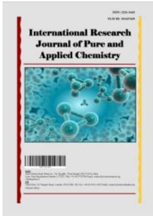

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An Analytical Investigation Study of Potential Human Health Risks Caused by Petroleum-contaminated Surface Water Containing Various Toxic Heavy Metals at the Okpoka Creek, Niger-Delta, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author FC conceptualized, ensure the ethics and protocols, carried out the experiments and performed the analytical quality (quality assurance (QA) / control (QC), and write the manuscript. Authors SJS and DAD analyzed the data, supervised the research and manuscript. Author HAC-N was involved in the results and discussion. All authors read and approved of the final version of the manuscript.

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ABSTRACT

Surface water samples were collected from the Okpoka Creek, Niger-Delta using the grab samples method and were analytically investigated for petroleum contamination. The liquid-liquid extraction of petroleum hydrocarbons was carried out following standard procedures of U.S EPA 3510; 1664 method and ASTM D3695 -95(2013). The US EPA 3005A method was adopted for acid wet digestion (Aqua regia mixture of concentrated HNO_3 and HCl in ratio 1:3) for toxic heavy metal (HMs) determination. Total petroleum hydrocarbons (TPHs) was analytically identified and quantified with the representative extract (sample) using Gas chromatography mass spectrometry

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detection (GC-MSD) Agilent Technologies 7890A in adherence to the standard analytical method of U.S EPA 8270;625. Atomic absorption spectrophotometer (AAS) Buck Scientific 210VGP in adherence in to the manufacturer's specifications was employed for HMs. The recorded elevated levels of the TPHs were significantly above the permissible limit of DPR/EGASPIN and HMs were also overwhelmingly above permissible limits of relevant regulatory agencies. The elevated concentrations of these contaminants of concern provided evidences of severe contamination in the study site and severe threats to environment and human health.

Keywords: Contaminated surface water; petroleum hydrocarbons; heavy metals; Niger-Delta.

1. INTRODUCTION

Freshwater is a scarce and valuable resource in Nigeria particularly at the Niger-Delta region because of its regular petrogenic and other anthropogenic activities. Surface water has sensitive and different concerns from groundwater as groundwater is pulled out of the ground, which acts as a natural filter, but surface water is exposed to all elements and picks up something from anything it touches. Niger-Delta is faced with portable water challenge; the communities mostly depend on their surface waters despite the physical evidences of pollution such as oil sheen, dead aquatic animals, floating objects (municipal and industrial waste).

Every human needs about 20 litres of freshwater a day for basic survival (drinking and cooking) and an additional 50 to 150 litres for basic household use [1]. However with growing population and an overall increase in living standards, not only is the overall demand for freshwater pushing limits (one third of world now lives in areas of portable water scarcity) but increasing pollution from urban, industrial and agricultural sources is making available water resources unsuitable while increasing health risk [2]. Almost 5 million deaths in the developing world (Mozambique, Chad, Niger, Sudan, DR Congo, Angola, Somalia, Ethiopia, Papua New Guinea, Uganda, Eritrea, other parts of Africa and South America) annually are due to water related diseases, this could have been avertable with adequate supplies of safe water [1] and [3]. Countries like Brazil, Russia, United States of America, Canada, China, Colombia and European Union benefit from large volume of renewable fresh water resources or bodies while recording less death rate of water related diseases [4,3] and [1].

Niger-Delta is known for its crude oil exploration in the world, which is the hub of petroleum production in Nigeria (all oil exploration companies are located in the Niger-Delta region) with a maximum crude oil production of 2.5 million barrels per day. Nigeria ranks as Africa's largest producer of oil, the sixth largest oil producing country in the world and the world's fifth largest exporter of liquefied natural gas (LNG). Although Nigeria oil exploration and production has devastated the marine environment of Niger-Delta that has been for 6 decades. Mostly the indigenous communities depend on marine resources for their livelihood, the ecosystem supports a wide variety of flora (timber species, vegetables, fruits, medicinal plants, palm trees, tannins and grasses) and fauna (monkeys, apes, otters, squirrels, antelopes, reptiles, different species of birds and among others) species. Ironically all these are degrading daily as a result of petroleum contamination of surface waters with million tons of oil have been spilled for a couple of decades without revamping. Nigeria's crude oil and natural gas resources are the mainstay of the country's economy with the confirmation of International Monetary Fund (IMF) [5,6] and [7]. The growth in export revenue has continuously improved Nigeria's fiscal position yet Niger-Delta suffers the necessary social amenities to improve the living standard of the communities.

