



Integrated assessment of air quality pollutants and environmental stressors in oil-producing and non-oil-producing communities of Ughelli South, Niger Delta, Nigeria

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Abstract

This study assessed air quality and environmental stressors in six communities within Ughelli South Local Government Area, Delta State, comprising three oil-producing communities (Edjophe, Ihwerekan, and Otujeremi) and three control communities (Oginibo, Imode, and Okwagbe). The objective was to determine the concentrations, spatial variations, and relationships of selected pollutants—Total Volatile Organic Compounds (TVOC), Formaldehyde (HCHO), Halogen gases (Cl₂, F₂, Br₂)—and physical stressors (Temperature and Noise). Field monitoring was conducted for fourteen consecutive days, with data collected twice daily (morning and evening) using calibrated digital sensors. Results showed that oil-producing communities recorded significantly higher pollutant concentrations compared with control sites. Mean TVOC ranged between 93.7 and 95.4 µg/m³ in oil-producing areas, compared with 35–37 µg/m³ in controls. HCHO concentrations averaged 3.6 mg/m³ in industrial communities and 1.7 mg/m³ in non-industrial zones. Halogen gases were also elevated (mean 2.7 ppm versus 0.8 ppm), while temperature and noise levels were substantially higher in oil-producing locations (96–97°C sensor readings and 60–63 dB(A) respectively) than in controls (29–30°C and 30–31 dB(A)). Temporal variations revealed marginally higher evening readings, reflecting limited dispersion under stable atmospheric conditions. Two-way ANOVA indicated significant spatial differences ($p < 0.05$) among communities, while Tukey's post-hoc test confirmed that the oil-producing triad differed significantly from control sites. Strong correlations were observed between TVOC and HCHO ($r \approx 0.9$) and TVOC and Halogens ($r \approx 0.8$), signifying common petrochemical emission sources. The findings reveal an ecosystem characterised by combined chemical and physical stressors resulting from oil production activities. These conditions pose potential respiratory, cardiovascular, and ecological risks to residents. The study provides baseline data for environmental health risk assessment and recommends continuous air-quality monitoring, stricter emission regulation, and adoption of cleaner technologies to protect community health and achieve sustainable industrial operations in the Niger Delta.

Keywords: Air quality assessment, petrochemical air pollutants, volatile organic compounds, environmental noise and thermal stress, niger delta communities

Introduction

Environmental quality in the Niger Delta has become an issue of increasing scientific and public health concern due to the long-standing coexistence of dense human settlements with intensive petroleum exploration and production activities (Ola *et al.*, 2024) [26]. Air pollution, in particular, represents a critical pathway through which industrial operations exert both acute and chronic impacts on human health and ecosystem stability (Tavella *et al.*, 2025) [32]. In oil-producing regions, continuous gas flaring, hydrocarbon processing, vehicular emissions, and ancillary industrial activities release complex mixtures of gaseous pollutants into the atmosphere, often in close proximity to residential areas (Oyewale *et al.*, 2024) [28]. These emissions are frequently compounded by physical stressors such as elevated ambient temperature and environmental noise, creating a multifactorial exposure environment that may exacerbate health risks beyond those associated with individual pollutants (Shkemi *et al.*, 2025) [31].

Volatile organic compounds and formaldehyde constitute key indicators of petrochemical air contamination because of their prevalence in oil and gas operations and their established roles in respiratory irritation, oxidative stress, and long-term cardiopulmonary effects (Notardonato *et al.*, 2025) [21]. In addition, halogen gases, although less routinely monitored in ambient air studies, are increasingly recognised as important contributors to oxidative and

mucosal injury, particularly in industrial settings where chemical processing, gas treatment, and leakages may occur (Baljinnayam *et al.*, 2023) [8]. When these chemical stressors coexist with elevated thermal conditions and persistent noise exposure, they may interact synergistically to heighten physiological stress responses, disrupt circadian regulation, and compromise overall environmental comfort and habitability (Grasso-Cladera *et al.*, 2025) [17].

