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ASSESSING THE DISTRIBUTION OF PAHS IN WATER AND SEDIMENT OF SELECTED OIL-PRODUCING COMMUNITIES IN DELTA SOUTH SENATORIAL DISTRICT, DELTA STATE, NIGERIA.

[1*]Udowa, E. O and [2]Etchie, T. P.

[1]Department of Chemistry, College of Education, Warri, Nigeria
[2]Department of Political Science, College of Education, Warri, Nigeria

Corresponding author's email: udowa.emily@coewarri.edu.ng

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ABSTRACT

To enhance the understanding of the distribution of polycyclic aromatic hydrocarbons (PAHs) and their immediate ecological risks from crude oil pollution, this research work examined the concentrations, distribution patterns, and environmental risks of PAHs in soil and water polluted by crude oil in sediment and water samples collected from the 8 locations (BAT, BOB, KOK, OKE, OLO, ORE, TSE, and UZE), in the Delta State, Southern region in Nigeria. The PAH distribution in the sediments from the 8 locations reveals the presence of benzo[b]fluoranthene as the dominant PAH type with a concentration of up to 4.03 µg/L, which was closely followed by acenaphthylene and benzo[k]fluoranthene with concentrations corresponding to 2.33 µg/L/Land 2.14 µg/L, respectively. The distribution of various PAH concentrations in different water samples indicates that PAH types Benz(a)anthracene and Benzo(a)pyrene were present in the highest concentrations, 0.57 µg/L and 0.53 µg/L, in the water sample from location BAT. The findings established that sediment from BAT was most contaminated with PAHs, while sediment from TSE was the least contaminated with PAHs. However, the findings from water analysis proved that across all 8 locations under investigation, the water sample collected from KOK is the most contaminated with the various PAH types, with a cumulative PAH concentration of 4.51 µg/L, and ranking 1st in PAH contamination levels, corresponding to a 16.2% in the percentage PAHs spatial distribution.

Keywords: Delta South Senatorial District, Poly Aromatic Hydrocarbons, sediments, Water, pollution.

1.0. INTRODUCTION

Polycyclic Aromatic Hydrocarbons, abbreviated as PAHs, are a group of more than one hundred organic compounds, which are chiefly colourless, but which sometimes assume a whitish or straw colour. They are very common and may be derived from either natural or anthropogenic sources (Okedere & Elehinafe, 2022). Natural sources of PAHs include occurrences such as volcanic eruptions, open burning, and escape from the deposit of coal or petroleum. The anthropogenic sources are man-made and may be associated with incomplete combustion or pyrolytic processes of organic substances. Consequently, methods such as the treatment of crude oil, tar sands, bitumen, coal, and gas, as well as the use of refined products from petroleum, constitute the primary anthropogenic sources of PAHs (Emoyan *et al*., 2020). Other anthropogenic Sources include the burning of medical and municipal wastes, vegetative waste products, and biomass in general (Nduka, *et al.,* 2025).

The Niger Delta area of Nigeria harbours many anthropogenic sources of polluting organic PAH compounds, and the exploration of crude oil is believed to be mainly responsible for most of these polluting agents (Saunders *et al*., 2022). The Niger Delta, however, is susceptible to various sources of pollution from both land and sea, having been and remaining in a highly contaminated state due to significant exports and imports of crude oil and petroleum products (Faboya *et al*., 2023). Ivwurie & Okorodudu (2021) investigated the sources, both primary (pure hydrocarbons) and secondary (soils), of petroleum hydrocarbons (PAHs) in specific locations in Ughelli and its surrounding areas in Delta State, Nigeria, which were found to be polluted with hydrocarbons. It was found that the most essential constituents of soil PAHs in these cases were the lower homologues (2-3 rings) and the non-carcinogenic hydrocarbons. Similarly, the spatial and temporal distribution of sixteen polycyclic aromatic hydrocarbons (PAHs) in soils and the assessment of human health hazards have been investigated (Emoyan,*et al.,* 2022) The results showed significant variation in the concentration of PAHs, indicating a possible risk of exposure for ecosystems and mankind. The percentage composition, the molecular weight distribution and potential sources of pollution of PAHs have been studied. (Okoye *et al., 2023*).

The presence of high molecular weight (HMW) PAHs, along with specific molecular diagnostic ratios, indicates that the pollution originates from both pyrogenic and petrogenic sources (Umudi *et al.,* 2025). In some areas of the Niger Delta, the Risk quotient values exceeded 800, indicating that remediation is warranted in these areas to avert adverse effects on environmental health. To enhance its understanding of the distribution of polycyclic aromatic hydrocarbons (PAHs) and their immediate ecological risks associated with crude oil pollution, this research work examined the concentrations, distribution patterns, and environmental risks of PAHs in soil and water contaminated by crude oil. The research work is limited to eight communities in the Delta South Senatorial District of Nigeria, drawn from four of the eight Local Government Areas in the State. The table below identifies the community chosen for the study.

Table 1.0: Community and Their Local Government Area

COMMUNITIES	INDIGENOUS TRIBE	LOCAL GOVERNMENT AREA
Bateren	Itsekiri	Warri North
Bobi	Itsekiri	Warri South West
Kokodiagbene	Ijaw	Warri North
Okerenkoko	Ijaw	Warri south west
Olomoro	Isoko	Isoko South
Orere	Itsekiri	Warri South West
Tsekelewi	Ijaw	Warri North
Uzere	Isoko	Isoko South

2.0. MATERIALS AND METHODS

In this research, the analytical test method for polycyclic aromatic hydrocarbons (PAHs), based on USEPA method 8270, was conducted using high-quality reagents. The reagents included analytical-grade dichloromethane (DCM, HPLC grade) sourced from Fisher Scientific in Loughborough, UK. Anhydrous sodium sulfate (Na_2SO_4), acetone, and powdered silica gel (60-120 mesh) were obtained from BDH Laboratory Supplies in Poole, England. Additionally, the PAH reference standard mix (2000 ppm), which includes sixteen different PAHs, was acquired from Accu Standard Inc. in New Haven, USA.

2.1 Sample Collection and Preparation for PAH Analysis

Randomly selected portions of sediment and water samples were collected from three Ijaw communities: Tsekelewu (TSE), Okenrenkoko (OKE), and Kokodiagbene (KOK), three Itsekiri communities: Orere (ORE), Bobi (BOB) and Bateren (BAT) and two Isoko communities: Olomoro (OLO) and Uzere (UZE). The sediment samples were ground and mixed into fine particles using a ceramic mortar and pestle, ensuring uniformity. The homogenized sample was combined with anhydrous sodium sulfate (Na_2SO_4) to effectively absorb moisture in a ratio of 1:3 of sample to anhydrous sodium sulphate (Na_2SO_4) (USEPA,2014).

2.1.1 Ultrasonic Extraction (Solid-Liquid Extraction method)

A known amount of finely ground, thoroughly mixed sediment (10g) was weighed into a clean extraction vessel using an electronic analytical balance (S-Mettler; FA210A model, USA). (USEPA,2014). Thirty milliliters of a dichloromethane and acetone (in the ratio 1:1 v/v) solvent mixture was added to the vessel containing the sediment sample. The mixture was sonicated for 15–30 minutes and then filtered. The supernatant was collected in a clean 100-ml glass beaker. This extraction process was repeated three times to maximize recovery, and the three supernatants were combined (USEPA,2014).

A procedural blank using dichloromethane (DCM) was also processed using the same extraction procedure as part of the Quality Control and Quality Assurance (QA/QC) measures (USEPA,2014).

