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Analysis, Evaluation and Stochastic Modeling of Emission Levels of Three Greenhouse Gases (CO_2, H_2O and SO_2) through Vehicular Activities within Enugu Metropolis

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Abstract Research was conducted to determine the level of emission of three greenhouse gases (CO_2, H_2O and SO_2) through vehicular activities within Enugu Metropolis using gaseous pollutant sampler envirotech ARM 433 and fourier transform infra-red spectroscopy. The analysis showed that CO_2 emission was above the permissible limits of 350mg/m^3 in nine out of the 12 calendar month of the study year, 2015. SO_2 and H_2O were within their respective emission permissible limits across the length of the year studied. Stochastic model equations showed that relative humidity and traffic density greatly influenced the levels of emission of pollutant/greenhouse gases through vehicular activities in any given environment. Stochastic modeling equation successfully predicted the level of gaseous emissions in 2017 within Enugu metropolis which could be adopted by relevant government agencies towards pollution control measures.

Keywords Stochastic modeling, Greenhouse gases, Pollution and meteorological data

1. Introduction

Clean air is essential for good health of humans, animals and birds [2]. Since the industrial revolution, the quality of the air we breathe has deteriorated considerably mainly as a result of human activities [16]. All the countries in the world are facing a common problem of air pollution. Rising industrial production and dramatic rise in traffic on our roads all contribute to air pollution in our towns and cities. This in turn can lead to serious health problems to living things when the air pollution exceeds permissible limits [17]. Pollution is an undesirable change in the physical, chemical or biological characteristics of air, water and soil that has potential health hazard to any living organism particularly man [4]. Any substance that causes pollution is called a pollutant. A pollutant may include any chemical or agrochemical substance, biotic component or its product or physical factor (heat) that is released by man into the environment that may have adverse harmful or unpleasant effects [4]. Pollutants are residues of the things we make use of and throw away. Air pollution is a deliberate or inadvertent deposition of materials in pure air, which affects the physical and/or chemical properties of the air and subsequently, caused detectable deterioration of air quality [11]. Thus polluted air is one which in addition to its normal constituents contains other substances called pollutants. Air pollution has three components; the emitting source, atmospheric transport and dispersal and the receptor [14]. The degree of air pollution depends on the interaction of these identified components. Air pollution results mainly from gaseous emissions of industry, thermal power stations, automobiles, domestic combustions, smoke from fire, burning coal mines, decaying vegetation, volcanic eruption, sewers and smelting industries [1]. The main air pollutants emitted from these different sources include: carbon components (CO and CO_2), Sulphur compounds (SO_2 and H_2S) nitrogen oxides (NO, NO_2 and HNO_3) and Ozone e.t.c.

According to the World Health Organisation [18], millions of untimely deaths are occurring due to the urban air pollution created from burning of solid fuel. Most of the deaths due to air pollution are from developing nations [13]. Usually, children are the most susceptible to harmful influences due to their tender tissues, higher surface volume ratio and relative inhalation rate for healthier growth and build-up [12]. Other effects air pollutants include, greenhouse effects, global warming, acid-rain, eye-irritation, breathe difficulties, genetic abnormalities, blood poisoning, heart diseases, damage to fruits and vegetables and blackening and corrosion of building materials [9].

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Air pollution control involves a number of measures which include, treatment of industrial wastes before disposal by industries, enlightenment of citizens through different media on the dangers of indiscriminate disposal of waste materials, regular maintenance of vehicles to ensure complete combustion of petrol and construction of motor parks in every nook and cranny of the society to reduce traffic jams which could lead to increased pollution from exhaust fumes of vehicles [7]. On the other hand, air pollution control involves an inter play of issues and interests that are dealt with on daily basis. Many issues involved in air pollution control are mobile sources, cost benefit-ratios in control enterprise and the complimentary efforts of regulatory agencies.

Control techniques for limiting pollutant formation and emission include system enclosure, emission capture, products reformations and feed stock modifications e.t.c. [15]. In principle the emission level air quality problem could be resolved with the use of a reliable, fully validated mathematical model based on fundamental description of atmospheric transport and chemical process [10]. The model involves emission patterns, metrology, chemical transformations and removal processes. The efficient management of air resource means the ability to translate a specified time and location pattern of discharges of gaseous residuals into the resulting time and space pattern of ambient concentrations, including consideration of synergistic effects and chemical and physical reactions in the atmosphere after discharge [3]. This translation reflects mostly the impact of various meteorological processes on the transportation and dilution of pollutants in the atmosphere. A host of mathematical and decision support techniques have been developed and employed to aid in forming air-quality planning optimization models. The first category examines deterministic models in which parameters are assured to be known with certainty in advance. In the late seventies and eighties, researchers began to recognize short comings in deterministic models. This led to stochastic approaches that mainly deal with great variability in meteorological conditions [8]. Hence the stochastic approach which accounts for the uncertainties in the parameters. Stochastic models are based on the analysis of past and present data and consist of the observed relationship between variables describing ambient air quality and variable describing the pollution source.

