

Assessment Level of Polycyclic Aromatic Hydrocarbons in Soil Groundwater around Yenagoa and Environs, Southern Nigeria

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ABSTRACT

The assessment of levels of Polycyclic Aromatic Hydrocarbons (PAHs) in groundwater and soils in Yenagoa and its environs, Southern Nigeria was carried out. A total of 10 samples each of soils and groundwater were collected and analysed using GC model: HP 6890 GC-FID, USA). Results indicates that average PAH values (concentrations in mg/l) for the groundwater in the area are: naphthalene (3.4036), acenaphthylene (0.0845), acenaphthene (0.0410), fluorine (9.0688), phenanthrene (4.4480), anthracene (0.9650), fluoranthene (0.5230), pyrene (10.0204), benz(a) anthracene (0.4920), chrysene (23.8938), benzo(b) fluoranthene (6.5118), benzo(k) fluoranthene (1.2597), indo(1,2,3-cd) pyrene (15.6872), dibenz(a,h) anthracene (26.8413). Standard Deviation (SD) for Water (PAH) as follows naphthalene ± 4.57 , acenaphthylene ± 0.13 , acenaphthene ± 0.035 , fluorine ± 16.66 , phenanthrene ± 5.064 , anthracene ± 1.247 , fluoranthene ± 0.348 , pyrene ± 8.177 , benz(a) anthracene ± 0.376 , chrysene ± 25.36 , benzo(b) fluoranthene ± 15.208 , benzo(k) fluoranthene ± 1.152 , indo(1,2,3-cd) pyrene ± 10.828 , dibenz(a,h) anthracene ± 10.228 . The mean concentrations of these PAHs in soils (mg/kg) in the area of the study are as follows: 6.148 \pm 18.21, 1.26 \pm 2.659, 70 \pm 27.00, 2.56 \pm 6.10, 8.18 \pm 23.97, 1.87 \pm 4.89, 12.92 \pm 36.30, 422.58 \pm 1267.77, 157.99 \pm 491.41, 125.80 \pm 376.34, 218.03 \pm 1127.72, 67.65 \pm 256.79, 757.20 \pm 1609.17 and 4592.8 \pm 1286.13 respectively. The findings shows that PAHs concentrations are generally higher than the World Health Organization (WHO) recommended limits for both soil and water within the study area. The fairly strong correlation between the selected PAH ratios in the soil & groundwater (except for the B(a)A/Chr) clearly suggest common contamination pathways for both soil & groundwater in the area. The study also suggests the urgent need for hydrocarbon waste management control in the area.

Keywords — Polycyclic, Aromatic, Hydrocarbon, Contamination, Soil and Groundwater

1. INTRODUCTION

The Niger delta region of Nigeria including Yenagoa has been a hub for petrochemical exploration and exploitation since the discovery of crude oil in Oloibiri in 1956. This has led

to high and rapid generation of environmental waste linked to petroleum product exploitation, oil spills, oil flows, mud fluids degeneration and gas flaring. It is against this background that this study is carried out to assess concentrations of organic compounds in

groundwater and soils in Yenagoa. Obasi and Akudinobi, 2019 a, Udom et al., 2018; Akakuru and Akudinobi, 2017; Oki and Akana, 2016; Oyem et al., 2015; Edet et al., 2011). As observed by Okiongbo (2013), groundwater pollution is a major cause of chronic and epidemic diseases. It is generally accepted that shortage or pollution of water results in a significant reduction in productivity or in the demise of living organisms (Galadima et al., 2011). Similarly, conditions of high PAH content in the soil may result to negative impacts on plants, animals and humans due to the bioaccumulation of these substances in the food chain (Osakwe and Okolie, 2015; Obasi and Akudinobi, 2020b). Akakuru, 2018; Nwankwoala, and Ngah, 2014. In the past few years, the BTEX group of organic pollutants has received a lot of attention due to the fact that they are ranked among the most prevalent and main threats to the safety of groundwater and indoor environments which are located around sites which are contaminated (Uzoekwe and Oghosanine, 2011). The threats which these compounds pose to environmental and human health is attributed to the adverse effects which benzene is able to exert, being that it has been shown to be strongly carcinogenic and exhibits high mobility within the soil and in groundwater (Nwankwoala and Ngah, 2014). Aside from their inherent carcinogenicity, their high

solubility in water and associated toxicity is another reason why these compounds have received so much attention. In addition to causing cancer, these compounds cause mucosal pain, blood-related diseases, damages to the central nervous and respiratory systems, and impairment of renal and hepatic functions Nourmoradi et al. 2012; Obasi and Akudinobi, 2019b). PAHs are present in deposits of oil, coal and tar, while the combustion of fuels, whether biomass or fossil fuels, releases these compounds as by-products (Fetzer, 2000). According to the united nation environmental protection (UNEP) report of 2014 in Ogoniland, polycyclic aromatic hydrocarbons (PAHs) are among the main contributors to environmental and health problems of the Ogoni people due to the continued pollution of the environment by the multinational's companies which are a major part of the problems in this region. There is strong evidence showing that the activities of humans and natural phenomena (Figures 1-4) among which are leakages from wellheads, pipelines and storage tanks kept underground, overflow of materials at gathering stations, the indiscriminate and haphazard disposal of waste generated from petroleum along with other industrial processes contribute to the contamination recorded in the study area.



Figure 1: Gas flaring at Obugha in Yenagoa L.G. A.



Figure 2: Oil spill in Egbebiri in Yenagoa L.G. A.



Figure 3: Oil spill area in Biseni in Yenagoa LGA



Figure 4: Oil spill area in Okadia in Yenagoa LGA

Several reports pertaining to the discharge of untreated industrial effluents by companies based or operating in Yenagoa and its environs have been recorded (Omishakin, 1986; Egborge, 1994; 2000).

Gases are also implicated in the acidification of soil and water bodies due to the formation of acid rain around gas flaring facilities (Alakpodia, 2001).

Table 1: Showing Research Gap in the Study

Osu and Asuoha (2010):	Findings: They looked into the sources and levels of PAHs in a specific environmental setting, on soil.	Gap: There's not much analysis on how PAH concentrations change over time or with the seasons. Also, groundwater was not part of their research.
Alinnor et al. (2014):	Findings: This study focused on the health risks linked to PAH exposure, especially in urban areas.	Gap: There's a noticeable lack of community-based research that evaluates public awareness and preventive actions in rural communities
Nganje et al. (2014):	Findings: They examined the legislative frameworks related to PAH emissions and their impact on public health.	Gap: There's a noticeable absence of long-term studies that evaluate how effective these regulations are in actually lowering PAH levels.

This study tends to address these gaps by putting up a robust database for the future research in Yenagoa local government area of Bayelsa State, because no such database is available for now.