2.1.3 Silica Gel Cleanup of Extracts

To ensure accurate PAH analysis, which can be tricky due to their low concentrations and the presence of interfering substances, a thorough clean-up step is essential. We prepared a glass column by packing it with glass wool, silica gel (to remove polar interferences), and anhydrous sodium sulfate (Na_2SO_4). The column was then conditioned with dichloromethane (DCM). Furthermore, the combined extract was carefully transferred into the prepared column. PAHs were then eluted using 20 ml of dichloromethane. The resulting eluate was collected in a clean 50 ml glass beaker and prepared using a rotary evaporator-MSD Analysis for PAH concentrations (USEPA, 2007).

2.2. GC-MSD Analysis for PAH concentrations

The analyte was separated and detected using an Agilent 6890 gas chromatograph and Agilent 5973N Mass Selective Detector (GC-

MSD). The PAH eluate was concentrated using a rotary evaporator (Searchtech instrument, RE52-2 model, USA) until its volume was reduced to about 1–2 mL. The concentrated eluate was transferred to a clean 2mL Teflon screw-cap vial, tightly capped, labeled, and stored to prevent oxidation before GC-MSD analysis. GC-MS analysis determined PAH concentrations using an Agilent 6890 gas chromatograph and Agilent 5973N Mass Selective Detector (GC-MSD) from Agilent Technology, Palo Alto, CA, USA. The column was an Agilent 19091J-413 - HP-5 Capillary column (30 m × 0.25 mm I.D. × 0.25 μm film thickness), with helium as the carrier gas (purity ≥99.999%) at a constant flow of 1.0 mL/min. The injection was slit less, with a 1 μL injection volume. The MS ion source temperature was 230 °C, the injection temperature was 50 °C, and the pressure was 13 psi. The full scan acquisition mode covered a mass range of 50–500 amu, with a 2.00 min purge time, a total flow of 23 mL/min, and a solvent delay of 3.5 min. A 1 μL aliquot of the extracted sample was injected into the GC-MSD. PAHs were identified by their retention times, with those having shorter retention times eluting first. PAH standard solutions were run under the same chromatographic conditions, and mean peak areas were plotted against concentrations to create calibration curves for the 16 priority PAH compounds. Procedural blanks were included for each sample batch to account for sample preparation and determination steps. Duplicate analyses were performed for every 10 to 20 batches of samples.

3.0. RESULTS AND DISCUSSION

3.1 Characteristics of the Water Samples

The physicochemical properties of the water samples collected from 8 locations coded as BAT, BOB, KOK, OKE, OLO, ORE, TSE, and UZE in the Delta State, Southern region in Nigeria are presented in **Table 2.0** below.

Table 2.0: Characteristics of the Water samples from various location under investigation

Parameters	Test Method	BAT	BOB	KOK	OKE	OLO	ORE	TSE	UZE
pH	APHA 4500-H^+	7.70	6.60	5.60	5.00	5.70	7.10	6.50	5.20
Conductivity (μS/cm)	APHA 2510B	340	160	40	44	400	150	60	51
Salinity (ppt)	APHA 2520B	0.18	0.08	0.02	0.02	0.23	0.08	0.03	0.03

DO (mg/L)	APHA 4500-O-G	6.2	6.3	6.3	6.4	5.8	6.4	6.2	6.2
Turbidity (NTU)	APHA 2130B	1.34	2.09	0.83	0.75	4.50	0.90	1.36	1.44

The results showed that the pH levels of the water samples from the KOK (5.60), OLO (5.70), and UZE (5.20) locations were acidic. The outcome indicates significant implications for the concentration, mobility, and persistence of contaminants in these water samples (Ovuoraye *et al.,* 2021; Chinenye *et al.,* 2022). Additionally, the highly acidic pH signifies reduced microbial degradation and enhanced adsorption of contaminants to sediments in these locations (Naz *et al.,* 2022; Aryal, 2024). The water sample from UZE is the most acidic, with higher contaminant retention and the lowest microbial degradation. The pH of water samples from KOK, OLO, and UZE was significantly low, and did not satisfy the WHO pH (6-8) stipulated for clear water (Zheng *et al.,* 2006; Naz et al., 2022). The pH of water samples from ORE (7.10) and BAT (7.70) lies within the pH range of neutral water. The outcome showed that samples from ORE and BAT satisfied the WHO pH range (6-8), indicating a balance in the degree of acidity and alkalinity of the solution, which suggests a lower tendency for persistence of contamination and improved detoxification. However, the pH of samples from BOB (6.60) and TSE (6.50) were close to neutral (7.0) and fell within the WHO range of pH (6-8), indicating a less acidic contamination level.

In terms of conductivity of the water samples across all 8 locations, the sample from OLO has the highest electrical conductivity of 400 µS/cm, followed by the sample from BAT (340 µS/cm). Other locations BOB (160 µS/cm), and ORE (150 µS/cm) recorded moderate conductivity, while samples from UZE, KOK, TSE, and OKE recorded conductivity ≤ 60 µS/cm.

The degree of salinity in the water samples varies significantly, with higher values recorded at 0.23 ppt in the OLO location, closely followed by 0.18 ppt at the BAT location. Salinity of water samples from BOB and ORE was equal to 0.08 ppt. The higher the salinity, the lower the tendency for bioavailability of contaminants, influencing partitioning between water and sediments. However, the degree of salinity in samples from locations KOK, OKE, TSE, and UZE was relatively low ≤0.03 ppt. In terms of dissolved oxygen content (DO), it is essential for aerobic

microbial degradation of contaminants in water samples. Low DO values slow down the breakdown of contaminants, increasing persistence (Bozorg-Haddad *et al*., 2021). In this case, the DO values range from 5.8 to 6.4, indicating that there are no significant variations in the DO levels of water across all samples, regardless of location.

Turbidity is a clear indicator of the presence of suspended particles that can adsorb PAHs, affecting their transport and concentration (Rugner *et al.,* 2013). In terms of contamination levels, the turbidity of the samples are BAT (1.34 NTU), BOB (2.09 NTU), KOK (0.83 NTU), OLO (4.50 NTU), OKE (0.75 NTU), ORE (0.90 NTU), TSE (1.36 NTU), and UZE (1.44 NTU). The turbidity of the samples from the various locations under investigation was relatively < 5NTU, suggesting the samples satisfied the WHO standard for clear water (Ovuoraye *et al.,* 2021; 2022). Although turbidity levels of 4.5 NTU were detected in OLO and 2.09 NTU in BOB, these indicate some level of total suspended solids (TSS) contamination in the water (Ugonabo *et al*., 2022). This outcome suggests possible contaminant accumulation with partial microbial access due to the mild turbidity in samples (Ovuoraye *et al.,* 2021; 2022).

3.2 Physicochemical Properties of the Sediments

The pH variation across the soil samples collected across the various locations is presented in Table 3.0. The results proved that the pH of the sediments was predominantly acidic, irrespective of location. The pH of sediments from BAT (5.05), KOK (5.02), UZE (5.12), and TSE (5.84) was less than 6.0, indicating signals that signify reduced microbial degradation, a high degree of persistence, and enhanced adsorption of contaminants to sediments in these locations. The pH of sediments from ORE (6.15), OLO (6.10), and OKE (6.50), although less acidic, can also affect microbial degradation, solubility, and adsorption. Acidic pH slows biodegradation and increases the persistence of PAHs (Hu et al., 2025).

