



Oxygenated Polycyclic Aromatic Hydrocarbons in Surface Water of Four Major Rivers in the Niger Delta of Nigeria

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Abstract: The aim of this study was to determine the occurrence and distribution pattern of oxygenated polycyclic aromatic hydrocarbons (OPAHs) in surface water of four major rivers in the Niger Delta of Nigeria. A total of 20 surface waters were collected from the Warri, Forcados, Benin and Escravos rivers. Samples were extracted with a mixture of dichloromethane and hexane. The cleaned extracts were analyzed for eleven OPAHs using a gas chromatograph equipped with mass spectrometry (GC-MS). Total OPAH concentrations ranged from 46-186 µg/L in the Benin River, 290-716 µg/L in the Escravos River, 338-492 µg/L in the Forcados River, and 308-640 µg/L in the Warri River. The concentrations of OPAHs in the rivers were in the order of Escravos River > Warri River > Forcados River > Benin River, while the occurrence pattern of PAHs was in the order 3-ring > 1-ring > 2-ring > 4-ring. Result from Pearson's correlation analysis indicated that the OPAHs in the surface water of these rivers were from similar sources and have similar fate in the aquatic environment.

Keywords: Surface water, Niger Delta, OPAHs, GC-MS

INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) are among the most extensively investigated classes of organic contaminants because of their persistence, widespread occurrence, and adverse effects on ecosystems and human health (Ididama *et al.*, 2025; Tesi *et al.*, 2025). They originate from both petrogenic sources, such as crude oil and petroleum products, and pyrogenic sources, including incomplete combustion of fossil fuels, biomass, and industrial emissions (Iloma *et al.*, 2024; Idowu *et al.*, 2019). In aquatic environments, PAHs are of particular concern because they can accumulate in sediments and aquatic organisms, resulting in long-term ecological consequences and potential human exposure through the food chain (Iwegbue *et al.*, 2021; Ihunwo *et al.*, 2021).

In recent years, increasing attention has shifted from the parent PAHs to their transformation products, particularly oxygenated polycyclic aromatic hydrocarbons (OPAHs) (Qiao *et al.*, 2022; Ogwuche *et al.*, 2026). Oxygenated PAHs are formed through abiotic processes such as photooxidation and atmospheric reactions, as well as through microbial degradation of parent PAHs in contaminated environments (Lundstedt *et al.*, 2007; Pulleyblank *et al.*, 2019). They may also be released directly during combustion processes and from industrial discharges (Lundstedt *et al.*, 2007; Pulleyblank *et al.*, 2019). Compared with their parent compounds, many OPAHs exhibit greater polarity and water solubility, allowing them to partition more readily into aquatic systems (Idowu *et al.*, 2019; Krzyszczak

& Czech, 2021). Consequently, surface waters frequently contain appreciable concentrations of OPAHs even where concentrations of parent PAHs are relatively low (Qiao *et al.*, 2014; Qiao *et al.*, 2018; Qiao *et al.*, 2022). More importantly, several OPAHs have been reported to possess higher biological activity than their corresponding parent PAHs, including enhanced oxidative stress, mutagenicity, developmental toxicity, and cytotoxicity, making them contaminants of emerging environmental concern (McCarrick *et al.*, 2019; Clergé *et al.*, 2019; Cunha *et al.*, 2020).

Despite these concerns, environmental monitoring programmes have traditionally focused almost exclusively on the sixteen priority PAHs identified by the United States Environmental Protection Agency (USEPA) (Srogi, 2007), whereas oxygenated derivatives remain poorly characterised in many environmental matrices (Pulleyblank *et al.*, 2019). This disparity has resulted in substantial knowledge gaps regarding their environmental occurrence, transport pathways, ecological risks, and environmental fate, particularly in aquatic ecosystems (Krzyszczak & Czech, 2021; Qiao *et al.*, 2022). Recent evidence suggests that OPAHs are widely distributed in surface waters worldwide and may occur at concentrations comparable to or even exceeding those of their parent PAHs because of continuous formation through environmental transformation processes (Qiao *et al.*, 2014; Qiao *et al.*, 2018; Qiao *et al.*, 2022; Zhu *et al.*, 2022). Studies of rivers, wastewater-impacted waters, tap water, and coastal environments have demonstrated the occurrence of OPAHs in aquatic systems (Liu *et al.*, 2021; Qiao *et al.*, 2022). OPAHs can enter surface waters through wastewater-treatment-plant effluents, atmospheric deposition, and surface runoff, while photochemical and microbiological transformation of parent PAHs can also contribute to their formation within aquatic systems (Qiao *et al.*, 2022). Oil contamination may further contribute to the occurrence and environmental distribution of OPAHs, as demonstrated during the Deepwater Horizon oil spill (Tidwell *et al.*, 2016).

