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Short message / Сообщение

Carcinogenic contaminants in groundwater in the Ebocha and Mgbede oil fields of Southern Nigeria

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Abstract. In accordance with the purpose and objectives of this study, standard methods were applied with the aim and objectives of this study, standard methods were applied in evaluating groundwater contamination from an oil waste pit in the Mgbede and Ebocha Oil Fields of South-south Nigeria. The study attempted to determine the composition of the oil waste pit and how it affected groundwater by using hydrogeochemical methods. It was discovered that the Oil waste pit contained an acidic pH, a very negative redox potential, borderline zinc concentration and above limits cadmium, polycyclic aromatic hydrocarbons (PAHs) concentration. The study discovered a widespread ubiquity of above limits concentrations of PAHs in the whole of the study area. Groundwater in the study area was characterised by unacceptable levels of acidity, oxygen reduction potential (ORP), PAHs, cadmium and borderline cases of zinc contamination which can cause serious public health problems and major health risks including exposure to cancer. Provision of an alternative water sources to the inhabitants of this oil field was among recommendations.

Keywords: oil waste pit, groundwater pollution, environmental health

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Канцерогенные загрязнения в подземных водах нефтяных месторождений Эбоча и Мгбеде на юге Нигерии

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Аннотация. Цель исследования – определение состава нефтяных отходов и их влияния на грунтовые воды с помощью гидрогеохимических методов. Применены стандартные методы оценки загрязнения подземных вод из ямы с нефтяными отходами на нефтяных месторождениях Мгбеде и Эбоча в южной части Нигерии. Обнаружено, что в яме с нефтяными отходами кислый pH, очень отрицательный окислительно-восстановительный потенциал, пограничная концентрация цинка и концентрация полициклических ароматических углеводородов (ПАУ), кадмия выше пределов. Выявлено повсеместное распространение превышающих предельные концентрации ПАУ на всей исследуемой территории. Подземные воды в районе исследования характеризовались неприемлемыми уровнями кислотности, окислительно-восстановительного потенциала (ОВП), кадмия, ПАУ и пограничными случаями загрязнения цинком, что может вызвать серьезные проблемы со здоровьем населения и риски для здоровья, включая рак. В число рекомендаций вошло предоставление альтернативных источников воды жителям этого нефтяного месторождения.

Ключевые слова: нефтяной карьер, загрязнение подземных вод, состояние окружающей среды

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Introduction

Over the years, groundwater contamination has emerged as a pressing environmental concern, threatening ecosystems and public health, especially in communities within the oil field exploration activities. Groundwater, a vital resource for drinking water source and agriculture has been compromised by various forms of pollutants, posing significant challenges for sustainable development and ecosystem integrity Groundwater contamination emanates from various sources including industrial activities, agricultural runoff and improper waste disposal practices [1].

Increasing demand for fossil fuels, depletion of traditional oil and gas reservoirs, and decades of public and private-sector investment in methods to extract oil and gas from low-permeability formations have accelerated the development of more and more oil fields. The volume of produced wastewaters, has also increased and these liquid wastes from oil and gas production pose potential risks to water quality and the health of organisms, including humans, because produced waters contain chemical additives or naturally occurring salts, metals or radioactive elements may enter the environment from accidental or intentional releases [2].

Oil field exploration activities involve the extraction and refining of petroleum products which generates and accumulates deleterious substances that contributes to groundwater and aquifer contamination. Consequently, communities whose source of water supply depends on groundwater, face heightened risk of exposure to toxic compounds, including hydrocarbons, heavy metals and associated volatile organic compounds [3].

The production of oil and gas is often accompanied with large quantity of produced water. There is estimation that wastewater production is three times larger than oil and gas product. This ratio increases with the age of wells. In the United States, oil production generates about 21 billion barrels of produced water every day. This water can pollute surface, groundwater and soil. There are various limits in different countries for produced water for operators to achieve. In Australia produced water discharge limit is 30 mg/l. On the other hand, based on the United States Environmental Protection Agency (USEPA) regulations, daily maximum limit for oil and grease is 42 mg/l and the monthly average is 29 mg/l. In Nigeria, it is currently required that produced water should meet an oil-in-water concentration of 40 ppm, 20 ppm and 10 ppm prior to discharge in offshore, near shore and onshore locations respectively [4; 5].

