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Spatial Patterns of Urban Air Pollution in an Industrial Estate, Lagos, Nigeria

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Abstract:- This study investigated the distribution of SO_2, NO_2, PM_{10}, CO, H_2S, CH_4 and noise in ambient air of Tin-Can port industrial estate Apapa, Lagos, Nigeria. Measurement was carried out at seven selected sampling sites in the months of October and November 2011. As a general finding, the selected air pollutant concentrations for SO_2 and NO_2 exceeded the USEPA national ambient air quality standards indicating traffic emissions and industrial sources. A statistical analysis using principal component analysis revealed that PC1 had high contributions from SO_2, CO, H_2S, Noise and moderate contribution from PM_{10}(38.92 %) and was strongly associated with fossil fuel combustion, industrial sources and some non-road diesel equipment releasing sulphur dioxide into the air. PC2 was heavily enriched with NO_2 (18.84 %) and was attributed to emissions from vehicles such as buses, vans, taxis, cars, motorcycles and trucks. Cluster analysis (CA) revealed two subgroups: Cluster 1 (NO_2), Cluster 2 (SO_2, CO, H_2S), which agree with the PCA results. Our results suggest that appropriate vehicle emission management coupled with industrial air pollution control should be applied to coarse particulate (PM_{10}) and gaseous pollutants in the study area.

Keywords:- Industrial sources, gaseous pollutants, PM_{10}, spatial variations, statistical analysis.

I. INTRODUCTION

Over the last 50 years, the world's urban has grown faster (27% yr^{-1}) than the total population (1.8% yr^{-1}) and is estimated to reach 5 billion by 2030. For the first time in human history the world now has more urban than rural residents with many environmental consequences [5, 7, 17]. An offshoot of this rapid industrialization is the emergence of megacities (population > 10 million) with a combined worldwide population of nearly 300 million. Megacities are dense centers of population, economic activity and pollutant emissions, at the same time they are areas where effective pollution control strategies could realize maximum benefit [6, 16, 17]. The recent estimate of the World Health Organization [24] that 4.6 million people die each year due to causes directly attributable to air pollution raises global concern as epidemiologic studies worldwide have provided enough insights into the association between exposure to gaseous and particulate pollutants and the occurrence of respiratory infections, cardiovascular diseases and cardiopulmonary mortality among the habitations [10, 14]. The level of air pollutants is increasing rapidly in many urban areas of megacities in the developing world [24]. By 2015 eight of the ten largest megacities will be in developing countries. Urban air pollution is a complex mixture of toxic components, which may have detrimental effects on human health or upon its environment. It may be viewed as dense sources of enormous anthropogenic emissions of pollutants which can alter the atmospheric composition, chemistry and life cycles in its downwind regimes, extending over several hundred kilometers. It is stated that world motor vehicle population growth reached 700 million in the year 2000 [9]. As a result of the exponential increase in motor vehicles, the motor fuel consumption triggered sharp increase in air pollution levels worldwide.

In Nigeria, air pollution has become a topic of intense debate at all levels because of the enhanced anthropogenic activities. Urban air pollution in Nigeria has increased rapidly with population growth, numbers of motor vehicles, use of fuels with poor environmental performance, badly maintained transportation systems and above all, ineffective environmental regulations [19]. Lagos had been experiencing such air pollution problems in all its severity over the past decades. Urban areas are associated with high density of industries and transport networks. These pollutants occur in many forms but can generally be thought of as gaseous and particulate contaminants that are present in the earth's atmosphere. Gaseous pollutants include sulphur dioxide (SO_2), nitrogen oxides (NO_x), ozone (O_3), carbon monoxide (CO), volatile organic compounds (VOCs), hydrogen sulphide (H_2S), hydrogen fluoride (HF) and various gaseous forms of metals. These pollutants are emitted from both mobile and stationary sources which include fossil fuel, fired power plants, smelters,

industrial boilers, petroleum refineries, incinerators and manufacturing facilities. The impacts of air pollution include loss of life, chronic respiratory illness, cardiovascular defects and carcinogen. Other consequences of air pollution include corrosion to various materials which causes damage to cultural resources, acid rain, damage of crops and other vegetation including damage to aesthetic values and reduce visibility. Primary pollutants are emitted directly into the air while secondary pollutants are formed when primary pollutants undergo chemical changes in the atmosphere. Ozone is an example and it is formed when nitrogen oxides (NO_x) and volatile organic compounds (VOCs) are mixed and warmed by sunlight.

