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Assessing Groundwater Vulnerability to the Activities of Artisanal Refining in Bolo and Environs, Ogu/Bolo Local Government Area of Rivers State; Nigeria

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Research Article

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ABSTRACT

Artisanal refining typically involves primitive illegal stills in which crude oil is boiled and the resultant fumes are collected, cooled and condensed in tanks to be used locally for lighting, energy or transport. The distilleries are heated on open fires fed by crude oil that is tipped into pits in the ground. As part of the oil burns away, some seeps into the ground. The waste from the process is stored in open pits thereby increasing the risk of the contamination of the environment and possibly impacting the underground aquifer. It is this concern of crude oil seeping to the groundwater that necessitated the current investigation with the sole objective of assessing the vulnerability of the aquifer to the activities of artisanal refining. Soil, water and crude oil samples from artisanal refining sites were collected according to standard procedures and transferred to the laboratory for analyses to determine their properties.

An empirical method was adopted in estimating the permeability. The Kozeny – Carman equation for deriving the coefficient of permeability takes the porosity (η) into account. Using a typical soil porosity η = 0.4, mean particle size = 0.05 and mean viscosity determined from crude samples permeability estimate was calculated to be 3.6×10^{-8}cm/s, infiltration was assessed using a simplified version of Darcy's law. With a typical superficial soil permeability of 3.6×10^{-8} cm/s, depth of ponding of 0.5m, and a wetting front of 0.4m, an estimated infiltration rate of 1.15×10^{-8}cm/s can be expected. Given the infiltration rate and the depth to groundwater (water table is between 3m and 8m), we calculated the time for crude oil contaminant plume to intercept the water table simply re-expressing the equation for velocity as distance/time which results in approximately 4.6 years. The character of the water from the area indicates that groundwater is already

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being impacted given that artisanal refining has been going on in the area since 2002.

Keywords: Artisanal refining; groundwater; infiltration; permeability; vulnerability; aquifer; pollution.

1. INTRODUCTION

Groundwater has been described as the main source of potable water supply for domestic, industrial and agricultural uses in the southern part of Nigeria especially the Niger Delta, due to long retention time and natural filtration capacity of aquifers (Odukoya et al., 2002; Agbalagba et al., 2011; Ehirim and Ofor, 2011). Water that is safe for drinking, pleasant in taste, and suitable for domestic purposes is designated as potable water and must not contain any chemical or biological impurity (Horsfall and Spiff, 1998).

Pollution of groundwater has gradually been on the increase especially in our cities with lots of industrial activities, population growth, poor sanitation, land use for commercial agriculture and other factors responsible for environmental degradation (Egila and Terhemen, 2004). The concentration of contaminants in the groundwater also depends on the level and type of elements introduced to it naturally or by human activities and distributed through the geological stratification of the area.

It has been reported that petroleum refining contributes solid, liquid, and gaseous wastes in the environment (Ogbuagu, et al., 2011). Some of these wastes could contain toxic components such as the polynuclear aromatic hydrocarbons (PAHs), which have been reported to be the real contaminants of oil and most abundant of the main hydrocarbons found in the crude oil mixture (El-Deeb and Emara, 2005). Once introduced in the environment, PAHs could be stable for as short as 48 hours (e.g. naphthalene) or as long as 400 days (e.g. fluoranthene) in soils (Martens and Frankenberger, 1995). They thus, resist degradation and, remain persistent in sediments and when in organisms, could accumulate in adipose tissues and further transferred up the trophic chain or web (Decker, 1981; Boehm et al., 1981).

The Niger Delta region of Nigeria is the crude oil and natural gas hub of Nigeria with several networks of product pipelines (both surface and subsurface) dotting the entire landscape which has created a social problem of vandalization of product pipelines and artisanal refining and the associated environmental hazards. Artisanal refining typically involves primitive illegal stills – often metal pipes and drums welded together – in which crude oil is boiled and the resultant fumes are collected, cooled and condensed in tanks to be used locally for lighting, energy or transport (UNEP, 2011).

