*American Journal of Environmental Protection*
2025, Vol. 14, No. 4, pp. 136-144
https://doi.org/10.11648/j.ajep.20251404.12

Research Article

# Baseline Assessment of Ambient Total Volatile Organic Compounds in Urban Streets of Freetown, Sierra Leone

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## Abstract

Background: This study addresses the critical issue of air pollution and its implications for public health, especially in rapidly urbanizing regions such as Freetown, Sierra Leone. Total volatile organic compounds (TVOC) are significant pollutants that play a crucial role in the formation of ground-level ozone and are associated with various adverse health effects. Objective: The primary objective of this research was to conduct the first comprehensive assessment of ambient TVOC levels within the urban streets of Freetown. Methods: Measurements were carried out over a four-week period on fourteen major streets using calibrated DM502 air quality monitors, held approximately 2 meters above ground to simulate breathing zone conditions. The collected concentration data were subsequently extrapolated to estimate 24-hour average levels, providing a more accurate depiction of typical exposure. Additionally, toxicity potentials (TP) were calculated for each sampling location to evaluate potential health risks. Results: The findings revealed that the average extrapolated 24-hour TVOC concentrations across the sampled streets ranged from 0.06 and 0.18 mg/m$^3$, with the highest average at Pademba Road (FS3). Overall, the average TVOC level across all streets was 0.08 mg/m$^3$, which is below the World Health Organization's (WHO) guideline limit of 0.3 mg/m$^3$. The maximum toxicity potential observed was 0.59 at FS3, with an overall average TP of 0.26, indicating moderate potential health risks. Weak correlations were observed between TVOC concentrations and environmental parameters such as temperature ($R^2 \approx 0.16$) and relative humidity ($R^2 \approx 0.0025$), suggesting that other factors might influence VOC levels. Conclusion: Despite the current levels are within safety standards, continuous monitoring is recommended due to the possible health implications of long-term exposure. This research provides vital baseline data essential for urban air quality management and policy development in Sierra Leone.

## Keywords

Total Volatile Organic Compounds, Ambient Air Quality, Air Pollution, Sierra Leone, Urban Streets.

## 1. Introduction

Air pollution remains a critical public health and environmental challenge worldwide, particularly in rapidly urbanizing regions where vehicular emissions, industrial activities, and domestic sources contribute significantly to ambient air contaminants. Ambient (outdoor) air pollution is estimated to have caused approximately 4.2 million premature deaths worldwide in 2019 [1], and its impact is increasingly felt in low- and middle-income countries (LMICs), including many in Sub-Saharan Africa. These regions are experiencing accelerated urban growth, often without commensurate devel-

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**Received:** 30 June 2025; **Accepted:** 14 July 2025; **Published:** 5 August 2025

opment of air quality management systems, leading to higher levels of hazardous pollutants.

Among these pollutants, Volatile Organic Compounds (VOC) comprise a broad class of carbon-based chemicals characterized by their high vapor pressure at ambient temperatures, which allows them to readily evaporate into the atmosphere [2]. VOCs are central precursors in the formation of ground-level ozone, secondary organic aerosols (SOAs), and other secondary pollutants responsible for smog formation, respiratory problems, and other health issues [3].

Total volatile organic compounds (TVOC) serve as an overarching indicator of organic emissions in the environment, reflecting combined contributions from various sources such as vehicle exhaust, solvent use, industrial processes, biomass burning, and waste management activities [4, 5].

The health and environmental impacts of VOCs are well-documented, including their toxicity, carcinogenicity, and role in climate change. Several VOCs such as benzene, formaldehyde, acetaldehyde, and 1,3-butadiene, are classified by the International Agency for Research on Cancer (IARC) as Group 1 carcinogens, emphasizing the importance of monitoring and controlling their levels in urban atmospheres [6, 7]. Excessive ambient VOC concentrations are associated with adverse health outcomes such as respiratory diseases, cardiovascular problems, and increased cancer risk [8].

