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Determination of the Effect of Oil Exploration on Galvanized Steel in Niger Delta, Nigeria

T. I. Mohammed[1], I. C. Nwankwo[1] and T. O. Olugbade[1*]

[1]*Department of Mechanical Engineering, Federal University of Technology, P.M.B 704, Akure, Ondo State, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. Author TOO designed the study, wrote the protocol and the first draft of the manuscript. Author TIM monitored the design process and the final draft. Author ICN managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This paper determined the effect of oil exploration on engineering infrastructures in Niger Delta area of Nigeria where oil explorations are commonly practiced.
Study Design: Treatment of legal measure for the protection of the three environmental media: air, land, and water.
Place and Duration of Study: Department of Mechanical Engineering, Federal University of Technology, Akure, Ondo State, Nigeria, between November 2013 and December 2014.
Methodology: Verification of Niger Delta seawater and rainwater contaminated with gas flaring for concentrations of sulphate, nitrate and hydrogen ions were thoroughly done using JENWAY 6850 UV/Vis Spectrophotometer and JENWAY 3505 pH Meter. For the purpose of validation, rainwater from non oil exploration area of Nigeria were likewise verified for the same composition. Because of variation in composition of these materials, a test was conducted on metals using iron filings to test for corrosion effect.

**Corresponding author: Email: tkolugbade@futa.edu.ng;*

Results: Materials (rainwater and seawater) from different locations of exploration areas of Niger Delta proved to be acidic with average pH value of 5.35, while that of non oil exploration area contain average pH of 5.97. The result from the test, using confirmed acidic water from Niger Delta area of Nigeria, shows more rapid corrosiveness as against test of water from non exploration area which shows normal effect on corrosion.

Conclusion: Corrosion is more rapid on the materials made of metals (infrastructures) from Niger Delta area than what obtains in ordinary are. Also, engineering infrastructures in oil exploration environment corrode more rapidly than those found in a non exploration area looking at it within the same period of time.

Keywords: Acid rain; environmental; exploration; flaring; infrastructure; spillage.

1. INTRODUCTION

Engineering infrastructures in Niger Delta area of Nigeria have suffered damages due to oil exploration over the years in the area. Oil exploration includes the location of an area in which hydrocarbon accumulations may occur and drilling of an exploration well; once oil and gas is found, development begins with the drilling of 10 to 30 wells per platform [1]. It is a well-known fact that Nigeria's oil deposits are naturally located in the Niger Delta region of the country and that oil exploration started over 50 years ago in the area. Constitutional and statutory provisions vest the ownership of oil in the Nigerian State. Moreover, by the Land Use Act of 1979, the ownership of all land comprised in the territory of a state of the Federation is vested in the state in trust for all Nigerians. In essence, by the Land Use Act, all the lands in Nigeria have been nationalized. Therefore, the oil companies embark on large scale explorations under- minding the adverse effects their activities may have on engineering infrastructures in the area or on the environment generally.

Oil spill is the accidental release of crude or refined oil products into the environment [2]. Oil spills happen when operators make mistakes or are careless and cause an oil tanker to leak oil into the ocean. Spills from offshore facilities can occur due to leaks, equipment failure, accidents, or human error involving tankers, pipelines, refineries, and storage facilities, usually while the oil is being transported [2]. When there is an oil spill on water, spreading immediately takes place. Spreading over the sea surface begins as soon as oil is spilled followed by evaporation, dispersion, emulsification, dissolution, oxidation sedimentation and sinking, then biodegradation [3]. In Nigeria, fifty percent (50%) of oil spills is due to corrosion of oil pipes, twenty eight percent (28%) to sabotage and twenty one percent (21%) to oil production operations. One percent (1%) of oil spills is due to engineering drills, inability to effectively control oil wells, failure of machines, and inadequate care in loading and unloading oil vessels. According to the Department of Petroleum Resources (DPR), between 1976 and 1996 a total of 4647 incidents resulted in the spill of approximately 2,369,470 barrels of oil into the environment [4]. Of this quantity, an estimated 1,820,410.5 barrels (77%) were lost to the environment. A total of 549,060 barrels of oil representing 23.17% of the total oil spilt into the environment was recovered. The heaviest recorded spill so far occurred in 1979 and 1980 with a net volume of 694,117.13 barrels and 600,511.02 barrels respectively [5].

