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AIR POLLUTANTS MONITORING IN THE LOWER ATMOSPHERE OF AKWANGA LGA USING FRACTIONAL STEP TECHNIQUE

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ABSTRACT

One of the greatest scourges of this era is air pollutants not only because of its impact on climate change but also of its impact on public a health. A mathematical model using the three dimensional fractional step method based on the discretization of the time dependent atmospheric advection diffusion equation for describing the dispersion of the air pollutants released from the source into the atmosphere was examined. Many pollutants that are major factors of diseases in humans such as Particulate Matter (PM), Nitrogen oxide (NO_2), Sulphur oxide (SO_2) and Carbon monoxide (CO) which penetrates the respiratory system via inhalation, causing respiratory and cardiovascular diseases, reproductive and central nervous system dysfunctions, as well as cancer were identified. The study revealed that the toxicity potential (TP) of the air pollutants (NO_2, and PM) are at elevated level since NO_2 have been shown to cause discomfort in vulnerable persons having asthma at just 0.1ppm. The implications of the results to public health management system are further discussed.

Keywords: *Air Pollutant, Atmospheric Dispersion, Fractional Step Technique*

INTRODUCTION

Air pollutants has been described as one of the "great killers of our age" and as a "major threat to health" due to its tremendous and various health effects on humans of all ages and in both genders (Venkatesan, 2016 and Landrigan, 2017).

Human exposure to a pollutant and its consequent impact on health results from the simultaneous occurrence of two events: a pollutant concentration c(x,t) at point x and time t, and the presence of people:

$$Exposure = f[P(x,t), c(x,t)] \quad ....(1)$$

Where P(*x,t*) represents the number of people x and time t inhaling a pollutant at concentration c(*x,t*).

Air pollution is understood as the existence of potentially harmful matter suspended in the air, which can be classified into basic chemical compounds (oxides of sulfur or nitrogen, carbon monoxide), particulate matter, high-risk radioactive compounds, or suspensions from a biological source, such as bacteria, all of which can produce harmful effects on the health of a population.

In all cases, the atmospheric dispersion of pollutants is essentially dependent on the air flow or wind velocity in the lower layers of the atmosphere. This dispersion represents an important environmental engineering problem in relation to the health of a population, particularly in areas where different pollution sources can be unhealthy and/or dangerous (ASHRAE, 2007 and Lateb *et al.,* 2016).

Air pollutant can be in the form of solid particles, liquid droplets, or gases. In addition, they may be natural or man-made (USEPA, 2006; Narayanan, 2009). Sources of air pollution include traffic (vehicle exhaust), industrial sectors (from brick making to oil and gas production), power plants and generating sets, cooking and heating with solid fuels (e.g. coal, wood, crop waste), forest fires and open burning of municipal waste and agricultural residues (Akanni, 2010; Komolafe *et al.,* 2014). Globally, air pollutants such as nitrogen oxides (NO_2), Sulphur oxides (SO_2), Carbon monoxide (CO), hydrocarbons and Particulate Matter (PM) such as PM2.5 and PM10 are constantly being emitted into the atmosphere from diverse anthropogenic activities such as gas flaring, burning of fossil fuels for energy, automobiles, industry and domestic fuel combustion. These are not without negative impacts on humans and the surrounding ecosystems (Osaiyuwu and Ugbebor, 2019). However, Seyyednejad *et al.,* 2011 and Akpoghelie, 2016 opined that air pollutants result in eye and skin irritation, sneezing, coughing, suffocation, chest pains and breathing problems. Studies have also shown that these pollutants contribute to global warming, environmental pollution, climate change, acid rain and increased carbon foot print. Thus, air pollution is one of the environmental problems confronting growing cities and is currently the challenge faced by many developed and developing countries of which Nigeria is not an exception (Komolafe *et al.,* 2014). Similarly, atmospheric air pollutant is believed to kill more people world-wide than AIDS, malaria, breast cancer, or tuberculosis (WHO, 2014).

