

# Precursors Influencing Tropospheric Ozone Formation and Apportionment in Three Districts of Ilupeju Industrial Estate, Lagos

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**Abstract** This study determined concentrations of toxic pollutants, volatile organic compounds and meteorological parameters in three sampling locations (SL1, SL2 and SL3) at Ilupeju industrial Estate. Average concentrations of toxic pollutants; CO (14.70 ppm), NO<sub>2</sub> (0.88 ppm), and SO<sub>2</sub> (0.55 ppm) and O<sub>3</sub> (17.67 ppb) were determined. These had high correlation with temperature, wind speed, pressure and relative humidity. In terms of air quality, unhealthy air quality was obtained for CO, NO<sub>2</sub> and SO<sub>2</sub> while O<sub>3</sub> gave a good air quality. Seventeen VOCs species belonging to alkane, alkene, aromatic and chlorinated hydrocarbons were determined. m/p - xylene was the most abundant species accounting for 16.28%, 11.66% and 14.06% at SL1, SL2 and SL3 respectively. Different ratios such as *toluene/m,p - xylene*,  $\Sigma$  *Xylene/CO*, *trichloroethene/CO* and *tetrachloroethene/CO* indicated solvent related emissions from these locations while *Benzene/Toluene* ratio indicated a traffic related emission. m/p - xylene and propene were the major contributors to O<sub>3</sub> formation at SL1, SL2 and SL3 respectively. Ozone determined was VOC sensitive at all locations. Factor analysis using principal component analysis suggested traffic, industrial related emission sources solvent evaporation as sources for toxic pollutants and VOCs.

**Keywords** Toxic pollutants, Ozone formation, Principal component analysis, Diurnal pattern, VOCs

## 1. Introduction

Air pollution is a well-documented problem in urban centres especially where residential houses are in the neighborhood of industries. Anthropogenic emissions such as vehicular activities, industrial emissions and solvent evaporation are the largest sources of air pollution in most urban cities [1-3]. Air emissions from these sources are usually critical and have been associated with numerous diseases such as cardiovascular diseases, fatigue, headache, immune impairment and cancer [4, 5]. Most of these primary pollutants are acid anhydrides reacting with moisture to form acidic compounds that are dangerous to human health, plants and materials [6, 7]. Aside high toxicity these pollutants induce, they also combine to form secondary pollutants which are sometimes more toxic than them [8, 9].

Tropospheric Ozone (O<sub>3</sub>) also known as bad ozone is a

secondary air pollutant formed in the atmosphere through a complex photochemical reaction sequence requiring reactive hydrocarbons, sunlight and nitrogen oxide (NO<sub>x</sub>) [10, 11]. It is one of the criteria air pollutants, a major constituent of photochemical smog and a powerful oxidant which plays important role in the oxidative capacity of atmosphere [12]. It is a highly corrosive and toxic air pollutant whose pollution is still a serious problem that needs our collective attention [13].

O<sub>3</sub> is an irritant to lung tissues and has been reported to cause respiratory inflammation, impair photosynthesis and damage human health by oxidizing biological tissues [14, 15]. O<sub>3</sub> concentration is usually high at noon basically due to photo-oxidation of the precursor gases such as CO, CH<sub>4</sub> and non-methane hydrocarbons in the presence of sufficient amount of nitrogen oxide (NO<sub>x</sub>) [16]. O<sub>3</sub> production during the day could also be driven by the photochemical reaction between hydroxyl radicals, organic peroxy radicals and NO while it is removed at night by deposition and destruction by alkenes and NO [17].

Non-methane hydrocarbons (NMHCs) are major volatile organic compounds (VOCs) in the ambient atmosphere.

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They are ozone-producing precursors and also play key role in the formation of secondary organic aerosol. They are usually emitted from vehicular activities and solvent evaporation [15, 18, 19, 20]. They have been reported to induce a wide range of acute and chronic health effects, such as sensory irritation, nervous system impairment, asthma and cancer. Many VOCs are known to be toxic, carcinogenic and mutagenic [21]. Benzene, formaldehyde and carbon tetrachloride have been shown to damage liver, kidney, lung and intestine and DNA [22].

