Journal of Air Pollution and Health (Winter 2020); 5(1): 11-32

Original Article

Available online at http://japh.tums.ac.ir

Correlation between air pollutants concentration and meteorological factors on seasonal air quality variation

Sunday Oji, Haruna Adamu*

Department of Environmental Management Technology, Abubakar Tafawa Balewa University, Bauchi-Nigeria

ARTICLE INFORMATION

Article Chronology:
Received 24 February 2020
Revised 29 February 2020
Accepted 18 March 2020
Published 29 March 2020

Keywords:
Air pollution; Air quality; Fate; Human health

CORRESPONDING AUTHOR:

hadamu2@atbu.edu.ng
Tel: +2348065309319
Fax: +2348065309319

ABSTRACT:

Introduction: Hitherto studies have concentrated on the pollution concentration in an ambient environment not putting into cognizance meteorological factors that can determine the fate/trail of the pollutant in the atmosphere.
Materials and methods: Accordingly, the study monitored ambient topical air triplicate day-time concentration of NO_2, PM_{10}, SO_2, H_2S and CO using portable digital air pollution detecting device for 30 days in each of the representative apex months of dry (April) and wet (August) months of 2018 in Kano Metropolis. However, meteorological data were collated from Nigerian Meteorological Agency (NiMet).
Results: The result showed pollution concentration for Bompai and Sabon Gari are the highest followed by Dowrawa and school of technology. On the other hand Bompai and Sabon Gari had higher concentration in all pollutants in dry season followed by school of technology and Dowrawa. Furthermore, temperature, relative humidity and precipitation washout or scavenging effect on the pollutants were analyzed quantitatively. The result showed concentration of the pollutants in the atmosphere where lower under condition of increased precipitation, low temperature and increased humidity level compared to that of the dry season.
Conclusion: Consequently, the study exposes the influence of meteorological parameters on the seasonal variability, concentration and environmental fate of pollutant, which could be used in controlling urban air pollution thereby sustainably improving environmental quality and protecting human health.

Introduction

In current scenario, in modern society, the air quality remains one of the famous environmental issues [1]. The entire human race is affected by quality of air as well as plant and animal populations on the earth. The population growth, economic development, growing transportation demand as well as living standards contribute major role to polluting the surrounding area and atmosphere [2]. Urban areas release complex gases and particulates whose characteristics depend upon a wide range of factors such as: population density, energy consumption, industrial processes, and modes of transportation and usage, which affects public health, damage agriculture, weather, and climate [3]. At present, urban outdoor air pollu-

Please cite this article as: Oji S, Adamu H. Correlation between air pollutants concentration and meteorological factors on seasonal air quality variation. Journal of Air Pollution and Health. 2020; 5(1): 11-32.

tion causes an estimated 1.3 million mortality per year worldwide, according to the World Health Organization [4].

In recent times, urban areas in Nigeria witness unprecedented growth rate of the vehicle population. Thus, motor vehicles produce more air pollutants than any other single human activity. Motor vehicle emissions from roads might be viewed as a mobile line source with an emission rate per unit length of road. In city centers and congested streets, traffic is responsible for 80% to 90% of these pollutants and this situation is particularly severe in cities of developing countries [5, 6]. Emissions from motor vehicles with spark ignition engines are from the exhaust, engine crankcase, and fuel system. Carbon monoxide (CO) and water vapor (H_2O), the main products of combustion, are emitted in vehicle exhaust [7]. The major pollutants emitted from gasoline-fueled vehicles are carbon monoxide (CO), Hydrocarbons (HCs), Oxides of Nitrogen (NOx) and lead (Pb). Transportation of goods and passengers, especially in Nigeria's urban cities, is primarily dependent on road traffic. Because of the high traffic density in such areas, the average speed within the city is relatively low. Therefore, large quantities of CO, H_2S, NO_2, SO_2 and particulate matter (PM) are emitted regularly from motor vehicles. The mobile air toxins such as benzene, formaldehyde, acetaldehyde, and lead (Pb), along with secondary pollutants can cause adverse human health impacts [8].

Similarly, typical results of industrialization have indicated many problems arising from urban air pollution [9]. In most industrialized countries, people who live in urban areas tend to be more affected by allergic respiratory diseases than those who live in rural areas. In Nigeria, most large cities such as Lagos, Porthcourt, Ibadan, Kano, and Kaduna are feeling the pinch of air pollution from both vehicular and industrial emissions.

However, since motor vehicles are the fastest growing source of carbon monoxide (CO), and contribute a significant portion of the emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and particulate in urban areas [10], emissions from automotive engines are considered as a major source of urban air pollution [11-13]. Previous research revealed that the estimated contribution of these so called "mobile sources" to global emission of CO_2 varies from 13% to 30%, and accounts for 22% of CO_2, 87% of CO, 87% of volatile organic compounds (VOC), 57% of NOx and 4% of sulfur dioxide (SO_2) emissions in the European Union [14, 15]. Although mobile sources have significant impacts on urban air quality, the behaviour and fate of the emitted pollutants are still poorly understood, and considerable effort needs to be devoted to this issue.

In Nigeria, several research works focused on the assessment of the effects of air pollution characteristically dwelled on monitoring the ambient concentration of CO, NOx, lead (Pb), particulate matter (PM), while studies on pollutants in terms of their concentrations and relationship with meteorological parameters and/or seasonality is lacking despite that air quality and meteorological factors are closely linked through atmospheric chemical reactions and dynamic processes.

Increased air pollutant concentrations in the urban environment do not typically result from sudden increases in emissions, but rather from meteorological conditions that impede dispersion in the atmosphere or result in increased pollutant generation [16, 17]. There are many aspects

of variations in air pollution that are still difficult to understand. One of these aspects is the estimation of the sensitivity of air pollutants to individual meteorological parameters. A combination of meteorological variables important to these conditions includes temperature, winds, radiation, atmospheric moisture, and mixing depth. It is well known that concentrations of pollutant within local air sheds are affected by meteorological parameters [16].

Meteorological conditions play a crucial role in ambient air pollution by affecting both directly and indirectly the emissions, transport, formation, and deposition of air pollutants. Several research studies pertaining to weather and atmospheric pollution effects on humans have established associations between meteorological conditions and parameters to air pollutants. These studies have provided evidence that meteorological factors such as wind velocity and direction, temperature and relative humidity can significantly affect air quality [18].

The most important role of meteorology is in the dispersion, transformation and removal of air pollutants from atmosphere [19]. Also, in a study [20] has been suggested that adverse health consequences of ambient ozone pollution increase when temperatures are higher. Aerosol sulfate concentrations are influenced by temperature-dependent oxidation of SO_2 in both the gas and aqueous phases. Another research also found that the concentrations of oxidants that react with SO_2 to be dependent on temperature and sunlight intensity [21]. Levels of semi-volatile nitrate and organic aerosol species are temperature and relative humidity dependent [22].

So, the main purpose of the present work is to investigate the relationships between pollutants, namely, NO_2, CO, SO_2, H_2S and PM_{10}, and meteorological parameters such as temperature, precipitation, sunlight intensity, and wind speed to determine the influence of meteorological conditions on pollutants concentrations and their fate in the atmospheric environment. The effect of seasonal variability in connection to relationship between air pollutants concentration and meteorology was also studied.

Materials and methods

The study area was Kano metropolis, Nigeria (Fig. 1). Kano is the biggest commercial and industrial centre in Northern Nigeria. It has 43 existing market places and over 400 privately owned manufacturing industries [23]. The study locations used for this research work are Dorawa street, SabonGari market, Bompai industrial area and school of technology in Kano metropolitan area.

Dorawa is located in the heart of Kano municipality within the coordinate of 11°58’17’’N and 8°33’31’’E and is a residential area that is moderately populated. The area is a high income residential area with lots of greenery and serene environment. The area is characterized by good road network within the residential area. Sabon Gari market is situated between 12°00’45’’N and 8°32’23’’E, the busiest commercial area in the city of Kano. It has in it lots of traders trading variety of goods and services from perishables, non-perishable and consumables. Sabon Gari is densely populated during the day time due to the traders that come from far and wide to trade their goods and also buyers who come from far places also. Bompai is an industrial area with traceable coordinate of 12°00’41’’N and 8°33’21’’E, which is home to several industries that are involved