Aside from investigating the levels of a range of present in the soil and in groundwater resources, this present study will integrate the levels of PAH with the view of providing a more accurate evaluation of the

impacts of human activities taking place in the study area. This will raise awareness on the impact of the petrochemical activities in the area. This investigation is also aimed at providing reliable information regarding the concentrations, sources and trends which heavy metals and organic pollutants present in soils and groundwater to authorities concerned with environmental

management within and around Yenagoa. It could also be a guide for the planning of remedial action for contaminated lands while serving as a reference point for future studies on the subject.

Osu and Asuoha (2010) undertook an assessment of the level of soil contamination by PAHs and BTEX chemicals around automobile mechanic workshops located within the Port-Harcourt metropolis. Their observation was that all samples from the various workshops evaluated during the study showed evidence of contamination by PAHs and BTEX chemicals; also, they found that the concentrations of these substances in the soil was not significantly affected by the depth of the soils. A study by Alinnor et al. (2014) characterised the total petroleum hydrocarbon (TPH) and BTEX chemicals present in samples of soils and groundwater obtained from parts within the Niger Delta which have been affected by oil spillage. They found that all assessed water samples collected at the various sampling stations contained TPH and BTEX compounds. The distribution patterns exhibited by organic compounds and selected heavy metals including lead, zinc, iron and cadmium, in soils affected by crude oil in Rivers State, Nigeria, were examined by Osu and Okoro (2015).

The results of their analyses showed that the concentrations of BTEX compounds increased with increasing soil depth and there was no observed distinct pattern in the distribution of the heavy metals at different depths in the soil profile. In a study conducted by Li et al. (2011) involved a characterisation of vertical pollution in a site located in the Jiangnan oil field in China used for the storage of oil sludge, due to the presence of polycyclic aromatic hydrocarbons (PAHs). According to Wildet et al. (1990), the concentrations of naphthalene ranges between 0 to 3 mg/kg in untreated agricultural soils. Bradley et al. (1994) recorded the mean concentration of naphthalene in urban soil samples collected from Boston, Massachusetts, Providence, Rhode Island, and Springfield, Massachusetts to be

0.125 mg/kg. Several other studies on contaminated soils have reported various concentrations for naphthalene, among these are 6.1 µg/g in soils contaminated by coal-tar detected by Yu et al. (1990); Weissenfels et al. (1992) recorded 16.7 mg/kg in soils taken in the vicinity of a refinery where tar-oil was formerly processed; and in soils treated with sludge, Wild et al. (1990) recorded 66 mg/kg.

A study undertaken by Hawthorne et al. (2021) assessed soils around an unnamed gas manufacturing plant located in the mid-west region of the United States found that the mean concentrations of naphthalene was 48 mg/kg. The detection of naphthalene in groundwater from the Gas Works Park in Seattle, Washington was carried out by Turney and Goerlitz (1990) and the results obtained ranged between 0 and 46 mg/l and 0 and 6.3 mg/l respectively. Aside from when they are being manufactured, exposure to PAHs involves a suite of these compounds rather than a single one. The main routes of exposure to PAHs are inhalation, oral ingestion, trans-placental and breast milk transfer, and through the skin. Among the factors which influence the routes and magnitude of PAH exposure are culture, occupation and geography. also, various studies have recorded the impacts of exposure to acenaphthene and other PAHs at the occupational level (Ares, 1993; Omland et al., 1994; Petry et al., 1996; Brandt et al., 2000; Bieniek et al., 2004; Campo et al., 2006). From the results obtained, severe pollution of the study area by PAHs was observed. Among the major pollutants present were naphthalene, fluorene, indeno(1,2,3,-cd) pyrene, chrysene, benzo(b) fluoranthene, acenaphthylene, benzo(a)pyrene, phenanthrene, dibenzo(a,h) anthracene, benzo(k) fluoranthene and benzo(g,h,i) perylene, while small amounts of acenaphthene, pyrene, benzo(a) anthracene and fluoranthene were also observed.

The maximum concentrations of PAHs were recorded as 1899ng/g at depths between 30 - 40 cm.

For the characterisation of the potential for downward transport through the soil profile, the following trends was observed: 2-ringed PAHs > 3-ringed PAHs > 4-ringed PAHs > 5-ringed PAHs > 6-ringed PAHs. A post-impact assessment of groundwater wells following leakage of hydrocarbons in Egita/Obite community of Rivers State was conducted by Umunnakwe and Aharanwa (2015). Their major observation was that organic pollution due to hydrocarbons leaking into the wells caused groundwater to become slightly acidic. In an investigation conducted by Tse and Nwankwo (2013), the geochemical and geoelectrical properties of a site where crude oil spillage occurred in south-east Port-Harcourt were explored. High levels of total petroleum hydrocarbon contamination were recorded as the observed concentrations of TPH in the study were greater than the background value set for THP in soils by the Department of Petroleum Resources (50ppm). Akakuru (2018) determined how suitable groundwater from sources around the

Nigeria National Petroleum Corporation (NNPC) Depot in Aba were for human usage, by assessing the levels of pollution of these waters by heavy metals and organic compounds. The result indicated that the concentrations of selected heavy metals including arsenic, copper and lead, together with those of organic pollutants including Benzene, Xylene and Ethylbenzene exceeded the permissible limits for these substances in water, while the concentration of Toluene in groundwater samples was deemed to not be a source of health concern. The aim is the assessment of levels of Polycyclic Aromatic Hydrocarbons (PAHs) in groundwater and soils in Yenagoa and its environs. The objectives will include to assess the concentrations of PAHs in soils & groundwater, investigate the distribution pattern of PAHs in soils & groundwater of the study area, and to determine the association between soils & groundwater in the area using Pearson’s significant correlation analysis.

