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Full Length Research Paper

Air quality assessment of carbon monoxide, nitrogen dioxide and sulfur dioxide levels in Blantyre, Malawi: a statistical approach to a stationary environmental monitoring station

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Air quality in urban areas is a cause of concern because of increased industrial activities that contribute to large quantities of emissions. The study assess levels and variations of carbon monoxide (CO), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) in Blantyre, Malawi using a stationary environmental monitoring station (EMS). Results show that CO level (2.47 ± 1.23 mg m^{-3}) were below the Malawian limit value (10.31 mg m^{-3}). Although, NO_2 (4.02 ± 2.47 mg m^{-3}) and SO_2 (8.58 ± 2.88 mg m^{-3}) were significantly higher than allowable Malawian Standards (0.52 and 0.23 mg m^{-3}, respectively). Discernible variations in hourly, diurnal, monthly and seasonal CO, SO_2 and NO_2 were apparent. Independent t-test confirmed that day time values were higher than those at night ($p < 0.05$). Thus, variations in local weather affect the disparity in hourly and diurnal values. Analysis of variance (ANOVA) confirmed significant variations in monthly observations. Moreover, independent t-test showed that wet season CO (2.32 mg m^{-3}), SO_2 (5.10 mg m^{-3}) and NO_2 (9.41 mg m^{-3}) levels were higher than dry season values (CO = 2.32 mg m^{-3}; SO_2 = 3.42 mg m^{-3}; NO_2 = 8.13 mg m^{-3}). A hierarchical cluster analysis (HCA) divided the 10 months into three groups based on distribution of CO, SO_2 and NO_2, air temperature, wind speed and wind direction. Furthermore, factor analysis (FA) showed that air temperature had significant contribution to variations in mean values of CO, SO_2 and NO_2 for the entire study period. The study shows a need for constant urban air quality monitoring in Blantyre and all urban areas in Malawi. It is recommended that the experimental site widen the scope of the study by utilizing the flexibility of the EMS.

Key words: Air pollutants, principal component analysis, developing countries, environmental monitoring station, Kaiser normalization.

INTRODUCTION

Malawi, like many developing countries, has faced increased levels of urbanization and population growth over the last few years. Most cities in developing countries have population sizes more than twice that of 50 or so years ago (Baldasano et al., 2003). Urbanization and population growth have resulted in a corresponding

Table 1. Ambient air quality standards limits for Malawi (MSB, 2005).

Pollutant	Maximum concentration in ambient air	Average period
Suspended particulate matter	0.5	1 Year
- PM_{10}, µg/m^{-3}	25	1 Day
- $PM_{2.5}$, µg m^{-3}	8	1 Year
Carbon monoxide, mg m^{-3}	10.31	8 Hours
	40.10	1 Hour
Sulfur dioxide, mg m^{-3}	0.52	1 Hour
	0.21	1 Day
	0.05	1 Year
Nitrogen dioxide, mg m^{-3}	0.23	1 Hour
	0.06	1 Year
Ozone, mg m^{-3}	0.14	1 Hour
Lead, µg m^{-3}	0.50	1 Year
Photo-chemical oxidants (as ozone), mg m^{-3}	0.26	1 Hour
	0.08	4 Hours

increase in mobile and stationary fuel combustion emissions. Mobile sources e.g. motor vehicles, motor cycles and locomotives account for a large part of total emissions in major cities (Gerardo and Maricruz, 1997; Holloway et al., 2000; Makra et al., 2010). Of the mobile sources, diesel engines produce comparatively lower concentrations of CO and hydrocarbons (HC) than petrol engines (Bendelius, 1996). But, diesel engines emit large quantities of NO_x and SO_x as compared to petrol (Chan et al., 1997). These factors and challenges in waste management have contributed to the atmospheric deterioration such as acid rain, formation of smog and different ailments to people living in polluted air environment.

The atmospheric deterioration is deleterious to buildings, statues, devices, ecosystem integrity, causes visibility problems (Agrawal et al., 2003; Jalaludin et al., 2004; Lin et al., 2004; Kan et al., 2010; Fattore, et al., 2011) and many human health ailments (Cohen et al., 2004; Shah and Balkhair, 2011). Carbon monoxide and NO_2 are considered to be amongst other tropospheric O_3 precursors (Macdonald et al., 2011). Yet, tropospheric ozone is a threat to human health (WHO, 2003), has deleterious impact on vegetation (Fowler et al., 2009). During wet deposition, NO_2 and SO_2 react to produce acid rain which damages building structures and vegetation.

Human vulnerability to air pollutants depends on time and extent of sensitivity to particular air pollutants (Laumbach, 2010). The nature and significance of air quality issues depend on the many factors. Such factors include size of a city, physical and chemical industrial processes, meteorological processes, geographical features and social factors (Pires et al., 2008).

Urban air quality has received great attentions in recent years as attested by several research and documentation (Wolf, 2002; Agrawal et al., 2003; Vargas, 2003; Riga-Karadinos and Saitanis, 2005; Brajer et al., 2006; Oudinet et al., 2006). The growing concerns on air pollution have seen most developing countries introducing strict regulations (Bailey and Solomon, 2004; Mao and Zhang, 2003). Despite scientific investigations and abatement strategies, urban air pollution is still on the rise in many cities worldwide, or has experienced only small improvements (Makra et al., 2010). Besides, ambient air pollution serves as a major source of gaseous pollutants for indoor air quality (Freijer and Bolemen, 2000). In Malawi, we have the Malawi Standards (MS) that were developed and published by Malawi Standards Board (MSB, 2005). The MS stipulates threshold values for air quality (Table 1).

