Original Research Article

Temporal variations in ambient carbon monoxide concentrations between weekdays and weekends in Akure central business district, South West Nigeria.

ABSTRACT

The temporal variations in ambient carbon monoxide (CO) concentration has been investigated between weekdays and weekends through the analysis of a year-long measurement data between March 2009 - February 2010 taken at the central business district in Akure, Nigeria. This area has air pollution problems, and the study of the weekdays-weekends effects is used as a tool to plan and develop strategies for air pollution mitigation measures considering the on-going extremely rapid urban growth.CO was measured using portable Lascar EL-USB-CO sensor and logger mounted 3 meters above the ground on a lamp post with a sampling frequency of 30 seconds.1 hour and 8 hour averages were then computed from the raw data using descriptive statistics: weekly evolution,weekdays-weekendsdifferencesand average daily difference between weekends minus workdayswere computed and hypothesis on the difference in holiday and non-holidaycarbon monoxide concentrations was tested.Based on daily parameters and weekend-weekday differences, all the measured air pollutants exhibited clearly reduced concentrations**.**Results show distinct weekdays and weekend variations with respect to traffic rush hours. Weekdays exhibited two peaks that coincide with morning rush hours to work and evening rush hours back home. Weekends had two and one peak related to traffic for morning church service and evening social outingsrespectively. The highest CO concentrations during the morning and evening rush hours for 1 hour averages were 12.57 ppm and 14.51 ppm for weekdays and 8.50 ppm and 14.62 ppm for weekends respectively. While the highest CO concentrations during the morning and evening rush hours for 8 hour averages were 9.57 ppm and 13.17 ppm for weekdays, it was 8.40 ppm and 11.72 ppm for Sunday morning and evening peaks respectively, for Saturday the value was 14.51 ppm.Weekdays CO concentration for daytime mean 1 h values of 8-20 ppm and daytime mean 8 h values of 4-12 ppm were observed while the weekends concentration exhibited a consistent similar cyclic diurnal pattern throughout the week, with daytime mean 1 h values of 2-10 ppm and day-time mean 8 h values of 4-8 ppm. The magnitude of the differences between mean weekdays and weekends CO concentration during December, January, February (DJF), was 45% compared to 21% between March, April, May (MAM). While June, July, August (JJA) was 18% compared to 16% between September, October, November (SON) in the central business district.

Key words: Carbon monoxide ppm (CO), Weekdays, Weekends, WHO, Holiday, Akure.

1.0 INTRODUCTION

Considered as a criterion of air pollutant, CO concentration is an important component in urban and indoor air pollution because of its short-term harmful health effects. The probability of inhalation of particles depends on factors such as aerodynamic diameter, air movement around the body and breathing rate (WHO 1999).The size, structure, concentration and chemical compositionare important parameters that determine the health risks of particles (Crilley et al. 2014).Transportation accounts for 90% of its total emissions (Sathitkunarat*et. al.,* 2006). Twopollutants that are usually surveyed for alongside other pollutants in most air quality studies are Fine Particulate Matter (PM2.5) and Carbon Monoxide (CO). These pollutants are listed among the criteria air pollutants by the United States Environmental Protection Agency (USEPA, 2015).The impact of motor vehicle emissions extend far beyond the local area (Ndoke and Jimoh, 2005).The temporal variation of concentration of pollutant throughout the day varies with the influence of local wind parameters such as direction and speed and other meteorological aspects (Charles and Shelley *et. al.,*2006). The weekly cycle of activities of population explain distinct temporal variation in pollution levels from weekdays (Monday to Friday) to weekend (Saturday and Sunday) KakoliKarar*et.al.,*(2005). The changes of most gaseous pollutant emissions during weekdaysand weekends are directly or indirectly linked to changes intrafficand to industrial emissions (Beirle*et al.,*2003; Steinbacher*et. al.,*2005). Furthermore, anthropogenic weekend effect in ambient air quality, due to human habits associated with a weekly cycle, has been reported in various studies (Bronnimann and Neu, 1997; Beirle*et. al.,*2003). The highest CO concentrations occur in close proximity to motor vehicles emissions (Liu *et. al.,* 1994; Chaloulakou*et. al.,* 2002).

The estimate of the maximum value of concentration experienced in a given period of time represents an important factor in the quality of the air and it is widely used to define air quality standards for urban and industrial areas. Health based guidelines for maximum ambient CO-levels are: 86 ppm for 15 min, 52 ppm for 30 min, 26 ppm for 1 h and 9 ppm for 8 h exposure (WHO, 2004).Most differences between weekdays and weekends are statistically significant, but their sign might be opposite for different regions or seasons (Forster and Solomon, 2003; Gong *et. al.,*2006a). This ``weekend effect'' observed in meteorological parameters has been attributed to anthropogenic influences (Cerveny and Balling, 1998; Beaney and Gough, 2002; Forster and Solomon, 2003). The weekend effect of air pollutant concentrations and meteorological parameters is a useful tool to detect the influence of human-related activities on the environment and climate system. This effect depends an individual country's working and nonworking lifestyle, degree of industrialization, or religious and cultural background (Forster and Solomon, 2003; Beirle*et. al.,*2003), so it may not be consistently observed everywhere in the world. Thus, other similar effects, such as a ``holiday effect'', defined as differences in air pollutant concentrations or meteorological parameters between holiday and non-holiday periods, provide a possibility to study such phenomena for regions not showing a clear weekend effect.Carbon monoxide concentration showed signs of an increase in recent years. Several researches involved measuring pollution near the streets or employing personal monitoring devices have been carried out in several cities, but limited work has been performed on the atmospheric carbon monoxide in the tropics and mostly in the developing world. Similar work was done in Lagos (Baumbach*et al.,* 1995) showed distribution of carbon monoxide with highest concentration in the morning. Amongst the few work done in West Africa is the work done on carbon monoxide in Ouagadougou, Burkina Faso.Recent study by (Balogun*et al.,* 2009) indicated the variations in bioclimatic condition and carbon monoxide in the city having three peaks periods; morning afternoon and evening.Balogun*et al.,* 2014 also reported that CO concentrations in the Akure urban centre exhibited distinct diurnal and day of week variations with respect to traffic rush hours. The holiday effect has not been explored as much as the weekend effect.Therefore, the main objective of the research was to determine the differences between weekdays/weekends and holiday carbon monoxide concentrations in the tropical environment.

