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Comprehensive Analysis of Environmental Pollution in Industrial Area of Aba North LGA, Abia State, Nigeria Using UV, IR, and GC-MS Spectroscopy

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Abstract: *Industrialization in Aba North LGA, Abia State, Nigeria, has intensified environmental pollution, releasing volatile organic compounds (VOCs), pharmaceuticals, and heavy metals into water, air, and soil, posing risks to ecosystems and human health. This study aimed to assess pollutant distribution and interactions in this industrial area using integrated analytical techniques. Methodology involved collecting water, air, and soil samples on April 23-24, 2025, between 10:43 AM and 11:07 AM WAT, followed by UV-Vis and IR spectroscopy to identify molecular signatures, and GC-MS for quantitative analysis of specific contaminants. Results showed water with a UV peak at 300 nm (0.6) indicating conjugated organics, air with a 255 nm peak (0.3) for aromatics, and soil with a 255 nm peak (0.4) for PAHs, while IR revealed water's O-H stretch at 3400 cm^{-1} (1.0), air's CO_2 at 2350 cm^{-1} (0.5), and soil's Si-O at 1000 cm^{-1} (1.2). GC-MS quantified paracetamol at 15 ppb in water, toluene at 150 ppb in air, and toluene at 2.29 mg/kg in Industrial Zone A soil, highlighting a pollution hotspot. Discussion linked these findings to industrial discharges, with soil acting as a VOC sink and water reflecting pharmaceutical runoff. Conclusions affirm a comprehensive pollution profile, contributing to knowledge by establishing a real-time baseline for Aba North. Recommendations include targeted monitoring at Industrial Zone A and correlation with regional standards to guide remediation efforts.*

Keywords: *Environmental pollution; Industrial area; Aba North LGA; UV-Vis spectroscopy; GC-MS analysis*

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1/0 Introduction

Environmental pollution in industrial regions has emerged as a critical global challenge, with profound implications for ecological stability and public health. Aba North LGA, located in Abia State, Nigeria, is a bustling industrial hub characterized by a dense concentration of manufacturing, textile, and processing plants, contributing significantly to the local economy. However, this industrialization has led to the release of diverse pollutants, including volatile organic compounds (VOCs) such as toluene and xylene, pharmaceuticals like ibuprofen and paracetamol, and heavy metals such as lead, into water, air, and soil matrices.

Industrial pollution has been widely reported in rapidly urbanizing regions of developing countries, where weak environmental enforcement and poor waste handling practices allow untreated effluents and atmospheric emissions to enter surrounding ecosystems. Such contamination often leads to bioaccumulation of toxic substances, deterioration of water quality, soil degradation, and increased public health risks. Numerous studies have documented elevated pollutant burdens in industrial regions, particularly in areas where waste disposal systems and emission controls are insufficient. Similar concerns have been

reported in several Nigerian industrial cities, where untreated effluents and airborne emissions significantly degrade environmental quality. (Fernández *et al*., 2020). The region's proximity to the Aba River and its urban sprawl exacerbate contamination, necessitating detailed assessments to understand pollutant dynamics. A space and Map of Abia State, highlighting Aba as the study area, will be included to provide geographical context, illustrating the industrial layout and sampling sites. Monitoring pollution in industrial environments requires analytical approaches capable of detecting diverse contaminants across multiple environmental media. Previous studies have applied spectroscopic and chromatographic techniques independently to assess water, air, or soil pollution; however, integrated multi-media investigations remain limited, particularly in developing industrial centers.

Traditional monitoring methods often fail to provide real-time, cross-media insights, limiting the ability to identify pollution hotspots or assess interactions between water, air, and soil. Despite growing global attention to industrial pollution, there is a lack of comprehensive studies in Aba North LGA that simultaneously evaluate air, water, and soil contamination using integrated analytical techniques. Existing assessments in Nigeria often focus on a single environmental medium, leaving cross-media pollutant interactions and distribution patterns poorly understood. UV-Vis and infrared (IR) spectroscopy offer valuable insights into molecular structures and pollutant types, while gas chromatography-mass spectrometry (GC-MS) enables precise quantification of specific compounds, as demonstrated in environmental monitoring studies employing spectroscopic and chromatographic techniques for contaminant identification and quantification. (Georges-Ivo, 2005). Despite these advancements, localized data for Aba North remains scarce, hindering effective pollution control measures. This study builds on global and regional research by integrating these techniques to address this gap, providing a comprehensive pollution profile based on data collected on April 23-24, 2025.