The Niger Delta of Nigeria represents one of the world's largest petroleum-producing regions and has experienced decades of intensive oil exploration, production, transportation, refining, and associated industrial activities (UNEP, 2011; Anyanwu *et al.*, 2023). Although these activities have contributed significantly to the Nigerian economy, they have also resulted in chronic environmental contamination associated with oil spills, petroleum-industry effluents, accidental crude-petroleum discharges, artisanal refining, and industrial and sewage discharges into rivers and creeks (UNEP, 2011; Osuji & Uwakwe, 2006; Anyanwu *et al.*, 2023). The extensive network of rivers that supports domestic water supply, fisheries, transportation, and agriculture is therefore continuously exposed to petroleum-derived contaminants, including polycyclic aromatic hydrocarbons (UNEP, 2011; Asagbra *et al.*, 2015; Iwegbue *et al.*, 2021; Ihunwo *et al.*, 2021). Numerous studies conducted within the Niger Delta have documented the occurrence, distribution, sources, and risks of parent PAHs in water, sediments, soils, and aquatic organisms (Asagbra *et al.*, 2015; Anyanwu *et al.*, 2020; Iwegbue *et al.*, 2021; Ihunwo *et al.*, 2021). These studies demonstrate the widespread occurrence of PAHs in Niger Delta environmental matrices and highlight petroleum-related activities among the important anthropogenic sources of PAH contamination in the region (Anyanwu *et al.*, 2020; Iwegbue *et al.*, 2021). However, information on oxygenated PAHs is remarkably scarce despite growing international recognition of their environmental significance (Pulleyblank *et al.*, 2019; Qiao *et al.*, 2022). This lack of information limits understanding of contaminant transformation processes in tropical aquatic systems and introduces uncertainty into ecological risk assessments, since

OPAHs may contribute substantially to the overall toxicity of petroleum-contaminated environments (Lundstedt *et al.*, 2007; Idowu *et al.*, 2019; Krzyszcak & Czech, 2021; Qiao *et al.*, 2022). The absence of baseline data is particularly important in the Niger Delta, where petroleum hydrocarbons released into the environment undergo weathering and degradation under local environmental conditions (Osuji *et al.*, 2006; Osuji *et al.*, 2010), processes that can contribute to the formation of oxygenated PAH derivatives (Lundstedt *et al.*, 2007; Qiao *et al.*, 2022).

Surface water serves as an important transport medium through which contaminants are dispersed across aquatic ecosystems and subsequently become available to aquatic organisms (Qiao *et al.*, 2014; Nguyen *et al.*, 2021; Qiao *et al.*, 2022). Assessing the occurrence and distribution of OPAHs in river water therefore provides valuable information on contaminant sources, environmental behaviour, and potential ecological exposure (Qiao *et al.*, 2014; Qiao *et al.*, 2022; Zhu *et al.*, 2022). Such information is essential for improving pollution monitoring programmes, supporting environmental management decisions, and providing scientific evidence for the protection of aquatic ecosystems and communities that depend heavily on river resources in the Niger Delta. Against this background, the present study investigated the occurrence and spatial distribution of oxygenated polycyclic aromatic hydrocarbons in the surface waters of selected rivers in the Niger Delta, Nigeria. The study provides baseline information on the levels and distribution patterns of these emerging contaminants in a region where petroleum-related pollution remains a major environmental challenge and contributes to the limited body of knowledge on OPAHs in tropical aquatic environments.

Description of Study Area

The study area comprised four major rivers including Warri, Forcados, Escravos and Benin Rivers in the Niger Delta of Nigeria. The map of the study area is shown in Figure 1.

