

Research Article

Spatial Deposition of Soot and Polycyclic Aromatic Hydrocarbons around a Gas-Flaring Corridor in Omoku, Rivers State, Nigeria

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Abstract

Gas flaring contributes to atmospheric particulate emissions and the deposition of polycyclic aromatic hydrocarbons (PAHs) in petroleum-producing environments. This study investigated the spatial distribution of soot deposition and PAHs around a gas-flaring corridor in Omoku, Rivers State, Niger Delta, Nigeria. Sampling was conducted at five distances (100, 250, 500, 750 and 1,000 m) from the flare corridor and at a reference location. Soot deposition, the 16 priority PAHs ($\Sigma 16\text{PAHs}$), PAH deposition flux, benzo[a]pyrene toxic equivalency (BaP-TEQ), PAH ring-number composition and diagnostic ratios were evaluated. One-way analysis of variance (ANOVA), exponential regression and Pearson's correlation were used to examine spatial differences, distance-decay relationships and associations between soot deposition and $\Sigma 16\text{PAHs}$. Soot deposition decreased from $18.64 \pm 1.12 \text{ mg m}^{-2} \text{ day}^{-1}$ at 100 m to $3.21 \pm 0.42 \text{ mg m}^{-2} \text{ day}^{-1}$ at 1,000 m, compared with $1.18 \pm 0.16 \text{ mg m}^{-2} \text{ day}^{-1}$ at the reference location. $\Sigma 16\text{PAHs}$ declined from $2,639.36 \mu\text{g kg}^{-1}$ at 100 m to $640.65 \mu\text{g kg}^{-1}$ at 1,000 m, compared with $257.84 \mu\text{g kg}^{-1}$ at the reference location. Phenanthrene, fluoranthene and pyrene were the dominant PAHs at 100 m, while benzo[a]pyrene reached $214.75 \mu\text{g kg}^{-1}$. BaP-TEQ decreased from $337.4 \mu\text{g kg}^{-1}$ at 100 m to $80.5 \mu\text{g kg}^{-1}$ at 1,000 m. Exponential regression showed strong distance-decay relationships for soot deposition ($R^2 = 0.978$) and $\Sigma 16\text{PAHs}$ ($R^2 = 0.994$), while soot deposition and $\Sigma 16\text{PAHs}$ were strongly correlated ($r = 0.999$). Four-ring PAHs accounted for approximately 40% of $\Sigma 16\text{PAHs}$ across the sampling locations. The findings demonstrate substantial spatial variation in soot and PAH deposition around the gas-flaring corridor and underscore the importance of environmental monitoring in surrounding communities.

1. Introduction

Gas flaring remains a major environmental concern in petroleum-producing communities because incomplete combustion releases soot, particulate matter and potentially hazardous organic compounds into the surrounding environment. Emissions from gas flaring can contribute to atmospheric pollution and the deposition of contaminants on nearby surfaces, including soil, vegetation and water. Black carbon and other combustion-derived particles are particularly important because their environmental distribution reflects the influence of emission sources and atmospheric transport [1, 2]. Once deposited, these particles can introduce associated contaminants into terrestrial and aquatic environments, where they may persist and interact with biological systems [3, 4].

Soot is a carbon-rich particulate material produced mainly by incomplete combustion of hydrocarbon fuels. Its deposition around gas-flaring installations provides an indication of particulate loading and the potential transfer of combustion-derived contaminants to surrounding environments [5]. The quantity deposited at a particular location depends on emission intensity, distance from the source, atmospheric conditions and particle characteristics. Soot may also carry polycyclic aromatic hydrocarbons (PAHs), a group of organic compounds formed primarily during incomplete combustion and released through petroleum-related activities. PAHs are environmentally important because some are persistent and toxic, while their distribution and accumulation depend on molecular structure, environmental transport, degradation and affinity for particulate matter [6].

PAHs have been reported in environmental media including soils, sediments, dust and aquatic organisms exposed to petroleum-related contamination. Their occurrence in affected soils and sediments demonstrates the potential for these compounds to persist beyond their original emission or discharge sources [7, 8]. Dust collected from communities surrounding gas-flaring points and soils from similar environments have also been investigated for PAH concentrations, compositional patterns, potential sources and associated risks [9, 10]. Research in tropical mangrove sediments has demonstrated that human activities can influence PAH distribution, while investigations of river sediments have highlighted the importance of examining organic contaminants in relation to their environmental occurrence and potential ecological implications [11, 12].