This research aims to assess the pollution level of the greenhouse gases (CO_2, SO_2 and H_2O) through vehicular emission in Enugu Metropolis. The objectives are to employ stochastic model in relation to understanding variables that precipitates persistent presence of greenhouse gases in our environment and predict the future emission levels with a view to formulating air pollution control policy.

2. Materials and Methods

The meteorological data (traffic density, wind speed, dry-bulb temperature and relative humidity were obtained from Enugu State University of Science and Technology, meteorological observation. The quantity of gasoline (litres) consumed per hour was obtained through questionnaire analysis.

The quantity of CO_2, H_2O and SO_2 emitted through vehicular emission was obtained and analysed using gaseous pollutant sampler environtech ARM 433 and Fourier – transform infra-red spectroscopy [13]. This is an independent instrument used for monitoring and quantifying gaseous pollutants like SO_2, CO_x, H_2S etc, in ambient condition using chemical methods. Sampled is bubbled through reagents that absorb specific gaseous pollutants and absorbing media analyzed.

Analysis: The data obtained were subjected to analysis of variance and regression at 99% confidence level.

The model: Level emission

$$A_t(\gamma) = y = \int (x_1, x_2, x_3, x_4) \quad (1)$$

and the transform is as follows;

$$\text{Log } y = \log b_o + B_1 \log X_1 + B_2 \log X_2 + B_3 \log X_3 + B_4 \log X_4 \quad (2)$$

Where

X_1 = volume of traffic

X_2 = Dry bulb temperature (°C)

X_3 = Wind speed (km/hr)

X_4 = Relative humidity (%)

The models seeks to evaluate and verify the dependence of $A_t(\gamma)$ on meteorological conditions (X_1, X_2, X_3 and X_4) at 99% confidence level.

The second model predicts the level of gaseous pollution of the environment at any given time thus:

$$\text{Log } A_t(\gamma) = b_o + B_1 \log X_1 + B_4 \log X_4 \quad (3)$$

The prediction performance of the model is based on the availability of parameters such as the meteorological data that influence the level of emission of gases in a given environment. The stochastic model was calculated using a speed optimized version, SMSIM version 2.0 [10].

3. Results and Discussion

X_1 = Traffic density; X_2 = Wind speed; X_3 = Dry-bulb temperature; X_4 = Relative humidity. Table 1 shows that the months of September to December, 2015 witnessed the highest traffic density in the metropolis which could be due to approach and celebration of yuletide season, while the lowest traffic density was recorded in the months of February, March and May.

The wind speed was highest in the months between December to March, which could be due to the wind movement from the Sahara region, a sign of peak of dry-season. The dry bulb temperature has averagely similarly values across the period under review. The percentage relative humidity was highest in the months of

June, July and September which were peak period of rainy season while the lowest percentage of relative humidity was between the months of January –March which represents peak periods of dry-season.

Table 2 shows that average quantity of three greenhouse gases (CO_2, SO_2 and H_2O) emitted as a result of gasoline consumption through vehicular activities was highest in the months of June, July and September while the least emission was in the months of January to April. This observation could be because the months of June to September were peak periods of rainy season, in which the humidity is usually very high and temperature low thus necessitating the increased pressure in the engine to heat-up and circulation fuel-flow [6]. However, the months with comparable low greenhouse gas emission (January to April) were periods of dry season in which the humidity is usually low and temperature of the surrounding usually high.

The result shows that the quantity of SO_2 and H_2O emitted per hour of the period of the study covering Enugu Metropolis were within the permissible emission range of 350 and 4000mg/m^3 respectively [5]. The high level of vehicular activities within the metropolis resulted to the emission of CO_2 per hour above the permissible level of 350mg/m^3 in the months of January, February, June, July, August, September, October, November and December. The emissions at this level could increase the average global temperature which is capable of triggering severe weather events with wild extremes in temperature and precipitation [6]. In other to verify the dependence of level of greenhouses emission on X_1, X_2, X_3 and X_4, the results of Table 1 and 2 were evaluated by subjecting it to stochastic and regression analysis at 99% confidence level.