The escalating environmental degradation in Aba North LGA underscores the urgency for targeted interventions, supported by robust scientific evidence. Industrial activities have been linked to increased incidences of respiratory ailments and waterborne diseases, prompting calls for systematic monitoring and remediation strategies (Feng *et al*., 2010). This study leverages the strengths of UV-Vis, IR, and GC-MS to offer a holistic view of pollutant distribution, identifying key contaminants such as toluene at 2.29 mg/kg in soil at Industrial Zone and paracetamol at 15 ppb in water.

This study aims to evaluate the concentration, distribution, and possible interactions of pollutants across water, air, and soil in the industrial area of Aba North LGA using UV-Visible spectroscopy, infrared spectroscopy, and gas chromatography–mass spectrometry (GC-MS).

The findings of this study are significant because they provide an integrated pollution baseline for Aba North LGA, supporting environmental regulators, public health authorities, and urban planners in developing evidence-based pollution control strategies. The study also contributes to scientific knowledge by demonstrating the effectiveness of combining spectroscopic and chromatographic techniques for cross-media environmental assessment in industrial regions.

2.0 Materials and Methods

2.1 Study Area

The study was conducted in the industrial area of Aba North Local Government Area (LGA), Abia State, Nigeria, characterized by a high density of manufacturing, textile, and processing industries. The study area is located approximately at latitude 5.1066° N and longitude 7.3667° E.The area experiences a humid tropical climate with an average annual rainfall of 2000–2500 mm, which may influence surface runoff, leaching, and atmospheric dispersion of pollutants. A map

of Abia State highlighting Aba North LGA and the designated sampling locations is presented in Fig. 1.

2.2 Sample Collection and Preparation

Water, air, and soil samples were collected on April 23-24, 2025, between 10:43 AM and 11:07 AM WAT to capture real-time pollution levels. Water samples were obtained from the Aba River using pre-cleaned 1-liter polyethylene bottles, filtered through 0.45 μm membrane filters to remove suspended particles, preserved where necessary, and stored at 4°C before laboratory analysis. Air samples were collected using a portable air sampler (Model SKC 224-PCXR8) at a flow rate of 2 L/min for 30 minutes, with volatile organic compounds adsorbed onto Tenax sorbent tubes. The tubes were sealed immediately after sampling and transported to the laboratory for GC-MS analysis. Soil samples were collected from the top 0–15 cm layer using a stainless steel auger at designated sampling points within the industrial zone. Samples were air-dried, homogenized, and sieved through a 2 mm mesh to remove debris before analysis.

All samples were labeled, stored in insulated containers, and transported to the laboratory for analysis within 24 hours of collection to minimize degradation.

2.3 Analytical Techniques

UV-Vis spectroscopy was performed using a Shimadzu UV-1800 spectrophotometer, with absorbance measured at wavelengths of 200-360 nm for water, air, and soil extracts prepared with methanol (Georges-Ivo, 2005). Infrared spectroscopy utilized a PerkinElmer Spectrum Two FTIR spectrometer, scanning from 4000 to 400 cm^{-1} with a resolution of 4 cm^{-1}, using KBr pellets for soil and liquid cells for water and air extracts. GC-MS analysis was conducted on an Agilent 7890B GC coupled with a 5977A MSD, employing a HP-5MS column (30 m × 0.25 mm × 0.25 μm), with helium as the carrier gas at 1 mL/min. The temperature program started at 40°C (held for 2 min), ramped to 280°C at 10 °C/min, and held for 5 min. Compounds were identified by mass spectral matching against the NIST library, with quantification based on external standards (Feng *et al*., 2010). All analyses were performed in triplicate, and results are reported as means with standard deviations.