Table 2: Summary of the environmental effects of some polycyclic aromatic hydrocarbons

PAHs	EFFECTS
Anthracene	Toxicity, sensitization of the skin, irritation of the eyes, confusion, nausea, diarrhoea and vomiting
Acenaphthylene	Toxicity and irritation of the eyes
Benzo(a) anthracene	Toxicity, carcinogenicity, malformations in the heart, induction of asthma in children and irritation of the skin
Benzo(a) fluoranthrene	Toxicity
Pyrene	Toxicity and irritation of the eyes
Benzo(a) pyrene	Carcinogenicity, mutagenicity, toxicity, occurrence of congenital malformations, reduction in body weight, irritation of the skin and eyes, asthma in children, confusion, nausea, diarrhoea and vomiting
Chrysene	Carcinogenicity, toxicity, renal and hepatic damage and formation of jaundice cataracts
Benzo(k) fluoranthrene	Toxicity, carcinogenicity and formation of tumours in the intestines and lungs
Benzo(j) fluoranthrene	Toxicity and formation of tumours in the breasts and lungs

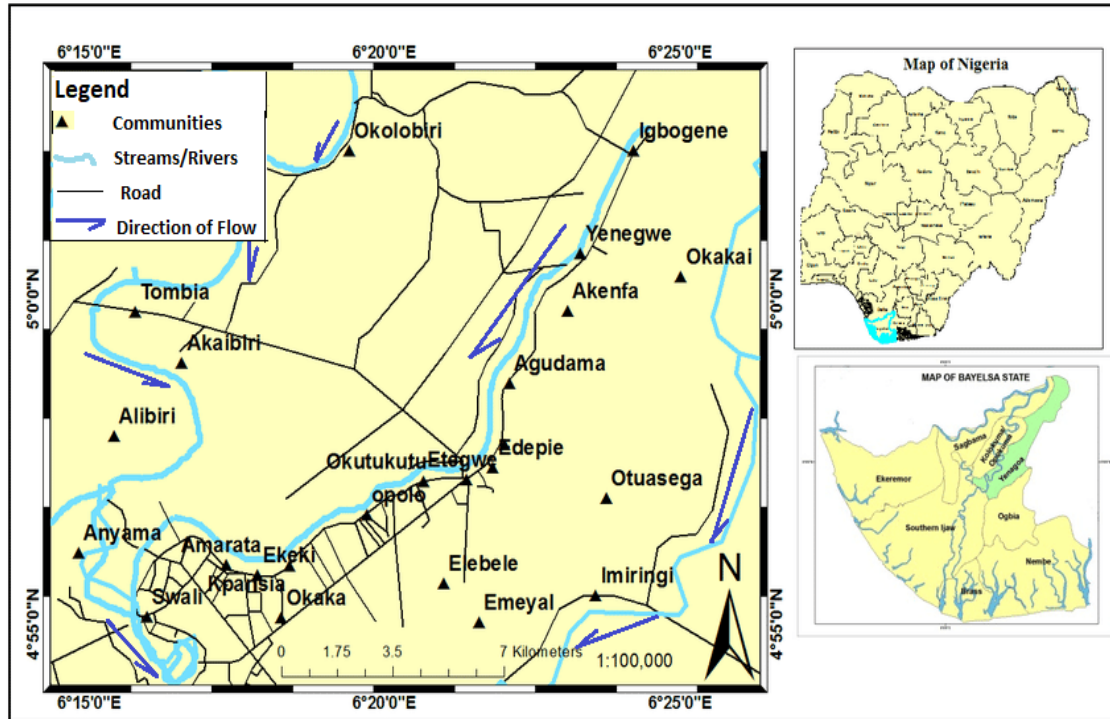


Figure 5: Showing location map of Bayelsa state

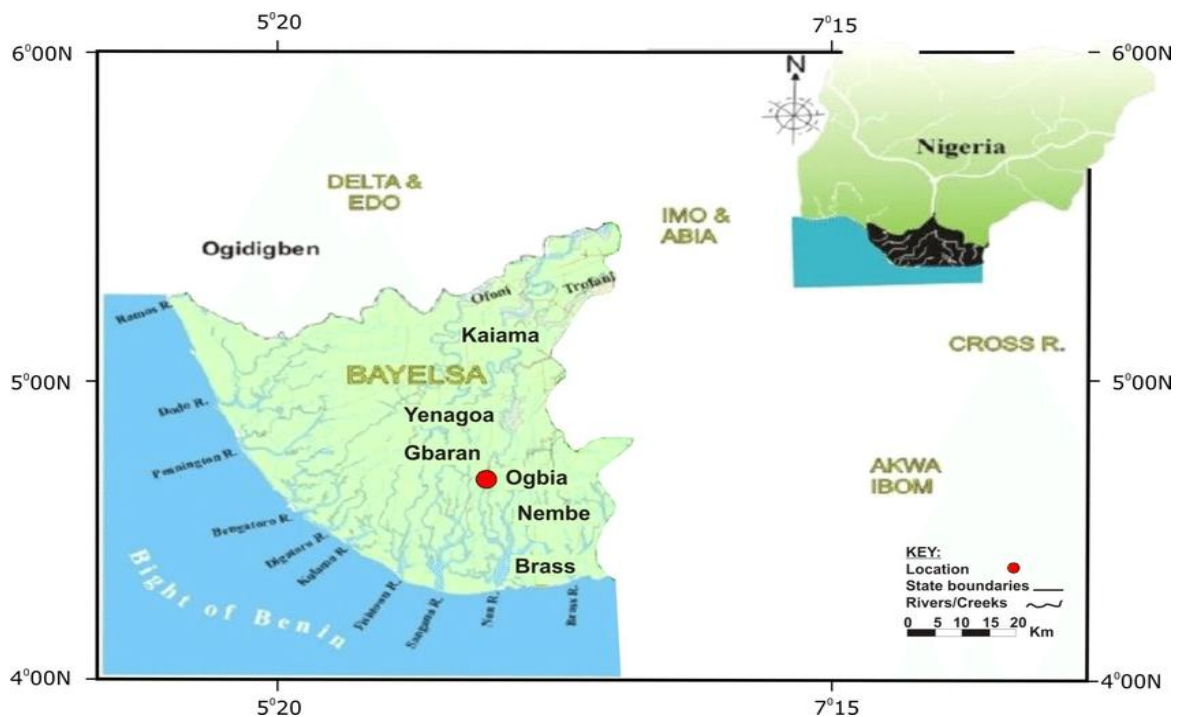


Figure 6: Communities around the study area

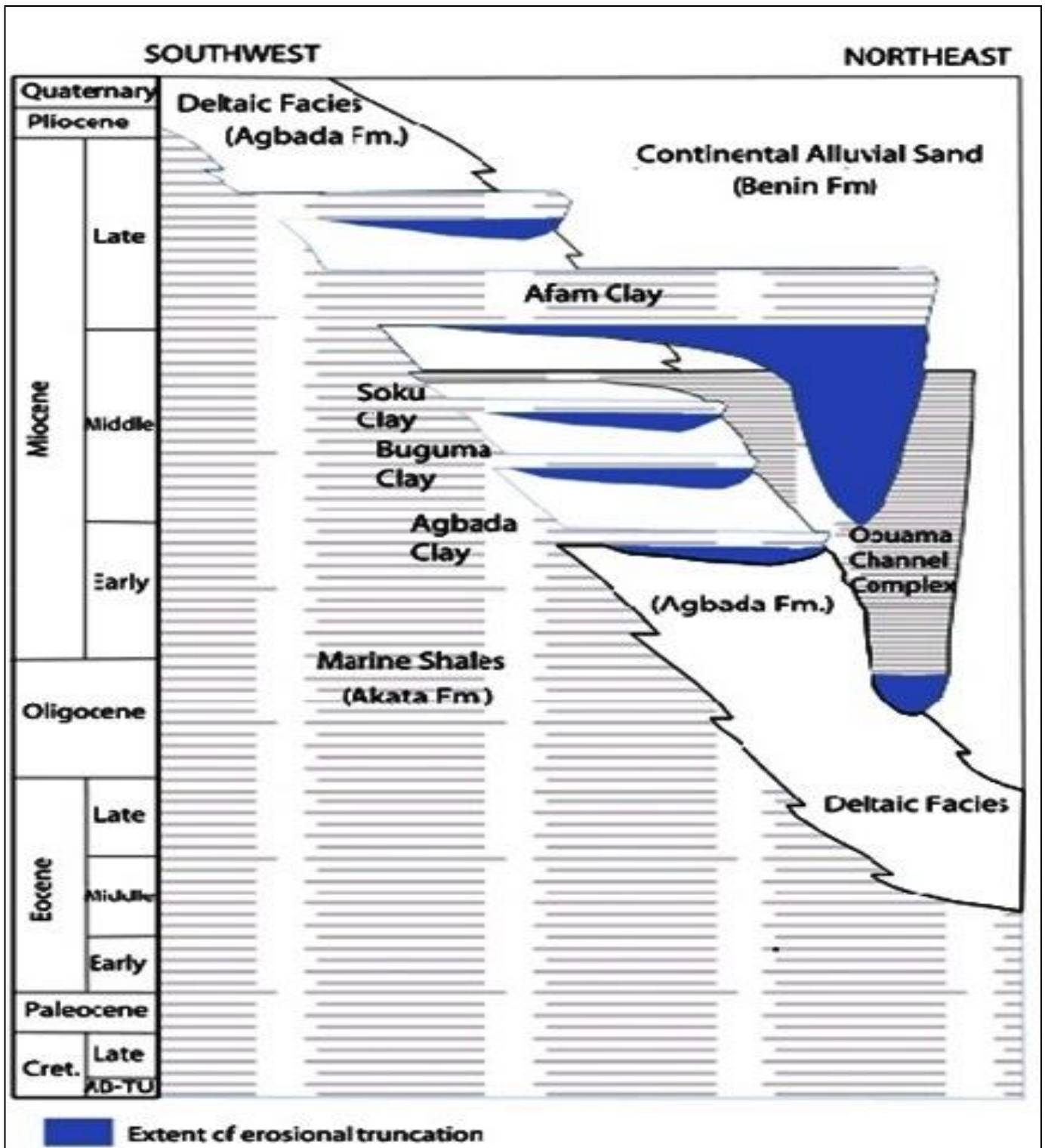


Figure 7: Regional Stratigraphy of the Niger Delta and its environs (after Doust & Omatsola, 1990)

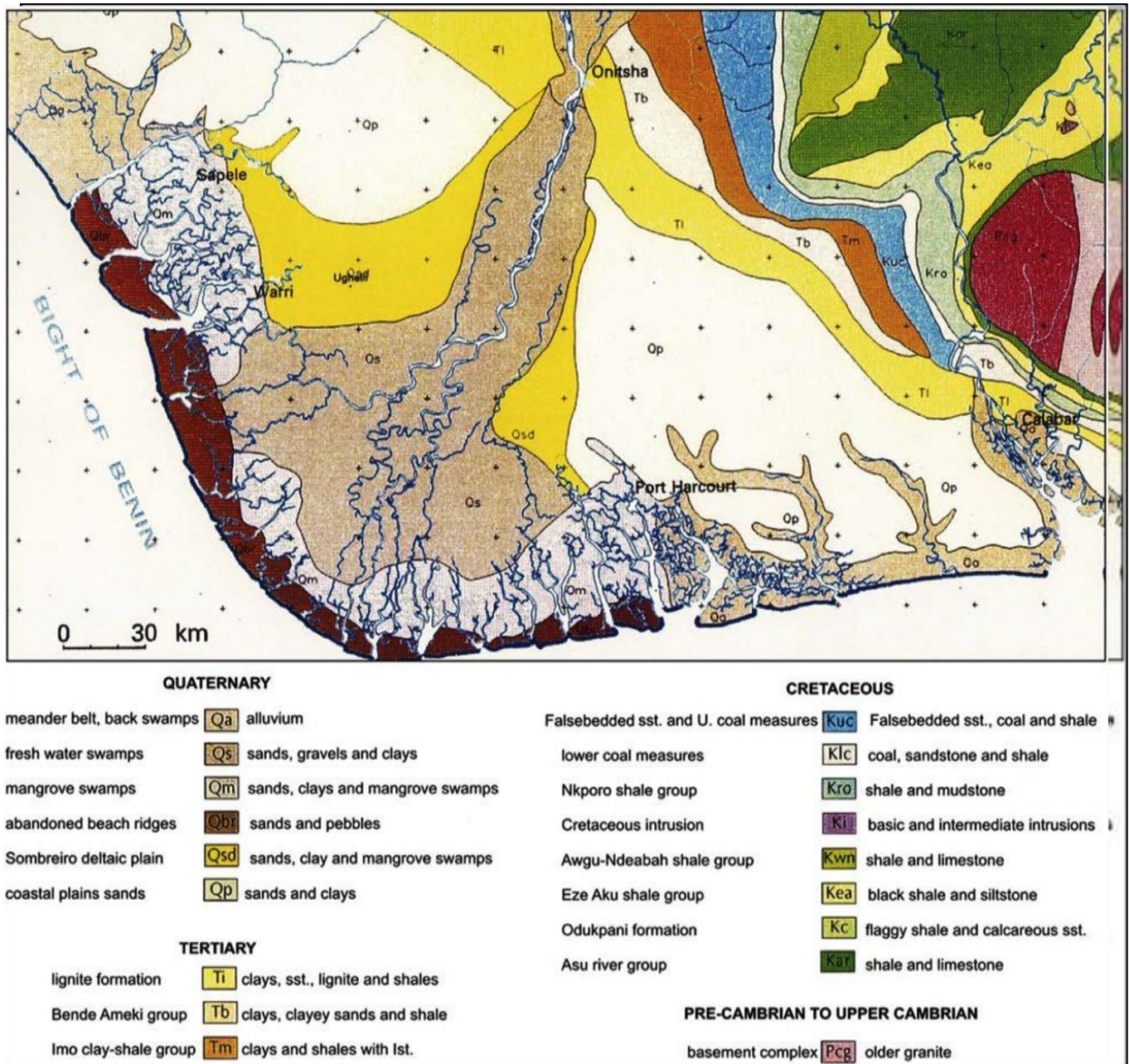


Figure 8: Geological map of the Niger Delta and its environs (Reijers et al.,2011)