Hence, the aim of this study is to analytically investigate the potential human health risks of petroleum hydrocarbons and various toxic heavy metals present in the surface water at Okpoka creek.

2. LITERATURE REVIEW

Water contamination becomes a noteworthy problem because water is an essential natural resource for human life. Water is an important resource of developing economic and society in terms of agriculture, industry and various facilities [8] and [1]. Lakes and rivers not only supply water for human consumption but sometimes receive wastewater discharge from all human activities. Due to the adverse effects of exposure from continuous unsystematic discharge of untreated effluents, there have been raises in public awareness to avert this public concern recently [9] and [8].

Consequently, Nigeria has recorded oil spill incidents at different times along its coastline. Available literatures revealed that oil spillage routinely occurs in the Niger Delta region, despite its fragile ecosystem and biodiversity. Approximately, 5,334 reported cases of crude oil spillage occurred between 1976 and 1997, with an estimated 2.8 million barrels of oil released into coastal waters, land and swamps of Nigeria [9,10] and [11].

The associated impacts of oil spills in mangrove vegetation and coastal waters cannot be overemphasized in Niger-Delta [12]. Generally, oil spills in Nigeria are not completely reported, compared to the magnitude of environmental devastation. Nigeria's largest spill was an offshore well-blow out in January 1980 when an estimated 200,000 barrels of oil (8.4million US gallons) spilled into the Atlantic Ocean from an oil industry facility, damaging 340 ha of mangrove [11] and [12]. Nigeria's Niger Delta as one of the world's most severely impacted ecosystem by petroleum, with an estimate of 9 to 13 million barrels of oil spilled in the Niger Delta ecosystem in the past 55 years [11], [12], [13] and [10].

Oil spills pose one of the greatest environmental challenges globally, constituting harmful effects on both human health and aquatic organisms. Fishing resources can be damaged through physical contamination, bio-accumulation, and damaging of spawning grounds, as well as habitat destruction, depending on the circumstances of the spill and time of response [14] and [15]. There is various human health complications associated with petroleum hydrocarbons contamination. Some of these include carcinogenicity, genotoxicity, deoxyribonucleic acid (DNA) damage, birth defects, childhood leukaemia, infertility and miscarriages in women, sterility, skin rashes and irritation, respiratory system disorders, and cancers of different parts (organs) of the body [3,15,16] and [17]. In some parts of the world, research has primarily been focused on high-doses and short-term occupational exposures to crude oil during remediation of oil spills. It has been reported that workers exposed to petroleum hydrocarbons have adverse health symptoms such as headaches, eye and skin irritation, respiratory difficulties and among others [18] and [19]. Acute exposures to high concentrations of petroleum hydrocarbons is often associated with the problem of central nervous system toxicity, resulting in symptoms such as headaches, fatigue and dizziness [19], [20] and [21]. It is known that continuous exposures to petroleum hydrocarbons can impair the immune system and exposure to benzene, a known human carcinogen, is often associated with hematopoietic system disorders [16] and [18]. Polycyclic aromatic hydrocarbons; contaminants in petroleum cause symptoms such as nausea, vomiting and skin and eye irritation following acute, high-level exposures [21,22,23] and [24]. Exposures to PAHs during pregnancy have been linked to decreased birth weight and impaired child development. Chronic occupational exposures are associated with dose-dependent increased risks of certain types of cancers, including lung, skin and bladder cancer [24] and [23].

The co-existence of toxic heavy metals and hydrocarbons (HCs) at many of contaminated sites poses a severe threat to the environment. In fact, the significance of trace elements in water chemistry is increasingly becoming an issue of global concern especially as water constitutes a crucial component of rural and urban environment [2] and [4]. Heavy metals such as cadmium (Cd), copper (Cu), chromium (Cr), lead (Pb), manganese (Mn), nickel (Ni) and zinc (Zn) which are often contained as additives in petroleum and products are non-degradable in the water. Some of them have been classified as priority pollutants by United State Environmental Protection Agency. At the moment very few technologies, such as bioremediation is available to treat these mixed toxic wastes [5].