Understanding and identifying ozone precursors' emission sources are important for policy-makers and for the improvement of air quality. Moreover, these precursors have been well documented and discussed as part of criteria air pollutants in most countries especially Nigeria but same attention has not been given to tropospheric ozone formation and its distribution. Therefore, this study was focused on providing baseline concentration data on toxic air pollutants, and their contribution to ozone formation and apportionment in one of the largest industrial estates with a lot of commercial activities.

## 2. Sampling Location

Ilupeju Industrial Estate is one of the industrial estates established in Lagos in Oshodi-Isolo, Local Government Area. The Estate has a number of industries such as PZ Cussons Nigeria Plc; Poly Products Nigeria Plc (manufacturer of polyethylene products); Bhojsons Industries Plc; Nestles Nigeria Plc, Patplast and Allied Rubber Products Nigeria Limited, Nigeria Foundries limited, Atlantic Textile Manufacturing Company Limited; Enpee

Industries; Absco Industries; Pharmchem Industries; Kiwi Industries. Vehicular activities are usually high on the roads within the industrial estate because many houses and other towns are connected together by these roads.

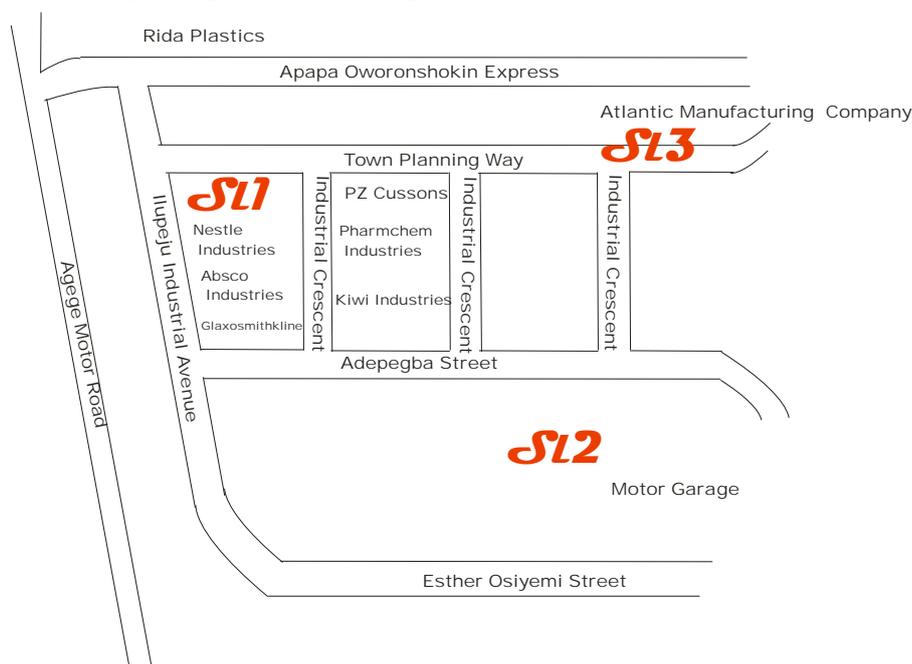
Measurements of pollutants were conducted in three (3) different sampling locations (SL) selected randomly within the Estate for three consecutive months (February – April, 2014). Measurements were carried out between 0700hr and 1800hr daily. Geographical locations of sampling locations 1, 2 and 3 are  $06^{\circ}33'16.8''N$  and  $003^{\circ}21'15.4''E$ ,  $06^{\circ}33'03.1''N$  and  $003^{\circ}21'33.4''E$ , and  $06^{\circ}33'22.9''N$  and  $003^{\circ}21'27.0''E$  respectively. Sampling locations and industries cited within are shown in figure 1.