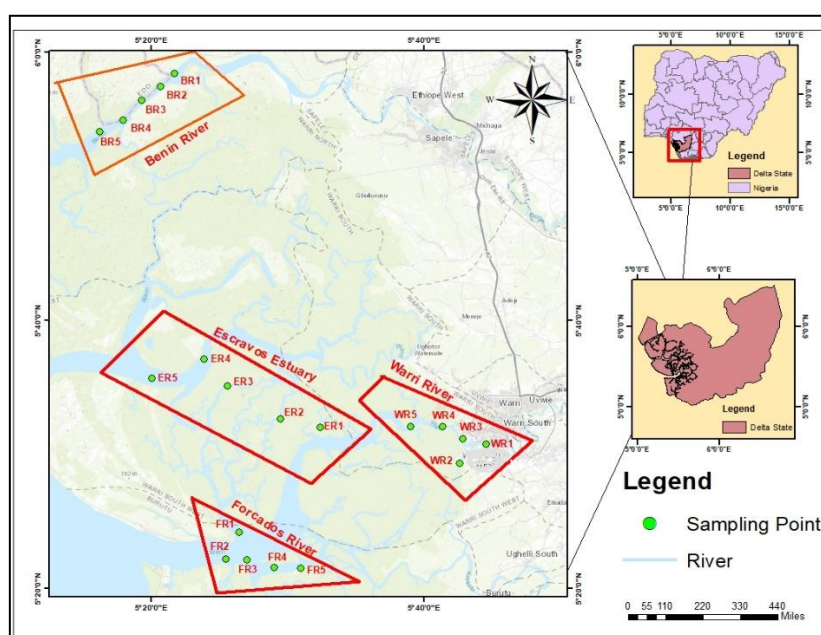


Figure 1: The map of the study area showing the sampling locations

Detailed description of the study area has been given in previous studies (Okonkwo *et al.*, 2025; Iwegbue *et al.*, 2021; Iwegbue *et al.*, 2020; Tesi *et al.*, 2019; Iwegbue *et al.*, 2018).

Sample Collection and Preparation

Five samples of surface water each were collected from each of the four rivers totaling twenty (20) samples. Water samples were collected with pre-cleaned amber-coloured bottles. All the collected samples were labelled appropriately, stored in a chest containing ice block, and taken to the laboratory and stored in the refrigerator prior to analysis.

Reagents

A standard mixture consisting of 11 OPAHs (Benzoquinone, 1,2-naphthoquinone, 1,4-naphthoquinone, 9-fluorenone, Anthraquinone, Phenanthrenequinone, 5,12-naphthacenequinone, Xanthone, Benz[a]anthracene-7,12-dione, 1-indanone and Benzanthrone) was purchased from GFS Chemicals, Columbus. Hexane, dichloromethane, copper powder, anhydrous sodium sulfate, florisil and silica gel was purchased from Merck (Darmstadt, Germany).

Extraction, Cleanup and Quantification of OPAHs in Water Samples

The USEPA Method 3510 was used in the extraction of OPAHs from the water samples. A 100 mL of water sample was measured into a separating funnel containing 100 mL of hexane/dichloromethane (DCM).

The mixture was extracted for 30 min and the extract was collected into a flask. The extraction process was repeated with another 100 mL of hexane/DCM and the extract was collected into the same flask. The combined extract was reduced to approximately 2 mL with a rotary evaporator. The concentrated extract was cleaned in a column containing alumina-silica gel packed bottom to top with neutral silica gel, neutral alumina and anhydrous Na₂SO₄. The OPAHs were subsequently eluted with 50 mL of hexane/DCM from the column, concentrated to 2 mL, and stored in a vial prior to chemical analysis. The OPAHs in the extracts were quantified by means of a gas chromatograph equipped with mass spectrometry (GC-MS).

Quality Control and Assurance

The guidelines of the European Commission (2019) for quality control and assurance were followed. Method blanks, spiked recovery, the limit of detection (LOD), the limit of quantification (LOQ), precision and linearity were used for quality control. The OPAHs were not detected in the method blanks. The percentage recoveries of the OPAHs from the spiked surface water ranged from 91.9 to 95.4%. The OPAHs in the samples were quantified using external calibration method. The limits of detection (LODs) and quantification (LOQs) were measured as the concentrations that give a signal-to-noise ratio of 3 and 10 respectively, of the blank samples ($n=3$). The LODs and LOQs of the emerging contaminants ranged from 0.01 to 1.0 ng g⁻¹ and from 0.03 to 3.0 ng g⁻¹ respectively. The r^2 of the calibration curves

obtained from the plot of known concentrations of emerging contaminants against their peak areas varied from 0.9993 to 0.9999.