Flaring is the burning of natural gas extracted along with crude [6]. Major percentage of natural gases is flared since Nigeria is not equipped to utilize them. Gas flaring is a constant phenomenon in the Niger Delta. Gas flaring occurs in all oil exploration locations, meaning that it takes place in all the oil producing states of the Niger Delta. The gas released when crude oil is brought to the surface is known as associated gas. Drilling companies routinely flare or vent this material for safety reasons or where no infrastructure exists to bring it to market [6]. Associated gas, is a form of natural gas which is found with deposits of petroleum, either dissolved in the oil or as a free "gas cap" above the oil in the reservoir. Examples are methane, propane, butane etc. This practice has been dramatically curbed in developed countries, partly because of the recent rise in natural gas prices [7]. However, the World Bank estimates show that more than 100 billion cubic meters of gas is still flared or vented worldwide annually [8].

Toxic substances in the flare include: sulphur dioxide, sulphur monoxide, hydrogen sulphide, carbon dioxide, carbon monoxide, nitrogen dioxide, nitrogen monoxide, phosphor monoxide, phosphor dioxide, soot, smoke, lead, asbestos, methane, benzene, toluene, ethylbenzene, and xylene, mercury, arsenic and chromium etc. It is the presence of these toxic substances (pollutant gases mainly) that give birth to the presence of pollutant chemicals which corrode metal surfaces in contact. This occurs when these toxic substances (pollutant gases mainly) mix with rainwater and form acidic solutions, though, vary in concentrations. These pollutants speed up the erosion of statues and buildings, which in most instances, destroys works of engineering [9].

Acid rain is a popular term referring to the deposition of wet (rain, snow, sleet, fog, cloud water, and dew) and dry (acidifying particles and gases) acidic components. Distilled water, once carbon dioxide is removed, has a neutral pH of 7 [10]. Liquids with a pH less than 7 are acidic, and those with a pH greater than 7 are alkaline. Unpolluted rains have an acidic pH, but usually not lower than 5.6, because carbon dioxide and water in the air react together to form carbonic acid, a weak acid according to the following reaction:

$$H_2O\ (l) + CO_2\ (g) \rightleftharpoons H_2CO_3\ (aq)$$ [10]

Carbonic acid then can ionize in water forming low concentrations of hydronium and carbonate ions:

$$H_2O\ (l) + H_2CO_3\ (aq) \rightleftharpoons HCO_3^-\ (aq) + H_3O^+\ (aq)$$ [10]

Pollutant chemicals resulting from crude oil refining can be; toxic to workers, corrode equipments, while acid rain has impacts on exposed machines and bridges among other engineering facilities. The functional service life of engineering infrastructures in Niger Delta is drastically affected due to high rate of corrosion induced by excessive corrosive pollutant chemicals in the area. For example, the mean time for diffusion to corrosion initiation of 12% of steel material for bridges, and other exposed engineering structures in Niger Delta is about 37 years as against the normalized mean time of about 114 years. It implies that an exposed steel structure (e.g steel bridge) in Niger Delta would have been replaced twice while an equivalent steel structure outside Niger Delta will still be functional [11].

Oil exploration has been on-going for several decades in the Niger Delta. It has had disastrous impacts on the environment in the region and has adversely affected people inhabiting that region. The Niger Delta consist of diverse ecosystems of mangrove swamps, fresh water swamps, rain forest and is the largest wetland in Africa and among the ten most important wetland and marine ecosystems in the world, but due to oil pollution the area is now characterized by contaminated streams and rivers, forest destruction and biodiversity loss in general the area is an ecological wasteland. This affects the livelihood of the indigenous people who depend on the ecosystem services for survival leading to increased poverty and displacement of people [12].

The oil industry located within this region has contributed immensely to the growth and development of the country which is a fact that cannot be disputed but unsustainable oil exploration activities has rendered the Niger Delta region one of the five most severely petroleum damaged ecosystems in the world [12].

The Niger Delta region has a steady growing population of approximately 30 million people as of 2005, accounting for more than 23% of Nigeria's total population [13,14].