2. MATERIALS AND METHODS

2.1. Field Mapping

Twenty samples of soils and groundwater for PAH (10 each) was collected. In order to obtain a

composite representative sampling, a regular sampling grid network composed of cells was adopted in this study. PAH for soil and groundwater was measured using the GC-MS (Gas Chromatography). This method involves solvent

extraction of the water with dichloromethene, followed by analysis of the concentrated extract by gas chromatography on a glass scot. The distinctive chromatogram pattern assists analysts in discerning the specific product types present in the soil. Additionally, GC-MS is a pivotal tool in identifying various compounds in water samples. Among the materials used during the study are a portable Global Positioning System (GPS) device (model GARMIN GPS 76 CSX). Other relevant include Geological and Topographical maps were collected from the Federal University of Petroleum Resources, Effurun and Ebonyi State University, Abakaliki. (GC model: HP 6890 GC-FID, USA) was used for both soil and groundwater in PAHs analysis.

2.2 Data Analysis Statistical analysis

The SPSS 20.0 software was used in determining the Pearson correlation which showed the associations that existed amongst the various PAH present within the study area. Descriptive statistics (range and mean) for the various physical and chemical properties and the concentrations PAH were determined using the statistical functions available in Microsoft Excel. Additionally, comparison of the mean values of the results obtained from the study with known standards was done. Finally, ArcGIS software version 9.3 was employed in the production of contour maps of the spatial distribution of PAH in soil and groundwater within the study area.

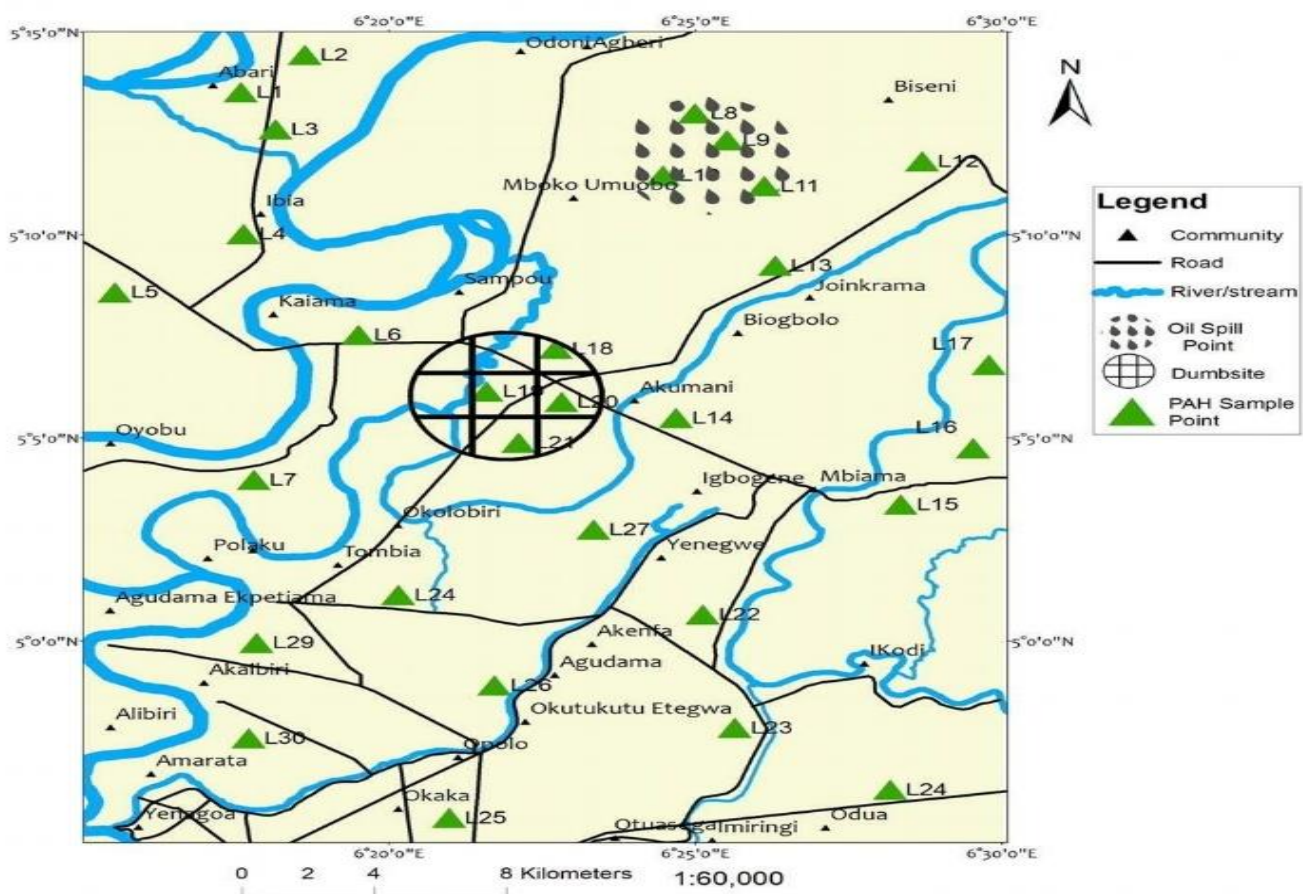


Figure 9: Location map of PAH for both water and soil samples

3. RESULTS AND DISCUSSION

3.1. PAH Assessment of Groundwater and Soil

Table 3: Summary of PAHs in Groundwater and Soil samples

PARAMETERS	Range mg/l	Mean	SD	Range mg/kg	Mean	SD	WHO LIMITS (2017)
Naphthalene	0.00-14.31	3.4036	4.57	0.0001-69.14	6.148	18.21	0.01 mg/kg
Acenaphthylene	0.00-0.66	0.0845	0.13	0.0002-11.25	1.26	2.65	0.06 mg/kg
Acenaphthene	0.00-0.14	0.0410	0.035	0.0007-111.87	9.70	27.00	Non
Fluorene	0.01-54.36	9.0688	16.66	0.0005-27.17	2.56	6.10	0.2 mg/kg
Phenanthrene	0.00-15.74	4.4480	5.064	0.001-106.00	8.18	23.97	Non
Anthracene	0.01-4.31	0.9650	1.247	0.0001-23.60	1.87	4.89	0.2 mg/kg
Flouranthene	0.05-0.94	0.5230	0.348	0.0036-146.89	12.92	36.30	Non
Pyrene	1.03-23.40	10.0204	8.177	0.0003-4282.5	422.58	1267.77	0.2 mg/kg
Benz(a)anthracene	0.00-0.98	0.4920	0.376	0.0001-1964.9	157.99	491.41	0.2 mg/kg
Chrysene	0.00-82.99	23.8938	25.367	0.0004-1401.7	125.80	376.34	0.2 mg/kg
Benzo(b) flouranthene	0.01-56.28	6.5118	15.208	0.0001-6025.5	218.03	1127.72	Non
Benzo(k) flouranthene	0.01-3.89	1.2597	1.152	0.0002-1191.8	67.65	256.79	Non
Indeno (1,2,3-cd) pyrene	0.83-38.11	15.6872	10.828	0.0483-6470.8	757.20	1609.17	Non
Dibenz (a, h) anthracene	12.08-65.75	26.8413	10.228	1008.1-48942.5	4592.83	1286.1	Non