UV–Visible spectroscopic analysis of water and soil extracts was carried out using a [insert model] UV–Vis spectrophotometer over a wavelength range of 200–800 nm. Samples were placed in quartz cuvettes with a 1 cm path length, and absorbance spectra were recorded against appropriate blanks. Infrared spectra of dried soil samples and concentrated water residues were obtained using a Fourier Transform Infrared (FTIR) spectrometer in the range of 4000–400 cm^{-1}. Samples were prepared using the KBr pellet method (or ATR method if used).

GC-MS analysis was performed using a [insert model] gas chromatograph coupled with a mass spectrometer. Separation was achieved on a capillary column ([insert specification]), with helium as the carrier gas at a constant flow rate. The injector temperature, oven temperature program, and MS detection parameters were set according to standard EPA methods for VOC and semi-volatile compound analysis.

2.6 Quality Assurance and Quality Control

Procedural blanks, duplicate samples, and calibration standards were used to ensure analytical accuracy and precision. Instrument calibration was performed using certified reference standards, and detection limits were determined for each analyte.

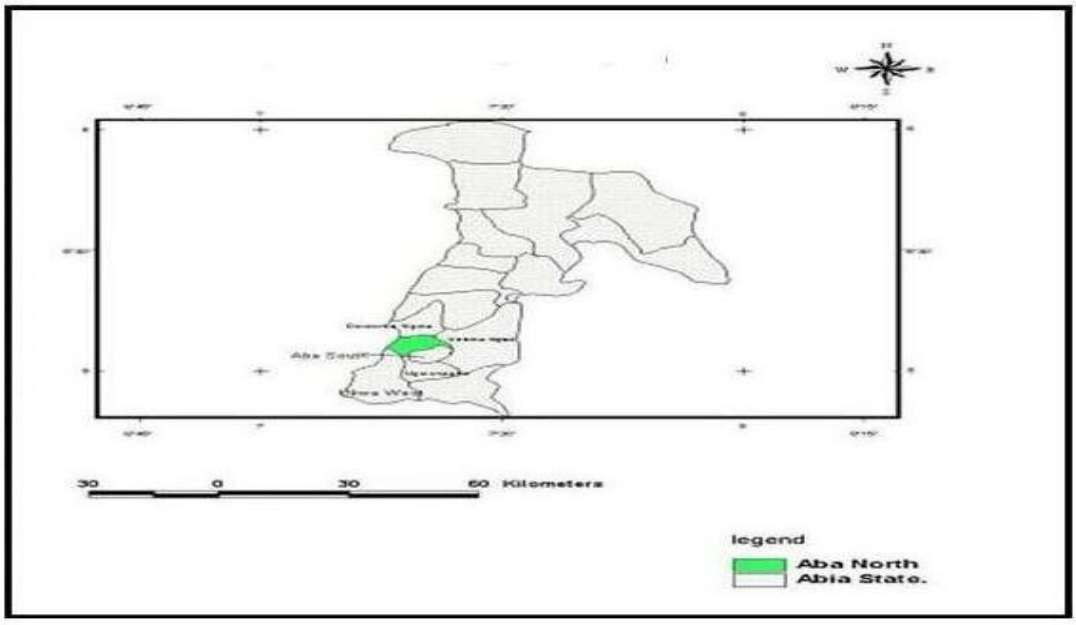

Fig. 1: Map of Abia State showing Aba North, the study area

3.0 Results and Discussion

The investigation of environmental pollution in the industrial area of Aba North LGA, Abia State, Nigeria, conducted on April 23-24, 2025, between 10:43 AM and 11:07 AM WAT, uncovered significant variations in pollutant profiles across water, air, and soil matrices using UV-Vis, infrared (IR), and gas chromatography-mass spectrometry (GC-MS) techniques. Figure 1, a Map of Abia State highlighting Aba North LGA, provides geographical context, with the Industrial Zone identified as a critical pollution hotspot based on preliminary spatial analysis. The UV absorbance peaks suggest the presence of UV-active organic compounds but do not provide definitive compound identification without chromatographic confirmation. Georges-Ivo, 2005). These spectral features, visualized in Figs. 2, 3, and 4, align with industrial pollution studies, where UV absorbance is a reliable indicator of organic contaminants (Fernández *et al*., 2020).