The distilleries are heated on open fires fed by crude oil that is tipped into pits in the ground. As part of the oil burns away, some seeps into the ground. Apart from the high risk of self-harm from artisanal refining – a large number of accidents, fires and explosions on refining sites claim dozens of lives every year, quite apart from the longer-term health effects of ingestion, absorption and inhalation of hydrocarbons. The crude which is usually stored in open containers or open pits increases the risk of fire and the contamination of the environment and possibly impacting the underground aquifer.

It is this concern of crude oil seeping to the groundwater that necessitated the current investigation with the objective aimed at assessing the vulnerability of the aquifer to the activities of artisanal refining which is eminent to the availability of potable water resources both for present and future generation given the fact that aquifers in the Niger Delta zone are near to the surface.

2. MATERIALS AND METHODS

2.1 The Study Area

Bolo Community, Geo referenced on Lat 4°34´ S to Lat 4°45´ S and Long 7°10´E to Long 7°15´E is in the South Eastern part of Ogu/Bolo Local Government Area, sharing boundaries with Tai, Gokana, and Bonny Local Government Areas of Rivers State, in the Niger Delta of Nigeria. Bolo itself is an Island settlement with several archipelago type of villages and fishing ports straddled along its numerous and dense network of creeks. Bolo is host to two oilfields: Bodo West and parts of Bomu II oilfields with the associated product pipelines including the Trans Niger Pipeline. These pipelines are being tapped illegally for artisanal refining, in some cases leading to spills and fires.

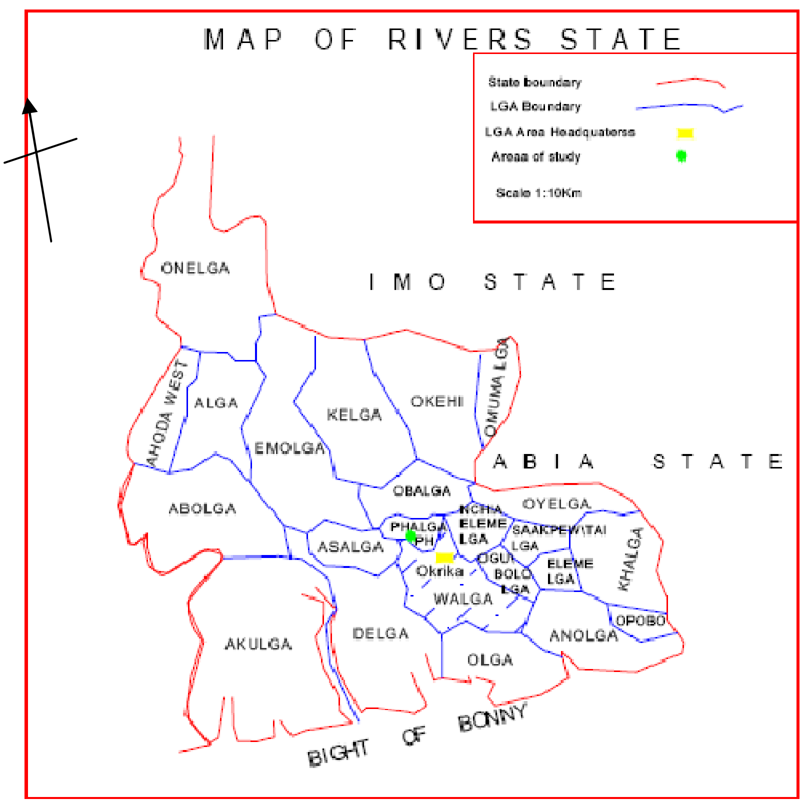

Fig 1. Map of Rivers State showing Ogu/Bolo Local Government Area
(Source: Rivers State Ministry of Land & Housing)

There are hundreds of artisanal refineries in and around Bolo, and the neighboring Ogoni communities as a result, Bolo community has experienced heavy human and marine traffic plying its creeks and water ways to these artisanal refineries dotting the area with the resultant wastes generated.

