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Impacts of varied industrial activities within southern Nigeria on air environment and human health

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Abstract

The contamination of air environment by industrial activities is a global problem mostly in the underdeveloped and developing Nations where environmental issues are handled with levity. This research investigated the impact of industrial activities on air environment at the following companies; Crude Oil processing (COPC), beer processing (BPC), asphalt processing (APC), metal processing (MPC), and construction Company machinery Yard (CCMY) in Southern Nigeria. Air Monitors were employed to quantify nitrogen (IV) oxide (NO_2), sulphur (IV) oxide (SO_2), hydrogen sulphide (H_2S), cabon (II) Oxide CO, total volatile organic carbon (TVOC), and suspended particulate matter (SPM) at the studied locations. The mean values of NO_2, SO_2, H_2S, and CO obtained at all the industrial locations were higher than their recommended limits by the Federal Environmental and protection Agency (FEPA) except at BPC. The mean levels of TVOC were higher than the limit at all the locations apart from BPC and CCMY. However, the mean levels of SPM at all locations were higher than the permissible limit. The general trend for the discharge of air pollutants indicated that, COPC and BPC were rated the highest and lowest, respectively. The air quality index (AQI) values obtained revealed that, all the air pollutants at all the locations except BPC were harmful to human health. Nevertheless, the mean AQI value of SPM at BPC was also in the hazardous class. The Principal component analysis (PCA) confirmed that, industrial activities at the studied locations were responsible for the accumulation of these toxic substances in the adjoining air environment. Hierarchical cluster analysis (HCA) for the air pollutants corroborated that most of the parameters were from a common source. HCA for the studied locations indicated similarities between BPC and CCMY, APC and MPC, while COPC was in a separate cluster. Thus, this study has shown the effects of untreated gases released from industries into the air on the environment and appropriate measures should be adopted to ameliorate the trend.

Keywords: Air pollution; Industrial wastes; Toxic gases, Environmental impact; Air quality index; Nigeria

1. Introduction

Environmental pollution has been one of the most challenging problems of human beings on earth. However, the contamination of the human environment is caused mostly by human-related activities [1, 2, 3]. Industrial activities can release high levels of toxic substances into the environment especially air [4, 5, 6]. Elevated levels of toxic substances such as CO, CH_4, NO_2, SO_2, Cl_2, NH_3, HCN, CH_2O, VOCs, SPM, PAHs, and metals are emitted into the air environment from industries [7, 8]. These substances have negative effects on both the environment and human health [9, 10]. Air pollution affects human health in diverse ways; it can cause diabetes, asthma, respiratory disease, damage the immune system and even death [11, 12]. According to Vohra *et al.* [13], prolonged exposure to polluted air environment has been a major source of human death worldwide.

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The entire industrial activities investigated in this study are related to the combustion of fossil fuel hence, they have the tendency of releasing obnoxious substances including gases into the surrounding air environment [14, 15]. The processing of crude oil has the potential of discharging high levels of toxic substances into the air [16, 17, 18]. Studies have revealed that processing of metals can pollute the air, soil and aquatic environments, affects human health as well [19, 20]. Literature has also indicated that, the processing of asphalt has the potentials of releasing high concentrations of harmful substances into the atmosphere [21, 22, 23]. Heavy-duty trucks, machines, and road construction can release significant amounts of poisonous gases and SPM into the environment [24, 25, 26]. Beer production processes have the capacity of polluting the environment including air with harmful substances [27, 28, 29]. Hence, this study was undertaken to assess the potentials of each of these companies on the release of toxic gases and SPM into the adjoining air environment. Results of this study will be useful to both the workers and the public on the use of safety gadgets. It will also inform the government on the enforcement of rules concerning the proper management of industrial wastes.