Produced water or brine, is a by-product of oil and gas production. It consists of water from the geologic formation, injection water, oil and salts. Brine has a high salt concentration the ions of the salts negatively affect the site's soil and vegetation, impairing its ability to produce crops and forage. A higher quantity of brine will need to be stored, transported and disposed of as the result of increased energy development. These larger quantities can lead to greater risks for spills and seepage and contamination of groundwater systems when they are not properly stored in waste pits. Brine has a high salt concentration that has been recorded up to four times the salinity of ocean water. Brine solutions can have electrical conductivities (EC) in excess of 200 Deci Siemens per meter (dS/m; 1 dS/m = 1 millimho per centimetre [mmho/cm]), sodium adsorption ratios (SAR) of more than 300 and total dissolved solids (TDS) concentrations of 100,000 parts per million. The high salt concentrations in brine come from salt deposits in oil-producing rock formations containing oil and are known to be highly injurious to plants when exposed to them and cause soil fragmentation thereby engendering soil erosion [6].

Oil waste may include produced water, drilling fluids, drilling muds, well cuttings, and well-treatment chemicals which contribute to pollution. Studies of well blowouts and possible development of communication between a fresh-water aquifer and oil-bearing sand have been made. However, that brines produced with oil and gas can contribute to groundwater pollution is well known but no universally satisfactory method of their disposal is available [7].

Kharaka et al. [8], has also stated that most nonexperts do not realize that for every barrel of oil produced today, oil companies also recover approximately ten barrels of produced water that is highly toxic to human health and the environment. Produced water is toxic because of high salinity and high concentrations of inorganic and organic chemicals and isotopes that far exceed the water quality criteria for drinking and irrigation water. Approximately 60 percent of produced water is currently reinjected into oil production zones for enhanced recovery and it has proven a great challenge to manage this wastewater without contaminating soil, vegetation, surface water, groundwater, and ecosystems [9], has also stated that produced water is an inextricable part of the hydrocarbon recovery process and the need to optimize water management cannot be overstated. Produced water must be adequately handled, at a considerable cost to operator, to prevent and/or minimize environmental degradation. When hydrocarbons are produced, they are brought to the surface as a produced fluid mixture. The composition of this produced fluid generally includes a mixture of either liquid or gaseous hydrocarbons, produced water. The produced water contains dissolved or suspended solids, produced solids (sand or silt), injected fluids and additives that may have been placed in the formation during exploration and production activities.

It has been reported that U.S. wells produce an average of more than 7 bbl of water for each barrel of oil whereas wells elsewhere in the world produce on average about 3 bbl of water for each barrel of oil. As at 1999, it was estimated that an average of 210 million bbl of water was produced each day worldwide [10]. The effect of produced water from oil and conventional natural gas production on the environment derive from the many chemical constituents found in produced water.

These liquid and dissolved pollutants when present individually or collectively in a high enough concentration, can present a threat to biota. The different potential impacts are dependent on concentration and discharge point. The constituents of produced water affect the environment into which it is discharged and operations. As the well ages, the volume of produced water increases and this present challenge which calls for finesse and some degree of understanding of the constituents of produced water and their effects on the environment of discharge. Because of its sheer volume and its high handling cost management of produced water is a key issue in any hydrocarbon recovery program; its potential environmental impacts if not properly managed, could be substantial [9].

The consequences of groundwater contamination extend beyond immediate health concerns, impacting ecological systems and biodiversity. Aquatic habitats and species dependant on groundwater resources are particularly vulnerable to the adverse effects of pollution with implications for ecosystem stability and resilience. Moreover, the migration of contaminants through groundwater pathways can exacerbate environmental degradation, affecting downstream water users and sensitive ecosystems beyond the confines of the oil field. Central to the challenge of groundwater contamination in the Mgbede and Ebocha oil field is the presence of an oil waste pit, serving as a repository for adverse array of hazardous substances generated by over fifty years of oil extraction activities. It is suspected that the inadequate containment and management of waste materials have facilitated the infiltration of pollutants into groundwater aquifers, exacerbating the environmental risk associated with the oil production in the region. This study therefore investigated the quality of groundwater in an oil field where decades of poor oil waste pit management is suspected to be polluting groundwater sources in Nigeria. The study adopted both in situ and laboratory methods in investigating contaminants in the waste pit and in various groundwater sources in the study area.

Study area

Description of Study Area

According to Clinton-Ezekwe [11], the Ebocha and Mgbede Oil Fields cover an area of 920 km^2 in the northern part of the Niger Delta region located within the Rivers Niger flood plains. It is bordered on the west by the Orashi River and on the east by the Sombreiro River. The Oil Fields fall within the Egbema district of the Ogba/Egbema/Ndoni Local Government Area of Rivers State and the Ohaji/Egbema Local Government Area of Imo State, Nigeria (Figure 1). The Area is host to the Ebocha Oil Centre, and other facilities and has been operational since around 1970. The study area is located within longitudes N05°.464546 and N05°.447248 and latitudes E006°.687214 and E006°.791868.