To improve air quality in cities, a need for air pollution control and prediction of trends is urgent. In addition, short-term forecasting of air quality is crucial since it assists in taking preventive and evasive action during episodes of elevated air pollution (Makra et al., 2010). Blantyre city is one of such cities where air pollution needs scientific evaluation and monitoring hence this study. But, information on CO, NO_2 and SO_2 pollution in Blantyre city is scarce and if any, the information is

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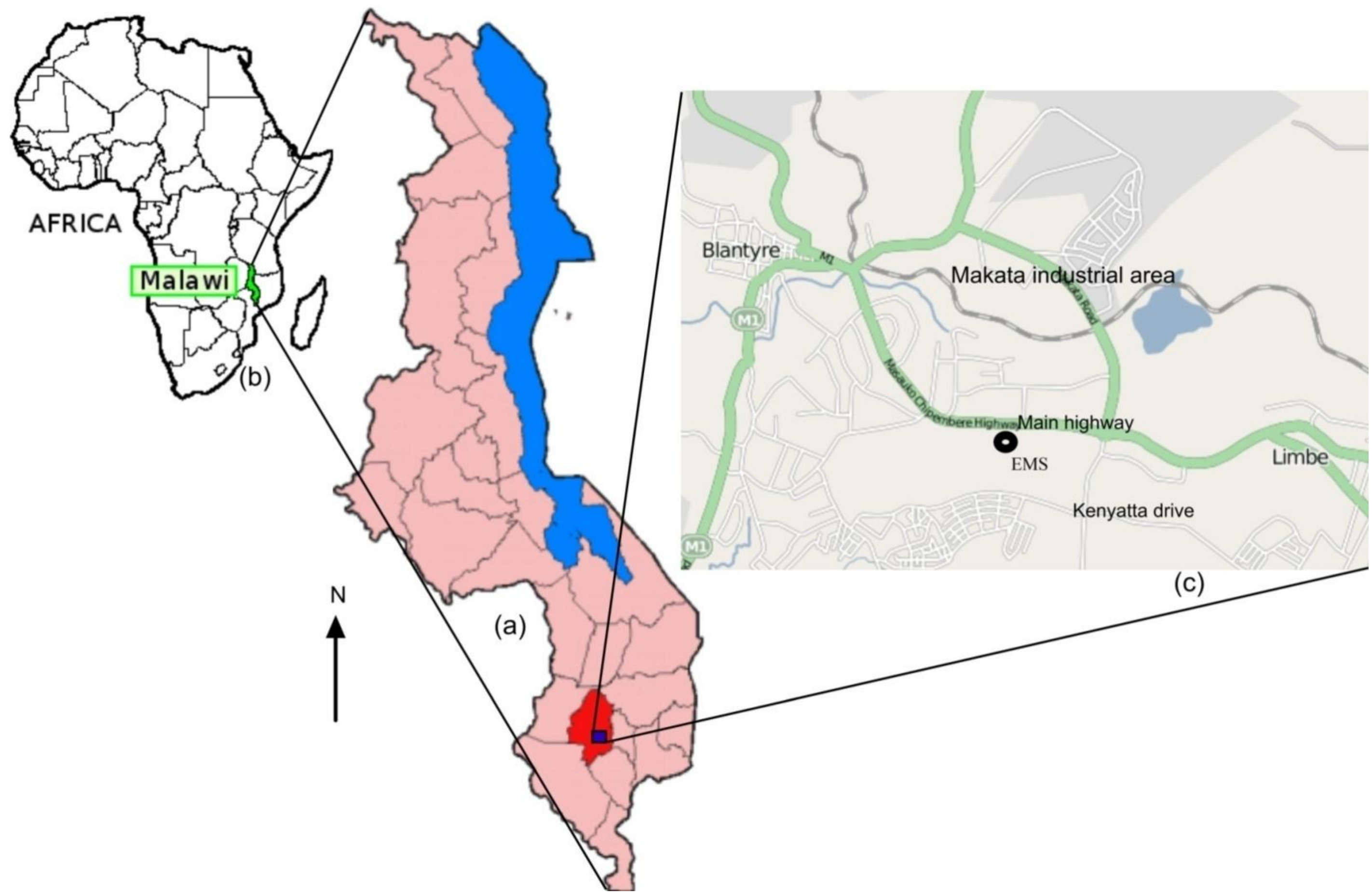

Figure 1. Location of Blantyre district in Malawi (a) found in southern Africa region (b). The blue rectangle is extruded to show the exact location of the study site.

unpublished (Mapoma et al., 2013; Mapoma and Xie, 2013).

The study evaluated diurnal, monthly and seasonal variations in CO, NO_2 and SO_2 levels. We envisaged high concentrations of CO, NO_2 and SO_2 during working hours (day time) as compared to non-working hours due to emissions from mobile and industrial activities. Furthermore, the study evaluated the effect of air temperature, wind speed and wind direction on levels of CO, NO_2 and SO_2. Data was collected between April 2011 and January 2012 using a fixed continuous active environmental monitoring station (EMS) located in Blantyre city along the main highway connecting Blantyre city and Limbe business district in Malawi (Figure 1).

MATERIALS AND METHODS

Experimental site

The study took place in Blantyre city, Malawi. Tables 2 and 3 summarize data on Blantyre City, elaborating on average climate condition, geographic data and commercial activities of the city. Furthermore, Figure 1 illustrates the geographical location of the city. Blantyre is a commercial city with high vehicle and motorcycle traffic in its main roads. Blantyre has designated industrial areas with Makata being the main industrial site (Figure 1). The experimental site is located near the main highway (Figure 1). The main highway (Chipembere) shown in Figure 1 connects Blantyre business district and Limbe business district. As such, the highway is one of the roads with higher vehicle traffic intensity during peak hours. Running parallel south of the main highway is another busy road (Kenyatta drive) that reduces congestion in the main highway when driving to Limbe (Figure 1). As such Kenyatta drive is one of the busiest roads in Blantyre.

Study design

A stationary EMS is located at 25 m above ground on top of the building at the experimental site in Blantyre city (Figure 1). The experimental site is at 1080 m mean altitude above sea level on coordinates 15°48'07''S, 035°01'37''E. The EMS (model MM900) is a dynamic and continuous data logger (http://www.nr.no/nb/projects/environmental-monitoring-station?

Table 2. Average climate data for Blantyre district[a].

Month	January	February	March	April	May	June	July	August	September	October	November	December	Year
Average high °C	28	28	28	28	26	24	24	26	29	32	31	29	27.8
Average low °C	20	19	19	18	15	13	13	14	17	19	21	20	17.3
Precipitation mm	208	206	170	43	8	3	3	3	5	20	86	132	887

[a]Source: http://www.weatherbase.com/weather/weather.php3?s=39676&cityname=Blantyre-Malawi.

Table 3. Summary of location and important productive activities in Blantyre.

