which causes short, medium and long-term impacts.

**Keywords:** hydrocarbons, mining, pollutant.

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The lack of studies that will integrate environmental variables did not allow vulnerability to be analyzed considering the complexity of the geographic space, for which the establishment of a methodology based on the use of geographic information systems was required, which would determine the degree of vulnerability of habitats with direct or indirect influence with polyducts and oil pipelines, by assessing the impacts generated on populations and natural ecosystems, by extraction and a possible oil spill.

As a measure to carry out a possible predictive analysis of the impacts generated by this phenomenon, spatial analysis with geographic information systems has been one of the most widely used tools to determine the sections that could cause the greatest impact on the environment, by simulating possible superficial spills, therefore this methodology allowed analyzing the elements of the medium that were found along a pipeline, taking into account the interaction between each one of them.

In order to carry out an integrated analysis of environmental factors and their relationship with the environment, the elements of the ecosystems and the possible causes were prioritized by using the hierarchical analysis process methodology proposed by Saaty (2018), to determine what the interaction is. Therefore, with this proposal, a methodology was developed for the analysis of environmental vulnerability to a possible spill from the polyducts and oil pipelines, considering the biotic, abiotic and socioeconomic factors.

**Definition of the problem**

The hydrocarbon industry in Colombia, today is one of the most dynamic, compared to other mining production fronts. Hydrocarbons have become fundamental elements for the development of society, since it is not limited to the economic sphere, but also addresses politics, the environment and the social factor of a society (Martínez, 2012).

The production of hydrocarbons in terms of geographic coverage is found in sedimentary basins and covers approximately 646 000 $km^2$, which is equivalent to 40% of the national territory. This is distributed throughout all the natural regions of the country, including the continental shelf of the Atlantic and Pacific oceans (ANH, 2011).

The geographical location and the climatic characteristics of Colombia make it a nation with great biodiversity (Andrade, 2011a); therefore, it is a country potentially vulnerable to events of anthropogenic and natural origin, which increase the probability of impact due to an eventual oil spill, since the infrastructure of mining activity coincides with the bordering areas of the national natural parks (PNN).

The impacts generated by the oil spill cause toxic effects on fauna and flora due to the physicochemical composition, causing the variability of biological systems. These alterations cause interference in the reproduction, growth and behavior of animals. They affect root systems causing leaf fall and tree death. Additionally, it causes economic losses and migration of the affected population. The magnitude of the damage caused is reflected by the amount of oil spilled, since a small amount of oil in a vulnerable area can cause much more damage than a large amount of spill in a less vulnerable area (Etter *et al*., 2008).

Some studies carried out by the ombudsman's office have determined that in Colombia the oil spill is eleven times more than the spill that occurred in 1989 by the oil tanker Exxon Valdez, in Alaska, classified as the incident with the highest contamination and impact environmental in the world, whose effects have not been fully remedied (Ruiz, 2004).

Oil spills in the country occur accidentally as a result of the failure and deterioration of the infrastructure used, but most are attributed to the blasting of pipelines by armed groups present in Colombia, according to the Ombudsman's Office (Andrade *et al*., 2012; Franco *et al*., 2013).

Spatial analysis with geographic information systems has been one of the most widely used tools to determine the sections that could cause the greatest impact on the environment, by simulating possible surface spills. This methodology allows analyzing the elements of the medium that are found along the pipeline, without taking into account the interaction between them. To carry out an integrated analysis of environmental factors and their relationship with the environment, methodologies must be complemented with existing methods in order to determine the interaction of each of the elements with the pipeline.

The lack of studies that integrate the variables of the environment and allow the vulnerability to be analyzed considering the complexity of the geographic space, requires the establishment of a methodology that, based on the use of geographic information systems, determines the degree of vulnerability of the habitats that have direct or indirect influence with polyducts and oil pipelines, by evaluating the impacts generated on populations and natural ecosystems, by extraction and a possible oil spill, for which this research aims to answer the following question: in what way can oil spill modeling and vulnerability assessment be integrated into a methodology to classify polyducts and oil pipelines according to the impact on the environment?

