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Original
Environmental monitoring in a Cuban oil storage plant to characterize the hydrocarbons pollution exposure in the fence-line community / Castro Rodríguez, David Javier; Gutiérrez, Omar; Poma, José; Acosta, Jelvys; Demichela, Micaela. - ELETTRONICO. - 31:(2021), pp. 2299-2304. (Intervento presentato al convegno European Safety and Reliability Conference tenutosi a Angers, France nel 19-23/09/2021) [10.3850/978-981-18-2016-8_649-cd].

Availability:
This version is available at: 11583/2927974 since: 2021-09-29T11:17:22Z

Publisher:
Research Publishing, Singapore

Published
DOI:10.3850/978-981-18-2016-8_649-cd

Environmental monitoring in a Cuban oil storage plant to characterize the hydrocarbons pollution exposure in the fence-line community.

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Due to the wide application of oil in industry, large amounts of petroleum hydrocarbons have been annually released into the environment. Legacy contamination and its interaction with other risks, continue impacting a new generation of residents in the fence-line communities. The goal was to characterize the hydrocarbon pollution which could impact on the community living near to an oil plant. A Cuban oil storage plant was analyzed as a case study, in order to address the environmental monitoring of physic-chemical parameters from process industry, as factors which may be used in the spatial modelling of local vulnerability and communities resilience analysis. Firstly, the engineering research on the interest area were reviewed, from which, four comprehensively geographical strata were established. Furthermore, 19 wells were identified around the industry, which were almost exclusively used for human being consumption water. Subsequently, a monitoring program upstream, downstream and inside the plant was design. The lab results regarding hydrocarbons, fats and oils, and organic load frequently trespassed the standard requirements. The causal analysis suggested that the contamination with hydrocarbons in the aquifer was produced by infiltration in the unsaturated area, derived from the poor management of oily residuals in the plant. The results highlighted the negative impacts linked to the plant operations, which have acted as a dynamic stressor against the territory, increasing the vulnerability on the local community. The case study results not only contributed to raise the vulnerability awareness in the decision-making process, but also, have supported the effectiveness of the framework adopted.

Keywords: aquifer, local vulnerability, hydrocarbons pollution, oil storage plant, monitoring, spatial modeling, resilience analyses.

1. Introduction

The United Nations Agenda in 2015 presented a comprehensive vision about sustainability and set the Sustainable Development Goals (SDGs), showing how sustainability aims at reaching certain goals which are specified in advance and can be achieved through the transformation of a system. (Voghera and Giudice, 2019). Particularly, SDGs 3 underlined the importance of substantially reducing the number of deaths and illnesses from hazardous chemicals, pollution, and contamination, in order to ensure healthy lives and promote well-being for all. (ONU, 2015).

With industrial development, there is an increase in the amount of oil used, and due to this wide application of petroleum products, large amounts of petroleum hydrocarbons are annually released into the environment. (Yu et al., 2017). Pollution from hydrocarbons poses a variety of serious hazards to the environment and human health. (Abouee et al., 2019). On the one hand, the presence of this pollutant in soil has damaging consequences on living organisms and on the ecosystem, as it has direct toxic effects and provoke changes in the chemical and physical properties of the soil, such as the oxygen diffusion or water content capacity. In addition, this kind of impacts causes extensive damage to the ecosystem since accumulation of pollutants in the tissues of animals and plants may cause progeny death or mutation. (Bosco et al., 2019a). Moreover, these compounds pose a serious threat to humans too, due to their genotoxic, mutagenic, and carcinogenic potential. (Sangeetha and Thangadurai, 2014). Furthermore, the International Agency for Research on Cancer (IARC) considered hydrocarbons for the assessment of cancer risk from contaminated sites. They have further been classified as probable/possible human carcinogens by the United

Proceedings of the 31st European Safety and Reliability Conference
Edited by Bruno Castanier, Marko Cepin, David Bigaud, and Christophe Berenguer
Published by Research Publishing, Singapore.
ISBN: 978-981-18-2016-8; doi:10.3850/978-981-18-2016-8_649-cd

States Environmental Protection Agency (US EPA). (IARC, 2010); (OEHHA, 2015).