Geology and Climate: Rivers State lies on the recent Coastal Plain of the Eastern Niger Delta. Its surface geology consists of fluvial sediments. This includes the recent sediments transported by Niger River distributaries and other rivers, such as Andoni, Bonny and New Calabar. The studies area falls within the tropical monsoonal climate classification [12], characterised by a short dry season and a pronounced wet season which starts from March and last till October with a break, usually around August, Temperatures are fairly constant throughout the year, ranging between a maximum of 280 and 330°C to a minimum of 21–23°C. Agriculture and oil industries are dominant and across many rural communities.

The area lies in a low-lying gently sloping deltaic plain of not more than 25 m above sea level. It is drained mainly by the North-south flowing Orashi River and the east-west flowing smaller Nkissa-Sombreiro stream system which are fed by the groundwater system. Groundwater occurs in shallow aquifers of the Coastal Plain Sands comprising of sand, gravel and clan intercalations, with water table decreasing to 1m below surface at the peak of the rainy season.

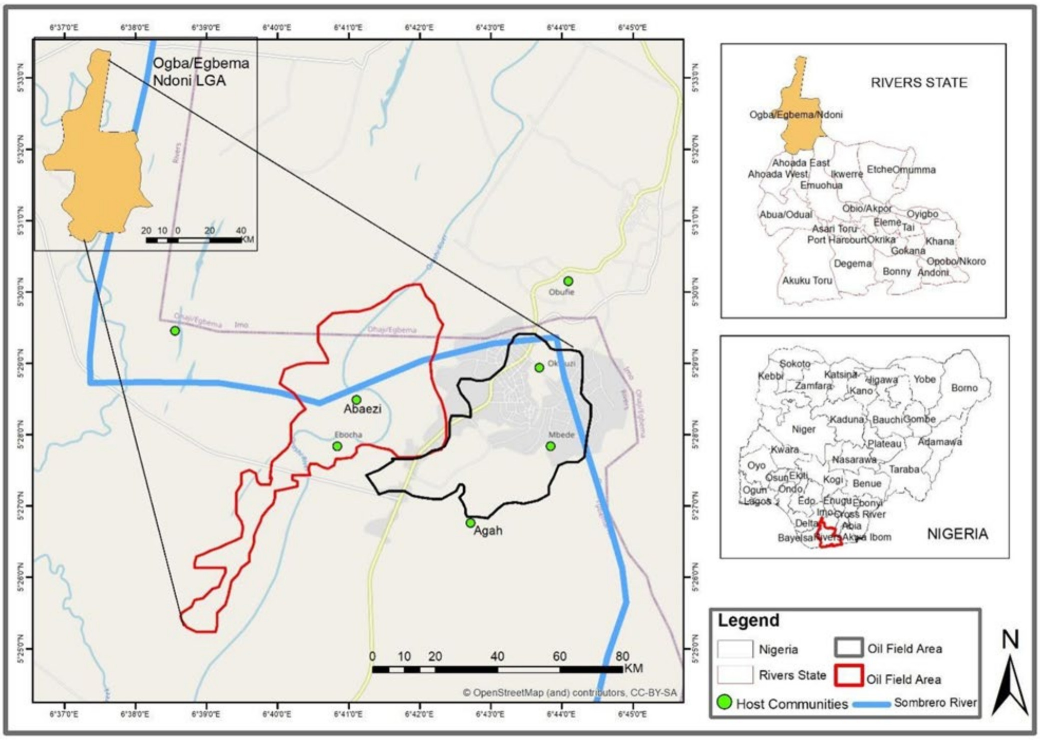

Figure 1. Location of Study Area

Source: compiled by M.H. Ikwulemenze, I.C. Ezekwe, E.I. Emereibeole, L.U. Mgbeahuruike, J.I. Nwachukwu.

Materials and methods

Sources and Method of Data Collection/Instrumentation

5 water sampling points including the oil waste pit were identified for this study. They included groundwater source upgradient from the waste pit and 3 sampling points downgradient from the point of impact or waste pit (see Figure 2, [13 in press]). were identified and used for this investigation.