### 2.1. Sampling Methodology

#### 2.1.1. Measurement of Toxic Pollutants and Meteorological Parameters

The concentrations of air pollutants of concerns were determined in-situ with the use of digital hand-held MultiRAE IR monitoring instruments. The MultiRAE IR is a programmable multi-gas monitor designed to provide continuous exposure monitoring of toxic gases (CO, NO, NO<sub>2</sub>, SO<sub>2</sub>) in potentially hazardous environments. It uses the following sensors; Organic vapours with the supplied Photo-Ionization Detector (PID) using 9.8eV, 10.6eV gas discharge lamp and toxic gases with several interchangeable electrochemical sensors. All instruments underwent background checks and were purged with high purity zero air to correct instrument drifts.

Meteorological parameters were measured using Kestrel 4500 NV Weather Meter (USA).



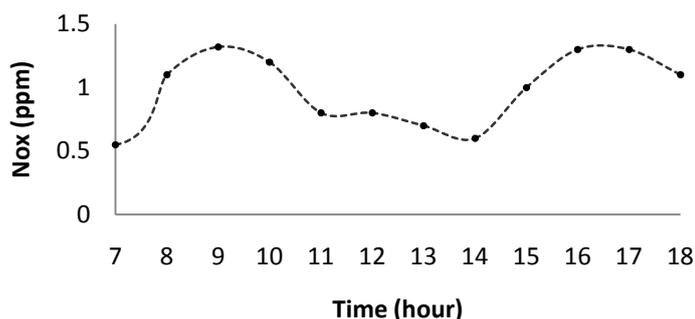
**Figure 1.** Map of Ilupeju Industrial estate showing sampling locations

### 2.1.2. Determination of Ozone

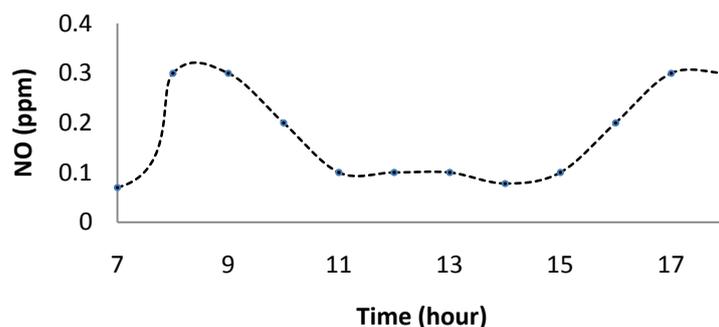
Method of Olajire et al. [23] was used to determine ozone concentration. Air samples were drawn with P4LC air sampler into the impinger containing 10 ml oxidant absorbing solution (1% KI in 0.1 M phosphate buffer at pH 6.8) at a flow rate of 2 l min<sup>-1</sup> for 1 hr. The absorbance of

exposed absorbing solution was read at 352 nm using unexposed solution as reference. Concentrations of ozone in each solution was extrapolated from the calibration curve prepared from standard iodine solution against ozone concentration. Oxidant concentration in the air was calculated using this equation

$$\text{Ozone } (\mu\text{g}/\text{m}^3) = \frac{\text{total } \mu\text{g } O_3 \text{ per } 10\text{ml absorbing solution}}{\text{volume of air sampled in } \text{m}^3}$$



**Figure 2a.** Diurnal variations of nitrogen (IV) oxide (NO<sub>2</sub>)



**Figure 2b.** Diurnal variations of nitrogen (II) oxide (NO)

**Table 1.** Average concentrations of toxic pollutants and meteorological parameters

Pollutants	SL1	SL2	SL2
	Mean	Mean	Mean
NO <sub>2</sub> (ppm)	1.1 ± 0.23	0.56 ± 0.03	0.98 ± 0.29
NO (ppm)	0.2 ± 0.01	0.08 ± 0.02	0.23 ± 0.05
SO <sub>2</sub> (ppm)	0.52 ± 0.13	0.32 ± 0.19	0.81 ± 0.21
CO (ppm)	14.6 ± 1.73	13.90 ± 3.30	15.59 ± 1.07
O <sub>3</sub> (ppb)	17.2 ± 1.40	17.0 ± 1.10	18.8 ± 2.50
TVOC (ppm)	8.22 ± 0.13	6.86 ± 0.05	7.08 ± 0.12
Wind speed (ms <sup>-1</sup> )	0.74 ± 0.04	1.00 ± 0.16	1.26 ± 0.22
Temperature (°C)	32.84 ± 0.99	32.22 ± 0.49	32.68 ± 1.04
Pressure (hPa)	14.15 ± 0.07	14.52 ± 0.14	14.59 ± 0.61
Heat Index (°C)	35.40 ± 3.95	36.70 ± 1.74	36.22 ± 2.49
Humidity (%)	66.26 ± 1.48	66.14 ± 1.87	64.88 ± 2.13
TVOC/NO <sub>x</sub>	6.32	10.72	5.85