2. Material and methods

2.1. Study Area

Akwa Ibom State, the study area is within the Niger Delta Area of Nigeria. The State lies between latitudes 4^0 32′ and 5^0 33′ North and longitudes 7^0 25′ and 8^0 25′ East in Nigerian Map. The State is bounded by Cross River, Rivers/Abia States, and Atlantic Ocean on the east, west, and south, respectively [30]. The two outstanding seasons experienced in the area are dry and wet seasons. The dry season begins in November and ends in March, while the wet season runs from April to October. The studied location is within the humid tropics and has abundant rainfall with high temperature. The yearly rainfall and temperature range from 2,000 to 3,000 mm and 25 to 29 °C, respectively. As a State within the oil rich zone of Nigeria, it has high population density, high commercial and industrial activities, and very high levels of wastes are generated within the area. Nevertheless, the waste products so generated are improperly managed. The flaring of gas by Oil processing Company in the area has generated very high levels of toxic pollutants into the air environment. Consequently, the gaseous wastes generated by the Oil and other companies in the State have negative effects on the air environment and the food chain.

2.2. Analytical Procedures

Gasman Air Monitors were used for the collection of data concerning the studied air pollutants and the industrial areas investigated. The study was conducted by placing the handheld portable equipment in an open air space at each location, adjusts it to the TEST point, and maintained it for 120 seconds. The Monitor was later set to the GAS point and readings were obtained in triplicates when the display on the LCD was constant [31, 32]. The air Monitors and their respective air pollutants measured are shown in Table 1 below.

Table 1 Air Monitors used for the determination of Air pollutants

Air Pollutant	Equipment	Range	Alarm Level
NO_2	NO_2 Crowcon Gasman Model 19831H	0- 10 ppm	2.0 ppm
SO_2	SO_2 Crowcon Gasman Model 19648H	0- 10 ppm	3.0 ppm
H_2S	H_2S Crowcon Gasman Model 19502H	0- 50 ppm	10.0 ppm
CO	CO Crowcon Gasman S/N: 19252H	0- 500 ppm	50.0 ppm
SPM	Haz-DustTm 10 μg/m^3 particulate monitor	0.01 – 200 μg/m^3	1.50 μg/m^3

2.2.1. Air Quality Index (AQI)

The evaluation of Air quality index of the pollutants was done with Equation (1) as described by USEPA [33].

$$\text{AQI} = \frac{Concentration of Air Contaminant}{Recommended Limit of the Contaminant} x\ 100 \text{ --- (1)}$$

According to Longinus *et al*. [34], there are six categories of air quality index and their associated human health problems (Table 4).

2.2.2. Extent of variability among the determined air pollutants

The coefficient of variation (CV) used to assess the degree of variability among the studied air pollutants was done using Equation 2.

$$CV = \frac{Standard\ Deviation}{Mean} \ x\ 100 \text{ -- } (2)$$

Based on the Judice*et al*. [35] classifications, CV < 10.3% is in the low class, CV between 10.3 and 31% belongs to the medium class, CV in the range of 31.6 - 61.7% is in high class, while CV > 61.7% belongs to the very high class.

2.2.3. Data Treatment

Data for each the air pollutants were collected at the various studied industrial locations and treated statistically using IBM SPSS Statistics 20 (IBM USA). The mean, standard deviation, minimum, and maximum values were obtained from the Excel sheet of the SPSS Statistics 20. Multivariate analyses (Principal component analysis, and Hierarchical cluster analysis) were carried out using Duncan's multiple tests. Principal component analysis (PCA) was done on six (6) air pollutants with Varimax rotation procedures and values below 0.622 were not considered. The Hierarchical cluster analysis (HCA) was performed with Dendrograms to categorize common air pollutants and locations into similar clusters.