Spatial heterogeneity in pollutant distribution is a defining characteristic of industrialised landscapes in the Niger Delta (Egemba *et al.*, 2024) [14]. Communities situated near oil facilities often experience markedly different air-quality profiles compared with neighbouring non-industrial settlements, despite their shared climatic and geographical setting (Igibah *et al.*, 2024) [19]. Such contrasts provide an opportunity to disentangle the influence of petroleum-related activities from background environmental conditions. However, many existing assessments in the region have focused on single pollutants or short-term monitoring, limiting the understanding of combined chemical–physical stressor dynamics and their temporal variability. Furthermore, baseline data for several gaseous pollutants, particularly halogen compounds, remain scarce for many local government areas (Uhlhorn *et al.*, 2025) [33]. Temporal patterns of air pollution are equally important in exposure assessment, as diurnal changes in atmospheric

stability, human activity, and emission intensity can significantly influence pollutant accumulation and dispersion (Chen *et al.*, 2024) [11]. Evening periods, characterised by reduced atmospheric mixing, may facilitate pollutant build-up and prolong exposure duration for residents, especially in densely populated communities with limited ventilation corridors (Chen *et al.*, 2024) [11]. Understanding these temporal dynamics is essential for accurate risk characterisation and for the development of effective monitoring and mitigation strategies (Brimblecombe *et al.*, 2021) [9].

Against this backdrop, the present study undertakes an integrated assessment of selected chemical pollutants and physical environmental stressors across oil-producing and non-oil-producing communities in Ughelli South Local Government Area of Delta State. By combining spatial and temporal analyses with robust statistical evaluation, the study seeks to elucidate patterns of pollutant distribution, inter-relationships among contaminants, and contrasts between industrial and control communities. The findings are intended to provide context-specific baseline information, support environmental health risk evaluation, and inform policy interventions aimed at improving air quality and safeguarding public health in oil-impacted regions of the Niger Delta.

Materials and Methods

The study was conducted in Ughelli South Local Government Area of Delta State, Nigeria, within the Niger Delta region, characterised by intense petroleum activities and a humid tropical climate. Six communities were selected, comprising three oil-producing settlements (Edjophe, Ihwerekan, and Otujeremi) located near active flow stations, gas flare sites, and petroleum infrastructure, and three non-industrial control communities (Oginibo, Imode, and Okwagbe) dominated by agrarian activities. Sampling locations within each community were geo-referenced using GPS to ensure spatial accuracy and reproducibility, with monitoring points representing residential, roadside, and industrial microenvironments. Ughelli South Local Government Area, the study area, is located within the Niger Delta region of southern Nigeria and lies approximately between latitude 5°20' and 5°40' North and longitude 6°00' and 6°15' East.

A comparative cross-sectional field monitoring design was adopted to assess spatial and temporal variations in air pollutants and environmental stressors. Monitoring was carried out for fourteen consecutive days, with measurements taken twice daily during morning (07:00–10:00 h) and evening (17:00–20:00 h) sessions to capture diurnal variability. At each sampling point, triplicate readings were obtained for all parameters, and mean values were used for analysis to enhance measurement reliability.

Air quality parameters measured included Total Volatile Organic Compounds (TVOC), formaldehyde (HCHO), and halogen gases, using calibrated portable digital sensors equipped with photo-ionisation and electrochemical detection systems. Environmental stressors assessed were ambient temperature, relative humidity, and noise level, measured using a digital thermo-hygrometer and an IEC-compliant sound level meter. Measurements were conducted

at standardised heights and under calm meteorological conditions, with personnel adhering to safety protocols and personal protective equipment use.

Quality assurance procedures involved daily instrument calibration, triplicate sampling, routine sensor inspection, field documentation, and systematic data screening for outliers and inconsistencies. Data were compiled and processed using Microsoft Excel, SPSS, and R software. Descriptive statistics were generated, followed by two-way ANOVA to test spatial and temporal differences, with Tukey's HSD post-hoc analysis applied where significant effects were observed. Pearson correlation analysis was used to examine relationships among pollutants and stressors, providing an integrated evaluation of air quality dynamics across oil-producing and control communities.

