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ASSESSING THE ATMOSPHERIC CONCENTRATIONS OF FORMALDEHYDE (HCHO) AND TOTAL VOLATILE ORGANIC COMPOUNDS (TVOCs) IN THE URBAN ENVIRONMENT OF MAIDUGURI METROPOLIS

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ABSTRACT

Formaldehyde (HCOH) and Total Volatile Organic Compounds (TVOCs) are prevalent air pollutants with adverse health effects. This study examined the outdoor atmospheric concentrations of HCOH and TVOCs at selected points and their daily variability in Maiduguri Metropolis, Borno State. Data on HCOH and TVOCs levels were collected for multiple 24-hour periods at twelve (12) different Emissions Monitoring Stations (EMSs) across the city, over a period of 3-4 months. The data were collected using a high accuracy hand-held air quality monitor (Xtester-BR-smart 128s Meter). For each EMS, measurements were taken for 24 hours at 3-hour intervals (from 6am to 3am). The average concentrations were obtained both by point (for each of the 12 EMSs) and by time (at the 3-hour interval for 24 hours). The average results at the EMSs for HCHO and TVOCs range between 0.007-0.020 mg/m^3 and between 0.060-0.326 mg/m^3, respectively, while for the daily time series, they range between 0.006-0.018 mg/m^3 and 0.001-0.272 mg/m^3 respectively. The overall average concentrations for HCHO and TVOCs at the city level stand at 0.011 mg/m^3 and 0.137 mg/m^3 respectively. Considering the maximum concentrations, the daily time series for HCHO and TVOCs range between 0.007-0.052 mg/m^3 and 0.002-0.764 mg/m^3 respectively, while the city average stand at 0.028 mg/m^3 and 0.376 mg/m^3 respectively. All 12 EMSs show "Excellent" air quality status for the gases at all times, except 2 EMSs for TVOCs, which show "Good" status. However, continuous air quality monitoring is crucial to ensure a sustained healthy air quality in the long-term.

Keywords: Air quality; Emissions stations; Environment; Health; Pollutants.

INTRODUCTION

Formaldehyde (HCHO) is a colorless, flammable gas at room temperature with a strong odor. Formaldehyde sources in the environment include natural (forest fires, volcanic eruptions, and the decomposition of organic matter) as well as anthropogenic (industrial processes, automobile exhaust, and the off-gassing from building materials and household products), forming the bulk of environmental formaldehyde source (Kherkher, 2024). It is a common chemical compound widely used in a wide range of industrial processes and household products, including adhesives, coatings, and plastics.

Formaldehyde exposure poses significant risks to human health (depending on the severity and duration of exposure) and the

environment. Short-term exposure to HCHO, typically at high levels, can cause acute health effects. Prolonged inhalation of formaldehyde may lead to respiratory problems, chronic bronchitis, asthma, and increases the risk of developing certain types of cancer. Certain populations are more vulnerable to the adverse effects of formaldehyde (Kherkher, 2024; USEPA, 2025; Xiaoyan *et al.*, 2025).

Formaldehyde emissions can have a range of harmful effects on the environment, deteriorating air quality, and posing risks to natural environment. It reacts with other pollutants to form ground-level ozone and secondary organic aerosols, which can contribute to smog and air pollution. Formaldehyde can also deposit onto soil and water surfaces, where it undergoes further chemical transformations or is broken down by microorganisms, leading to contamination and potential harm to ecosystems and aquatic life (Donghui *et al.*, 2025; NIEHS, 2025). Although it degrades relatively quickly in the environment, continuous emissions can lead to sustained high concentrations, especially in urban and industrial areas (Kherkher, 2024; Montrose Environmental Group, 2023).

Understanding formaldehyde effects on human health and the environment is essential for mitigating the potential dangers associated with it (Kherkher, 2024). Formaldehyde emissions are regulated by a range of government agencies, including the Federal Government of Nigeria (FGN, 2020), Environmental Protection Agency (EPA) in the United States (USEPA, 2025).

Volatile organic compounds (VOCs) are organic chemical compounds found in various products that easily vaporize, which are released as gases from different liquids or solids. The most common VOCs are the aromatic hydrocarbons, such as benzene, toluene, xylene and ethyl benzene, and halogenated hydrocarbons, such as chloroethylene and trichloroethylene. Among VOCs, trichloroethylene and vinyl chloride are the most toxic and carcinogenic compounds. The summation of all these compounds is called Total Volatile Organic Compounds (TVOCs). TVOCs are present in different household, industrial/commercial and products, but their accumulation in air and water has primarily gained attention. Volatile compounds are highly spontaneous and readily react with the particles of ambiance and produce a polluted atmosphere through several physical and chemical reactions (Debra *et al.*, 2010; Elena and Niculescu, 2021).