Table 3.0: Physicochemical properties of the Sediment samples from different locations

Parameters	Test Method	BAT	BOB	KOK	OKE	OLO	ORE	TSE	UZE

pH	APHA 4500-H^+	5.05	4.93	5.02	6.50	6.10	6.15	5.84	5.12
Conductivity (µS/cm)	APHA 2510B	1320	2944	64	104	36	1264	52	68

The concentration of the PAH contaminant in the Water and Sediment samples collected across all eight locations under investigation is presented in Tables 4a, 4b, **and 5b**. The results in Tables **4a and 4b** proved that PAH type naphthalene was predominantly absent across 8 locations. In contrast, of all the PAH contaminant types under investigation, benzo[b]fluoranthene, although relatively absent in samples collected from OKE and OLO locations, was significantly present in the water samples collected from the other 6 locations under investigation. The results in **Tables 4a and 4b** confirmed that the principal PAH contaminant in the water across all locations under investigation was benzo[b]fluoranthene, with a maximum 1.34 µg/L in water from the KOK location, and a cumulative concentration of 3.34 µg/L.

The results in Tables 5a and 5b show the concentration of PAHs obtained from the sediment samples in the 8 locations. A close observation reveals that Benzo[b]fluoranthene has the highest concentration of 16.23 mg/kg

Table 4a: PAHs Concentration in Water samples from locations BAT, BOB, KOK and OKE

Parameters	Test Method	BAT-W	BOB-W	KOK-W	OKE-W	Cumulative total
PAH (µg/L)						
Naphthalene	USEPA 8270	N.D.	N.D.	N.D.	N.D.	--
Acenaphthylene		0.38	0.03	0.38	0.29	1.08
Acenaphthene		N.D.	0.22	0.01	N.D.	0.23
Fluorene		0.47	N.D.	N.D.	0.19	0.66
Phenanthrene		N.D.	0.52	0.25	0.20	0.97
Anthracene		0.28	N.D.	N.D.	0.71	0.99
Fluoranthene		0.51	0.11	0.51	0.48	1.61
Pyrene		0.34	N.D.	0.34	N.D.	0.68
Benz[a]anthracene		0.57	0.74	N.D.	0.38	1.69
Chrysene		N.D.	0.42	0.46	0.16	1.04

Benzo[b]fluoranthene		0.34	0.26	1.34	N.D.	1.94
Benzo[k]fluoranthene		0.11	0.46	0.71	0.50	1.84
Benzo[a]pyrene		0.53	0.45	N.D.	0.17	1.15
ndeno[1,2,3-cd]pyrene		0.26	N.D.	N.D.	N.D.	0.26
ibenz[a,h,]anthrancene		0.35	0.25	0.35	0.48	1.43
Benzo(g,h,I)perylene		0.16	0.68	0.16	0.20	1.20
Sum of PAH (µg/L)		**4.30**	**4.14**	**4.51**	**3.76**	**16.71**

Table 4b: PAHs Concentration in Water samples from locations OLO, ORE, TSE and UZE

Parameters	**Test Method**	**OLO-W**	**ORE-W**	**TSE-W**	**UZE-W**	**Cumulative total**
PAH (µg/L)						
Naphthalene	USEPA 8270	N.D.	N.D.	N.D.	N.D.	--
Acenaphthylene		0.76	0.17	N.D.	0.20	1.13
Acenaphthene		0.19	0.16	0.18	0.62	1.15
Fluorene		0.06	0.32	0.39	0.31	1.08
Phenanthrene		N.D.	N.D.	0.41	N.D.	0.41
Anthracene		N.D.	N.D.	N.D.	0.19	0.19
Fluoranthene		0.53	0.22	0.33	0.33	1.41
Pyrene		0.38	0.41	0.29	0.29	1.37
Benz[a]anthracene		N.D.	N.D.	N.D.	0.32	0.32
Chrysene		N.D.	0.14	0.37	N.D.	0.51
Benzo[b]fluoranthene		N.D.	0.42	0.49	0.49	1.40
Benzo[k]fluoranthene		0.47	0.67	N.D.	0.35	1.49
Benzo[a]pyrene		0.49	0.12	N.D.	0.12	0.73
Indeno[1,2,3-cd]pyrene		0.18	N.D.	0.14	0.14	0.46
Dibenz[a,h,]anthrancene		N.D.	0.36	0.41	0.41	1.18
Benzo(g,h,I)perylene		N.D.	0.16	0.77	0.57	1.50
Sum of PAH (µg/L)		**3.06**	**3.15**	**3.78**	**4.34**	**14.33**

NOTE: ND= Not detected

Table 5a: PAHs Concentration in Sediment samples from locations BAT, BOB, KOK and OKE

Parameters	Test Method	BAT-S	BOB-S	KOK-S	OKE-S	Cumulative total
PAHs (mg/kg)						
Naphthalene	USEPA 8270	0.76	1.17	0.76	1.92	3.45
Acenaphthylene		1.15	2.20	1.15	0.78	5.28
Acenaphthene		2.33	0.16	2.33	1.04	5.86
Fluorene		1.40	1.39	1.40	0.57	4.76
Phenanthrene		0.76	0.55	0.76	0.84	2.91
Anthracene		0.83	1.91	0.83	0.13	3.70
Fluoranthene		1.53	0.13	1.53	0.75	3.94
Pyrene		1.03	0.42	1.03	1.82	4.30
Benz[a]anthracene		1.70	1.11	0.70	1.15	4.66
Chrysene		0.37	0.27	1.37	3.39	5.40
Benzo[b]fluoranthene		4.02	3.78	4.02	0.16	11.98
Benzo[k]fluoranthene		2.14	1.47	0.14	1.51	5.26
Benzo[a]pyrene		1.60	0.35	0.60	2.30	4.85
Indeno[1,2,3-cd]pyrene		0.77	0.81	0.77	0.51	2.86
Dibenz[a,h,]anthrancene		1.04	0.74	1.04	1.44	4.26
Benzo(g,h,I)perylene		0.49	2.03	0.49	0.60	3.61
Sum of PAH (mg/kg)		**21.16**	**17.32**	**18.16**	**16.99**	**73.63**

Table 5b: PAHs Concentration in Sediment samples from locations OLO, ORE, TSE and UZE

Parameters	Test Method	OLO-S	ORE-S	TSE-S	UZE-S	Cumulative total
PAHs (mg/)						
Naphthalene	USEPA 8270	0.01	0.29	0.12	0.92	1.34
Acenaphthylene		0.29	1.02	1.32	1.19	3.82
Acenaphthene		0.16	1.68	0.32	0.04	2.20
Fluorene		0.19	0.96	0.46	0.16	1.77
Phenanthrene		1.03	0.96	0.23	1.23	3.45
Anthracene		1.70	1.84	1.46	0.46	5.46
Fluoranthene		0.58	0.66	0.98	0.98	3.2
Pyrene		1.15	1.24	1.17	0.17	3.73
Benz[a]anthracene		0.71	1.13	0.97	0.97	3.78
Chrysene		0.59	0.31	0.10	0.10	1.10

Benzo[b]fluoranthene		1.36	0.27	1.16	1.46	4.25
Benzo[k]fluoranthene		1.70	1.01	1.25	1.65	5.61
Benzo[a]pyrene		1.48	1.32	0.03	1.15	3.98
Indeno[1,2,3-cd]pyrene		0.15	0.71	0.43	0.43	1.72
Dibenz[a,h,]anthrancene		1.87	1.17	0.22	0.22	3.48
Benzo(g,h,I)perylene		0.31	0.48	0.11	0.41	1.31
Sum of PAH (mg/kg)		13.27	**14.76**	**10.21**	**10.62**	**48.86**

3.3 Spatial Distribution of PAH Types in Sediment Samples across Locations in Delta State

Figure 1(a-h) below shows the spatial distribution of the selected PAH type in sediment samples collected from the 8 locations (BAT, BOB, KOK, OKE, OLO, ORE, TSE, and UZE), all in the Delta State, Southern region in Nigeria. The findings from Figure 1(a) proved that in location 1 (BAT), the presence of benzo[b]fluoranthene is the dominant PAH type, with a concentration of 4.03 µg/L. This was closely followed by acenaphthylene and benzo[k]fluoranthene with concentrations corresponding to 2.33 µg/L and 2.14 µg/L, respectively. Other PAH types, such as benzo(a)pyrene, benzo(a)anthracene, dibenz[a,h]anthracene, and fluorene, were present in moderate concentrations of < 2 µg/L. The PAHs least present in the sediment sample were chrysene and benzo[ghi]perylene in low concentrations of 0.37 µg/L and 0.49 µg/L, respectively. A similar trend is also observed in Figure 1(b). The sediment in location 2 (BOB) was mainly contaminated with benzo[b]fluoranthene(3.78µg/L), acenaphthene (2.20µg/L), and Benzo[ghi]perylene (2.03 µg/L). Benzo(a)anthracene, anthracene, naphthalene, benzo(k) fluoranthene, and fluorene were, however, in moderate concentrations of < 2 µg/L. In contrast, other PAH types such as benzo(a)pyrene, chrysene, fluoranthene, dibenz[a,h]anthracene, and acenaphthene were present in the sediment in low concentrations < 0.5 µg/L.