3. MATERIALS AND METHODS

3.1 Study Site

The petroleum-contaminated surface water samples were obtained from Okopoka creek, (Port Harcourt, River State) Niger-Delta. Okpoka creek is one of the adjoining creeks off the upper Bonny River estuary in the Niger-Delta. Bonny River is a major shipping route for crude oil and other cargoes that leads to the Port Harcourt quays, Federal ocean terminals, Onne, Port Harcourt Refinery Company Terminal Jetty and Okirika. Port Harcourt is the chief oil refining city in Nigeria. Okpoka creek is about six kilometres long and continues to Abuloma town of Rivers State where it finally joins the Bonny River before fading into the Atlantic Ocean. There are about 12 communities along the main course namely; Oginigba, Azubiae, Woji, Okujagu, Okuru-ama, Abuloma, Ojimba, George-ama, Oba-ama, Kalioama, Marine base and Okirika. The petrogenic activities going on around the creek, oil slick floating on the surface water and some dead aquatic animals gave evidences of petroleum contamination. Collection of samples were obtained with the location coordinates of N04^{0}46’ 38’’ E007^0 03’ 55’’ and 4.94 km from the heart of the Pipelines and Product Marketing Company (PPMC) Oil Company, (Fig. 1). The investigational studies and analytical preparations were performed in the Chemistry Postgraduate Research Laboratory, University of Jos, Jos Nigeria with the location coordinates N09053’46.2” E008053’58.5”.

3.2 Ethics, Protocol and Management

Collections and sampling were conducted under the standard specifications, ethics, protocols and management of U.S Environmental Protection Agency (EPA). - For analysis of wastewater, drinking water and environmental monitoring under the Clean Water Act and Safe Drinking Water Act (1999) was adopted aptly. Standard methods for the examination of water and wastewater 20th editions APHA (American Public Health Association), AWWA (American Water Works Association) and WEF (Water Environment Federation) were also considered.

3.3 Sample collection

Petroleum-contaminated surface water samples were collected from the study site using the analytical grab samples method. Discrete grab samples were taken using a glass cup and amber bottles with Teflon-lined caps. Collections of samples were obtained at different depths (2, 5 and 10cm) of a selected location at the study site. Thus, collected samples were pooled together to give a representative sample of 60,000cm^3. The homogenised sample was filtered and preserved (acidified) on the site with 120cm^3 concentrated H_2SO_4 to bring the pH to ≤ 2. The sample was refrigerated at ≤ 4^{0}C and extracted within 14days of collection for the analysis of total petroleum hydrocarbons (TPHs) ASTM D3695-95(2013) was considered while acid digestion was carried out for the analysis of heavy metals within the time span (holding time) of 30days.

3.4 Method of Analysis

The analytical test procedures used to investigate the surface water petroleum contamination were total petroleum hydrocarbons (TPHs) and heavy metals determinations.

3.5 Total Petroleum Hydrocarbons

The TPHs was classified into surrogated fractions (C_8 – C_{10}, C_{11} – C_{28} and C_{29} – C_{40}) characterised by similar adverse health effects, toxicological information, chemical and physical properties; in accordance to the guidelines developed by the Agency for Toxic Substances and Disease Registry [25], Environmental Protection Agency [26], TPH Criteria Working Group [27], U.S Department of Environmental Quality [28] and American Petroleum Institute [29] for ease of quantification and interpretation.

3.5.1 Extraction of petroleum hydrocarbons

The liquid-liquid extraction of surface water sample for total petroleum hydrocarbons was carried out following standard procedures [30]. The filtered surface water samples were subjected to different separatory funnels extraction using U.S EPA 3510; 1664 method. Homogenized 500cm^3 surface water sample of 4 replicates was extracted three times (sequential extraction) in 1000cm^3 glass separatory funnels fitted with glass stoppers. Acetone and n-hexane (1:1, v/v) of 125 cm^3 was added to each sample and were shaken on a reciprocating mechanical shaker at 120 oscillations per minute for 4hours. The mixtures of each sample were poured into different separatory funnels and allowed to stand for a couple of minutes for the organic layer to separate clearly from the aqueous phase. The organic (extract) layers were collected and pooled together to give a representative (extract) sample, stored in an amber bottle with Teflon-lined cap and refrigerated at 4^{0}C.