The environmental significance of PAHs depends not only on their total concentrations but also on the composition and toxicological properties of individual compounds. PAHs differ in persistence, mobility and toxicity, and their relative abundance can provide information about potential pollution sources. Diagnostic ratios are commonly used to investigate petrogenic and pyrogenic contributions, although their interpretation requires caution because environmental transformation and overlapping source signatures may influence the observed patterns [13]. In environments affected by petroleum operations, contributions from crude oil and combustion processes may occur simultaneously, making source interpretation particularly important [14]. Evaluating the concentrations of individual PAHs, their ring-number distributions and diagnostic ratios can therefore provide complementary information about contamination patterns. Furthermore, benzo[a]pyrene toxic equivalents provide an estimate of the relative toxic potency of a PAH mixture, allowing toxicological significance to be considered alongside total contaminant concentrations.

PAH contamination may also affect aquatic ecosystems and organisms through the transfer of deposited particles and contaminants into surface waters and sediments. Investigations of commercially available fish and other aquatic organisms have demonstrated the relevance of examining petroleum-associated contaminants in species that may contribute to human dietary exposure [15, 16]. Research involving fish and crustaceans has further highlighted the importance of evaluating biological responses to exposure to petroleum hydrocarbons and other environmental contaminants [17]. The persistence and potential bioaccumulation of PAHs reinforce the need to understand their distribution in communities exposed to combustion-related pollution [18].

Distance from an emission source is an important factor in determining the distribution of soot and associated PAHs. Particulate deposition may be greater near a flare corridor and decline with increasing distance because of atmospheric dispersion and particle settling. However, the pattern and magnitude of this decline may depend on emission characteristics, meteorological conditions and particle properties [4]. Measuring soot deposition and PAH concentrations along a distance transect makes it possible to determine whether these pollutants follow consistent spatial gradients and whether their relationships with distance can be described using exponential or power-law models. Comparing soot deposition rates with total PAH concentrations can also establish whether increased particulate loading corresponds to higher PAH contamination [2, 19].

Despite existing evidence of soot pollution and PAH contamination around gas-flaring installations, the relationship between soot deposition and PAH loading along defined distance gradients requires further investigation. An integrated investigation of soot deposition rates, the 16 priority PAHs, total PAH deposition fluxes, compound composition, diagnostic ratios and benzo[a]pyrene toxic equivalents can provide a more comprehensive understanding of the distribution and potential significance of combustion-associated contamination [9]. Examining these parameters alongside distance-decay models and correlation analysis can clarify the spatial relationship between particulate deposition and PAH loading [10, 18]. This study investigated soot deposition and PAH contamination along a distance transect around a gas-flaring corridor in Omoku.

2. Materials and Methods

2.1. Study Area and Research Design

The study was conducted around a gas-flaring corridor in Omoku, Rivers State, Niger Delta, Nigeria. A spatial transect was established to investigate the distribution of soot deposition and associated polycyclic aromatic hydrocarbons (PAHs) with increasing distance from the flaring source. Five sampling locations were established at 100, 250, 500, 750 and 1,000 m from the flare corridor, alongside a reference location situated away from its immediate influence. The study design enabled comparisons of soot deposition, PAH concentrations, deposition fluxes, toxic equivalency, PAH ring-number composition and diagnostic ratios across the sampling locations as shown in Figure 1.

2.2. Soot Deposition Sampling and Determination

Soot deposition was measured at the six sampling locations using three replicate measurements per location. Deposition rates were expressed in milligrams per square metre per day ($\text{mg m}^{-2} \text{day}^{-1}$) and calculated using the mass of collected soot, exposed collection area and