In 1(c) of Figure 1, the spatial distribution trend of PAHs observed in location 3 (KOK) indicates that the sediment sample was mainly contaminated by benzo[b]fluoranthene (4.02 µg/L), which was closely followed by acenaphthylene (2.3 µg/L). Only a slight disparity in terms of the concentrations of the PAHs present in the sediments can be observed. However, in contrast to the PAHs

distribution in location 1, the concentrations of chrysene, pyrene, acenaphthalene, dibenz[a,h]anthracene, and fluorene in location 3 where significantly present in concentrations of < 1.50 µg/L, while the PAH type present in the lowest concentration in the sediment is benzo(k)fluoranthene, benzo[a]pyrene, and benzo(a)anthracene ranging from 0.14 µg/L to 0.7 µg/L

In contrast to the spatial distribution of PAHs in sediment samples from locations 1 to 3, the distribution results recorded for the sediment in location 4 (OKE) proved that chrysene and benzo(a)pyrene were majorly present in high concentrations, amounting to 3.39 µg/L and 2.30 µg/L, respectively. The concentrations of PAH type naphthalene, benzo(a)anthracene, benzo(k)fluoranthene, and acenaphthylene were significantly ≤ 1.98 µg/L. The PAHs with the lowest concentrations in the sediments were naphthalene and benzo[b]fluoranthene. The results for location 5 (OLO) shows that naphthalene (2.03 µg/L) and phenanthrene (1.72 µg/L) were the dominant PAH types present in the sediment. The concentrations of fluorene, acenaphthylene, anthracene, and benzo(a)pyrene were significantly less than 1.5 µg/L, while acenaphthene and chrysene were present in the lowest concentrations of 0.18 µg/L and 0.39 µg/L, respectively. For samples in location 6 (ORE), the results in Figure 1, part (f), show that anthracene (1.84 µg/L) and acenaphthene (1.68 µg/L) were the dominant PAHs in the sediment sample. The concentrations of other PAH types, including pyrene, benzo(a)pyrene, benzo(a)anthracene, benzo(k)fluoranthene, and acenaphthylene, were present in ≤ 1.4 µg/L, while benzo[b]fluoranthene and naphthalene were present in the smallest concentrations of 0.27 benzo[b]fluoranthene 0.27 µg/L, and 0.29 µg/L, respectively.

However, the findings from the outline of the bar chart in 1(g) of Figure 1 indicate that the concentrations of the dominant compounds translate to anthracene (1.46 µg/L) and acenaphthylene (1.32 µg/L). The concentrations of pyrene, benzo[b]fluoranthene, benzo(k)fluoranthene, and fluoranthene were relatively ≤ 1.17 µg/L, while the concentrations of chrysene, phenanthrene, dibenz[a,h]anthracene, and benzo(a)pyrene were less than 0.5 µg/L. The least concentration present in the sediment was 0.03 µg/L recorded for benzo(a)pyrene. The outcome of the spatial distribution of the PAHs in location 8 (UZE) in Figure 1(h) confirmed that benzo[b]fluoranthene (1.65 µg/L) and benzo(k)fluoranthene (1.65 µg/L) were dominant PAHs in the sediment. Other PAHs such as acenaphthylene, benzo(a)pyrene, and phenanthrene were present in concentrations ≤

1.19 µg/L. However, the PAH with the least concentration in the sediment from the UZE location is acenaphthalene, present in trace amounts corresponding to 0.04 µg/L.

3.4 Distribution of PAH types in Water Samples across Locations in Delta State

Figure 2 (a – h) shows the PAH distribution in the Water samples from the 8 locations.The outlines of the bar graphs across Figure 2(a-h) indicate the distribution of various PAH concentrations in different water samples collected from the multiple locations in Delta State. The outline of 2(a) in Figure 2 showed that PAH type Benz(a)anthracene, and Benzo(a)pyrene were present in the highest concentrations, 0.57 µg/L and 0.53 µg/L in the water sample from location BAT. In location 2 (BOB), the PAH types benz(a)anthracene and benzo[ghi]perylene concentrations in the water corresponding to 0.74 µg/L and 0.68 µg/L, respectively, can be observed in 2(b) in Fig. 2. This outcome established that PAH type benz(a)anthracene dominates the water with a higher concentration. In (KOK) location 3, PAH types benzo[b]fluoranthene, and benzo[k]fluoranthene mainly were present in higher concentrations 1.34 µg/L and 0.71 µg/L respectively, while the water sample collected from (OKE) location 4, anthracene and benzo[k]fluoranthene were mainly present in higher concentrations of 0.71 µg/L, and 0.51 µg/L as can be observed in the bar charts in Figure 2 (c-d). In location 5 (OLO), the PAH types naphthalene and benzo[ghi]perylene were recorded at higher concentrations of 0.18 µg/L and 0.16 µg/L, respectively, in the water samples. Higher concentrations of benzo mostly contaminate the water samples from locations 6 (ORE) [b]fluoranthene (0.67µg/L), and benzo[k]fluoranthene (0.42 µg/L), while higher concentrations of benzo[ghi]perylene (0.77µg/L), and benzo[b]fluoranthene (0.49µg/L), were found in the water sample in location 7(TSE). In location 8 (UZE), the major PAH types identified in the water sample were predominantly acenaphthylene, present at 0.62 µg/L, and benzo[ghi]perylene, present at 0.57 µg/L.

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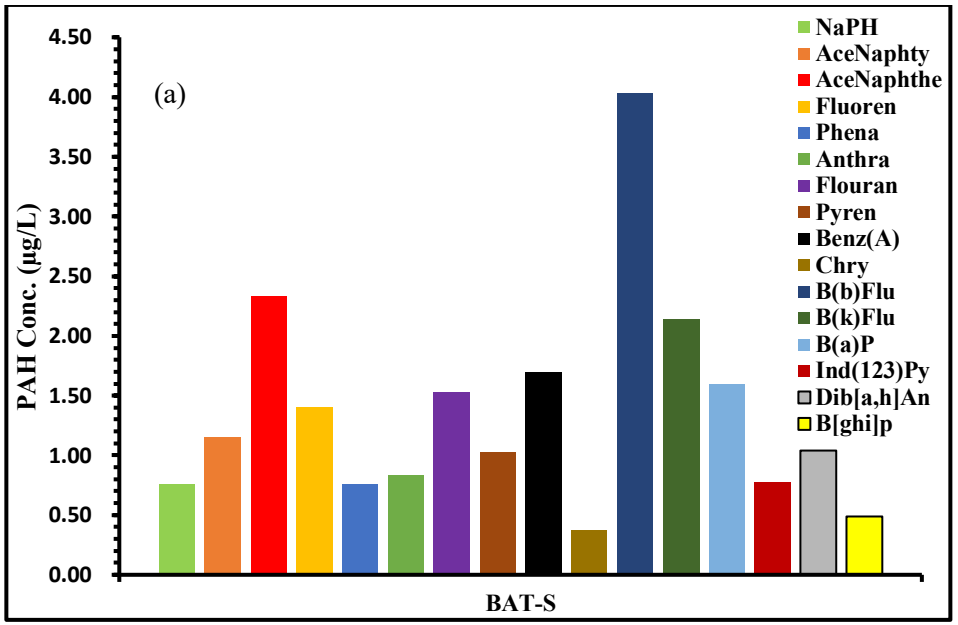