Location / important productive activities	Description
District area	228 km^2
Population	1,895,973 (www.worldgazetteer.com, 2012)
Average Elevation	1,039 m above mean sea level
Coordinates	15°47'10"S; 35°0'21"E
Some commercial activities related to air quality issues	Manufacturing and production of paint, fertilizers, soft drinks, detergents, milk pasteurization, steel industries. Petroleum storage and distribution. Waste management Locomotive transportation Road transport network hub for the southern region

language=en). It is capable of monitoring a wide range of air quality parameters due to its flexibility. Up to 30 sensors can be attached to the equipment based on needs. At the moment of data collection, the EMS sensors available were for average air temperature (°C), wind speed ($m\ s^{-1}$), wind direction (degrees), SO_2 (parts per million (ppm)), NO_2 (ppm) and CO (ppm). Hourly recording of data for a continuous 24 h period was chosen for 10 months (1 April 2011 to 31 January, 2012). Choice of hourly data logging as opposed to half hourly recording was to lessen battery power loss. Thereafter, the units (ppm) for CO, SO_2 and NO_2 were converted to $mg\ m^{-3}$ before data analysis (Formula 1). Then, hourly values were grouped into non-working and working h of the 24 h period. The non-working hours are between 7:00 pm and 7:00 am while the working hours are between 7:00 am and 7:00 pm.

$$x\,(mg\,m^{-3}) = \frac{x\,(ppm) x\ Molar\ mass\,(g\,mol^{-1})\ x\,1000\,mg\,g^{-1}}{Molar\ volume\,(L\,mol^{-1})\ x\,1000\,m^3\,L^{-1}} \quad (1)$$

Statistical analysis

Data analysis used IBM® SPSS® statistics version 20 coupled with SigmaPlot 12.5 (http://www.sigmaplot.com/) for graphical illustrations. SPSS is a versatile statistical package used for statistical data analysis in many scientific and medical studies.

The SPSS base software includes descriptive statistics, parametric and non-parametric tests, linear regression and multivariate statistics (IBM, http://www-01.ibm.com/software/analytics/spss/). In this study, outliers and extreme values were removed using through box plot method. One sample t-test was used to compare CO, SO_2 and NO_2 mean values with national standards for air pollutants (MSB, 2005). Moreover, independent samples t-test compared diurnal and seasonal mean values while ANOVA assisted in understanding hourly and monthly variations amongst the dataset.

Multivariate statistics identified the underlying factors attributing to variations in CO, SO_2 and NO_2. The multivariate tools selected for this analysis were hierarchical cluster analysis (HCA) and factor analysis (FA). HCA and FA are quantitative and independent approaches used to classify months and making of correlations amongst variables, respectively. The goal of HCA was to examine and classify months based on distribution of the dataset. The Squared Euclidian distance was used as a similarity/dissimilarity measure, while Ward's linkage method linked the clusters (Yidana, 2010; Hair et al., 2011). Raw data was standardized by converting each variable to standard scores by subtracting the mean and dividing by the standard deviation for each variable (Hair et al., 2011).

The FA technique was considered useful in this study to identify underlying variables that explain the pattern of correlations within the dataset. Principal component analysis (PCA) was the extraction method employed while the rotation method was Varimax with Kaiser Normalization (Hair et al., 2011).

RESULTS AND DISCUSSION

Levels of CO, NO_2 and SO_2

Table 4 presents results obtained between April 2011 and January 2012. The averages are direct computations from hourly recorded data over a 24 h continuous period. A one sample t-test compared the results with national air quality standards (MSB, 2005). With this test the mean value of CO (2.47 mg m^{-3}) was significantly lower than the threshold limit value (Table 4). Similar CO observations were made in an earlier performed in the main highway (Mapoma et al., 2013) near the experimental site (Figure 1). However, the current study's sampling and experimental design were different from that of Mapoma et al. (2013). The earlier study's sampling position was at 3 m elevation (ground surface reference) as compared to 25 m above ground. Conversely, the test results for SO_2 (4.02 mg m^{-3}) and NO_2 (8.58 mg m^{-3}) were significantly higher than standard limit values averaged over a 1 h period (Table 4). Such higher values are detrimental to infrastructure and a health hazard to human beings.

The recorded microclimatic variables show that November had the highest recorded air temperature over the experimental site while the lowest mean monthly air temperature was recorded in July (Table 4). On the contrary, the highest mean value for wind speed was in August and the lowest computed for June and December (Table 4).

The concentration of NO_2 and SO_2 were relatively highest in April 2011 and January 2012 (Table 4). The lowest concentrations for NO_2 and SO_2 were observed in August. Across the entire year, it shows that the month of August is the turning point since it is the month of the lowest recorded average NO_2 and SO_2 concentration.

Concentration of CO was highly variable with highest levels in April 2011 and January 2012 (Table 4). Thus, differences in local weather contributed to the observed trends with wind direction and air temperature as main factors (Figures 2 and 3, respectively).

The study scope concentrated on three pollutants due to lack of sensors to detect more pollutants. Besides, reliance on battery mains that requires constant checking and recharging has effect on continuity of data collection unless constant checking is employed.

Variances

Hourly and diurnal variations

The mean value of air temperature for the working hours was 21.7°C (standard deviation, SD = 4.05) while that of non-working hours was 18.4°C (SD = 3.51). This is an obvious characteristic considering daily sunlight energy routine. Even though, wind speed varied on hourly basis ($F = 4.077$, $p < 0.05$), the mean value for working hours (WS_{mean} = 4.88 mg m^{-3}; SD = 2.04) did not differ from that of non-working hours (WS_{mean} = 4.87 mg m^{-3}; SD = 2.10) as compared to when using independent t-test ($p < 0.05$).

The study noted remarkable hourly variations of CO, SO_2 and NO_2 characterized by high values during the day time as compared to night time (Figure 4). ANOVA results show significant variations in hourly values over the entire study period for CO ($F = 32.049$, $p < 0.05$), SO_2 ($F = 9.488$, $p < 0.05$) and NO_2 ($F = 12.709$, $p < 0.05$). Thus, indicating significant influence of human activities and variations in weather (Elminir, 2002). Independent samples t-test showed that working hours mean values of CO (2.81 mg m^{-3}), SO_2 (4.37 mg m^{-3}) and NO_2 (9.10 mg m^{-3}) were significantly higher ($p < 0.05$) than those of non-working hours mean values of CO (2.13 mg m^{-3}), SO_2 (3.66 mg m^{-3}) and NO_2 (8.06 mg m^{-3}). More so, the computed standard deviations (SD) for working hour values of CO (1.28), SO_2 (2.47) and NO_2 (2.86) were higher than those of non-working hours CO (1.08), SO_2 (2.42) and NO_2 (2.81) suggesting that working hour values varied more than non-working hour values (Figure 4). This suggests that these pollutants are a result of human activities. During working hours (day time) human activities are more than at night. Transportation in Blantyre city is more active during the day. The same can be said of heavy traffic in the main roads such as the Chipembere highway and industrial activities near the experimental site. Based on variations in air temperature (Figure 3) as compared to CO, SO_2 and NO_2 variations (Figure 4), much of the variations can be attributed to temperature changes and may be the persistent wind direction (Figure 2).