Given the widespread concern of ambient air pollution in large urban centers and its broad ranging impacts, the present study is focused on one of the most populous, but visibly polluted Nigerian urban environments, Lagos metropolis. The objective of this study is to present the spatial distributions of selected gaseous pollutants (SO_2, NO_2, CO, CH_4, noise) and particulate matter (PM_{10}) within the study area and to estimate the major sources of air pollutants. For these purposes, varimax rotated factor analysis (FA) was appliedto data sets obtained during this study [11].

II. MATERIALS AND METHODS

2.1. Sampling

The city of Lagos was formerly the capital of Nigeria. Although, it is one of the smallest of the Nigerian States in size, it is the commercial nerve of the country, the most populous city and has about 70 percent of the nation's industries and commercial activities. It is second fastest growing city in Nigeria and the seventh fastest in the world. It is located to the west of Lagos Island, across Lagos harbor. It is one of Nigeria's 774 local government areas. The city has a tropical climate with an average relative humidity of 79 %. Mean monthly temperature ranges from 23 – 32^oC. Being located in a coastal area and influenced by strong sea-based disturbances, Lagos experiences an average wind speed of 4.3 km / h. The sampling sites (Fig. 1) were selected at Tin-Can port industrial estate. Additional details of the sampling sites are provided in Table 1. The sampling period was between October and November 2011. A total of 250 samples were collected over the course of the study. Particulate matter (PM_{10}), and gaseous air pollutants (CO, SO_2, NO_2, CH_4, and noise) were measured in the present study. Meteorological parameters like wind velocity and temperature were collected during the study period from the Nigerian Meteorological Agency (NIMET) and locations were determined by GPS 12-channel. The particulate matter concentration was obtained using a particulate matter monitor (Gillian BDXII) that can measure level of PM_{10} hourly.Levels of gases such as CO, SO_2, NO_2, CH_4 were analyzed by automatic (IBRID MX6) analysers. Coarser particles larger than 10 µm were separated from the air stream before filtration on a preweighed 0.45 µm glass fibers filter. Gases from the atmosphere were absorbed in their respective media at a flow rate of 4 L / min. The concentration of SO_2 was analyzed by West-Gaeke method at wavelength of 560 nm. Nitrogen dioxide was analyzed by employing the Jacob and Hochheiser method at wavelength of 540 nm [2].

2.2. Statistical methods

PCA and CA are the most common multivariate statistical tools used in environmental studies [21, 25]. PCA is widely used to reduce data and extract a smaller number of latent factors for analyzing relationships amongst observed variables [20, 25]. PCA relies on an eigenvector decomposition of the covariance or correlation matrix. By restricting original variables to linear functions, PCA can produce linear functions of the N variables. The number of these linear functions is equal to N, and the variance of each linear function can be calculated. The first principal component (PC) is the linear function that explains the most variance. The second PC is a linear function that explains the next most variance, but is not correlated with the first PC, etc. Generally, if the first factor takes into account the majority of information, it describes something obvious; the other factors can, however, reveal interesting phenomena hidden within the data matrix.

The CA technique comprises an unsupervised classification procedure that involves measuring either the distance or the similarity between the objects to be clustered. Objects are grouped in clusters in terms of their similarity.

In this study, PCA and CA were applied to the pollution dataset to estimate the quantitative and qualitative contributions of particulate matter and gaseous pollutants. PCA with varimax rotations was applied to the data matrix to ascertain the possible contributions. CA was used to analyse the characteristics of air pollutants based on the similarities of the pollutants and the relationship among air quality monitoring components.