VOCs are naturally occurring in the environment, but man-made VOCs emissions have been accelerating in recent decades, making urban areas highly prone to the impacts of VOCs (Xihe *et al.*, 2023). VOCs are synthetic chemicals broadly used in the production of numerous day-to-day products for residential and commercial-based applications (Xihe *et al.*, 2023). Health impacts of VOCs associated with their prolonged exposure are gaining attention in recent times (Xihe *et al.*, 2023). The nature and impact of TVOCs are dependent on the VOCs concentrations as well as the exposure time.

Certain VOCs were identified as greenhouse gases, which can absorb radiated energy from Earth, contributing to global warming. Furthermore, VOCs from wastewaters decrease the possibility of water reuse, such as in irrigation, thereby placing a higher demand on the limited existing primary water resources. VOCs can be removed via efficient approaches involving nano materials, by using techniques such as adsorption, catalysis or photocatalysis (Elena and Niculescu, 2021).

The aim of this paper is to assess the atmospheric concentration levels of HCHO and TVOCs in the urban environment of Maiduguri Metropolis, evaluate their health risk, and to suggest mitigation actions by relevant stakeholders.

The objectives are to measure the ambient air quality for HCHO and TVOCs at 12 points within Maiduguri city, identify the potential sources of the pollutants, compare the results of the study against other research findings as well as standard air quality guidelines, and to highlight relevant recommendations for air quality management.

A number of research works have been done on HCHO and TVOCs levels in the urban environment in Nigeria. These works are limited in either the combination of the gases, the extent of coverage of the study area, the study environment, the number of EMSs or the time period and time intervals of data collection.

Ibrahim *et al.* (2025) conducted an assessment of the concentrations of indoor air pollutants for CO_2, TVOCs, CH_2O, PMs, in university hostels in Southwestern Nigeria, using air quality monitor. The study has limitations in that it focused on limited geographic area within the city and to specific time periods. Similarly, Salami *et al.* (2020) assessed the ambient air quality (VOC, H_2S, CO, $PM_{2.5}$, PM_{10}, O_2, LEL, and HCHO), but limited to five major motor parks in Ilorin Metropolis, Kwara State, Nigeria.

Abulude *et al.* (2018) conducted an indoor air quality of HCHO, TVOCs and PMs in Akure, South-West Nigeria. However, the study focused on indoor environment and did not consider data collection at different times of the day. Olumayede (2014) studied the relative contribution of individual VOCs species to photochemical ozone formation, in an attempt to evaluate the ozone creation potential of ambient VOCs captured in Urban Center of Southern Nigeria.

Olumayede and Okuo (2013) examined the ozone creation potential for reactive VOCs in urban atmosphere of southwestern, Nigeria. The study did not take HCHO into consideration and did cover 24 hour period of the day. Ojiodu *et al.* (2013) examined VOCs in Iganmu industrial area of Lagos State. Their study was confined to a specific area, limited to VOCs and did not consider the overall urban environment.

Okuo *et al.* (2011) examined the air quality status of VOCs in Benin City, Nigeria. They collected ambient air samples from indoor and outdoor of five (health and financial institutions) microenvironments, using passive sampling method with diffusion tubes from Drager Safety, Lubeck, Germany. The study scope was limited to VOCs pollutants and to a limited data collection points.

This paper is novel as it considered twelve (12) EMSs across Maiduguri Metropolis (as an urban environment), for outdoor assessment of both HCHO and TVOCs, for 24-hour period at 3-hour intervals. Averages of the values were considered both for the stations and for the time intervals, and discussions were provided as appropriate.

The following limitations are acknowledged. Data records may not have been taken at the exact target hour, because moving through a few close stations to take records for the target hour may result in an increase/decrease of about ±15 minutes. For data at 12am and 3am, the EMSs may not be accessible due to security concerns. For those times, accessible stations were arbitrarily considered as proxy stations. This is based on the justification that anthropogenic activities responsible for air pollution usually diminish by 10pm in

Maiduguri, and may come to a standstill by 12am. Hence, considering the time period of inactivity at midnight (12am-3am), air pollutants were assumed to have been somewhat uniformly distributed across the city due to wind movements, and thus pollutants concentrations are not expected to differ widely. Finally, the study did not take account of meteorological data (temperature, humidity, wind speed, wind direction) which may also affect the accuracy of the results.