## Justification

The extraction of hydrocarbons in Colombia, has generated in its different stage's environmental impacts, pollution and changes in biotic, abiotic and socioeconomic factors. The effects of the hydrocarbon on each of the factors can be caused, either by its physical properties or by its chemical components, generating great concern, since accidental spills often cause contamination of habitats and bodies of water. Therefore, the formulation of new methodologies is required for the analysis of the effects that, directly or indirectly, may affect ecosystems and the population in general.

Additionally, no tools have been developed in the country that provide information to assess the vulnerability of all factors to environmental impacts, as a result of oil spills. Therefore, it is necessary to develop a methodology that improves the study against this problem and contributes to the development of new knowledge in the country.

**Vulnerability**

Vulnerability is described as the degree of physical, biotic and socio-economic and cultural sensitivity to anthropic activity or a natural event. It is used as a tool that reduces the uncertainty of the data that is analyzed against the damage or exposure of an environmental aspect, which are based on environmental indicators and do not depend exclusively on the weighting prepared by the evaluator, but are also determined by the status of the site indicators, where the activities and projects involved are carried out. The concept of vulnerability reduces subjectivity in the results obtained, since the interpretation is influenced by the pressure of the projects on each of the components of the environment, which is why it is important for the compression of alterations that are generated in the ambient.

Vulnerability in more general terms is defined as the susceptibility to damage, due to the sensitivity or exposure of a system, people and places to impacts or disturbances and the capacity of the system to adapt to changing conditions (Kelly and Adger, 2000; Smith and Pilifosova, 2002; Luers *et al*., 2003; Turner *et al*., 2003).

**Multicriteria analysis**

Multicriteria analysis is a set of techniques, models, methods and tools that aims to improve the overall quality of decision processes in terms of effectiveness, effectiveness and efficiency and thus increase knowledge of them. The use of these techniques allows the realization of a more realistic and at the same time more practical resolution without taking into account other factors that give erroneous results 1. This analysis compares the alternatives that can be both qualitative and quantitative, using scores obtained of different criteria (Belacel, 2000; Smith *et al*., 2000).

**Hierarchical analysis process (PAJ)**

The hierarchical analysis process was developed by Thomas Saaty in the late 1960s, who, based on his teaching experience and military-type research, designed a tool that would facilitate decision-making on a particular issue, which has the basis of many software packages has been applied to complex decision-making processes.

The PAJ is a methodology to structure, measure and synthesize data, where alternatives are evaluated when several criteria are taken into account, and is based on the principle of the experience and knowledge of the actors involved and the data used in the process the data used in the process (Frei, 1998; Fulcrum, 2000; UNAM, 2001; Bahurmoz-Asma, 2003; Bascetin, 2004; Subramaniam, 2009).

The hierarchical analysis process uses comparisons between pairs of elements, building matrices from these comparisons, and using elements from matrix algebra to prioritize elements on one level, relative to an element on the next higher level.

When the priorities of the elements in each level are defined, they are added to obtain the global priorities against the main objective. The results versus the alternatives then become an important support element for those who must make the decision (Figure 1).

The procedure to use the PAJ can be summarized in the following premises: the first step of the PAJ is to model the decision problem to be solved as a hierarchy, decision making is a process of selection among alternative courses of action, based on a set of criteria, to achieve one or more objectives (Figure 1).