3.5.2 TPH analysis

The representative extract (sample) of total petroleum hydrocarbons was analytically identified and quantified using Gas chromatography mass spectrometry detection (GC-MSD) Agilent Technologies 7890A in adherence to the standard analytical method of U.S EPA 8270;625. The instrument’s setting and operational conditions were done in accordance with the manufacturer’s specifications. The result obtained for TPH in surface water is shown in Table 1.

3.5.3 Analytical quality (AQ) for TPH

Quality control measures in analysis procedure were taken to confirm the accuracy of the analytical data. The protocol prescribed by the U.S Environmental Protection Agency (EPA), Agency for Toxic Substances and Disease Registry (ATSD), TPH Criteria Working Group (TPHWG), U.S Department of Environmental Quality (DEQ) and American Petroleum Institute (API) for TPHs analysis were used. In order to establish the quality assurance (QA) and quality control of the result, collected samples were pooled together to give a representative sample for the analysis.

All laboratory glassware used for analysis were from pyrex, washed with 0.1N HNO_3, rinsed twice with distilled water then with deionized water and placed in laboratory oven until dry.

All reagents used were of analytical grade (BDH) certified standard solutions.

Standard management of practice for estimation of holding time for water/wastewater samples of organic and inorganic constituents as stipulated by American Society for Testing Materials D4841-88 was applied appropriately. In concurrence with the holding times and preservation of TPHs (28 days) in environmental quality guidance for evaluating performance-based chemical data (EM 200-1-10) by the U.S Army Corps of Engineers (USACE) and EPA 1664 method.

The use of certified standard reference data from Department of Petroleum Resources/ Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (DPR/EGASPIN), U.S Environmental Protection Agency (EPA) and Agency for Toxic Substances and Disease Registry (ATSD) were employed.

3.6 Heavy Metals (HMs) Digestion Method

The US EPA 3005A method was adopted via the wet acid digestion (Aqua regia, mixture of concentrated HNO_3 and HCl in ratio 1:3) of the petroleum contaminated surface water sample for the determination of some related HMs (Lead (Pb), Cadmium (Cd), Chromium (Cr), Nickel (Ni) and Manganese (Mn) present. The representative sample was measured ($25cm^3$) and digested in $100cm^3$ beaker covered with a watch glass by adding $6.25cm^3$ HNO_3 and $18.75cm^3$ HCl. The mixture was heated on steam bath for 30 minutes in the laboratory fume hood and then cooled. The resulting light coloured sample (digest) was filtered and made up to 50 cm^3 with deionised water in standard Pyrex beakers. The solution was transferred into labelled plastic bottle and refrigerated at 4^0C.

3.6.1 Heavy metals analysis

The concentrations of Pb, Cd, Cr, Ni and Mn in the final solution were determined by atomic absorption spectrophotometer (AAS) Buck Scientific 210VGP. The instrument's setting and operational conditions were done in accordance with the manufacturer's specifications. The instrument was calibrated with analytical grade metal standard stock solutions (1 mg/L). The result obtained is shown in Table 2.

Table 1. Total Petroleum Hydrocarbons (TPHs) Concentrations for Raw Petroleum-contaminated Surface Water [30]

Components	Categories	Concentrations
	[1]TPHCWG [2]USEPA/ [3]DEQ/ [4]API	(mg/L)
C_8 - C_{10}	+ GRO	1397.53
C_{11} - C_{28}	++ DRO	102305.63
C_{29} - C_{40}	+++EDRO	1059.25
C_8 - C_{40}	TPH	104762.42
*DPR/EGASPIN (MCL)	TPH	10.00

MCL Maximum Contamination Limit (2002) on Surface water, [1]Total Petroleum Hydrocarbons Criteria Working Group, US (1998)

