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The Influence of Temperature and Relative Humidity on Indoor Ozone Concentrations during the Harmattan

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Abstract
A study to understand the influence of temperature and relative humidity on indoor ozone levels during the Harmattan season over Kotei, a suburb of Kumasi in Ghana has been carried out. The hourly-maximum and average ozone concentrations were measured using the A-22 Eco sensor. A strong diurnal variation of ozone levels within 0.004 and 0.229 ppm for the measurement period was observed. Ozone levels were found to be slightly above the World Health Organisation (WHO) recommended ambient air quality ozone concentration. A strong correlation coefficient of 0.75 and -0.63 for ozone was found with temperature and relative humidity respectively. This indicates that in addition to particulate matter, high ozone levels could contribute to respiratory health problems during the Harmattan season.

Keywords: harmattan, health, humidity, ozone, temperature.

INTRODUCTION

The Harmattan season in Ghana spans between December and March each year. This period is characterised by cold nights, hot afternoons, and highest daily temperature range in the year, very low humidity, dry and dying vegetation, reduced visibility and massive deposition of the grey or yellow Saharan dust particles on surfaces (Sunnu, 2006). During the Harmattan, average daily temperatures are usually very high which are expected to enhance ozone (O_3) production. The tropospheric ozone is an important trace gas regarding its role in the oxidative capacity of the global atmosphere, its climate effect and its impact on air quality (Quansah, 2004). It is produced photochemically in the lower atmosphere from reactions involving a variety of volatile organic compounds (VOCs) composed mainly of non-methane hydrocarbons, and nitrogen oxides (NO_x), composed of nitric oxide (NO) and nitrogen dioxide (NO_2) in the presence of sufficient UV-radiation from the sun (Elampari *et al*., 2010). The NO_x are emitted from a variety of natural and anthropogenic sources, and through the reactions R1 to R4 producing ozone (Quansah, 2004):

$$HO_2 + NO \rightarrow OH + NO_2 \qquad R1$$

$$CH_3O_2 + NO \rightarrow CH_3O + NO_2 \qquad R2$$

$$NO_2 + h\nu \rightarrow NO + O \quad (\lambda \leq 424\,\text{nm}) \qquad R3$$

$$O + O_2 + M \rightarrow O_3 + M \qquad R4$$

where N_2 or O_2 represents M, a third body molecule required for simultaneous conservation of energy and momentum. Measurements of surface ozone levels and their changes are of great importance, because exposure to higher concentrations of ground level ozone will aggravate respiratory problems including: coughs, throat dryness thoracic pain and increased mucous production in humans (Tarasova *et al.*, 2003). Furthermore, tropospheric O_3 is harmful to vegetation and synthetic materials like fibres and paints (Lahnemann, 2005; Reid, 2007; Waldner *et al.*, 2007). It has also been observed that ambient ozone produces early inflammatory changes in the airways of children at levels slightly below daily maximum 8-hour mean air quality standard of 0.050 ppm (WHO, 2005; Nickmilder *et al.*, 2007).

The amount of ozone present in the troposphere varies from day to day and from place to place (de Laat *et al.*, 2009). It has been shown that in contrast to the high elevation site, the diurnal behaviour of ozone at low elevation sites followed a typical solar radiation cycle with high ozone levels during the day and low during the night. Observed ozone episodes appear to have been either generated locally or the precursors transported via the prevailing winds (Adeeb *et al.*, 2004). It has also been revealed that chemical ozone generation is strongly affected by meteorological conditions (Tarasova *et al.*, 2003). For instance, ozone levels tend to increase under hot sunny conditions favourable for photochemical ozone production. However, wet, rainy weather with high relative humidity is typically associated with the low ozone levels provided by wet ozone deposition on the water droplets (Tarasova *et al.*, 2003; Kovač-Andrić *et al.*, 2009).

Ghana as a developing economy has limitations to the activities of O_3 monitoring and relevant research issues (WMO, 2008). Most of the works carried out, are on the levels of O_3 precursors such as NO_x = (NO and NO_2). For example, Aboh (2004), reported fluctuations in NO_x concentrations between 0.003 - 0.01 ppm for Beposo (05° 7' 0" N, 01° 37' 0" W). In the same period levels at Aboadze (04° 58' 0" N, 01° 37' 60" W) showed 0.006 - 0.015 ppm. Even though these concentrations were found to be below the Environmental Protection Agency's maximum limit of 0.050 ppm, it is difficult to translate these levels into ozone values. Nevertheless, Cazorla and Brune (2010), showed the existence of a strong positive correlation between NO_x levels and ground level ozone.