Moreover, researchers are considering acute exposures resulting from inadvertent industrial releases, including those resulting from extreme weather events linked to climate change. In this sense, oil industry is not the exception. Pollution by hydrocarbons has, in general, an anthropogenic origin, often due to accidental spills, stockpile leakages, mining and improper or illegal behaviors in waste treatment and disposal. (Bosco et al., 2019b). Consequently, the legacy contamination continues to adversely impacts the residents in fence-line communities, while the interaction with other cumulative risks may amplify these adverse effects. (Johnston and Cushing, 2020). Hence, the ability to identify all the possible risks and hazards in locations surrounding industrial plants has become very important for the correct assessment of the economic, physical, and human dimensions of the disaster. (Rebeeh et al., 2019).

Regarding these dimensions, vulnerability is mainly identified as "exposure to the risks in terms of population" according with the criteria of Pilone, et al. (2019). In addition, vulnerability, is also recognized as the sum of a linear or nonlinear relation between sensitivity, exposure, and the coping capacity. (Brunetta and Salata, 2019). Therefore, the measurement and representation of vulnerability result a central issue in order to develop a systematic analysis of the state and pressures of the communities. The previous statement agrees with the concept argued that community is defined as a location-based entity that can be as small as a neighborhood or as large as a country. (Mulligan et al., 2016). In the present research the smaller definition was considered to address the local vulnerability analysis.

Despite of several research have been contributed to the state-of-the-art of resilience analyses throughout the application of techniques commonly used in planification of territories; little attention has been paid to the integration of environmental chemistry and industrial management tools as factors which may be used in the modelling of vulnerability against the legacy contamination provoked by process industry, which impacts the residents in the local communities.

Given all above, the goal was to characterize the hydrocarbon pollution exposure which could impact on the community living near to an oil plant. A Cuban oil storage plant was analyzed as a case study, in order to address the environmental monitoring of physic-chemical parameters from process industry, as factors which may be used in the spatial modelling of local vulnerability and communities resilience analysis.

2. Materials and Methods

2.1. Brief description of the case study

The oil storage plant (ECCVC in advanced) is located at the middle of the country, in Santa Clara City, Cuba. Specifically, at coordinates N 22°25´10.66´´and W 79°58´35.84´´. This industry belongs to the Cuba Petroleum Union (CUPET), inside of Ministry of Energy and Mines. Figure 1 shows the ECCVC location and the analyzed surrounding areas.

Fig. 1. ECCVC location in Sub Planta Neighborhood, Santa Clara, Cuba and Representation of land strata in satellite view.

The ECCVC is composed by the following physical facilities:

- socio-administrative building
- warehouses
- fuel deposit 440.

In the fuel deposit 440 are carried out the reception, storage, and the delivery of fuels liquid. There are 19 storage tanks for diesel, kerosene, lubricants, oils used also exist facilities for the loading of fuels. A workshop and scrubber plant services for fuel transportation trucks, are also set in the deposit 440. Finally, there is a collection, treatment, and disposal system ("the system" in advance) for industrial wastewater and oil sludge.

The system is composed by following elements:

- A stabilization lagoon
- API physical separator
- Pipeline system
- Receptor bodies in the environment.

The lagoon with an operating surface of approximately 552.00 m^2, receives petroleum wastewater from any structure for confinement in the deposit 440, also from tanks purge and the effluent of API separator.

The API separator presented all its compartments saturated with oily residues of colors that vary among reddish, orange, and yellowish. It receives the wastewaters from workshops and scrubber plant services.

The receptor bodies in the environment are composed by a trench that was born near the fence perimeter in the northwest sector of the storage plant and conduce the fluids through a stream which is tributary of the *Arroyo Grande* Stream, which in turn, integrates the *Cubanicay* River. This river is channeled through agricultural exploitation areas and is qualitatively classified according to Cuban's standards as: Rivers and Streams, Class B. This category corresponds with "Rivers, reservoirs and hydrogeological areas where waters are collected for agricultural irrigation especially where there are crops that are consumed raw, as well as bodies of water that are exploited for industrial use in processes that need water quality requirements". Despite superficial waters were classified as a principal recipient body, also soils and groundwaters were of enormous interest to the research, due to the aquifers of the zone was used as human being consumption water for the neighborhoods near the ECCVC.

2.2. Methodology

First, the engineering background research on the interest area were reviewed. The previous investigation was totally composed by technical reports which includes construction projects, maps, topographic information, geology and hydrogeology of the site, and a qualitative environmental diagnosis of ECCVC. (ENIA, 2013).