Statistical Analysis

The statistical analysis of data was done using the IBM-SPSS software (version 27). The Kolmogorov-Smirnov and Shapiro-Wilks normality tests were performed on the data. The data were not normally distributed and as such the non-parametric Kruskal Wallis test was used to determine if there were significant spatial variations in the concentrations of the OPAHs in the water samples while Pearson's correlation coefficient was used to determine the relationships between the individual OPAH compounds.

RESULTS AND DISCUSSION

Concentrations of OPAHs in the Water Samples

The concentrations of OPAHs in surface water of the four rivers is shown in Table 1.

Table 1: Oxygenated PAHs concentrations (µg/L) in the water

OPAHs	Rings	BENIN RIVER					ESCRAVOS RIVER				
		BR01	BR02	BR03	BR04	BR05	ER01	ER02	ER03	ER04	ER05
1-Indanone	1	2	4	2	2	12	20	6	28	12	14
1,2-Naphthoquinone	2	30	6	6	6	4	18	32	84	16	132
1,4-Naphthoquinone	2	6	2	4	10	10	22	34	36	22	90
9-Fluorenone	3	24	10	8	4	12	66	42	58	18	66
5,12-Naphthacenequinone	4	4	2	12	10	6	20	18	44	20	64
Phenanthrenequinone	3	4	2	4	4	10	26	32	42	22	58
Anthraquinone	3	6	6	8	12	36	26	128	150	64	154
Benzanthrone	4	6	2	6	2	8	28	18	28	10	12
p-Benzoquinone	1	4	6	6	6	36	142	104	16	70	88
Xanthone	3	2	4	2	10	30	46	36	50	20	20
Benz (a) anthracene-7,12-dione	4	4	2	8	4	22	24	36	24	16	18
TOTAL		92	46	66	70	186	438	486	560	290	716
1-Ring		6	10	8	8	48	162	110	44	82	102
2-Rings		36	8	10	16	14	40	66	120	38	222
3-Rings		34	18	20	20	58	118	202	250	104	278
4-Rings		14	6	26	16	36	72	72	96	46	94
OPAHs	Rings	FORCADOS RIVER					WARRI RIVER				
		FR01	FR02	FR03	FR04	FR05	WR01	WR02	WR03	WR04	WR05
1-Indanone	1	18	18	12	14	10	10	10	14	10	14
1,2-Naphthoquinone	2	32	24	10	22	34	18	14	170	20	16
1,4-Naphthoquinone	2	20	12	22	14	18	16	16	84	14	18
9-Fluorenone	3	22	16	30	16	48	18	140	80	14	28
5,12-Naphthacenequinone	4	18	14	28	14	20	12	20	54	26	42
Phenanthrenequinone	3	16	26	34	12	12	12	20	60	36	26
Anthraquinone	3	152	86	104	108	116	100	98	86	156	112
Benzanthrone	4	18	14	18	12	14	16	48	16	10	8
p-Benzoquinone	1	50	70	58	36	54	58	132	20	130	70
Xanthone	3	124	36	24	88	58	28	36	40	48	34
Benz (a) anthracene-7,12-dione	4	22	22	22	16	28	20	52	16	18	22
TOTAL		492	338	362	352	412	308	586	640	482	390
1-Ring		68	88	70	50	64	68	142	34	140	84
2-Rings		52	36	32	36	52	34	30	254	34	34
3-Rings		190	128	168	136	176	130	258	226	206	166
4-Rings		58	50	68	42	62	48	120	86	54	72

Total OPAH concentrations ranged from 46-186 µg/L in the Benin River, 290-716 µg/L in the Escravos River, 338-492 µg/L in the Forcados River, and 308-640 µg/L in the Warri River. The comparatively higher concentrations observed in the Escravos and Warri Rivers may be related to greater anthropogenic influence, including petroleum-related activities, shipping operations and urban discharges within these river systems. The occurrence of OPAHs in water samples from the four rivers demonstrates the widespread distribution of OPAHs within the aquatic environment of the Niger Delta. The significantly higher concentrations ($p < 0.05$) recorded in the Escravos, Forcados and Warri Rivers compared with the Benin River suggest greater contaminant inputs and/or more active transformation of parent PAHs within these river systems. Similar spatial variations in OPAH concentrations have been reported in aquatic environments where anthropogenic activities influence contaminant occurrence and distribution (Qiao *et al.*, 2022; Zeng *et al.*, 2021). The highest total OPAH concentrations observed at ER05, WR03 and FR01 indicate the presence of localized contamination hotspots. OPAHs are formed through atmospheric, photochemical and microbial oxidation of parent PAHs and may also originate from direct industrial and combustion-related inputs (Qiao *et al.*, 2022; Peng *et al.*, 2023). The elevated concentrations observed in these locations may therefore reflect continuous hydrocarbon inputs associated with petroleum exploration, transportation and other industrial activities characteristic of the Niger Delta region.