METHODOLOGY AND DATA

Strategic EMSs were identified for on-site data collection exercise. Data were collected at all the 12 EMSs for 24 hours, from 6:00am to 3:00am at 3-hour intervals, using a portable emissions detector (Xtester-BR-Smart 128s Meter). The study took a period of 3-4 months to end. The study was conducted in the capital city of Maiduguri, Borno state, North-Eastern Nigeria. Figure 1 below shows the EMSs distribution in the city.

Real-time data were collected for the 12 EMSs by on-site data monitoring (Table 1). The averages of both HCHO and TVOCs for each station were determined. Similarly, the averages of both HCHO and TVOCs for each data collection hour across all stations were obtained.



Figure 1: Map of Maiduguri showing EMSs distribution across the city

Description of Air Quality Meter

The Xtester-BR-smart 128s (BLATN) is a handheld 5-in-1, or 12-item, portable air quality monitor designed to measure CO_2, $PM_{1.0}$, $PM_{2.5}$, PM_{10}, TVOCs, and Formaldehyde (HCHO) in real-time. It features high-precision laser and NDIR (Non-Dispersive Infrared) sensors with data

logging, a 2.4" TFT (Thin-Film Transistor) color screen, and a 2200mAh battery, suitable for indoor/outdoor use. Key features and capabilities include comprehensive monitoring, innovative sensor technology, data logging & display, and portability and functionality.

Data Collection Procedure

1. Selecting strategic emissions monitoring stations (EMSs) across Maiduguri metropolis.
2. Utilizing hand-held emissions monitoring device to take real-time emissions readings.
3. Determining the average HCHO and TVOCs levels at each station and at each interval hour.

RESULTS AND DISCUSSION

This section presents the study results, provides a comparison of the study results with other relevant findings, analyzes the daily HCHO and TVOCs levels and trends in Maiduguri city and assesses the air quality status against relevant national guidelines and standards. Table 1 presents the results of the study from all the EMSs at the selected time intervals.

Table 1: Atmospheric concentrations of HCHO and TVOCs in Maiduguri metropolis

Station	Pollutants (mg/m^3)	06:00 am	09:00 am	12:00 pm	03:00 pm	06:00 pm	09:00 pm	12:00 am	3:00 am	Average
Post Office	HCHO	0.006	0.003	0.003	0.010	0.003	0.009	0.012	0.007	0.007
	TVOCs	0.002	0.088	0.037	0.327	0.764	0.029	0.183	0.002	0.179
Baga Park	HCHO	0.007	0.002	0.008	0.012	0.013	0.016	0.012	0.007	0.010
	TVOCs	0.001	0.184	0.511	0.430	0.324	0.309	0.194	0.001	0.244
Chabbal Junction	HCHO	0.008	0.002	0.004	0.004	0.010	0.005	0.012	0.004	0.006
	TVOCs	0.001	0.002	0.135	0.001	0.117	0.070	0.192	0.000	0.065
Custom Flyover	HCHO	0.046	0.029	0.005	0.009	0.012	0.009	0.008	0.006	0.016
	TVOCs	0.008	0.082	0.188	0.115	0.538	0.063	0.098	0.001	0.137
Unimaid Gate	HCHO	0.013	0.025	0.000	0.010	0.005	0.010	0.008	0.005	0.010
	TVOCs	0.015	0.044	0.406	0.204	0.163	0.167	0.126	0.002	0.141
Muna Park	HCHO	0.052	0.012	0.020	0.013	0.038	0.007	0.008	0.007	0.020
	TVOCs	0.134	0.176	0.749	0.287	0.698	0.427	0.136	0.001	0.326
Borno Express Airport Junction	HCHO	0.016	0.013	0.006	0.013	0.016	0.010	0.008	0.004	0.011
	TVOCs	0.000	0.030	0.233	0.037	0.042	0.093	0.141	0.000	0.072
	HCHO	0.010	0.000	0.001	0.008	0.017	0.012	0.008	0.005	0.008
	TVOCs	0.000	0.003	0.146	0.000	0.126	0.065	0.138	0.002	0.060
1000 Housing NNPC Depot	HCHO	0.010	0.002	0.007	0.005	0.000	0.017	0.005	0.006	0.007
	TVOCs	0.000	0.001	0.181	0.003	0.000	0.240	0.139	0.001	0.071
	HCHO	0.008	0.014	0.002	0.020	0.007	0.011	0.005	0.007	0.009
	TVOCs	0.000	0.194	0.201	0.197	0.298	0.181	0.141	0.001	0.152
FRSC Junction	HCHO	0.011	0.021	0.000	0.010	0.004	0.007	0.014	0.007	0.009
	TVOCs	0.008	0.015	0.164	0.021	0.106	0.077	0.233	0.001	0.078
Molai Park	HCHO	0.024	0.020	0.048	0.014	0.009	0.010	0.014	0.004	0.018
	TVOCs	0.073	0.265	0.312	0.045	0.038	0.041	0.216	0.001	0.124
Average values	HCHO	0.018	0.012	0.009	0.011	0.011	0.010	0.010	0.006	**0.011**
	TVOCs	0.020	0.090	0.272	0.139	0.268	0.147	0.161	0.001	**0.137**
Maximum values	HCHO	0.052	0.029	0.048	0.020	0.038	0.017	0.014	0.007	**0.028**
	TVOCs	0.134	0.265	0.749	0.430	0.764	0.427	0.233	0.002	**0.376**