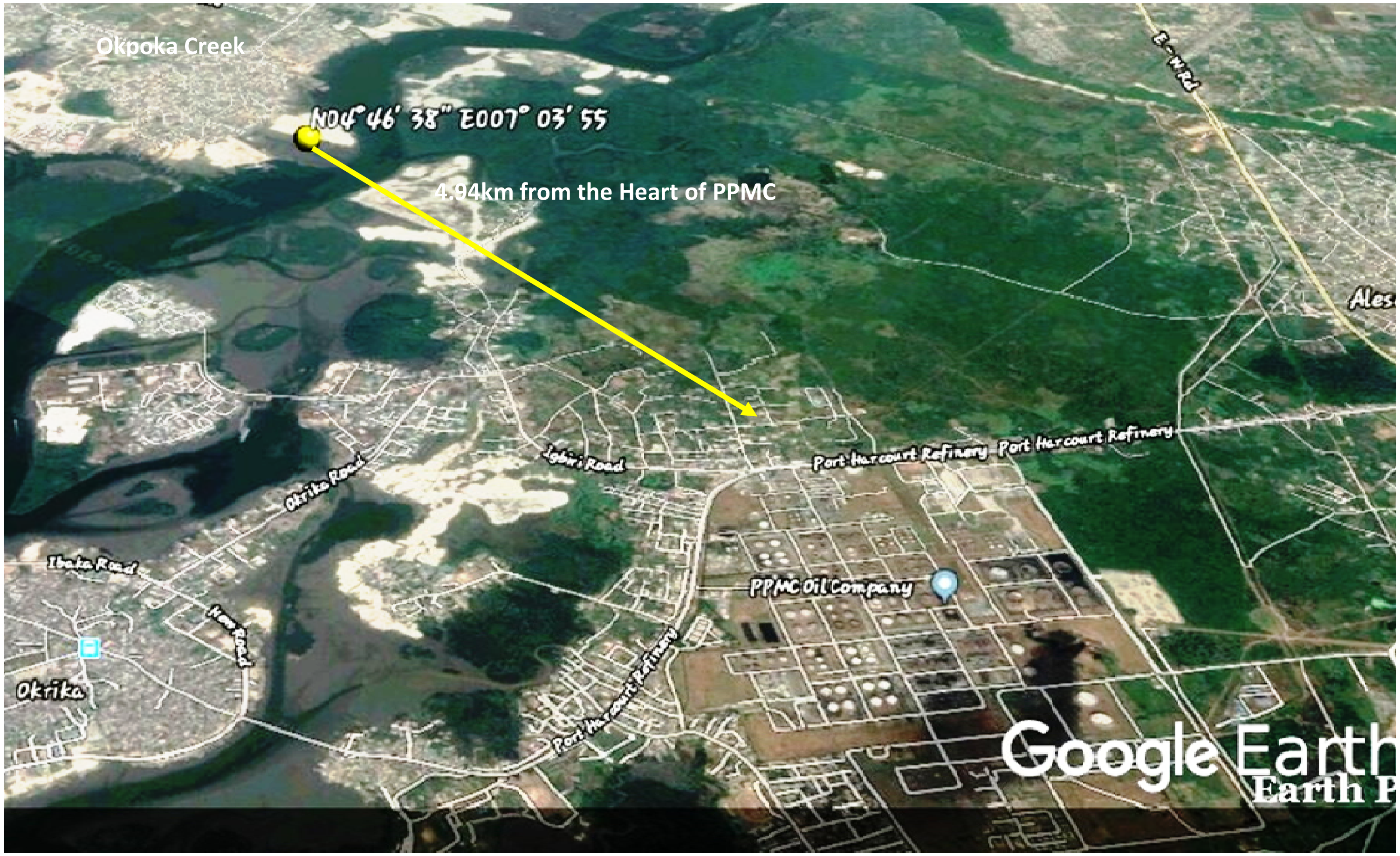

Fig. 1. Location of the study in the Akpoka creek, 4.94km from the heart of Nigeria Pipelines and Product Marketing Oil Company (PPMC)

Table 2. Level of Concentrations of Toxic Heavy Metals in Petroleum-contaminated Surface