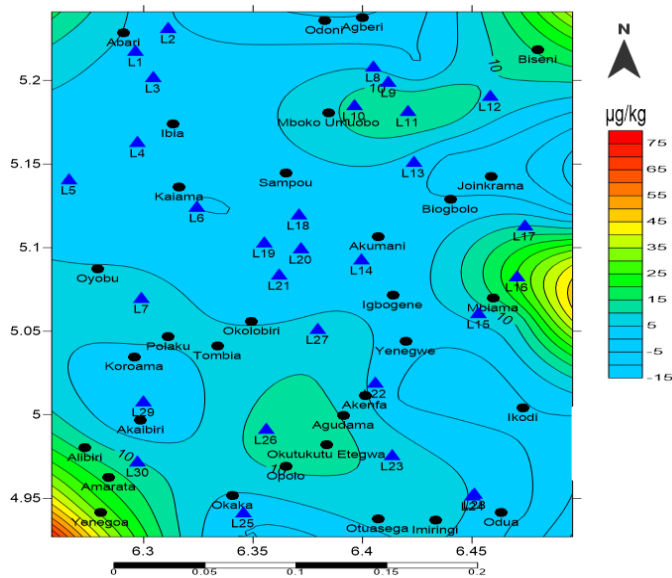


Figure 10: Distribution of phenanthrene in ground water of the study area

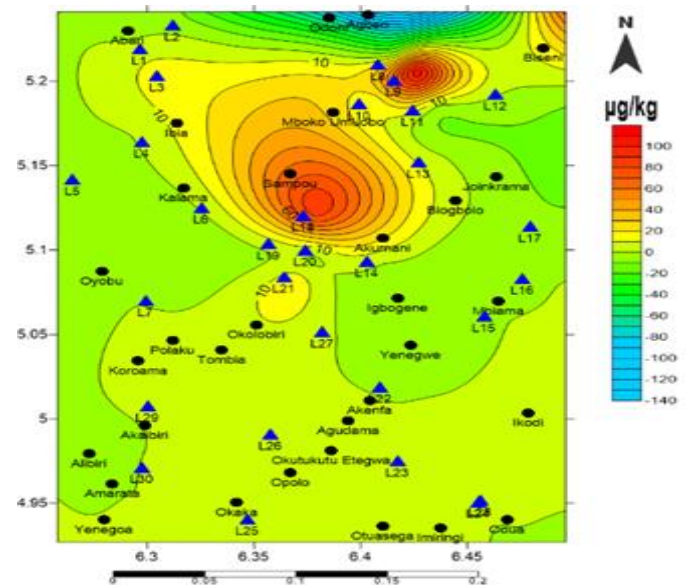


Figure 11: Distribution of phenanthrene in soils of the study area

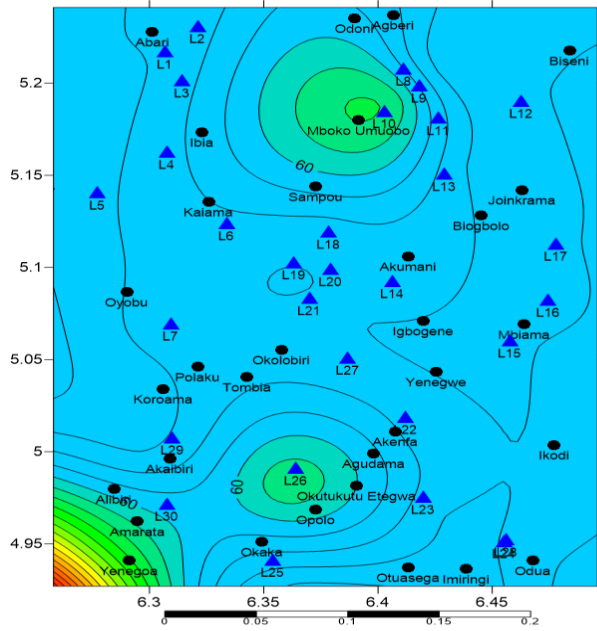


Figure 12: Distribution of fluoranthene in ground water of the study area

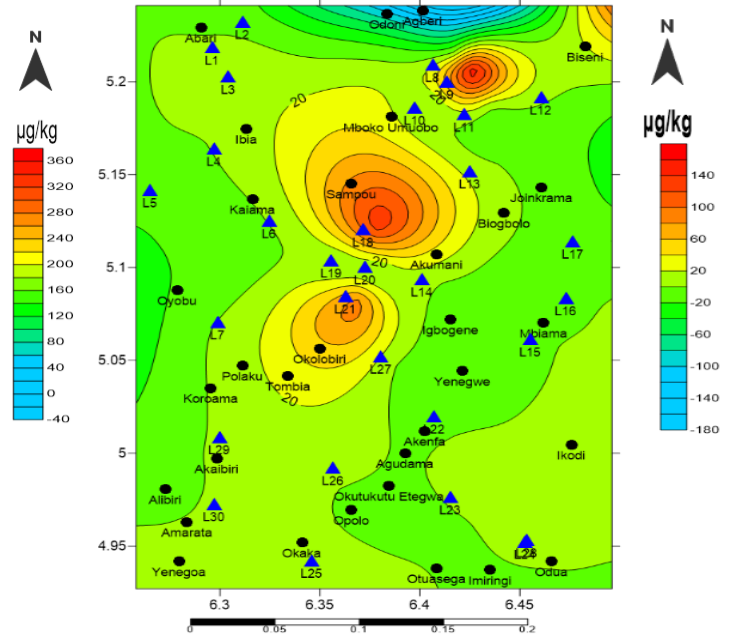


Figure 13: Distribution of fluoranthene in soils of the study area

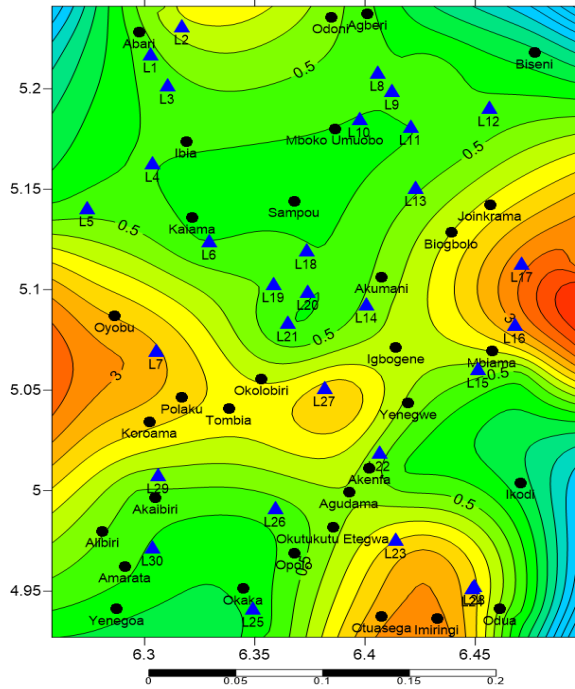


Figure 14: Distribution of Anthracene in ground soil of water of the study area

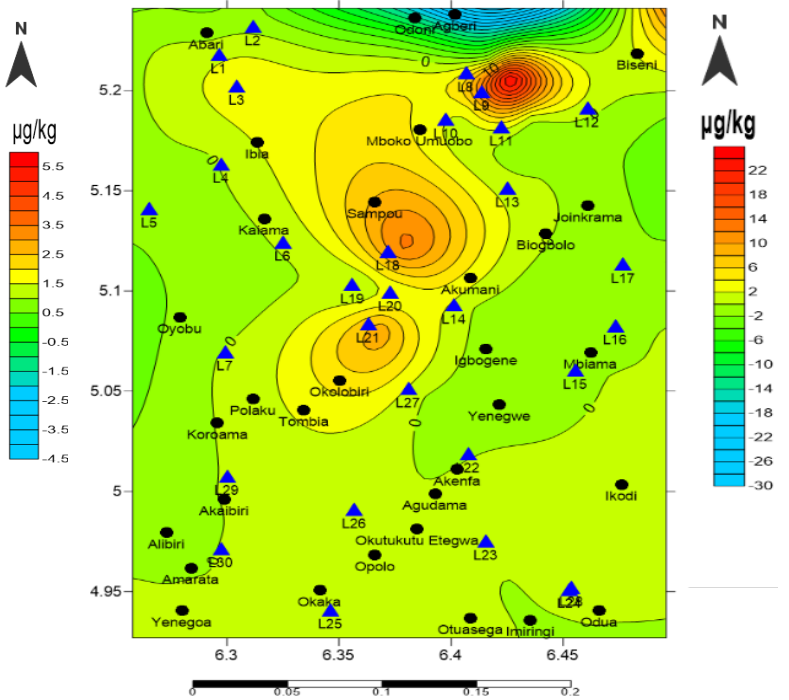


Figure 15: Distribution of Anthracene in the study area

Table: 4 Correlation between SOIL and GROUNDWATER

(Mg/kg)	Nephtalene	Acemaphthylene	Acenaphthene	Fluorinen	Penanthyrene	Anthracene	Fluoranthene	Pyrene	Benza(a) Anthracene	Chrycene	Benzo(b) Fluoricene	Benzo(k) Fluoracene	Indeno(1,2,3 cd)pyerene	Dibenz(a,h) anthracene
Nephtalene (Mg/l)	1	-0.099	-0.051	.425*	0.268	-0.227	0.195	0.003	0.223	-0.126	-0.027	-0.218	0.006	-0.165
		0.609	0.791	0.019	0.152	0.228	0.302	0.986	0.237	0.507	0.888	0.247	0.976	0.383
	30	29	30	30	30	30	30	30	30	30	29	30	30	30
Acemaphthylene	-0.099	1	-0.152	-0.197	0.130	-0.045	-0.077	0.343	-0.064	-0.143	-0.067	-0.045	0.051	0.077
		0.609	0.430	0.305	0.500	0.816	0.693	0.069	0.743	0.461	0.734	0.817	0.794	0.690
	29	29	29	29	29	29	29	29	29	29	28	29	29	29
Acenaphthene	-0.051	-0.152	1	-0.152	-0.145	0.139	-0.204	0.069	-0.052	0.051	-0.112	-0.143	0.034	-0.039
		0.791	0.430	0.422	0.445	0.464	0.280	0.715	0.784	0.789	0.562	0.450	0.859	0.838
	30	29	30	30	30	30	30	30	30	30	29	30	30	30
Fluorine	.425*	-0.197	-0.152	1	0.151	0.009	-0.015	-0.092	0.068	0.060	-0.011	0.184	-0.073	0.111
		0.019	0.305	0.422	0.426	0.961	0.937	0.628	0.722	0.752	0.953	0.332	0.701	0.558
	30	29	30	30	30	30	30	30	30	30	29	30	30	30
Penanthyrene	0.268	0.130	-0.145	0.151	1	.555**	0.005	-0.036	-0.027	0.110	-0.055	-0.117	0.034	0.165