Recent regional studies have highlighted the severity of VOC pollution in African urban environments. In Nairobi, Kenya, and Lagos, Nigeria, research has reported elevated VOC levels, with average ambient concentrations exceeding 142 $\mu g/m^3$ and hotspots near e-waste recycling sites reaching up to 485 $\mu g/m^3$, likely due to intense vehicular and industrial activities combined with open biomass burning [9, 10]. For example, Cordell et al. [9] documented the high spatial variability of VOCs in Nairobi, emphasizing the need for localized assessments. Similarly, Lin et al. [10] observed elevated VOC concentrations in e-waste recycling zones in Ghana, directly linking these levels with potential health risks.

Despite these findings, data gaps persist across much of West Africa, including Sierra Leone, where urban air pollution research remains limited. Existing studies have primarily focused on particulate matter (PM) and associated air quality parameters, often highlighting PM levels that significantly exceed WHO guidelines [11].

In Freetown, the capital city, rapid socio-economic developments, ongoing urbanization, traffic congestion, unregulated waste burning, and informal fuel stations contribute to an increasingly complex air pollution profile. However, comprehensive measurements of VOC levels, especially TVOC, are scarce, impeding effective policy formulation and targeted mitigation interventions.

The paucity of data constrains local capacity to assess health risks accurately and develop evidence-based regulatory standards. Given the region's vulnerability to air pollution-related health issues and the potential contribution of VOC to secondary pollutant formation, there is a pressing need to fill these knowledge gaps. Recent studies in the sub-region have started to recognize the importance of characterizing VOC; for example, a study in Lagos State reported Seven VOCs as the major contributors to ambient air pollution in Ikeja and Isolo industrial areas [12].

In light of these developments, this study aims to conduct the first comprehensive assessment of ambient TVOC levels across major streets in Freetown, Sierra Leone. Using calibrated air quality monitors over an extended period, the research will provide baseline data on spatial-temporal TVOC distributions, evaluate potential health risks, and inform policies for urban air quality management. The findings will be pivotal in designing effective emission control strategies, raising public awareness, and guiding future research endeavors in Sierra Leone and similar urban centers across West Africa, where air quality issues are becoming increasingly urgent.

## 2. Materials and Methods

### 2.1. Study Area

The study was conducted across fourteen prominent streets in Freetown, Sierra Leone, selected to represent diverse urban environments with varying traffic densities and land-use activities. These streets include Cambell Street, Siaka Stevens Street, Pademba Road, Circular Road, Regent Road, Spur Road, Aberdeen Road, Kissy Road, Wilkinson Road, Bai Bureh Road, Main Mortor Road, Lightfoot Boston Street, Sanni Abacha Street, Rawdon Street and they are designated as FS1, FS2, FS3, FS4, FS5, FS6, FS7, FS8, FS9, FS10, FS11, FS12, FS13, and FS14, respectively. The sites were chosen to ensure a comprehensive assessment of ambient TVOC affecting different parts of the city.

Freetown is the capital and largest city of Sierra Leone. It is a major port city in the Atlantic Ocean and is situated in the Western Area of the country (Figure 1). It is located on the latitude of 8.48714 and longitude of -13.235.


***Figure 1.*** *Map and Pictorial View of Freetown, Sierra Leone.*

## 2.2. Data Collection Protocol and Instrumentation

Ambient air quality measurements were taken over a period of four weeks from September 1 to September 28, 2024. Data collection was conducted during three time periods each day - morning (07:00 - 10:00), afternoon (12:00 - 15:00), and evening (17:00 - 20:00) - to capture temporal variations in VOC levels.

At each site, measurements of total TVOC levels, temperature, and relative humidity were taken using a portable, handheld digital air quality monitor (DM502) (Figure 2). Before the sampling campaign, the device was calibrated according to the manufacturer's instructions to ensure high accuracy. The monitor was positioned approximately 2 meters above ground level, the approximate human breathing zone, following the World Meteorological Organization (WMO) standard for ambient weather measurement [13]. The monitor was stabilized for a few seconds before measurement. Each measurement session lasted 15 minutes, during which the device continuously recorded the TVOC concentration. For each site and period, three replicate measurements were performed to promote data reliability and account for short-term fluctuations.

Meteorological parameters—temperature, humidity, wind speed, and wind direction—were logged simultaneously during each session to investigate their influence on VOC dispersion.