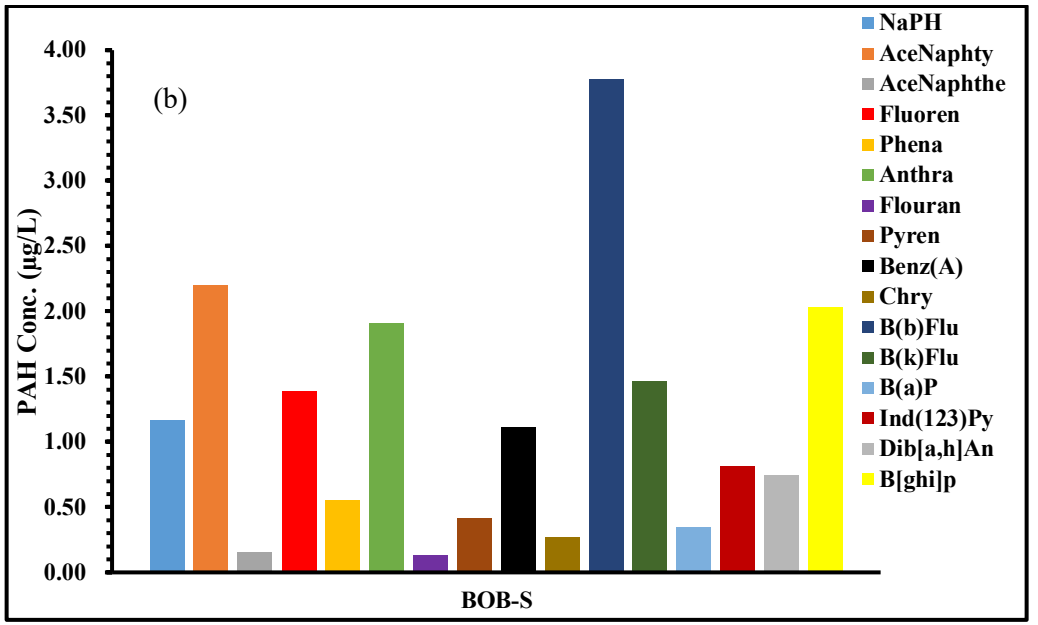

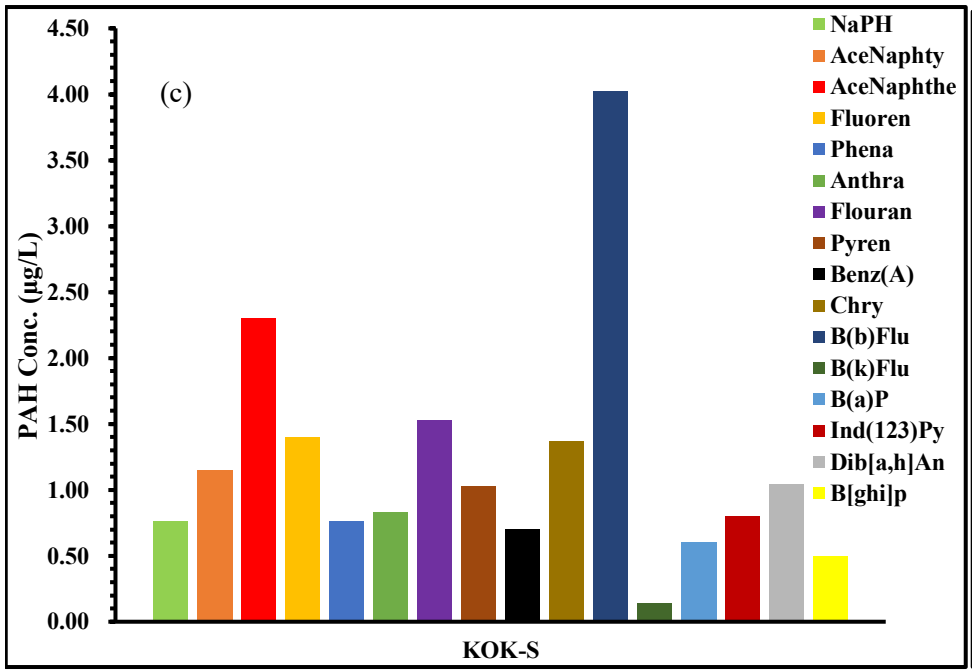

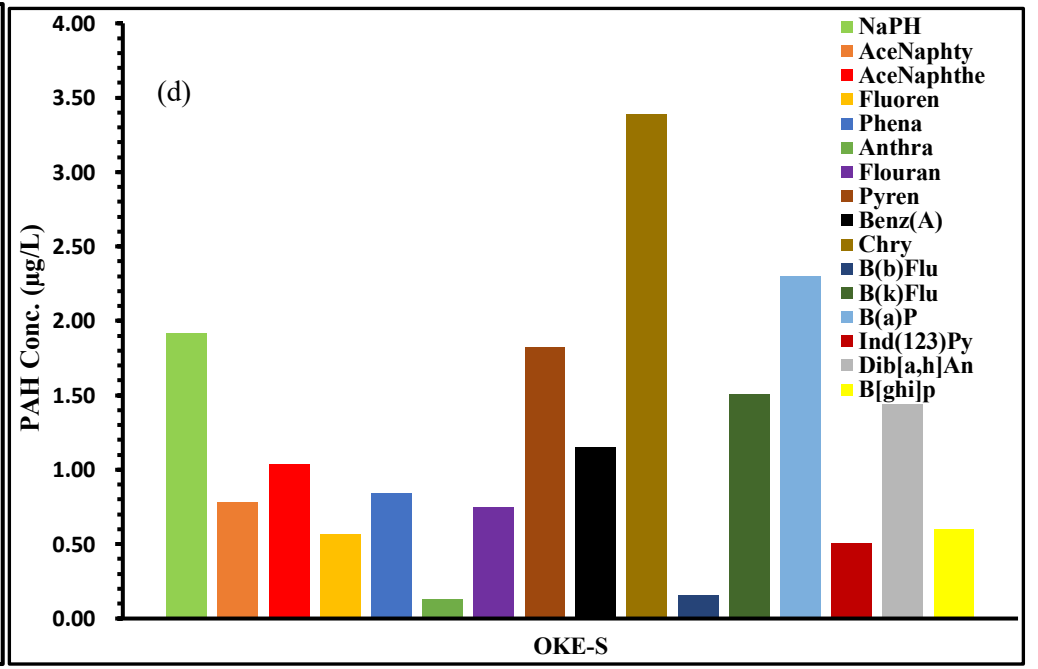

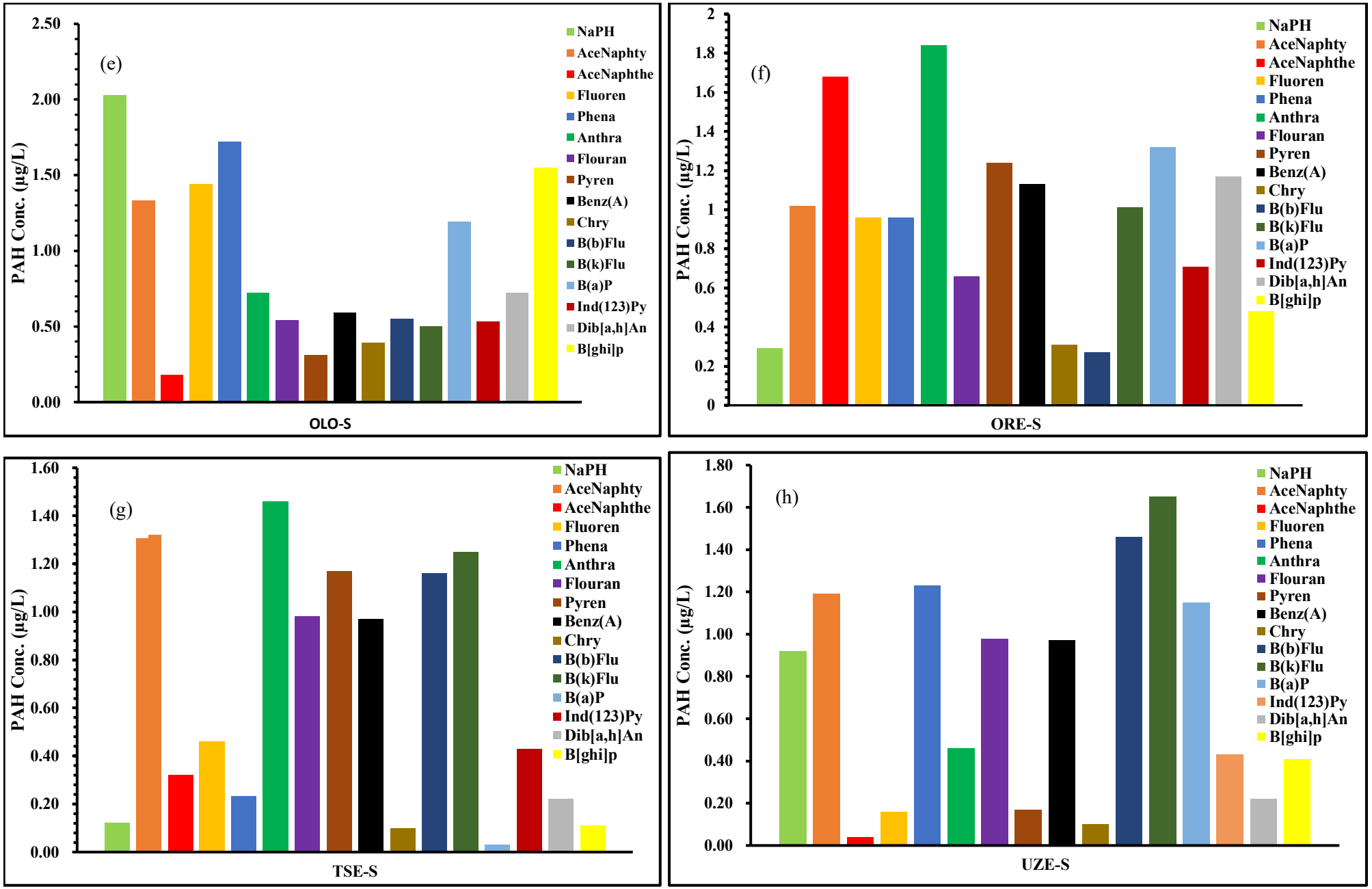

