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PROJECTION OF CRITERIA AIR POLLUTANTS EMISSION FROM ON-ROAD VEHICLES IN THE MEGACITY OF LAGOS, NIGERIA.

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ABSTRACT

The increase in the mode of transportation has become a serious environmental threat that has resulted in the emission of criteria air pollutants (CAPs) into the atmosphere. These CAPs are sulphur oxides (SO_x), particulate matter (PM), lead (Pb), carbon monoxide (CO), and nitrogen oxides (NO_x). This study examined the emission of CAPs from road traffic use in Lagos State. Data for the inventories of the production of these five sources were taken from 1997–2011 and were used to forecast CAPs emissions from 2012–2030. The petroleum products consumption data were sourced from the Nigerian National Petroleum Corporation (NNPC). Five categories of CAPs were studied and their corresponding emissions from 1997–2011 were computed as follows: SO_x: 209–15,358t, NO_x: 2,038–25,692t, CO: 24,996–186,202t, PM: 155–995t, Pb: 0.8 4.5t. Projection and forecasting of CAPs emissions from 2012 to 2030 were carried out using the Box Jenkins ARIMA method. There were close similarities between the observed and forecast values. The predicted CAPs emissions between 2012 to 2030 will be 309t for SO_x, 22,600 – 41,300t for NO_x, 100,000 – 300,000t for CO, 414t for PM, and 0.7t for Pb. The study concluded that there is tendency for these CAPs emissions to increase if the authorities and stakeholders do nothing. Several mitigation measures aimed towards reducing future CAPs emissions in Lagos State were recommended for the various sources.

Key words: Criteria air pollutant; emissions; ARIMA method, mitigation; megacities; projection

1.0 Introduction

The emergence of megacities has been accompanied by air pollution (Amann *et al*., 2017; Folberth *et al*., 2015; Baklanov, 2016) and it is now a global concern (Hossain-Khan, 2012). In Nigeria, the problem of inadequate power supply coupled with the growing economy and increased transportation has led to sharp increases in the consumption rates of refined petroleum products (Adenikinju, 2003; Olatunji *et al*., 2015; Fakinle *et al*., 2020). Nigeria relies greatly on transportation by private vehicles which leads to frequent driving of the vehicles and has led the country to be a major emitter of criteria air pollutants (Oladimeji *et al*., 2015). Similarly, the inadequate supply of power for domestic, commercial and industrial uses has prompted the citizenry to make use of alternative sources of power that is generator-based. These, however, have led to unwanted consequences such as air pollutants emissions, more fuel consumption, and people being exposed to hazardous pollution that result in aggravated health consequences (Krzyzanoswki *et al*., 2005). Various studies point to the severities of these unfavorable health effects and to the need to proffer solutions that will reduce the risks to health while meeting the demands for power and movement. This becomes a major hurdle for the authorities concerned: environmental authorities, public health institutions and governments as well as those saddled with the responsibilities urban planning, transportation and power planners, as well as the citizenry. To meet these challenges, a number of policy initiatives are formulated. The use of spaces, peoples' behavioral patterns, population, and transport types and energy users have effect on how people are exposed to pollution and the associated risks to health (Krzyzanoswki *et al*., 2005).

An air pollutant is a substance that can poison the population, vegetation, animals and has a pungent and irritating odour that can obscure visibility, cause damage to property and irritates our senses.. The effects of air pollution on human health have been found to be wide-ranging and deleterious and have become a major global issue (Newby *et al*., 2015). The global impact of air pollution has been found to be 3.1 million of 52.8 (cause and deaths) in 2010 (Lim *et al*., 2012). Among the disease risk factors, ambient air pollution is ranked ninth and accounts for 3.1% of global disability-adjusted life years. This is an index that measures the time spent in states of ill-health (Lim *et al*., 2012).