III. RESULTS AND DISCUSSION

Table 2 shows the Air Quality Index (AQI) for describing ambient air quality. It is an indicator of air quality based on pollution levels for the criteria air pollutants that have adverse effects on human health and the environment. USEPA has divided the AQI scale into six levels of health concern. The indexes for each of the pollutants were derived using the mathematical formula in Eq. (1):

$$AQI_{pollutant} = \frac{\text{pollutant data reading}}{\text{standard}} \times 100 \quad (1)$$

The air quality index (AQI) is a rating scale for outdoor air. The lower the AQI value the better the air quality. The AQI rating for the criteria air pollutants is shown in Table 3. The results obtained in this study were compared with air quality index (AQI). In Nigeria, there is neither a legislative framework nor a set standard to monitor emission from mobile source. The regulatory framework put in place by government through FEPA is limited to emission generated through stationary source. In the absence of these standards, the data in this study is compared with the USEPA national ambient air quality standards. Similar studies have been carried out by [1, 15, 19].

The descriptive statistics of air pollutants in the study area are summarized in Table 4. The average concentration ± standard deviation of CO, NO_2, SO_2, PM_{10}, CH_4, noise level were 3.89 ± 1.54 ppm, 0.30 ± 0.10 ppm, 0.40 ± 0.03 ppm, 67.13 ± 1.92 µg m^3, 0.96% ± 0.33 and 78.33 ± 4.6dB, respectively.

Comparing PM_{10} with AQI levels, the quality of ambient air was moderate in SS1, SS2, SS5 and SS6 and good in other sites. The concentration of PM_{10} was in the range of 38.5 – 138.8 µg m^3 against the USEPA ambient air quality of 150 µg m^3. The variation of particulate concentration in the study area was found to be minimal and below USEPA standards. Significantly higher PM_{10} values were obtained at SS1, SS2 and SS5. The higher concentration of particulate pollution at these sampling sites may be attributed to re-suspension of road dust, entrainment of dust into the air from nearby industrial sectors (flourmills and sugar refinery) and vehicular traffic around the study area.Spread of air pollution sources and non-uniform mixing conditions in the study area result in spatial variations of pollutant concentrations.

The concentration of SO_2 was higher than the USEPA ambient air quality standard of 0.075 ppm (average of 1 h) at all the sampling sites in the study area. The high concentrations of SO_2 observed at the sampling sites may possibly be due to emissions from power plants, numerous marine vessels which dock in the harbour, industrial processing activities, refuse dumpsite and some non-road diesel equipment releasing sulphur dioxide into the air. However, the results obtained were compared with published mean air values in other countries, lower values to the study area were (3.21 – 5.18 ppm, 7.4 – 15.5 ppm and 16 – 64 ppm) respectively reported [3, 8, 13]. Comparing data with AQI levels, the air quality for SO_2 was in the range of unhealthy to very unhealthy in all the sampling sites.

Carbon monoxide (CO) is formed by incomplete combustion of carbon in fuel. The main source of carbon monoxide is motor vehicle exhaust along with industrial processes and biomass burning. Carbon monoxide levels in urban and industrial areas closely reflect traffic density (in combination with weather conditions). Other man-made sources are power stations and waste incinerators. The highest concentration of CO was recorded at SSI and SS2 with a concentration of 5.5 ppm. In terms of air quality index (AQI), the CO variation across the sampling sites revealed that the air quality is moderate at SS1 and SS2 while it is good at other sites. Carbon monoxide binds to haemoglobin in red blood cells, reducing their ability to transport and release oxygen throughout the body. Moderate exposure of CO to the occupants along thestudy area can aggravate cardiac ailments such as the brain andheart [4]. CO also plays a role in the generation of ground-level ozone. Comparing the concentrations of CO at different sampling sites in the study area, the CO levels were below the US national ambient air quality standard of 9 ppm (8 h average). The CO in this study when compared with values reported in literature,similar values was recorded by Abam and Unachukwu [2], (3.3 – 8.7 ppm);Olajire et al., [19] (9 – 34 ppm) reported higher values while Kalabokas et al., [13] and Ettouney et al., [8] recorded respectively lesser concentrations (1.6 – 3.8 ppm) and (0.7-1.9 ppm) of urban air pollutants

The concentration of NO_2 was found in the range of 0.1 – 0.5 ppm (Table 4). The highest concentration of NO_2 found at SS2 may be due to the increase in the number of vehicles and the local emissions from industrial units. In addition, the burning of fossil fuels may contribute to the total NO_2 load. The NO_2 concentrations at all the sampling sites exceeded the maximum ambient concentration of 0.1 ppm (1h average). In terms of AQI rating, the air quality for NO_2 in the study area was unhealthy for sensitive groups.