2.0 MATERIALS AND METHODS

2.1 THE STUDY AREA

The study area of this research is Akure, the capital city of Ondo State, Nigeria located on latitude 7.25 ˚N and longitude 5.20 ˚E. The rapid growth of the city, particularly within the last few decades, has made it one of the fastest growing metropolitan cities in the South Western Nigeria. 1991 census put the population of Akure at 324,000; the current population of the city is put at 387,087 (2006 population census).

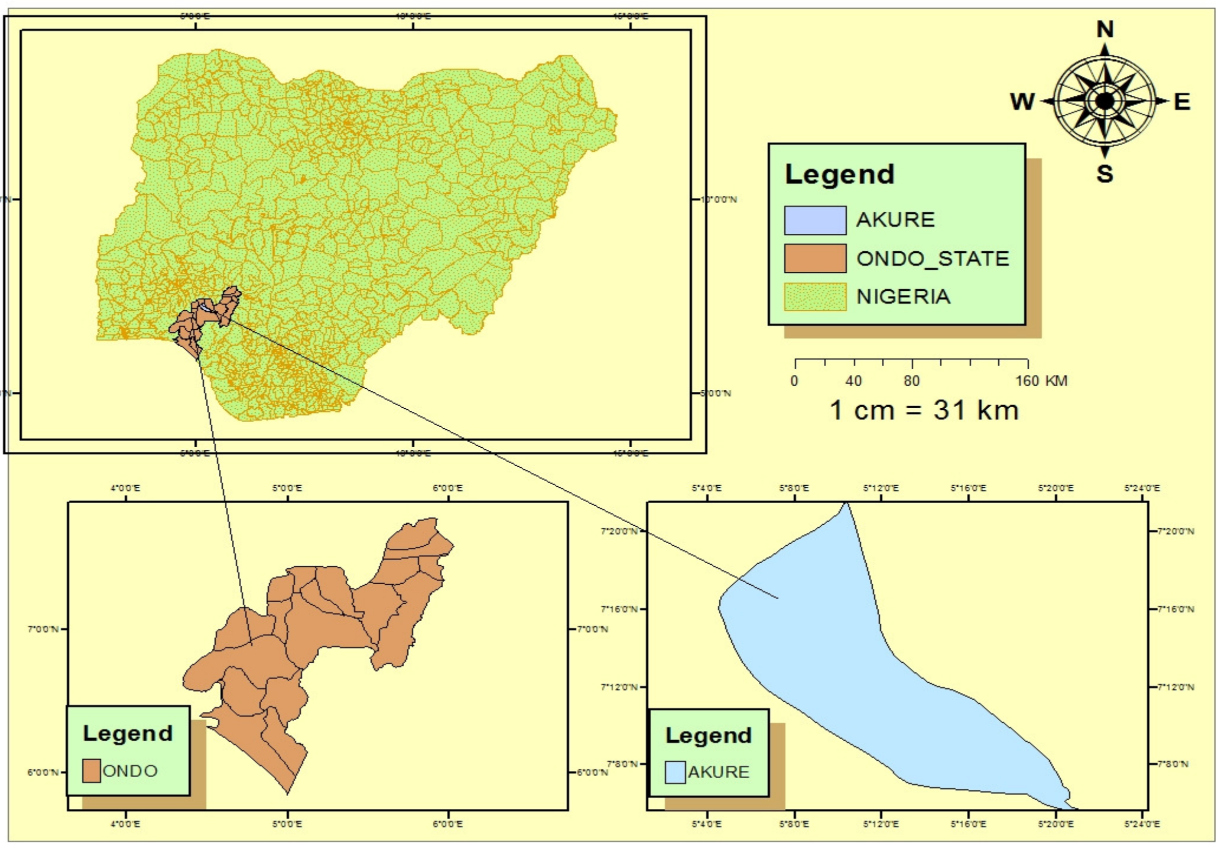

Figure 1: Map showing position of Akure (blue) in Ondo (brown) and Nigeria (yellow)

2.2 DESCRIPTION OF THE NIGERIA HOLIDAY/FESTIVE DAYS

The Nigerian Holiday or Spring Festival is the most important holiday for the Nigerian people, who heavily emphasize family values, making family reunions an important tradition during the festive or holiday periods. Nigerian holidays and festive holidaysare set according to the calendar for Nigeria. Thus, the exact date of Islamic holiday varies from year to year but moves within themonths of February, March, September and November of the Julian calendar. Usually, Nigerian holiday lasts from 2 to 3 days. The definition of the Nigeria holidays is set according to the official record of the holidays and observation of Calendar for Nigeria. These specific dates are listed in (Table 1).