Comparison of results with other studies

The results in this study are compared with other relevant studies to assess their extent of variability and thus, accuracy. The average outdoor city level concentrations of HCHO and TVOCs are 0.011 mg/m^3 and 0.137 mg/m^3 respectively. Table 2 presents the results of the current study side by side with other studies. A total of three results for HCHO and six results for TVOCs are presented for the comparison. HCHO level in Maiduguri (0.011 mg/m^3) is greater than those for Southwestern Nigeria (0.000 mg/m^3) and Akure, Southwest, Nigeria (0.000 mg/m^3), but less than that for Ilorin Kwara state, Nigeria (0.120 mg/m^3). On the other hand, TVOCs level in Maiduguri is greater than four other results, less than one, and within the range of one. Figure 2 provides a diagrammatic presentation of the variation of the results of the current study in relation to other findings in Nigeria.

Table 2: Comparison of current results for average HCOH and TVOCs to other relevant findings

Author	Area of study	Result(s) from other studies (mg/m^3)	Remark (Current results) **HCHO**: 0.011 mg/m^3; **TVOCs**: 0.137 mg/m^3
Ibrahim *et al.* (2025)	Southwestern Nigeria	HCHO: 0.000 TVOCs: 0.099	HCHO: 0.011 > 0.000 TVOCs: 0.137 > 0.099
Salami *et al.* (2020)	Ilorin Kwara state, Nigeria	HCHO: 0.120 VOCs: 0.320	HCHO: 0.011 < 0.120 TVOCs: 0.137 < 0.320
Abulude *et al.* (2018)	Akure, Southwest, Nigeria	HCHO: 0.000 TVOCs: 0.000-0.362	HCHO: 0.011 > 0.000 TVOCs: 0.137 within range
Olumayede (2014)	Southern Nigeria	TVOCs: 0.024	TVOCs: 0.137 > 0.024
Olumayede and Okuo (2013)	Southwestern, Nigeria	TVOCs: 0.015	TVOCs: 0.137 > 0.015
Okuo *et al.* (2011)	Benin City, Nigeria	TVOCs: 0.016	TVOCs: 0.137 > 0.016