The public is generally less aware of the impact of air pollution on human health. Air pollution is an important factor for the occurrence and multiplication of respiratory diseases like lung cancer, asthma, and chronic obstructive pulmonary disease. Other studies in the 1990s, such as the Harvard Six Cities (Dockery *et al*., 1993) and American Cancer Society cohort studies, (Dockery *et al*., 1993; Pope *et al*., 1995) showed a direct relation between cardiovascular mortality and prolonged exposure to air pollution as a result of disease of the coronary artery (Pope *et al*., 2004). In Europe, the Netherlands Cohort Study on Diet and Cancer corroborated this finding (Hoek *et al*., 2002). Relationship between mortality and cardiovascular morbidity have been established with short-term pollutant exposures of residents in large urban areas across the globe (Samet *et al*., 2000) and Europe (Katsouyanni *et al*., 1997; Katsouyanni *et al*., 2001). The most relevant among multiple pathways linking air pollution to mortality and cardiovascular morbidity are the endothelial dysfunction, atherothrombosis, oxidative stress, systemic inflammation and arrhythmogenesis (Mills *et al*., 2009).

Due to large number of people and increased transport-related activities in Nigeria leading to increased emission of air pollutants, there is the need to carry out a detailed analysis of the consequences of these activities on the environment with particular reference to Lagos State, a state of about 18 million residents.

1.1 The criteria air pollutants

Six gases make up the criteria air pollutants (CAPs). These pollutants are products of combustion processes (Sonibare and Jimoda, 2006). They are particulate matter (PM), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), lead (Pb), and sulphur dioxide (SO_2) (Mills *et al*., 2009; Uzoigwe *et al*., 2013; Zhao *et al*., 2021). A complex mixture of thousands of components make up outdoor air pollution. From a health point of view, important components of this mixture include gaseous pollutants like nitrogen dioxide (NO_2), ozone (O_3), sulphur dioxide (SO_2), carbon monoxide (CO), airborne particulate matter (PM) and the volatile organic compounds (including benzene) (Mills *et al*., 2009; Uzoigwe *et al*., 2013; Sun *et al*., 2019). Primary pollutants (oxides of nitrogen and sulphur and soot particles) are directly emitted into the air by fossil fuels combustion. NO_2 are mostly emitted from power generation, industrial sources, motorized road traffic and residential heating. Other components in the atmosphere lead to the formation secondary pollutants like ozone which is a result of complex photochemical reactions of volatile organic components and nitrogen oxides (Newby *et al*., 2015).

The effects on human health of air pollution are shown in Figure 1 (Mills *et al*., 2009; Forastiere and Agabiti, 2013).

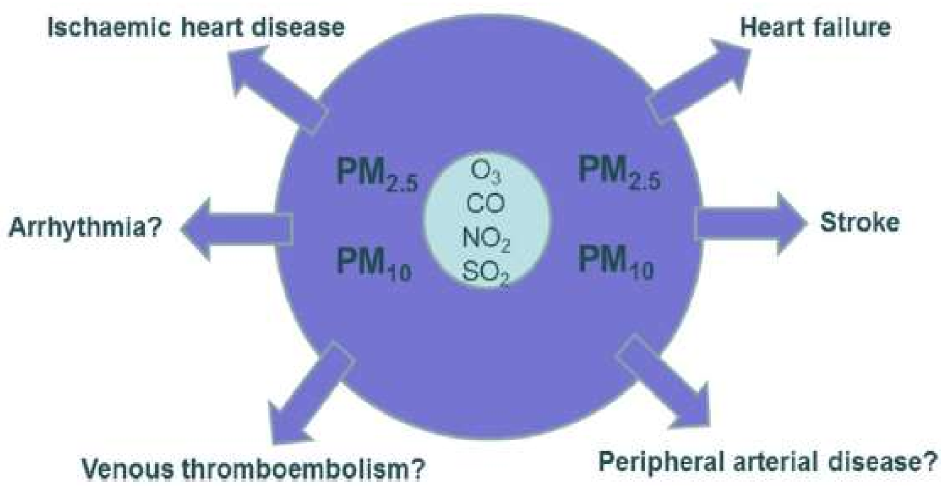

Figure 2.2: Established and unsettled clinical outcomes related to air pollution (gaseous and particulate) (Mills *et al*., 2009; Forastiere and Agabiti, 2013).