3. Results and discussion

Table 2 Levels of Air Pollutants at the various Industrial Areas investigated

	NO_2 ppm	SO_2 ppm	H_2S ppm	CO ppm	TVOC mg/m^3	SPM ppm
COPC	0.50	0.66	0.62	21.0	4.731	421.5
BPC	0.10	0.11	0.11	3.02	0.053	135.8
APC	0.42	0.50	0.28	10.03	2.704	361.3
MPC	0.40	0.51	0.48	16.03	1.665	319.0
CCMY	0.64	0.30	0.40	11.20	0.452	155.3
Min	0.08	0.10	0.10	2.96	0.05	134.00
Max	0.66	0.67	0.63	22.00	4.821	423.00
Mean	0.41	0.42	0.37	10.67	1.923	278.30
SD	0.19	0.20	0.19	6.23	1.781	119.78
CV	46.3	47.6	51.4	59.0	92.7	43.0
RL	0.10	0.50	0.20	5.00	0.50	15.00

COPC = Crude oil processing company; BPC = Beer processing company; APC = Asphalt processing company; MPC = Metal processing company; CCMY = construction company machinery yard; Min = Minimum; Max = Maximum; SD= Standard Deviation; CV = Coefficient of Variation; RL = Recommended Limit

Table 3 Air quality index (AQI) of air pollutants obtained at the different industrial areas

	NO_2	SO_2	H_2S	CO	TVOC	SPM
COPC	500	132	310	420	946.2	2,810
BPC	100	22	55	60.4	10.2	905.3
APC	420	100	140	200.6	540.8	2,408.7
MPC	400	102	240	320.6	333	2,126.7
CCMY	640	60	200	224	90.4	1,035.3

COPC = Crude oil processing company; BPC = Beer processing company; APC = Asphalt processing company; MPC = Metal processing company; CCMY = construction company machinery yard

Table 4 Air quality Index Ranking and their implications on human health

Range of AQI	AQI RATING	Health status	Related health risk
0 – 50	A	Good	Slight or no health hazard
51 – 100	B	Moderate	Favourable for all manners of people except those sensitive to ozone of air particulate may experience respiratory signs.
101 – 150	C	Unhealthy for sensitive groups	It may affect those in the sensitive group however; the non-sensitive class may not be susceptible to the impact.
151 – 200	D	Unhealthy	Those in the sensitive class may experience serious health problems.
201 – 300	E	Very Unhealthy	It causes health alert to everyone hence,it can affect everyone health.
> 300	F	Hazardous	Serious human health problems for both sensitive and non-sensitive classes.

3.1. Levels of Air Pollutants at the Industrial Areas examined and their Air Quality Indices

Results of the levels of air pollutants determined at the different industrial areas are in Table 2. The general results indicated that nitrogen (IV) oxide (NO_2) ranged from 0.08 to 0.66 ppm with an average value of 0.41±0.19 ppm. The reported range is higher than 0.1 – 0.2 ppm obtained at Najaf, Iraq by Kizar *et al*. [36]. The mean concentrations of NO_2 at all the industrial locations investigated except beer processing Company (BPC) were higher than the FEPA [37] recommended limits of 0.10 ppm (Table 2). Hence, industrial activities might have discharged high levels of NO_2 into the air environment. Prolonged exposure to these levels of NO_2 can have serious health problems such as lung cancer, asthma, stroke, heart diseases, etc on the workers at the studied companies [38]. The highest level of NO_2 was recorded at the construction company yard (CCMY) where a lot of trucks, buses, cars, and machineries are operated. This corroborates the findings by Restrepo [39] that, transportation and burning of fossil fuels are the major sources of NO_2. The trend recorded for the distribution of NO_2 at the studied locations varied as follows: CCMY > COPC > APC > MPC > BPC. The Air quality index (AQI) of NO_2 for the studied locations revealed that, all the locations except BPC were in the hazardous group (Table 3). Thus, the air pollutant can have adverse health effects on those exposed to it for a long time as indicated in Table 4 [34].