Comparison of OPAH Concentrations in the Water with Previous Studies

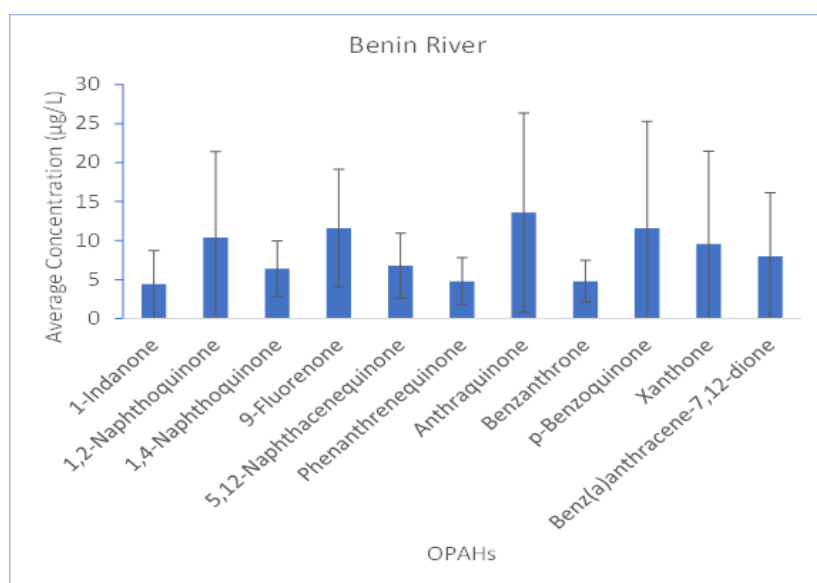
The concentrations of OPAHs recorded in the present study were generally low compared with those reported in many aquatic environments worldwide (Table 2). The concentrations obtained in the present study were substantially lower than those reported for the Willamette River, USA (1,000-300,000 µg/L) and the Gulf of Mexico, Mexico (ND-600,000 µg/L) (Tidwell *et al.*, 2016; Tidwell *et al.*, 2017). The elevated OPAH concentrations in these environments were attributed to intensive petroleum contamination and the transformation of parent PAHs in contaminated sediments. Similarly, Lundstedt *et al.* (2007) reported that OPAHs are important co-contaminants at PAH-polluted sites and may accumulate in sediments through both direct release and the environmental oxidation of parent PAHs, resulting in high concentrations in heavily contaminated systems. The considerably lower concentrations recorded in the present study therefore suggest lower levels of OPAH contamination in the sediments of the Niger Delta rivers. The concentrations observed in this study were also lower than those reported for the Krycklan Catchment, Sweden (ND-17,000 µg/L) (Nguyen *et al.*, 2018). Despite being a relatively less industrialized catchment, the occurrence of OPAHs in that study demonstrated the widespread distribution and persistence of these compounds in aquatic environments. The lower concentrations obtained in the present study may therefore indicate relatively lower inputs of parent PAHs and their oxidation products into the studied rivers. Furthermore, although detectable concentrations of OPAHs were observed in all four rivers, the levels were comparatively lower than those reported in other contaminated aquatic environments worldwide, indicating relatively low OPAH contamination in the sediments of the Benin, Escravos, Forcados and Warri Rivers. Supporting evidence indicates that OPAHs are persistent environmental contaminants that can form through the transformation of parent PAHs and accumulate in sediments over time (Lundstedt *et al.*, 2007).