The H_2S concentrations ranged from 0.1 – 0.5 ppm with the highest concentration of 0.5 ppm at sites 1, 2, 3 and 7. H_2S is a gas emitted during the decay of organicmatter. The decay of waste and bad odour generated at dumpsite (SS7) could be one of the contributors for the high H_2S emission. The H_2S concentration in this study is higher than the range (0.37 – 3.17 ppm)and 0.167 – 0.265 ppm reported respectively by [18].

The noise level ranged from 61.6 – 92.65 dB, SS2 had highest noise levels of 81.8 dB in the morning and 87.4 dB in the afternoon which is the peak periods of traffic volume. Methane (CH_4), the simplest and most long-lived VOC, is of importance both as a greenhouse gas and as a source of background tropospheric ozone. Major anthropogenic sources of CH_4 include leaks during fossil fuel, rice paddles, raising livestock (cattle and sheep) and municipal landfills. CH_4 had the highest at SS4 in the afternoon (1.75 %). The overall average mean of CH_4 in the study area was 1.0 %. Wind velocity ranged from 3.5 – 4.6 km / h with the highest observed at SS46.

The criteria air pollutants levels were generally found to be higher at SS2 than any other sites. This could be attributed to high number of industries and volume of traffic.

3.1. Identification of ambient pollution sources by PCA

PCA was used to analyze the relationship between pollution sources and air pollutants. Seven variables were considered for PCA. Table 5 presents orthogonal rotation criteria that maximize the variance of the squared elements in the columns of a factor matrix for seven parameters in Tin-Can industrial estate Apapa. Only the factors with an eigenvalue > 1 [25] were chosen. PCA identified two factors that accounted for 61.23 % of the total variance in the entire dataset.

SO_2 (0.84), CO (0.89), H_2S (0.73), Noise (0.64), PM_{10} (0.57) contributed greatly to (43.72 %) PC1 which was strongly associated with vehicular emissions and industrial sources, are likely the major contributors to air pollution in Tin-Can port. The linear correlation between SO_2 and CO and H_2S ($p < 0.01$) and PM_{10} and noise ($p < 0.05$) were all significant (Table 6), demonstrating the need for a tracer for vehicle emissions in industrial and urban areas. This result was similar to the air pollution pattern in an industrial area in Korea [25].
PC2 explains 17.53 % of total variance. It has strong positive loadings on NO_2 but strong negative loadings on CH_4. The negative value of CH_4 is due to low emission in the study area which in turns leads to the reduction of ozone formation from photochemical reactions of sunlight on nitrogen dioxide (NO_2) and VOCs, typically emitted from road vehicles. NO_2 was associated with emissions from vehicles such as diesel engines of trucks, vans, taxis, cars, motorcycles and buses. It was confirmed that NO_2, a secondary air pollutant that is mainly formed in the atmosphere, is not linked to SO_2, NO_2 may be an oxidation product of NO_x, which is derived mostly from vehicular emissions [22].

3.2. Similar patterns in pollution components

Cluster analysis was used to analyze air pollutants based on the similarity of the pollutants standardized concentration values. Euclidean distance was used to compute the distance among the pollutants and the average linkage method was used for clustering. This procedure is based on the average distance between all pairs, considering that the two sites must belong to different clusters. The two sites with the lowest average distance are linked to form a new cluster. Before CA, the variables were standardized by means of z-scores; then Euclidean distances for similarities in the variables were calculated. Finally, a hierarchical clustering was performed using the standardized dataset by applying Ward's methods.

Hierarchical Agglomerative Cluster Analysis (HACA) was performed on seven parameters (CO, NO_2, SO_2, CH4, PM_{10}, H_2S and noise. The results of CA are shown in Fig. 3. At a Euclidean distance of 25, two subgroups were classified based on the patterns of the various sites: The first cluster consists of sites SS1 and SS4. The branching out SS4 in the dendrogram in Fig. 3 was attributed to NO_2 emissions from vehicles; similar results were found by PCA (Table 5). Cluster 1 consists of five sites: SS2, SS6, SS5, SS7 and SS3. SS6 clustered closely with SS2, suggesting the need for a vehicle emission tracer in industrial and urban areas. The similarity between SS2 and SS6 was higher than that between SS5 and SS7 implying that SS5 and SS7 originated from various sources such as industrial sources in addition to vehicle emissions. Overall, PCA and CA produced similar results, with clusters 1 and 2 corresponding to PC2 and PC1, respectively.