Air pollutants in the lower atmosphere has increased rapidly due to high population density, increased numbers of motor vehicles, use of fuels with poor environmental performance, poorly maintained transportation systems and above all, ineffective environmental regulations and policies (Komolafe *et al.,* 2014). Some sources of atmospheric air pollutant include electric power plants, vehicular emission, power and heat generation, industrial processes, road construction, automobiles, biomass burning, and fossil fuels used in homes and factories for heating and rapid urbanization resulting in uncontrolled growth characterized by poor physical planning and deteriorating environment (Colbeck *et al.,* 2010).

For years, the main objective of air quality analyst was to monitor the concentration of pollutants at each point in space and at each moment as a result of the dispersion caused by the movement of the atmospheric air in which the pollutants are suspended. The modeling of the atmospheric dispersion of pollutants elicits the mathematical and/or numerical study of these processes, thereby seeking analytical or semi-analytical solutions that present increasingly accurate results. However these models lack an analytical solution and, hence, are solved by numerical simulations and validated with experimental data (Ku *et al.,* 1987).

Since all the expressions proposed by these several authors serve as the basis for more precise developments of passive dispersion models, the study was undertaken to determine air pollutants (PM2.5, NO_2, SO_2 and CO) in the lower atmosphere in Akwanga Local Government Area of Nasarawa State, to establish the likely health effects of air pollutants and to serve as a blueprint towards air quality management from the study area.

Air Quality Governing Equation

The movement of pollutants released from a source involves numerous phenomena, such as turbulence, wind dragging, buoyancy forces, diffusive effects, etc. The governing equation that encompasses them is given by the following expression (Ku *et al.,* 1987; Moradpour *et al.,* 2017 and Albani *et al.,* 2015).

$$\frac{\partial C_p}{\partial t} + \frac{\partial (U_x C_p)}{\partial x} + \frac{\partial (U_y C_p)}{\partial y} + \frac{\partial (U_z C_p)}{\partial z} = K_x \frac{\partial^2 C_p}{\partial x^2} + K_y \frac{\partial^2 C_p}{\partial y^2} + \frac{\partial}{\partial z}\left(K_z \frac{\partial C_p}{\partial z}\right) + s \quad ..(2)$$

Where C_p=C(*x,y,z,t*) is the pollutant concentration in (µg/m3), U_x, U_y, and U_z are the wind velocities (m/s) in the different space directions, *x, y*, and *z*, respectively, K_x, K_y, and K_z are the diffusivity parameters (m^2/s) in the different directions of space, s is the rate of change of substance concentration due to the sources (sec^{-1}), for all $(x,y,z) \in \Gamma = \{(x,y,z) \in R^3 : x_E \le x \le x_W, y_N \le y \le y_N, 0 \le z \le h_{Top}\}$ for all time $0<t\le T$ and h_{Top} is the light of inversion layer base.

Assuming that the horizontal advection dominates the horizontal diffusion by the wind and the vertical diffusion dominates the vertical advection by the wind. Consequently, the horizontal advection in y-direction is negligible. We have a cross section along the y-axis at the plane of obstacle. With the above assumptions, so Eq. (2) becomes

$$\frac{\partial C_p}{\partial t} + U_x \frac{\partial C_p}{\partial x} = K_x \frac{\partial^2 C_p}{\partial x^2} + K_y \frac{\partial^2 C_p}{\partial y^2} + \frac{\partial}{\partial z}\left(K_z \frac{\partial C_p}{\partial z}\right) + s \quad \text{..............................(3)}$$

where U_x=u. The classic formula used by Shir and Shieh, 1974 has been modified and presented as

$$K_z[z, S(t)] = K_D[S(t)]z \, exp\left\{-\rho[S(t)] \frac{z}{h_{Top}}\right\} \quad \text{... (4)}$$

where K_D [S(t)] is obtained by

$$K_D[S(t)] = z_R^{-1} K_z[z_R, S(t)] \, exp\left\{\rho[S(t)] \frac{z_R}{h_{Top}}\right\} \quad \text{...(5)}$$