NO<sub>x</sub> – Nitrogen oxide, SO<sub>2</sub> – Sulphur dioxide, CO – Carbon monoxide, TVOC – Total volatile organic compounds

### 2.1.3. Determination of Volatile Organic Compounds (VOCs)

Concentrations of volatile organic compounds (VOCs) were determined using method described by Olajire and Azeez [34] with slight modification. Tubes for sampling were conditioned at 90°C and checked for target VOCs before sampling. Air was drawn into tube containing 100 mg activated charcoal with P4LC sampler at rate of 0.5 l/min for 30 min. After each sampling, the tubes were tightly sealed and wrapped in aluminum foil. Duplicate samples were collected at each sampling point. The content in each tube was transferred into 10 ml vial borosilicate glass. The vial and its content were stoppered by silicone material and were transferred to the cell of headspace sampler coupled with gas chromatography equipped with flame ionization detector (GC-FID) for analysis of VOCs. An HP-VOC capillary column (25 m x 0.32 µm i.d x 0.12 µm film thickness) was used and carrier gas was ultra-pure hydrogen. The GC oven temperature was set initially to 35°C for 2 min., increasing at a rate of 5°C /min to 80°C and then holding for 10 min. Detector and injector temperatures were maintained at 300°C. The target VOC species were identified by their individual retention time.

Laboratory and field blanks were prepared and analyzed as sample.

### 2.2. Statistical Analysis

Data obtained are expressed as mean  $\pm$  standard deviation and were subjected to multivariate statistics using correlation and factor analyses. Correlation analysis was done using Pearson correlation to establish the relationship among different toxic pollutants. R was obtained at 99% confidence levels. Factor analysis was done using principal component analysis (PCA) technique. It was employed to reveal the likely sources and the contributions of different pollutants. Time series was used to provide diurnal pattern of pollutants. SPSS 17 was used for all analyses.

## 3. Results and Discussion

### 3.1. Toxic Pollutants and Meteorological Parameters

Concentrations of toxic pollutants and meteorological data

are presented in table 1.

NO<sub>2</sub> concentration was highest at SL1 and lowest at SL2. In terms of air quality index (table 2), NO<sub>2</sub> concentrations were very unhealthy in all locations [25]. Diurnal variation of NO<sub>2</sub> (Fig. 2a) shows two distinct peaks; one in the morning between 07.00-09.00 while the second was in the evening between 16.00-17.30. This could be as a result of high vehicular activities which are predominant sources of NO<sub>2</sub> at these locations in the morning and evening that coincide with the rush hours [20, 26].

NO concentration was highest at SL3 and lowest at SL2. Diurnal pattern (fig 2b) shows two peaks; early in the morning and in the evening. This was in agreement with results obtained by [11, 20].

Concentrations of CO ranged from 10.60 ppm at SL2 to 16.66 ppm at SL3. Average concentration of CO exceeded 8-hr maximum of 9 ppm and fell short of 1-hr maximum of 35 ppm of US national ambient quality standard at all locations [25]. This poses a great danger in terms of air quality index (table 2) because the air was unhealthy. CO is a product of incomplete combustion of fossil fuels; therefore, high average concentrations measured suggest vehicular and industrial burning of fossil fuels [26].