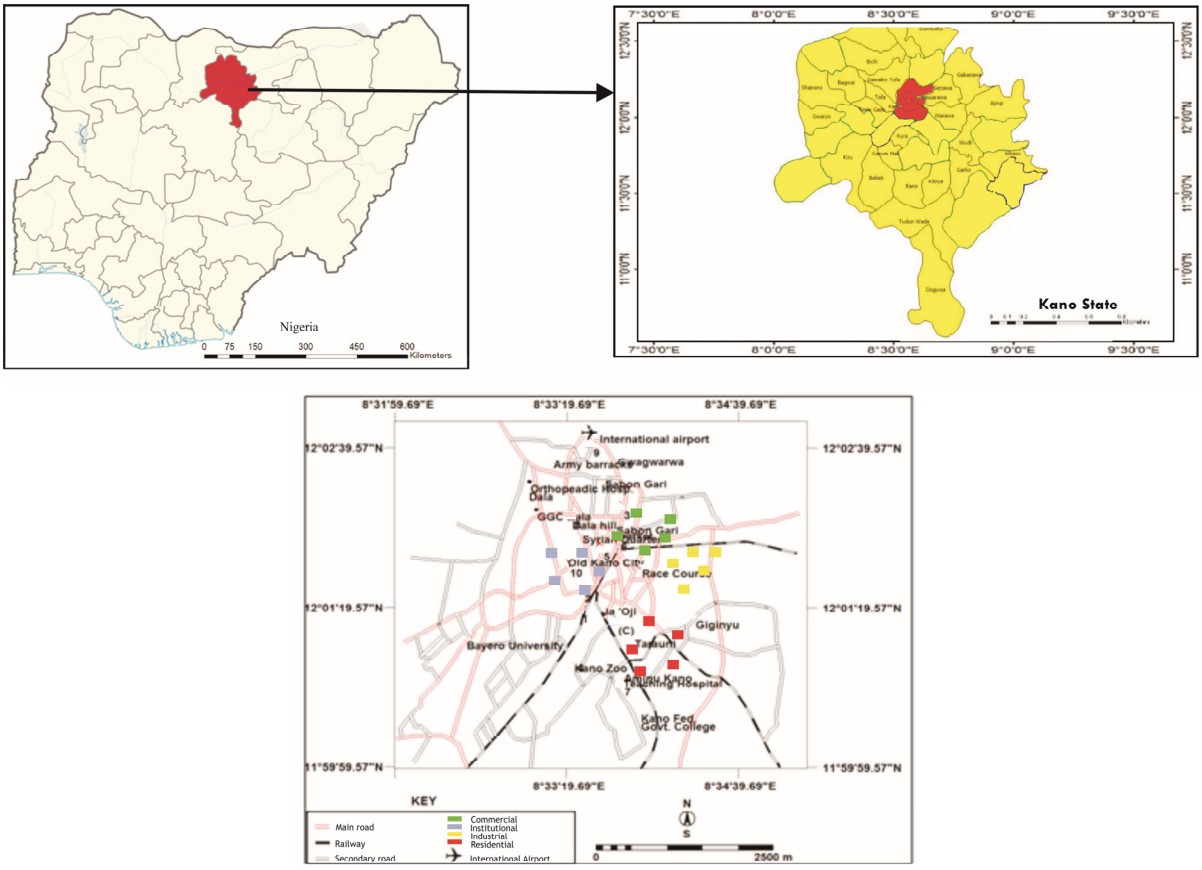

Fig. 1. Map of Kano municipal area and the sampling locations

with the processing of industrial materials. These places are characterized with lots of manufacturing industries with heavy duty machines. However, school of technology which is an institutional area situated between 11°59'28''N and 8°32'28''E. It is an academic environment characterized with high traffic of people coming in and out of the college and thus, considered very important to the study.

Study design

The sampling was done at industrial, commercial, residential and institutional locations in the study area and the average values for respective parameter readings were recorded at each identified sampling point using calibrated sampling devices. The assessed parameters included carbon monoxide (CO), Sulfur dioxide (SO_2), Hydrogen sulphide (H_2S), nitrogen dioxide (NO_2) and particulate matter (PM_{10}). All measurements were done in one-hour triplicates (i.e. repeated three times- morning, afternoon and night) per day based on the air pollution monitoring guideline set by the United States Environmental Protection Agency (USEPA) and the Nigerian Federal Ministry of the Environment (FMEnv).

Sampling and sampling locations

For the purpose of this study, purposive and random sampling techniques were employed in the study. The air sampling was performed continuously on daily basis throughout April and August 2018 (represented apex of dry and

wet seasons) in each of the 4 land-use air monitoring locations, three times per day (morning, afternoon and evening) covering a period of 30 days in each of the representative apex month of dry and wet seasons, respectively. A total of 60 samples were collected daily covering morning, afternoon and evening, 15 for each land use i.e. industrial, residential, commercial and institutional represented by Bompai, Dorawa, SabonGari market and school of technology, respectively.

Determination of concentration of CO, SO_2, H_2S, NO_2, and PM_{10} in various landuse

Sampling was done *in situ* using various calibrated handheld devices and each location was geo-referenced using a handheld 72H GPS device. The average values for each locations were computed. The individual levels of CO, SO_2, H_2S and NO_2 were monitored using a separate Crowcon Gasman gas-monitor for one-hour exposure time, which are all flexible portable gas detectors. Particulate matter levels (PM_{10}) were measured using a handheld air tester (HT 1001), designed to measure the particulate level in the air for 60 s at a flow rate of 500 ml.

Seasonal variations influence on pollutants concentration

In an attempt to understand the effect of seasonality on the concentration of pollutants, spatial variability of the pollutants was carried out. Spatial variation plots of the air pollutant concentrations were modeled using Surfer 12 and ArcGIS. The maps were presented as colored gradients representing the distribution pattern of the respective ranges of the parameters.

Results and discussion

Carbon monoxide (CO) assessment

The mean concentrations of CO in the study areas were 51.869±4.022, 50.487±3.838, 37.858±169, 39.748±6.668 μg/m^3 recorded in the topical period of dry season, whereas 39.714±4.289, 37.486±2.708, 30.737±4.577, 31.710±5.006 μg/m^3 represents wet season recorded values for Bompai, Sabon Gari, Dowrawa and school of technology, respectively. The highest average value of 51.869 and 39.714 μg/m^3 recorded both for dry and wet seasons, respectively appeared to be found in Bompai (an industrial area). The second-highest CO concentration values corresponded to Sabon Gari (commercial area), while the third occurred in school of technology (institutional area) and least concentration values were recorded in Dowrawa (residential area). The highest values recorded in Bompai is typically characterized with high rate of industrial activities which ranges from plastic processing, manufacturing and production, which may be responsible in contributing to high pollution level of CO in the area. Bompai is among the three major industrial layouts in Kano municipal council area namely Challawa and Sharada, which together constitutes a total of 243 industries in Kano municipality. According to a study, the main sources of air pollution in this area considered include products and residues of production from tanneries, grain mills, upholstery, plastics, textiles and incomplete combustion of gasoline from the industries' power generators [24]. This further buttresses, who reported that emission of air pollutants and related compounds in Bompai reflects the poor pollution control and waste management practices being carried out by the industries in the study area and thus, its position

as the highest CO polluter is not surprising [25]. Sabon Gari (Commercial) was also plaque with high concentration of CO with its climax in the afternoon values of 52.332and 40.377 μg/m^3 for dry and wet seasons, respectively. This is however associated to the high vehicular and traffic congestion within the area. This further supports the findings of [26], where reported that in the afternoon and evening were the period most of the customers tripped into the market from far distance to trade their goods and services. In addition, the need to close and return home may also be a cause to high vehicular and tricycle movement during the afternoon and evening times. This phenomenon coupled with poorly serviced vehicles used for good and service conveyances, as well as fuel inefficient cars exacerbate the concentration of the CO during this period of time in the area. It is reported that an estimated vehicular movement of 793 cars in the morning hours also tends to increase as the day proceeds climaxing between the hours of 2 and 4 pm [27]. Also, alternative sources of energy to complement the inefficient and insufficient power supply bedeviling the area is also considered as one of the factors responsible for the increases in the concentration of CO in the area. The alternative sources of energy are used in the market by traders to keep perishable goods in refrigerating condition to avoid spoilage.

The CO concentration observed in the institutional land-use (school of technology) during the peak period of the dry and wet seasons may be attributed to the witnessed vehicular movement around the school domain, which dominated by the conveyance folds of students in and out the school. In a similar study, it was concluded that institutional area has the least carbon footprint because of the use of alternative power sources is limited to the school alone in the events of power outages [28]. The least CO concentration with the minimum average value compared to the other study areas is the residential area. The highest concentration values of 41.028 and 32.787 μg/m^3 were recorded in the evening hours both in the dry and wet seasons, during which household wives heavily commence cooking for night meals for the family circles, which was in addition to turning of power generators to argument the epileptic national power supply.

Sulfur dioxide (SO_2) assessment

The mean concentration of SO_2 in the areas were 0.656±0.123, 0.605±0.082, 0.409±0.125, 0.301±0.057 μg/m^3 and 0.591±0.112, 0.526±0.135, 0.300±0.052, 0.273±0.070 μg/m^3 for Bompai, Sabon Gari, Dowrawa and school of technology for dry and wet season, respectively. The study results showed that the average concentration of sulfur dioxide recorded in Bompai during the dry season was high, which by far exceeded the WHO recommended minimum outdoor concentration of 0.2 ppm over a one hour duration. This is as a result of anthropogenic activities carried out in the study area. The use of fossil fuel locomotive engines, alternative power sources, and high influx of vehicles into the study area was a visible cause for this heightened level of SO_2 air pollution. The concentration was however higher during the peak of the dry season, as SO_2 concentration in Bompai reaching an all-time high as mostly recorded during the afternoon and evening hours of the days of investigation. Although NIOSH recommends a daily limit of 0.5 ppm for sulfur dioxide, the average concentration recorded was therefore found to be above the rec-

ommended level [29].