Second, the procedure of eight-step in the problem solving was adopted, which allowed to introduce different engineering tools fallowing the methodologic convergence principle. (Gutiérrez and de la Vara, 2013).

Subsequently, a monitoring program upstream, downstream and inside the plant was design with the purpose of characterize the hydrocarbons pollution of ECCVC. Integrated monitoring of risks for Seveso plants criteria were chosen, in agreement with the described for Baldissone et al. (2018).

The selection of the sampling stations was carried out using a non-random procedure, where the expert selection was chosen as the criterion. Decisions were based fundamentally on the physical elements selectable for taking samples, their location, the homogeneity of the matrix and the pollutant to be analyzed. The scope of the sampling program was limited by economic and logistical criteria as well as ethical issues such as the privacy property. Table 1 contains the characteristics of the sampling stations. The environmental samples and the analytic quantification were developed by a certified laboratory according to the stablished standard.

Table 1. Characteristics of sampling stations.

Stations	**Classification**	**Type**	**Test**	**Frequency**
1	Tributary API	composed (water)	Fats & Oils	(1) 24.nov.2011 (2) 1.jun.2012
2	Effluent API	composed (water)	(F&O), BOD_5,	(3) 4. sept.2012 (4) 8.nov.2012
3	Final Disposal	composed (water)	COD. (For all water	(5) 4.may.2013 (6) 5.jul.2013 (7) 23.oct.2013
4	Recipient body	Punctual (water)	samples)	(7) 23.oct.2013
		Sediments	TPH	(1) 24.nov.2011

The stratification area was a central issue in order to sample the groundwater. The following criteria were considered.

- potential pollution origin,
- characteristics of the recipient body
- coexistence of other industries that dispose oily waters.

Four geographical strata were established, as could be appreciated in the Figure 1. They are described below:

(i) Stratum I: It corresponds to the area within the ECCVC where fuel storage and transfer operations are carried out. It constitutes the potential source of contamination.

(ii) Stratum II: It covers the southwest area of the entity, close to the fuel storage area. It is in the area with the highest altitude elevation, is the zone located upstream the ECCVC. Other industries are in this stratum, for instance: a meat company and transportation unit. A little further, is located a fuel-oil power plant. The community settled in this stratum has rural characteristics.

(iii) Stratum III: It is located at north and east of the ECCVC. For its southern part, it borders strata II, I and IV in that order from west to east. It includes a furniture factory, an animal feed storage plant and a mayonnaise fabric, as well as other plants like fishmongers and a drilling and construction company. The settled community of this stratum has rural characteristics.

(iv) Stratum IV: It is located south-east of the industry, near the ECCVC scrubbing plant. A diesel generator set is located in the upstream zone. The community that populates this stratum presents a level of urbanization higher than strata II and III.

The physic-chemicals parameters selected during the characterization were chosen from established national and international standard which are listed below:

(i) (ONN-National Office of Standardization): NC 93-02: 1985 "Drinking water. Sanitary requirements"

(ii) NC 27: 2012 "Discharge of wastewater to terrestrial water and sewage-Specifications"; NC 1021: 2014 "Sources of water supply. Quality and sanitary protection"

(iii) NC TS 1067: 2015 "Petroleum industry - Used lubricating oils-Specifications").

(iv) NC 1021:2014 “Communal hygiene - Water supply sources - quality and sanitary protection (Mandatory)”

(v) SEMARNAT- Secretary of Environment and Natural Resources) NOM-138-SEMARNAT / SSA1-2012 “Maximum permissible limits of hydrocarbons in soils and the specifications for their characterization and remediation”.