Sulphur (IV) oxide (SO_2) at the air environment within the studied industrial areas varied from 0.10 to 0.67 ppm. Concentrations of SO_2 obtained are higher than 0.03 – 0.135 ppm reported at Jemita/Yola Metropolis, Adamawa State, Nigeria by Maitera *et al*. [40]. The highest SO_2 level was obtained in air environment within a crude oil processing Company. The high levels of the air pollutant at Oil processing environment is in agreement with the findings by Hannun and Razzaq, [41]. The mean levels of SO_2 at all the locations examined except BPC and CCMY were higher than the recommended limit by FEPA [37] (Table 2). These levels of SO_2 can affect the respiratory system; it can also cause asthma, coughing, bronchitis [42]. Consequently, the processing of crude oil, asphalt, and metals can discharge high levels of SO_2 into the air environment. The discharge of SO_2 into the surrounding air environment by the various industries followed the order: COPC > MPC > APC > CCMY > BPC. Hence, the processing of beer discharged the lowest level of SO_2 into the air environment.

AQI values of SO_2 for the different studied locations were 132.0, 22.0, 100.0, 102, and 60 for COPC, BPC, APC, MPC, and CCMY, respectively (Table 3). Thus, COPC and MPC were in the unhealthy for the sensitive group's class, BPC in the good category, while APC and CCMY were in the moderate class. The respective human health problems associated with each class is indicated in Table 4.

Hydrogen sulphide (H_2S) in the industrial areas studied ranged between 0.10 and 0.67 ppm. The obtained range is higher than 0.1-0.2 ppb reported in western Canada by Burstyn *et al*. [43]. Results in Table 2 indicate that, the mean concentrations of H_2S at all the studied locations except BPC were higher than the permissible limit of 0.20 ppm for unpolluted air by FEPA [37]. Thus, industrial activities at all the studied areas except beer processing could have released high levels of H_2S and pollute the atmosphere. The highest level of H_2S was recorded in an oil processing area thus; burning of fossil fuels is associated with the discharge of high amounts of H_2S into the atmosphere [44]. H_2S is referred to as "knock down gas" because prolonged exposure to elevated levels of H_2S as reported in this study at all the stations examined except BPC can result in the loss of consciousness and death [45]. Exposure to the gas over time can also cause dizziness, headache, vertigo, nausea, and delirium [46]. The levels of H_2S discharged by the different industrial activities followed the order: COPC > MPC > CCMY > APC > BPC.

Air quality indices of the H_2S at the different locations revealed that, COPC belongs to the hazardous class, BPC is in the moderate class, APC belongs to the Unhealthy for sensitive group's class, MPC is in the very unhealthy class, while CCMY belongs to the unhealthy class [34]. The implications for each of the classes on human health are shown in Table 4.

Carbon (II) oxide (CO) discharged by the various industrial activities varied from 2.96 to 22.0 ppm (Table 2). The range reported is lower than 7.67 - 35.83 ppm reported in industrial area of Orchard Street Batam City, Indonesia by Yodi *et al*. [47]. The mean concentrations of CO at the studied locations except BPC were higher than the recommended limit by FEPA [37] (Table 2). Exposure to the reported levels of CO can cause fatigue, nausea, chest pain, confusion, headache, blurred vision, vomiting, and brain and heart damage over time [48, 49]. The highest level of CO was reported at a crude oil processing Company (COPC). This confirms that the processing of fossil fuel can discharge high levels of CO into the atmosphere as reported by Perera, [15]. Levels of CO discharged by the different industrial facilities investigated varied as follows: COPC > MPC > CCMY > APC > BPC.

Results of the AQI of CO for the various industrial areas investigated revealed that, COPC and MPC were in the hazardous class, BPC in moderate class, APC in unhealthy for sensitive groups class, whereas CCMY was in the very unhealthy class (Table 3). The relative human health problems for each of the classes are in Table 4.