Monthly and seasonal variations

Across the entire study period, CO, SO_2 and NO_2 concentrations varied significantly amongst months (F = 65.781, 437.652 and 119.553 respectively; $p < 0.05$). Also, the variations in mean air temperature and wind speed across amongst months for the study period were significant (F = 281.124 and 53.977, respectively; $p < 0.05$). As mentioned earlier, the variation in weather for each month may contribute to the observed differences. A post hoc pair wise analysis implemented with least square deviations (LSD) showed some pairs of months

Table 4. Summary of results of the entire study period aggregated into minimum and maximum monthly values.

Month		Air temperature (°C)	WS ($m\ s^{-1}$)	CO ($mg\ m^{-3}$)	SO_2 ($mg\ m^{-3}$)	NO_2 ($mg\ m^{-3}$)
April 11	Min	14.3	0.0	1.15	3.76	0.00
	Max	29.8	10.7	8.02	18.82	20.96
	Mean	20.4	4.5	3.04	7.91	11.26
	Std. Dev	2.7	1.9	1.12	3.32	5.07
May 11	Min	13.6	0.0	0.00	0.00	2.62
	Max	28.0	10.5	3.44	9.41	15.72
	Mean	20.2	4.4	2.32	3.73	8.49
	Std. Dev	2.6	1.7	0.64	1.15	1.37
June 11	Min	10.0	0.0	0.00	0.00	0.00
	Max	27.0	11.0	4.58	9.41	15.72
	Mean	18.0	4.1	1.95	3.83	8.67
	Std. Dev	3.6	2.6	0.92	1.69	1.76
July 11	Min	10.1	0.0	0.00	0.00	0.00
	Max	26.9	10.7	12.60	11.29	15.72
	Mean	17.0	4.7	2.81	3.18	7.77
	Std. Dev	3.7	2.2	2.15	1.45	1.75
August 11	Min	10.3	0.0	0.00	0.00	0.00
	Max	27.1	11.0	4.58	16.93	20.96
	Mean	17.0	5.8	2.02	2.89	7.67
	Std. Dev	4.0	2.3	1.07	1.63	1.93
September 11	Min	10.3	0.0	0.00	0.00	0.00
	Max	30.1	11.0	6.87	9.41	18.34
	Mean	20.9	5.2	2.32	3.28	7.80
	Std. Dev	3.2	1.8	0.75	1.28	1.88
October 11	Min	10.5	0.0	0.00	0.00	0.00
	Max	34.8	11.0	6.87	11.29	15.72
	Mean	22.5	5.4	2.52	3.61	8.41
	Std. Dev	5.0	2.1	0.99	1.84	2.32
November 11	Min	11.9	0.2	0.00	0.00	0.00
	Max	34.7	11.0	4.58	9.41	15.72
	Mean	23.5	5.5	2.66	3.31	8.68
	Std. Dev	3.9	2.3	0.91	1.60	2.56
December 11	Min	10.2	0.0	0.00	0.00	0.00
	Max	32.5	10.8	9.16	18.82	20.96
	Mean	21.5	4.4	2.39	3.59	8.03
	Std. Dev	3.1	1.7	0.85	1.53	2.32
January 12	Min	12.3	0.0	0.00	0.00	0.00
	Max	27.7	10.4	11.46	18.82	20.96
	Mean	20.7	4.6	3.10	6.60	10.18
	Std. Dev	2.5	2.4	2.28	4.52	5.27
	Overall mean	20.1	4.9	2.47	4.02	8.58
	MSB			10.31	0.21	0.23
	p-value			< 0.05	< 0.05	< 0.05

Min = Minimum, Max = maximum, Std. Dev = standard deviation, MSB = Malawi standards (MSB 2005), p-value = significance level for a one sample t-test.

that had similar results. The paired mean CO values that were not significantly different were for pairs of April/January, May/September, May/December, September/December and June/August ($p > 0.05$). The