Concentrations of SO<sub>2</sub> ranged from 0.32 ppm to 0.82 ppm. Average concentrations at all locations were higher than 0.14 ppm (24-hr average) of US national ambient quality standard [25]. Air quality index (table 2) in terms of SO<sub>2</sub> shows that at SL1 and SL2, the air was very unhealthy while at SL3, the air was hazardous. Since SO<sub>2</sub> is emitted from combustion processes, its high concentrations are indicative of vehicular activities and industrial emissions [23].

Average O<sub>3</sub> concentrations ranged from 15.8 ppb at SL2 to 21.3 ppb at SL3. Average concentrations of O<sub>3</sub> at all locations were lower than 8-hr maximum of 80 ppb of US national ambient quality standard [25]. In terms of air quality index (table 2), the air was good at all locations. Its diurnal pattern (fig. 2c) shows two peaks; a broad peak spanning for two hours between 11.00-13.00 while a sharp peak occurred at 15.00. High peaks of O<sub>3</sub> observed in the noon could be due to the formation of ozone from photo-oxidation of the precursor gases such as CO, CH<sub>4</sub> and non-methane hydrocarbons in the presence of sufficient amount of nitrogen oxide (NO<sub>x</sub>) [16].

**Table 2.** Air quality index for criteria pollutants (USEPA 2000)

AQI CATEGORY	AQI rating	PM <sub>10</sub> (µgm <sup>-3</sup> )	NO <sub>2</sub> (ppb)	SO <sub>2</sub> (ppb)	CO (ppm)	O <sub>3</sub> (ppb)
Good (0-50)	A	0-54	0-53	0.000-34	0.0-4.4	0.0-59
Moderate (51-100)	B	55-154	54-100	35-144	4.5-9.4	60-75
Unhealthy for sensitive group (101-150)	C	155-254	100-360	145-224	9.5-12.4	76-95
Unhealthy (151-200)	D	255-354	360-640	225-304	12.5-15.4	96-115
Very unhealthy (200-300)	E	355-424	640-1240	305-604	15.5-30.4	116-374
Hazardous	F	>424	>1240	>605	>30.5	

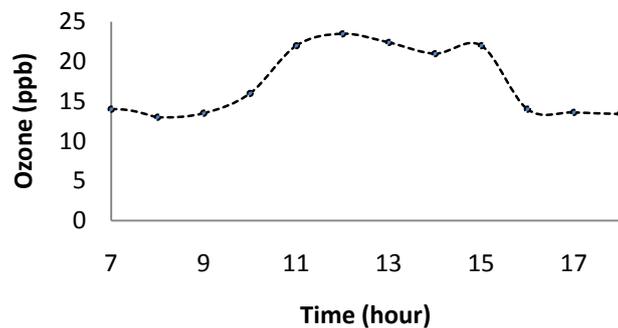


Figure 2c. Diurnal variations of ozone (O<sub>3</sub>)

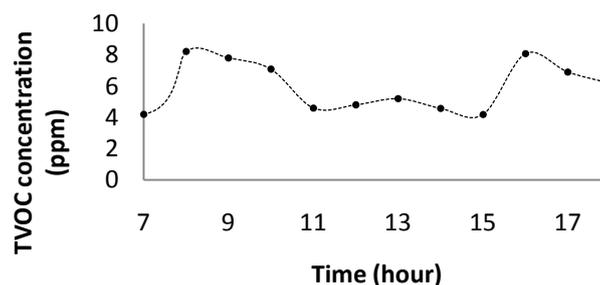


Figure 2d. Diurnal variations of total volatile organic compounds (TVOC)

Total volatile organic compounds (TVOC) concentrations were found in the range of 6.33 ppm to 8.35 ppm. Highest concentration was measured at SL1. Diurnal pattern (fig. 2d) of TVOC shows a distinct peaks in the morning between 08.00 – 08.30 and in the evening between 16.00 – 16.30. Like NO<sub>x</sub>, high concentrations of TVOC coincided with the rush hours in the morning and evening.