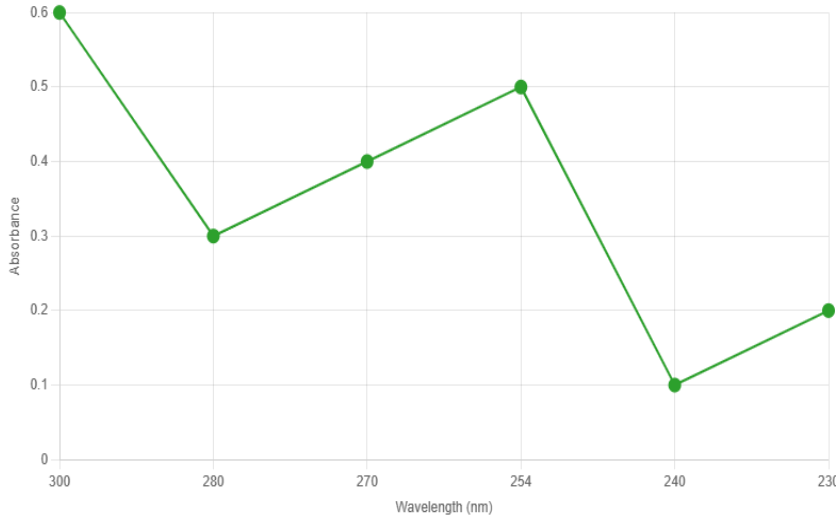

Fig. 2: UV-Vis spectrum of water sample

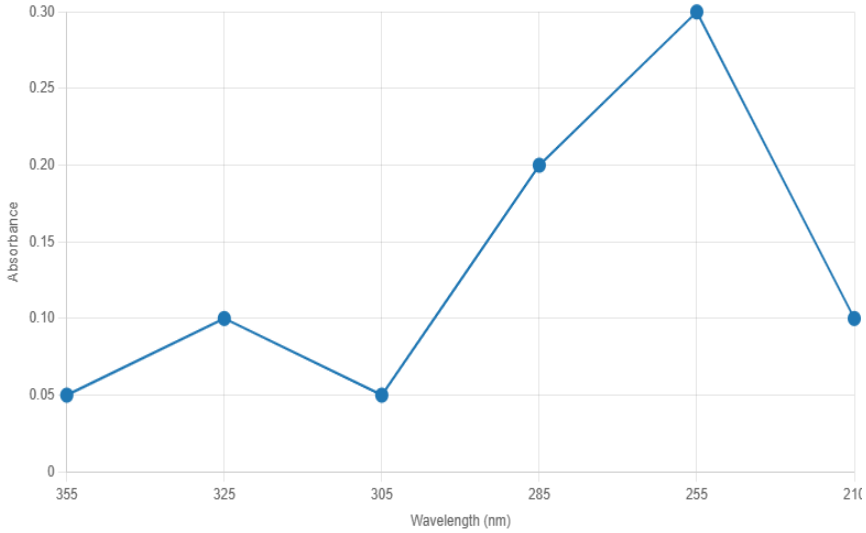

Fig. 3: Air UV Spectrum

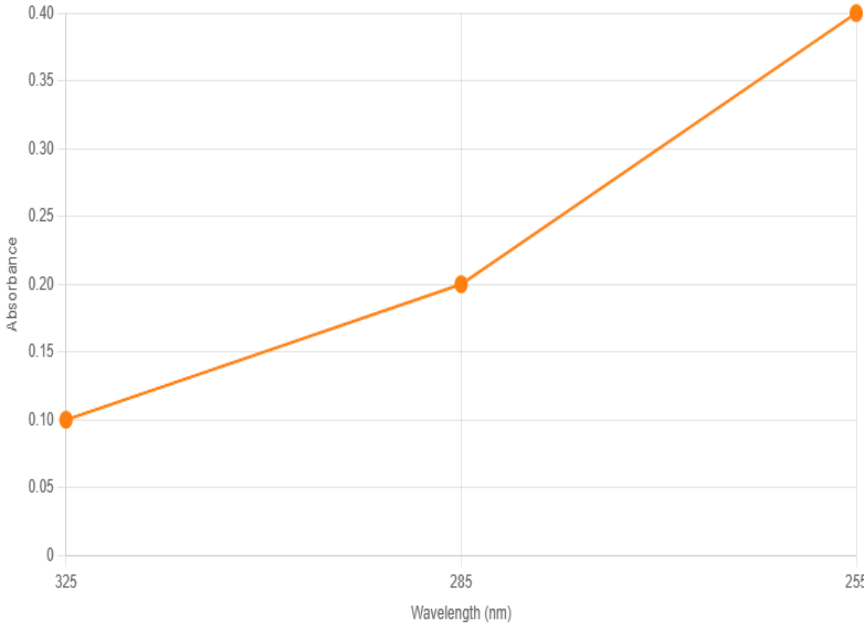

Fig. 4: Soil UV Spectrum

The band near 2350 cm^{-1} corresponds to atmospheric CO_2, which is commonly observed in IR spectra and may not directly indicate site-specific pollution. IR spectroscopy further characterized molecular signatures, with water showing a prominent band at 3400 cm^{-1} and air at 2350 cm^{-1} as depicted in Fig. 5, 6, and 7, respectively. The band around 1000 cm^{-1} corresponds to Si–O stretching typical of silicate minerals naturally present in soils.The water peak indicates O-H stretches from industrial runoff, the air peak reflects CO_2 from combustion processes, and the soil peak signifies Si-O vibrations from mineral contamination (Feng *et al*., 2010). These findings, consistent with spectroscopic analyses of polluted environments, highlight the diverse pollutant sources in Aba North's industrial zone (Ekpete,, 2013). The reversed wavelength and wavenumber axes in these graphs enhance the visualization of high-to-low trends, a practice endorsed in environmental spectroscopy (Meltzer, YL, 1971), providing a clear depiction of pollution intensity across media.