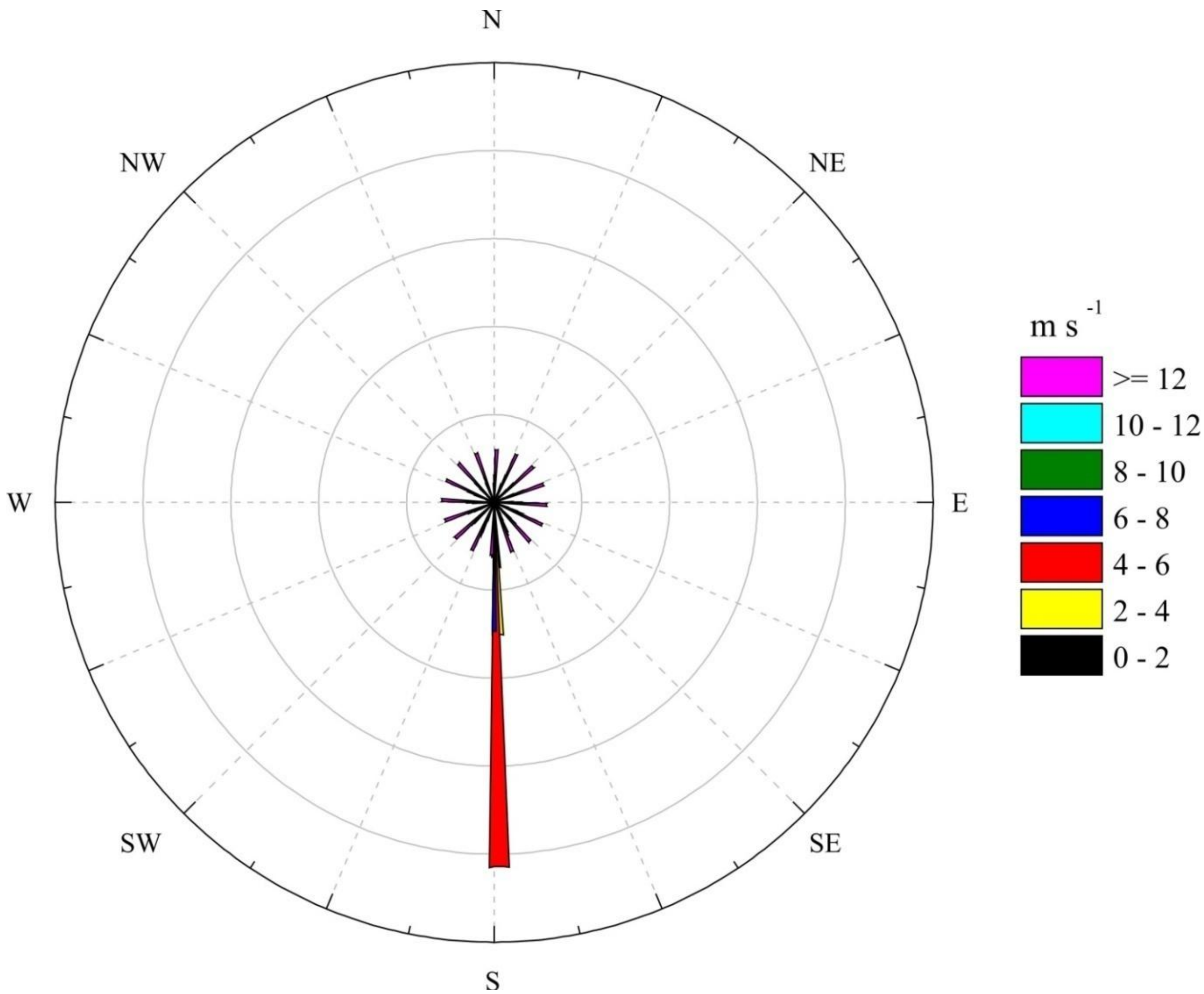

Figure 2. Wind direction in Blantyre illustrating the prevailing southerly winds consistent with a wind speed of 4-6 m s^{-1}.

months of May, June, October and December SO_2 mean values did not significantly differ ($p > 0.05$) as was the case for the months of July, September, November paired against each other. Similar observations were noted for NO_2 results for two groups (May, June, October, November) and (July, August, September, December) when paired against each other within the group ($p > 0.05$).

As indicated earlier, there were significant diurnal variations ($p < 0.05$) on a daily basis. As such, the same pattern showed up in seasonal diurnal variations except for wind speed (Figure 5). Furthermore, independent t-test showed that there were significant differences ($p < 0.05$) between wet season mean values (CO = 2.73 mg m^{-3}; SO_2 = 5.10 mg m^{-3}; NO_2 = 9.41 mg m^{-3}) and dry season mean values (CO = 2.32 mg m^{-3}; SO_2 = 3.42 mg m^{-3}; NO_2 = 8.13 mg m^{-3}). Similarly, there were significant differences between dry and wet season mean air temperature and wind speed ($p < 0.05$). Higher air temperature values were noted in wet season (21.7°C) as compared to dry season (19.3°C). But, higher wind speed values occurred in dry season (4.94 m m^{-1}) as compared to wet season (4.77 m m^{-1}) (Figure 3).

Temperature is a driving force in chemical reactions while lower wind speed may promote buildup of chemicals in the atmosphere since there will be less dispersive force to dilution effect. Thus, pollutants will readily react to form new compounds in ambient air such as (Bailey et al., 2005):

$$NO_2 + O_2 \rightarrow NO_3 \text{ (dry deposition)} \quad (2a)$$

$$NO_3^- + H_2O \rightarrow HNO_3 + OH^- \text{ (wet deposition)} \quad (2b)$$

$$CO + 2O_2 + hv \rightarrow CO_2 + O_3 \text{ (fast process)} \quad (3)$$

$$SO_2 + O_2 \rightarrow SO_3 \text{ (slow process)} \quad (4a)$$

$$SO_3 + H_2O \rightarrow H_2SO_4 \quad (4b)$$

During wet season, the humid atmosphere and high air temperature may promote photochemical reactions of

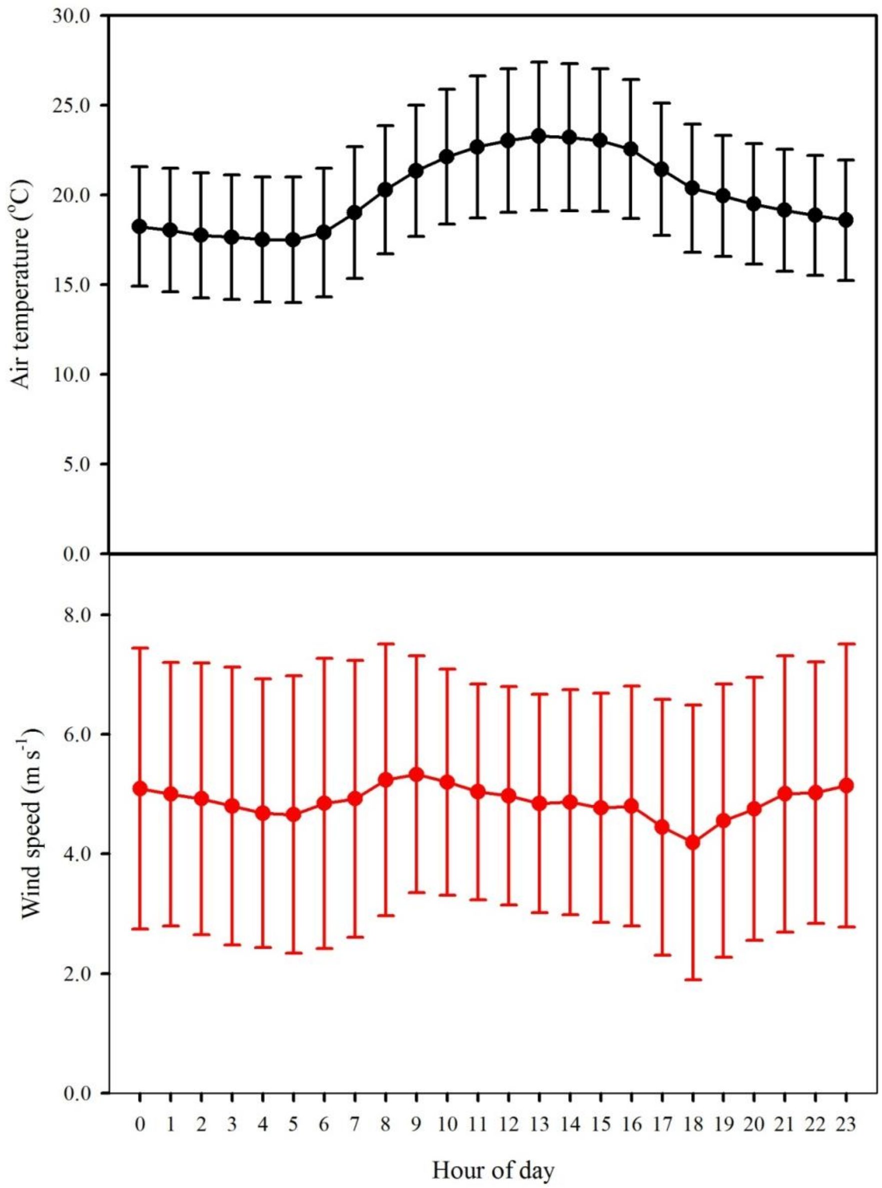

Figure 3. Hourly variations of air temperature and wind speed recorded using the EMS. The graphs indicate mean values where error bars represent standard deviation of mean.