Results

Figure 1 presents the mean concentrations of Total Volatile Organic Compounds (TVOC) during morning and evening sessions across the six selected communities of Ughelli South LGA. The data reveal that Edjophe, Ihwerekan, and Otujeremi recorded the highest TVOC concentrations in both sessions, with mean values exceeding 90 $\mu\text{g}/\text{m}^3$, while Oginibo, Imode, and Okwagbe showed considerably lower levels, typically below 40 $\mu\text{g}/\text{m}^3$. The marked disparity between the oil-producing and non-oil-producing communities suggests a strong influence of industrial emissions on air quality. TVOC levels were marginally higher in the evening, particularly at Otujeremi and Edjophe, indicating the likely effect of reduced atmospheric dispersion, lower wind speeds, and temperature inversion during late hours. This diurnal variation implies that volatile organic emissions from gas flaring, vehicle exhausts, and associated oil operations remain trapped in the lower atmosphere, elevating local pollutant concentration.

Furthermore, the magnitude of the difference between the oil-producing and control communities illustrates a persistent emission pattern that aligns with continuous flaring and evaporation of hydrocarbons during production processes. The lower TVOC values observed in the control communities reflect ambient background conditions with minimal industrial influence. The consistency of the high values across multiple days reinforces the view that hydrocarbon emissions are chronic rather than sporadic occurrences in these industrial zones.

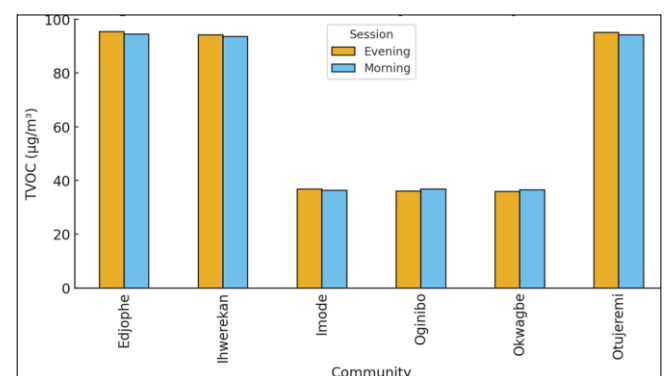


Fig 1: Mean Concentrations of Total Volatile Organic Compounds (TVOC $\mu\text{g}/\text{m}^3$) in Morning and Evening Sessions across the Six Communities of Ughelli South LGA

Figure 2 illustrates the mean concentrations of formaldehyde (HCHO) in morning and evening sessions across the study communities. Similar to TVOC, HCHO levels were considerably higher in oil-producing areas, with mean concentrations around 3.5–3.7 mg/m³, while control communities exhibited values below 2.0 mg/m³. The elevated formaldehyde levels in the industrial zones signify secondary photochemical formation and incomplete combustion processes commonly associated with hydrocarbon oxidation. The marginal evening increase in HCHO across all sites suggests accumulation of aldehydes and related compounds as air stagnation occurs after sunset. The uniformity in formaldehyde concentration trends among Edjophe, Ihwerekan, and Otujeremi further points to common emission sources and atmospheric reactivity conditions in the oil-producing corridor. Conversely, the subdued formaldehyde concentrations at Oginibo, Imode, and Okwagbe imply cleaner atmospheric conditions with limited exposure to combustion or industrial off-gassing. The strong co-occurrence of elevated HCHO and TVOC in the same communities reinforces the dominance of industrial influence on local air composition.