IV. CONCLUSION

PCA produced two principal components that revealed information about source contributions. The application of PCA, combined with CA, is an effective technique for quantitative and qualitative interpretation of the chemistry of ambient air pollution, and for identifying the emission sources. Appropriate vehicle emission management coupled with industrial air pollution control should be applied to reduce the criteria air pollutants in the study area.

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Table 1 Characterization of the air quality sampling sites

S/No	Land use	Location (lat., long.)	Road gradient	Characteristics
1.	Industrial site	$3^{o}21.387^{'}$E, $6^{o}26.128^{'}$N	Flat	Tin-can port industrial estate main gate
2.	2. Industrial site	$3^{o}21.450^{'}$E, $6^{o}26.114^{'}$N	Flat	Duncan terminal consisting of loading

3.				and offloading of containers
3.	Industrial site	3°21.513'E, 6°26.060'N	Flat	Main gate to the honey-well flour mill
4.	Industrial site	3°21.511'E, 6°26.050'N	Flat	Crown flour mill consisting of manufacturing facilities
5.	Industrial site	3°21.602'E, 6°26.126'N	Flat	Crown flour main gate
6.	Industrial site	3°21.631'E, 6°26.097'N	Flat	Crown flour mills warehouse
7.	Industrial site	3°21.490'E, 6°26. 234'N	Flat	Steam emission from Bua sugar refinery

Table 2 Air quality index for criteria air pollutants

Level of health concern /numerical value	**AQI rating**	**PM_{10} µg m^3**	**CO (ppm)**	**NO_2 (ppm)**	**SO_2 (ppm)**
Very good (0 - 50)	A	0 - 54	0 – 4.4	0 – 0.053	0 - 0.035
Moderate (51 - 100)	B	55 – 154	4.5 – 9.4	0.054 – 0.1	0.036 – 0.075
Unhealthy for sensitive group (101 - 150)	C	155 - 254	9.5 – 12.4	0.101 – 0.36	0.076 – 0.185
Unhealthy (151 - 200)	D	255 – 354	12.5 – 15.4	0.361 – 0.64	0.186 – 0.304
Very unhealthy (201 - 300)	E	355 – 424	15.5 – 30.4	0.65 – 1.24	0.305 – 0.604
Hazardous warning (301 - 400)	F	425 – 504	30.5 – 40.4	1.25 – 1.64	0.605 – 0.804
Hazardous emergency (401 - 500)	G	505 – 604	40.5 – 50.4	1.65 – 2.04	0.805 – 1.004
Hazardous serious harm (500)	H	605 - 4999	nd	nd	nd

nd = no data

Table 3 Summary of AQI rating for ambient air quality from study area

Sampling site	**Sampling location**	**AQI (CO)**	**AQI (NO_2)**	**AQI (SO_2)**	**AQI (PM_{10})**
SS1	Tin-Can Port Main Gate	B	C	E	B
SS2	Duncan Terminal	B	C	E	B
SS3	Honeywell Gate	A	C	E	A
SS4	Crown flourmill	A	C	D	A
SS5	Crown flourmill Gate	A	C	E	B
SS6	Crown flourmill warehouse	A	C	D	B
SS7	Bua loading Bay	A	C	E	A

Table 4 Descriptive statistics of air pollutants in the study area

Variables	SS1		SS2		SS3		SS4		SS5		SS6		SS7		TOTAL MEAN	Min. Max.	USEPA NAAQS Avg Time
	am.	pm	am	pm	am	pm	am	pm	am	pm	am	pm	am	pm			
PM_{10}, µg/m^3	109.1 ± 1.	136.9 ± 1.	78.0 ± 0.8	79.9 ± 1.1	39.8 ± 1.5	45.4 ± 1.1	29.3 ± 0.8	38.3 ± 1.5	90.0 ± 7.5	96.0 ± 1.5	59.6 ± 1, 9	59.3 ± 0, 8	38.3 1.5	40.1 1.1	67.13	38.5 - 138.	150 µg/m^3 24h