Table 2: Comparison of OPAHs in the water of Benin, Escravos, Forcados and Warri rivers with others previously reported

River System	No. of OPAHs analyzed	Concentrations ($\mu\text{g/L}$)	References
Benin River, Nigeria	11	46-186	This Study
Escravos River, Nigeria	11	290-716	This Study
Forcados River, Nigeria	11	338-492	This Study
Warri River, Nigeria	11	308-640	This Study
Jialing and Yangtze Rivers, China	10	20200 $\pm$ 7490	Zhu <i>et al.</i> (2022)
Yangtze River, China	4	7700-90400	Zeng <i>et al.</i> (2021)
Bai, Chao & Chaobai Rivers, China	6	49000-4659000	Qiao <i>et al.</i> (2020)
Guangdong River, China	6	115000-384000	Qiao <i>et al.</i> (2019)
Beijing River, China	4	192000 $\pm$ 54000	Qiao <i>et al.</i> (2018)
Wenyu & Beiyun Rivers, China	4	60000-190000	Qiao <i>et al.</i> (2014)
Krycklan Catchment, Sweden	9	ND-17000	Nguyen <i>et al.</i> (2018)
Willamette River, USA	22	1000-300000	Tidwell <i>et al.</i> (2017)
Gulf of Mexico, Mexico	22	ND-600000	Tidwell <i>et al.</i> (2016)
Australian Estuary, Australia	7	110000-2180000	Idowu <i>et al.</i> (2020)

Distribution of Individual OPAHs in the Water

The distribution of individual OPAHs in the water are displayed in Figure 2. The distribution of individual OPAHs in water revealed clear differences among the rivers, with Forcados, Warri and Escravos Rivers exhibiting substantially higher concentrations than the Benin River. Anthraquinone was consistently the most abundant OPAH across all rivers, indicating its importance as a major oxygenated derivative in the aquatic environment. Similar studies have reported anthraquinone as one of the dominant OPAHs in water because it is a common oxidation product of anthracene and is relatively persistent under environmental conditions (Qiao *et al.*, 2022; Peng *et al.*, 2023). The elevated concentrations of anthraquinone, p-benzoquinone, 1,2-naphthoquinone and 5,12-naphthacenequinone in the Forcados, Warri and Escravos Rivers suggest enhanced transformation of parent PAHs and greater hydrocarbon contamination within these river systems.



