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Air Emissions of Sulphur Dioxide From Gasoline and Diesel Consumption in the Southwestern States of Nigeria

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The contribution of SO_2 emissions from the consumption of petroleum products to Nigerian airshed has been of great concern over the years because of the resulting adverse environmental and health effects. It is in the light of this that air emissions of SO_2 from gasoline and diesel consumed in the Southwestern States of Nigeria were estimated in this study. Lagos state being the highest consumer of gasoline and diesel in Southwestern Nigeria emitted the highest quantity.

Keywords: diesel, gasoline, Nigeria, sulphur dioxide

1. INTRODUCTION

Persistent unsolved epileptic power supply and the growing economy have led to increase in the rate of petroleum products consumption in Nigeria (Adenikinju, 2003). The air emissions of sulphur dioxide (SO_2) and its environmental and health impacts from the consumption of refined petroleum products with nonuniformity in sulphur contents in Nigeria could be mitigated, provided there is proper and consistence investigation. Significant amounts of SO_2 particles have been released to the air globally, due to combustion characteristics of various engines and a widespread use of fuels with nonuniform qualities in terms of sulphur levels (Kasper et al., 2007). Sulphur is chemically bonded to the hydrocarbons of the fuel and during combustion; most suphur is oxidized to SO_2 (MAN B&W Diesel, 1996). Sulphur, which is mostly oxidized to SO_2 during combustion, is a major constituent of the primary particles in the exhaust from gasoline and diesel powered engines from the combustion of fuel (Kasper et al., 2007; Agrawal et al., 2008; Petzold et al., 2008; Moldanová et al., 2009; Popovicheva et al., 2009). Sulphate particles in the exhaust system form during the cooling of the exhausts and a reaction between SO_3 and water, which forms H_2SO_4. Kasper et al. (2007) found that 1.4% of the sulphur in the fuel was in the form of sulphate in exhaust gas particles. Agrawal et al. (2008) showed a sulphate particle formation between 7% and 5% for the same mechanisms during exhaust gas measurements after dilution with air, while Moldanová et al. (2009) concluded on 1.3%. Endresen et al. (2003) estimated that approximately half of the amount of emitted SO_2 from fuel combustion was deposited mainly by dry deposition. The two different pathways for

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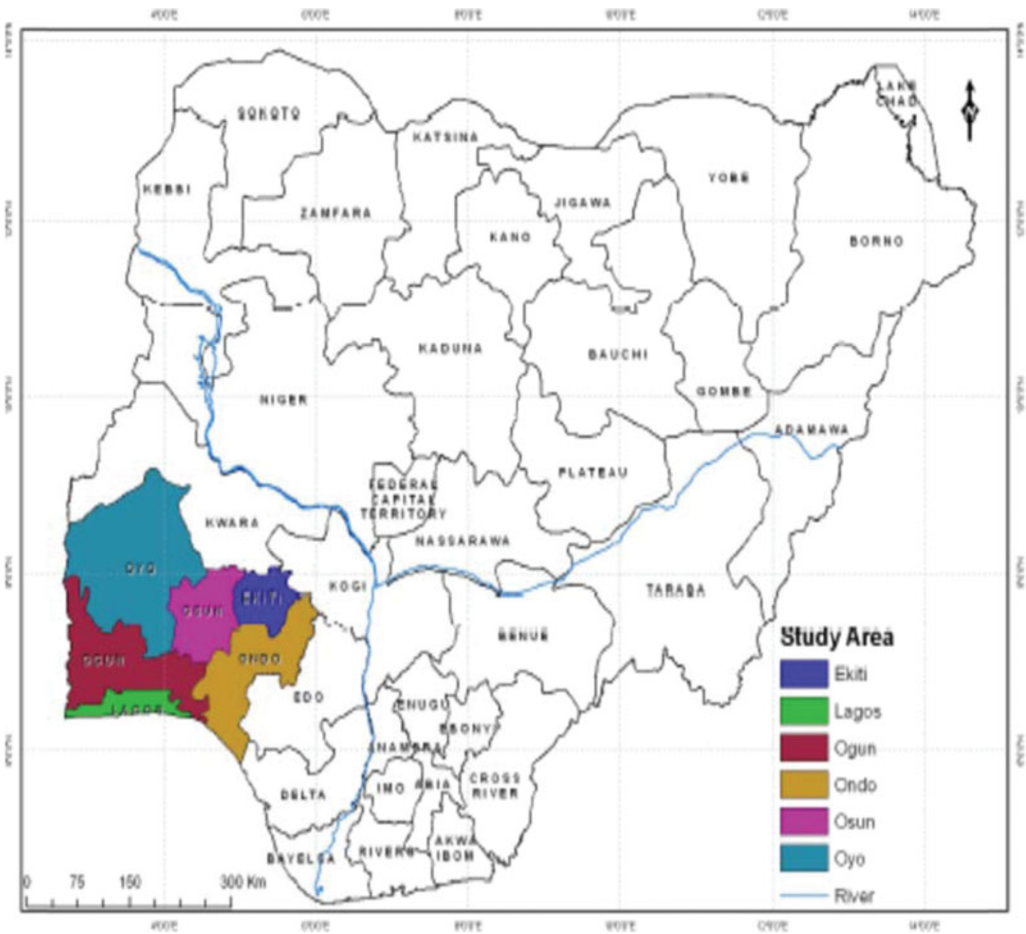

FIGURE 1 The study areas in Nigeria.