Note: Scope of VOCs vary by study

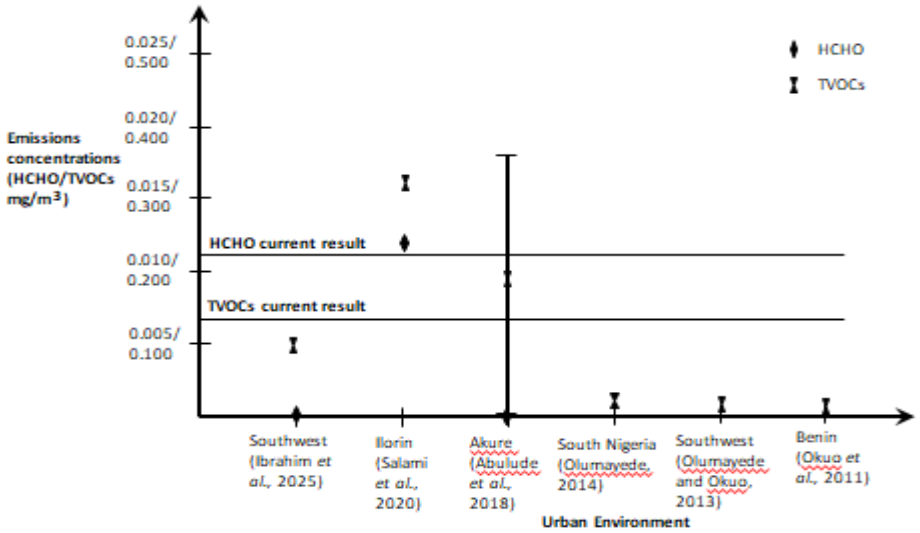


Figure 2: Interactive comparison of the current results in relation to other findings

Daily Emissions Trends

A graphical presentation of the hourly trends of the average and maximum concentrations of HCHO and TVOCs for the city indicates distinct variability across the day. HCHO levels show high values in the morning, low values at midnight, with moderate intermediate dynamics. TVOCs levels show low values in the morning and at midnight, with higher intermediate dynamics. TVOCs show more consistent response to daily anthropogenic activities than HCHO. Figure 3 presents the daily trends of the pollutants in Maiduguri city.

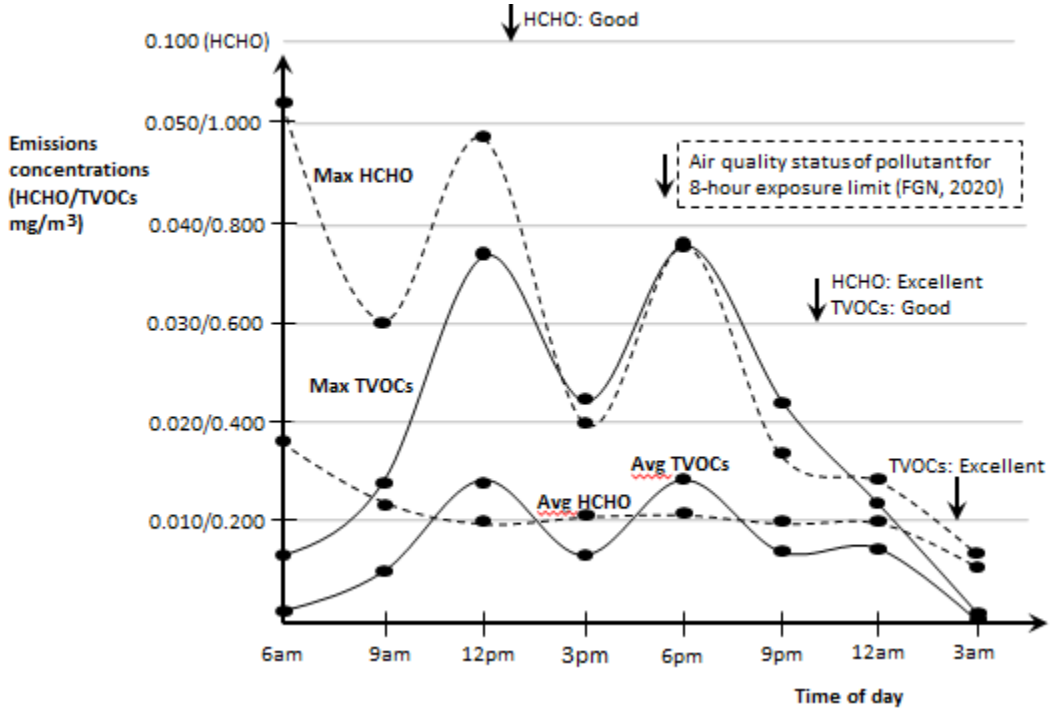


Figure 3: Daily trends of atmospheric levels of HCHO and TVOCs in Maiduguri Metropolis

Air Quality Assessment

As shown on Table 1, HCHO concentrations for the EMSs range between 0.007-0.020 mg/m^3 (with a city of 0.011 mg/m^3), while TVOCs range between 0.060-0.326 mg/m^3 (with a city average of 0.137 mg/m^3). The National Environmental (Air Quality Control) Regulations, 2020, of Nigeria, under the National Environmental Standards and Regulations Enforcement Agency (Establishment) Act, 2007, set recommended air quality guidelines for HCHO (< 0.030 Excellent and < 0.100 Good) and for TVOCs (< 0.200 Excellent and < 0.600 Good), for 8-hour averaging time (FGN, 2020). The air quality statuses of the EMSs are presented on Table 3 below.