Temperature ranged from 31.64°C to 33.83°C. Wind speed was found in the range 0.70 ms<sup>-1</sup> to 1.48 ms<sup>-1</sup>. Pressure, heat index and relative humidity ranged from 14.08 – 15.20 hPa, 31.45 – 39.35°C and 62.75 – 67.74% respectively. Meteorological parameters such as those measured in this study have been found to play important roles in the formation, dilution, transport and dispersal of pollutants. They have also been found to influence tropospheric ozone concentrations and its precursors [11, 27, 28]. Increase in temperature and pressure as obtained in this study led to increase in ozone concentration while decrease in humidity and wind speed led to increase in ozone concentration. This is in agreement with results obtained by [29, 30].

Factor analysis using principal component analysis (PCA) was used to predict the possible sources and contributions of each pollutant measured. The result is presented in table 3. Three factors were extracted by PCA and they accounted for 82.89% of total variance (eigenvalue ≥ 1). Factor 1 (F1) with variance of 41.23% highly correlated with wind speed, NO<sub>x</sub>, TVOCs and averagely correlated SO<sub>2</sub>, and CO. This is identified as a factor indicating anthropogenic sources such as vehicular activities and industrial emission [23]. It also shows that emission and dispersal of these pollutants are controlled by meteorological parameters such as wind speed

[28]. Factor 2 (F2) with variance of 21.91% highly correlated with O<sub>3</sub> and pressure but averagely correlated with temperature. This suggests photochemical production of O<sub>3</sub> influenced by temperature and pressure. Factor 3 (F3) with variance of 19.75% correlated with temperature, CO and total volatile organic compounds. This shows that the emission and reaction of CO and volatile organic compounds are temperature dependent.

Table 3. Factor analysis of toxic pollutants and meteorological parameters

Pollutants	Component			Communalities
	F1	F2	F3	Extraction
Nitrogen oxide	0.882			.850
Sulphur (IV) oxide	0.512			.945
Carbon (II) oxide	0.618		0.617	.839
Pressure		0.850		.795
Wind speed	0.899			.842
Temperature		0.610	0.568	.903
Ozone		0.919		.930
TVOCs	0.710		0.799	.653

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Only factor loadings ≥ 0.5 listed

Correlation analysis using Pearson correlation established negative correlations between O<sub>3</sub> and NO<sub>2</sub> (r = -0.766), O<sub>3</sub> and CO (r = -0.814) and moderate correlation between O<sub>3</sub> and pressure (r = 0.543). This shows that as CO and NO<sub>2</sub> were consumed, ozone was produced, and pressure played

important role in the formation of O<sub>3</sub>. It has been discovered that photo-oxidation of CO, NO<sub>x</sub> and non-methane hydrocarbons in the presence of meteorological parameters favours the formation of O<sub>3</sub> [11, 16]. High correlations were also obtained for CO and temperature ( $r = 0.799$ ), TVOC and temperature ( $r = 0.918$ ), pressure and wind speed ( $r = 0.737$ ). This could point to meteorologically-controlled emissions from anthropogenic sources.

### 3.2. Volatile Organic Compounds Concentrations

Average concentrations of seventeen VOCs measured belonging to alkane, alkene, aromatic and chlorinated hydrocarbons are presented in table 4. Abundance of VOCs species measured follows SL2 (34.70%) > SL1 (34.20%) > SL3 (31.10%). n - ethane, propene, m,p - xylene and tetrachloroethene dominated alkane, alkene, aromatic and chlorinated hydrocarbons groups respectively. Aromatic hydrocarbons were found to be most abundant at SL1 and SL3 while alkane hydrocarbons accounted for highest abundance at SL2. Alkene hydrocarbons had the lowest

abundance at all locations. m/p - xylene was the most abundant at all locations accounting for 16.28%, 11.66% and 14.06% at SL1, SL2 and SL3 respectively.

VOCs in the atmosphere are emitted from mainly two sources; combustion and solvent evaporation [18]. They are very reactive and are dependent on meteorological parameters, thus, their levels are not determined only by their emissions. However, the ratios of levels for VOC pairs, which are not influenced by dilution, can be used to trace sources if they remain relatively stable during atmospheric reactions or are changed with atmospheric reactions [29, 31].