A public holiday or gazetted holiday marks the day-off for all government offices,schools and many private institutions. The holiday effect on such a leave is exhibited for the period of March 2009 to February 2010 for approximately 15 public holidays occurring per year. The pollution levels falls on the holiday and again starts rising from the next day for the non-holiday periods.

CALENDAR FOR (NIGERIA)

TABLE 1: Holiday and Observation Table (March 2009- February 2010)

MARCH 9TH	ID EL MAULUD (MON)	HOLIDAY
APRIL 10TH	GOOD FRIDAY (JUMAT)	HOLIDAY
APRIL 12TH	EASTER DAY (SUN)	FESTIVE
APRIL 13TH	EASTER MONDAY	HOLIDAY
MAY 1ST	WORKER'S DAY (JUMAT)	HOLIDAY
MAY 29TH	DEMOCRACY DAY (JUMAT)	HOLIDAY
SEPTEMBER 24TH	ID EL FITR (THUR)	FESTIVE
SEPTEMBER 25TH	ID EL FITR ADDITIONAL (JUMAT)	HOLIDAY
OCTOBER 1ST	NATIONAL DAY (THUR)	HOLIDAY
NOVEMBER 2OTH	ID EL KABIR (JUMAT)	FESTIVE
DECEMBER 24TH	CHRISTMAS EVE (THUR)	HOLIDAY
DECEMBER 25TH	CHRISTMAS DAY (JUMAT)	FESTIVE
DECEMBER 26TH	BOXING DAY (SAT)	HOLIDAY
JANUARY 1ST	NEW YEAR'S DAY (JUMAT)	FESTIVE
FEBRUARY 26TH	ID EL MAULUD (JUMAT)	FESTIVE
FESTIVE = 6 = 9,		TOTAL=15 HOLIDAY

The holiday and observation table above is adapted from Work Calendar for Nigeria (March 2009– February 2010). The total numbers of Nigerian holidays and festive days are 9 and 6 respectively. Note that Nigeria holiday denotes the holidays and festive periods and non-holidays are the working day periods.

2.3 METHODS OF DATA COLLECTION, MANAGEMENT AND ANALYSIS

CO was measured using portable Lascar EL-USB-CO sensor and logger mounted 3 meters above the ground on a lamp post with a sampling frequency of 30 seconds. The presence of the easylog USB control software allows the continuous measurement of the CO concentrations at night. The sampling approach has been used by (Balogun*et al.,* 2009) because of high accuracy, direct readout, and wide spatial coverage. 1 hour and 8 hour averages were then computed from the raw data using descriptive statistics: weekly evolution, weekdays-weekends differences and average daily difference between weekends minus workdays were computed and hypothesis on the difference in holiday and non-holidaycarbon monoxide concentrations was tested.Based on daily parameters and weekend-weekday differences, all the measured air pollutants exhibited clearly reduced concentrations**.**The data used is from a yearlong carbon monoxide measurement campaign conducted through March 2009 - February 2010 in the central business district of Akure.The required time averages (1hr and 8hr) were computed from the raw data that was subsequently analysed. Microsoft Excel and the R Statistics software (Open air) were used to carry out hypothesis testing of variance between weekdays and weekends. Statistical approach was used to test the significance of the data. The daily, weekly and monthly means were carried out for the weekdays and weekends for the period of twelve months. The data set were further analysed for seasonal changes and holiday effect so as to ascertain the conformity with WHO regulatory limits in the city centre. Health based guidelines for maximum ambient CO-levels are: 86 ppm for 15 min, 52 ppm for 30 min, 26 ppm for 1 h and 9 ppm for 8 h exposure WHO (2004). Maximum and minimum values were computed daily for the twelve months periods for both 1hour and 8 hours averages to examine the differences between holiday and non-holidaycarbon monoxide concentrations. In order to test for the significance of the diurnal variation of CO concentration for weekdays and weekends hypothesis testing was used.

3.0 RESULTS AND DISCUSSION

The diurnal variation ofCO concentrations for all days is shown in Akure that CO concentrations tend to peak around 9am(Figure 2). It is evident that morning rush hour concentrations have become more important, and Fridays have become relatively more important because Friday is the most polluted of all week days particularly between 14:00 and 18:00associated with Muslim (Jumat) service in the city centre.The plot at the top right shows how CO concentrations vary by day of the week and there is strong evidence that CO is much lower at the weekends and that there is a significant difference compared with weekdays hence, it also shows that concentrations tend to increase during the weekdays. The time variation function produces four plots: day of the week variation, mean hour of day variation and a combined hour of day to day of week plot and a monthly plot. These uncertainty limits can be helpful when trying to determine whether one candidate source differs significantly from another. Variations in time can be used to compare one part of a time series with another. There is often interest in knowing how diurnal/weekdays/seasonal patterns vary with time.

The seasonal CO diurnal cycle during the day time in the city centre is greatly influenced by local meteorology, which is high in March and October and low in May and November. Akure is a weak wind area with mean wind speed of 10m annually <2m/s and October records the lowest monthly wind speed. This observation is in agreement with previous CO study (Balogun*et. al.,* 2011). Carbon monoxide concentration showed signs of an increase in recent years. However, splitting the data set and comparing each part together can provide information on what is driving the change.