In Sabon Gari, the attendant concentration was found higher than that of the institutional study area. The incessant practice of open refuse burning and high traffic influx of people into the market with automobiles can be attributable to this high concentration. Therefore, inappropriate waste management and peoples' attitude in the environment are deemed to be part of the major factor which influence the high concentration of SO_2 in the study areas. The concentration of SO_2 in the residential area was also above the permissible limit. This is quite worrisome and revealed that the concentration of these pollutants requires continuous periodical checkup. The lowest averages were recorded in these areas during the peak of the wet season, which may be due to dilution effect of rain in the atmosphere. The least concentration of SO_2 was recorded in the institutional area, a pointer to the fact that the lowest recorded concentration of SO_2 was in the school of technology, which may connected to low population of vehicular movement due to restriction imposed on tricycle in this area.

Nitrogen dioxide (NO_2) assessment

The calculated mean concentrations for NO_2 were recorded as 0.637±0.091, 0.593±0.082, 0.395±0.102, 0.456±0.126 μg/m^3 and 0.479±0.114, 0.463±0.102, 0.325±0.117, 0.314±0.093 μg/m^3 for Bompai, Sabon Gari, Dowrawa and school of technology for dry and wet seasons, respectively. Bompai due to the high rate of anthropogenic activities with attached economic benefits such as welding, power generating sets and also improper/incomplete vehicular fuel combustion may all be possible reasons for the high rate of emissions of NO_2 in the area. The average concentrations of NO_2 recorded in the area was also found to be above the recommended level between 0.12 and 0.40 ppm on an hourly base set by United States standards. Similarly, Sabon Gari as one of the commercial place of the selected locations for this study was also discovered with NO_2 concentration above the daily international standards. This conceivably related to high human and vehicular traffic congestion that usually characterizes the area. The high NO_2 concentrations of 0.705 and 0.941 μg/m^3 recorded in the afternoon for both dry and wet seasons, respectively corroborates with earlier study carried out [30]. The study found out that increased formation of NO_2 and other compounds occur from the reaction of NO- a vehicular exhaust gas constituent during the sunny hours in the atmospheric environment. An average concentration of NO_2 was also recorded in the institution (school of technology), which may be attributed to populous vehicular movement in this particular study area than in the residential area. The vehicular movement in and out of the institute could be responsible and accounted for NO_2 concentration higher than the permissible limit in the study. Therefore, high levels of NO_2 recorded in industrial and urban environments is because of the burning of fossil fuels [31]. Both CO and NO_2 are primary pollutants that are mainly emitted from motor vehicles [32]. The exhaust gases of cars and trucks are major sources of nitrogen oxides, but automobile exhaust has more NO than NO_2, but once the NO is released into the atmosphere it quickly combines with oxygen and NO_2 are formed during high-temperature combustion in the atmosphere [33]. This therefore supports the reason for an elevated level of NO_2 in all the study locations during the sunny hours

of this investigation.

The least concentrations of NO_2 was recorded in Dowrawa, which emanated from the use of alternative power generating and diesel power sources. Interestingly, all the study locations displayed the same pattern of low concentrations of NO_2 in the topical period of wet season compared with the concentrations recorded for the dry season. This is because during wet season episode, the gaseous pollutants from the point of emission travel/disperse restrictively due to a scavenging effect of meteorological elements.

Hydrogen sulfide (H_2S) assessment

The result of mean concentrations of H_2S were 0.474,0.317±0.057 ,0.435±0.046 ,0.113± 0.290±0.088 µg/m^3 and 0.487±0.080, 0.469±0.086, 0.339±0.058, 0.323±0.027 µg/m^3 for Bompai, Sabon Gari, Dowrawa and school of technology for wet and dry seasons, respectively. The average concentration recorded for the dry season shows that Bompai had the highest concentrations of H_2S amongst all the other study areas and also likewise in the wet season. This is due to influx of vehicles and the artisanal activities that is taking place in the study area. This further agrees with results reported by other researchers, who examined the concentration of air pollutants in Imo state and found out that the mean concentrations of H_2S in the industrial areas was higher than residential and commercial areas [34].

The concentration of H_2S in Sabon Gari could be attributed to the microbial anaerobic oxidation of dumped organic wastes that are day-in and- out being generated and heighted the level within the area. The institutional study area (school of technology) had one of the least concentration of H_2S, which was the lower than Sabon Gari and Bompai during the wet and dry seasons. This level can be due to the incomplete combustion engines that are been used in and around the study area. Finally, the study area had the least concentration of H_2S in all the study areas was the residential area, where the mean average of H_2S recorded was higher in the dry season than in the wet season. This is an indication that among the other land uses the one that had the smallest concentration was the residential areas. This is in agreement with the earlier result reported in the literature [35], who opined that the major contributor of residential H_2S is from power generators and vehicles which are often limited in the residential area.

Particulate matter (PM_{10}) assessment

The results of the concentrations of PM_{10} are presented in Table 1 and 2, which were 7.392±0.702, 6.875±0.694, 5.497±0.560, 5.714±0.418 µg/m^3 and 11.456±7.938, 11.0±1.081, 5.585±0.436, 6.501±0.447 µg/m^3 for Bompai, SabonGari, Dowrawa and school of technology for wet and dry seasons, respectively. The results indicated that generally higher PM_{10} values were observed in the dry season than in the wet season with Sabon Gari showing the highest mean value as shown in Table 1.

The highest dry seasonal mean obtained in this study is above that reported in related studies conducted in Nigeria [36]. The elevated levels of PM_{10} in the afternoon in Sabon Gari was due to dust re-suspension from human and vehicle traffic in the park, fugitive dust suspension and other anthropogenic PM sources in the market that usually peak at the afternoon. There was a sharp reduction in the concentration of PM_{10} during the wet season in Sabon Gari, however still showing

Table 1. Mean concentrations of CO, SO_2, NO_2, H_2S and PM_{10} in dry season 2018

Pollutant	Concentrations (ppm)/(μg/m^3)			
CO	***Bompai***	***Sabon Gari***	***Dowrawa street***	***School of technology***
Morning	51.205±1.303	48.950±2.661	32.128±1.153	36.784±4.397
Afternoon	52.571±2.495	52.332±2.348	40.418±3.825	41.728±6.466
Evening	51.832±8.270	50.181±6.507	41.028±4.529	40.732±9.141
Mean	51.869±4.022	50.487±3.838	37.858±3.169	39.748±6.668
SO_2	***Bompai***	***Sabon Gari***	***Dowrawa street***	***School of technology***
Morning	0.675±0.106	0.574±0.068	0.341±0.109	0.264±0.045
Afternoon	0.675±0.125	0.647±0.091	0.410±0.136	0.280±0.055
Evening	0.620±0.138	0.595±0.088	0.477±0.130	0.358±0.071
Mean	0.656±0.123	0.605±0.082	0.409±0.125	0.301±0.057
NO_2	***Bompai***	***Sabon Gari***	***Dowrawa street***	***School of technology***
Morning	0.538±0.056	0.504±0.053	0.280±0.043	0.354±0.083
Afternoon	0.630±0.093	0.705±0.137	0.372±0.1	0.461±0.117
Evening	0.745±0.125	0.572±0.057	0.534±0.163	0.555±0.178
Mean	0.637±0.091	0.593±0.082	0.395±0.102	0.456±0.126
H_2S	***Bompai***	***Sabon Gari***	***Dowrawa street***	***School of technology***
Morning	0.508±0.040	0.375±0.075	0.365±0.025	0.210±0.018
Afternoon	0.521±0.084	0.478±0.104	0.347±0.079	0.328±0.040
Evening	0.432±0.117	0.555±0.079	0.305±0.070	0.431±0.024
Mean	0.487±0.080	0.469±0.086	0.339±0.058	0.323±0.027
PM_{10}	***Bompai***	***Sabon Gari***	***Dowrawa street***	***School of technology***
Morning	8.070±0.573	7.395±0.803	5.296±0.606	6.309±0.469
Afternoon	10.635±0.997	16.413±1.274	5.729±0.576	6.697±0.523
Evening	15.664±22.244	9.192±1.168	5.467±0.5	6.499±0.349
Mean	11.456±7.938	110±1.081	5.497±0.560	6.501±0.447

trend of a peak period concentration in the afternoon hours. Pollutants proximity, source strength, topography, local meteorology and atmospheric reactivity have been reported to influence pollutant concentration in an area [37-39]. Likewise, Bompai experienced higher concentration of PM_{10} in the dry season than in the wet season. Although its concentration was found to be less compared with Sabon Gari, but higher than that of school of technology. Surprisingly, the school of technology had a mean concentration less than the level found in Bompai study locations. This may be connected with the availability of potential wind breakers and high-rise buildings in and around the area, which could be responsible dust basins that led to witness low concentration

Table 2. Mean concentration of CO, SO_2, NO_2, H_2S and PM_{10} in Wet Season 2018