Figure 1 (a-h): Variation of the concentrations of different PAH types in Sediment samples across various

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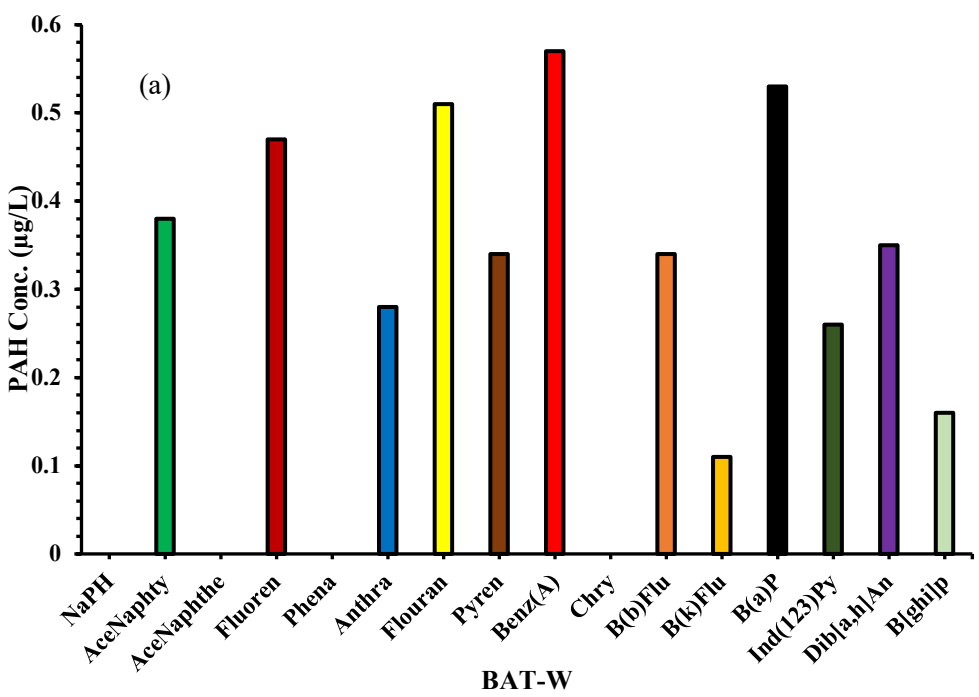