2.0 Materials and methods

The categories considered were transport, and energy generation. Emission factors and consumption of refined petroleum products are the essential inputs. Data for petroleum products consumption were obtained from the Nigerian National Petroleum Corporation (NNPC). The data covered the period of 1997 – 2011**.** All the annual petroleum product consumption and petroleum products distribution in Lagos State were assessed in terms of quantity (tonnes) and volume (m^3). Past consumption and distribution (1997 – 2011) were determined and projections were made up to the year 2030 by using the Auto-Regressive Integrated Moving Average (ARIMA). To compute concentration of the CAPs, fuel-based emission factors from the European countries (EU, 2006) and Asian nations were used (Yli-Tuomia *et al*., 2005). The levels of fuel consumption levels and the relevant emission factors were combined to compute the potential emission of criteria air pollutants as a result of the combustion of LPG and kerosene in cooking. The emission factor approach was used for the computation of emission of CAPs from the combustion of LPFO for the period under investigation.

2.1 Criteria Air Pollutants Calculations

The criteria air pollutants calculations were carried out with the help of emission factors of each pollutant using equation (1):

Annual emission = Annual consumption x emission factor x pollutant content (1)

The carbon dioxide emission coefficients by fuel is shown in the Table 1 (EIA, 2014).

Table 3.2: Emission factors for refined petroleum products

S. No.	Type	Emission Factor (g/l)		
		CO_2	CH_4	N_2O
1.	Diesel fuel (AGO)	2663	0.133	0.40
2.	Kerosene (DPK or HHK)	2534	0.026	0.006
3.	Gasoline (petrol or PMS)	2289	0.32	0.66
4.	Aviation gasoline	2342	2.2	0.23
5.	Aviation turbo fuel	2534	0.028	0.071
6.	Light fuel oil (LPFO)	2725	0.18	0.031
7.	Heavy fuel oil (HPFO)	3124	0.034	0.40
8.	Motor cycle	2289	0.77	0.041

3.0 Results and discussion

The results are shown in Table 2.

Table 2: Criteria air pollutant emission (1997 – 2011)

Year	SO_x	NO_x	CO	PM	Pb
1997	718,849,753	9,918,450,679	32,104,162,901	177,045,159	3,294,576
1998	15,357,858,321	3,748,917,277	25,586,429,050	155,352,587	3,399,131
1999	191,458,572	4,674,290,442	24,996,074,674	186,683,302	4,043,360
2000	14,402,358,123	2,037,785,636	40,805,540,984	197,342,805	3,295,721
2001	1,397,041,029	25,692,155,258	57,348,311,251	392,576,363	4,177,382
2002	2,058,578,197	11,080,555,822	82,731,416,190	607,786,297	3,386,016
2003	2,302,092,206	13,214,683,123	76,776,588,967	668,907,748	4,490,392
2004	2,562,534,207	24,693,075,832	85,743,872,998	947,084,538	4,330,940
2005	2,807,036,947	13,883,561,155	97,213,544,102	829,110,690	3,801,094
2006	3,362,440,635	14,909,129,638	118,322,866,139	995,989,083	3,518,177
2007	295,626,704	15,663,041,497	121,010,308,456	242,575,363	3,173,528
2008	268,618,484	11,659,376,558	113,916,643,153	283,376,197	2,828,879
2009	343,812,903	23,571,719,361	186,202,922,870	299,350,501	2,597,078
2010	177,265,383	22,241,056,999	86,346,974,719	361,077,017	1,199,685
2011	164,542,156	19,770,219,754	87,906,403,668	421,827,867	857,139

The emission of these CAPs did not follow any regular pattern. This makes it difficult to attribute the irregular pattern to any of the indices responsible for the emissions – be it transportation, power, household use or industrial activities. One noticeable trend was that emission reductions were observed for sulphur oxides (SO_x) from 2007 and lead (Pb) from 2004. That of the lead could be due to improvements in car engines. These observed values were plotted using each pollutant and the results are shown in Figs 2 – 6.