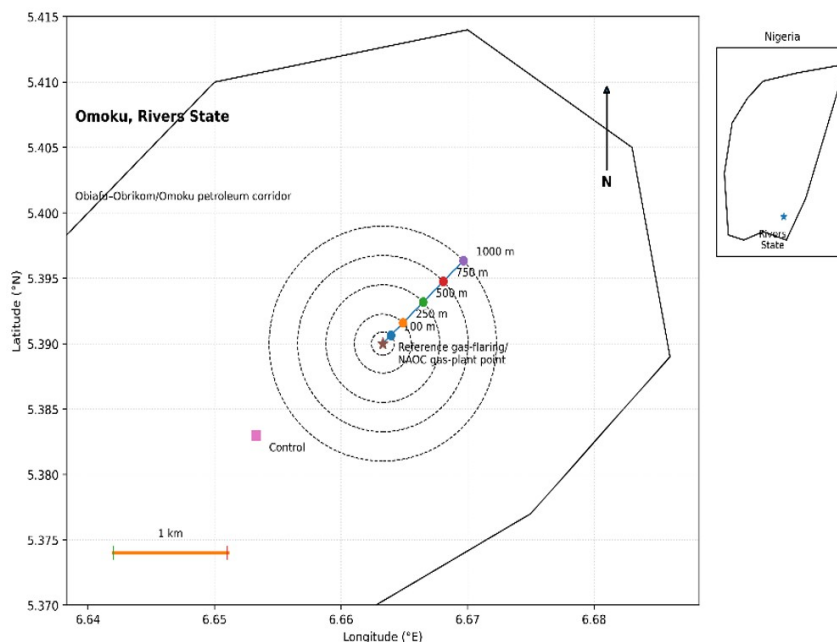


Figure 1: Map of the Omoku showing the gas flaring corridor

sampling duration:

$$S = \frac{m}{(A \times t)}$$

where S is the soot deposition rate ($\text{mg m}^{-2} \text{day}^{-1}$), m is the mass of collected soot (mg), A is the exposed collection area (m^2), and t is the exposure duration (days). Mean deposition rates and standard deviations were calculated from the replicate measurements.

2.3. Extraction and Determination of Polycyclic Aromatic Hydrocarbons

The deposited soot samples were analysed for the 16 priority PAHs: naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, dibenzo[a,h]anthracene and benzo[g,h,i]perylene.

PAHs were extracted from the soot samples using organic-solvent extraction, followed by appropriate extract clean-up and chromatographic analysis for compound identification and quantification. Individual PAH concentrations were expressed in micrograms per kilogram ($\mu\text{g kg}^{-1}$) of deposited soot. The total concentration of the 16 priority PAHs (Σ 16PAHs) was calculated by summing the concentrations of the individual compounds at each sampling location.

2.4. Calculation of PAH Deposition Flux

PAH deposition flux was calculated to estimate the quantity of PAHs deposited per unit surface area per day. The calculation combined the PAH concentration in deposited soot with the corresponding soot deposition rate, with appropriate unit conversion:

$$F(\text{PAH}) = C(\text{PAH}) \times S \times 10^{-3}$$

where $F(\text{PAH})$ is the PAH deposition flux ($\text{ng m}^{-2} \text{day}^{-1}$), $C(\text{PAH})$ is the PAH concentration in soot ($\mu\text{g kg}^{-1}$), and S is the soot deposition rate ($\text{mg m}^{-2} \text{day}^{-1}$).

2.5. Calculation of Benzo[a]pyrene Toxic Equivalency

The toxic equivalency of the PAH mixture was expressed as benzo[a]pyrene toxic equivalents (BaP-TEQ). This was calculated by multiplying the concentration of each individual PAH by its corresponding toxic equivalency factor (TEF) and summing the resulting values:

$$\text{BaP-TEQ} = \sum (C_i \times \text{TEF}_i)$$

where C_i is the concentration of an individual PAH and TEF_i is its toxic equivalency factor relative to benzo[a]pyrene. The resulting BaP-TEQ values were expressed in $\mu\text{g kg}^{-1}$.

2.6. PAH Ring-Number Composition and Diagnostic Ratios

The 16 PAHs were classified into two-, three-, four-, five- and six-ring groups according to their molecular structures. The percentage contribution of each ring group was calculated by dividing the summed concentration of the compounds in that group by the total Σ 16PAHs concentration and multiplying by 100.

Four diagnostic ratios were calculated to investigate the compositional characteristics and potential sources of the PAHs: anthracene (anthracene + phenanthrene), fluoranthene (fluoranthene + pyrene), benzo[a]anthracene/(benzo[a]anthracene + chrysene), and indeno[1,2,3-cd]pyrene (indeno[1,2,3-cd]pyrene + benzo[g,h,i]perylene). The calculated ratios were compared with established diagnostic criteria to evaluate potential combustion-related and petroleum-related contributions.