***Figure 2.*** *DM502 Multifunctional Air Quality Monitor.*

## 2.3. Data Processing and Analysis

Data acquired by the DM502 were transferred to a secure computer and processed using Microsoft Excel. Raw data were inspected for inconsistencies or anomalies; outliers and invalid readings were identified through statistical analysis and excluded from further processing.

The extrapolated 24-hour averaging TVOC levels were calculated for each four-hour interval using the atmospheric stability equation [14, 15] given by equation (1) as

$$C_0 = C_1 \left(\frac{t_1}{t_0}\right)^n \quad (1)$$

Where $C_0$ = the concentration at the averaging time $t_0$ $C_1$ = the concentration at the averaging time $t_1$ n = 0.28, the stability dependent exponent.

Toxicity potential, a valuable method for assessing the adverse health effects associated with TVOC emissions, is determined by dividing the observed concentration of TVOC in the air by the established regulatory limit for ambient TVOC concentration (Equation (2)) [15].

$$\text{Toxicity Potential, TP} = \frac{O_{TVOC}}{R_{TVOC}} \quad (2)$$

Where $O_{TVOC}$ = the observed or measured extrapolated 24-hour average TVOC level, and

$R_{TVOC}$ = the regulatory limit for TVOC.

# 3. Results and Discussions

## 3.1. Measured TVOC Levels

Table 1 shows all mean measured TVOC concentrations during the sampling periods at all locations. Mean measured TVOC range between 0.01 and 0.49 mg/m$^3$ with the lowest and highest recorded between 7:00 AM to 11:00 AM at FS6 and FS3, respectively. The average of all mean measured levels range between 0.06 and 0.29 mg/m$^3$, the lowest and highest at FS5 and FS3, respectively. Figure 3 represents a plot of the mean measured ambient TVOC levels against the sampled streets.

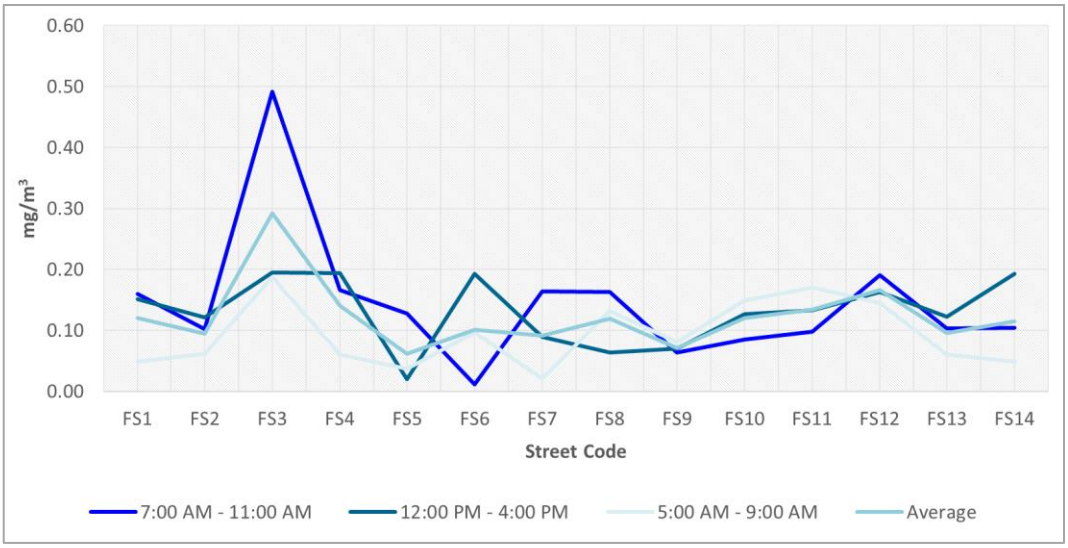


***Figure 3.*** *Plot of Mean Measured Ambient TVOC Levels.*

***Table 1.*** *Mean Measured Ambient TVOC Levels.*

| Street Code | Mean Measured Ambient TVOC Levels (mg/m$^3$) | | | |
|---|---|---|---|---|
| | 7:00 AM - 11:00 AM | 12:00 PM - 4:00 PM | 5:00 AM - 9:00 AM | Average |
| FS1 | 0.16 | 0.15 | 0.05 | 0.12 |
| FS2 | 0.10 | 0.12 | 0.06 | 0.10 |
| FS3 | 0.49 | 0.20 | 0.19 | 0.29 |
| FS4 | 0.17 | 0.19 | 0.06 | 0.14 |
| FS5 | 0.13 | 0.02 | 0.04 | 0.06 |
| FS6 | 0.01 | 0.19 | 0.10 | 0.10 |
| FS7 | 0.16 | 0.09 | 0.02 | 0.09 |