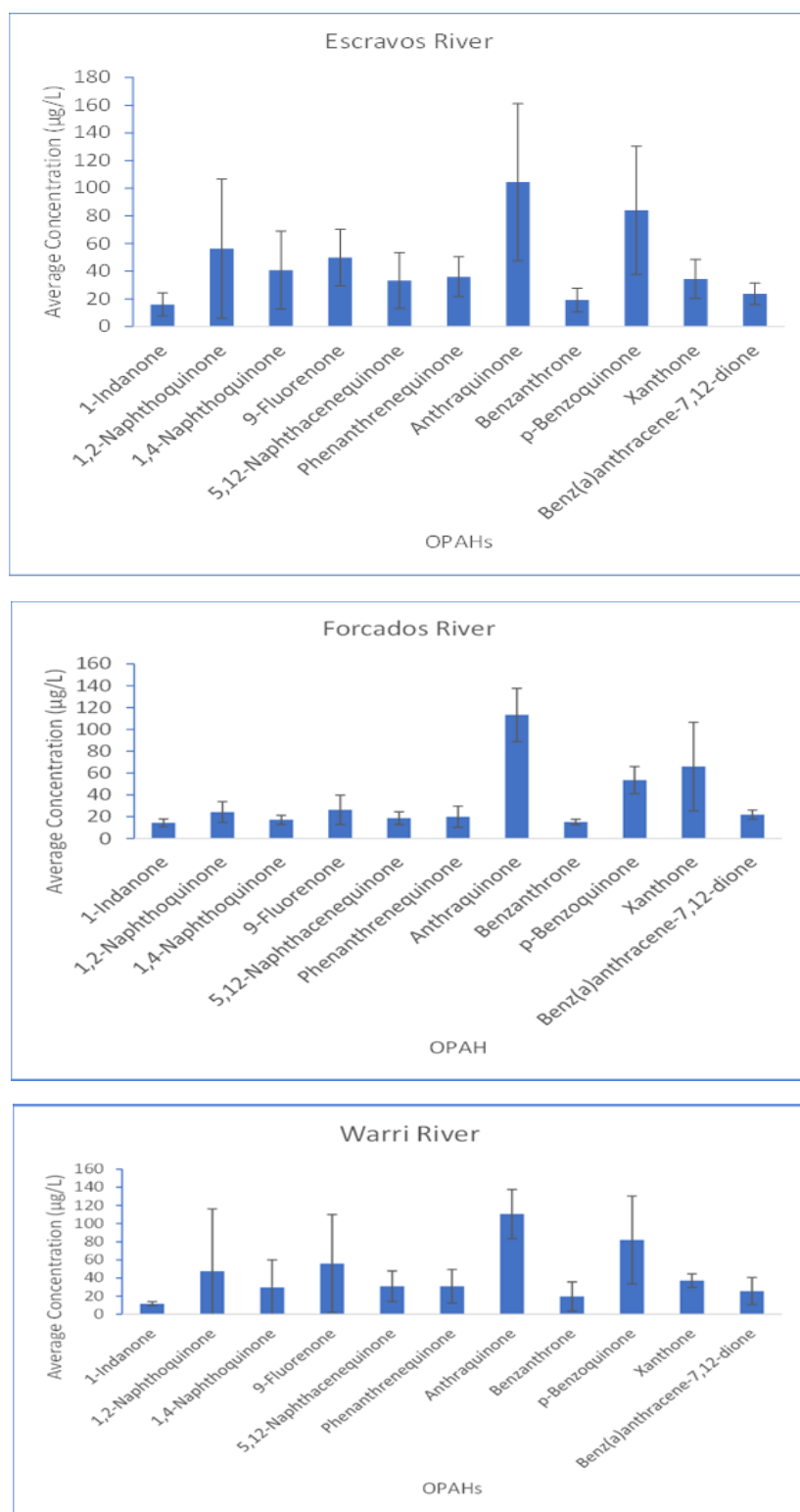


Figure 2: Average distribution of the individual OPAHs concentrations in water from the different rivers

The predominance of quinone compounds is consistent with previous reports that identified quinones as major OPAHs in aquatic environments due to their formation through photochemical and microbial oxidation processes (Lundstedt *et al.*, 2007; Qiao *et al.*, 2022). In contrast, the comparatively low concentrations of all OPAHs in the Benin River indicate

lower levels of oxygenated PAH contamination. The consistently low concentrations of 1-indanone across the four rivers further suggest that this compound contributes minimally to the overall OPAH burden in the study area. Overall, the dominance of anthraquinone and other quinone derivatives highlights the significance of PAH transformation processes in controlling the composition of OPAHs in Niger Delta waters and suggests continued inputs of hydrocarbon precursors into these aquatic systems (Peng *et al.*, 2023; Zeng *et al.*, 2021).

Ring-wise Distribution of OPAHs in the Water Samples

The ring-wise distribution of OPAHs in the surface water of the four studied rivers is shown in Figure 3. The predominance of 3-ring OPAHs in water from the Benin, Escravos, Forcados and Warri Rivers indicates that oxygenated derivatives of medium-molecular-weight PAHs constituted the major fraction of total OPAHs in the study area. The consistent dominance of this ring class across the rivers suggests similar sources and transformation pathways of parent PAHs within the aquatic environment. Medium-molecular-weight oxygenated derivatives are frequently detected in surface waters because they possess physicochemical properties that favour both environmental persistence and aqueous transport (Qiao *et al.*, 2014; Ghosh & Mukherji, 2023). The relatively higher contribution of 4-ring OPAHs compared with 1-ring and 2-ring compounds in most rivers further suggests the influence of higher-molecular-weight PAH precursors and their subsequent oxidation products. Oxygen-containing PAH derivatives are produced through various environmental transformation processes, including photochemical oxidation and microbial degradation, resulting in the formation of oxygenated compounds that can remain in aquatic systems for extended periods (Peng *et al.*, 2023).