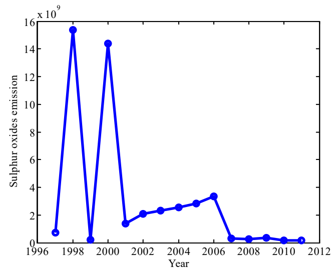

Figure 2: SO_x emission

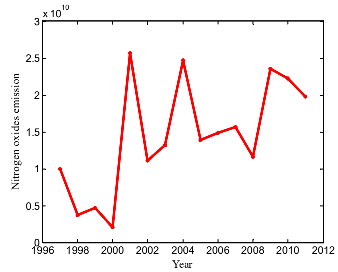

Figure 3: NO_x emission

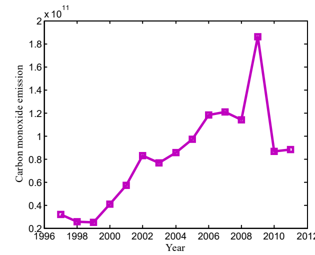

Figure 4: CO emission

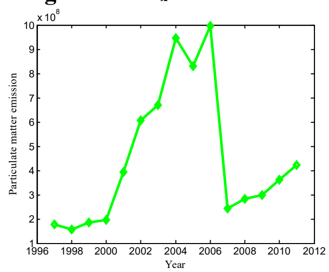

Figure 5: PM emission

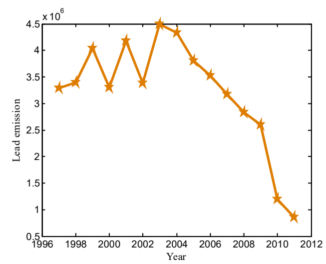

Figure 6: Pb emission

3.1 Projected emissions

The emissions of these pollutants were projected to 2030 using the ARIMA model of PASW 18 software.

For a good description of the overall performance of the proposed models, assessments of the results with various descriptive statistics were carried out. These include mean absolute percentage error (MAPE), Normalized Bayesian Information Criterion (BIC), root mean square error (RMSE) and the coefficient of determination (R^2). To test the validity of the models, the Ljung-Box statistics was used. Table 4 shows the model fit statistics for the pollutants. The coefficient of determination (R^2) values were between 0.909 (90.9%) and 0.971 (97.1%). These showed that less than 0.091 (9.1%) of the total variations could not be adequately explained by the model and are indications of good model fits.

Table 4: Model Fit statistics

CAP	R^2	RMSE	MAPE	MAE	MaxAPE	MaxAE	Normalized BIC
SO_x	0.965	4.9129	4.935	3.1799	17.374	12.610	44.811
NO_x	0.909	6.5639	5.495	4.5489	29.128	16.910	45.571
CO	0.970	2.9460	4.131	1.9490	20.878	13.021	48.574
PM	0.936	2.3478	6.852	1.3628	22.988	15.008	38.728
Pb	0.971	3.699	8.458	2.9182	12.661	24.512	27.519

The Ljung-Box Q statistics was used to validate the models and it showed that the models were correctly specified because they were all above 0.05 in significance. These implied that all structures in the observed series had been accounted for (Table 5).

Table 5: Ljung-Box Q statistics

	Ljung-Box Q(18)		
CAP	Statistics	DF	Sig.
SO_x	11.587	18	0.868
NO_x	15.282	16	0.589
CO	14.429	17	0.637
PM	13.314	17	0.715
Pb	14.999	17	0.596

3.2 Predicted and projected emission for sulphur oxides (SO_x)

The emission of sulphur oxides did not follow any specific pattern. It was fluctuating and reached the highest level in 1998 with an emission of 15,358 tCO_2. This was almost repeated in 2000 (14,402 tCO_2). Then followed a period of decline in emission reaching a low of 15,358 tCO_2 in 2011. This led to the averaging of the fitted and forecast emission at 3.09E+03 tCO_2 (Fig. 4.8). The emissions of sulphur oxide (SO_x) emissions reduced by 5%, or 64 kilotonnes (kt), from 2013 emission levels to 1142 kt in 2014. For SO_x', the emission in 2014 were 1963 kt (63%) lower than in 1990. This constant trend in SO_x emissions is due to the actions taken by the government to fight acid rain. Further reasons for the constant emissions could also be due to:

- upgrades in technology and new control methods on air pollution;
- lower emissions from utilities using fossil-fuels to generate power due to improved removal technologies;
- better controls of emission for the petroleum refining sector; and the use of low-sulphur fuels.