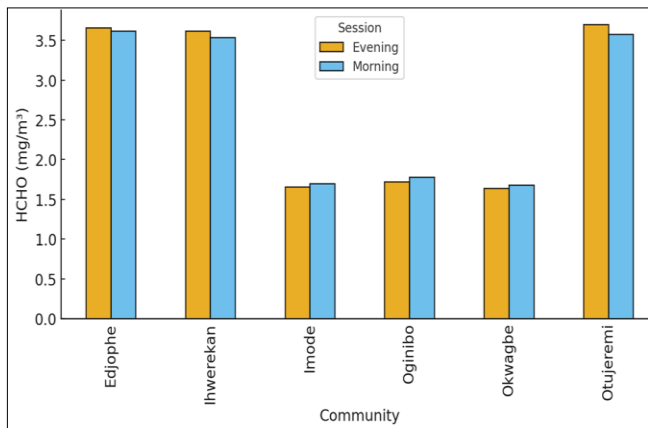


Fig 2: Mean Formaldehyde (HCHO mg/m³) Levels in Morning and Evening Sessions across the Six Communities of Ughelli South LGA

Figure 3 displays the mean temperature variations recorded during morning and evening sessions across the six studied communities. The temperature profile reveals a distinct thermal contrast between oil-producing and control locations. Edjophe, Ihwerekan, and Otujeremi exhibited markedly higher readings, averaging approximately 96–97°C on the temperature sensor scale, while the control communities—Oginibo, Imode, and Okwagbe—recorded much lower mean values of about 29–30°C. This difference signifies substantial microclimatic alteration in the oil-producing environments, likely resulting from continuous gas flaring and related industrial heat emissions. The evening values were slightly lower than morning readings, reflecting normal diurnal cooling after sunset, but the reduction was minimal in the oil-producing areas due to persistent radiant heat from flare stacks. The pronounced temperature disparity implies a sustained influence of industrial activity on local atmospheric conditions, which in turn may enhance pollutant dispersion during the day and inhibit it at night.

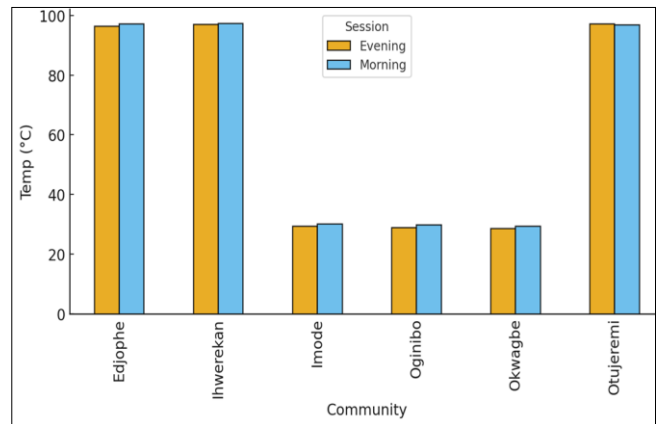


Fig 3: Mean Temperature (°C) Variations between Morning and Evening Sessions across the Six Communities of Ughelli South LGA

In Figure 4, the mean halogen gas concentrations (Cl₂, F₂, and Br₂) are shown for morning and evening sessions. The pattern mirrors those of TVOC and formaldehyde, with Edjophe, Ihwerekan, and Otujeremi displaying significantly higher mean halogen values (approximately 2.6–2.8 ppm) compared to the control communities, where concentrations ranged from 0.8–0.9 ppm. The elevated halogen gas levels in the oil-producing environments suggest emissions from combustion processes and chemical transformations of hydrocarbons in flare effluents. Slightly higher concentrations recorded in evening sessions across most locations may be attributed to reduced photochemical breakdown and limited vertical dispersion. The consistently low halogen levels in the control communities indicate the absence of industrial sources and reflect background atmospheric composition typical of non-industrial settings. The data therefore underscore the chemical complexity of emissions in oil-producing communities, where multiple reactive species coexist and interact with other pollutants such as VOCs and aldehydes.