| Street Code | Mean Measured Ambient TVOC Levels (mg/m$^3$) | | | |
|---|---|---|---|---|
| | 7:00 AM - 11:00 AM | 12:00 PM - 4:00 PM | 5:00 AM - 9:00 AM | Average |
| FS8 | 0.16 | 0.06 | 0.13 | 0.12 |
| FS9 | 0.06 | 0.07 | 0.08 | 0.07 |
| FS10 | 0.09 | 0.13 | 0.15 | 0.12 |
| FS11 | 0.10 | 0.13 | 0.17 | 0.13 |
| FS12 | 0.19 | 0.16 | 0.15 | 0.17 |
| FS13 | 0.10 | 0.12 | 0.06 | 0.10 |
| FS14 | 0.10 | 0.19 | 0.05 | 0.12 |

## 3.2. Extrapolated 24-hour Average TVOC Levels

The extrapolated 24-hour average of TVOC concentrations during the sampling periods is represented in Table 2 and plotted in Figure 4 to show the variation of extrapolated 24-hour ambient TVOC with time at the sampling locations. Overall, the lowest and highest extrapolated 24-hr average of 0.04 mg/m$^3$ at FS5 and 0.18mg/m$^3$ at FS3, respectively.

*Table 2. Extrapolated 24-hour average ambient TVOC levels in Freetown.*

| Street Code | Extrapolated 24-hr Average TVOC Levels (mg/m$^3$) | | | |
|---|---|---|---|---|
| | 7:00 AM - 11:00 AM | 12:00 PM - 4:00 PM | 5:00 AM - 9:00 AM | Average |
| FS1 | 0.10 | 0.09 | 0.03 | 0.07 |
| FS2 | 0.06 | 0.07 | 0.04 | 0.06 |
| FS3 | 0.30 | 0.12 | 0.11 | 0.18 |
| FS4 | 0.10 | 0.12 | 0.04 | 0.08 |
| FS5 | 0.08 | 0.01 | 0.02 | 0.04 |
| FS6 | 0.01 | 0.12 | 0.06 | 0.06 |
| FS7 | 0.10 | 0.05 | 0.01 | 0.06 |
| FS8 | 0.12 | 0.04 | 0.08 | 0.08 |
| FS9 | 0.05 | 0.04 | 0.05 | 0.05 |
| FS10 | 0.06 | 0.08 | 0.09 | 0.08 |
| FS11 | 0.07 | 0.08 | 0.10 | 0.09 |
| FS12 | 0.14 | 0.10 | 0.09 | 0.11 |
| FS13 | 0.08 | 0.07 | 0.04 | 0.06 |
| FS14 | 0.08 | 0.12 | 0.03 | 0.07 |