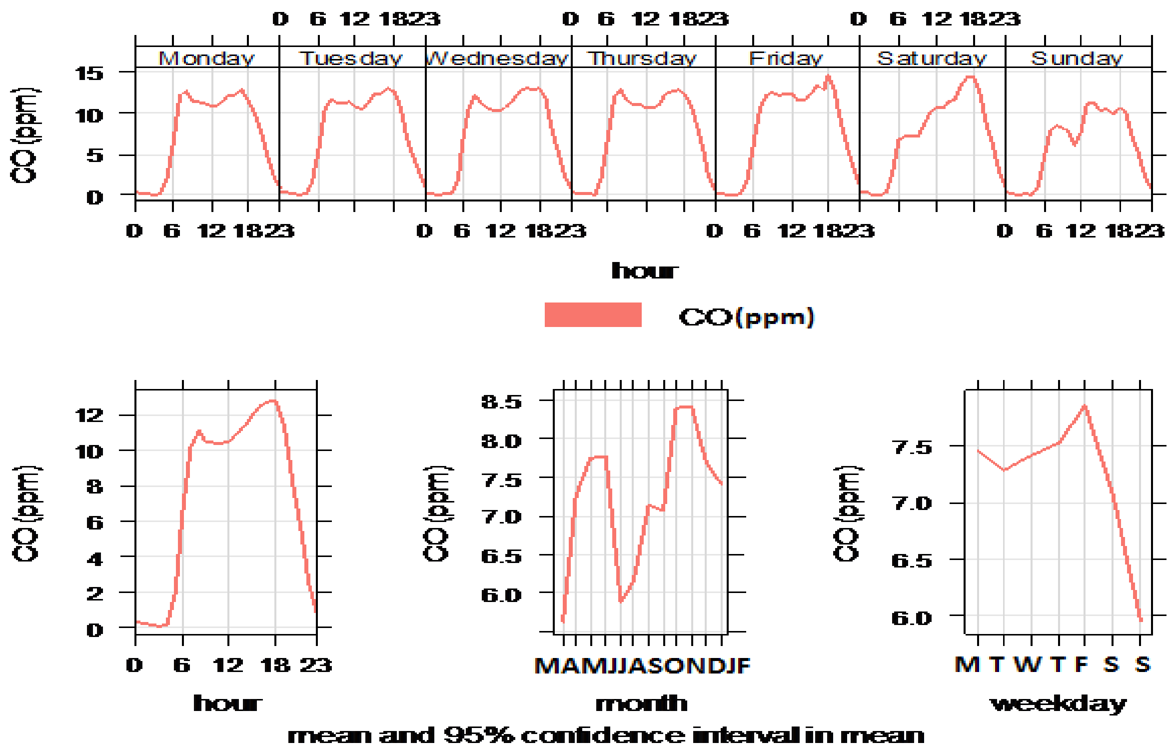

Figure 2: Time variation function of CO concentration.

3.1 TREND LEVEL PLOT FUNCTION

Trend level plot therefore provides information on trends, seasonal effects and diurnal variations. This is one of several similar functions that are being developed. This software allows the plot of variation in onepollutant against three other properties: month of year (as the x axis), hour of day (as the y axis) and year (as the type condition). This provides a convenient means of summarising a large amount of information about the carbon monoxide concentrations on the basis of trends, seasonal effectsand diurnal variations. However, thetrend level function provides a way of rapidly showing a large amount of data in a condensed way. In one plot, the variation in the concentration of carbon monoxide is shown by time of day, month of year and year. Furthermore, the way pollutant concentrations vary over different time scales including day of the year, month of the year and day of the week shows how carbon monoxide concentrations vary by month of the year. Road vehicle emissions in Akure district centre tend to follow very regular patterns both on a daily and weekly basis however, the shading on the plots shows the 95 % confidence intervals of the mean.

Consequently, the condensed redcolourshows the median concentration, which peaks in March and April. The highest hourly concentrations are observed in September and November presumably due to high regional scale pollution episodes. This plots show quite nicely the entire series of data as monthly means that the median and the peak concentrations of carbon monoxide increased in September and November 2009 which is now known to be due to increased emission of primary CO. Highest concentrations are recorded when the wind is westerly. This plot essentially shows the trend in variation of carbon monoxide concentration i.e. no change in wind speed slight dip in wind direction, a decrease in CO in May 2009 and an increase in CO from around September 2009 and a slight increase in February 2010. It also shows that concentration of CO changes much with wind speed (street canyon effects) and that the highest concentrations are recorded when the wind is westerly.