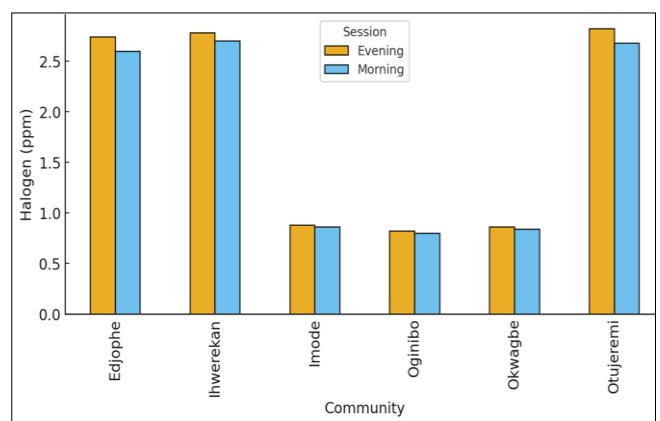


Fig 4: Mean Halogen Gas Concentrations (ppm) in Morning and Evening Sessions across the Six Communities of Ughelli South LGA

Figure 5 depicts the mean noise levels measured across all communities in morning and evening sessions. The results demonstrate a clear acoustic contrast between the oil-producing and control environments. Edjophe, Ihwerekan, and Otujeremi exhibited high mean noise intensities ranging between 60–63 dB(A), while Oginibo, Imode, and Okwagbe maintained much lower levels around 30–31 dB(A). These values indicate that industrial operations, vehicular

movement, and generator usage substantially elevate ambient noise in the oil-producing communities beyond the tolerable limits for residential and mixed-use areas. The evening readings showed slightly higher noise levels than morning measurements, reflecting increased social and commercial activity alongside continuous industrial operations. The distinct difference between oil and non-oil communities highlights a dual environmental burden—chemical and physical stressors—that may have compounding implications for public health and environmental quality.

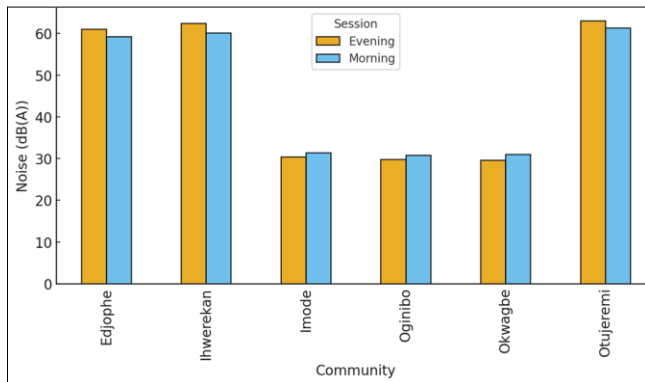


Fig 5: Mean Noise Levels (dB(A)) in Morning and Evening Sessions across the Six Communities of Ughelli South LGA

Discussion

The study demonstrates a clear and consistent deterioration of environmental quality in the oil-producing communities of Edjoppe, Ihwerekan, and Otujeremi relative to the control sites of Oginibo, Imode, and Okwagbe, driven by petroleum-related activities. Elevated TVOC concentrations reflect continuous gas flaring, fugitive emissions, and inefficient combustion from industrial and vehicular sources, a pattern widely reported across the Niger Delta (Aigberua *et al.*, 2024; Onojake & Osuji, 2023) [5,27]. Higher evening TVOC levels further indicate the role of atmospheric stability, reduced vertical mixing, and nocturnal pollutant trapping, consistent with observations in other Nigerian oilfield communities (Akindele *et al.*, 2021; Okoro *et al.*, 2024; Ede *et al.*, 2020) [6, 13, 24]. These VOCs contribute to secondary pollutant formation, including ozone and fine particulate matter, with established implications for oxidative stress, inflammation, and long-term respiratory and neurological outcomes (Cao *et al.*, 2024; Yu *et al.*, 2023; Ogbonna & Agbaji, 2022; WHO, 2021) [10, 23, 37, 39].