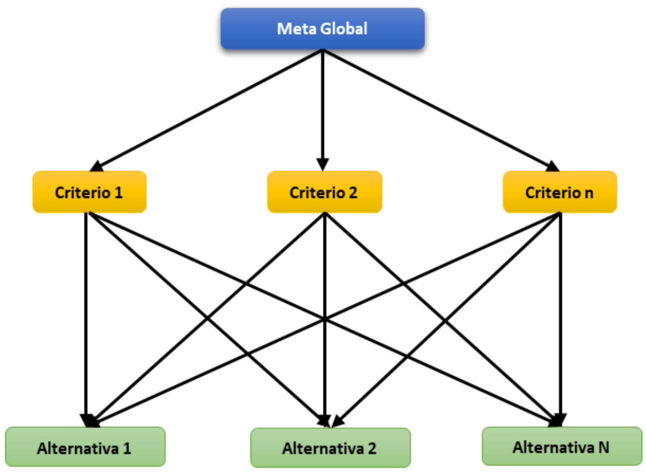


**Figure 1. Schematic hierarchical analysis process (Saaty, 2008).**

## Environmental zoning

Environmental zoning is a valuable tool for planning and using natural resources, in its environmental management units are identified according to the extraction rate, use capacity, cultural heritage of the communities and self-recovery capacity of the ecosystems (Cardozo and Quintero, 2000).

The comprehensive analysis of the criteria allows the definition of strategic ecosystem management areas, recovery, sustainable use, sustainable production, and urban and suburban areas, which provide guidelines for the definition of integrated management guidelines for the area, so that the environmental zoning is constituted as a tool for the ordering and management of the territory, which is based on the definition and integration of criteria that consider biophysical, socioeconomic and governance aspects (Rodríguez *et al*., 2012).

A Geographic Information System (GIS) is a set of specific components that allow end users to create queries, integrate, analyze and efficiently represent any type of referenced geographic information associated with a territory. Geographic information is going to be that information that has some spatial component; that is to say, a location and, an attributive information that details us more about that element in question. This location can be defined with a street name, for example, or with spatial coordinates (Martínez and Coll, 2005).

A Geographic Information System (GIS) allows any type of data to be related to a geographical location. This means that in a single map the system shows the distribution of resources, buildings, populations, among other data from municipalities, departments, regions or an entire country. This is a set that mixes hardware, software, and geographic data and displays it in a graphical representation. GIS are designed to capture, store, manipulate, analyze and display information in all possible ways in a logical and coordinated way. In general, GIS are used for the storage, analysis and integration of field data, information from remote sensors (aerial images or photographs), mapping, statistics and community perception.

**Project development**

In order to carry out the multi-criteria evaluation using the hierarchical analysis process (PAJ) method proposed by Saaty (2008), the decision units were defined, establishing as criteria the environmental and alternative components, the consequences that are generated in the event of a possible oil spill, where the hierarchical structure is established and the weighting is carried out to determine which criteria may be most affected compared to the evaluated alternatives, to identify the most vulnerable components of the environment; therefore, after carrying out the expert judgment (Table 1), it is established that the water bodies (59%) and the vegetation cover (26%) present the highest values of vulnerability to a spill (Figure 1), since the affectation in these environmental components can generate extremely negative impacts.

**Table 1. Comparison matrix of pairs-environmental components.**

| | Vegetable cover | Tracks | Population | Water bodies | Normalized matrix | | | | Average vector |
|---|---|---|---|---|---|---|---|---|---|
| Vegetable cover | 1 | 9 | 5 | 1/5 | 0.158451 | 0.375 | 0.378788 | 0.137555 | 0.262448 |
| Tracks | 1/9 | 1 | 1/5 | 1/9 | 0.017606 | 0.0416667 | 0.015152 | 0.076419 | 0.037711 |
| Population | 1/5 | 5 | 1 | 1/7 | 0.03169 | 0.208333 | 0.0757576 | 0.098253 | 0.103509 |
| Water bodies | 5 | 9 | 7 | 1 | 0.792254 | 0.375 | 0.530303 | 0.687772 | 0.596332 |
| Sum | 6.311111 | 24 | 13.2 | 1.453968 | | | | | |