Benzene to toluene ratio has been used to identify VOCs sources. A *B/T* ratio of 0.5 has been reported to be characteristic of combustion from vehicular activities while higher values have been reported for bio-fuel burning, charcoal and coal burning [19, 32]. The main source of benzene is the combustion process from traffic exhaust and industrial emissions because of its use as solvent has been forbidden in the industries [18, 19, 26].

**Table 4.** Average concentrations and ozone formation abilities of VOC species

VOC	Concentration ( $\mu\text{g m}^{-3}$ )			MDL ( $\mu\text{g m}^{-3}$ )	MIR <sup>a</sup>	O <sub>3</sub> formation ( $\mu\text{g m}^{-3}$ )		
	SL1	SL2	SL3			SL1	SL2	SL3
Alkane H/C								
Ethane	10.39±0.50	7.89±0.13	11.70±2.14	0.64	0.25	2.60	1.97	2.93
Propane	9.22±0.76	7.61±0.28	7.47±0.69	0.1	1.15	10.60	8.75	8.59
Butane	12.09±0.27	13.27±1.12	10.03±0.23	0.1	2.54	30.71	33.71	25.48
Pentane	8.46±0.49	10.55±1.45	5.66±0.27	0.1	3.94	33.33	41.57	22.30
Hexane	2.19±0.31	7.12±0.61	4.41±0.04	0.1	5.61	12.29	39.94	24.74
Heptanes	5.58±0.52	2.64±0.05	5.51±0.08	0.2	7.15	39.90	18.88	41.38
Octane	4.81±0.15	9.33±0.99	2.53±0.19	0.3	8.68	41.75	80.98	21.96
Decane	2.65±0.45	6.03±0.13	3.88±0.22	0.3	11.60	30.74	69.95	45.01
Alkene H/C								
Ethene	6.88±1.01	5.27±0.47	8.05±0.16	0.13	8.52	58.62	44.90	68.59
Propene	13.97±2.70	17.15±0.40	12.75±1.72	0.6	26.30	367.41	451.05	335.33
Aromatic H/C								
Benzene	8.45±0.27	8.82±0.84	9.18±0.50	0.19	1.23	10.39	10.85	11.29
Toluene	13.39±0.03	15.58±0.19	15.06±3.20	0.47	5.96	79.80	92.86	89.76
Ethylbenzene	6.32±0.10	4.88±0.12	6.78±0.66	0.82	7.10	44.87	34.65	48.14
m,p-Xylene	28.53±5.29	20.76±0.17	22.36±0.81	0.51	19.00	542.07	394.44	424.84
o-xylene	10.97±2.52	11.51±3.15	8.01±0.28	0.29	13.70	150.29	157.69	109.74
Chlorinated H/C								
TCE	9.94±0.32	13.06±0.30	7.35±0.55	0.14	0.64	6.36	83.58	4.70
TeCE	21.39±0.75	16.61±1.14	18.26±0.72	0.66				
B/T	0.63	0.57	0.61					
<i>Toluene/m,p-xylene</i>	0.45	0.75	0.67					
$\Sigma$ Xylene/CO	2.71	2.32	1.95					
TCE/CO	0.68	0.94	0.47					
TeCE/CO	1.47	1.19	1.17					

Alkane H/C – Alkane hydrocarbons, Alkene H/C – Alkene hydrocarbons, Aromatic H/C – Aromatic hydrocarbons, Chlorinated H/C – Chlorinated hydrocarbons, O<sub>3</sub> formation ( $\mu\text{g m}^{-3}$ ) = <sup>a</sup>[VOC]×MIR, MDL – Method detection limit

*B/T* ratios (table 4) of 0.63, 0.57 and 0.61 for SL1, SL2 and SL3 respectively suggest that vehicular activities were the major VOC contributors to aromatic hydrocarbons emission in this study. The ratios in this study are in agreement with results obtained by [18, 20].