The APHA (2017)[1] methods and protocols for sampling and analysis of wastewater were applied. It involved taking samples for laboratory analysis and in situ analysis of unstable water quality parameters. The complexity of water quality as a subject is reflected in the many types of measurements of water quality indicators. The most accurate measurements of water quality are made on-site because water exists in equilibrium with its surroundings [14]. Measurements of physico-chemical parameters was made on-site and in situ including temperature, pH, dissolved oxygen, conductivity, oxygen reduction potential (ORP) and turbidity with the Horiba 52 Water Checker. Other parameters including heavy metals (Pb, Cr, Cd, As, Hg) and hydrocarbons was measured in the laboratory using standard methods (APHA, 2017)[1]. Water sampling for physio-chemical analysis will be collected with new 1L plastic containers pre-rinsed with dilute nitric acid and rinsed three to four times with the water sample before being filed to capacity and labelled; samples for heavy metal analysis was treated with 2 ml of nitric acid (100 %, trace metal grade, Fisher Scientific) to stabilize the oxidization states of the metals; while samples for PAHs was taken in breakable bottles and treated with hydrochloric acid to avoid contamination by hydrocarbon chelation.

The samples were then placed in ice-packed coolers and stored below 4°C prior to laboratory analysis. Heavy metals were analysed by atomic absorption (AA) spectrophotometry using a Perkin-Elmer and Analyst 100 AA spectrophotometer (detection limit 0.001 mg/L); while, two methods using headspace solid-phase microextraction and gas chromatography-mass spectrometry developed by [15] for the determination of polycyclic aromatic hydrocarbons (PAH). All manipulations will be done in duplicates under controlled conditions to avoid contamination.

Results and discussions

The results from the field and laboratory investigations of water quality and groundwater contamination in the Mgbede and Ebocha Oil Fields following the aim and objectives of this study are presented as follows.

Physico-Chemical Properties of Water

Table 1 shows the concentrations of measured physico-chemical parameters and heavy metals found in groundwater in the study area. Table 1 shows the results for pH, Conductivity (Us/cm^2), TDS (mg/l), ORP (M_v), heavy metals, anions and cations in groundwater including chloride, sodium, potassium, chromium, magnesium, zinc, cadmium, lead and manganese while Table 2 shows the concentration of PAH contaminants in the groundwater system. Concentrations indicated in RED occurred above acceptable limits while those in GREEN are considered as borderline cases.

[1] APHA (2017). *Standard Methods for the Examination of Water and Wastewater* (23rd ed.). Washington DC American Public Health Association

pH ranged from 5.61 to 7.52, showing that the water is generally acidic and above maximum acceptable limits of the WHO apart from the water sample site upgradient to the waste pit (SWP) in site SWC which was neutral to alkaline. It has also had stated that the acidic nature of the water will make them very corrosive and cause metal ions to be leached into groundwater systems. Signs of acid water are corrosion of fixtures, blue staining (from copper pipes) or rust staining (from iron pipes) leading to pinhole leaks and pipe failure over time and sour taste in water. Also, body pH profile has been linked to many diseases.

Table 1. **Physico-Chemical Parameters and Heavy Metals**

S/N	PARAMETER	UNIT	TEST METHOD	SW1	SW2	SW3	SWC	SWP	WHO STANDARDS
1	pH	–	APHA 4500-H^+-B	5.90	5.87	5.61	7.52	5.87	6.5–8.5
2	EC	μS/cm	APHA 2510	45	38	34	1123	64	<1500
3	Total Dissolved Solids	mg/L	APHA 2540-C	24	18	17	32	558	<600
4	Redox Potential (ORP)	Mv	APHA 2580	–41.7	–18.4	–29.0	–44.3	–42.6	200–600
5	Chloride (Cl)	mg/L	APHA 4500-Cl-B	21.9	18.9	16.9	246.9	26.9	<250
6	Sodium (Na)	mg/L	APHA 3111-B	4.265	4.174	0.049	5.316	8.375	<200
7	Potassium (K)	mg/L	APHA 3111-B	2.448	2.114	0.887	3.813	6.534	<20
8	Magnesium (Mg)	mg/L	APHA 3111-B	3.055	2.620	1.079	4.118	10.149	<50
9	Chromium (Cr)	mg/L	APHA 3111-B	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05
10	Zinc (Zn)	mg/L	APHA 3111-B	0.569	0.304	0.078	0.879	1.267	<3
11	Cadmium (Cd)	mg/L	APHA 3111-B	<0.001	<0.001	<0.001	<0.001	0.037	<0.003
12	Lead (Pb)	mg/L	APHA 3111-B	0.042	<0.001	<0.001	0.033	<0.001	<0.01
13	Manganese (Mn)	mg/L	APHA 3111-B	<0.001	<0.001	<0.001	<0.001	<0.001	<0.1

Source: compiled by M.H. Ikwulemenze, I.C. Ezekwe, E.I. Emereibeole, L.U. Mgbeahuruike, J.I. Nwachukwu.