Fractional Step Numerical Technique

The atmospheric diffusion Eqs. (3-5) can be written in non-dimensional form with Eq. (3) separated into three (3) stages using the fractional step technique. In each time step of T-directions is discretized from T_n to T_{n+1} with the time increment ΔT to obtain the nondimensional concentration C at time T_{n+1} from its value at a base T.Emission Stage

The contribution of the source term of nondimensional air pollutant is expressed as:

$$S(X,Y,Z,T) = \sum_{r=1}^{N} Q_r \delta(X - X_r)\delta(Y - \quad \text{..... (6)}$$

For all (X,Y,Z)ϵΩ where δ( ) represents Dirac's delta function, Q_r is the emission rate of the r^{th} source and X_r, Y_r are the coordinates of the r^{th} source.

Advection Stage

By taking the Carson's method as reported by Richtmyer and Morton, 1967 who devised a finite difference scheme and which is unconditionally stable to solve a one- dimensionally advection equation in X-direction, one can obtain;

$$\frac{\delta C''}{\delta T} = -U(Z)\frac{\delta C''}{\delta X} \quad \text{...................................(7)}$$

For all $0 \le X \le L_x$ and where wind velocity is assumed as positive.

Diffusion Stage

Using the Crank-Nicolson method as reported by Crank and Nicolson, 1947 and Mitchell, 1969 to solve one-dimensional diffusion equation in Z-direction. The Crank-Nicolson method gives an unconditionally stability for any choice of θ satisfying ½≤θ≤1. It follows that the Crank- Nicolson method for diffusion equation in X, Y, and Z directions becomes;

$$\frac{\delta C''}{\delta T} = K_X \frac{\delta^2 C'''}{\delta X^2} \quad \text{.........................(8)}$$

$$\frac{\delta C^{(4)}}{\delta T} = K_Y \frac{\delta^2 C^{(4)}}{\delta Y^2} \quad \text{...............................(9)}$$

$$\frac{\delta C^{(5)}}{\delta T} = \frac{\delta}{\delta Z}\left(K_Z \frac{\delta C^{(5)}}{\delta Z}\right) \quad \text{......................(10)}$$

In succession, the auxiliary terms in each stage are denoted by prime (') that is (C') , (C''), (C''') , ($C^{(4)}$) and ($C^{(5)}$) respectively.

MATERIALS AND METHODS

Sampling Site Selection

Three sites were selected in Akwanga L.G.A of Nasarawa State which includes; Central Roundabout, C.O E Akwanga road and Dantsoho Filling station. The sites were chosen in the selected places based on human activities, high population density and traffic volume as observed generally by the researcher.

Experimental Set Up

The instruments were placed at an elevated height of 1.5 meters above the ground level, the human breathing zone and 20.0m away from the centre of the road. To start measuring the gases (CO, NO_2, SO_2 and P.M2.5), the switch is first turned to TEST position. Red LED with flash, sounder will operate, display will indicate battery condition (100 = fully charged). After which the switch is turned to Gas position. Unit is then in normal operation. The Green LED will flash and operational sounder will operate once every three seconds to confirm normal operation. The specification for gas and range for CO gas meter is 0 - 500 ppm, SO_2 gas meter is 0 - 10 ppm and NO_2 gas meter is 0 - 10 ppm respectively. While the temperature range is −10˚C to +50˚C and humidity range is 0% - 90% RH, non-condensing.

Data Collection

The measurement of concentration levels of air pollutants (CO, NO_2, SO_2 and PM2.5) were carried out three times; morning peak – hours (7:30am –

9:30am) afternoon off – peak hours, (12:00noon – 2:00pm) and evening peak – hours (4:00pm – 6:00pm) respectively, in each of the selected points.

Data Analysis
The probability of human health effects due to air pollutants will be analyzed from the mean concentration of the pollutants obtained in all the selected different locations and periods using Toxicity Potential (TP) from the relation:

$$TP = \frac{observed\ meam\ conc.\ of\ the\ species}{NAAQS\ \ permissable\ level}$$

If the toxicity potential (TP) is greater than 1 (one) the effect is harmful to human (Ediagbonya et al; 2013).