Since the critical value of t was 2.95, for X_1, t – calculated was 70.25, which suggests that volume of traffic can influence the level of greenhouse gas emission at any given time. The t – calculated for X_2 was 0.337 and lower than the critical t (2.95). This shows that dry bulb temperature may not influence the level of greenhouse gas emission at any time. For X_3, the t – calculated (0.869) was lower that the critical t (2.95), with suggests that wind speed may not influence the level of emission of greenhouse gases at any particular period (especially through vehicular activities).

Table 1. Average traffic density, wind speed, dry-bulb-temperature and relative humidity across the seasons of the year (Jan-Dec, 2015)

Month and year	Traffic density (X_1)	Wind speed (X_2)	Dry-bulb temperature (X_3)	Relative humidity (X_4)
January 2015	7122	39.90	30.60	43
February 2015	4346	38.13	28.80	42
March 2015	4110	43.42	29.50	41
April 2015	4708	28.30	27.30	658
May 2015	4014	25.50	26.20	74
June 2015	5424	27.40	26.00	81
July 2015	5011	27.89	25.40	83
August 2015	7430	29.66	26.20	72
September 2015	8224	28.81	27.80	87
October 2015	8716	26.94	28.30	63
November 2015	9860	30.06	28.10	58
December 2015	11448	42.00	28.90	50

Table 2. Average rate of emission of greenhouse/pollutant gases from automobile exhaust per hour in 2015, within Enugu Metropolis

Month and year	Quantity of gasoline (litres)	Quantity of CO_2 emitted (mg/m^3) per hour	Quantity of SO_2 emitted (mg/m^3) per hour	Quantity of H_2O emitted (mg/m^3) per hour	Total quantity emitted (mg/m^3)
January	10282	390	287	404	1081
February	9500	385	280	399	1064
March	9843	348	255	417	1020
April	8533	335	240	433	1008
May	9305	321	272	451	1044
June	10146	408	317	522	1247
July	10035	416	303	510	1229
August	10212	394	286	503	1183
September	10138	411	310	538	1259
October	10108	375	291	481	1147
November	10117	388	283	446	1117
December	10405	409	274	427	1110

Table 3. Result of observed and predicted levels of greenhouse gas emission

Month and year	Traffic density (no.of cars per day)	Observed level of pollution (mg/m^3 per day)	Predicted level of pollution (for 2017) (mg/m^3 per day)
January	7122	1081	1587.92
February	4346	1064	1529.13
March	4110	1020	1521.01
April	4708	1008	1566.67
May	4041	1044	1572.33
June	5424	1247	1611.80
July	5011	1229	1611.56
August	7430	1183	1634.70
September	8224	1259	1662.53
October	8716	1147	1639.69
November	9860	1117	1645.37
December	11448	1110	1647.91

The calculated value of t for X_4 was 292.06 and this represents a significant higher value compared to the critical t (2.95). The consequence of this is that X_4 (relative humidity) has a major influence on the level of emission of greenhouse gases though vehicular activities in an environment at any given time.

The stochastic model equation 2 was reduced to $\text{Log } A_t(\gamma) = b_o + B_1\log X_1 + B_4\log X_4$, which represents the meteorological conditions that influence the level of emission of gases in a given environment and thus futuristic emission of gases from vehicular activities could be predicted. The 2017 emission levels within Enugu metropolis was successfully predicted using the stochastic model equation as presented in Table 3.

The result of Table 3 shows that in 2017, the level of emission of pollutant/greenhouse gases through the exhaust of vehicles will increase by over 60% which could be due to the increase in number of vehicles on the road, the increase in the number of poorly maintained vehicles on the road (due to economic stagnations) and vagaries of the weather conditions.

4. Conclusions

The study showed that factors like traffic density and relative humidity can greatly influence the level of emission of pollutant/greenhouse gases especially through vehicular activities at any time in any environment which were validated using stochastic model equation. Stochastic model equation was used to predict the level of emission of greenhouse/pollutant gases for 2017 and the prediction revealed increase in level of emission by over 60%. The consequence of this development to man and his ecosystem should be unpleasant. Policy makers across every government level could adopt this model approach in coming up with strategies that will control and regulate the level of emission of pollutant gases to the environment.

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