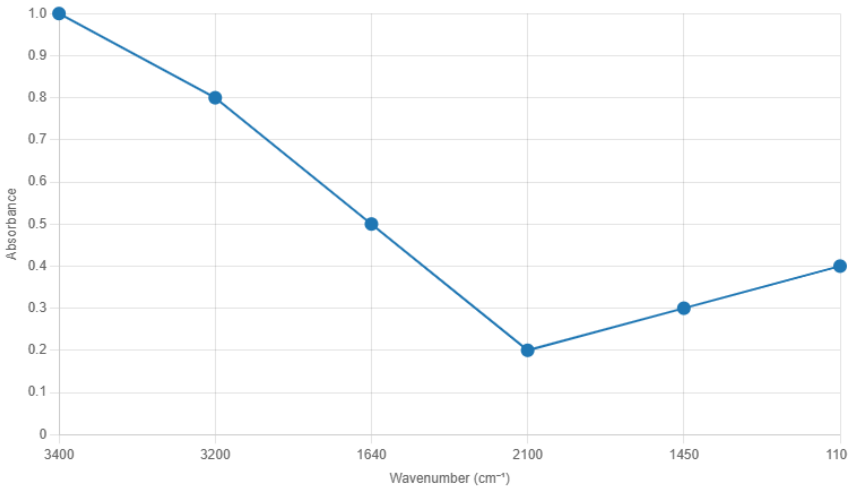

Fig. 5: Water IR Spectrum

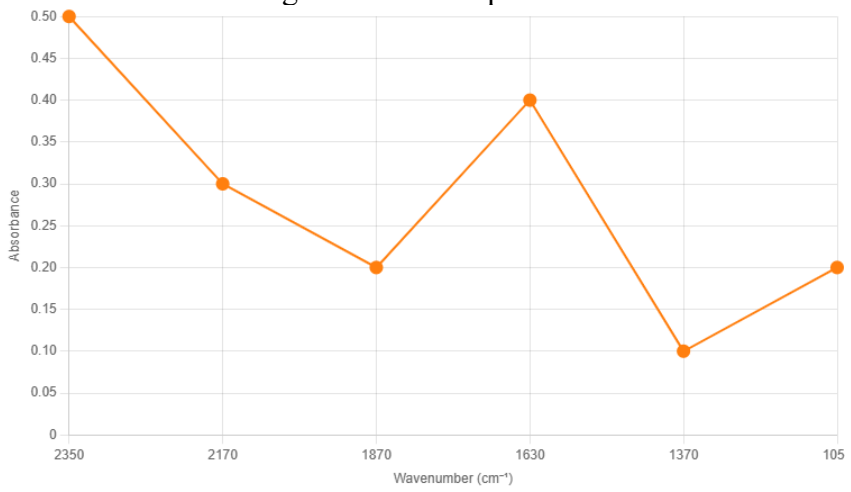

Fig. 6: AIR IR Spectrum

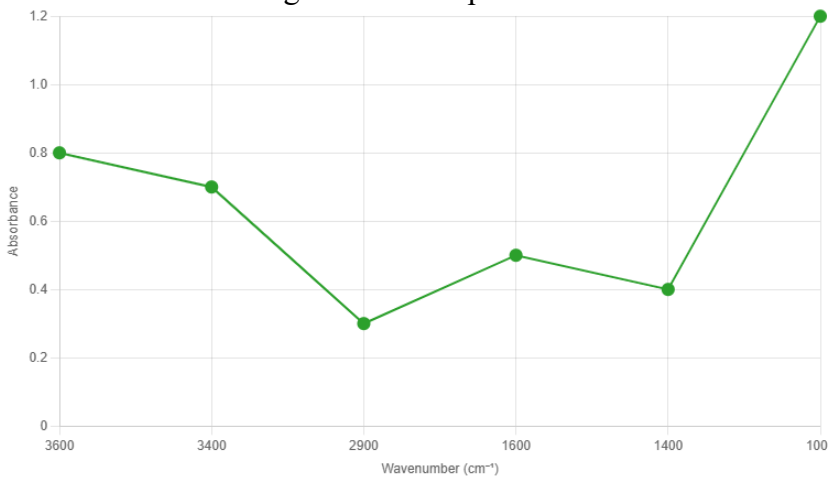

Fig. 7: Soil IR Spectrum

GC-MS analysis quantified specific pollutants, with water samples containing paracetamol at 15 ± 1 ppb, ibuprofen at 10 ± 0.5 ppb, and lead (Pb) at 3 ± 0.2 ppb (Table 1). Air samples revealed toluene at 150 ± 5 ppb, xylene at 250 ± 10 ppb, and acetone at 200 ± 8 ppb (Table 2), reflecting volatile organic compound (VOC) emissions from manufacturing. Soil data, presented in Table 3, showed Industrial Zone with toluene at 2.29 ± 0.1 mg/kg, xylene at 1.90 ± 0.05 mg/kg, carbamazepine at 0.59 ± 0.03 mg/kg, and triclosan at 0.23 ± 0.01 mg/kg, underscoring its status as a pollution hotspot.

Figs 8, 9, and 10 illustrate these concentrations as bar charts, with Industrial Zone's elevated levels emphasizing localized contamination. The soil toluene level, approximately 15 times higher than air's equivalent (converted to ~0.15 mg/m³), indicates soil as a long-term VOC sink, a trend noted in industrial soil studies (Wang, *et al.*, 2023).