As part of the efforts to investigate the impact of meteorological variables on the variability of indoor ozone concentrations, measurements were carried out using the A-22 Eco sensor at a residential area during the Harmattan periods of 2010 - 2011. The findings in this study could serve as a first step towards the investigations of the causes of respiratory health problems during the Harmattan season.

We present results of the investigations of the effect of relative humidity and temperature on the variability of indoor ozone concentrations. And compare the maximum and minimum hourly-values with those observed from a previous work carried out before the onset of the Harmattan. Lastly, these values are compared with the World Health Organisation (WHO) recommended current air quality standard for ambient ozone.

MATERIALS AND METHODS

Site Description

The study area Kotei (232 m a.s.l, 06° 39' 48.7" N, 01° 33' 32.4" W) is an Inland (residential) location in the Kumasi metropolis and is about 6 km from the Kwame Nkrumah University of Science and Technology (KNUST), Figure 1. Few major roads are tarred in Kotei traditional residential areas. Other roads are untarred and are predominantly dusty.

Measurement with the Eco Sensor

The A-22 Eco sensor ozone monitor was used for the measurements. The ozone sensor was mounted on a sensing board, which included a microprocessor and the Electrically Erasable Programmable Read-Only Memory (EEPROM). The A-22 host instrument adjusted the sensor readings for temperature and relative humidity based on data sent from the sensor module. The internal signal processing was done by digital microprocessors. The instrument automatically selected 0 - 1.999 ppm or 2.00 - 20.00 ppm range as required. The operating temperature and relative humidity ranges were 0 - 40 °C and 0 - 80% respectively. The plug-in replaceable sensor was precalibrated. A selected continuous reading, the maximum, average or minimum over a period of time could be used. However, for the purpose of this work, sixty (60) minutes maximum and average values of the data stream were determined using the control knob. The outdoor temperature and relative humidity values were obtained from the Ghana Meteorological Agency's office in Kumasi.

Correlation Analysis

In order to check the quality of the fit shown in Figure 5, the sum of the square of the residual, A, given in Equation (1) is employed.

$$A = \sum_{i=1}^{N} [f(x_i) - t_i]^2 \tag{1}$$

where $f(x_i)$ is the fitting function and t_i is the set of collected data. The sum of the square of the deviation of the collected data, S, from the mean is given by Equation (2):

$$S = \sum_{i=1}^{N} (t_i - \bar{t})^2 \tag{2}$$

where $\bar{t}$ is the mean value of the measured data. The correlation coefficient, r, is given by Equation (3):

$$r = \left(1 - \frac{A}{S}\right)^{1/2} \tag{3}$$

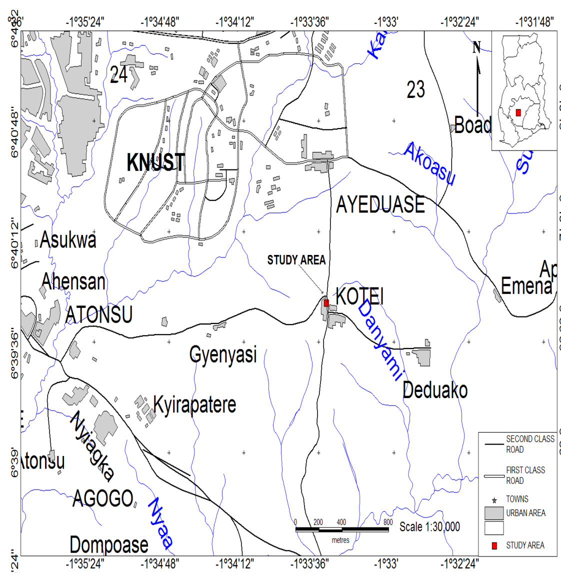

Fig. 1: Location of the study area at Kotei, a suburb of Kumasi

RESULTS AND DISCUSSION

The variation in the indoor ozone levels for six measurements days is shown in Figure 2. The individual graphs for all the days are also shown in Figure 3. The results revealed a strong diurnal variation of the ozone concentrations for all the measurements. For each indoor ozone measurements, the corresponding ambient temperature and relative humidity plots were also obtained. As temperature increases relative humidity decreases and vice versa

(Figure 4). In addition, average daily wind speeds for each of the measurement periods yielded 1.84±0.72, 1.27±0.60, 1.68±0.45, 1.03±0.62, 0.88±0.61 and 1.88±0.53 ms^{-1} respectively. A comparison of the results from Figures 3 and 4 suggested that peak values of the ozone concentrations occurred in the afternoons when temperature values were high and relative humidity values were low indicating a strong dependence of ozone production on sunlight and relative humidity.