2.1.1 Geology of the study area (soil, hydrometeorology and aquifer system)

There is no hydrometeorogical information that is readily available on Bolo Community, but because of its proximity in both distance and latitude to Port Harcourt City, hydro meteorological parameters for Port Harcourt are generally adopted for Bolo. Rainfall in the area varies over a wide range in temporal context because of the occurrence of wet and dry season.

The superficial soils in the area fall under the geomorphic classification of coastal Plain sands, although described as sands; they contain substantial amounts of clay at the upper horizon which impede effective drainage within the vadoze zone. Some researchers refer to the coastal plain sands as the surface expression of the Geologic Benin Formation (Short and Stauble, 1967) but in the context of engineering applications, they are referred to as lateritic soils. They are rich in iron content.

The bulk of groundwater in the Niger Delta is contained in very thick and extensive sediments of Benin Formation. The exploited aquifers including Bolo are derived from the Benin Formation. Based on geophysical and borehole data collected over the years, the Niger Delta hydro geological set up can be classified into:

(a) Impermeable/Semi permeable horizons from ground level to 10m below mean sea level.

(b) A permeable/gravel sand layer up to 80m below sea level.

(c) From 80m to 225m below sea level, the formation consists of a permeable sand/gravel layer with thin impermeable/semi permeable clay/silt layers.

The water levels measured in the area fluctuate between 3m below ground level and 8.3m above sea level. In this aquifer more than 1500 wells are sunk in various part of Rivers State by private developers. The ground water levels respond to seasonal variations in rainfall and recharge. Groundwater level Monitoring at the site of the Bonny Export Terminal at the Port Harcourt Refinery revealed a lag in response time of a little over two months during the wet season; groundwater level is considerably close to the ground surface, thereby making groundwater highly vulnerable to pollution. In general the higher values are obtained from the north and the lower values in the southern part. The general direction of groundwater flow is southwards (Abam, 2011).

2.1.1.1 Sample collection from the field

Soil and crude oil samples from the impacted area were collected for laboratory analyses according to standard procedures (AMPHA).

The component of water budget was analyzed for Bolo using the equation:

$$P = E + I + R + D \qquad (1)$$

Precipitation = Evaporation + Infiltration + Runoff + differential Storage

An empirical method was adopted in estimating the permeability. The Kozeny – Carman Bear (1972) equation for deriving the coefficient of permeability takes the porosity (η) into account as well as the specific surface area of the porous medium (Sa) which is defined per unit volume of solid. It expresses permeability as:

$$K = \frac{\rho wg}{\mu} \frac{\eta^3}{(1-n)^2} \frac{(d^2 m)}{180} \quad \ldots\ldots \quad (2)$$

Where dm = mean particle size
ρw = fluid density
µ = Fluid viscosity

3. RESULTS AND DISCUSSION

Properties of crude oil samples collected from the artisanal sites as well as the fresh water in the area and analysed in the laboratory are presented as Table 1 below:

Table 1. Properties of crude oil samples at Room Temperature

Oil Sample	Density (g/cm3)	Viscosity (g/cm/s)	Surface Tension of oil (g/s^2)	Surface tension of oil/water (g/s^2)
Sample I	0.86053	0.063822	38	29
Sample II	0.8650	0.027944	31	38
Sample III	0.9	0.071667	39	28
Fresh Water	0.997	0.011667	74	-

Using a typical soil porosity η = 0.4, mean particle size = 0.05 and mean viscosity determined from crude samples as given above, permeability estimate was calculated to be 3.6×10^{-8}cm/s

Having estimated permeability, infiltration was assessed using a simplified version of Darcy's law. In this model the ponded hydrocarbon is assumed to be equal to h_o and the head of dry soil that exists below the depth of the wetting front soil suction head is assumed to be equal to –ψ- L

$$F = K \frac{(h_o - (- \psi - L))}{L} \quad \ldots\ldots \quad (3)$$

where:
h_0 is the depth of ponded hydrocarbon above ground surface.
K is the hydraulic conductivity of the soil with respect to crude oil.
L is the total depth of subsurface ground in question.
ψ is moisture potential.