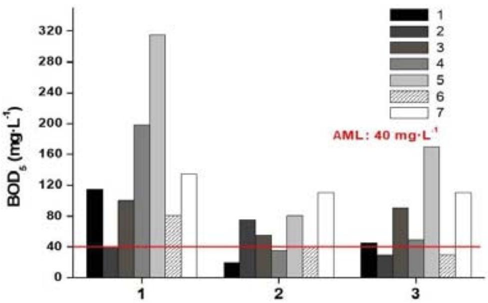
3. Results

3.1. *Background review*

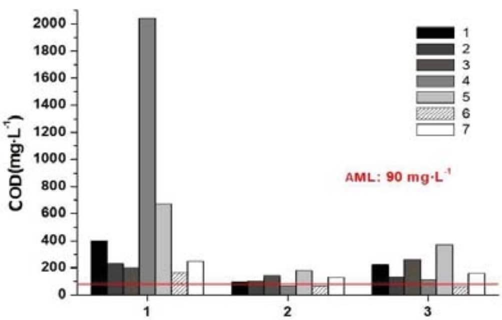
The reviewed engineering research background offered the behavior of the underground flow direction. Indeed, it revealed that the basin run in the north-northeast direction, with the upstream corresponding to the south-southwest sector of the ECCVC. Likewise, the previous studies provided elements about the composition of the rocks, which have several cracks, enabling the passage throughout, not only of water, but also of viscous contaminants (ENIA, 2013).

3.2. ***Wastewater sampling stations***

Figure 2 shows the behavior of the variables BOD_5 and COD in stations 1, 2 and 3. BOD_5 is an indicator which determine the amount of oxygen needed by microorganisms to decompose the organic matter present in wastewater. The higher the organic matter present in the wastewater, the higher the BOD_5 is required for the decomposition. On the other hand, COD is the amount of oxygen required to oxidize chemical substances present in wastewater. COD also increase with increase in chemical substances in water.



a)



b)

Fig. 2. a) BOD_5 and b) COD behavior during the monitoring time.

Station 1 corresponds to the affluent of API separation system. Due to the wastewater in 1 have not received a treatment yet, then, it was excluded from the contrast with the Average Maximum Limit (AML line). In this station a fluctuating behavior is appreciated and the peaks in the reported values of BOD_5 and COD are notable, the most critical were which corresponding with November 2012 and May 2013 with a value of 315 $mg \cdot L^{-1}$. The results obtained in stations 2 and 3 were contrasted with the AML for both variables analyzed. In both cases, 71.42% of the samples trespass the threshold for the characteristics of the recipient body. The BOD_5/COD ratio is often lower than 0.5 suggesting the presence of toxic substances that delay or inhibit biodegradation. Table 2 shows the results of fats and oils (F&O) in the period.

Table 2. Results F&O from the wastewater sampling.

Frequency Station	1	2	3	4	5	6	7
1	151	71	3110	242	16.5	3.3	15.1
2	*	3.2	10.7	4.1	6.5	2.95	4.3
3	**	11	11.1	6.7	22.3	*	6.0
4	3260	TPH (sediment) ($mg \cdot kg^{-1}$)			F & O (water)		4700

F & O (water): AML for recipient's bodies class B = 10 $mg \cdot L^{-1}$
*< D.L Below the detection limit
**< Q.L Below the quantification limit

As could be seen in Table 2, F&O had a variable behavior in station 1, reporting a peak of 3110 $mg \cdot L^{-1}$ in September 2012. It is remarkable that this station receives the wastewater from the scrubbing plant of fuel transportation trucks. Station 2 do not indicate serious problems. On the contrary, in station 3 could be appreciated how the limit was exceeded for the variable F&O most of the times.

Furthermore, the sediments on station 4 were sampled in November 2011, and the reported value of total petroleum hydrocarbon (TPH) was 3260 $mg \cdot k^{-1}$. This value made evident the deeper hydrocarbons pollution provoked by ECCVC, also in sediments. In turn, the F&O monitored in October 2013 reported water values of 4700 $mg \cdot L^{-1}$. These results are comparable in magnitude, with similar oily waste treatment systems in other installations of Cuban Industrial sector. (Castro et al., 2020).

3.3. ***Wells water characterization***

In the area under study, 56 wells were identified, 19 of them belonging to the public sector and the rest corresponding to the private sector. The 71.43% of the wells have been classified as potable water, 17.86% as unused and the rest as used for industry and agriculture. Likewise, 13 wells with historical evidence of hydrocarbon contamination based on their organoleptic characteristics were reported. Strata III and I were the ones that totalized the historical evidence regarding to contamination with hydrocarbons, according to organoleptic characteristics. In stratum I, 100% of the existing wells refered historical antecedents of contamination, while in stratum III, 38.46% resulted in similar evidence.

Table 3. Characteristics and results of well water sampling.