2.7. Statistical Analysis

Descriptive statistics were used to summarise soot deposition and PAH concentrations. Results were expressed as means and standard deviations where replicate measurements were available. Homogeneity of variance was evaluated using Levene's test. One-way analysis of variance (ANOVA) was used to assess differences in soot deposition among the six sampling locations, followed by Tukey's honestly significant difference post-hoc test for pairwise comparisons.

Exponential regression was used to describe the relationships between distance from the flare corridor and soot deposition or Σ 16PAHs concentration. The models were expressed as:

$$\ln(Y) = a + bd$$

where Y represents soot deposition or Σ 16PAHs concentration, a is the intercept, b is the distance-decay coefficient, and d is the distance from the flare corridor in metres. Model fit was evaluated using the coefficient of determination (R^2). The half-distance was calculated as

$$d_{1/2} = \frac{\ln(2)}{|b|}$$

Power-law models were also evaluated for comparison. Pearson's correlation coefficient was used to examine the association between soot deposition and Σ 16PAHs using the six location means. Statistical significance was set at $p < 0.05$.

3. Results

3.1. Soot Deposition

Soot deposition decreased with increasing distance from the flare corridor, declining from $18.64 \pm 1.12 \text{ mg m}^{-2} \text{ day}^{-1}$ at 100 m to $3.21 \pm 0.42 \text{ mg m}^{-2} \text{ day}^{-1}$ at 1,000 m. The reference location recorded the lowest deposition rate ($1.18 \pm 0.16 \text{ mg m}^{-2} \text{ day}^{-1}$). Deposition at 100 m was approximately 15.8 times the reference value. Levene's test indicated no significant evidence of unequal variances ($p = 0.62$), while one-way ANOVA indicated significant differences among locations ($F(5,12) = 432.4$, $p < 0.001$). Tukey's post-hoc test reportedly identified significant differences between all pairs of locations ($p < 0.008$) as shown in Table 1.

Table 1: Soot deposition rates along the distance transect

Location	Replicate 1	Replicate 2	Replicate 3	Mean $\pm$ SD
100 m	17.82	19.91	18.19	18.64 ± 1.12
250 m	14.26	15.18	14.72	14.72 ± 0.46
500 m	9.63	10.41	9.87	9.97 ± 0.40
750 m	6.41	6.93	6.62	6.65 ± 0.26
1,000 m	2.84	3.67	3.12	3.21 ± 0.42
Reference	1.03	1.35	1.16	1.18 ± 0.16

Unit: $\text{mg m}^{-2} \text{ day}^{-1}$.

3.2. Individual Polycyclic Aromatic Hydrocarbons

All 16 priority polycyclic aromatic hydrocarbons (PAHs) were reported as detected at each sampling location. At 100 m, phenanthrene recorded the highest concentration ($426.30 \text{ } \mu\text{g kg}^{-1}$), followed by fluoranthene ($382.74 \text{ } \mu\text{g kg}^{-1}$) and pyrene ($318.62 \text{ } \mu\text{g kg}^{-1}$). Benzo[a]pyrene was $214.75 \text{ } \mu\text{g kg}^{-1}$. Concentrations reportedly declined with increasing distance. The ratio between the concentration at 100 m and that at the reference location ranged from 7.1 for acenaphthylene to 10.9 for dibenzo[a,h]anthracene as shown in Table 2.

3.3. Total PAHs, Deposition Flux and Benzo[a]pyrene Toxic Equivalents

The sum of the 16 priority PAHs (Σ 16PAHs) declined from $2,639.36 \text{ } \mu\text{g kg}^{-1}$ at 100 m to $640.65 \text{ } \mu\text{g kg}^{-1}$ at 1,000 m, compared with $257.84 \text{ } \mu\text{g kg}^{-1}$ at the reference location. Relative to the reference, Σ 16PAHs was 10.24 times higher at 100 m and 2.48 times higher at 1,000 m. The reported PAH deposition flux decreased from 49.20 to $2.06 \text{ ng m}^{-2} \text{ day}^{-1}$ over the same transect. Benzo[a]pyrene toxic equivalency (BaP-TEQ) declined from 337.4 to $80.5 \text{ } \mu\text{g kg}^{-1}$, with $31.7 \text{ } \mu\text{g kg}^{-1}$ at the reference location as shown in Table 3.