Pollutant	Concentrations (ppm)/(µg/ m^3)			
CO	***Bompai***	***Sabon Gari***	***Dowrawa street***	***School of technology***
Morning	34.382±1.957	31.817±0.916	28.138±3.757	28.397±2.996
Afternoon	41.375±4.529	40.377±1.961	31.287±4.765	32.807±6.457
Evening	43.384±6.382	40.264±5.247	32.787±5.210	33.943±5.564
Mean	39.714±4.289	37.486±2.708	30.737±4.577	31.710±5.006
SO_2	***Bompai***	***Sabon Gari***	***Dowrawa street***	***School of technology***
Morning	0.594±0.075	0.518±0.069	0.212±0.018	0.201±0.066
Afternoon	0.588±0.085	0.525±0.140	0.302±0.060	0.274±0.056
Evening	0.592±0.177	0.534±0.196	0.387±0.078	0.345±0.087
Mean	0.591±0.112	0.526±0.135	0.300±0.052	0.273±0.070
NO_2	***Bompai***	***Sabon Gari***	***Dowrawa street***	***School of technology***
Morning	0.444±0.110	0.450±0.125	0.315±0.094	0.295±0.121
Afternoon	0.498±0.104	0.491±0.096	0.337±0.131	0.338±0.095
Evening	0.495±0.129	0.448±0.085	0.322±0.127	0.310±0.062
Mean	0.479±0.114	0.463±0.102	0.325±0.117	0.314±0.093
H2S	***Bompai***	***Sabon Gari***	***Dowrawa street***	***School of technology***
Morning	0.364±0.062	0.438±0.034	0.245±0.052	0.307±0.040
Afternoon	0.494±0.130	0.480±0.032	0.337±0.064	0.288±0.090
Evening	0.565±0.148	0.387±0.072	0.37±0.055	0.275±0.134
Mean	0.474±0.113	0.435±0.046	0.317±0.057	0.290±0.088
PM_{10}	***Bompai***	***Sabon Gari***	***Dowrawa street***	***School of technology***
Morning	6.124±0.311	6.159±0.623	4.730±0.357	5.254±0.459
Afternoon	9.213±1.257	8.025±0.925	6.438±0.521	6.156±0.385
Evening	6.839±0.538	6.440±0.533	5.586±0.429	5.733±0.411
Mean	7.392±0.702	6.875±0.694	5.585±0.436	5.714±0.418

in the area. The land use with the least recorded concentration was Dowrawa, a residential area characterized with beautiful scenery topography, covered by green vegetation due to tree planting and artificially created micro-climate that pre-conditioned the meteorology of the area, all of which could be responsible for the least levels of PM_{10} recorded in this residential area. This however further supported by the study carried out on the levels of pollution concentration in indoor and outdoor pollution of Particulate matter [40].

Influence of temperature on concentration of pollutants

Fig. 2 demonstrates the temperature profile recorded in the study area, which ranged between 33.2°C and 35°C during the topical period of wet season and 43.4°C and 49.8°C during climax pe-

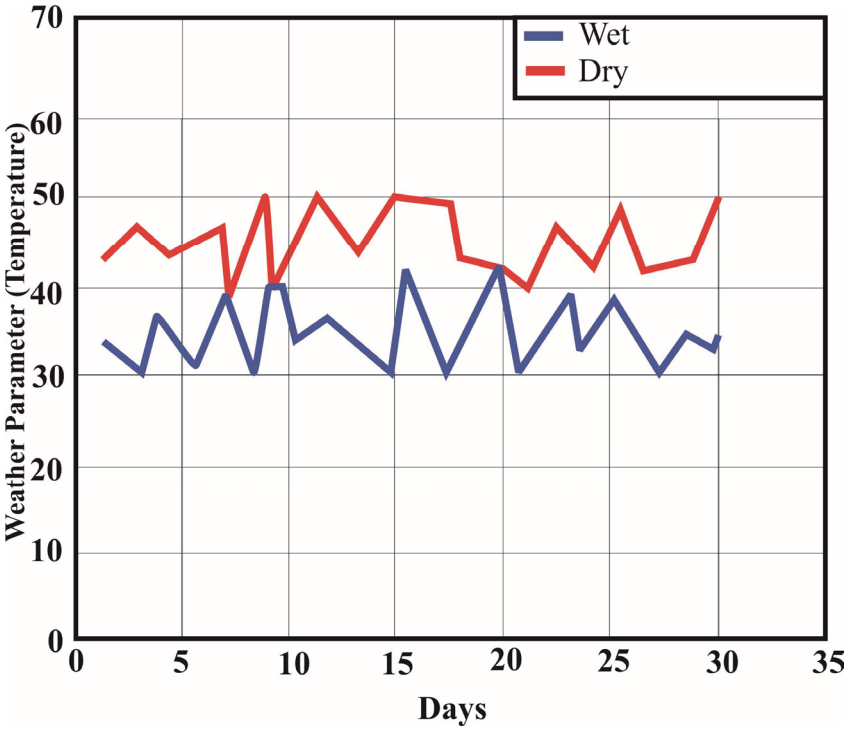

Fig. 2. Temperature profile for the months of April and August, 2018

riod of dry season.

The predominant characteristic of atmosphere is its unceasing change, of which temperature contributes. So as it is, the vertical distribution of temperature in the atmosphere varies with season and location in latitude and longitude, as well as from day to night. The temperature variations and its influence on concentrations of CO, SO_2, H_2S, NO_2, andPM_{10} in the ambient air were analysed for the climax period of wet and dry seasons. The atmospheric temperature near the earth surface experienced maximum during the dry season and thus, enhanced the vertical mixing and increase of the mixing height that account the high concentration of the pollutants recorded during the season. The uneven heating of land and sea during day time of the dry season occurs quicker, than that of wet season, that responsible for of higher temperature range recorded than in the other season. As Kano metropolitan area is not located in a coastal area, the land breeze flew inwards the domain ward-sides of the study locations in the afternoon hours, exacerbate the temperature of the locations, and maximise the vertical mixing, resulted in higher concentrations of CO, SO_2, H_2S, NO_2 and PM_{10}during dry season than the levels recorded for the wet season. However, the lower temperature range during the peak

period of wet season reduces the vertical mixing and lowering the mixing height and thus, resulted in decrease in the examined pollutants concentration significantly. Another study have studied the annual variation of mixed layer characteristics at New Delhi and found that the mixing height is very low during cold season due to very low value of surface sensible heat flux and higher during hot season due to large sensible heat flux from the surface [41]. Consequently, heating of earth by the sun induces thermal turbulence during hot season, largely determined by the rate of change of air temperature with altitude and increases the mixing height. The heat from the solar radiation is absorbed by the air, resulting in minimizing atmospheric temperature nearer to the surface of the earth. The air layer nearer to the surface of the earth becomes colder than the upper layers, thus reducing the up going air currents and leading to the increase of pollutant concentrations. In effect, temperature over the land space at lower altitude discourages the dispersion and dilution of pollutants. The same explanation has been reported in the literature [18]. Therefore, this establishes the reason for higher levels of the pollutants recorded in dry season than in the wet season. This obviously indicates that seasonal temperature helps determine the ability of the atmosphere to dilute emissions; hence, it is crucial to air quality.

Influence of precipitation on concentration of pollutants

To further investigate the pollutants dependencies on the seasonal component, the study carried another cross-dependence analysis between precipitation and examined pollutants concentration profiles. Fig. 3 shows the precipitation distribution under varied seasonal conditions at the study area.

The amount of precipitation recorded ranged between 63 and 70 mm during the topical period of wet season and 0 and 5 mm during climax period of dry season. Lower pollutants concentration was observed during the high-intensity fall of precipitation during wet season than the levels recorded for dry season. The enhancement of low pollutants concentration during wet season could have been due to an increase in the amount of precipitation in the atmospheric environment and possibly imposed scavenging effect on the pollutants. The observed impact due to rainfall on pollutants concentration in dry season was generally low, which indicates that decrease of amount of water in the atmospheric environment always elevate the ambient pollutants level. Thus, rain acts as natural scrubber during wet season and brought down the pollutants levels, as the concentration of pollutants in the atmosphere decreased due to erosion and diffusion dilution caused by rain. This suggests that that removal of pollutants process takes place and affects deposition in the atmospheric environment to a great extent during wet season than the dry season. In addition, owing to the fact that during wet season the atmosphere is less stable as compared to dry period resulting inmore pollutants dispersion [18] and as a result, low pollutants concentration was recorded during the apex period of wet season compared to the levels found for dry season.

Influence of relative humidity on concentration of pollutants

Fig. 4 displays relative humidity, which ranged between 54 and 70 % during wet season, 24 and 27 % during dry season. Thus, the minimum relative humidity of 24 %was recorded in dry and

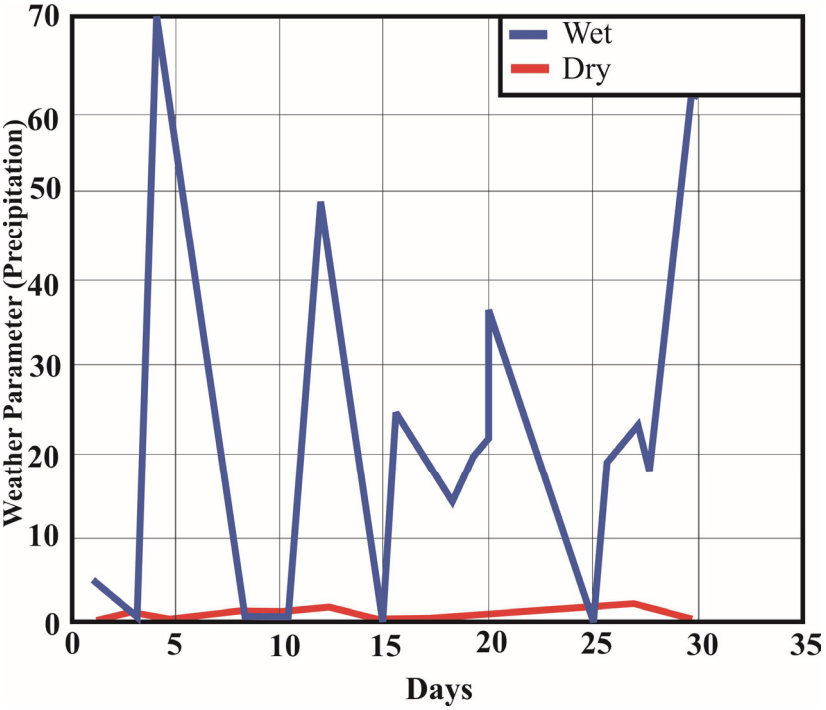

Fig. 3. Precipitation profile for the months of April and August, 2018.