Well	Stratum	F&O ($mg \cdot L^{-1}$)	Description
ECCp1	I	<L.C	Human consumption
ECCp2	I	299 000	Industrial consumption
ECCp3	I	4.50	Scrubbing plant
ECCp4	II	<L.C	Human consumption
ECCp5	IV	<L.C	Human consumption
ECCp6	III	1.95	Animal consumption and crop irrigation.
ECCp7	III	4.27	Water for crop irrigation.

Result undeniable that stratum I is the source point of the contamination, due to stratum III is located downstream of it. Moreover, strata II and IV, are located upstream of ECCVC. Additionally, a supernatant fuel layer of approximately 1 m was observed during sampling in the ECCp2. These results were analyzed by the ECCVC Fuel Laboratory, which reported that the supernatant, corresponds to a diesel fuel. This product fulfils the indicators established in the internal normative document DT-GC/C 0702 "Catalog of Quality Specifications of Fuel Products". The ECCp6 and ECCp7 wells are in the northwest and northeast section respectively of the ECCVC. Both showed levels of contamination by F&O.

Based on potential causes, the following failures were identified: deficiencies in the engineering design and/or construction of treatment systems elements and interconnections (900); deficiencies in the pipeline system (800); spills (700); increase of load for lack of a waste minimization program at the origin source (500); increase of load for non-segregation of rainwater (500); technological indiscipline (360); non conformed operations and maintenance practices (280). The numbers shown between parentheses corresponded with the risk priority number (NPR), obtained from the multiplication of severity, occurrence and determination according to the Failures Modes and effects Analysis (AMFE). Consequently, these factors act as a dynamic stressor, increasing the local vulnerability in the fence-line community.

A package of 53 counter measures was designed which constituted an instrument for the stakeholders. Spatial representation of the vulnerable area was deeply recommended, in correspondence with ideas detailed afterwards for Brunetta et al. (2019). The proposed short-term implementation solutions were related to preventive and periodic maintenance actions, management and the adoption of good practices. The proposed medium-term solutions which required investment had conceptual engineering ideas scope. Some proposed measures are listed below for a better illustration.

- Clean and maintain the API Separator, restore its pumping system, and separate its feed in two channels with independent operation.
- Set up a tubular mechanical skimmer on the API separator, connected to the lateral hydrocarbon collectors.
- Implement the operation of the subsystem API separator-slop tank.
- A hydraulic and civil study must be carried out for the canalization system which should include one for rainwater and another for wastewater.
- An operator must be designated for the treatment system for which he must be trained.
- Once the subsystem formed by the API separator and its slop tank will be putting into operation, the liquid content of the lagoon must be pumped towards the separator and a bioremediation technology should be applied to the polluted soil collected.
- The V-shaped pipes in the different areas must be covered with prefabricated elements to prevent them from obstruction with solids.
- In the laboratory of fuels, oil waste and fuel samples must be collected, and sent to the recovery oil tank.
- Maintain control operation of the water pumps in the different areas to avoid spills.
- Carry out the scrubbing only for the vehicles programed for maintenance.
- Reuse the rainfall water as technical water to the scrubber plant services.
- Eliminate leaks from hydrants in fire lines.
- Eliminate leaks by seal in fire pumps.
- Measure the services with the highest water consumption in the company.
- Promote a culture of saving water in managers, technicians and workers.

The implementation of measure package proposed to the Cubans stakeholders, was depended not only on the study scope, but also on the bureaucracy models and government performance of the Cuban state.

4. Conclusions

The hydrocarbons presence not only in superficial waters, but also in wells inside and outside of ECCVC boundaries, confirmed the aquifer hydrocarbons contamination caused by the oil storage plant operations. The infiltration of surface runoff from sewage and rainwater contaminated with hydrocarbons was propitiated by deficient technological issues inside the industry, combined with geological characteristics of the soils. The integration of physic-chemical parameters monitoring demonstrates the hydrocarbon pollution generated by ECCVC operations, which impact as a dynamic chronic stressor the environment around the plant, enhancing the neighbor community exposure to this hazardous, therefore, increasing the local vulnerability.

The case study results, not only contributed to raise the vulnerability awareness to the stakeholders in the decision-making process, but also, had offered support to the effectiveness of the framework adopted. It should be used in further research which addressing environmental chemistry and industrial management tools as factors able to be used in the spatial modelling of vulnerability for the planification of territories ad resilience analyses.

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