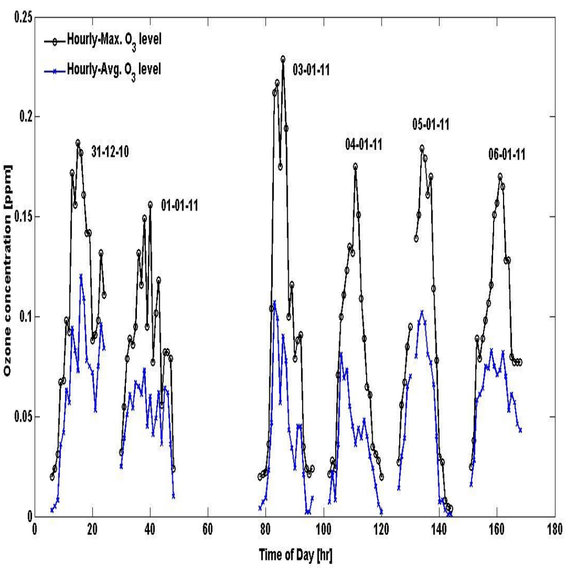

Fig. 2: Variation of hourly-maximum and hourly-average ozone concentrations over a six day period between December 2010 and January 2011.

The highest and lowest hourly-maximum ozone levels occurred on the 3rd and 5th days of January 2011. The ozone values of these dates were 0.229 and 0.004 ppm respectively (see Figure 3c and 3e). The 3rd of January had one of the highest average daily temperatures of 26.22 °C and lowest average daily relative humidity of 27% (Figure 4c). Hence, the corresponding hourly-maximum value of 0.229 ppm on that day revealed that hot sunny and low humidity conditions were favourable for photochemical ozone production. Similarly, the highest and lowest hourly-average values of 0.120 and 0.001 ppm were recorded on the 31st of December 2010 and 5th of January 2011 respectively (Figure 3a and 3e). Investigations also revealed that the peak values for the hourly-maximum levels in all the measurements exceeded the WHO recommended level of 0.050 ppm for 8-hour exposure.

Correlation between ozone concentrations, temperature and relative humidity values revealed a strong positive correlation between hourly-maximum ozone concentrations and temperature with a correlation coefficient, r, of 0.75 (Figure 5a). This suggests that ozone production increases as temperature increases. The correlation between hourly-maximum ozone concentrations and relative humidity gave r = -0.63 (Figure 5b), an indication that O_3 concentration is directly related to temperature and inversely related to relative humidity. Arundel *et al.* (1986), showed that indoor ozone levels were enhanced by low indoor relative humidity whereas high indoor relative humidity reduced concentrations by accelerating the adsorption of ozone molecules onto indoor surfaces.

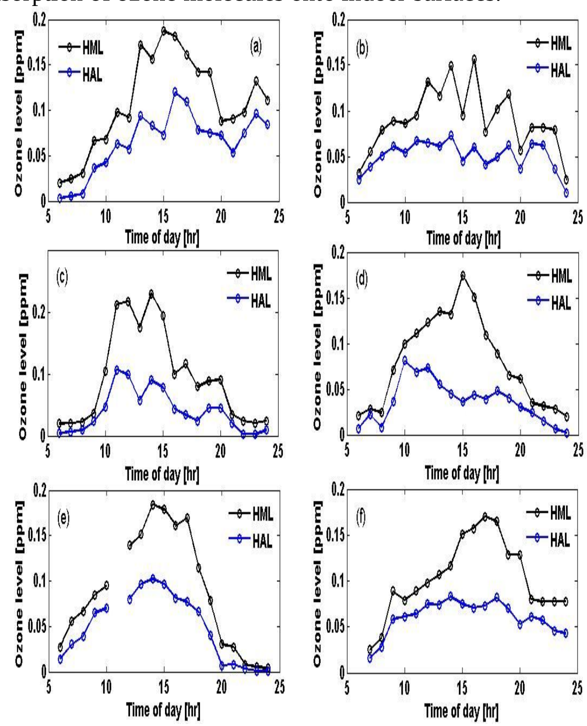

Fig. 3: Hourly-maximum ozone levels (HML) and hourly-average ozone levels (HAL) for each day in Fig. 2