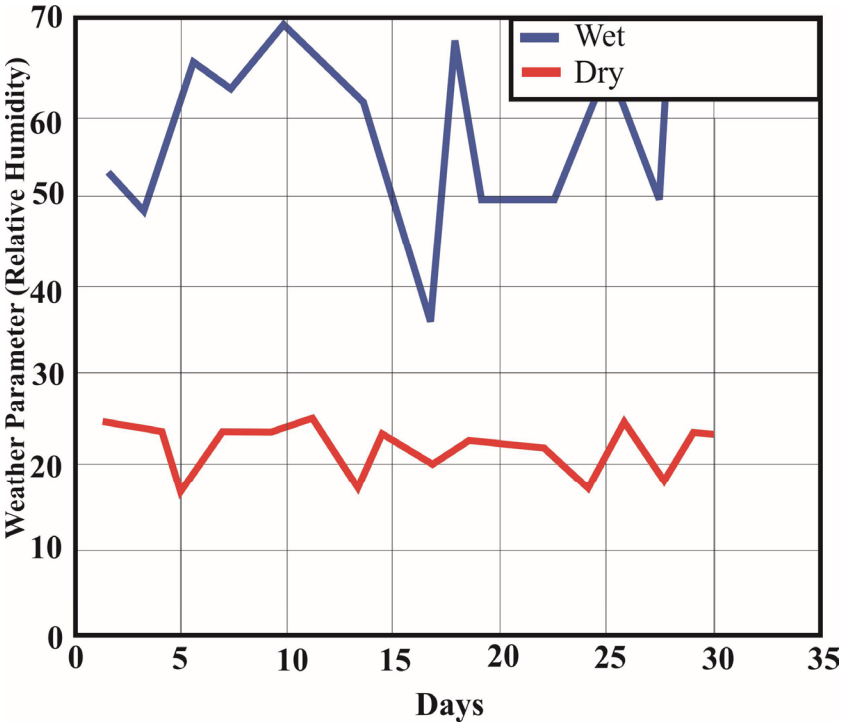

Fig. 4. Relative humidity profile for the months of April and August, 2018

maximum of 70 % during wet season.

With this variation, the season wise variations of humidity and its influence on the concentration of CO, SO_2, H_2S, NO_2 and PM_{10} were analysed. It is obvious that the increase of humidity in the atmosphere reduces the amount of solar radiation reaching the earth's surface and therefore, leading to an increase of rate of absorption of pollutant in the atmosphere [18]. This explains the low pollutants concentration recorded during wet season, while effective pollutants discharge into the atmosphere hardly control with low relative humidity and eventually the air quality remains worst in dry season. Therefore, the influence of humidity and rain on pollutants concentration found to be high during wet season and are important factors that affect seasonal variations in pollutant concentrations. Another research examined the effect of humidity on pollutants concentration and found that the pollutants concentration was the lowest in wet season compared to dry season, because the accumulative and capturing effect of air is relatively higher in wet season due to raised humidity than that of dry periods [42]. This is further corroborated with the postulation, that high temperature and low humidity reduce the rate of dispersion of air pollutants, thus increasing ground concentration of same pollutants and vice versa [43]. Hence, meteorological factors which influence the dispersion and dilution of pollutants include atmospheric temperature, precipitation and relative humidity. These explained seasonal differences in concentration of pollutants.

In Kano, dry seasons are characterised by high temperatures and low humidity, as evidenced by Figs 2 and 4, while the reverse is the case for wet seasons. This explains why higher readings were recorded for all pollutants during the peak month of dry season, when compared with lower readings recorded during the apex month of rainy sea-

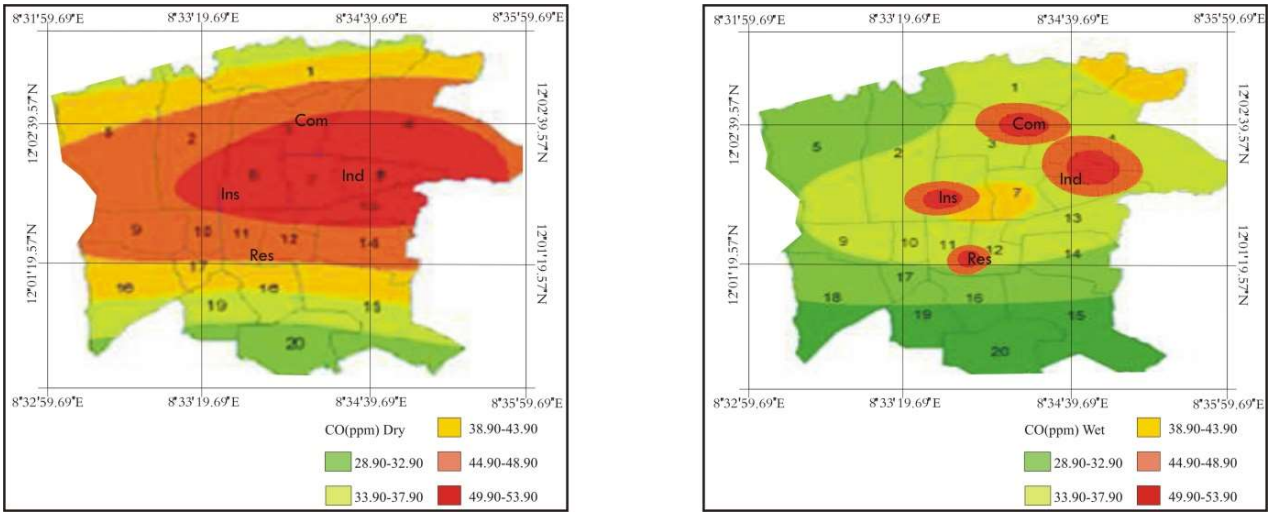

Fig. 5. Spatial distributions of seasonal average concentrations of CO between topical periods of dry and wet seasons

son.

Seasonal variability of air pollutants concentrations of CO, SO_2, H_2S, NO_2, PM_{10}

Meteorological parameters such as temperature, precipitation, relative humidity and wind speed play a pivotal role in air pollutants dynamics and spatial distribution in many different ways [44]. The study investigated the spatial distribution of the CO, SO_2, H_2S, NO_2 and PM_{10} in consideration of seasonal variability, which was influenced by the corresponding meteorological parameters, namely, temperature, precipitation and relative humidity over the topical periods of dry and wet seasons in 2018. The local meteorological conditions affect the seasonal variability in both the levels of pollution and the long-term trends of air pollutants in the environment, where specifically temperature, precipitation and relative humidity are deemed to be the major contributors in seasonal variability of atmospheric pollutant concentrations [45].

Spatial distributions of seasonal average concentrations of CO between topical periods of dry and wet seasons are displayed in Fig. 5, which shows that the air quality in terms of CO concentration was modest, as there was not much amount for inhalation from the atmospheric environment when compared with the trend of distribution during the dry season period. The spatial variation of seasonal average CO concentrations in wet season were bearable and air quality over the non-heating period was good. This is evidently demonstrated that most of the study locations are covered by light colouration that shows minimum concentrations of CO and thus, were found most not affected by CO pollution.

Despite the increase number of vehicular and human traffic, the CO concentrations during wet season stayed relatively tolerable. This may be explained by a combination of washout effect of precipitation from the atmosphere during wet season [46, 47]. In addition, low CO production caused by reduction of photochemical reactions during rainfall reduces the concentration of pollutant during the wet season [48]. Relative humidity is generally higher during the wet season, which in turn high relative humidity results to lower atmospheric temperature, and consequently high rate of pollutant plume ascent, and vice versa [49, 50].

Fig. 5 shows the spatial plots of carbon monoxide (CO) in dry and wet season. The results showed an attendant increased levels depicting higher pollution concentration in Bompai, Sabon Gari, school of technology and Dowrawa. The percentage increases were Bompai 30.6%, Sabon Gari 34.68%, Dowrawa 23.16% and school of technology 25.34% from wet to dry season. The result thus corroborates the postulation made by Jacobson that high temperature and low humidity reduce the rate of dispersion of CO and thus, increasing ground concentration of the pollutant. Also, higher concentration of CO pollution observed during the dry season is as a result of higher ambient temperatures, leading to downward movement of pollutants and consequently high ground level concentrations. If temperature of pollutant gases is higher than the surrounding air, the plumes will tend to rise [38, 39, 43].