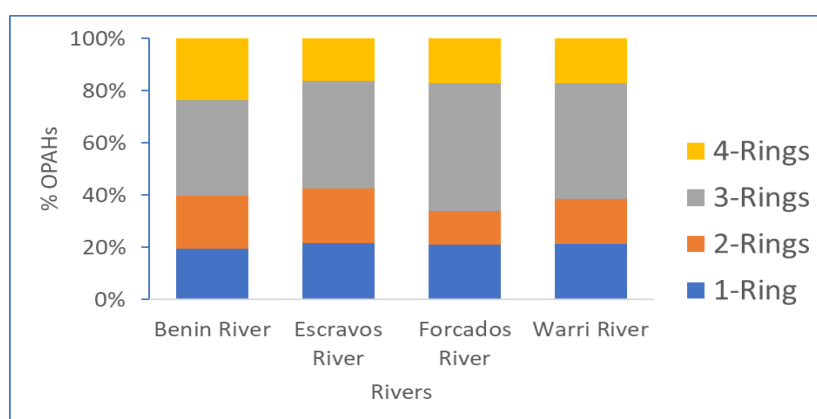


Figure 3: Ring-wise distribution of OPAHs in the water samples

The comparatively lower proportions of 1-ring and 2-ring OPAHs indicate that these compounds contributed less to the overall OPAH burden in water. Differences in ring-class composition may reflect variations in precursor PAH composition, environmental conditions and transformation mechanisms operating within the rivers. The observed distribution pattern therefore suggests that oxidation products of medium-molecular-weight PAHs represent the dominant class of OPAHs in the study area and may play an important role in determining the environmental behaviour of oxygenated hydrocarbons in Niger Delta waters (Qiao *et al.*, 2022; Peng *et al.*, 2023).

Correlation Analysis of OPAHs in the Water Samples

The Pearson's correlation coefficient of OPAHs in the water from these rivers is shown in Table 3. The predominance of significant positive correlations among OPAHs in the water of these rivers suggests that many of the compounds may share common sources, formation pathways, or environmental transport mechanisms. The strong associations observed among several quinone derivatives, indicate that these compounds may originate from similar precursor PAHs and undergo related oxidation processes. Recent studies have shown that OPAHs are frequently formed through photochemical and microbial transformation of parent PAHs, resulting in the simultaneous occurrence of multiple OPAH compounds within environmental matrices (Qiao *et al.*, 2022; Peng *et al.*, 2023). The stronger and more consistent positive correlations observed in this study suggest greater homogeneity in the distribution and mobility of OPAHs within the aqueous phase. The near-perfect positive correlations recorded for several compound pairs in the water further support the likelihood of common origins and similar environmental fate of these OPAHs within the aquatic ecosystem (Peng *et al.*, 2023; Qiao *et al.*, 2022).

Table 3: Pearson's correlation coefficient of OPAHs in the water from these rivers

	1-IND	1,2-NQ	1,4-NQ	9-FLO	5,12-NAPQ	9,10-PQ	ATQ	BZO	p-BQ	XA	BAQ
1-IND	1.00	0.74**	0.79**	0.66*	0.80**	0.85**	0.92**	0.87**	0.84**	0.75**	0.88**
1,2-NQ		1.00	0.99**	0.96**	0.99**	0.98**	0.72**	0.91**	0.96**	0.21	0.83**
1,4-NQ			1.00	0.91**	0.97**	0.98**	0.71**	0.89**	0.94**	0.23	0.81**
9-FLO				1.00	0.97**	0.95**	0.76**	0.93**	0.96**	0.25	0.88**
5,12-NAPQ					1.00	1.00**	0.82**	0.96**	0.99**	0.35	0.91**
9,10-PQ						1.00	0.84**	0.97**	0.99**	0.40*	0.91**
ATQ							1.00	0.94**	0.88**	0.82**	0.98**
BZO								1.00	0.99**	0.58*	0.99**
p-BQ									1.00	0.46*	0.96**
XA										1.00	0.68*
BAQ											1.00

**Significant at 0.01 level of significance; *Significant at 0.05 level of significance; Benzoquinone p-BQ), 1,2-naphthoquinone (1,2-NQ), 1,4-naphthoquinone (1,4-NQ), 9-fluorenone (9-FLO), Anthraquinone (ATQ), Phenanthrenequinone (9,10-PQ), 5,12-naphthacenequinone (5,12-NAPQ), Xanthone (XA), Benz[a]anthracene-7,12-dione (BAQ), 1-indanone (1-IND) and Benzanthrone (BZO)

CONCLUSION

This study has provided comprehensive information on the concentrations and distribution pattern of OPAHs in surface water of four major rivers in the Niger Delta. The concentrations of OPAHs in the rivers were in the order of Escravos River > Warri River > Forcados River > Benin River, while the occurrence pattern of PAHs was in the order 3-ring > 1-ring > 2-ring > 4-ring. Result from Pearson's correlation analysis indicated that the OPAHs in the surface water of these rivers were from similar sources and have similar fate in the aquatic environment.

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