Most forms of diseases flourish in an acidic environment which is why drinking high acidic water in combination with our lifestyle changes and diet are a path for future health problems. The human body can only be healed of any chronic illness when blood is at normal or slightly alkaline pH [16].

An imbalanced pH affects the cellular activity in the body, leading to the progression of most degenerative diseases, including cardiovascular and heart disease, high blood pressure, high cholesterol levels, kidney stones, urinary incontinence, arthritis, osteoporosis, cancer, diabetes, systemic weight gain and obesity. A poor pH balance in the body can cause many other health problems and a general feeling of ill health. Health effects of acidosis or an elevated level of acidity in the body include insomnia, headaches, frequent sighing, water retention, low blood pressure, foul-smelling stools, difficulty swallowing, sensitivity to vinegar and acidic fruits and bumps on the tongue, fatigue, lack of energy, low body temperature, depression, frequent infections, teary eyes, sensitive teeth, gastritis, dry skin, brittle nails, hives, and leg cramps[2].

[2] Biomedx (2017). *The pH Equation & Health*. Available from: https://biomedx.com/microscopes/rrintro/rr4.html (accessed: 25.12.2023).

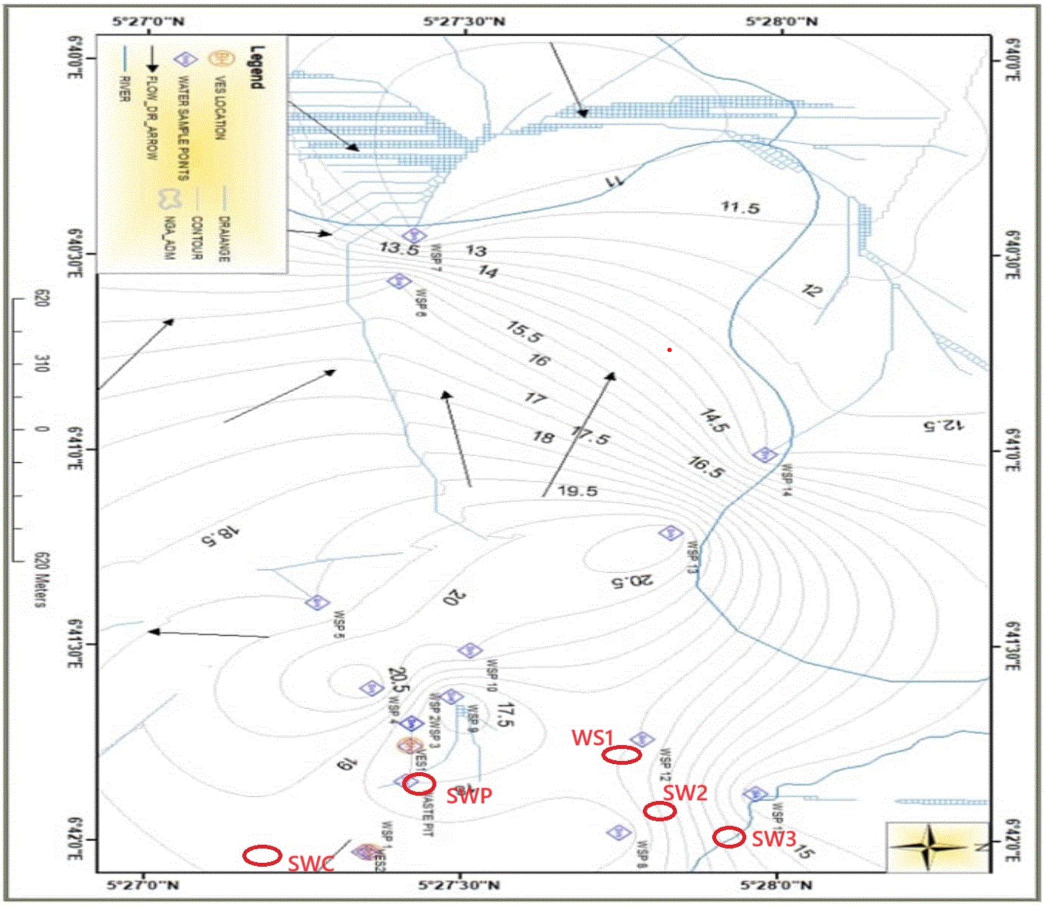

Figure 2. Groundwater Flow Patterns from elevation and coordinate data
Source: compiled by M.H. Ikwulemenze, I.C. Ezekwe, E.I. Emereibeole, L.U. Mgbeahuruike, J.I. Nwachukwu.