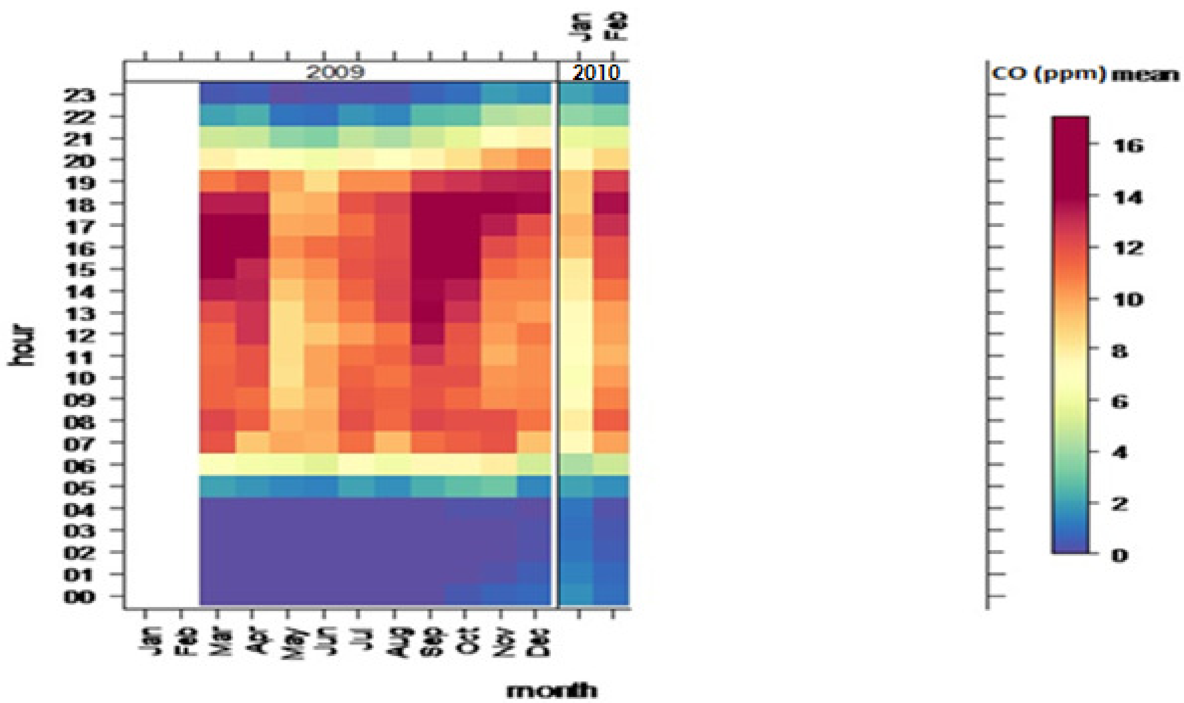

Figure 3: Trend level plot functionof CO concentration.

3.2 THE CALENDAR PLOTFUNCTION

Calendar plot function (Figures 4a and 4b)provides an effective way to visualise data and overlaying the day of the month in this way by showing daily concentrations laid out in a calendar format. The frequency of occurrence for the classification of carbon monoxide concentration is shown by its colours from March 2009 to February 2010 with a user-defined categorical scale with annotations highlighting those days where the concentration of CO >9 ppm. The calendar plot highlights those days where CO concentrations exceed 9 ppm by making the annotation for those days in colour purple and orange while days below are colour green and blue respectively. Plotting the data in this way clearly shows the days where CO >9 ppm. This approach is useful for highlighting daily air quality limits of 9 ppm for maximum daily 8-hour mean concentrations. The adapted work calendar for Nigeria holiday and observation further show that CO concentration has highest frequency of occurrence for weekdays and weekends with respect to World Health Organisation (WHO) health-based guidelines for maximum daily 8 hour mean recommendations consistently exceeded between March, April, September, October, November, December and February except the observed high concentrations in 13th of September and 16th of December respectively.

The colours represent the categorical interval the concentration on a day corresponds to and the actual value itself is shown. The estimate of the maximum value of concentration experienced in a given period of time represents an important factor in the quality of the air and it is widely used to define air quality standards for urban and industrial areas. The calendar plot shows the daily mean concentration as a number on each day and extended to highlight those conditions where daily mean or maximum.

Table 2: 8-hourly average of categorical scales for Calendar Plot (values in ppm)

Band	Description	Carbon monoxide (CO)
6	Very Low	6 (ppm) or below
8	Low	8 – 9 (ppm)
10	Moderate	10 – 11(ppm)
12	High	12 (ppm) or more

In the code above, the labels and breaks are defined for each pollutant in the Table above to make it easier to use the index in the calendar plot function.