	9	9														8	
CO, ppm	4.75 ±1.7	5.5 ± 1.3	5.25 ± 2.1	5.5 ± 1.3	4.75 ± 1.2	3.75 ± 1.7	2.5 ± 1.3	2.25 ± 0.9	3.75 ± 1.2	3.75 ± 0.5	2.75 ± 0.5	2.5 ± 0.6	3.5 ± 1.0	4.0 ±0.8	3.90	1.0-8.0	9ppm 8h
SO_2, ppm	0.47 ±0.05	0.53 ± 0.2	0.47 ± 0.05	0.48 ± 0.1	0.42 ± 0.0	0.43 ± 0.1	0.33 ± 0.0	0.3 ± 0.0	0.43 ± 0.1	0.37 ± 0.1	0.28 ± 0.05	0.25 ± 0.06	0.40 ± 0.08	0.40 ±0.1	0.40	0.2-0.7	0.075ppm 1h
NO_2, ppm	0.35 ±0.06	0.35 ± 0.06	0.38 ± 0.05	0.4 ± 0.08	0.3 ± 0.08	0.3 ± 0.08	0.23 ± 0.05	0.17 ± 0.05	0.23 ± 0.09	0.22 ± 0.05	0.28 ± 0.12	0.25 ± 0.13	0.35 ± 0.13	0.35 ±0.1	0.30	0.1-0.5	0.1ppm 1h
H_2S, ppm	0.42 ±0.1	0.35 ± 0.13	0.38 ± 0.1	0.38 ± 0.1	0.38 ± 0.12	0.35 ± 0.13	0.22 ± 0.15	0.22 ± 0.15	0.3 ± 0.08	0.28 ± 0.05	0.3 ± 0.08	0.3 ± 0.08	0.35 ± 0.13	0.3 ±0.16	0.32	0.1-0.5	
CH_4, %	1.0 ±0.0	1.0 ± 0.0	0.75 ± 0.5	0.75 ± 0.5	0.75 ± 0.5	1.0 ± 0.8	1.5 ± 0.6	1.75 ± 1.25	1.0 ± 0.0	1.25 ± 0.5	0.75 ± 0.5	0.5 ± 0.6	0.75 ± 0.5	0.75 ±0.5	0.96	0.0-3.0	
NOISE, dB	76.1 ± 6.4	82.5 ± 3.5	81.8 ± 5.0	87.4 ± 1.6	75.5 ± 8.4	77.3 ± 3.6	74.0 ± 4.1	70.7 ± 6.2	76.9 ± 6.6	82.8 ± 6.3	69.7 ± 4.4	78.2 ± 10.6	81.9 ± 5.0	81.6 ±1.6	78.33	61.6 - 92.65	
Temp. ^oC	29.2 ±0.02	28.5 ± 0.05	28.1 ± 0.1	28.7 ± 0.04	29.4 ± 0.2	29.1 ± 0.5	28.0 ± 0.06	28.3 ± 0.1	29.4 ± 0.02	29.0 ± 0.5	29.3 ± 0.03	29.3 ± 0.03	28.5 ± 0.3	28.3 ±0.1	28.8	27.8 - 29.8	
WV (Km/h)	4.4 ±1.2	3.9 ± 0.9	3.8 ± 1.4	4.2 ± 1.7	3.7 ± 0.8	4.2 ± 1.1	4.4 ± 0.5	4.3 ± 1.5	3.9 ± 0.9	3.9 ± 1,5	4.5 ± 1.0	4.1 ± 1.0	3.8 ± 1.1	3.9 ±0.9	4.1	3.5-4.6	

SS = Sampling site; USEPA: NAAQS = United States national ambient air quality standards

Table 5 Varimax rotated factor loadings of Tin-Can industrial estate Lagos

Variables	Factor 1	Factor 2	Communality (factors 1-2)
CO	0.89		0.81
SO_2	0.84		0.72
H_2S	0.73		0.55
Noise	0.64		0.41
PM_{10}	0.57		0.33
CH_4		-0.89	0.80
NO_2		0.75	0.67
Eigenvalue	3.06	1.23	4.29[a]
Percent of variance	43.72	17.53	
Cumulative percentage	43.72	61.25	

[a]Sum of communality

Table 6 Correlation coefficient of particulate matters and gaseous pollutants measured

Variables	SO_2	NO_2	H_2S	CO	CH_4	Noise	PM_{10}
SO_2	1.00						
NO_2	0.33	1.00					
H_2S	0.52**	0.25	1.00				
CO	0.76**	0.33	0.69**	1.00			
CH_4	-0.05	0.40*	-0.13	-0.10	1.00		
Noise	0.38*	0.23	0.33	0.44*	-0.02	1.00	
PM_{10}	0.42*	0.22	0.19	0.38*	-0.06	0.33	1.00

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

SS2 Duncan Terminal.