Table 2: Individual PAH concentrations in deposited soot

PAH	Abbreviation	Unit
Naphthalene	Nap	$\mu\text{g kg}^{-1}$
Acenaphthylene	Acy	$\mu\text{g kg}^{-1}$
Acenaphthene	Ace	$\mu\text{g kg}^{-1}$
Fluorene	Flu	$\mu\text{g kg}^{-1}$
Phenanthrene	Phe	$\mu\text{g kg}^{-1}$
Anthracene	Ant	$\mu\text{g kg}^{-1}$
Fluoranthene	Flt	$\mu\text{g kg}^{-1}$
Pyrene	Pyr	$\mu\text{g kg}^{-1}$
Benzo[a]anthracene	BaA	$\mu\text{g kg}^{-1}$
Chrysene	Chr	$\mu\text{g kg}^{-1}$
Benzo[b]fluoranthene	BbF	$\mu\text{g kg}^{-1}$
Benzo[k]fluoranthene	BkF	$\mu\text{g kg}^{-1}$
Benzo[a]pyrene	BaP	$\mu\text{g kg}^{-1}$
Indeno[1,2,3-cd]pyrene	IcdP	$\mu\text{g kg}^{-1}$
Dibenzo[a,h]anthracene	DahA	$\mu\text{g kg}^{-1}$
Benzo[g,h,i]perylene	BghiP	$\mu\text{g kg}^{-1}$

Table 3: $\Sigma 16\text{PAHs}$, relative concentration, deposition flux and BaP-TEQ

Location	Soot deposition $\text{mg m}^{-2} \text{ day}^{-1}$	$\Sigma 16\text{PAHs}$ $(\mu\text{g kg}^{-1})$	Multiple of reference	Increase above reference (%)	PAH flux $\text{ng m}^{-2} \text{ day}^{-1}$	BaP-TEQ $(\mu\text{g kg}^{-1})$
100 m	18.64	2,639.36	10.24	923.6	49.20	337.4
250 m	14.72	2,193.93	8.51	750.9	32.30	281.5
500 m	9.97	1,544.74	5.99	499.1	15.40	198.2
750 m	6.65	1,036.95	4.02	302.2	6.90	132.4
1,000 m	3.21	640.65	2.48	148.5	2.06	80.5
Reference	1.18	257.84	1.00	—	0.30	31.7

3.4. Distance-Decay Relationships

Exponential regression was used to describe the decline in soot deposition and $\Sigma 16\text{PAHs}$ concentrations with increasing distance from the flare corridor. For soot deposition, the reported model was $(\ln S = 3.176 - 0.00189d)$, with $(R^2 = 0.978)$ and a half-distance of approximately 368 m. For $\Sigma 16\text{PAHs}$, the reported model was $\ln C = 8.078 - 0.00156d$, with $R^2 = 0.994$ and a half-distance of approximately 443 m. The reported power-law models had lower coefficients of determination ($(R^2 = 0.83)$ for soot and $(R^2 = 0.86)$ for $\Sigma 16\text{PAHs}$) as shown in Table 4.

Table 4: Reported distance-decay model statistics

Variable	Regression model	R ²	Estimated half-distance
Soot deposition	$\ln S = 3.176 - 0.00189d$	0.978	368 m
$\Sigma 16\text{PAHs}$	$\ln C = 8.078 - 0.00156d$	0.994	443 m
Soot deposition	Power-law model	0.83	Not reported
$\Sigma 16\text{PAHs}$	Power-law model	0.86	Not reported

3.5. PAH Ring-Number Composition

Four-ring PAHs constituted the largest reported fraction at all sampling locations, accounting for approximately 40.2–40.8% of $\Sigma 16\text{PAHs}$. Three-ring and five-ring compounds contributed approximately 25–27%, whereas two-ring and six-ring PAHs made smaller contributions. The profile varied only modestly along the transect, suggesting that the relative distribution of PAH ring groups remained broadly similar despite the decrease in total concentration as shown in Table 5.

Table 5: Relative composition of PAHs by ring number

Location	2-ring (%)	3-ring (%)	4-ring (%)	5-ring (%)	6-ring (%)
100 m	3.1	25.6	40.8	25.7	4.8
250 m	3.2	25.5	40.8	25.8	4.8
500 m	3.1	25.6	40.7	25.8	4.8
750 m	3.0	25.8	40.7	25.6	4.8
1,000 m	2.9	26.4	40.6	25.4	4.7
Reference	3.5	26.8	40.2	24.8	4.6

3.6. Diagnostic Ratios and PAH Source Interpretation

The reported diagnostic ratios were relatively consistent across the transect and reference location. The anthracene (anthracene + phenanthrene) ratio ranged from 0.184 to 0.192, fluoranthene (fluoranthene + pyrene) ranged from 0.534 to 0.546, benzo[a]anthracene/(benzo[a]anthracene + chrysene) ranged from 0.475 to 0.479, and indeno[1,2,3-cd]pyrene (indeno[1,2,3-cd]pyrene + benzo[g,h,i]perylene) ranged from 0.510 to 0.513 as shown in Table 6.