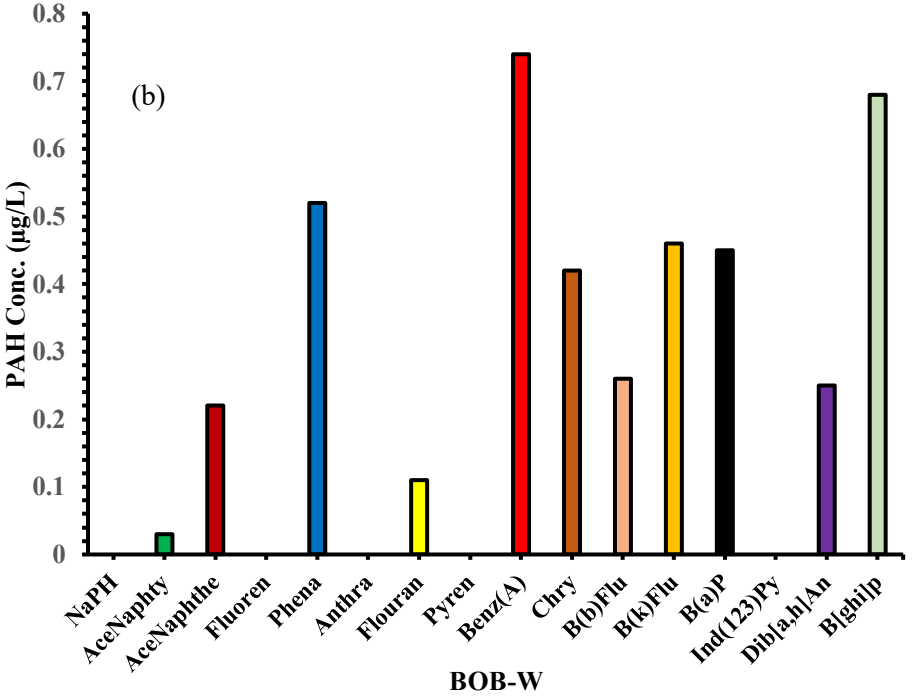

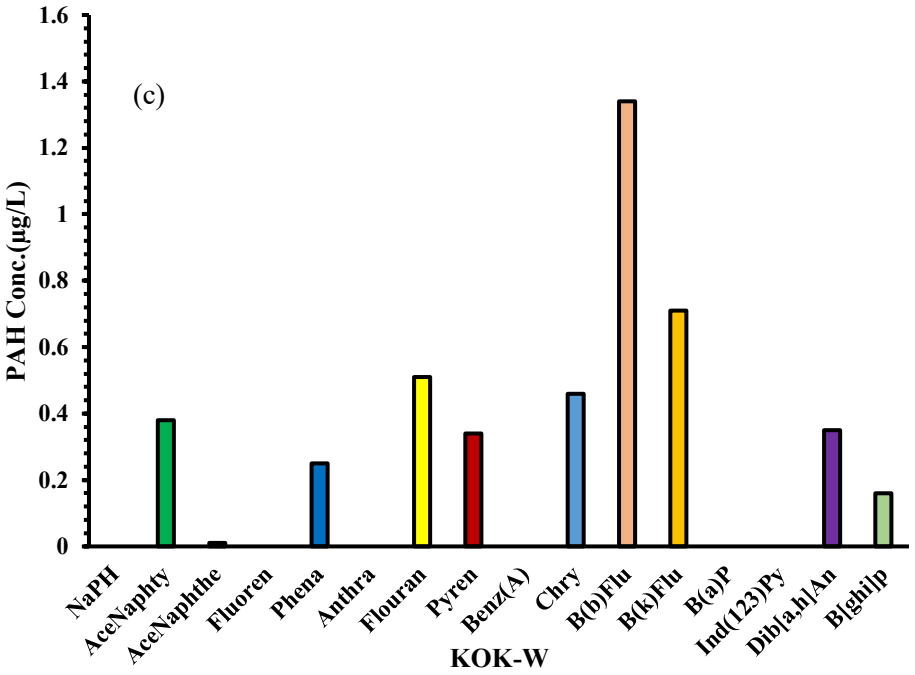

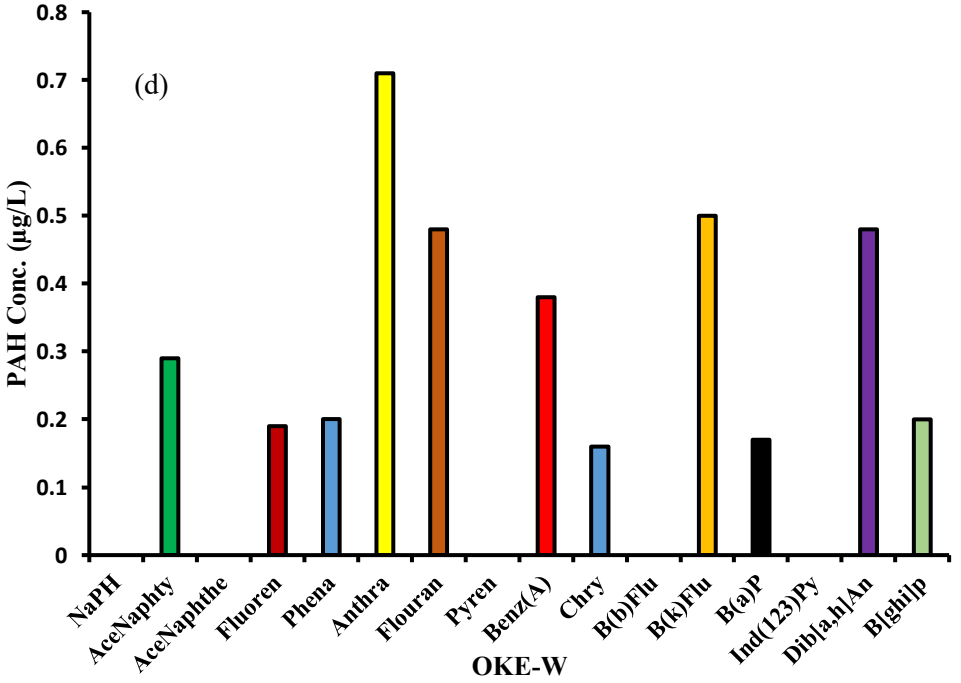

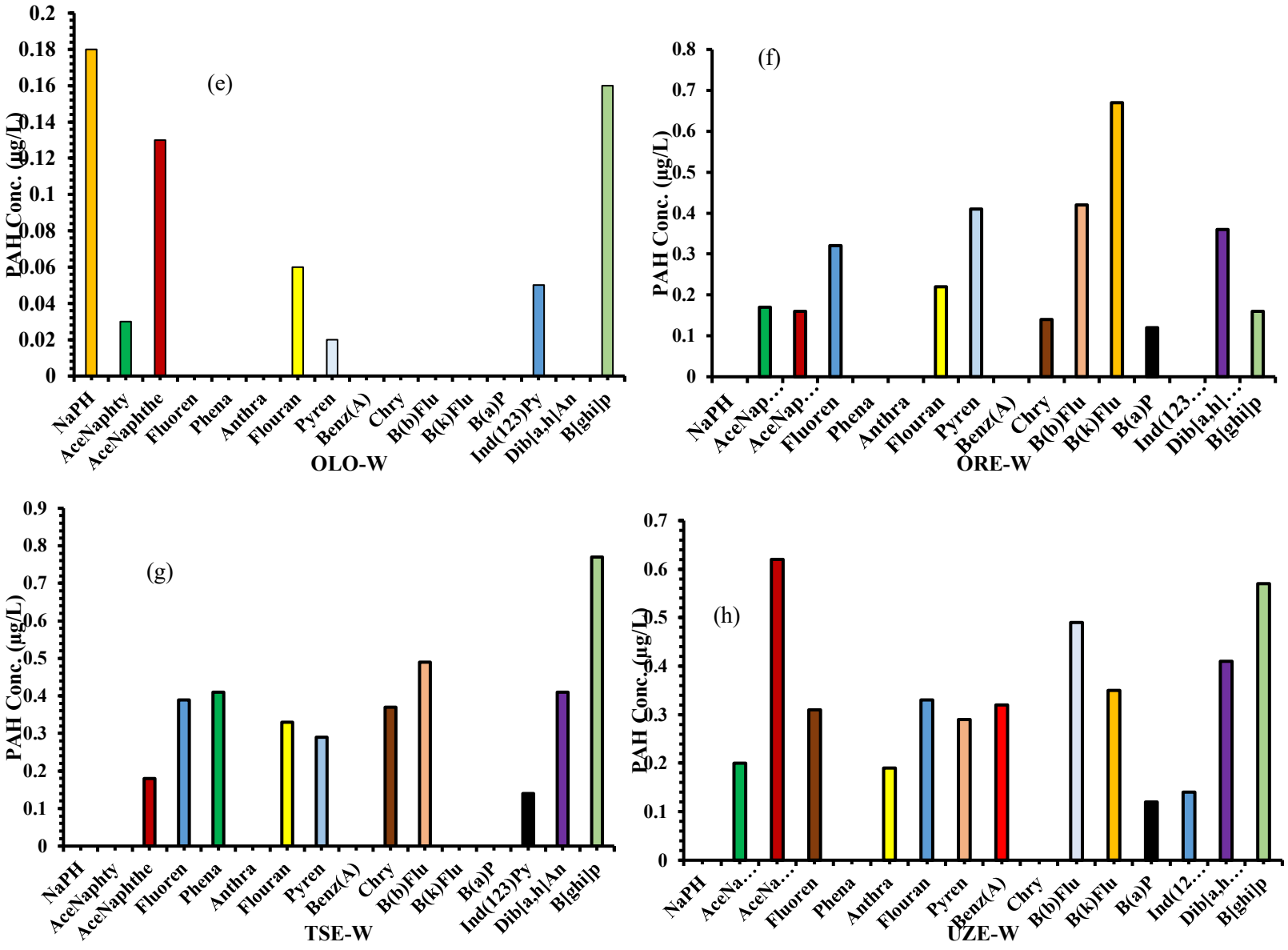

Figure 2(a-h): Variation of the concentrations of different PAH types in Water samples across various locations