Other ratios that can be used as markers to identify VOC emission sources are *toluene/m,p-xylene*, *xylene/CO*, *TCE/CO* and *TeCE/CO*. Xylene, trichloroethene and tetrachloroethene are used as industrial solvents in the production of paints, plastic and as degreasers while CO results from incomplete combustion [24, 26, 31]. These ratios are therefore indicators of solvent use relative to combustion sources. Low ratios (table 4) calculated for all locations suggest solvent evaporation. This agrees with results obtained by [31, 33]. Plastic industries and other manufacturing companies in and around the sampling locations could be the responsible sources of these pollutants.

**Table 5.** Factor analysis of VOC species

Compounds	Component			Communalities Extraction
	F1	F2	F3	
ethane				0.922
propane		0.948		0.956
butane	0.969			0.945
pentane	0.969			0.942
hexane				0.949
heptane		0.674		0.997
octane	0.950			0.991
decane	0.574			0.953
ethene				0.915
propene	0.835			0.892
benzene			0.900	0.819
toluene			0.775	0.709
ethylbenzene				0.890
m/p-xylene		0.947		0.900
o-xylene	0.765			0.821
TCE	0.977			0.987
TeCE		0.962		0.961

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Only factor loadings  $\geq 0.5$  listed

Factor analysis using PCA was employed to identify different sources of emission of VOCs. Factors extracted by PCA which accounted for 89.79% of total variance (eigenvalue  $\geq 1$ ) are presented in table 5. Factor 1 with variance 47.25% is highly loaded with ethane, butane, pentane, octane, propene, o-xylene and trichloroethene. Ethane, butane and pentane are usually products of unburned vehicular emission, gasoline evaporation, liquefied

petroleum leakage, propene is a characteristic product of internal combustion engine while o-xylene and trichloroethene are solvent related [18, 19, 20]. Factor 2 is highly loaded with propane, heptane, m/p-xylene and tetrachloroethene. This is related to solvent evaporation. Propane is emitted from gasoline evaporation while m/p-xylene and tetrachloroethene are emitted from fuel and other solvents evaporation [19]. Factor 3 correlated highly with benzene and toluene. This indicates combustion related emission for benzene and industrial applications using solvents for toluene [18].

Factor analysis and ratios calculated for volatile organic compounds reveal industrial emission, vehicle exhaust and solvent evaporation as their sources.

### 3.3. Ozone Formation and Apportionment

The ratio of  $VOCs/NO_x$  can be used to evaluate whether the production of  $O_3$  is VOC-sensitive or  $NO_x$ -sensitive [34]. Morning  $VOCs/NO_x$  ratios lower than 10 were equated with VOC-sensitive peak ozone and Morning  $VOCs/NO_x$  ratios greater than 20 correspond to  $NO_x$ -sensitive peak ozone [11, 35]. In this study, TVOC to  $NO_x$  ratios (table 1) are lower than 10 in SL1 and SL3 while it is higher than 10 at SL2. This indicates that at all locations,  $O_3$  formation is VOCs sensitive.

VOCs are ozone-forming species, thus, photochemical reactivity of measured VOCs were estimated using maximum incremental reactivity (MIR). The results are presented in table 4. m/p-xylene was the highest contributor to  $O_3$  formation at SL1 and SL3 while propene had highest contribution at SL2. Ethane contributed the least to  $O_3$  formation.

Since  $O_3$  formation at all locations was VOC sensitive and m,p-xylene which is solvent related played the most important role in  $O_3$  formation at all locations, it could therefore be deduced that solvent use and unburned fuel were the major contributors to  $O_3$  formation at all locations.

## 4. Conclusions

In this study, we have reported the concentrations of toxic pollutants, volatile organic compounds and meteorological parameters measured in three locations of Ilupeju industrial Estate. Concentrations of toxic pollutants such as CO,  $NO_2$  and  $SO_2$  were higher than acceptable limits and were dependent on meteorological parameters such as temperature, pressure, humidity and wind speed. Majority of VOCs ratios revealed solvent related and unburned fuel emissions from these locations except *B/T* ratio which indicated a traffic related emission. m,p-xylene and propene were the major contributors to  $O_3$  formation at SL1, SL2 and SL3 respectively. Ozone determined was VOC sensitive at all locations. PCA of the results showed traffic related emission sources for toxic pollutants and solvent use as sources for VOCs.

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