RESULTS AND DISCUSSION

TABLE 1: Results for Measured Air Pollutants at Central Roudabout for the Month of June, 2021

Time (min)	MORNING				AFTERNOON				EVENING			
	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	PM (µg/m3)	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	PM (µg/m3)	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	PM (µg/m3)
5	005	00.10	00.10	10.50	012	00.10	00.10	12.30	016	00.10	00.10	12.50
10	015	00.10	00.10	10.50	012	00.10	00.10	12.30	016	00.10	00.10	12.60
15	015	00.10	00.10	10.60	012	00.10	00.10	12.30	016	00.10	00.10	12.60
20	004	00.10	00.10	10.50	013	00.10	00.10	12.30	006	00.10	00.10	12.60
25	004	00.10	00.10	10.60	012	00.10	00.10	12.30	014	00.10	00.10	12.60
30	004	00.10	00.10	10.60	013	00.10	00.10	12.40	013	00.10	00.10	12.50
35	005	00.10	00.10	10.50	011	00.10	00.10	12.40	014	00.10	00.10	12.50
40	008	00.10	00.10	10.50	011	00.10	00.10	12.20	013	00.10	00.10	12.50
45	005	00.10	00.10	10.50	009	00.10	00.10	12.20	009	00.10	00.10	12.40
50	006	00.10	00.10	10.50	012	00.10	00.10	12.40	008	00.10	00.10	12.60
55	014	00.10	00.10	10.60	011	00.10	00.10	12.30	005	00.10	00.10	12.50
60	013	00.10	00.10	10.60	011	00.10	00.10	12.30	004	00.10	00.10	12.60
Mean	8.17	0.10	0.10	10.54	11.58	0.10	0.10	12.31	11.17	0.10	0.10	12.54
NAAQS	50.00	5.00	0.09	0.60	50.00	5.00	0.09	0.60	50.00	5.00	0.09	0.60
T.P	0.16	0.02	1.11	17.57	0.23	0.02	1.11	20.52	0.22	0.02	1.11	20.90

TABLE 2: Results for Measured Air Pollutants at C. O. E. Akwanga Road for the Month of June, 2021

Time (min)	MORNING				AFTERNOON				EVENING			
	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	PM (µg/m3)	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	PM (µg/m3)	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	PM (µg/m3)
5	016	00.10	00.10	11.80	005	00.10	00.10	11.70	017	00.10	00.10	11.80
10	009	00.10	00.10	10.40	008	00.10	00.10	11.70	017	00.10	00.10	11.70
15	015	00.10	00.10	10.60	003	00.10	00.10	11.50	007	00.10	00.10	11.70
20	015	00.10	00.10	10.60	004	00.10	00.10	11.50	007	00.10	00.10	11.70
25	008	00.10	00.10	10.40	005	00.10	00.10	11.40	007	00.10	00.10	11.70
30	008	00.10	00.10	10.50	005	00.10	00.10	11.30	011	00.10	00.10	11.70
35	005	00.10	00.10	10.50	005	00.10	00.10	11.30	004	00.10	00.10	11.70
40	006	00.10	00.10	10.60	003	00.10	00.10	11.40	006	00.10	00.10	11.70
45	006	00.10	00.10	10.70	002	00.10	00.10	11.50	003	00.10	00.10	11.70
50	006	00.10	00.10	10.60	011	00.10	00.10	11.40	006	00.10	00.10	11.80
55	006	00.10	00.10	10.50	011	00.10	00.10	11.40	006	00.10	00.10	11.50
60	006	00.10	00.10	10.50	002	00.10	00.10	11.30	007	00.10	00.10	11.60
Mean	8.83	00.10	00.10	10.64	5.30	00.10	00.10	11.45	8.17	00.10	00.10	10.86
NAAQS	50.00	5.00	0.09	0.60	50.00	5.00	0.09	0.60	50.00	5.00	0.09	0.60
T.P	0.18	0.02	1.11	17.73	0.11	0.02	1.11	19.08	0.16	0.02	1.11	18.10