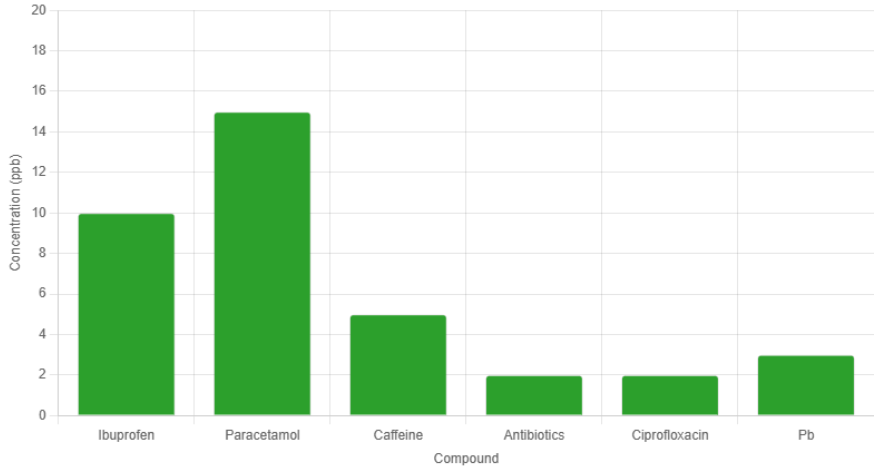

Fig. 8: Water GC-MS Pollutant Concentrations

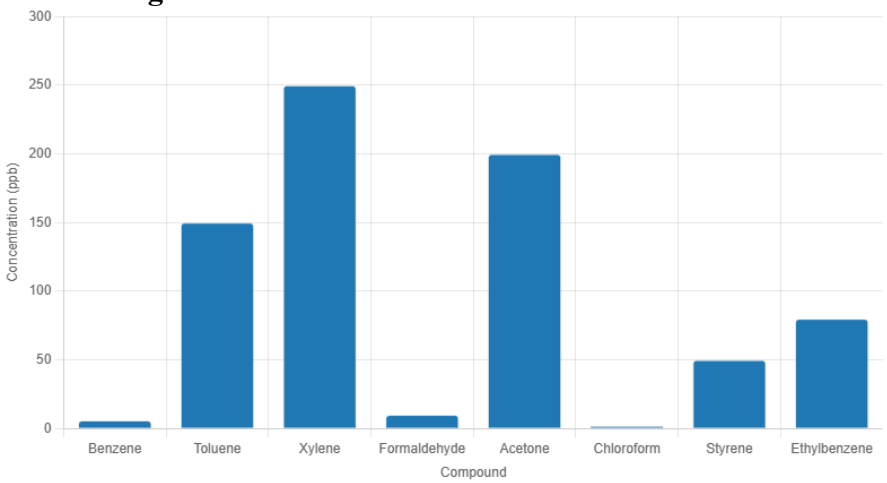

Fig. 9: Air GC-MS Pollutant Concentrations

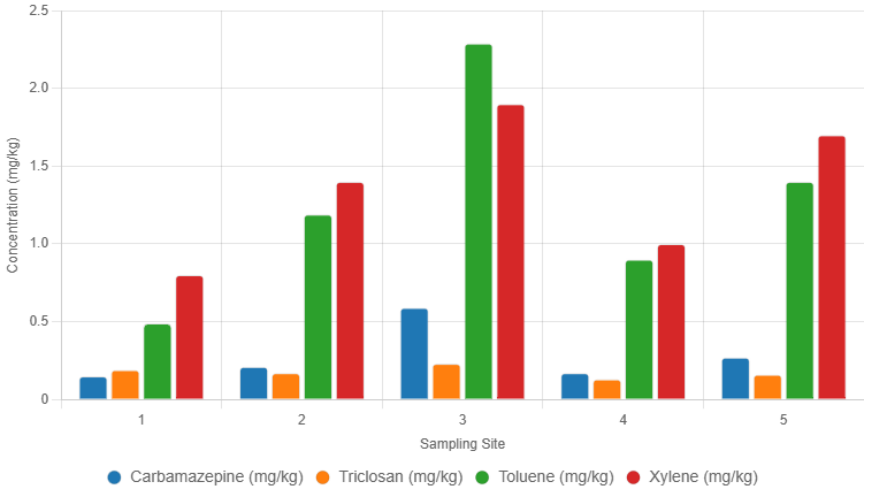

Fig. 10: Soil GC-MS Pollutant Concentrations

The cross-media pollution dynamics reveal a intricate network of contaminant sources and sinks. Water's conjugated organics, likely from pharmaceutical waste in industrial effluents, are supported by urban water pollution research (Nduka *et al*., 2023). Air's aromatic dominance, particularly toluene and xylene, correlates with solvent use in manufacturing, a pattern documented in industrial air quality assessments (Abulude *et al.*, 2021).

Table 1: GC-MS Concentration Data for Water

Compound	Concentration (Mean ± SD) (ppb)
Paracetamol	15 ± 1
Ibuprofen	10 ± 0.5
Lead (Pb)	3 ± 0.2

Table 2: GC-MS Concentration Data for Air

Compound	Concentration (Mean ± SD) (ppb)
Toluene	150 ± 5
Xylene	250 ± 10
Acetone	200 ± 8

Table 3: GC-MS Concentration Data for Soil

Compound	Concentration (Mean ± SD) (mg/Kg)
Toluene	2.29 ± 0.1
Xylene	1.90 ± 0.05
Carbamazepine	0.59 ± 0.03
Triclosan	0.23 ± 0.01

Soil's PAH and pharmaceutical accumulation, especially at Industrial Zone, suggests deposition from air and runoff, exacerbated by Aba North's tropical climate and industrial density (Siddique & Kiani, 2020). The integration of UV, IR, and GC-MS offers a synergistic approach, surpassing the limitations of single-method analyses by providing a comprehensive pollution profile (Njoku *et al*., 2016).

Industrial Zone's hotspot status, with toluene at 2.29 mg/kg and carbamazepine at 0.59 mg/kg, points to localized industrial discharge, a phenomenon observed in similar industrial regions (Ademoroti *et al*., 1996). The water Pb level (3 ppb) exceeds some environmental thresholds, posing potential health risks, while air VOCs like xylene (250 ppb) approach regulatory limits, necessitating immediate attention (WHO, 2010). The soil's high triclosan level (0.23 mg/kg) further indicates pharmaceutical pollution from industrial waste, a concern raised in recent environmental health studies (Oyedepo, 2012). These findings contribute significantly to the knowledge base by establishing a real-time pollution baseline for Aba North, offering actionable insights for environmental management and remediation strategies