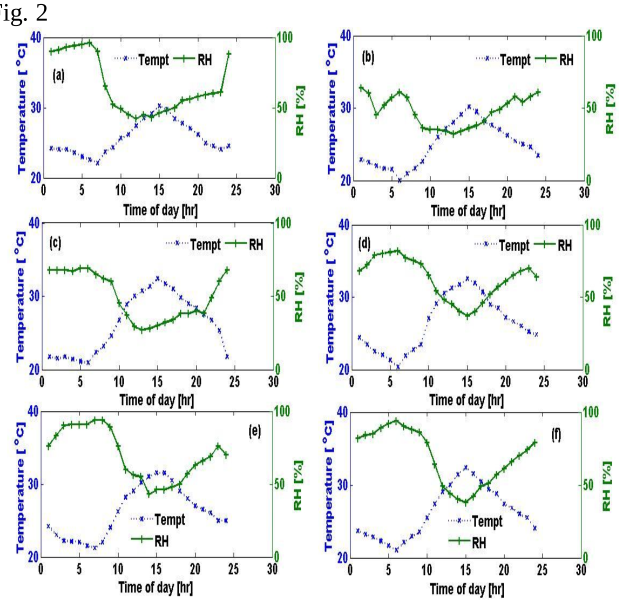

Fig. 4: Variation of ambient temperature and relative humidity corresponding to each day shown in Figure 3

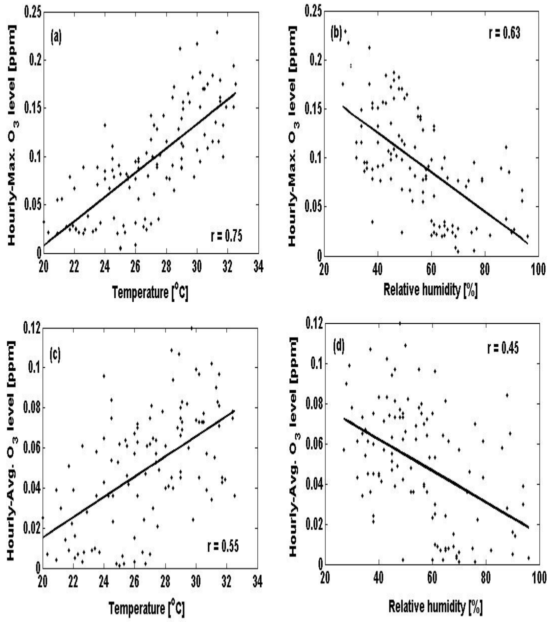

Fig. 5: Correlation between Hourly-Maximum Ozone Level and (a) temperature, (b) relative humidity and between Hourly-average Ozone level and (c) temperature, (d) relative humidity.

The correlation coefficient values between hourly-average ozone concentration and temperature and relative humidity were 0.55 and -0.45 respectively (Figure 5c and 5d). This indicates that the hourly-mean ozone levels were also fairly influenced by temperature and relative humidity.

CONCLUSION

The relationship between indoor ozone concentrations, temperature and relative humidity has been studied. The results revealed strong diurnal variation in ozone concentrations for all the measurements. Lower relative humidity corresponded to higher temperatures, higher solar radiation and higher O_3 formation rates. The least and most hourly-maximum levels of 0.004 and 0.229 ppm occurred on the 3rd and 5th days of January 2011 respectively, while the 31st of December 2010 and 5th of January 2011 recorded the least and highest hourly-average levels of 0.001 and 0.120 ppm respectively. Comparing these values with the least hourly-average level of 0.001 ppm and highest-hourly average level of 0.021 ppm that were obtained from measurements carried out before the onset of the Harmattan by Ofosuhene and Kuu-Ireme, (2010), suggested that during the Harmattan period, when most of these meteorological factors are severe, indoor ozone concentrations could exceed that of the WHO recommended ambient air quality standard value of 0.050 ppm for 8-hour exposure (WHO, 2005). Hence, surface or meteorological conditions like temperature, relative humidity, wind direction, wind speed, rainfall and convection play important roles in the formation and transport of ground level ozone and thus, influence indoor ozone concentrations. Observed ozone concentrations are valuable indicators of possible health and environmental impacts and for this purpose, the influence of meteorological variables is a confounding factor. We believe that even though the contributions from the diurnal evolution of key chemical players (NO_x, hydrocarbons, Aldehydes etc.) in the atmosphere could not be ascertained, the results revealed that large amounts of ozone were produced when these chemical players were exposed to UV radiation where NO_2 is broken down and the released oxygen contributes to the increasing concentration of ozone (Platt and Stutz, 2008).

We are also of the view that if indoor ozone levels could be that high, we cannot attribute the increase in respiratory problems during the Harmattan seasons to only the dust laden north east trade winds that blow across the country within this period (Sunnu, 2006), but also to high indoor ozone levels. Despite these trends, there are limited data on air pollution, especially ozone monitoring in Ghana to suggest that particulate matter should not be the only best indicator of the health effects of pollutant mixtures. Although this work could serve as a first step towards the study of the health impact of indoor ozone levels during the Harmattan season, it is limited with regards to its spatiotemporal representation required for detailed investigations at the regional to continental scales. Further studies need to be carried out to investigate the ozone variability during periods before the onset of the Harmattan.

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