NO_2 and SO_4 to form their acidic products leading to attenuation of the pollutant. For instance, in fog or cloud, SO_2 reacts with water to form sulfurous acid (H_2SO_3) followed by oxidation to form H_2SO_4, a similar outcomeof Equation 4 (Bailey et al., 2005). Yet, such products are caustic and may destroy natural and man-made infrastructure. However, low wind speed and maybe consistent wind direction lead to reduced air pollutant dilution. Also, maybe the fact that higher temperatures leads to air from lower level to rise, increasing pollutant concentration in air at the level of the EMS. As such, effective recording of emissions from vehicles and motor cycles by the instrument is increased. CO reacts in air to form CO_2 (Equation 3). Due to CO having a lower residence time than SO_2 and NO_2, the formation of CO_2 reduces the concentration in ambient air way below national threshold values in Blantyre.

Multivariate analysis

Hierarchical cluster analysis (HCA) revealed natural

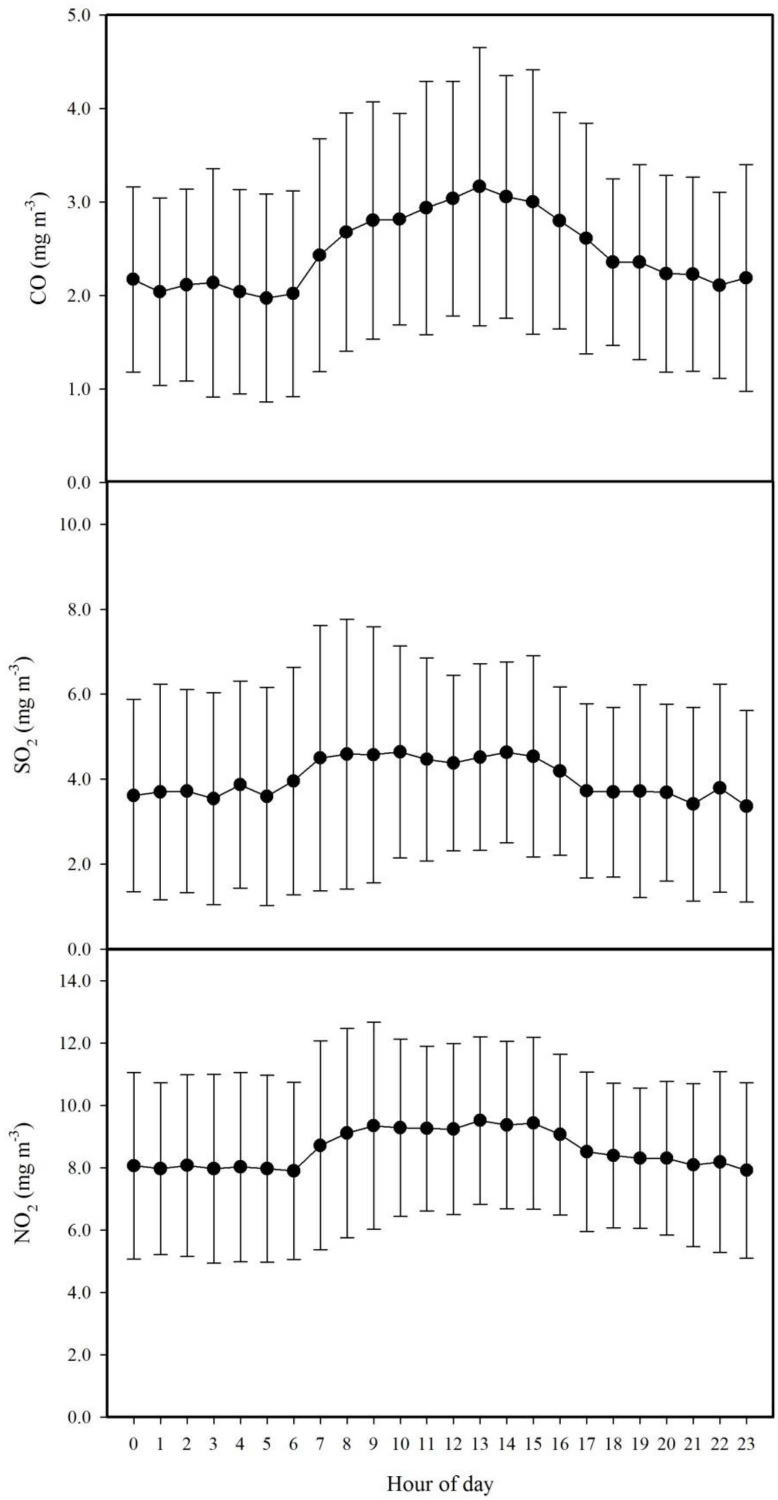

Figure 4. Hourly variations of CO, SO_2 and NO_2 recorded using the EMS. The graphs indicate mean values where error bars represent standard deviation of mean.

groupings of months within the study period. After drawing the phenon line at rescaled distance of 7.5, three clusters emerged. The choice of phenon line is based on semi-objective inspection of the dendrogram (Figure 6).