With a typical superficial soil permeability of 3.6×10^{-8} cm/s, depth of ponding of 0.5m, and a wetting front of 0.4m, an estimated infiltration rate of 1.15×10^{-8}cm/s can be expected.

Given the infiltration rate and the depth to groundwater (water table is between 3m and 8m), we calculated the time for crude oil contaminant plume or wetting front to intercept the water table. This is simply done by re-expressing the equation for velocity as distance/time. In this case, time taken to intersect the water table would be the ratio water table/infiltration Rate which results in approximately 4.6 years.

Table 2. Water Quality of borehole water from artisanal refining sites

Parameters	Bolo Island	Bolo Mainland	Aseminigolaka (Bodo West)
Temp. (℃)	28	31.2	29
pH (6.5 – 8.5)	7.0	5.3	6.2
Chloride (250mg/l)	35.50	63.90	98
Iron (0.3mg/l)	0.04	0.2	0.2
Elect Cond. (500 µs/cm)	300	312	19
Hardness	16	20	20
TDS (500mg/l)	18	200	197
THC (ppm)	-	236.78	986.07
T.Coliform (cfu/g)	1.4×10^3	2.6×10^3	4.2×10^3

** Values in parenthesis are World Health Organisation (2004) limits*
** Values are mean of all samples*

4. CONCLUSION

The water quality analyses on water samples from the study area showed that groundwater is already being impacted upon by crude oil related activities. Considering the cavalier attitude of this bunkers to the environment upon which they operate, groundwater is highly vulnerable to severe hydrocarbon pollution in Bolo and Environs and mostly likely all Niger Delta areas where the activities of artisanal refining and oil bunkering takes place, given that the surface of the Niger delta is dissected by a dense network of rivers and creeks, which create a condition of delta-wide hydrological continuity. Water pollution in one part of the delta can readily be felt in other part.

The water levels measured in the boreholes in nearby B-Dere a boundary community with Bolo seem to fluctuate between 3m below ground level and 8.3 meters above sea level. Published records of water levels of shallow wells of the upper aquifer which are the most exploited indicate the general structure of the groundwater surface. During the wet season, groundwater level is considerably close to the ground surface, thereby making groundwater highly vulnerable to pollution. Artisanal oil refining activities including the waste generated from such activities affect the environment as well as the groundwater system.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Agbalagba, O.E., Agbalagba, O.H., Ononugbo, C.P., Alao, A.A. (2011). Investigation into the physico-chemical properties and hydrochemical Processes of groundwater from commercial boreholes in Yenagoa, Bayelsa State, Nigeria. African Journal of Environmental Science and Technology, 5(7), 473-481.