3.3 Predicted and projected emission for nitrogen oxides (NO_x)

Nitrogen oxides emission dropped from 9,918 tCO_2 in 1997 to 2,038 tCO_2 in 2000. The emission then rose dramatically to 25,692 tCO_2 in 2001 and started fluctuating around 11,080 – 15,662 tCO_2 between 2002 and 2008. It then rose again to 23,571 tCO_2 in 2009. The emission of nitrogen oxides was fitted to follow an upward pattern. It is expected to rise from 22,600 tCO_2 in 2012 to 41,300 tCO_2 in 2030 (Fig. 4.8). It is a product of the reaction between oxygen and nitrogen gases in the air during combustion, especially at high temperatures. In Lagos where there is high motor traffic, very significant amounts of nitrogen oxides are emitted into the atmosphere.

3.4 Predicted and projected emission for carbon monoxide (CO)

The emission of carbon monoxide rose gradually rom 32,104 tCO_2 in 1997 to 186,203 tCO_2 in 2009. There was a slight reduction in emission to 87,906 tCO_2 in 2011. The predicted emission was fitted to follow an upward pattern. It is expected to rise from 100,000 tCO_2 in 2012 to 300,000 CO_2 in 2030 (Fig. 4.8). Carbon monoxide (CO) is produced when carbon-containing fuels, such as oil, gasoline, wood, natural gas, and coal are incompletely combusted. Vehicle emissions are the largest anthropogenic source of CO. Since Nigeria has become the dumping ground for second-hand vehicles, the continuous use of old vehicles will definitely increase the amount of CO emitted.