Parameter	Sample (mg/L)	WHO** (2011) mg/L	DPR (2002) mg/L	NESREA (2009) mg/L	US EPA[1] (2010) mg/L	US EPA* (2018) mg/L	EU (2014) mg/L	NEQS (mg/L)			CAN (2006) mg/L	Agriculture-Irrigation	
								into Land/ Surface water	into Sewage Treatment	into Sea		USEPA[1] (2012) mg/L	FAO[2] (1994) mg/L
Lead (Pb)	12.17 ± 0.25	0.01	0.05	0.05	0.02	0.02	0.01	0.50	0.50	0.50	0.01	NS	NS
Cadmium (Cd)	10.53 ± 1.92	0.00	NS	0.01	0.01	0.01	0.01	0.10	0.10	0.10	0.01	0.01	0.01
Chromium (Cr)	9.38 ± 0.04	0.05	0.03	0.05	0.10	0.10	0.05	1.00	1.00	1.00	0.05	0.10	0.10
Nickel (Ni)	8.10 ± 0.35	0.07	NS	0.01	0.07	0.07	0.02	1.00	1.00	1.00	NS	0.20	0.20
Manganese (Mn)	10.14 ± 0.23	NS	0.05	0.05	0.05	0.05	0.05	1.50	1.50	1.50	0.05	NS	0.20

[2] *United States Environmental Protection Agency (2003)*
[3] *Department of Environmental Quality, US (2003)*
[4] *American Petroleum Institute (2000)*
[+] *Gasoline Range Organics*
[++] *Diesel Range Organics*
[+++] *Extended Diesel Range Organics*
[*] *Department of Petroleum Resources/Environmental Guidelines and Standards for the Petroleum Industry in Nigeria*
Table 2. Level of Concentrations of Toxic Heavy Metals in Petroleum-contaminated Surface Water
^{a} ± b = Mean ± Standard Deviation, n = 4
DPR = Department of Petroleum Resources (Maximum Permissible Limits (MPL) standard for Portable and Domestic water).
NESREA = National Environmental Standards and Regulations Enforcement Agency (Maximum Permissible Limits (MPL) for Portable and Domestic water.
EU = European Union (Drinking Water) Maximum Permissible Limits (MPL). ND = Not Detected.
NEQS = National Environmental Quality Standards (Municipal and Liquid Industrial Effluents) China (Tolerance Limits).
CAN = Health Canada (Guidelines for Canadian Drinking Water Quality) MPL.
US EPA = United States Environmental Protection Agency (Maximum Permissible Limits standard for Portable and Domestic water).
*** = World Health Organization (Guidelines for drinking water quality).*
** = United States Environmental Protection Agency (Drinking Water Standards and Health Advisory). NS = Not Specified.*
[1] *= United States Environmental Protection Agency (Guidelines for Water Reuse) (EPA/600/R-12/618).*
[2] *= Food and Agriculture Organisation of the United Nations (Water Quality for Agriculture) MPL.*

3.6.2 Analytical quality (AQ) for HMs

Analytical quality protocol stipulated by the U.S Environmental protection Agency (EPA), APHA (American Public Health Association), AWWA (American Water Works Association) and WEF (Water Environment Federation) for heavy metal analysis were used. In order to control the analytical procedure; precision of the analytical result was estimated by four replicate analysis. Certified standard solutions (BDH) of elements Pb, Cd, Cr, Ni and Mn were used for AAS Analysis.

Standard management of practice for estimation of holding time (6 months), storage (plastic container) and preservation for water/wastewater samples containing heavy metals as stipulated by the U.S Environmental Protection Agency (EPA 200.7 / 200.8) was applied appropriately.

3.7 Data Analysis

Sample results were analytically pooled for statistical data analysis using Microsoft Excel 2007, version 12.0. The processed and interpreted data were compared with maximum permissible limits or maximum concentration limits of certified international standards of the relevant regulatory agencies.

4. RESULTS AND DISCUSSION

4.1 RESULTS

The data of TPHs and heavy metals contents in the surface water are shown in Tables 1 and 2 respectively. The values of the TPHs Table 1 were identified and quantified by classification of surrogated standard fractions (C_8 – C_{10}, C_{11} – C_{28} and C_{29} – C_{40}) that were characterised by similar adverse health effects, toxicological information, chemical and physical properties; in accordance to the guidelines developed by the (ATSDR), (EPA), (TPHCWG), (DEQ) and (API). The total concentration of TPHs illustrated 1.05E+05 mg/L ranged of C_8 – C_{40}. The surrogated fraction of TPHs; gas range organics (GRO) of volatile aromatic and aliphatic hydrocarbons (C_8 – C_{10}) was 1397.53 mg/L. TPHs diesel range organics (DRO) of aliphatic and aromatic hydrocarbons was (C_{11} – C_{28}) 102305.63 mg/L. TPHs extended diesel range organics (EDRO) of lube oil fraction (C_{29} – C_{40}) revealed 1059.25 mg/L.