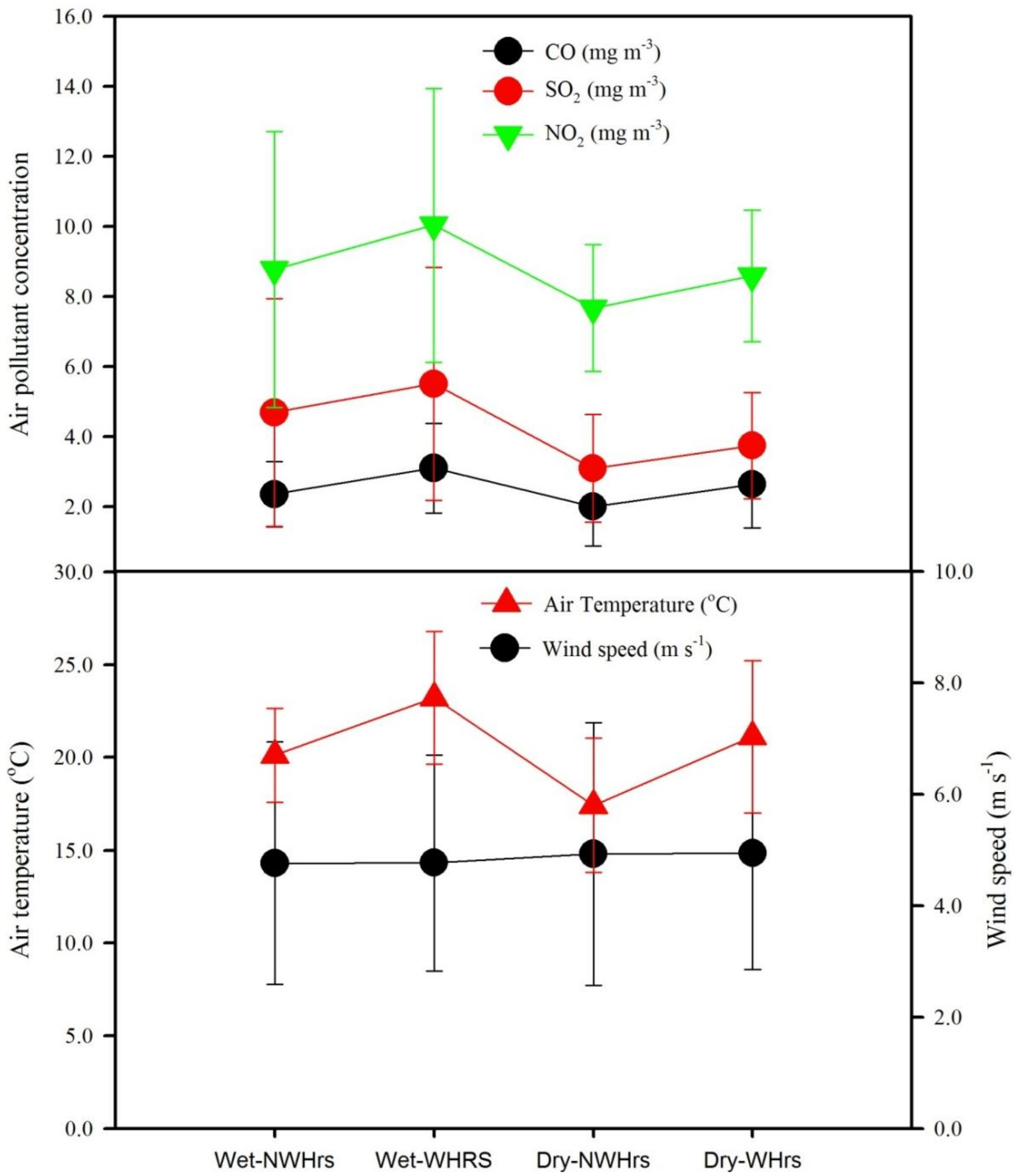

Figure 5. Diurnal and seasonal variations of air pollutants and microclimatic variables for the entire study period. The error bars represent standard deviations of mean. The labels in the x-axis represent wet season non-working hours, wet season working hours, dry season non-working hours and dry season working hours respectively.

Cluster I consists of August 2011, September 2011, October 2011 and November 2011. Cluster II is a group of May 2011, June 2011, July 2011 and December 2011 while Cluster III is a pair of April 2011 and January 2012.

The first cluster consists of months belonging to the dry warm season. The second cluster is dry cool and sometimes humid season except December which belongs to the warm wet season. The last cluster (April and January) is a pair of months in the wet season. Thus the first cluster describes months with lower air temperature, high wind speed and relatively lower CO, SO_2 and NO_2. The last cluster (April and January) describes months having the highest concentrations of CO, SO_2 and NO_2 (Table 4).

Furthermore, FA's principal component analysis (PCA) explained the impact of microclimatic variables on CO, SO_2 and NO_2. Based on significant Eigen values (Hair et al., 2011), PCA yielded two factors otherwise referred to as principal components (PCs) in this case. The two factors or PCs explained 52.3% of the total variance. The

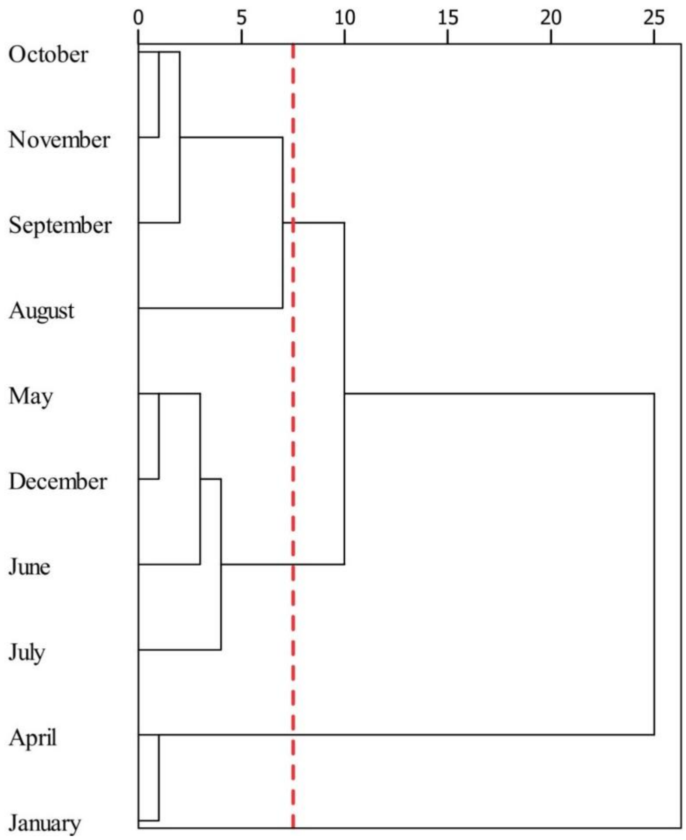

Figure 6. A dendogram produced from hierarchical cluster analysis. The phenon line (red) was drawn at a rescaled distance of 7.5 to identify monthly clusters based on distribution of CO, SO_2, NO_2, air temperature, wind speed and wind direction.

Table 5. Factor analysis' rotated component matrix showing significant factor loadings (principal components, PCs)[a].

Parameter	PC1	PC2
Air temperature		0.714
Wind direction		0.634
CO	0.669	-0.103
NO_2	0.933	
SO_2	0.940	
Wind speed		-0.498
Eigenvalue	2.039	1.099
Variance explained (%)	33.99	18.32

[a]Extraction method was principal component analysis and rotation method being Varimax with Kaiser normalization.

first factor accounted for 40.6% of the total variance. From the rotated component matrix (Table 5), PC1 explained the positive relationship amongst the three air pollutants (CO, SO_2 and NO_2) suggesting their co-occurrence in air in the vicinity of the experimental site.