Boehm, P.D., Fiest, D.L., Elskus, A. (1981). Comparative weathering patterns of hydrocarbons from Amoco Cadiz oil spill observed at a variety of coastal environment. International Symposium on the fate and effects of oil spill. Brest, France, pp. 159-173.
Decker, J.C. (1981). Potential health hazards of toxic residues in sludge. In sludge-health risk of land application. Ann. Arbon. Sci. Publ. Inc., pp, 85-102.
Egila, J.N., Terhemen, A. (2004). A preliminary investigation into the quality of surface water in the environment of Benue Cement Company Plc. Gboko, Benue State. Nigeria. Int. J. Sci. Tech., 3(1), 12-17.
Ehirim, C.N., Ofor, W. (2011). Assessing Aquifer vulnerability solid wastes landfill Sites in a Coastal Environment, Port Harcourt, Nigeria. Trends in Applied Sciences Research, 6(2), 165 –173.
El-Deeb, M.K.Z., Emara, H.I. (2005). Polycyclic aromatic hydrocarbons and aromatic plasticizer materials in the seawater of Alexandria Coastal area. Egyptian J. of Aquat. Res., 31, 15-24.
Horsfall, M., Spiff, A.I. (1998). Principles of environmental Chemistry. Metrol Prints Ltd, Nigeria, pp. 107–118.
Martens, D.A., Frankenberger, Jr.T. (1995). Enhanced Degradation of Polycyclic Aromatic Hydrocarbons in soil treated with an Advanced Oxidative Process—Fenton's Reagent. Journal of Soil Contamination, 4(2), 175-190.
Odukoya, O.O., Arowolo, T.A., Bamgbose, O. (2002). Effect of Solid Waste. Landfill on underground and surface water quality at Ring Road, Ibadan. Global J. Environ. Sci., 2(2), 235–242.
Ogbuagu, D.H., Okoli, C.G., Gilbert, C.L., Madu, S. (2011). Determination of the contamination of groundwater sources in Okrika Mainland with Polynuclear Aromatic Hydrocarbons (PAHs). British Journal of Environment & Climate Change, 1(3), 90-102.
Short, K.C., Stauble, A.J. (1967). Outline Geology of Niger Delta. American Association of Petroleum Geology Bulletin, 51, 761-779.
UNEP. (2011). Environmental Assessment of Ogoniland. United Nations Environmental Programme, Nairobi, Kenya, pp. 262.

APPENDIX

Metal pipes and drums welded together used for boiling crude oil

Riparian and mangrove forest cleared by the artisanal refining

Aerial View of vegetation cleared by the activities of artisanal refining

Fig. 2: Visible impact of artisanal refining (courtesy of UNEP, 2011)

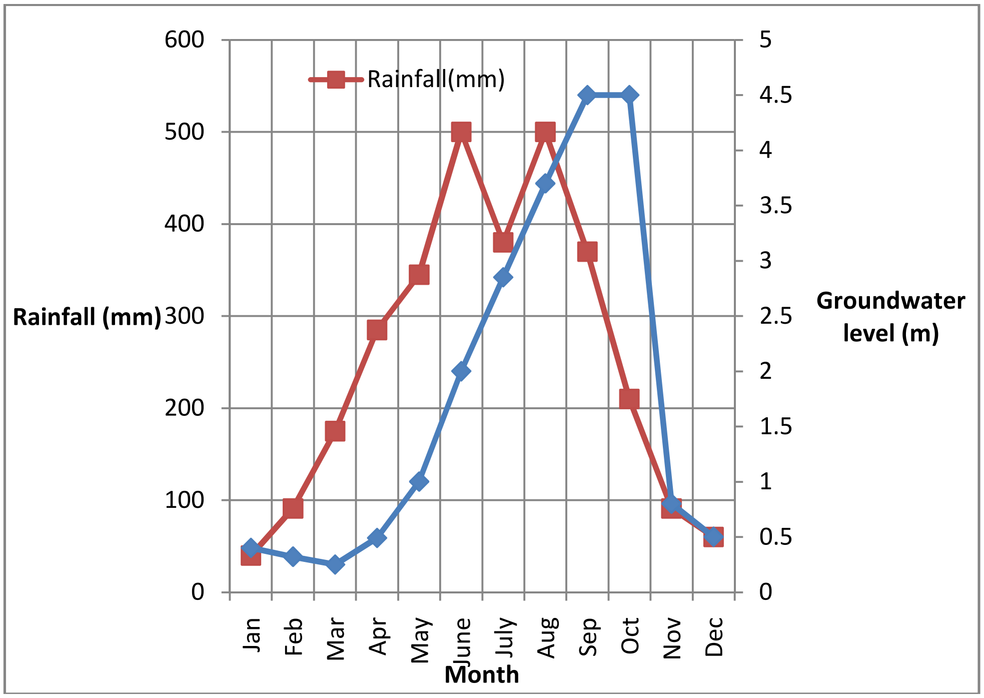

Fig. 3: Seasonal variation of rainfall and groundwater levels in nearby Port Harcourt