Formaldehyde concentrations exhibited a similar spatial and temporal pattern, with markedly higher levels in oil-producing communities, reflecting incomplete combustion and secondary formation from hydrocarbon oxidation (Cao *et al.*, 2024) [10]. The strong co-occurrence of HCHO and TVOC indicates shared petrochemical origins, consistent with reports from major flaring zones in the Niger Delta (Aigberua *et al.*, 2024; Ede *et al.*, 2020) [5,13]. Slight evening accumulation of HCHO reflects reduced photolysis and limited dispersion after sunset (Sadhukhan *et al.*, 2023) [30]. Given that formaldehyde is a recognised carcinogen and respiratory irritant, the concentrations recorded in oil-producing areas raise significant public-health concerns, particularly for vulnerable populations (Okoye *et al.*, 2025; Abereton *et al.*, 2025; Ogbonna & Agbaji, 2022) [2, 23, 25].

Thermal measurements revealed persistently elevated temperatures in oil-producing communities, attributable to continuous gas flaring and energy-intensive operations, resulting in localised heat-island effects and altered microclimatic conditions (Amaechi, 2025; Richard *et al.*, 2023; Echendu *et al.*, 2022) [7, 12, 29]. Limited diurnal cooling indicates sustained anthropogenic heat loading, consistent with thermal anomalies detected around flare sites using remote sensing (van Donkelaar *et al.*, 2021) [35]. Elevated temperatures enhance photochemical reactivity, influence pollutant dispersion, and exacerbate heat stress, thereby amplifying the toxic effects of co-existing air pollutants (Vázquez-Santiago *et al.*, 2024; Yang *et al.*, 2023; Cao *et al.*, 2024; Foraster *et al.*, 2022) [10, 16, 36, 38].

Halogen gases also showed pronounced enrichment in oil-producing communities, reflecting emissions from flaring, hydrocarbon processing, pipeline corrosion, and lubricant degradation (Amaechi, 2025; Richard *et al.*, 2023; Ede *et al.*, 2020) [7, 13, 29]. Evening accumulation of halogens suggests reduced photochemical breakdown and atmospheric stagnation (Sadhukhan *et al.*, 2023; Vázquez-Santiago *et al.*, 2024) [30, 36]. Their strong correlation with TVOC and formaldehyde indicates integrated multi-pollutant emission processes, with important implications for atmospheric oxidation chemistry and secondary toxic by-product formation (Cao *et al.*, 2024) [10]. In contrast, low halogen levels in control communities reflect background conditions typical of non-industrial tropical environments (Abah *et al.*, 2023) [1].

Environmental noise levels were substantially higher in oil-producing communities, exceeding recommended residential limits and reflecting continuous industrial activity, vehicular movement, and machinery operation (Environmental Health Perspectives, 2025) [15]. Persistent exposure to elevated noise is associated with cardiovascular stress, sleep disturbance, cognitive impairment, and reduced quality of life (Héritier *et al.*, 2022; Foraster *et al.*, 2022; Abereton *et al.*, 2025) [2, 16, 18]. The strong association between noise and gaseous pollutants further indicates shared emission sources, reinforcing the cumulative nature of environmental stress in petroleum-impacted areas (Echendu *et al.*, 2022; Okoye *et al.*, 2025) [12, 25].

Overall, the findings depict a multi-stressor exposure scenario in oil-producing communities, where chemical pollution, thermal alteration, and acoustic stress interact to heighten ecological degradation and human health risks. The comparatively low pollutant levels and stable microclimatic conditions in the control communities underscore the dominant role of petroleum exploitation in shaping environmental quality within Ughelli South LGA (Abah *et al.*, 2023; Uzoekwe & Oghenekohwo, 2024; Adewuyi *et al.*, 2023) [1, 3, 34]. These outcomes highlight the need for integrated environmental monitoring, inclusion of halogen gases in routine air-quality regulation, effective flaring control, and strengthened enforcement of national and international environmental standards to protect community wellbeing in the Niger Delta.

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