Ukoli [15] in his study made a summary of some significant pollutants from the oil industry region released into the environment as follows:

1. Exploration and Production activities include: Drilling Muds, Cuttings, Oil and Greases, Salinity, Sulphides, Turbidity, Suspended Solids, Temperature, pH, Heavy metals, Biological Oxygen Demand and COD.
2. Petroleum refining activities include; Oil & Greases, BOD, COD, Phenol, Cyanide, Sulphide, Suspended solids, Toxic Additives, Hydrocarbons and Total Suspended Solids.

Anifowose [16] and Onuoha [17] cited in their studies that the region has about 606 oil fields with 355 situated onshore; 251 situated offshore with 5,284 drilled oil wells and 7,000km of oil and gas pipelines.

This paper therefore aims to determine the effect of oil exploration on engineering infrastructures in Niger Delta area of Nigeria where oil explorations are commonly practiced.

2. MATERIALS AND METHODS

The method adopted in carrying out this research includes extensive literature review on oil exploration in Nigeria. Attentions were again attracted to acid rain, pollutant chemicals and visitation to oil exploration companies for information. Also by direct observations of corrosion damages suffered by exposed engineering infrastructures of which most were engulfed with pitting like the buildings, bridges and all machines and equipments used in exploration itself.

Studies were made on some severely oil polluted sites in the Niger Delta with reference to the location, environment, impacted area (ha) and the nature of incidence. Nine (9) sites were considered in Bayelsa state, 20 sites in Delta state and four (4) sites in Rivers state. Rainwater analysis for potential of hydrogen ion was conducted using a pH meter. Also, rainwater analysis for concentrations of sulphate ions, nitrate ions and chloride ions was conducted using UV spectrophotometer. Both analyses were conducted on each of the collected rainwater samples from selected communities in Niger Delta, Rivers state as a case study which include Ugwuruta, Abuloma, and Rumuakwurushi and rainwater sample from Ado which is located outside Niger Delta.

Analysis for potential of hydrogen ion and concentrations of sulphate ions, nitrate ions and chloride ions were conducted on a sample of seawater contaminated with crude oil using a pH meter and UV spectrophotometer respectively. The seawater sample was taken from Gburuan in Niger Delta. The effect of acidity was tested on iron filings in the laboratory, using the rainwater samples, seawater contaminated with crude oil and acidified water as reactants, to determine the potential impact of acid rain and seawater contaminated with crude oil on similar materials. The effect of acidity was again tested on galvanized steel using the seawater sample and acidified water. The experiments were done at FUTA Central Research Laboratory and FUTA Science Laboratory.

3. RESULTS AND DISCUSSION

Table 1 shows some severely oil polluted sites in the Niger Delta, Table 2 shows the average pH value of rainwater samples from selected communities within Niger Delta as more acidic than rainwater sample outside Niger Delta. The acidity levels of rainwater in Niger Delta will have harmful effect on the exposed engineering infrastructures in the area since the acidity levels (Av. pH as 5.35) are at least 10 times the acidity of natural rainwater which is 5.60. This is supported by Odilison [8] research on the acidity of rainwater in Niger Delta obtained to be as low as 4.0 about 40 times the acidity of natural rainwater. It is evidence that acid rain is experienced more in Niger Delta than any other place in Nigeria.

The selected community outside Niger Delta will experience lesser effect on exposed engineering infrastructures since the acidity is above 5.6. Table 2 also reveals chloride, nitrate and sulphate as constituents of rainwater with sulphate more present in Niger Delta. It is an evidence that sulphate; a major pollutant chemical occurs in larger quantity within Niger Delta, Nigeria. Nitrate, a major pollutant is present more in the seawater within Niger Delta with pH of 5.66. These pollutant chemicals react with metal bodies in contact and thereby corroding them.

Table 3 shows peak change in pH with rainwater from Abuloma in Niger Delta which means the iron filings react more in more acidic medium. Rainwater sample from Abuloma in Niger Delta has initial pH of 5.28 when mixed with iron filings. The values of the medium after 24 hours are higher in all the samples but most basic (8.26) in mixture of Igwuruta, Niger Delta rainwater. This means that iron (III) hydroxide; a basic hydroxide had been formed in the solution. A precipitate of this is known as rust.