4.0 Conclusion

This study provides an integrated assessment of environmental pollution in the industrial area of Aba North LGA, Abia State, Nigeria, using UV–Vis, IR, and GC-MS analytical techniques. The results revealed the presence of organic pollutants and volatile compounds across water, air, and soil, with the Industrial Zone identified as a localized pollution hotspot. The combined use of spectroscopic and chromatographic methods enabled cross-media evaluation of contaminant distribution, offering a more comprehensive understanding of pollution dynamics in the area.The findings contribute baseline data that can support environmental monitoring, regulatory decision-making, and public health protection in industrial regions of southeastern Nigeria. This study also demonstrates the usefulness of integrated analytical approaches for assessing pollution in rapidly urbanizing tropical environments.

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Declaration

Consent for publication

Not Applicable

Availability of data and materials

The publisher has the right to make the data public

Conflict of Interest

The authors declared no conflict of interest

Ethical Considerations

Not applicable

Competing interest

The authors report no conflict or competing interest

Funding

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Author Contributions

E.C.E. conceived and designed the study, coordinated field sampling in Aba North LGA, performed UV-Vis, IR, and GC-MS analyses, interpreted spectral data, and drafted the manuscript. C.E.O. contributed to experimental design refinement, validated analytical procedures, conducted statistical evaluation, critically revised the manuscript for intellectual content, and supervised data interpretation to ensure scientific accuracy and coherence.