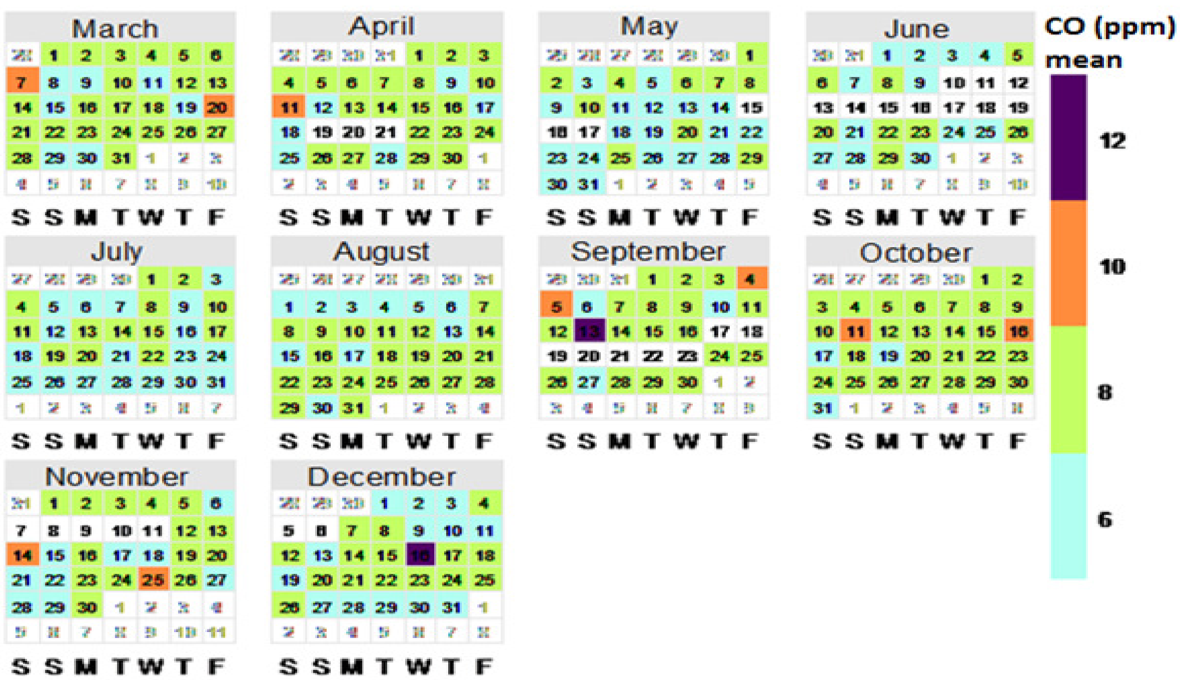

Figure 4(a): Calendar plot for CO concentration in 2009 with a user-defined categorical scale.

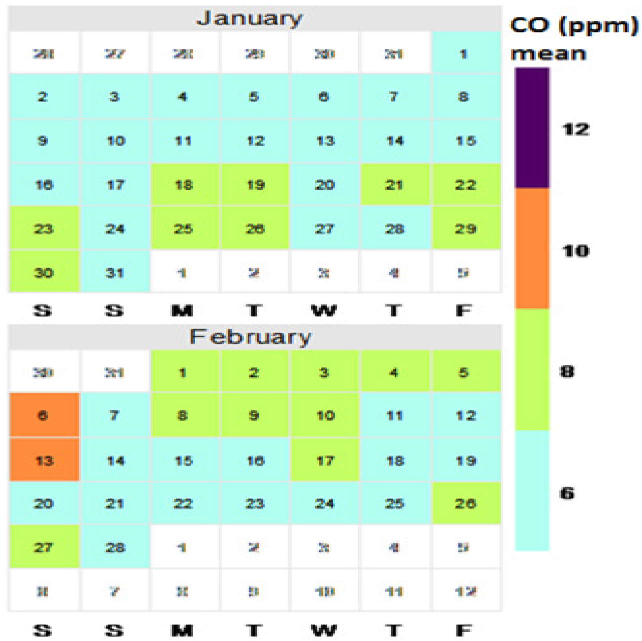

Figure 4(b): Calendar plot for CO concentration in 2009 with a user-defined categorical scale.

3.3COMPARISON BETWEEN WEEKDAYS AND WEEKENDS CO CONCENTRATION FOR 15 MINUTES EXPOSURE

The scatter plot function in Figure 5 shows the relationship between CO for weekdays and weekends respectively, dependent upon the concentration of the sources and levels but it is colour-coded by the concentrations. Differences between weekdays and the weekend highlight changes in emission sources, splitting by season's show seasonal influences in meteorology. The estimate of the maximum value of concentration experienced in a given period of time represents an important factor in the quality of the air and it is widely used to define air quality standards for urban and industrial areas. Colouring the data by the concentration of CO helps to show the significant level of concentrations of maximum ambient CO-levels. Health based guidelines for maximum ambient CO-levels of 86 ppm for 15 minutes exposure.

The summertime-weekday panel for weekdays clearly shows that the higher CO concentrations are associated with summer period (JJA). Indeed there are some hours where CO is >100 ppm at quite low concentrations of CO (≈100ppm). Scatter plots are used for considering how variables relate to one another. It is clearly shown that (DJF) has the highest frequency of occurrence of carbon monoxide concentration for weekdays while for weekends:- (DJF) has the lowest frequency of occurrence.

The scatter plot function reveals seasonally, the magnitude of the differences between mean weekdays and weekends of carbon monoxide concentration levels for

86 ppm for 15 minutes is 60% in the city centre. A smooth fit is automatically added to help reveal the underlying relationship between two variables together with the estimated 95% confidence intervals of the fit. It helps to show the (possibly) non-linear relationship between variables in or indeed whether the relationship is linear.