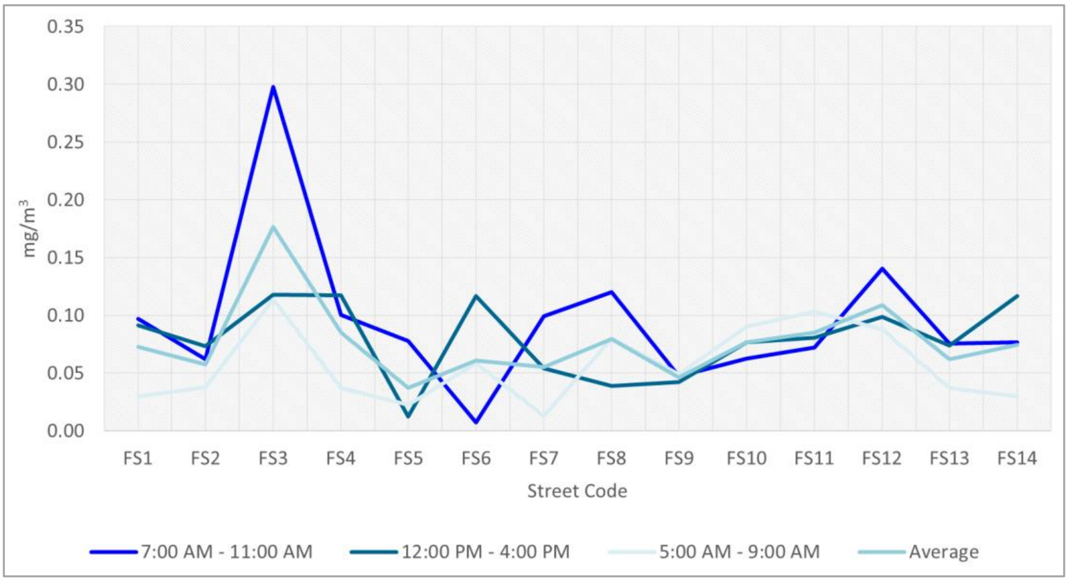


***Figure 4***. *Plot of Extrapolated 24-hour Average Ambient TVOC Levels.*

Table 3 presents a summary of Mean Environmental Parameters, Average Ambient TVOC Levels, and Toxicity Potential in the studied streets. The overall average temperature, relative humidity, extrapolated 24-hour average TVOC concentration, and toxicity potential is 26.34 $^{o}$C, 87.48%, 0.08 mg/m$^3$, and 0.26, respectively.

Figure 5 shows the comparison of the average ambient TVOC Levels with the recommended limit set by the World Health Organization (WHO). All average extrapolated 24-hour ambient TVOC concentrations are below the limit set by WHO.

***Table 3***. *Summary of Mean Environmental Parameters, Average Ambient TVOC Levels, and Toxicity Potential in the studied streets.*

| Street Code | Environmental Parameters | | Average Ambient TVOC Levels (mg/m$^3$) | | Toxicity Potential |
|---|---|---|---|---|---|
| | Temperature ($^{o}$C) | Humidity (%) | Measured | Extrapolated 24 - hour | |
| FS1 | 26.20 | 84.67 | 0.12 | 0.07 | 0.24 |
| FS2 | 24.83 | 91.00 | 0.10 | 0.06 | 0.19 |
| FS3 | 27.43 | 85.00 | 0.29 | 0.18 | 0.59 |
| FS4 | 23.67 | 93.33 | 0.14 | 0.08 | 0.28 |
| FS5 | 23.57 | 85.67 | 0.06 | 0.04 | 0.12 |
| FS6 | 26.43 | 84.00 | 0.10 | 0.06 | 0.20 |
| FS7 | 26.60 | 84.33 | 0.09 | 0.06 | 0.18 |
| FS8 | 24.57 | 79.83 | 0.12 | 0.08 | 0.27 |
| FS9 | 24.93 | 90.67 | 0.07 | 0.05 | 0.15 |
| FS10 | 25.47 | 92.33 | 0.12 | 0.08 | 0.26 |
| FS11 | 24.50 | 91.00 | 0.13 | 0.09 | 0.28 |
| FS12 | 38.67 | 90.67 | 0.17 | 0.11 | 0.36 |
| FS13 | 24.87 | 91.67 | 0.10 | 0.06 | 0.21 |
| FS14 | 26.97 | 80.50 | 0.12 | 0.07 | 0.25 |
| MAX. | 38.67 | 93.33 | 0.29 | 0.18 | 0.59 |

| Street Code | Environmental Parameters | | Average Ambient TVOC Levels ($mg/m^3$) | | Toxicity Potential |
|---|---|---|---|---|---|
| | Temperature ($^oC$) | Humidity (%) | Measured | Extrapolated 24 - hour | |
| MIN. | 23.57 | 79.83 | 0.06 | 0.04 | 0.12 |
| AV. | 26.34 | 87.48 | 0.12 | 0.08 | 0.26 |