Conductivity ranged between 34 in SW3 to 1123 at the upgradient site SWC; while TDS was very low and ranged between 17 in SW3 and 558 at the waste pit. ORP which is an indicator of the true oxidation state of the water was generally low (ranging between –42.6 in the waste pit area to –18 Mv in SW2 down gradient from the waste pit. These figures are below the optimal level for inhibiting microbial growth in drinking water [17]. Oxidation-reduction potential (ORP) measures the ability of a body of water to cleanse itself or break down waste products, such as contaminants and dead plants and animals. When the ORP value is high, there is lots of oxygen present in the water. Positive values for ORP indicate oxidizing conditions, whereas negative values indicate reducing conditions. Reducing condition means a geochemical condition where dissolved oxygen is depleted (< 1 mg/L). When ORP is low, dissolved oxygen is low, toxicity of certain metals and contaminants can increase, and this may indicate the presence of lots of dead and decaying material in the water that cannot be cleared or decomposed [18].

Lead concentration was 0.03–0.42 in SW1 and SWC and cadmium (0.037) in SWP respectively had concentrations above permissible levels, while all other heavy metals occurred either below detectable limits or within permissible limits. Zinc was 0.078 in SW3 and 1.27 in SWP was found in all the wells although within acceptable limits. Other contaminants were as follows; chloride (21.9–246.9), sodium (0.049–8.375), Magnesium (1.09 in SW3 – 10.149 in SWP), Sodium (1.680–22.206) and Potassium (0.887 in SW3 – 6.534 in SWP). Figure 3 shows the trend of heavy metal concentration in groundwater. Zinc concentration from the graph is clearly indicative of lowering concentration with distance away from the waste pit. Further graphic analysis (Figure 4) reveals that the highest concentrations of cadmium occurred in the waste pit while lead concentration were found in all the wells and high concentrations mostly found in the boreholes found closer to the waste pit.

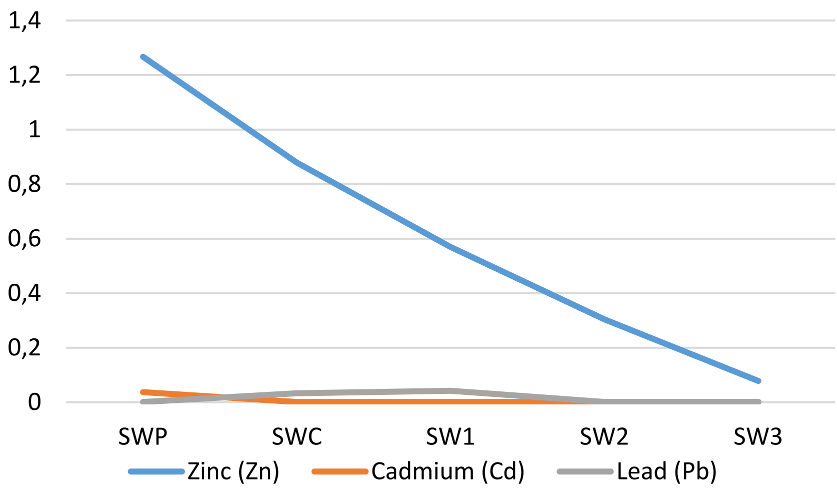

Figure 3. Heavy metal concentration
Source: compiled by M.H. Ikwulemenze, I.C. Ezekwe, E.I. Emereibeole, L.U. Mgbeahuruike, J.I. Nwachukwu.

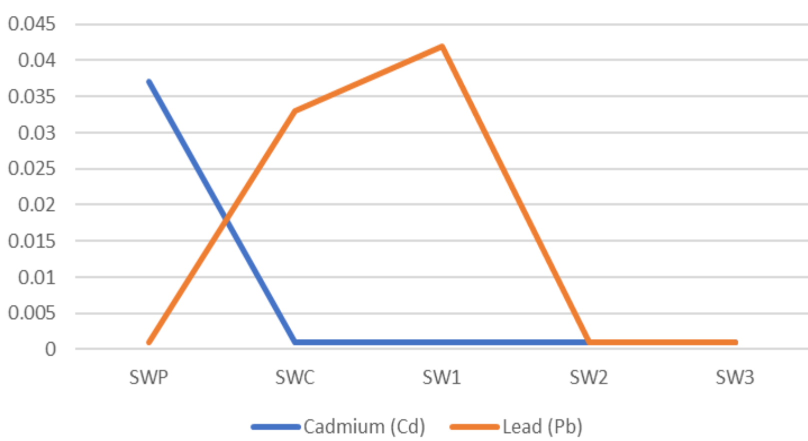

Figure 4. Plot of cadmium and lead only
Source: compiled by M.H. Ikwulemenze, I.C. Ezekwe, E.I. Emereibeole, L.U. Mgbeahuruike, J.I. Nwachukwu.