The second PC identifies the positive high loading of air temperature, wind direction and negative loading of wind speed (Table 5). In this PC, air temperature has a negative relationship with wind speed. Furthermore, a significant positive loading of CO is explained in PC2. The negative influence of air temperature on CO is shown and so is the positive impact of wind speed on CO. The rotated component in space (Figure 7) illustrates the relationship amongst the variables where mostly air temperature shows a strong influence on CO, SO_2 and NO_2 as compared to wind speed and wind direction. From the correlation matrix (Table 6), there is a strong correlation between SO_2 and NO_2 ($p = 0.611$) which suggests similar sources of SO_2 and NO_2.

Besides vehicles, industrial activities closer to the experimental site such as milk production, fertilizer manufacturing, animal slaughter company and matches making that may involve burning of fossil fuels as well as sulfur and nitrogen ingredients or products are emission sources. Moreover, motor vehicles contribute large

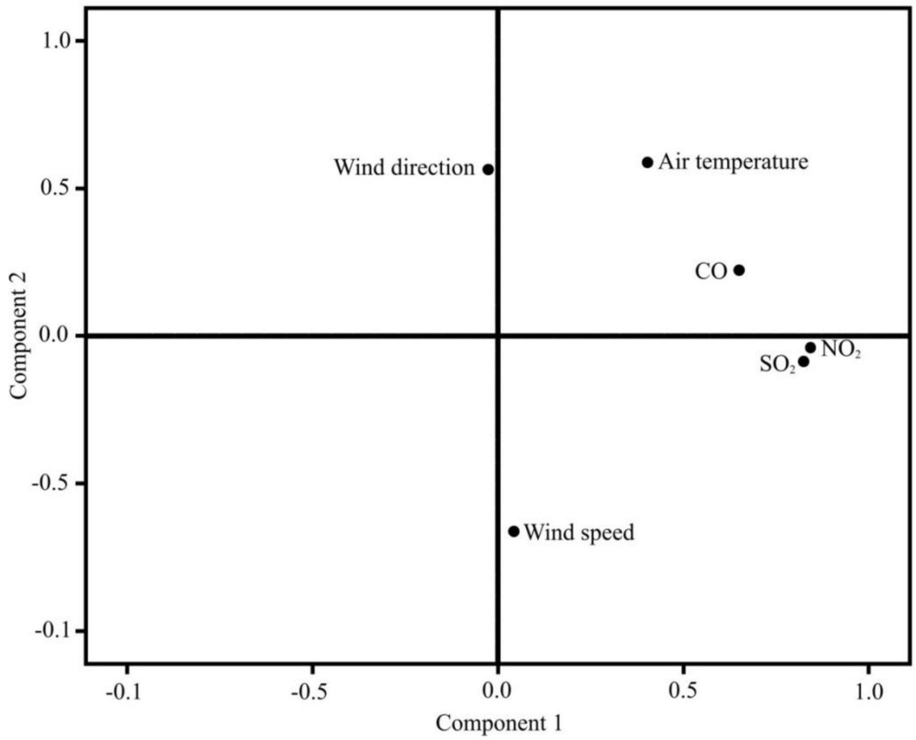

Figure 7. Rotated component graph showing relationship of variables in space.

Table 6. Correlation matrix of initial solutions showing coefficients and significance levels.

Parameter		Air temperature	WD	CO	NO_2	SO_2	WS
Correlation coefficients	Air temperature	1.000					
	WD	0.123	1.000				
	CO	-0.072	0.010	1.000			
	NO_2	0.006	0.022	**0.414**	1.000		
	SO_2	0.012	0.013	**0.438**	**0.900**	1.000	
	WS	-0.077	-0.047	0.011	-0.030	-0.012	1.000
P-value	Air temperature						
	WD	0.000					
	CO	0.000	0.236				
	NO_2	0.333	0.057	**0.000**			
	SO_2	0.192	0.171	**0.000**	**0.000**		
	WS	0.000	0.000	0.206	0.015	0.198	

WD = Wind speed, WS = wind direction.

quantities of atmospheric NO_2 pollutant in cities as compared to other sources (Makra et al., 2010). As such, most of the NO_2 detected may be from vehicular sources. Considering the low residence time of CO, we can conclude that the main source is vehicular emissions in the main highway (Mapoma et al., 2013) as opposed to industrial activities.

With the observed relationships between CO, SO_2 and NO_2 on one hand and micro climatic variables on the other, various remarks can be made from the results. Effect of wind speed and wet periods can be explained as: most of the time wind is calmer at night than day time, leading to a relatively stable atmosphere at night (Elminir, 2002). The stable atmosphere hinders mixing of air leading to reduced concentrations of CO, SO_2 and NO_2 to rise to 25 m. Moreover, transport effects due to increased wind speed in dry season give an explanation for the dilution and clearing of the local air (Elminir, 2002). This explains in part the low concentrations of CO, SO_2 and NO_2 recorded at the experimental site at night and in dry season coupled with lower air temperature. Effect of changes in wind direction is significant on hourly variations in CO, SO_2 and NO_2 while consistent southerly winds over the entire study period (Figure 2) show that wind direction effect is not critical in explaining the seasonal variations.

Conclusions and recommendations

The observed CO level (2.47 ± 1.23 mg m^{-3}) fell below the Malawian limit value of 10.31 mg m^{-3}. But, NO_2 (4.02 ± 2.47 mg m^{-3}) and SO_2 (8.58 ± 2.88 mg m^{-3}) were significantly higher than allowable Malawian Standards (0.52 and 0.23 mg m^{-3}, respectively). Such higher values are detrimental to infrastructure and are a health hazard to human beings. The variations in hourly, diurnal, monthly and seasonal CO, SO_2 and NO_2 signify the important contributions of industrial and transportation activities in the city. Variations in vehicle traffic during the day (peak hour as compared to non peak hours), coincides with variations in emission levels. Independent t-test showed that wet season CO (2.32 mg m^{-3}), SO_2 (5.10 mg m^{-3}) and NO_2 (9.41 mg m^{-3}) levels were higher than dry season values (CO = 2.32 mg m^{-3}; SO_2 = 3.42 mg m^{-3}; NO_2 = 8.13 mg m^{-3}). Factor analysis' (FA) showed that air temperature had significant contribution to variations in mean values of CO, SO_2 and NO_2. Based on results, the study shows a need for constant urban air quality monitoring in Blantyre and urban cities in Malawi. It is recommended that the experimental site widen the scope of the study by utilizing the flexibility of the EMS.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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