Table 6: PAH diagnostic ratios and indicative source criteria

Location	Anthracene/ (Anthracene + Phenanthrene)	Fluoranthene/ (Fluoranthene + Pyrene)	Benzo[a]anthracene/ (Benzo[a]anthracene + Chrysene)	Indeno[1,2,3-cd]pyrene/ (Indeno[1,2,3-cd]pyrene + Benzo[g,h,i]perylene)
100 m	0.184	0.546	0.476	0.512
250 m	0.186	0.541	0.477	0.513
500 m	0.190	0.538	0.475	0.511
750 m	0.192	0.538	0.477	0.511
1,000 m	0.189	0.538	0.477	0.510
Reference	0.191	0.534	0.479	0.511
Indicative criterion	>0.10	>0.40; values >0.50 may indicate grass, wood or coal combustion	>0.35	>0.20; values >0.50 may indicate grass, wood or coal combustion

3.7. Statistical Summary

One-way ANOVA indicated significant differences in soot deposition among the six locations, ($F(5,12) = 432.4$), ($p < 0.001$). The reported exponential models showed strong associations between distance and both soot deposition and $\Sigma 16\text{PAHs}$ concentration. Pearson's correlation between soot deposition and $\Sigma 16\text{PAHs}$ was reported as ($r = 0.999$), ($p < 0.001$), based on six location means as shown in Table ??.

Table 7: Statistical results for soot deposition and PAH measurements

Test	Variable	Result
Levene's test	Soot deposition	$p = 0.62$
One-way ANOVA	Soot deposition	$F(5,12) = 432.4$, $p < 0.001$
Tukey's post-hoc test	Soot deposition	All pairwise comparisons reported as $p \leq 0.008$
Exponential regression	Soot deposition	$R^2 = 0.978$; half-distance = 368 m
Exponential regression	$\Sigma 16\text{PAHs}$	$R^2 = 0.994$; half-distance = 443 m
Pearson correlation	Soot deposition versus $\Sigma 16\text{PAHs}$	$r = 0.999$, $p < 0.001$; $n = 6$ location means
One-way ANOVA	$\Sigma 16\text{PAHs}$ and ring groups	Requires replicate-level data for recalculation

4. Discussion

The soot deposition and PAH results show a clear spatial gradient around the Omoku gas-flaring corridor, with the highest concentrations recorded at 100 m and progressive reductions towards 1,000 m. The reference location had substantially lower soot deposition and total PAH concentrations, indicating that contaminant loading varied considerably across the sampling transect. This pattern is consistent with reported soot pollution in Port Harcourt and spatial variation in ambient air quality in Rivers State [1, 2]. Comparable spatial patterns of PAHs in dust collected around gas-flaring points in the Niger Delta have also been reported by Odali et al. [9], supporting the relevance of distance-dependent contaminant deposition in petroleum-producing communities.

The decline in soot deposition from $18.64 \pm 1.12 \text{ mg m}^{-2} \text{ day}^{-1}$ at 100 m to $3.21 \pm 0.42 \text{ mg m}^{-2} \text{ day}^{-1}$ at 1,000 m, compared with $1.18 \pm 0.16 \text{ mg m}^{-2} \text{ day}^{-1}$ at the reference location, indicates a pronounced spatial difference in particulate loading. The exponential decay model further described this pattern, with an (R^2) of 0.978 and an estimated half-distance of approximately 368 m. These findings are consistent with the documented occurrence of black-carbon pollution in Port Harcourt and the environmental influence of gas flaring in the Niger Delta [2, 3].

The concentrations of individual PAHs followed a similar spatial distribution to soot deposition. Phenanthrene, fluoranthene and pyrene were the dominant compounds at 100 m, and their concentrations declined with increasing distance from the flaring corridor. Benzo[a]pyrene reached $214.75 \mu\text{g kg}^{-1}$ at 100 m, highlighting the occurrence of a PAH of toxicological concern in the deposited material. These observations agree with reports of PAHs in dust and soils around gas-flaring points in the Niger Delta [9, 10]. The study is also consistent with previous investigations of PAHs in soils and sediments from petroleum exploration areas [7] and crude-oil-impacted soils in the region [8].