Table 2 shows the result of laboratory analysis of water samples for PAHs. Results show a widespread occurrence of PAHs in the groundwater system. It should be noted that all the sampled sites had concentrations of total PAHs above the USEPA drinking water limits of 0.2 µg/l (ASTDR, 2023)[3]. Benzo[a]pyrene which is a known carcinogen occurred in concentrations above acceptable limits (0.2 µg/l) in all the sampled boreholes except SWP where it occurred in borderline concentration of 0.17 µg/l.

The U.S. Environmental Protection Agency (USEPA) sets a maximum contaminant level (MCL) for benzo(a)pyrene, the most carcinogenic PAH, at 0.2 µg/l. USEPA also sets MCLs for five other carcinogenic PAHs. The goal of the recommendation was a zero (nondetectable level for carcinogenic PAHs in ambient water). It set 0.1 µg/l for benz (a)anthracene, 0.2 µg/l for benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene and chrysene, 0.3 µg/l for dibenz(a,h)anthracene and 0.4 µg/l for indenol(1,2,3-c,d)pyrene[4]. PAHs are organic compounds that have attracted global recognition because of their carcinogenic threats. PAHs are categorized into high (4–6 rings) and low-member (2–3 rings) weight groups17–19. PAHs are generally classified as relatively persistent organic and environmental pollutants [19].

Polycyclic Aromatic Hydrocarbons in Groundwater

Table 2. **Polycyclic Aromatic Hydrocarbons in Groundwater**

PARAMETERS	UNIT	SW1	SW2	SW3	SWC	SWP	USEPA STANDARDS (ASTDR, 2023)
Naphthalene	µg/l	0.29	0.08	0.26	<0.01	0.30	NA
Acenaphthylene	µg/l	0.51	0.28	<0.01	<0.01	0.33	NA
Acenaphthene	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	1.0 (Minnesota Health Dept)
Fluorene	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	NA
Anthracene	µg/l	<0.01	<0.01	<0.01	<0.01	0.15	NA
Phenanthrene	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	NA
Fluoranthene	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	NA
Pyrene	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	NA
Benz[a]anthracene	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	0.1
Chrysene	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	0.2
Benzo[b]fluoranthene	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	0.2
Benzo[k]fluoranthene	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	0.2
	µg/l	0.95	0.46	0.65	0.79	0.17	0.2
Dibenz(a,h)anthracene	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	0.3
Indeno(1,2,3-cd) pyrene	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	0.4
Benzo[ghi]perylene	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01	NA
TOTAL PAHs	**µg/l**	**1.75**	**0.82**	**0.91**	**0.79**	**1.95**	**0.2**

Source: compiled by M.H. Ikwulemenze, I.C. Ezekwe, E.I. Emereibeole, L.U. Mgbeahuruike, J.I. Nwachukwu.

[3] Agency for Toxic Substances and Disease Registry. Polycyclic Aromatic Hydrocarbons (PAHs). Available from: https://www.atsdr.cdc.gov/csem/polycyclic-aromatic-hydrocarbons/standards_and_regulations_for_exposure.html. (accessed: 25.12.2023).

[4] Ibid.

Discussions and Conclusions

The Oil waste pit contained an acidic pH, a very negative redox potential, borderline zinc concentration and above limits cadmium concentration. It also had high levels of naphthalene, Acenaphthylene, anthracene and above limits of carcinogenic Benzo[a]pyrene. According to the WHO[5], PAHs reach the hydrosphere mainly by dry and wet deposition and road runoff but additionally from industrial wastes containing PAHs and leaching from creosote-impregnated wood. PAHs are adsorbed strongly to the organic fraction of sediments and soils. Leaching of PAHs from the soil surface layer to groundwater is assumed to be negligible owing to the adsorption and to biodegradation in the aerobic soil surface layer, although their presence in groundwater has been reported, mainly at contaminated sites.

The volatility of the compounds from water phases is low, with half-lives of 500 and 1550 hours for B*a*A and B*a*P, respectively. The compounds are very slowly biodegradable under aerobic conditions in the aqueous compartment. The biodegradation rates decrease drastically with increasing number of aromatic rings. In laboratory experiments with soil samples, the calculated half-lives for the selected compounds vary widely, from about 100 days to a couple of years. PAHs are stable towards hydrolysis. For pure water, the photodegradation half-lives appear to be in the range of hours, whereas the half-lives increase drastically when sediment/water partitioning is considered.