Table 4 shows a significant change in the colour of the iron filings and the medium after 24 hours. Change in colour of the iron filings from silver gray to rust brown in the Niger Delta rainwater (max pH 5.01, min pH 5.72) signifies more formation of rust (or more corrosion) than in Ado rainwater (pH 5.97) where the iron filings turned reddish brown. The change in colour of the galvanized steel to silver from silver gray shows the dissolution (corrosion) of the coatings. Also, in the acidified water, the galvanized steel turned deep rust brown with visible change in texture showing the eventual effect of acidic environment on metallic bodies. This result validates the rapid increase in corrosion with rapid change of the engineering infrastructures in those areas.

Table 5 shows weight loss, 1.326 g of iron filings in samples of iron filings and rainwater as highest. This, as obtained from mixture of iron filings and Abuloma rainwater, signifies more corrosion of the iron filings in the medium. This is due to high acidic content of the Abuloma rainwater.

Table 1. Some severely oil polluted sites in the Niger Delta

Location	Environment	Impacted area (ha)	Nature of incidence
		Bayelsa State	
Biseni	Freshwater Swamp Forest	20	Oil Spillage
Etiama/Nembe	Freshwater Swamp Forest	20	Oil Spillage and Fire Outbreak
Etelebu	Freshwater Swamp Forest	30	Oil Spillage Incidence
Peremabiri	Freshwater Swamp Forest	30	Oil Spillage Incidence
Adebawa	Freshwater Swamp Forest	10	Oil Spillage Incidence
Diebu	Freshwater Swamp Forest	20	Oil Spillage Incidence
Tebidaba	Freshwater Swamp Forest Mangrove	30	Oil Spillage Incidence
Nembe creek	Mangrove Forest	10	Oil Spillage Incidence
Azuzuama	Mangrove	50	Oil Spillage Incidence
		Delta State	
Opuekebe	Barrier Forest Island	50	Salt Water Intrusion
Jones Creek	Mangrove Forest	35	Sipllage and Burning
Ugbeji	Mangrove	2	Refinery Waste
Ugbelli	Freshwater Swamp Forest	10	Oil Spillage-Well head leak
Jesse	Freshwater Swamp Forest	8	Product leak/ Burning
Ajato	Mangrove		Oil Spillage Incidence
Ajala	Freshwater Swamp Forest		Oil Spillage Incidence
Uzere	Freshwater Swamp Forest		Oil Spillage Incidence
Afiesere	Freshwater Swamp Forest		Oil Spillage Incidence
Kwale	Freshwater Swamp Forest		Oil Spillage Incidence
Olomoro	Freshwater Swamp Forest		QC
Ughelli	Freshwater Swamp Forest		Oil Spillage Incidence
Ekakpare	Freshwater Swamp Forest		Oil Spillage Incidence
Ughuvwughe	Freshwater Swamp Forest		Oil Spillage Incidence
Ekereiegbe	Freshwater Swamp Forest		Oil Spillage Incidence
Ozoro	Freshwater Swamp Forest		Oil Spillage Incidence
Odimodi	Mangrove Forest		Oil Spillage Incidence
Ogulagha	Mangrove Forest		Oil Spillage Incidence
Otorogu	Mangrove Forest		Oil Spillage Incidence
Macraba	Mangrove Forest		Oil Spillage Incidence
		Rivers State	
Rukpoku	Freshwater Swamp	10	Oil Spillage
Rumuakwurushi	Freshwater Swamp	20	Oil Spillage

Source: FME, NCF, WWF UK, CEEP-IUCN 2006 Niger Delta resource damage assessment and restoration project

It is glaring from Table 5 that magnitude of weight loss is lowest in the medium of rainwater collected from Ado-Ekiti which is located outside Niger Delta. Also, weight loss of 9.4 g of galvanized steel was obtained with medium of acidified water while weight loss of 2.6 g was obtained with medium of seawater contaminated with crude oil which reveals that the original galvanized steel had corroded or lost material and will lose more material (or corrode more) with time as it nears its end of functional service life. This laboratory experiment is a simulation of process of rust formation on exposed engineering infrastructures in Niger Delta. Acid rain in Niger Delta is mainly due to dissolution of sulphur dioxide and nitrogen oxides in rainwater. Carbon monoxide and carbon dioxide in the atmosphere form weak acids; hydrogen carbonates when they dissolve in rainwater. When sulphur dioxide, chlorine and nitrogen oxide dissolve in rainwater, dilute acidified water is formed and it comes in contact with steel structures. Over time, the iron constituent of the steel structures reacts in presence of atmospheric oxygen to form hydrated iron (III) hydroxide reddish brown in colour as end product which is known as rust. The chemical equation of reaction is as shown below:

Stage 1 $Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$ (oxidation) (1)
Stage 2 $2H^+(aq) + 2e^- \rightarrow H_2(g)$ (2)
Stage 3 $2H^+(aq) + 2e^- \rightarrow H_2(g)$ (3)
Stage 4 $4Fe^{2+}(aq) + 4H^+(aq) + O_2(aq) \rightarrow 4Fe^{3+}(aq) + 2H_2O(l)$ (4)
Stage 5 $4Fe^{2+}(aq) + 4H^+(aq) + O_2(aq) \rightarrow 4Fe^{3+}(aq) + 2H_2O(l)$ (5)

More acidity increases corrosion. Since the pH is very low, the hydrogen ions will quickly consume the electrons, making hydrogen gas instead of water:

That is, $2H^+(aq) + 2e^- \rightarrow H_2(g)$ instead of $4e^- + 4H^+(aq) + O_2(aq) \rightarrow 2H_2O(l)$

Hydrogen ions are being consumed by the process. As the iron undergo changes (corrodes), heat is emitted and the pH rises. Hydroxide ions (OH^-) appear in water as the hydrogen ion concentration falls. They react with the Iron (II) ions to produce insoluble Iron (II) hydroxides (green rust). The iron(II) ions also react with hydrogen ions and oxygen to produce iron(III) ions $4Fe^{3+}(aq)$. The Iron (III) ions react with hydroxide ions to produce hydrated iron(III) oxides (also known as iron(III) hydroxides) $Fe(OH)_3(s)$ (reddish brown).

$Fe(OH)_3$ can slowly transform into a crystallized form written as $Fe_2O_3.nH_2O$ (rust).

Equations 1, 2, 3, 4 and 5 show the various stages involved in rust formation and changes that occur. Evolution of hydrogen gas at stage 2 according to equation 2 signifies acidic environment otherwise water would have been formed. At stage 3 of the reaction, heat was evolved and colour of the solution turned green which indicates presence of rust (Iron (II) hydroxide). Further at stage 5, the colour of the solution changed to rust (reddish) brown which indicates oxidation of the Iron (II) hydroxide to iron(III) hydroxide. The process is gradual and continuous.

Table 2. Water analysis results

Locations	**Rainwater analysis parameter (mg/L)**				**Seawater analysis parameter (mg/L)**			
	pH	**SO_4^{2-}**	**Cl^-**	**NO_3^{2-}**	**pH**	**SO_4^{2-}**	**Cl^-**	**NO_3^{2-}**
A- Igwuruta-Niger Delta	5.72	2.33	21.24	0.28	5.66	0.98	87.86	3.56
B-Abuloma- Niger Delta	5.33	2.36	19.54	0.32	5.66	0.98	87.86	3.56
C-Rumuakwurushi-Niger Delta	5.01	2.21	20.35	0.21	5.66	0.98	87.86	3.56
Average:	5.35							
E-Ado -Non Niger Delta	5.97	1.51	26.78	1.56				

Table 3. Significant change in the ph and temperature of sample medium

S/N	**Sample and medium**	**Ini. pH**	**Ini. temp (℃)**	**pH after 4 hours**	**Temp after 4 hours (℃)**	**pH after 24 hours**	**Change (increase) in pH**
1	Iron filings + Abuloma rainwater	5.28	28	8.19	32	8.11	2.83
2	Iron filings + Ado rainwater	6.15	28	7.96	32	8.18	2.03
3	Iron filings + Igwuruta rainwater	5.63	28	8.35	32	8.26	2.63
4	Iron filings + Rumuakwurushi rainwater	5.35	28	6.93	32	7.82	2.47
5	Iron filings + Seawater contaminated with crude oil	5.00	38	6.47	32	7.70	2.70
6	Galvanized steel (A) + Acidified water	1.40	40	2.32	32	2.66	1.26
7	Galvanized steel (B) + Seawater contaminated with crude oil	5.00	38	6.15	32	7.20	2.20

Table 4. Significant change in colour of sample and medium

.