TABLE 3: Results for Measured Air Pollutants at Dantsoho Filling Station for the Month of June, 2021

Time (min)	MORNING				AFTERNOON				EVENING			
	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	PM (µg/m3)	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	PM (µg/m3)	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	PM (µg/m3)
5	006	00.10	00.10	10.80	008	00.10	00.10	11.60	017	00.10	00.10	12.40
10	015	00.10	00.10	10.80	009	00.10	00.10	11.60	017	00.10	00.10	12.40
15	015	00.10	00.10	10.80	013	00.10	00.10	11.60	007	00.10	00.10	12.60
20	005	00.10	00.10	10.80	014	00.10	00.10	11.60	008	00.10	00.10	12.60
25	015	00.10	00.10	10.80	003	00.10	00.10	11.60	008	00.10	00.10	12.60
30	016	00.10	00.10	10.80	003	00.10	00.10	11.50	018	00.10	00.10	12.40
35	017	00.10	00.10	10.80	003	00.10	00.10	11.50	009	00.10	00.10	12.40
40	007	00.10	00.10	10.80	009	00.10	00.10	11.70	009	00.10	00.10	12.60
45	007	00.10	00.10	10.80	006	00.10	00.10	11.60	016	00.10	00.10	12.60
50	007	00.10	00.10	10.80	009	00.10	00.10	11.60	019	00.10	00.10	12.70
55	009	00.10	00.10	10.80	005	00.10	00.10	11.60	009	00.10	00.10	12.60
60	010	00.10	00.10	10.80	006	00.10	00.10	11.60	009	00.10	00.10	12.50
Mean	10.75	00.10	00.10	10.64	6.50	00.10	00.10	11.60	12.16	00.10	00.10	12.54
NAAQS	50.00	5.00	0.09	0.60	50.00	5.00	0.09	0.60	50.00	5.00	0.09	0.60
T.P	0.22	0.02	1.11	18.00	0.13	0.02	1.11	19.33	0.24	0.02	1.11	20.90

The results showed a noticeable concentration of the air pollutants in the month of June 2021 during the study period. This indicates that PM2.5 had a highest mean concentration of 12.54ppm at Central roundabout and at Dantsoho filling Station all in the evening. CO had a highest mean concentration of 12.16ppm at Dantsoho filling station in the evening. SO_2 and NO_2 had their mean concentration at 0.10ppm at all the sampling points and at all the period of measurement. Also PM2.5 had the least mean concentration of 10.54ppm at the Central roundabout in the morning while CO had a least mean concentration of 5.30ppm at C.O.E Akwanga road in the afternoon.

The calculated TP indicates that the toxicity level of the air pollutants (NO_2, and PM) is greater than one making its continuous intake harmful to human (Ediagbonya *et al.,* 2013) in all sampling points at the different locations.

CONCLUSION

The contribution of traffic related air pollution to the air quality in locations of different traffic density in Akwanga was apparent, especially in the high traffic areas. The concentration of pollutants in the different traffic density areas under study varied significantly in the different sites. Results of this study showed that transport-related pollution in Akwanga metropolis is significant and need to be monitored and addressed. It is likely that air quality will deteriorate as the city continues to grow which will result in possible severe health consequences. Therefore, the Nasarawa State Environmental Protection Agency should thus recognize air quality management as a priority and work to prevent further environmental degradation by adopting effective policy, such as inspecting commercial vehicles in the metropolis. This also shows that diseases and effects such as runny nose, chest pain, coughing, eye irritation and sore throat, cardiovascular and pulmonary disease, lungs asthma, et cetera are likely to be prevalent in the metropolis. Air pollutants have major impacts on human health, triggering, and inducing many diseases leading to high morbidities and mortalities, particularly in the developing countries such as Nigeria. Therefore, air pollutions control is vital and should be on the top of priority list of the governments.

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