The mean and standard deviations values of heavy metals Table 2; Pb, Cd, Cr, Ni and Mn are 12.17 ± 0.25, 10.53 ± 1.92, 9.38 ± 0.04, 8.10 ± 0.35 and 10.14 ± 0.23 mg/L, respectively. In terms of highest mean concentration value, Pb, Cd, Mn, Cr and Ni, respectively were recorded in the petroleum-contaminated surface water of the study site.

5. DISCUSSIONS

The analytical investigation of the Okpoka creek illegal artisanal petroleum refinery and bunkering services echoed on the elevated levels of TPHs and toxic heavy metals in the petroleum-contaminated surface water. Petroleum contamination in water is one of the largest risks to human health and environment as considered by many regulatory agencies. The potential impact of petroleum contaminated site on human health can be pretty devastating and injurious to the relevant organs with long and short terms health effects that are irreversible and heritable in the cellular genetic materials. [9] and [10].

The TPHs (Table 1) high level of 1.05E+05 mg/L with the range C_8 – C_{40} gives high risk exposure of horrendous environment and human health for the adjoining communities of the study site. The TPHs concentration was noticeably higher than the recommended limit values for surface water by DPR/EGASPIN (10 mg/L). Long time exposure to elevated concentration of TPHs can affect the human central nervous system even death can occur [25] and [26]. Breathing the TPHs compound at concentrations greater than 100 parts per million (100 ppm) for more than several hours can cause fatigue, headache, nausea, and drowsiness [30]. However, the domestic usage of the study surface water by the communities further expose them to chronic health risks like breakdown of immune system, liver, spleen, kidneys, developing fetus, and lungs; difficulty in breathing, pneumonia, depression and among others. The exposures of surrogated TPHs also come with different kind of adverse health effects [27] and [28].

The presence of heavy metals (Table 2) in the environment leads to a number of adverse impacts. Such impacts affect all spheres of the environment, that is, hydrosphere, lithosphere, biosphere and atmosphere. Until the impacts are dealt with, health and mortality problems will break out, as well as the disturbance of food chains [3] and [5]. The toxic heavy metals concentrations as indicated revealed high level of contamination in the surface water of the study site. The elevated levels of these heavy metals constitute a serious threat to environment and human health. The investigation unveiled the high risk usage of the surface water for domestic, portable, agricultural, municipal and industrial. The significant health risks associated with excess exposures of the intolerable elevated levels of these systemic environmental contaminants are destructive to humans and plants even they are highly toxic in minor quantity; Pb, Cr and Cd have been implicated in causing cancer, bones, spleen, neurological, immunological, lungs, liver, testes, cardiac problems, brain, pancreas, reproductive, gastrointestinal and kidney damage [31] and [32]. Mn and Ni occur naturally are often found rocks and surface water. Human body needs some Mn and Ni to stay healthy, but too much can be harmful. Children and adults who drink water with high levels of manganese for a long time may have problems with memory, attention, and motor skills. Infants (babies under one year old) may develop learning and behaviour problems if they drink water with too much manganese in it [32] and [4]. Generally, human exposure to high level of Mn is at risks with hallucinations, forgetfulness, nerve damage, aggressiveness, irritability, Parkinson, lung embolism and for a long period time men may become impotent [14] and [32]. Ni is carcinogenic and toxic in high exposure. Women are more commonly allergic to Ni exposure than men [33]. Exposure to skin can cause dermatitis upon contact [15] and [33]. When ingested through water in small amount or within the acceptable limits, it is harmless to humans and in fact necessary in diet.

6. CONCLUSION

The elevated levels of petroleum hydrocarbons (TPHs) and various toxic heavy metals (HMs) from the Okpoka creek have provided evidences of severe petroleum contamination as compared with the international certified relevant regulatory agencies (standards). The levels are high enough to cause public health concerns, since the residents may ingest, inhale or directly exposed to this contaminants by skin contacts. Also livestock and plants can bioaccumulate these contaminants and magnify them along the food chain leading to man. Therefore, it is highly recommended that human health and ecological risk assessments be carried out as a follow up of this study. This will provide the additional relevant information needed for an effective cleanup of the Okpoka creek.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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