Also, note that the inhabitants of the study area have stopped the digging and using of hand-dug wells due excessive gas occurrence from depths of 3 metres below the surface. In fact, deaths and near-death scenarios had occurred due gas poisoning in the process of digging wells.

Groundwater in the study area was characterised by unacceptable levels of acidity, ORP, PAHs, cadmium and borderline cases of zinc contamination. It has also been noted that acidity in drinking water can cause serious problems through the leaching of heavy metals from plumbing systems such as lead. Lead exposure can lead to a host of neurological and reproductive problems, such as seizures, hearing loss and miscarriages. Leaching of heavy metals like copper and zinc causes a domino effect that can impact the gastrointestinal system. High dosage exposure to zinc and copper from corroded pipes can cause nausea, vomiting or diarrhoea [20–22].

Also, eating large amounts of cadmium can severely irritate the stomach and cause vomiting and diarrhoea. Breathing high levels of cadmium damages people's lungs and can cause death. Exposure to low levels of cadmium in food, water, and

[5] World Health Organization (2003). *Polynuclear aromatic hydrocarbons in drinking-water. Background document for development of WHO guidelines for drinking-water quality.* Geneva: World Health Organization; 2003

air over time may build up cadmium in the kidneys and cause kidney disease and fragile bones. Cadmium is considered a cancer-causing agent (US CDC, 2017)[6].

A very recent (March 2024)[7] report by The National Cancer Institute, an agency of the United States of America Government states that cadmium and its compounds are highly toxic, and exposure is known to cause cancer. It is primarily associated with human lung, prostate, and kidney cancers, and recently pancreatic cancer. It has also been associated with cancers of the breast and urinary bladder. The general population may be exposed to small amounts of cadmium daily through food, tobacco smoke, drinking water, and air, resulting in accumulation in the body. Cadmium levels are expected to be low in drinking water and ambient air, except in the vicinity of cadmium-emitting industries or incinerators.

The Illinion Department of Public Health (2023)[8] stated that the effects of exposure to PAHs may be short-term or long term. While short-term exposure to PAHs and other associated pollutants may produce reactions such as eye irritation, nausea, vomiting, diarrhoea, and confusion; long-term health effects of exposure to PAHs may include cataracts, kidney and liver damage, and jaundice. Repeated skin contact to the PAH naphthalene can result in redness and inflammation of the skin. Long-term exposure to low levels of some PAHs have also been found to cause cancer in laboratory animals. Also, studies of workers exposed to mixtures of PAHs and other compounds revealed an increased risk of skin, lung, bladder, and gastrointestinal cancers. It is also a fact that while inhaling or swallowing large amounts of naphthalene can lead to a breakdown of red blood cells, benzo(a)pyrene is known to commonly cause adverse reproductive and developmental effects and induce cancer in laboratory animals. It has also been established that long-term exposure causes skin, lung, and bladder cancer in humans.[9]

In conclusion, this study discovered that the Oil waste pit contained an acidic pH, a very negative redox potential, borderline zinc concentrations and above limits cadmium concentration. The study therefore concludes that the study area has a contaminated groundwater characterised by high acidity which can cause serious problems like the leaching of heavy metals from water pipes and plumbing systems and widespread occurrence of above limits concentrations of PAHs in the whole of the studied boreholes thereby posing a serious public health challenge. Potential

[6] US Centre for Disease Control and Prevention (CDC) (2017). *Cadmium Factsheets*. Available from: https://www.cdc.gov/biomonitoring/Cadmium_FactSheet.html#: (accessed: 25.12.2023).

[7] US National Cancer Institute. *Cadmium – Cancer Trends Progress Report*. March, 2024. Available from: https://progressreport.cancer.gov/prevention/chemical_exposures/cadmium#:~:text=Cadmium%20and%20its%20compounds%20are,the%20breast%20and%20urinary%20bladder (accessed: 25.12.2023).

[8] Illinois Department of Public Health (2023). *Cancer in Illinois. PAHs*. Available from: http://www.idph.state.il.us/cancer/factsheets/polycyclicaromatichydrocarbons.htm (accessed: 30.12.2023).

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health risks include a likelihood of exposure to cancer due to the long-term consumption of carcinogenic PAHs and cadmium in the groundwater sources.

In the light of the foregoing, we therefore recommend that the Federal Government of Nigeria and the oil companies operating in the study area should provide an alternative water sources to the inhabitants of this oil field, since groundwater sources which is the main source of domestic water has become a serious health hazard. The federal and state government to improve healthcare delivery in the study area and establish a special health insurance scheme/trust fund for inhabitants to cushion the effects of long-term exposure to pollutants from oil producing activities.

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