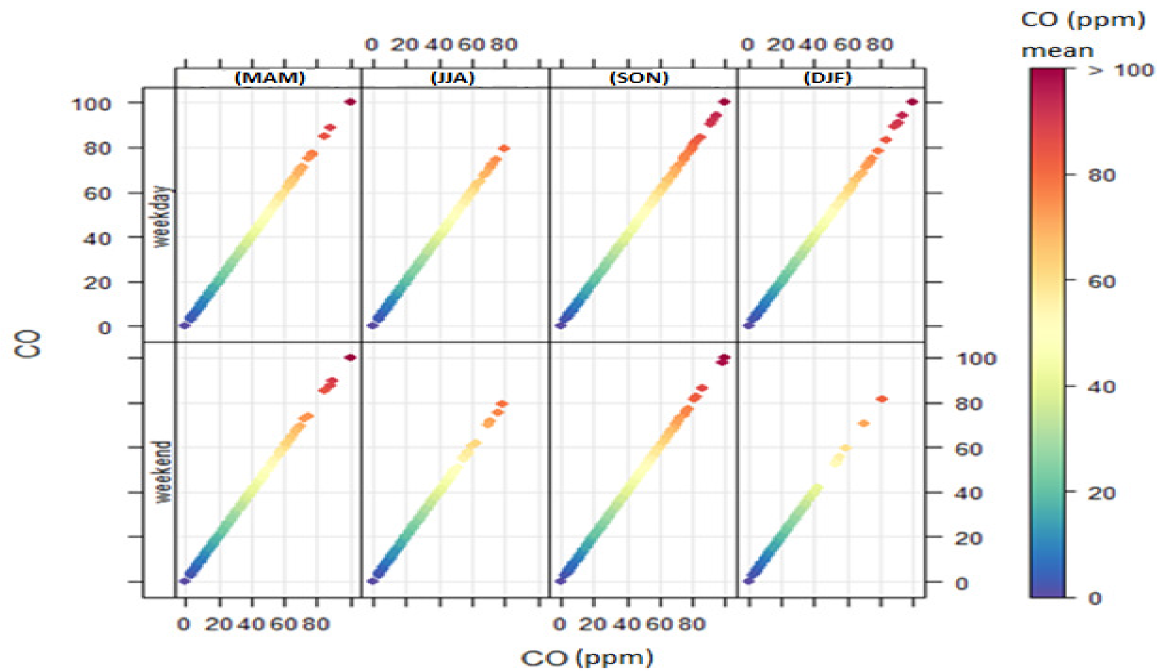

Figure 5: Comparison between Weekdays and Weekends CO concentration for 15 minutes exposure by different level Split by Season

3.4 TIME SERIES DEPARTURE OF YEARLY-MONTHLY PLOTS OF CO CONCENTRATION

Result further obtained justifies the observation in Figure 6 that the nocturnal (1900 to 0600h) carbon monoxide concentration is less dominant than the daytime (0700 to 1800h). The daytime CO concentrations (0700 to 1800h) were mostly observed during the wet and dry season for both holiday and non-holiday. At early hours of the day around 07:00 and 09:00 in the morning peak for both holiday and non-holiday (working days) is associated with passengers who travel very early in the morning including school runs, office runs and the returning market woman to their various shops.

The lunch hour peak for the diurnal around 14:00 and 15:00 is associated with school runs to pick children and little lunch hour traffic is observed. The late afternoon high peak around 16:00 and 18:00 is shown to be associated with school runs, rush hours related to office workers returning from their work place and people going to market for shopping in the late afternoon. The late evening peak around 19:00 and 20:00 is related to evening outing activities associated with merry makers and party traffic, with high in holidays and low in non-holidays and days linked with social event particularly Saturdays and Sundays traditional African social life which appends to travelers returning from journey back home for weekend.

The late mid-night concentration for both holiday and non-holiday period shows a persistent decrease in the city between mid-night and 05:00 in the morning at all days of the year, signifying when there are little or no movement of vehicles on the roads indicates that traffic is the main source of carbon monoxide concentration in the city centre as shown above. This study further shows that mean annual variation of carbon monoxide concentration between holiday and non-holiday period, indicates that the annual mean for holidays is higher than that of non-holiday periods.

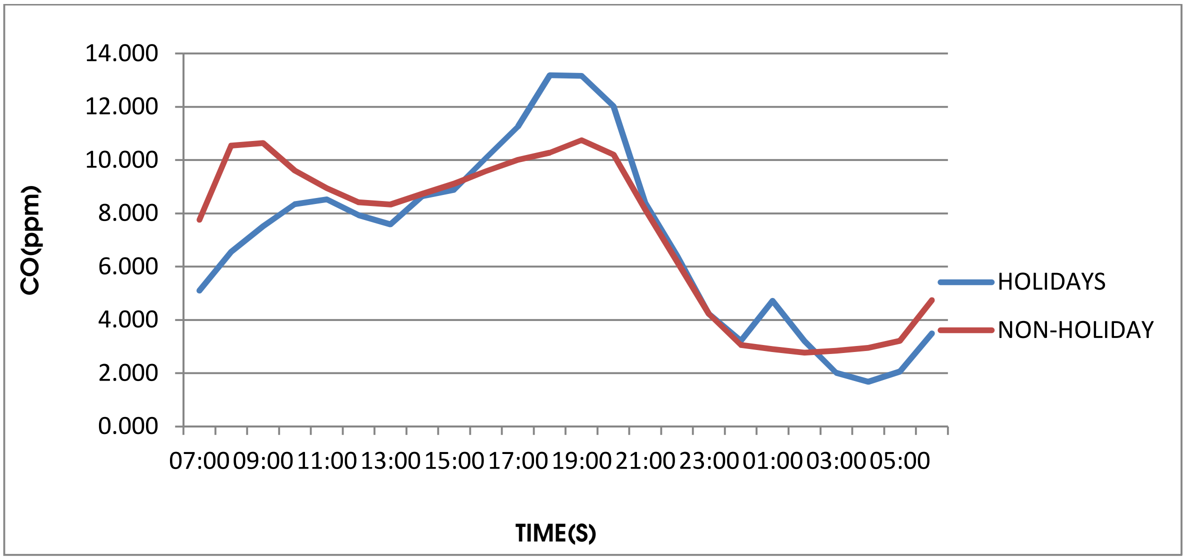

Figure 6: Time series departure of yearly-monthly plots of CO concentration at Akureduring March 2009 - February 2010.

3.5MEAN ANNUAL VARIATION OF CARBON MONOXIDE CONCENTRATION BETWEEN THE HOLIDAY AND NON-HOLIDAY EFFECT

Akure the capital city of Ondo State, South Western Nigeria being the city centre. This study has shown that there are three major factors that are needed to be considered in this research work. They include temperature, cloud cover and wind speed. These three important factors contribute to the mean annual variation of carbon monoxide concentration between holiday and non-holiday effect in dry and wet seasons.