Levels of total volatile organic compounds (TVOCs) at the industrial areas investigated ranged between 0.05 and 4.821 mg/m^3 (Table 2). The range of total volatile organic compounds obtained is higher than 32.81 – 47.22 $\mu g/m^3$ reported in Delhi, India by Singh *et al*. [50]. The mean values of TVOCs at COPC, APC, and MPC were higher than the recommended limit for unpolluted air by FEPA [37], whereas the values obtained at BPC and CCMY were within the limit. Hence, the activities at COPC, APC, and MPC might have discharged very high levels of TVOCs into the surrounding air environment. Consequently, exposure to the levels of TVOCs at these locations can affect the nose, throat, and eye; it can also cause loss of coordination, irritation, headache, nausea and damage to the central nervous system, kidney, and liver over time [51, 52]. The highest mean concentration of TVOCs was obtained at an oil processing Company (COPC). Thus, processing of fossil fuels is a major source of TVOCs in the air environment [53, 54]. The discharge of TVOCs into the air environment by the various companies investigated followed the order: COPC > APC > MPC > CCMY > BPC. This confirms the strong relationship between TVOCs and burning of fossil fuels as the crude oil and asphalt processing Companies were the first two in the sequence.

The AQI of TVOCs for the different companies indicated that, COPC, APC, and MPC were in the hazardous class, BPC in the good category, whereas CCMY was in the moderate class (Table 3). Hence, the workers and others constantly exposed to the levels of TVOCs discharged at COPC, APC, and MPC may experience related human health problems reported by Li and Yan, [51] and Zhou *et al.* [52].

Suspended particulate matter (SPM) at the studied locations varied from 134.0 to 423.0 ppm. This is lower than 229.0 – 537.0 $\mu g/m^3$ recorded at industrial Town of Punjab, India by Susheel *et al*. [55]. Results in Table 2 indicate that the mean concentrations of SPM at all the studied locations are higher than the permissible limit by FEPA [37]. Thus, the industrial activities at all the studied locations might have released significant amounts of SPM into the adjoining air environment. The highest SPM value was recorded for the air environment in an oil processing Company. This corroborates the reports that, burning of fossil fuel can discharge substantial amounts of SPM into the air environment [56, 57]. Levels of SPM reported at all the locations can cause asthma in both the children and adult populations. It can also cause irritation of the eyes, throat, and nose, cough, diseases of the heart and lungs [58, 59]. The rate for the discharge of SPM into the air environment by the studied industries followed the sequence COPC> APC > MPC > CCMY > BPC.

The air quality index (AQI) evaluation of SPM at the studied locations indicated that, all the locations were in the hazardous class (Table 3) [34]. Apart from the health issues reported by Pandey *et al*. [57], other health problems associated with human exposure to elevated SPM are shown in Table 4.

3.2. Variations among the air pollutants

Results in Table 2 indicate that, the degree of variability (CV) of NO_2, SO_2, H_2S, CO, and SPM were in the high class according to Judice *et al*. [35] classifications. However, the site-to-site variability of TVOC was in the very high category [35]. The overall results obtained indicated that, the site-to-site degree of variability among the air pollutants followed the order TVOC > CO > H_2S > SO_2> NO_2> SPM. Hence, the rate at which these air pollutants are discharged into the air environment varied with the industrial activities.

3.3. Multivariate Analyses of Air Pollutants

Table 5 Principal Component analysis (PCA) of Air Pollutants in the studied Industrial Areas

Air Contaminant	PC1
NO_2	0.624
SO_2	0.979
H_2S	0.924
CO	0.965
TVOC	0.902
SPM	0.892
% Total Variance	79.0
Cumulative %	79.0
Eigen value	4.74

3.3.1. Principal Component Analysis of Air Pollutants at the various studied Locations

Principal component analysis (PCA) employed for the identification of the actual source of air contaminants in the studied industrial areas identified one main factor as being responsible for the accumulation of these contaminants in the studied environments [2]. Results in Table 5 indicate that, the Factor (PC1) had Eigen value of 4.74 with total variance of 79.0%. Results of PC1 revealed that, the air environment within the studied industrial areas were significantly influenced by NO_2, SO_2, H_2S, TVOC, and SPM (Table 5). This confirms the negative impact of industrial activities on the air environment as previously reported [60, 61]. Consequently, industrial activities within the studied areas might have released substantial amounts of these air contaminants into the adjoining air environment [6].