Furthermore, when CO is release from vehicles, power plants and attendant refuse burning it does not rise enough or is not transported horizontally for long enough periods to become diluted. With no rain the dry periods worsens the problem because pollutants remain suspended in the air for extended periods which is further exacerbated by increased anthropogenic activities [51].

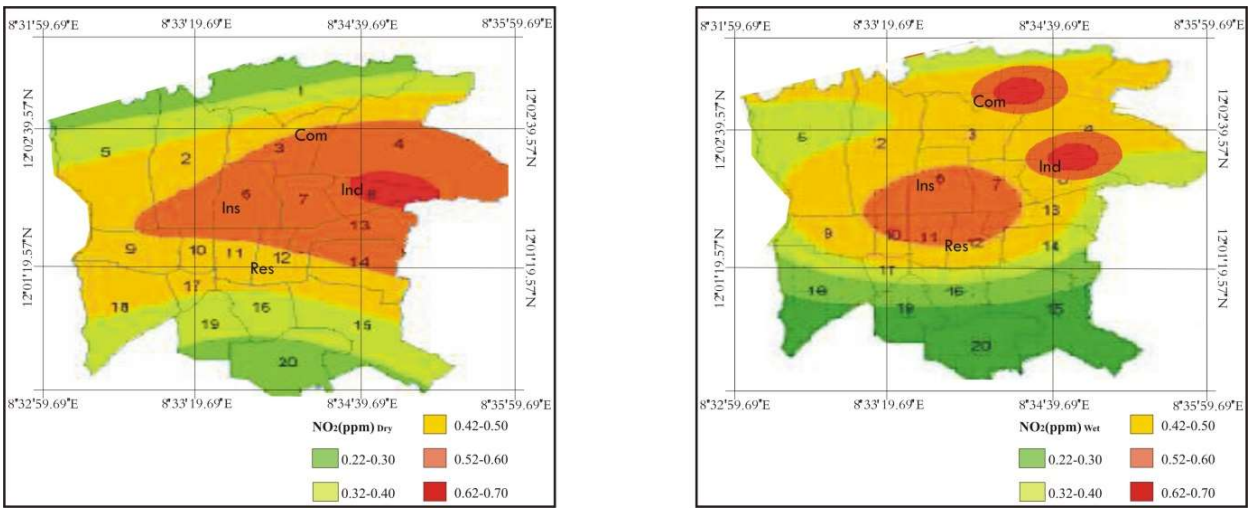

Fig. 6. The spatial plots of NO_2 in the topical periods of dry and wet seasons

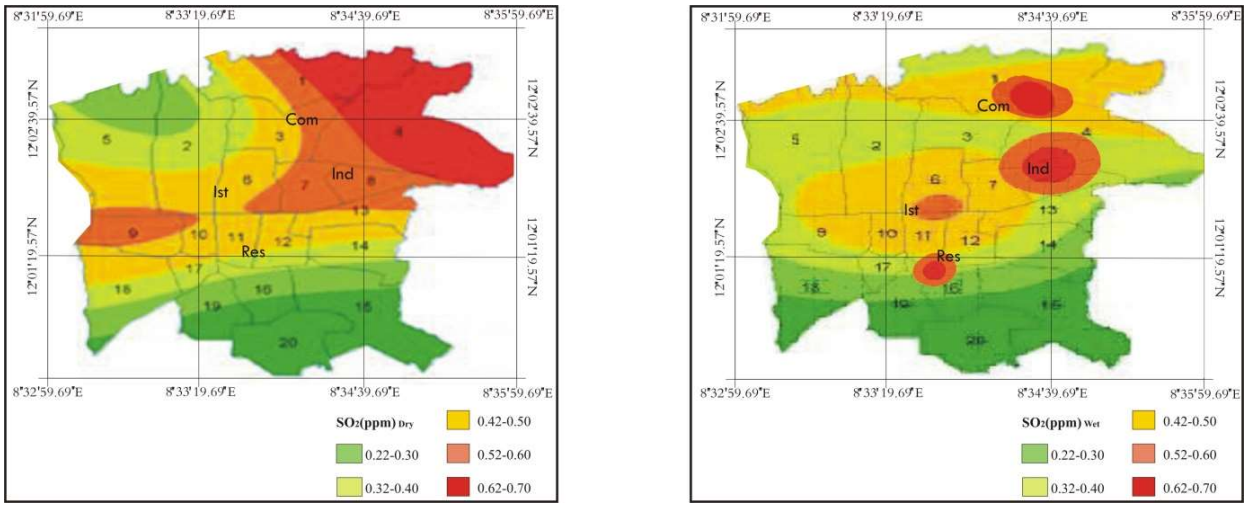

Fig. 7. The spatial plots of SO_2 in the study locations for dry and wet seasons

Fig. 6 presents the spatial plots of NO_2 in the topical periods of dry and wet seasons, respectively. The color schemes depicted shows the dry season in heavy shades of red and wet season shows tint of brighter hues. The variation in percentage increase from the wet season to the dry season shows Bompai 32.99%, Sabon Gari 28.07%, school of technology 45.22% and Dowrawa increased with 21.54% in concentration. Increased atmospheric concentrations of anthropogenic pollutants have also been observed during the winter, a decrease in concentrations during the wet season can be

explained by heavy rains and a well-developed mixing layer [52]. The pollutant concentrations in the atmosphere increase in dry season, which is caused by a combination of subsidence inversion, weak winds, and intensive solar radiation [53, 54]. Fig. 7 presents the spatial plots of SO_2 in the study locations for dry and wet seasons respectively. The result indicates that high concentrations of SO_2 were observed at Bompai, Sabon Gari, Dowrawa and school of technology in dry season which is depicted by heavy contour coloration pattern across the study locations and conversely, light hue coloration in the other depiction demonstrates low pollutants' concentrations in wet season. The SO_2 concentrations varied between wet and dry seasons by 10.99%, 15.02%, 36.33% and 10.26% for Bompai, Sabon Gari, Dowrara and school of technology, respectively. This could result from the fact that the pollutant undergoes transformation in the atmosphere to form acidic compounds such as sulfuric acid which are washed out and fall out as acid rain during heavy downpours thereby reducing the concentration of SO_2 in the atmosphere [25].

The episodic spatial distribution plots of H_2S in the wet and dry seasons, respectively are presented in Fig. 8. High concentration of H_2S recorded in the dry season is displayed in thick contour tones across all the study locations whereas soft variegation representation is earmarked for the wet season. The percentage increase for each of the study area from wet to dry season showed that Bompai, Sabon Gari, school of technology and Dowrawa had 2.74%, 7.82%, 11.38% and 6.94%, respectively. The concentration was found to be high in the dry season, which is evidently displayed by thick reddish coloration in the plot. However, the concentration of H_2S in wet season is characterised by lighter transparent coloration, this perhaps solely attributed to the fact that atmospheric instability conditions are more prevalent during wet seasons than the dry seasons [55, 56]. For unstable atmosphere, the vertical mixing of pollutants resulting in high dispersion rates,

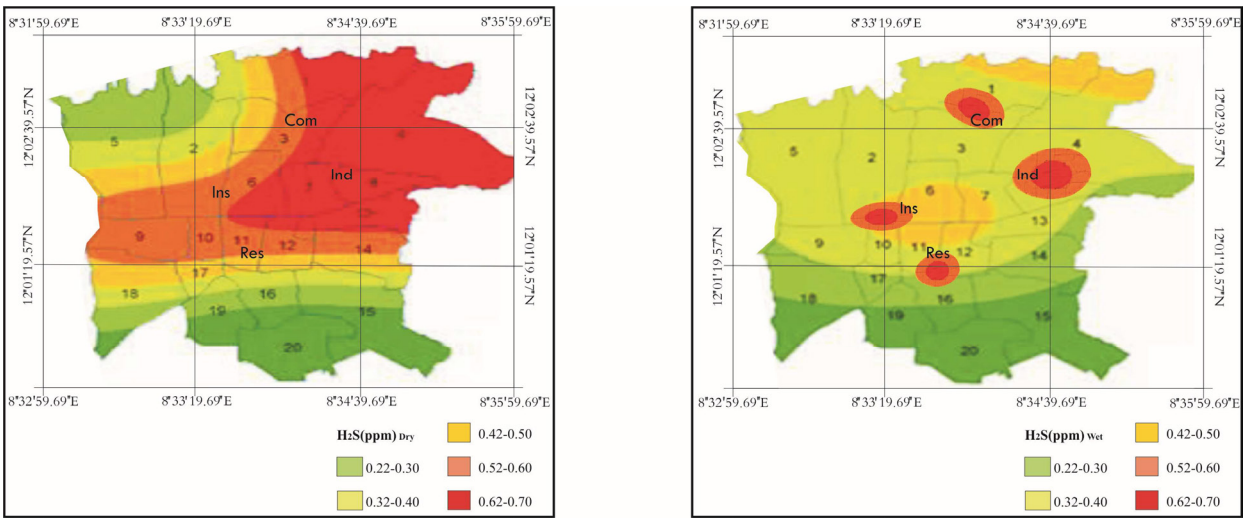

Fig. 8. The episodic spatial distribution plots of H_2S in the wet and dry seasons