All 12 EMSs show excellent status for HCHO and 10/12 EMSs show excellent status for TVOCs. Similarly in terms of the city averages, both HCHO and TVOCs have excellent conditions. Where the daily trends are considered at the city level, average trend for HCHO is within the “Excellent” level throughout the day, while TVOCs

trend shows overshoots at 12pm (between 10.30am-1.30pm) and at 6pm (between 4.30am-8.00pm). However, both time ranges for the overshoots are less than the related 8-hour averaging time for exposure.

Considering the maximum daily trends for the city, HCHO is within the "Good" level throughout the day, while TVOCs trend shows overshoots at 12pm (between 10.30am-1.30pm) and at 6pm (between 4.30am-8.00pm). Considering the "Excellent" status, HCHO indicates border crossings between 6am and 2pm, as well as between 4.30pm and 5.30pm. TVOCs levels indicate levels beyond its "Excellent" limits for longer periods, from 8.00am up till 11.00pm.

Table 3: Air quality status for HCHO and TVOCs levels at EMSs in Maiduguri Metropolis

Station	Pollutants (mg/m^3)	Average levels	Standard limits for 8-hour averaging time (FGN, 2020)	
			Excellent (mg/m^3)	Good (mg/m^3)
			HCHO < 0.030; TVOCs < 0.200	HCHO < 0.100; TVOCs < 0.600
Post Office	HCHO	0.007	✗	
	TVOCs	0.179	✗	
Baga Park	HCHO	0.010	✗	
	TVOCs	0.244		✗
Chabbal	HCHO	0.006	✗	
Junction	TVOCs	0.065	✗	
Custom	HCHO	0.016	✗	
Flyover	TVOCs	0.137	✗	
Unimaid	HCHO	0.010	✗	
Gate	TVOCs	0.141	✗	
Muna Park	HCHO	0.020	✗	
	TVOCs	0.326		✗
Borno	HCHO	0.011	✗	
Express	TVOCs	0.072	✗	
Airport	HCHO	0.008	✗	
Junction	TVOCs	0.060	✗	
1000	HCHO	0.007	✗	
Housing	TVOCs	0.071	✗	
NNPC	HCHO	0.009	✗	
Depot	TVOCs	0.152	✗	
FRSC	HCHO	0.009	✗	
Junction	TVOCs	0.078	✗	
Molai Park	HCHO	0.018	✗	
	TVOCs	0.124	✗	
Overall	HCHO	-	12	0
Result	TVOCs	-	10	2
Average	HCHO	**0.011**	✓	
levels	TVOCs	**0.137**	✓	
Maximum	HCHO	**0.028**	✓	
average	TVOCs	**0.376**		✓

Note: Standards limits used are for indoor air quality for offices and public places

The overall maximum-averages (by space and time) at the city level show "Excellent" status for HCHO (0.028 mg/m^3) and "Good" status for TVOCs (0.376 mg/m^3). TVOCs for both average and maximum trends show overshoots at the same points in time.

CONCLUSION

Atmospheric concentrations of HCHO and TVOCs in the outdoor environment of Maiduguri Metropolis have been measured at 12 randomly distributed Emissions Monitoring Stations (EMSs) for year 2025. Data was collected at 3-hour intervals from 6am to 3am for all the EMSs. The average daily concentrations of the pollutants for 24-hours were determined at each EMS. The average daily concentration trends were also determined by computing the averages at the 3-hour intervals to analyze the daily trends for the city. The results are compared to other findings (to assess their accuracy) and to air quality guidelines (to monitor their safety levels) given by Federal Government of Nigeria (FGN) through the National Environmental Standards and Regulations Enforcement Agency (NESREA). The results show that air quality in Maiduguri in terms of both HCHO and TVOCs concentrations is very safe. However, HCHO show safer levels than TVOCs.

Going by air quality status of the emissions stations, HCHO has excellent status in all the stations (12/12), including the average/maximum-average at the city level, while TVOCs has 10/12 of the stations with "Excellent" status and 2/12 with "Good" status, and an average "Excellent" and maximum-average "Good" status at the city level. It is important to note that even low concentrations of the pollutants can have adverse health effects for vulnerable populations like children, the elderly, and people with pre-existing medical conditions. Therefore, continued monitoring and assessment of air quality are crucial to ensure that the levels of the pollutants remain within safe limits.

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