3.3.2. Hierarchical cluster analysis (HCA) of Air pollutants and the studied locations

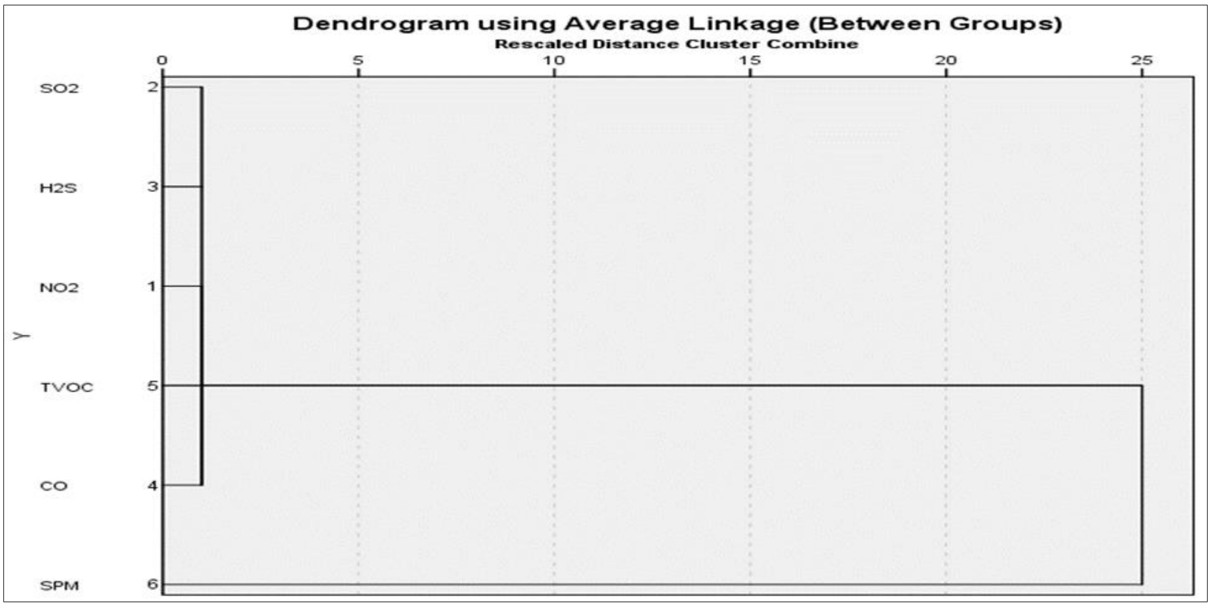

Figure 1 Hierarchical cluster analysis of Air Pollutants

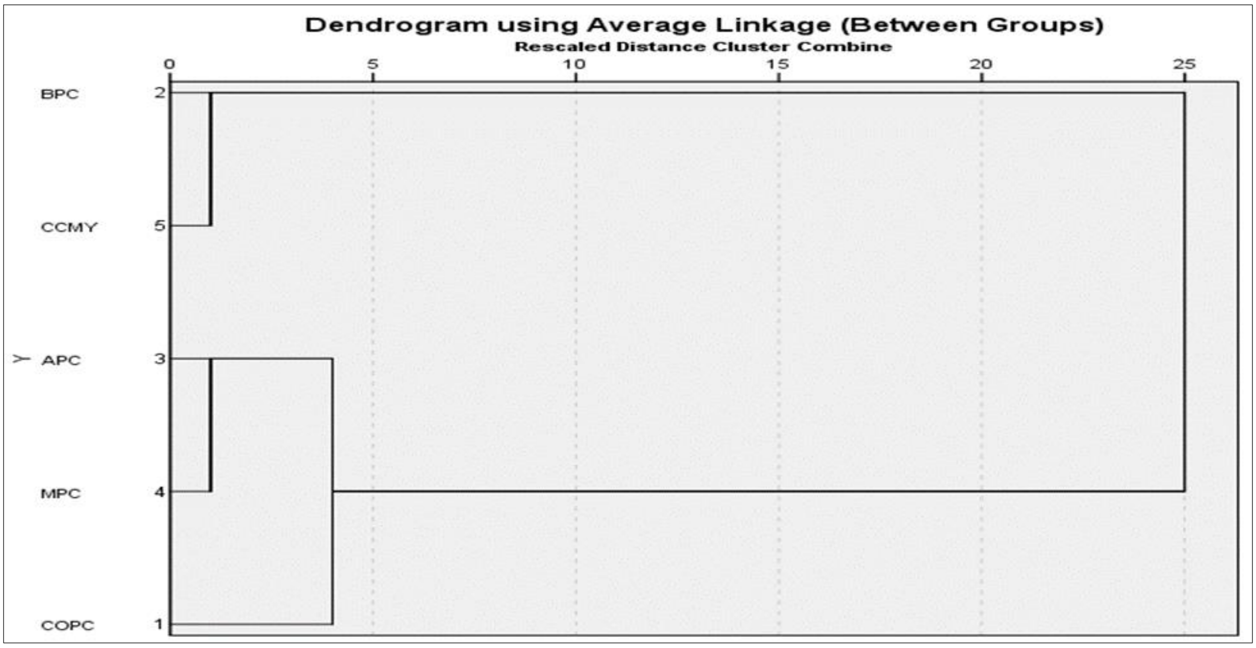

Figure 2 Hierarchical cluster analysis of the various studied Locations

Results of the Hierarchical cluster analysis of the air pollutants and the different studied locations are in Figures 1 and 2, respectively. Results of the Hierarchical cluster analysis (HCA) of air contaminants determined in the studied industrial areas are shown in Figure 1. The common associations among the air contaminants determined in the studied industrial areas revealed two principal clusters [62, 63]. The two clusters as shown in Figure 1 are

- The one that connects NO_2, SO_2, H_2S, CO, and TVOC
- The second cluster connects SPM only.

Consequently, all the parameters except SPM may have common source, while SPM emanated mostly from sources different from other parameters determined [64, 65].

The site-to-site relationships were evaluated using cluster analysis and the results obtained are shown in Figure 2. Results obtained showed three major clusters as follows:

- Cluster one groups beer processing company (BPC) and construction company machinery yard (CCMY) together
- Cluster 2 connects Crude oil processing (COPC) and Metal processing company (MPC) into a similar group
- The third cluster contains Crude Oil processing Company (COPC) only.

This is a clear manifestation of the fact that, BPC and CCMY might have discharged similar contaminants; APC and MPC released similar contaminants, while COPC released greater amounts of peculiar air contaminants into the surrounding air environment [66, 67].

4. Conclusion

The study examined the rate at which different industrial activities impacted on the human environment by releasing toxic substances into the surrounding atmosphere. It was observed that, all the industrial activities discharged some harmful substances into the air environment though at different rates. The mean levels of all the substances at all the industrial areas reached their nuisance levels except beer processing Company (BPC). Consequently, all the industrial areas investigated except BPC released high levels of these air pollutants into the adjoining air environment. The air quality index (AQI) evaluation also confirmed the hazardous nature of the substances released by all the industrial activities examined except BPC. Principal component analysis identified that, the major source of all the air pollutants examined were generated mainly by the industrial activities. The study also identified crude oil processing company (COPC) as the one that released the highest levels of all the air pollutants except NO_2, which was highest at construction company machinery yard (CCMY). The outcome of the study might have revealed that, most if not all the companies investigated did not treat their wastes properly. Hence, the workers could be exposed to serious health risks associated with these toxic air pollutants over time. Consequently, the authorities concern should enforced strict compliance to the proper waste management procedures to forestall severe human health issues in the areas where these industrial activities are carried out.

Compliance with ethical standards

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Disclosure of conflict of interest

There was no conflict of interest.

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