		0.152	0.500	0.445	0.426	0.001	0.980	0.851	0.889	0.561	0.776	0.538	0.857	0.385
	30	29	30	30	30	30	30	30	30	30	29	30	30	30
Anthracene	-0.227	-0.045	0.139	0.009	.555**	1	-0.107	0.021	0.000	0.178	-0.156	-0.191	0.078	0.236
		0.228	0.816	0.464	0.961	0.001	0.572	0.913	0.998	0.346	0.420	0.311	0.681	0.210
	30	29	30	30	30	30	30	30	30	30	29	30	30	30
Fluoranthene	0.195	-0.077	-0.204	-0.015	0.005	-0.107	1	0.133	0.311	0.098	-0.139	-0.278	0.160	-.436*
		0.302	0.693	0.280	0.937	0.980	0.572	0.483	0.094	0.606	0.472	0.137	0.398	0.016
	30	29	30	30	30	30	30	30	30	30	29	30	30	30
Pyrene	0.003	0.343	0.069	-0.092	-0.036	0.021	0.133	1	.556**	0.238	-0.034	-0.013	.609**	-0.154
		0.986	0.069	0.715	0.628	0.851	0.913	0.483	0.001	0.205	0.859	0.946	0.000	0.417
	30	29	30	30	30	30	30	30	30	30	29	30	30	30
Benza(a)Anthracene	0.223	-0.064	-0.052	0.068	-0.027	0.000	0.311	.556**	1	0.124	-0.166	-0.218	0.278	-0.345
		0.237	0.743	0.784	0.722	0.889	0.998	0.094	0.001	0.513	0.389	0.247	0.136	0.062
	30	29	30	30	30	30	30	30	30	30	29	30	30	30
Chrycene	-0.126	-0.143	0.051	0.060	0.110	0.178	0.098	0.238	0.124	1	0.054	-0.051	.605**	-.449*
		0.507	0.461	0.789	0.752	0.561	0.346	0.606	0.205	0.513	0.782	0.788	0.000	0.013
	30	29	30	30	30	30	30	30	30	30	29	30	30	30
Benzo(b)Fluoricene	-0.027	-0.067	-0.112	-0.011	-0.055	-0.156	-0.139	-0.034	-0.166	0.054	1	0.058	0.186	0.245
		0.888	0.734	0.562	0.953	0.776	0.420	0.859	0.389	0.782	0.765	0.765	0.333	0.200
	29	28	29	29	29	29	29	29	29	29	29	29	29	29
Benzo(k)Fluoracene	-0.218	-0.045	-0.143	0.184	-0.117	-0.191	-0.278	-0.013	-0.218	-0.051	0.058	1	-0.064	0.271
		0.247	0.817	0.450	0.332	0.538	0.311	0.137	0.946	0.247	0.788	0.765	0.736	0.147
	30	29	30	30	30	30	30	30	30	30	29	30	30	30
Indeno(1,2,3 cd)pyerene	0.006	0.051	0.034	-0.073	0.034	0.078	0.160	.609**	0.278	.605**	0.186	-0.064	1	-0.220
		0.976	0.794	0.859	0.701	0.857	0.681	0.398	0.000	0.136	0.000	0.333	0.736	0.243
	30	29	30	30	30	30	30	30	30	30	29	30	30	30