Figure 3(a-b) shows the cumulative percentage of PAH concentrations present in sediments and water samples across all locations, coded as BAT, BOB, KOK, OKE, OLO, ORE, TSE, and UZE, respectively. The results in Figure 3(a) show that sediments from the BAT and OLO locations were most contaminated with PAHs, accounting for 18% of the cumulative concentrations. The cumulative concentrations translate to 21.93 µg/L and 21.57 µg/L. ORE and OKE locations both have a cumulative PAH concentration of 12%, which translates to 15.06 µg/L and 14.60 µg/L, respectively. The output from TSE and UZE confirmed a cumulative PAH concentration of 10.33 µg/L and 14.54 µg/L, respectively. The findings established that sediment from BAT was most contaminated with PAHs, while sediment from TSE was the least contaminated with PAHs.

However, the findings from Figure 3(b) proved that across all 8 locations under investigation, the water sample collected from KOK (location 4) is the most contaminated with the various PAH types, with a cumulative PAH concentration of 4.51 µg/L, and ranking 1st in PAH contamination levels, corresponding to a 16.2% in the percentage PAHs spatial distribution. UZE closely followed this with a cumulative PAH concentration of 4.43 µg/L corresponding to approximately 16% of the distribution.

From Figure 3(b), BAT and BOB showed the 3rd and 4th highest PAH levels, at 15% and 14%, respectively. These outcomes translate to cumulative PAHs concentrations of 4.3 µg/L and 4.14 µg/L, respectively, in the water samples from the areas. The water samples in locations TSE and OKE ranked 5th and 6th in spatial distribution of the various PAH types, corresponding to in the 13.17% and 13.10% degree of contamination, which transcends to a cumulative concentration of 3.76 µg/L and 3.7 µg/L respectively, these were closely followed by the water sample from ORE location ranking 7th with a distribution of 10% and cumulative concentration of 3.15 µg/L. OLO locations ranked the least contaminated with PAHs, with a cumulative concentration of 0.63 µg/L, which translates to only a 2% degree of contamination.

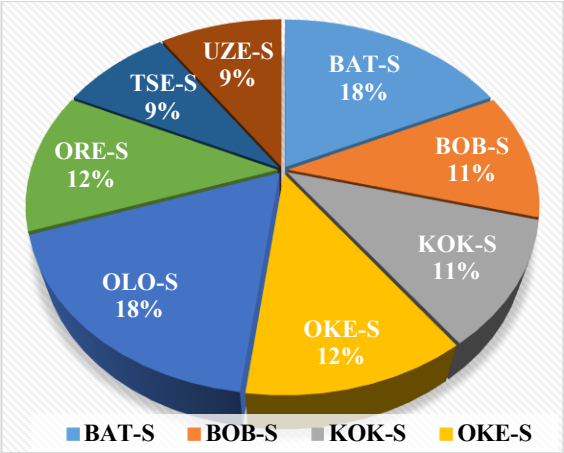

Figure 3(a): Percentage distribution of PAHs sediment Sample in terms of Cumulative concentrations across different locations under investigation

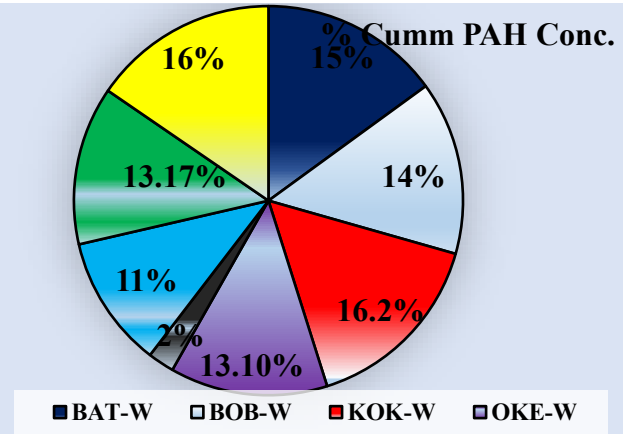

Figure 3(b): Percentage distribution of PAHs in the Water sample in terms of Cumulative concentrations across different locations under investigation

The presence of some PAH's in samples collected from locations 1-8, but their absence in other locations, is likely due to the different sources and exposures at these sites. Water samples containing PAH's likely originated from a site with significant sources, such as proximity to a landfill, coal tar or crude oil sources, or indoor use of repellents. In contrast, samples from locations 4, 7, and 8 have a much lower or non-existent source.

Additionally, the variation in physicochemical properties, such as turbidity and DO content, of the water and sediment samples across different locations confirmed the variations in biodegradability index and bioaccumulation, which may affect the partial distributions of PAH types in these locations.

This can account for the absence of specific PAH types from the various locations under investigation

4.0. CONCLUSIONS

The physicochemical properties of the water samples collected from the eight (8) locations studied proved that the pH of the water samples from KOK (5.60), OLO (5.70), and UZE (5.20) locations was acidic. The outcome indicates significant implications for the concentration, mobility, and persistence of contaminants in these water samples. Additionally, the highly acidic pH signifies reduced microbial degradation and enhanced adsorption of contaminants to sediments in these locations (Naz et al., 2022; Aryal, 2024). The findings established that sediment from BAT was most contaminated with PAHs, while sediment from TSE was the least contaminated with PAHs.

The findings on the distribution of PAH contaminants in the water samples collected across all eight locations under investigation are presented in **Tables 3a and 3b**. The results showed that PAH-type naphthalene was predominantly absent in water across 8 locations. In contrast, among all the PAH contaminant types under investigation, benzo[b]fluoranthene, although relatively absent in samples collected from the OKE and OLO locations, was significantly present in water samples collected from the other six locations under investigation.

However, the findings from Figure 3 (b) proved that across all 8 locations under investigation, the water sample collected from KOK is the most contaminated with the various PAH types, with a cumulative PAH concentration of 4.51 µg/L, and ranking 1st in PAH contamination levels, corresponding to a 16.2% in the percentage PAHs spatial distribution. UZE closely followed this with a cumulative PAH concentration of 4.43 µg/L corresponding to approximately 16% of the distribution.

5.0. RECOMMENDATIONS

The Communities studied in this research are associated with PAHs contamination as a result of oil exploration in such areas. PAHs in oil-producing areas can be remediated using three broad approaches. These include Bio-remediation, Chemical and Physical remediation.

- **Bio-remediation**: can be done through
  - Microbial degradation through the use of bacteria or fungi, which can break down PAHs into harmless compounds.
  - Myco-remediation involves the use of enzymes to degrade High Molecular Weight (HMW) PAHs.
  - Phyto-remediation, which involves using plants to stimulate microbial degradation of PAHs
- **Chemical remediation:** This involves the use of reagents to oxidize or transform PAHs, processes like advanced Oxidation, (AOPs) processes and chemical surfactant washing can be used
- **Physical remediation is essential when the contaminant concentration is exceptionally** high.
  - Soil excavation and replacement
  - Thermal desorption – heating soil to volatilize and capture PAHs
  - Solid-phase extraction and adsorption-using activated carbon, biochar or nano-materials to adsorb PAHs to adsorb from waste water or soils.

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