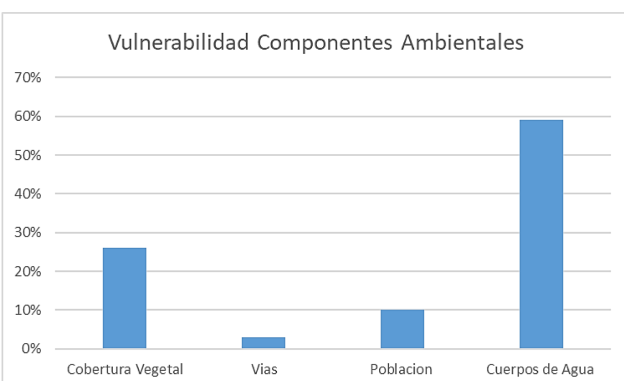


**Figure 1. Vulnerability to environmental components.**

According to Almeida (2006), oil exploitation activities generate destruction of biodiversity and the environment in general, where the affectations of this activity generate damage mainly to vegetation cover and water bodies.

Likewise, as mentioned by Di Toro *et al*. (2007), studies carried out on the environmental fate of oil show that although the toxicity of crude oil decreases with biological or physical degradation, it continues to be a source of contamination and toxicity for organisms present in an ecosystem for a long time, therefore that the population, the bodies of water and the vegetation cover are conducive to damages when oil spills occur, whether due to structural damage, fires, explosions or the presence of sliding surfaces (Figure 2).

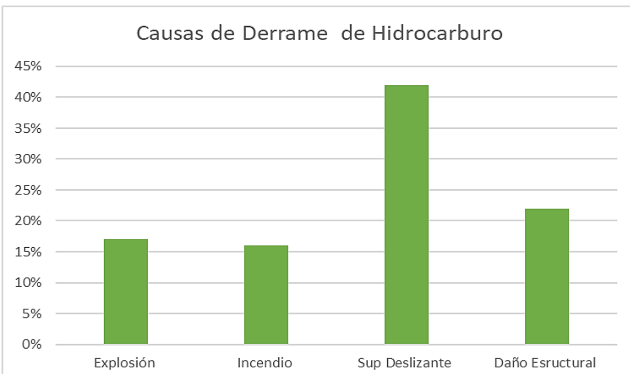


**Figure 2. Vulnerability to environmental components.**

According to the prioritization of the consequences of hydrocarbon spills with respect to environmental criteria, issued by the judgment of experts, it is determined that the sliding surface is the event that causes the greatest vulnerability in the environment with a weighting of 42% (Table 2), where Atlas and Bartha (2002), support this hierarchy, since for these researchers oil accidents can be more easily contained in the environment, because hydrocarbons are low viscosity fluids and can penetrate underground and persist, due to the prevailing anoxic conditions, as well as contamination due to the persistence of the spill in the aquifers.

**Table 2. Prioritization of the consequences of oil spills *vs* environmental components.**

| | Vegetable cover | Tracks | Population | Water bodies | Total |
|---|---|---|---|---|---|
| Explosion | 0.33419491 | 0.22037273 | 0.58859181 | 0.038084837 | 0.17965483 |
| Fire | 0.27954461 | 0.04174896 | 0.24238322 | 0.111019581 | 0.1662337 |
| Sliding surface | 0.23167764 | 0.63621376 | 0.04498064 | 0.568472032 | 0.42844966 |
| Structural damage | 0.15458284 | 0.10166454 | 0.12404433 | .0282423551 | 0.22566181 |
| Weighing | 0.26244829 | 0.03771076 | 0.10350858 | 0.596332369 | |

## Conclusions

Both Laurance (1989); Reyes and Ajamil (2005), consider that habitat losses as a consequence of their own activities for the exploitation of hydrocarbons are one of the items for which biodiversity has been notoriously lost and this is very evident today since in the in areas typical of this type of activity, it is common to see areas of erosion due to the devastation caused by the cutting down of trees, as well as the impacts on the vegetation cover, water bodies, population, and even roads when there are spills of this product.

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