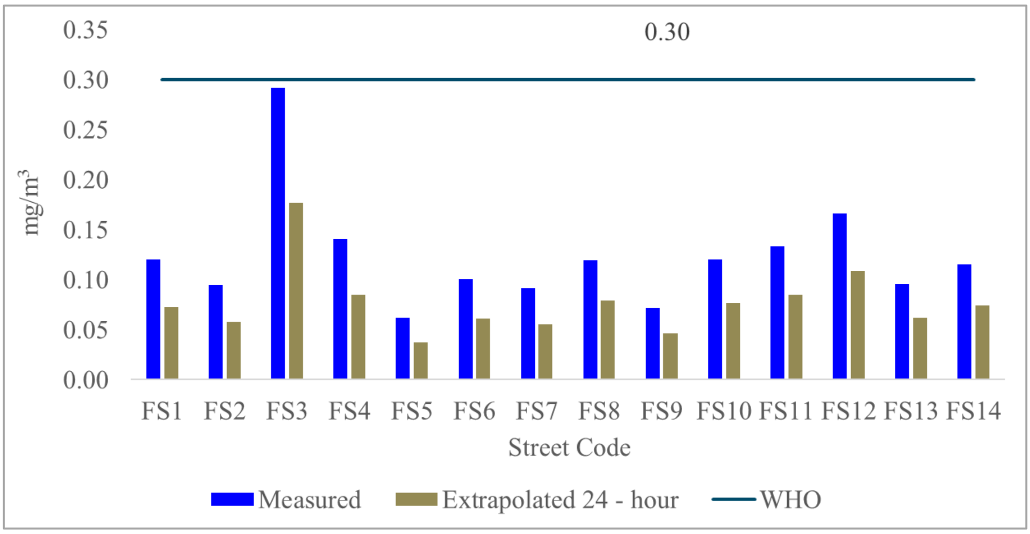


***Figure 5***. *Comparison of Average Ambient TVOC Levels with Recommended WHO Limit.*

## 3.3. Toxicity Potential

The calculated TP values ranging between 0.12 to 0.59 are plotted as shown (Figure 6), with FS3 exhibiting the highest TP (0.59), indicating a potential health concern in that zone if exposure persists or increases.

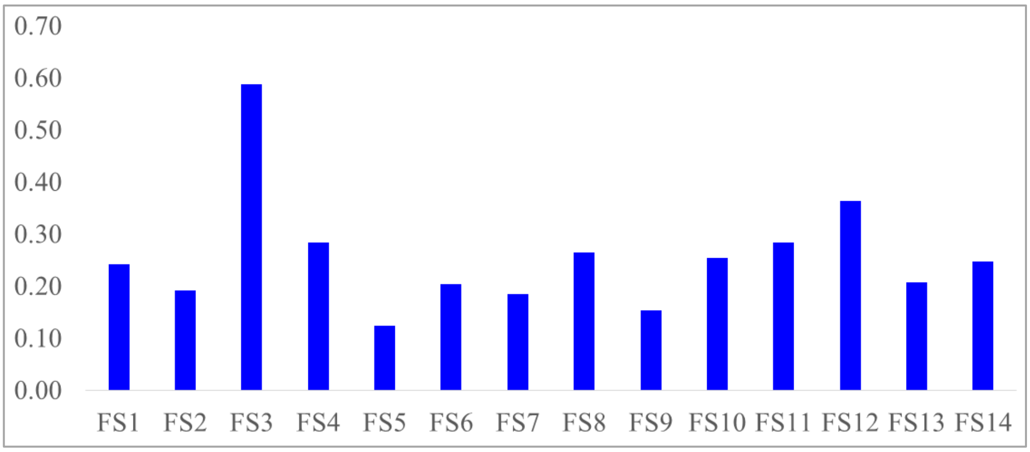


***Figure 6***. *Plot of Toxicity Potential of TVOCs.*

## 3.4. Correlation with Environmental Parameters

Regression analysis shows weak correlations between TVOC concentrations and environmental parameters:

Temperature: r = 0.40 (moderate positive correlation), $R^2 \approx 0.16$, suggesting temperature may influence VOCs volatilization but other factors dominate.

Relative Humidity: r = -0.05 (negligible negative correlation), $R^2 \approx 0.0025$, indicating humidity has minimal impact.