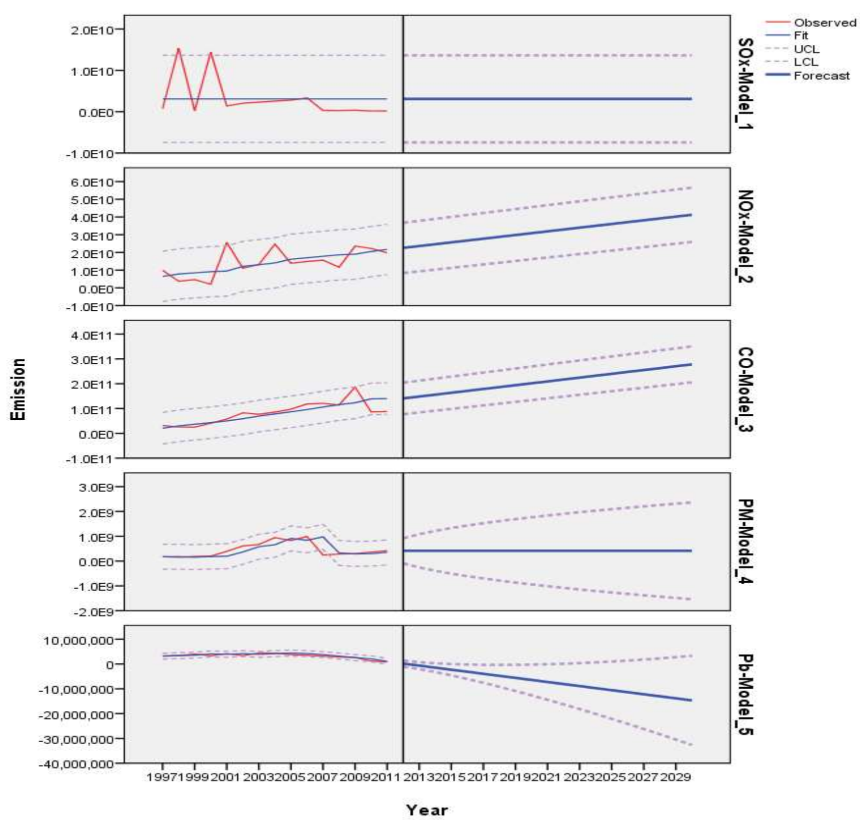

Figure 4.8: Combined observed, fitted and predicted emissions

3.5 Predicted and projected emission for particulate matter (PM)

The emission of particulate matter did not follow any specific pattern as it was rising and falling. This led to the averaging of the fitted and forecast emission at 414 tCO_2 (Fig. 8). Reductions in agricultural operations and industrial activities may be responsible for this constant trend predicted. Particulate matter (PM) components include finely divided solids or liquids such as smoke, dust, fumes, fly ash, soot, fumes, aerosols, fumes, and condensing vapours that are suspended in the air for long periods. A variety of stationary and mobile sources may cause particle formation. These could be primary emissions which aredirectly emitted or secondary emissions which are formed in the atmosphere by transformation of gaseous emissions.

Air contaminants are directly emitted into the atmosphere by secondary PM sources Hence, these pollutants are referred to as precursors to the formation of PM. These secondary pollutants include VOCs, NO_x, SO_x, and ammonia. When control measures that will reduce PM precursor emissions are put in place, it has a beneficial impact on ambient PM levels.

3.6 Predicted and projected emission for lead

The emission of lead was rising and falling and did not follow any specific pattern. Hence the fitted and forecast emission was predicted to be constant at 0.076925 tCO_2 (Fig. 4.11). Piston-engine aircraft operating on leaded aviation fuel and metals and ore processing are the major sources of lead in the air. Other sources are lead-acid battery manufacturers, utilities, and waste incinerators. Areas around lead smelters usually provide the highest air concentrations of lead. These sources of lead are lacking in Nigeria hence the low emission observed.

Table 4.5: Forecast CAP emissions (2012 – 2030)