The total concentration of the 16 measured PAHs decreased from $2,639.36 \mu\text{g kg}^{-1}$ at 100 m to $640.65 \mu\text{g kg}^{-1}$ at 1,000 m, while the reference concentration was $257.84 \mu\text{g kg}^{-1}$. The concentration at 100 m was approximately 10.2 times the reference value, demonstrating the magnitude of the spatial contrast. The exponential model for 16PAHs had an R^2 of 0.994 and an estimated half-distance of approximately 443 m, indicating a strong fit to the observed concentration decline across the sampled distances. These results agree with the spatial distributions of PAHs reported in dust and soils around Niger Delta gas-flaring locations [9, 10]. They are also relevant to the wider environmental-health concerns associated with PAH persistence and bioaccumulation in the region [18].

The PAH ring distribution was dominated by four-ring compounds, which accounted for approximately 40.8% of the measured PAHs at 100 m and remained close to 40% throughout the sampling transect. Three-ring and five-ring compounds constituted the next largest fractions, while two-ring and six-ring compounds contributed smaller proportions. The relatively stable ring distribution suggests that the

overall molecular-weight profile changed little with distance, even though total PAH concentrations declined substantially. PAH composition is influenced by molecular weight, environmental partitioning and the characteristics of the source mixture, and higher-molecular-weight PAHs are generally more strongly associated with particulate matter [5, 6].

The diagnostic ratios varied only slightly across the sampling locations. Ant (Ant + Phe) ranged from 0.184 to 0.192, Flt (Flt + Pyr) from 0.534 to 0.546, BaA (BaA + Chr) from 0.475 to 0.479, and IcdP (IcdP + BghiP) from 0.510 to 0.513. This consistency indicates that the relative composition of the measured PAHs was broadly maintained along the transect despite the substantial differences in total concentrations. However, the reference location also exhibited similar diagnostic ratios. Source identification based on diagnostic ratios requires cautious interpretation because environmental transformation, mixed emissions and overlapping source profiles can complicate the distinction between petroleum-derived and combustion-derived PAHs [6, 13].

The strong positive association between soot deposition and 16PAHs demonstrates that both parameters followed closely related spatial patterns. Soot and total PAH concentrations were highest at 100 m and declined towards the reference location. The reported correlation of ($r = 0.999$) across the six location-level observations indicates near-perfect co-variation between the two measured parameters. This finding is consistent with research documenting PAHs in dust around gas-flaring points in the Niger Delta and supports the interpretation that deposited particulate matter and PAH loading may be influenced by related environmental processes [2, 9].

The statistical analyses further supported the observed spatial differences in soot deposition and PAH concentrations. Soot deposition differed significantly among sampling locations, with the analysis of variance yielding $F(5,12) = 432.4$ ($p < 0.001$). The reported post-hoc comparisons indicated significant differences between sampling locations, reinforcing the spatial pattern observed in the descriptive results. These findings are consistent with studies documenting spatial heterogeneity in PAH concentrations around gas-flaring locations and petroleum-affected environments in the Niger Delta [8–10]. The results provide evidence supporting spatially resolved monitoring around gas-flaring corridors, particularly in communities where deposited particles may contribute to environmental exposure [1, 18].

5. Conclusion

Soot deposition and PAH concentrations around the Omoku gas-flaring corridor decreased substantially with increasing distance from the source. At 100 m, soot deposition was approximately 15.8 times the reference value, while $\Sigma 16\text{PAHs}$ was approximately 10.2 times the reference concentration. Benzo[a]pyrene concentrations and BaP-TEQ were also highest at the nearest sampling location. Four-ring PAHs dominated the compositional profile, while diagnostic ratios remained relatively consistent across the transect and reference location. The exponential regression models indicated strong distance-decay relationships for soot deposition and 16PAHs, and the two parameters exhibited a strong positive correlation. These findings demonstrate pronounced spatial variation in soot and PAH loading around the flaring corridor and highlight the importance of sustained environmental monitoring in nearby communities.

Article Information

Data Availability: The datasets supporting the findings of this study are available from the corresponding author upon reasonable request.

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