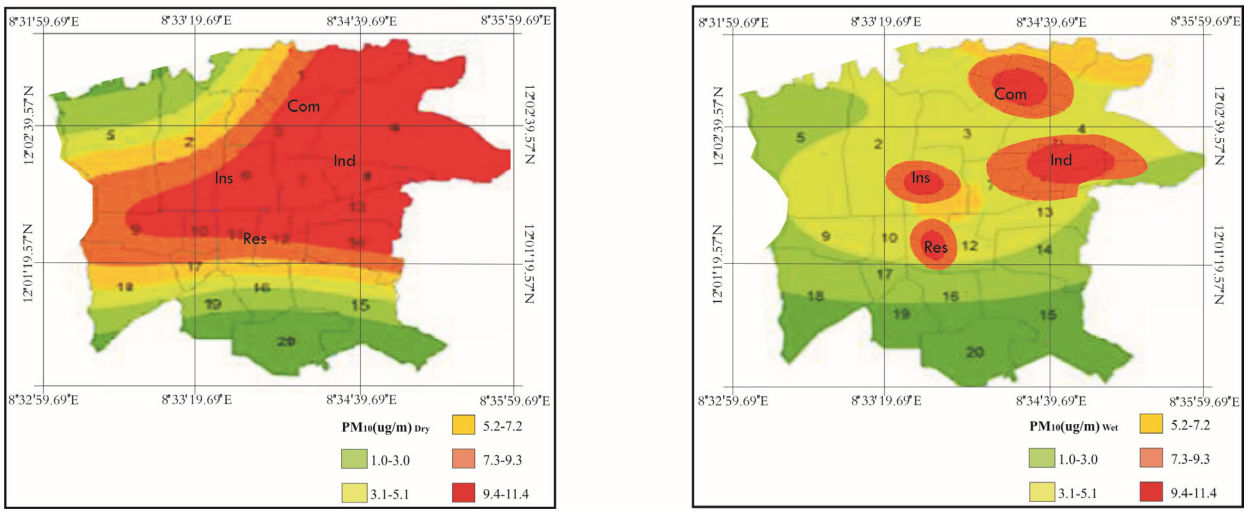

Fig. 9. The spatial distribution plots of PM_{10} during the dry and wet seasons

which in turn reduces pollutants' concentrations in the air [57, 58]. In effect, this causes dilution of the pollutants in the atmosphere due to advection downward and resulting in lower concentrations. However, under relatively stable atmosphere, the vertical mixing of pollutants is not vehement thereby leading to higher concentrations downward [59, 52]. This atmospheric condition is more in dry season than in wet season and hence dry season experienced higher concentration than the levels recorded for wet seasons.

Fig. 9 presents the spatial distribution plots of PM_{10} during the dry and wet seasons, respectively. The reddish pigmentation manifestly indicates high concentration recorded during the dry season whereas the light contour coloration across the study locations during wet season is attributable to less concentration of the pollutants examined. The calculated percentage increase in the concentrations of the studied pollutants from the wet to the dry season for Sabon Gari, Bompai, school of technology and Dowrawa were 60%, 54.98%, 13.77% and 1.6%, respectively. The High concentration of PM_{10} observed during the dry season could be a result of higher ambient temperatures, leading to downward movement of pollutants and consequently high ground level concentrations [60, 61]. If temperature of pollutant gases is higher than the surrounding air, the plumes will tend to rise [53, 49]. On the other hand, if temperature of ambient air is higher than that of a pollutant, PM_{10} gases become concentrated at ground level. Therefore atmospheric temperature is thus an important factor for the dispersion of pollutant gases, as the larger the difference between cool ambient air and plumes, the higher the plume rises, so also the rate of dispersion or spread of pollutants from its source before it reaches ground level [56, 62].

Summary

The aim of this research was to establish the in-

fluence of meteorological conditions on air pollutants concentration of NO_2, CO, H_2S, SO_2 and PM_{10} and their environmental fate associated with seasonal variation for the exposure scenario of air pollution in Kano municipal area.

The topical concentration of the air pollutants in wet season showed that Bompai had the highest concentration for all pollutants identified, followed by Sabon Gari. This is owned to the fact that Bompai and Sabon Gari is typically characterized by industrial, artisanal and heavily commercial activities which contribute immensely to the pollution matrix. Dowrawa had higher concentrations over and above school of technology in SO_2, NO_2, H_2S, whereas school of technology had higher CO and PM_{10} over and above Dowrawa. In contrast Bompai and Sabon Gari had higher concentrations in all the pollutants in dry season followed by school of technology which showed higher concentration in all the pollutants except for SO_2 where Dowrawa recorded the highest in this work.

In the same vein, the GIS and Surfer 12 map displayed that there is a wide variation in the concentration distribution of pollutants in the wet season and dry seasons. The dry season was characterized by deep hue coloration throughout the period for all pollutants branded as high pollution concentrations whereas in wet season, spatial variation maps depict lighter contrast for all pollutants portraying minimum concentrations. From the study, local meteorological conditions affect the seasonal variability in both the levels of pollution and the long term trends of air pollutants in the environment, where specifically temperature, precipitation and relative humidity are deemed to be the major contributors in seasonal variability of atmospheric pollutant concentrations. Despite the increase number of commercial, artisanal activities, vehicular and human traffic, the concentrations during wet season stayed relatively tolerable. This may be explained by a combination of scavenging activities of humidity and wash out effect of precipitation from the atmosphere during wet season.

Conclusion

In conclusion, this work provides empirical analysis of the interaction between meteorological conditions and how they affect pollution concentrations. Thereby, proffering better understanding on the issue of pollution, this would foster synergy between State, Federal Ministry of Environment and Nigerian Meteorological Agency by providing data on local and national air quality management planning.

Financial supports

There was no external funding for this investigation; it was performed as an element of public health practice to investigate the effect that weather patterns play on pollution concentrations.

Competing interests

None of the authors have competing interests to disclose.

Acknowledgements

We would like to thank the Nigerian Meteorological Agency (Nimet) for providing us with Kano State metropolitan meteorological data throughout the period of this research. Pollution Control Unit of REMASAP, (Rural Environmental Sanitation and Protection Agency) for the instruments used in reading pollution concentrations of the

examined pollutants.

Ethical considerations

Ethical considerations (including plagiarism, informed consent, misconduct, data fabrication or falsification, double publication and submission) have been completely observed by the authors.

References

1. Tiwary A, Colls J. Mitigating secondary aerosol generation potentials from biofuel use in the energy sector. Science of the total environment. 2010 Jan 1;408(3):607-16.
2. Onursal B, Gautam SP. Vehicular air pollution: experiences from seven Latin American urban centers. The World Bank technical paper. Washington, D.C.1997;373(3):52-74.
3. Pant P, Harrison RM. Critical review of receptor modelling for particulate matter: a case study of India. Atmospheric Environment. 2012 Mar 1;49:1-2.
4. World Health Organization WHO Dengue and Dengue Haemorrhagic Fever, 2012 - dl4a.org. 2012 Jun;94(Pt 2):5-79.
5. Whitelegg J, Haq G. Vision Zero: Adopting a target of zero for road traffic fatalities and serious injuries. Researchgate. The Institute; 2006.
6. Bastos J, Batterman SA, Freire F. Life-cycle energy and greenhouse gas analysis of three building types in a residential area in Lisbon. Energy and buildings. 2014 Feb 1;69:344-53.
7. Onursal B, Gautam SP. Vehicular air pollution : experiences from seven Latin American urban centers. The World Bank; no. WTP 373. Washington, D.C.1997 May;81(7):42-51.
8. Franke A, McGovern DP, Barrett JC, Wang K, Radford-Smith GL, Ahmad T, et al. Genome-wide meta-analysis increases to 71 the number of confirmed Crohn's disease susceptibility loci. Nature genetics. 2010 Dec;42(12):1118.
9. Grobéty B, Gieré R, Dietze V, Stille P. Airborne particles in the urban environment. Elements. 2010 Aug 1;6(4):229-34.
10. UNEP/WHO. Urban air pollution in megacities of the world, Atmospheric Environment. 1992;30(5):681-686.
11. Jorgensen WL, Jenson C. Temperature dependence of TIP3P, SPC, and TIP4P water from NPT Monte Carlo simulations: Seeking temperatures of maximum density. Journal of computational chemistry. 1998 Jul 30;19(10):1179-86.
12. Moragues A, Alcaide T. The use of a geographical information system to assess the effect of traffic pollution. Science of the total environment. 1996 Oct 28;189:267-73.
13. Gualtieri G, TartagliaM. Predicting urban traffic air pollution: A GIS framework, Transportation Research Part D. Transport and Environment. 1998;3(5): 329-336.
14. Cropper ML, Sahin S. Valuing mortality and morbidity in the context of disaster risks. The World Bank. 2009;27(4):93-97
15. Namdeo AK, Colls JJ. Development and evaluation of SBLINE, a suite of models for the prediction of pollution concentrations from vehicles in urban areas. Science of the total Environment. 1996;189(19):311-320.
16. Gorai AK, Tuluri F, Tchounwou PB, Ambinakudige S. Influence of local meteorology and NO2 conditions on ground-level ozone concentrations in the eastern part of Texas, USA. Air Quality, Atmosphere and Health. 2015;8(2):81-96.
17. Cheng CS, Campbell M, Li Q, Li G, Auld H, Day N, Pengelly D, Gingrich S, Yap D. A synoptic climatological approach to assess climatic impact on air quality in south-central Canada. Part II: future estimates. Water, air, and soil pollution. 2007 Jun 1;182(1-4):117-30.
18. Elminir HK. Dependence of urban air pollutants on meteorology. Science of the Total Environment. 2005 Nov 1;350(1-3):225-37.
19. Ocak S, Turalioglu FS. Effect of Meteorology on the Atmospheric Concentrations of Traffic- Related Pollutants in Erzurum, Turkey. J. Int. Environmental Application & Science. 2008;3(4):325-335.
20. Jacob DJ, Winner DA. Effect of climate change on air quality.Atmospheric Environment. 2009;43(8):51-63.
21. Seinfeld JH, Pandis SN. Atmospheric Chemistry and Physics: From Air Pollution to Climate Change. John Wiley & Sons; 2016 Apr 4.
22. Gillespie A. Climate change, ozone depletion and air pollution: Legal commentaries within the context of science and policy. Brill. ISBN: 9004145206, 9789004145207. 2006;52(2):32-39.
23. Ibrahim AM. Evolutionary Trend, Spatial Distribution of, and Issues Associated with markets in Kano Metropolis. Journal of Research on Humanities and Social Sciences. 2014;3(28):4-7.
24. Abelson P. The value of life and health for public policy. Economic Record. 2003 Jun;79(SpecialIssue):S2-13.
25. Benjamin, JR. Probability, statistics and decision for civil engineers. Courier Corporation. 2014;2(1):34-39
26. Abayomi YA, Fadayomi O, Babatola JO, Tian G. Evaluation of selected legume cover crops for biomass production, dry season survival and soil fertility improvement in a moist savanna location in Nigeria. African Crop Science Journal. 2001;9(4):615-27.
27. Wafula EM, Onyango FE, Mirza WM, Macharia WM, Wamola I, Ndinya-Achola JO, Agwanda R, Waigwa RN, Musia J. Epidemiology of acute respiratory tract infections among young children in Kenya. Reviews of Infectious Diseases. 1990 Nov 1;12(Supplement_8):S1035-8.
28. Aunan KG, Patzay H, Asbjorn A, Martin S. Health and environmental benefits from air pollution reductions