Year	SO_x			NO_x			CO			PM			Pb		
	Forecast	UCL	LCL	Forecast	UCL	LCL	Forecast	UCL	LCL	Forecast	UCL	LCL	Forecast	UCL	LCL
2012	3.09E+09	1.36E+10	-7.4E+09	2.26E+10	3.67E+10	8.38E+09	1.00E+11	2.00E+11	7.71E+10	4.14E+08	9.17E+08	-9.0E+07	76925	1966350	-1812501
2013	3.09E+09	1.36E+10	-7.4E+09	2.36E+10	3.78E+10	9.36E+09	1.00E+11	2.00E+11	8.42E+10	4.14E+08	1.09E+09	-2.6E+08	76925	1966350	-1812501
2014	3.09E+09	1.36E+10	-7.4E+09	2.46E+10	3.90E+10	1.03E+10	2.00E+11	2.00E+11	9.13E+10	4.14E+08	1.22E+09	-3.9E+08	76925	1966350	-1812501
2015	3.09E+09	1.36E+10	-7.4E+09	2.57E+10	4.01E+10	1.13E+10	2.00E+11	2.00E+11	9.84E+10	4.14E+08	1.33E+09	-5.1E+08	76925	1966350	-1812501
2016	3.09E+09	1.36E+10	-7.4E+09	2.67E+10	4.12E+10	1.23E+10	2.00E+11	2.00E+11	1.00E+11	4.14E+08	1.43E+09	-6.1E+08	76925	1966350	-1812501
2017	3.09E+09	1.36E+10	-7.4E+09	2.78E+10	4.23E+10	1.32E+10	2.00E+11	2.00E+11	1.00E+11	4.14E+08	1.53E+09	-7.0E+08	76925	1966350	-1812501
2018	3.09E+09	1.36E+10	-7.4E+09	2.88E+10	4.34E+10	1.42E+10	2.00E+11	3.00E+11	1.00E+11	4.14E+08	1.61E+09	-7.9E+08	76925	1966350	-1812501
2019	3.09E+09	1.36E+10	-7.4E+09	2.98E+10	4.45E+10	1.52E+10	2.00E+11	3.00E+11	1.00E+11	4.14E+08	1.69E+09	-8.6E+08	76925	1966350	-1812501
2020	3.09E+09	1.36E+10	-7.4E+09	3.09E+10	4.56E+10	1.62E+10	2.00E+11	3.00E+11	1.00E+11	4.14E+08	1.77E+09	-9.4E+08	76925	1966350	-1812501
2021	3.09E+09	1.36E+10	-7.4E+09	3.19E+10	4.67E+10	1.71E+10	2.00E+11	3.00E+11	1.00E+11	4.14E+08	1.84E+09	-1.0E+09	76925	1966350	-1812501
2022	3.09E+09	1.36E+10	-7.4E+09	3.30E+10	4.78E+10	1.81E+10	2.00E+11	3.00E+11	1.00E+11	4.14E+08	1.91E+09	-1.1E+09	76925	1966350	-1812501
2023	3.09E+09	1.36E+10	-7.4E+09	3.40E+10	4.89E+10	1.91E+10	2.00E+11	3.00E+11	2.00E+11	4.14E+08	1.97E+09	-1.1E+09	76925	1966350	-1812501
2024	3.09E+09	1.36E+10	-7.4E+09	3.50E+10	5.00E+10	2.01E+10	2.00E+11	3.00E+11	2.00E+11	4.14E+08	2.03E+09	-1.2E+09	76925	1966350	-1812501
2025	3.09E+09	1.36E+10	-7.4E+09	3.61E+10	5.11E+10	2.11E+10	2.00E+11	3.00E+11	2.00E+11	4.14E+08	2.09E+09	-1.3E+09	76925	1966350	-1812501
2026	3.09E+09	1.36E+10	-7.4E+09	3.71E+10	5.22E+10	2.20E+10	2.00E+11	3.00E+11	2.00E+11	4.14E+08	2.15E+09	-1.3E+09	76925	1966350	-1812501
2027	3.09E+09	1.36E+10	-7.4E+09	3.82E+10	5.33E+10	2.30E+10	3.00E+11	3.00E+11	2.00E+11	4.14E+08	2.21E+09	-1.4E+09	76925	1966350	-1812501
2028	3.09E+09	1.36E+10	-7.4E+09	3.92E+10	5.44E+10	2.40E+10	3.00E+11	3.00E+11	2.00E+11	4.14E+08	2.26E+09	-1.4E+09	76925	1966350	-1812501
2029	3.09E+09	1.36E+10	-7.4E+09	4.02E+10	5.55E+10	2.50E+10	3.00E+11	3.00E+11	2.00E+11	4.14E+08	2.31E+09	-1.5E+09	76925	1966350	-1812501
2030	3.09E+09	1.36E+10	-7.4E+09	4.13E+10	5.66E+10	2.59E+10	3.00E+11	4.00E+11	2.00E+11	4.14E+08	2.36E+09	-1.5E+09	76925	1966350	-1812501

4.0 Conclusion

The present work examines the emission of criteria air pollutants from traffic sources in Lagos State. Five pollutants were investigated for their environmental impacts. They are particulate matter (PM), nitrogen oxides (NO_x), sulphur oxides (SO_x), carbon monoxide (CO), and lead (Pb). The pattern of petroleum products consumption in Lagos State was found to be irregular. It was rising and falling. Liquefied petroleum gas (LPG) consumption was very high in 1997 and it started witnessing irregular pattern afterwards. Consumption dropped to 22,256 in 2000 and started increasing after that year. There was no definite consumption pattern for diesel (AGO). It was very high in 1997 and started declining but rose again in 2001. A long period of reduction was observed up to 2012 before consumption started rising again. Petro (PMS) consumption was initially reducing but picked up immediately and continued rising. Small reductions noted in 2011 and 2012 but picked up again in 2013. Ne definite pattern was discernable for the consumption of kerosene (HHK/DPK) but consumption stated declining in 2002 up to 2012. Rise in consumption was noted in 2013 and 2014.

The criteria air pollutants (CAPs) concentration levels are directly proportional to the consumption pattern of the petroleum products. Sulphur oxides emission was not following a defined pattern. Nitrogen oxides and carbon monoxide emissions were found to be rising even in their unsteady patterns. Particulate matter and lead emissions were not clearly defined. The future environmental impacts of CAPs were projected using the ARIMA model. SO_x, CO and lead emissions were projected to be constant while NO_x and PM emissions were projected to increase.

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