Scatter plots (Figures 7 and 8) visually illustrate these relationships. The weak correlations imply that traffic density, industrial activities, and other sources likely exert more significant influence on TVOC levels than meteorological variables alone.

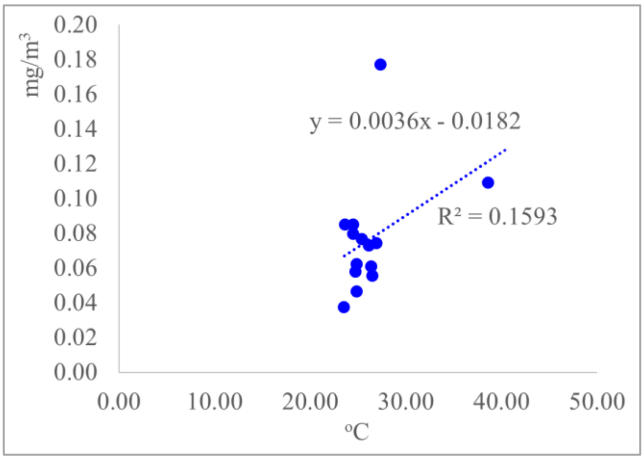


*Figure 7. Correlation plot of extrapolated 24-hour averaging TVOC concentration against temperature.*

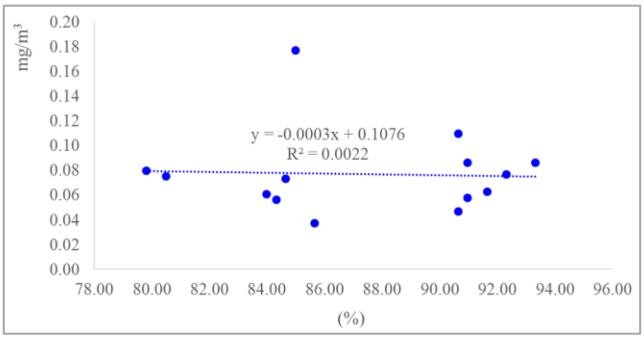


*Figure 8. Correlation plot of extrapolated 24-hour averaging TVOC concentration against relative humidity.*

## 4. Conclusion and Recommendations

### 4.1. Conclusion

In conclusion, while current TVOC levels in Freetown are within global safety standards, localized high concentrations and toxicity potential at certain sites underscore the need for sustained, comprehensive air quality management efforts.

### 4.2. Recommendations

The following are the recommendations for future monitoring and policy:

1. Implement continuous or periodic long-term monitoring to capture seasonal, weekly, and diurnal variations, helping to identify peak pollution periods.
2. Expand the monitoring network to include more neighborhoods, particularly near suspected point sources such as factories, markets, or high-traffic corridors.
3. Increase public awareness regarding traffic-related pollution and encourage behaviors that reduce individual exposure, especially for sensitive populations.
4. Enforce stricter emission standards for vehicles and promote cleaner transportation modes, such as electric vehicles or improved public transit.
5. Perform a source apportionment analysis or at least a qualitative attribution of likely VOC sources (e.g., traffic, open burning, industrial zones) based on site characteristics to enhance the interpretive depth of the findings and help guide targeted mitigation strategies.
6. Formulate and implement local regulations that will reduce VOC emissions and protect public health.

## Abbreviations

| | |
|---|---|
| TVOC | Total Volatile Organic Compounds |
| VOC | Volatile Organic Compounds |
| IARC | International Agency for Research on Cancer |
| WHO | World Health Organization |
| TP | Toxicity Potential |
| WMO | World Metrological Organization |
| LMICs | Low - and Middle - Income Countries |

## Acknowledgments

Alhamdilillah to Almighty Allah for His mercy, good health, and guidance to successfully complete this study. I am also very grateful to my late father and mentor, Alhaji Muhamed Hamid Kaipissy Abu, who provided all the necessary guidance and support for the achievement of this result. May Allah bless him with eternal rest in Paradise. Amin.

## Author Contributions

Mohamed Mustapha Abu is the sole author. The author read and approved the final manuscript.

## Data Availability Statement

The data supporting this article have been included in the article.

## Conflicts of Interest

The author declares no conflicts of interest.

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