in Hungary.The Science of the Total Environment. 1998;23(212):245-268.
29. Brook RD, Rajagopalan S, Pope III CA, Brook JR, Bhatnagar A, Diez-Roux AV, Holguin F, Hong Y, Luepker RV, Mittleman MA, Peters A. Particulate matter air pollution and cardiovascular disease: an update to the scientific statement from the American Heart Association. Circulation. 2010 Jun 1;121(21):2331-78. doi: 10.1161/CIR.0b013e3181dbece1
30. Harfenist E. Air pollution is choking cities in low-income countries. Vocative 2016 May Available from: http://www.vocativ.com/318345/air-pollution-is-choking-cities-in-low-income-countries/index.html. 2018 Jan;83(9):82-91
31. Dominick D, Juahir H, Latif M, Zain S, Aris AZ. Spatial assessment of air quality patterns in Malaysia using multivariate analysis. Atmospheric Environment. 2012 Dec 1;60:172-81.
32. Azmi SZ, Latif MT, Ismail AS, Juneng L, Jemain AA. Trend and status of air quality at three different monitoring stations in the Klang Valley, Malaysia. Air Quality, Atmosphere & Health. 2010 Mar 1;3(1):53-64.
33. Butler CD, Whelan J. Air pollution and climate change in Australia: a triple burden. Climate change and air pollution. Springer, Berlin. 2018;7(23):131-149.
34. Njoku LK, Akinola MO, Oboh BO. Phytoremediation of crude oil polluted soil: Effect of cow dung augmentation on the remediation of crude oil polluted soil by Glycine max. 2012.
35. Younossi Z, Anstee QM, Marietti M, Hardy T, Henry L, Eslam M, George J, Bugianesi E. Global burden of NAFLD and NASH: trends, predictions, risk factors and prevention. Nature reviews Gastroenterology & hepatology. 2018 Jan;15(1):11.
36. Ngele SO, Onwu FK. Measurement of ambient air fine and coarse particulate matter in ten South – East Nigerian cities. Research Journal of Chemical Sciences. 2015;5(1):71 – 77.
37. Hosseinibalam F, Hejazi A. Influence of meteorological Parameters on Air Pollution in Isfahan. The 3rd International Conference on Biology, Environment and Chemistry. IACSIT Press, Singapore. IPCBEE. 2012;46:7-12.
38. Wen CC, Yeh HH. Comparative influences of airborne pollutants and meteorological parameters on atmospheric visibility and turbidity. Atmospheric research. 2010 Jun 1;96(4):496-509.
39. Majewski G, Klenieewska M, BrandykA. Seasonal variation of particulate matter mass concentration and content of metal. Polish Journal of environmental studies. 2011 Jan 1;20(2):417-27.
40. Rene GT. An Air Quality Baseline Assessment for the Vaal Air Shed in South Africa. A Master Thesis Dissertation. Geoinformatics and Meteorology Department, University of Pretoria, South Africa. 2008;12(2):81.
41. Gamo M, Goyal P, Kumari M, Mohanty UC, Singh MP. Mixed-layer characteristics as related to the monsoon climate of New Delhi, India. Boundary-layer meteorology. 1994 Jan 1;67(3):213-27.
42. Srimuruganandam B, Nagendra SM. Analysis and interpretation of particulate matter–PM10, PM2.5 and PM1 emissions from the heterogeneous traffic near an urban roadway. Atmospheric Pollution Research. 2010 Jul 1;1(3):184-94.
43. Jacobson MZ. Fundamentals of Atmospheric Modelling. 2nd ed. Cambridge: Cambridge University Press; 2005. http://dx.doi.org/10.1017/CBO9781139165389
44. Wang XK, Lu WZ. Seasonal variation of air pollution index: Hong Kong case study. Chemosphere. 2006 May 1;63(8):1261-72.
45. Pathakoti M, Gaddamidi S, Gharai B, Sudhakaran Syamala P, Rao PV, Choudhury SB, et al. Influence of meteorological parameters on atmospheric CO2 at Bharati, the Indian Antarctic research station. Polar Research. 2018;37(1):144-207.
46. Nagendra S, Khare M. Diurnal and seasonal variations of carbon monoxide and nitrogen dioxide in Delhi city. International Journal of Environment and pollution. 2003;19(1):75–95.
47. Abdul-Wahab SA, Bouhamra WS. Diurnal variations of air pollution from motor vehicles in residential area. International Journal of Environmental Studies. 2004;61(1):73–98.
48. Lim D, Lee TJ, Kim DS. Development and Validation Test of Effective Wet Scavenging Contribution Regression Models Using Long-term Air Monitoring and Weather Database. Korean Society for Atmospheric Environment.2013;29(3):297-306.
49. Everitt BS. The analysis of contingency tables. CRC Press; 1992 Feb 1.
50. Dalu GA, Pielke RA. An analytical study of the sea breeze. Journal of the Atmospheric Sciences. 1989;46(12):1815–1825.
51. Floret N, MaunyF, Challier B, Arveux P, Cahn JY, Viel JF. Dioxin emissions from a solid waste incinerator and risk of non-Hodgkin's lymphoma. Epidemiology.2003;14(6):392–398.
52. Kan SF, Tanner PA. Inter-relationship and seasonal-variations of inorganic components of PM10 in a westernpacific coastal city. Water, Air, and Soil Pollution. 2005;165(1-4):113–130.
53. Temple PJ, Taylor OC. World-wide ambient measurements of peroxyacetyl nitrate (PAN) and implications for plant injury. Atmospheric Environment (1967). 1983 Jan 1;17(8):1583-7.
54. Ratti C, Raydan D, Steemers K. Building form and environmental performance: archetypes, analysis and an arid climate. Energy and buildings. 2003 Jan 1;35(1):49-59.
55. Belcher SE, Jerram N, Hunt JC. Adjustment of a turbulent boundary layer to a canopy of roughness elements. Journal of Fluid Mechanics. 2003 Jul;488:369-98.
56. Dimoudi A. NikolopoulouM. Vegetation in the urban environment: microclimate analysis and benefits. En-

ergy and Buildings. 2003 Jan 1;35(1):69-76.
57. Kirillova VI. Physical-statistical prediction of maximal concentration for urban air pollution. Dissertation, Voeikov Main Geophysical Observatory, St. Petersburg. 2003;2(7):68-69
58. Zannetti P, Melli P, Runca E. Meteorological factors affecting SO2 pollution levels in Venice. Atmospheric Environment (1967). 1977 Jan 1;11(7):605-16.
59. Mayer H. Air pollution in cities. Atmospheric Environment. 1999;33(5):4029–4037.
60. Witz S, Larm AM, Elvin BM, Moore AB. The relationship between concentration of traffic-related pollutants and meteorology at a Los Angeles site. Journal of the Air Pollution Control Association. 1982 Jun 1;32(6):643-5.
61. Summers PW. The seasonal, weekly, and daily cycles of atmospheric smoke content in Central Montreal. Journal of the Air Pollution Control Association. 1966 Aug 1;16(8):432-8.
62. Sahu LK, Lal S. Distribution of C2–C5 NMHCs and related trace gases at a tropical urban site in India. Atmospheric Environment. 2006;40(5):880–891.