- Temperature: High insolation and high wind during dry season, the high temperature tends to energize the wind speed and brings about the dispersal of pollutant as a result of instability in the atmosphere.
- Wind speed: High wind with high insolation during dry season energizes the dispersal of pollutant as a result of instability. When we have low wind speed and low temperature in wet season we have insufficient amount of energy to drive the wind which will result in higher concentration of pollutant as a result of stability in the atmosphere.
- Cloud cover: When we have overcast in the atmosphere, it tends to cast a shadow on the earth surface thereby preventing direct insolation during wet season and as a result it enhances the concentration of carbon monoxide as a

result of stability in the atmosphere. However, it is observed to be weaker and having a narrow margin with the daytime CO concentration throughout the wet season (April to September) especially during the monsoon, but prevailing from the transitional month of October through the dry season.

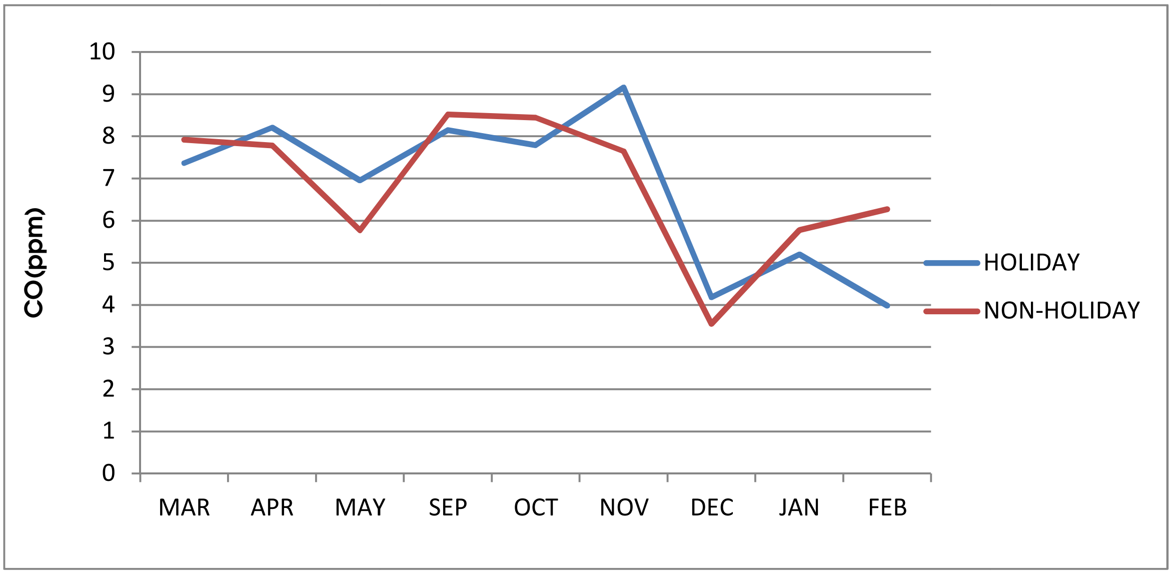

Figure 7: Mean annual variation of CO concentration between the holiday and non - holiday effect.

CONCLUSION

A temporal variation in ambient carbon monoxide concentration between weekdays-weekends and holiday hasbeen investigated. A year-long measurement data was obtained from site located at the central business districtAkure Nigeria, from March 2009-February 2010.Fridays have become relatively more important because it is the most polluted of all weekdays especially between 14:00 and 18:00 hours which could coincides with the Muslim (Jumat) service. However, for Saturday during weekends had the highest CO concentration between 18:00 in the city centre. Results show distinct weekdays and weekend variations with respect to traffic rush hours. Weekdays exhibited two peaks that coincide with morning rush hours to work and evening rush hours back home. Weekends had two and one peak related to traffic for morning church service and evening social outingsrespectively.The magnitude of the differences between mean weekdays and weekends CO concentration during December, January, February (DJF), was 45% compared to 21% between March, April, May (MAM). While June, July, August (JJA) was 18% compared to 16% between September, October, November (SON) in the central business district.This research work provides valuable baseline information for planning and the development of strategies for air pollution mitigation,considering the on-going extremely rapid urban growth.

RECOMMENDATIONS

There is need to curb the CO emission globally, a general understanding of the effects and sources should be oriented at home level. A sense of awareness will now be developed from there expanding to general populace. Improvements in technology and more importantly health has made way for the production of sensors that detect when CO emission in home is becoming too much. It is hypothesized meteorology factor also plays an important role; more cities in Akure must be investigated in order to attain a better overview of the CO concentration levels in Akure.

Consequently, wind speed should be taken into account because the effect of winds to interfere with the CO concentration values. Higher wind values tend to increase the dispersion rate thus decreasing rate thus decreasing the insitu CO concentrations.Also, areas downwind of high CO build-up will tend to have higher values than sites upwind. More commitment in terms of man power, finance and awareness of the benefits of carrying out such study must be made known to the relevant authorities. The findings in this research work could act as a valuable tool in reducing urban environmental health risks connected to air pollution.

Finally, further studies should be carried out relating other air pollutants with CO concentration in ambient air using statistical models. The use of these models allows quantifying atmospheric pollutant diffusion phenomena. This type of objective information is the basis for defining the predictive models to develop, and provides useful preliminary indications for planning of a suitable public health protection policy.

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