S/N	Sample and medium	Ini. colour of sample	Fin. colour of sample	Ini. colour of medium	Colour of medium after 24 hrs
1	Iron filings + Abuloma rainwater	Silver gray	Rust brown	Colourless	Rust brown
2	Iron filings + Ado rainwater	Silver gray	Reddish brown	Colourless	Redish brown
3	Iron filings + Igwuruta rainwater	Silver gray	Rust brown	Colourless	Rust brown
4	Iron filings + Rumuakwurushi rainwater	Silver gray	Rust brown	Colourless	Rust brown
5	Iron filings + Gburuan seawater contaminated with crude oil	Silver gray	Rust brown	Rust brown	Rust brown
6	Galvanized steel (A) + Acidified water	Silver gray	Rust brown	Colourless	Gray and Rust brown mixture
7	Galvanized steel (B) + Gburuan seawater contaminated with crude oil	Silver gray	Silver	Rust brown	Rust brown

Table 5. Significant change in weight of the sample

No	Sample and medium	Ini. weight (g)	Weight (g) after 24 hrs	Weight loss (g)	Observation after 24 hrs
A	Iron filings + Abuloma rainwater	2.0	0.674	1.326	Rust formation
B	Iron filings + Ado rainwater	2.0	1.983	0.017	Rust formation
C	Iron filings + Igwuruta rainwater	2.0	1.740	0.260	Rust formation
D	Iron filings + Rumuakwurushi rainwater	2.0	1.956	0.044	Rust formation
E	Iron filings + Gburuan seawater contaminated with crude oil	2.0	1.955	0.045	Rust formation
F	Galvanized steel (A) + Acidified water	409.4	400.000	9.400	Rust formation
G	Galvanized steel (B) + Gburuan seawater contaminated with crude oil	407.6	405.000	2.600	Pilling of the coatings of the galvanized steel

4. CONCLUSION

The rainwater and seawater contaminated with crude oil in Niger Delta have been determined to be acidic. The effect of this acid water has been determined on metal (iron filings) and found out to have rapid corrosive effect. If this is true, this corrosive effect will be applicable on engineering infrastructures exposed to acid rain in Niger Delta. The major constituents of pollutant chemicals are chlorides, nitrates and sulphates and they occur in high concentrations in Niger Delta water due to oil exploration activities in the area.

Oil exploration is responsible for the high acidity of rainfall in Niger Delta. Other sources of pollutant chemicals such as volcanic eruption, vehicle emissions, burning of coal, collision of electric charges in the atmosphere among others are present both in Niger Delta and outside Niger Delta but acidity of rainwater in Niger Delta continues to be higher which means that oil exploration which occurs only in Niger Delta is responsible. If rainwater in Niger Delta is more acidic, that means pollutant chemicals are present in higher concentrations in the area all as a result of oil exploration in the area.

Corrosion of engineering materials occurs easily and faster in acidic environment. Both acid rain and crude oil contaminated water, either freshwater or seawater, represent acidic environments so far their pH values are below

5.6 each. Once seawater or fresh water becomes acidic to the extent of having pH below 5.6 as in the case of seawater or freshwater contaminated with crude, corrosion of surfaces in contact is inevitable. These surfaces in contact could be cooling channels of hydro thermal plants, body of ships, water pipes etc. This condition is obtainable in Niger Delta where oil explorations are order of the day. Also, once rainwater becomes acidic to the extent of having pH less than 5.6 (pH of normal rainwater) as in the case of most rainfall in Niger Delta, corrosion of built environment: bridges, building, statues etc are likely to occur. The dissolved acids present in the water whether rainwater, seawater or fresh water will react with the iron in case of steel structures to form hydrated iron(III) oxide known as rust.

The functional service life of engineering infrastructures in Niger Delta is drastically reduced considering the adverse effect the acidic environment will have on them. Although, engineering infrastructures are meant to serve their purposes and deteriorate over time but the highlighted conditions more present in Niger Delta due to oil exploration tend to cause early initiation of deterioration of the engineering infrastructures in the area. We are able to see that effect of oil exploration is not only felt by aquatic life alone as hitherto been expressed. It is now clearly seen that oil exploration also affects engineering infrastructures through acidic rainwater and contaminated seawater with crude oil.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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