3.2. Findings and Discussions

The fairly strong correlation between the selected PAH ratios in the soil & groundwater (except B(a)A/Chr) clearly suggest common contamination pathways for both soil & groundwater in the area. (See table 4) The findings shows that PAHs concentrations are generally higher than the World Health Organization (WHO) recommended limits for both soil and water within the study area. The fairly strong correlation between the selected PAH ratios in the soil & groundwater (except for the B(a)A/Chr) clearly suggest common contamination pathways for both soil & groundwater in the area. The study also suggests the urgent need for hydrocarbon waste management control in the area.

Phenanthrene

In the groundwater samples obtained from various locations within the study area, phenanthrene was detected. The concentration of phenanthrene ranged between 0.00 and 15.74 mg/l and had a mean value of 4.4480 mg/l which is less than the mean value from soil samples taken within the self-same study area (Table 3; Fig10 and 11). Concentration of phenanthrene of soil samples ranges between 0.0011 mg/kg and 106.0 mg/kg in the area having a mean value of 8.18 mg/kg which is greater than the value obtained from groundwater samples. This was not well dispersed in the area but high concentrations were observed in the oil exploration areas of Yenagoa and Biseni. Exposure of living organisms to phenanthrene poses a high risk of toxicity and it is a possible carcinogen.

Fluoranthene

The value of fluoranthene found in the groundwater ranged between 0.05 and 0.94 mg/l with a mean concentration of 0.5230 mg/l as shown in (Table 3; Fig12 and 13). The highest concentration of fluoranthene was recorded at the Biseni and Okoloibiri areas. The concentration ranged between 0.0036 mg/kg and 146.89 mg/kg among the samples

of soils. Though this is non carcinogenic, its high concentration in these soils can lead to soil textural problems.

Anthracene

The mean value of anthracene concentration in groundwater sample was 0.9650 mg/l which ranges from 0.01 to 4.31 mg/l (Table 3, Fig14 and 15). The dispersion of Anthracene followed the trend of other non-carcinogenic PAHs. The concentration ranged between 0.0001 mg/l and 23.60 mg/l (Figure) in soil samples. The highest concentration was recorded at Biseni. The EPA has listed anthracene as a priority pollutant.

The findings from this study are higher compared to previous study but it is still comparable to those of previous studies on PAH contamination in other parts of Nigeria (Iwegbue et al., 2013; Nganje et al., 2014; Abdulrashid et al., 2017; Adetunde et al., 2018; Okereke et al., 2018; Olatunde et al., 2020; Ganiyu et al., 2021) and (Ekanem et al., 2021).

4. CONCLUSION AND RECOMMENDATION

Concentrations of PAH compounds largely vary in distribution among the soils and groundwater samples, although the random distribution pattern is fairly consistent between the measured concentrations in the soil and water. Relatively, the PAH values are markedly higher in the soil samples just as the highest mean concentrations were recorded in the dibenz(a,h) anthracene. This was seconded by indeno(1,2,3-cd) pyrene and pyrene, respectively. These comparatively lower concentrations observed in the water samples may have been due to effects of groundwater flow which may have dissolved some of these organic compounds into other soluble forms or compounds.

Following the findings on the organic assessment of groundwater and soil in Yenagoa and environs, Southern Nigeria, the following recommendations have been made: Hence, there is need for closer attention to be paid to the identified anthropogenic

sources: hydrocarbon exploration and associated activities, agricultural and industrial waste disposal. State and federal regulatory agencies should ensure strict compliance with environmental laws and safety policies with a view to protect the environment from the negative impacts which industrialization and urbanization exert.

Oil Exploration laws and Policies

For effective minimisation of the impacts of oil exploration ongoing within the host communities, the government, oil companies and the host communities must implement certain preventive actions. The government should put in place a strong legislation essential for the enforcement of mandatory practice of precautionary actions by companies during their operations with the view of minimizing or preventing environmental impairment. The government, through the legislature should show political will in the passage of the petroleum industry bill (PIB). This will solve bulk of the problems.

There is the need to strengthen the PIB with the following inputs:

Government should enact laws to control and incorporate the activities of the so called “illegal refineries” in these areas, as they form an integral part of the petroleum downstream sector.

Government should enact policies mandating the oil companies to ensure proper segregation of hydrocarbon sludge and other wastes, and treat such appropriately before dumping.

Government should equally ensure that oil exploration companies (including illegal refineries) restore each operational site to its original state after exploration activities, following the Environmental Impact Assessment (EIA) plan.

Groundwater development and waste management

In the aspect of groundwater development, the following recommendations have been made for sustainable water supply.

Siting of boreholes to cater for potable water supply within host communities is a necessity, reason being that most of the rural dwellers lack potable sources of water for their domestic uses. Before siting boreholes, adequate hydrogeochemical analysis in the area for groundwater exploration should be conducted. This is necessary as this research shows that oil exploration activities have effects on the soils and groundwater resources within the area. Hydrogeochemical analysis of groundwater and surface waters within the study area must be well carried out to establish the levels of chemical constituents present in such waters before use.

AUTHORS' CONTRIBUTION

D.P. Okumoko was responsible for the field work, laboratory analysis and putting the research work together while P.N. NNABO was responsible for the interpretation of the result from the lab and also proof-reading the entire research work.

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