SS7 Dumpsite at BUA sugar Refinery.

SS1 Tin Can Port Industrial estate main gate.

SS1 Tin Can Port Industrial estate main gate.

SS1 Tin Can Port Industrial estate main gate.

SS2 Duncan Terminal Gate.

SS4 Crown Flourmill factory.

SS6 rear entrance crown flour mills.

SS3 Honeywell flour mills

SS7 BUA sugar refinery.

SS5 Crown Flourmill Gate

SS2 Vehicular emission at Duncan Terminal.

SS1 Tin Can Port Industrial estate main gate.

SS2 Vehicular emission at Duncan Terminal.

Fig. 1. Location of air quality sampling sites.

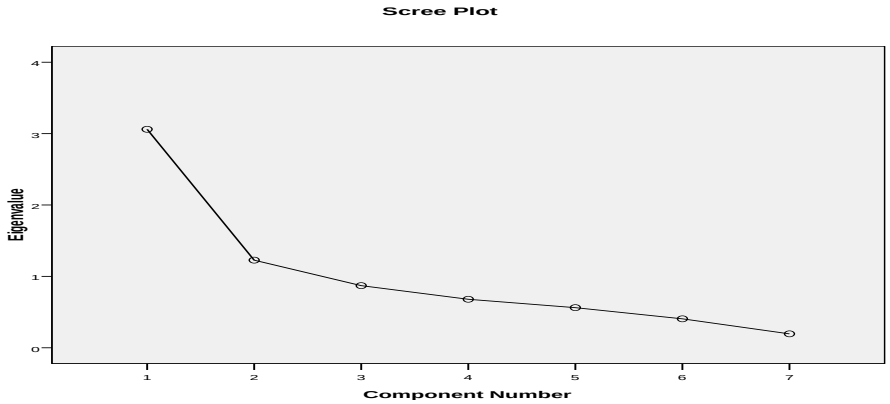

Fig. 2. Scree plot of the eigenvalues of principal components for air quality parameters

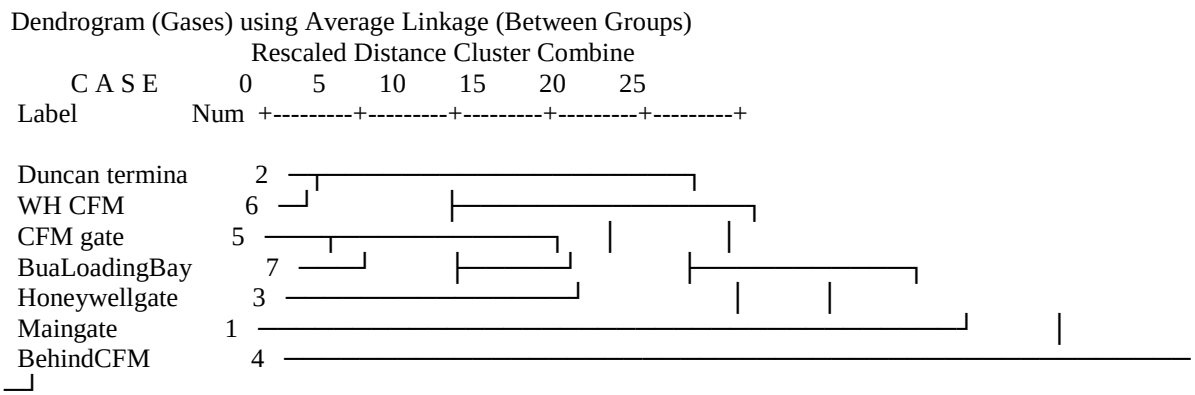

Fig. 3. Dendrogram of hierarchical cluster analysis for the seven variables.