H_2SO_4 formation are either gaseous SO_2 reacts with hydroxyl radical molecules (·OH), or it reacts heterogeneously in the liquid phase or on surfaces (Finlayson-Pitts and Pitts, 2000).

The main environmental concerns related to SO_2 emissions are acid rain and the formation of particulate matter (PM). Acid rain has many negative environmental impacts, which include the acidification of aquatic systems, increase in soil acidity, and damage to vegetation (Schmidt, 2006). Acid rain can also cause the degradation of buildings and other human infrastructure (U.S. Environmental Protection Agency, 1998). The PM emissions result in reduced visibility and also have impacts on human health. The Human health impacts of PM are generally related to respiratory illnesses, including increased frequency in bronchitis and asthma. These illnesses have led to an increase in premature mortality (Schmidt, 2006).

Several manual and continuous analytical techniques are used to measure SO_2 in the atmosphere. The manual techniques involve two-stage sample collection and measurement (Vallero, 2008). The West–Gaeke manual method is the basis for the U.S. Environmental Protection Agency (USEPA) reference method for measurement of SO_2 (Stern et al., 1994). Other methods such as emission factor and mass balance have been widely reported in earlier studies (Obioh et al., 1994: Sonibare and Akeredolu, 2006). The annual average global SO_2 emission was estimated to be 1,561,100

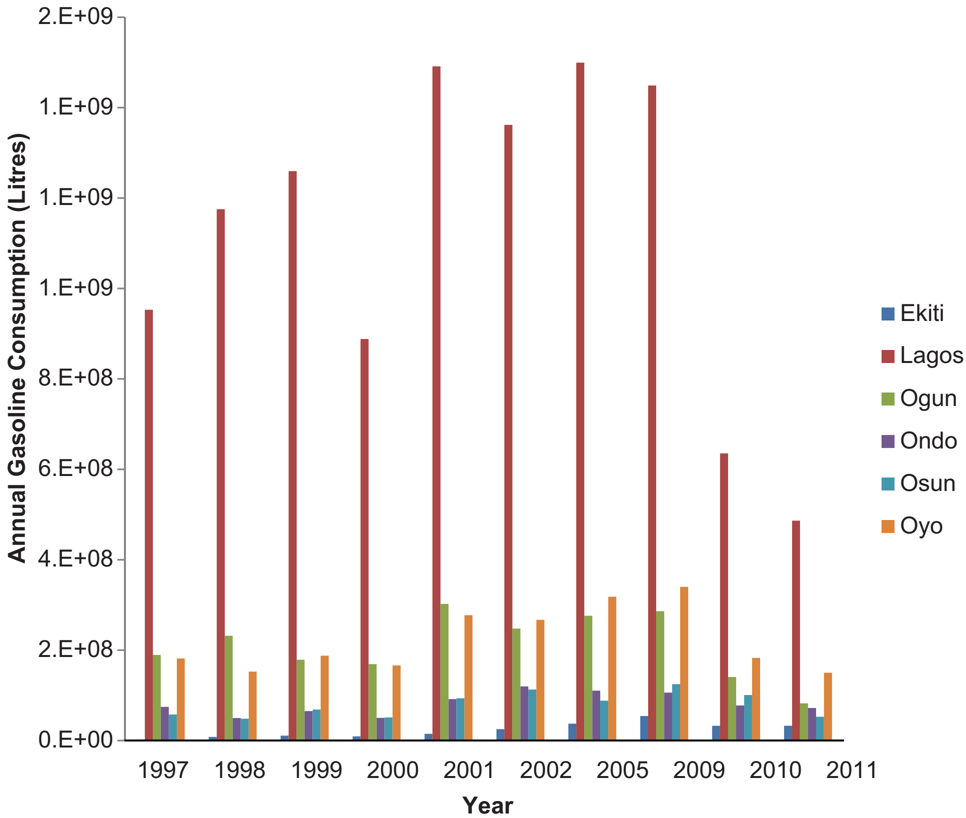

FIGURE 2 Gasoline consumption in the six states of Southwestern Nigeria for 10 selected years.

tons/km^2 and annual SO_2 emission of 190,000 tons/km^2 for Nigeria (Intergovernmental Panel on Climate Change, 2005). Obioh et al. (1994) reported the annual SO_2 emission of 85,920 tons/year for Nigeria. The contribution of SO_2 emissions from the consumption of refined petroleum products to the national and global SO_2 emission levels has been a threat over the years because of the resulting adverse environmental and health effects. It is with this view that the air emissions of SO_2 from gasoline and diesel consumption in the Southwestern states of Nigeria were investigated in this study for 10 selected years.

2. METHODOLOGY

2.1 Study Area

The six Southwestern states in Nigeria are Lagos, Ogun, Oyo, Osun, Ondo, and Ekiti. Lagos state is located between 6° 35′N and 3° 45′E. Although Lagos state is the smallest state in Nigeria, with an area of 3,671 km^2, yet it has the second highest population of 9,113,605. Osun state is an inland state with a population of 3,416,959, land area of 9,026 km^2 and located between 7° 30′N and 4° 30′E. Oyo state is located between 8° 00′N and 4° 00′E with land area of 9,026 km^2 and population of 5,580,894. Ogun state has a population of 3,751,140 with a land area of 16,400 km^2

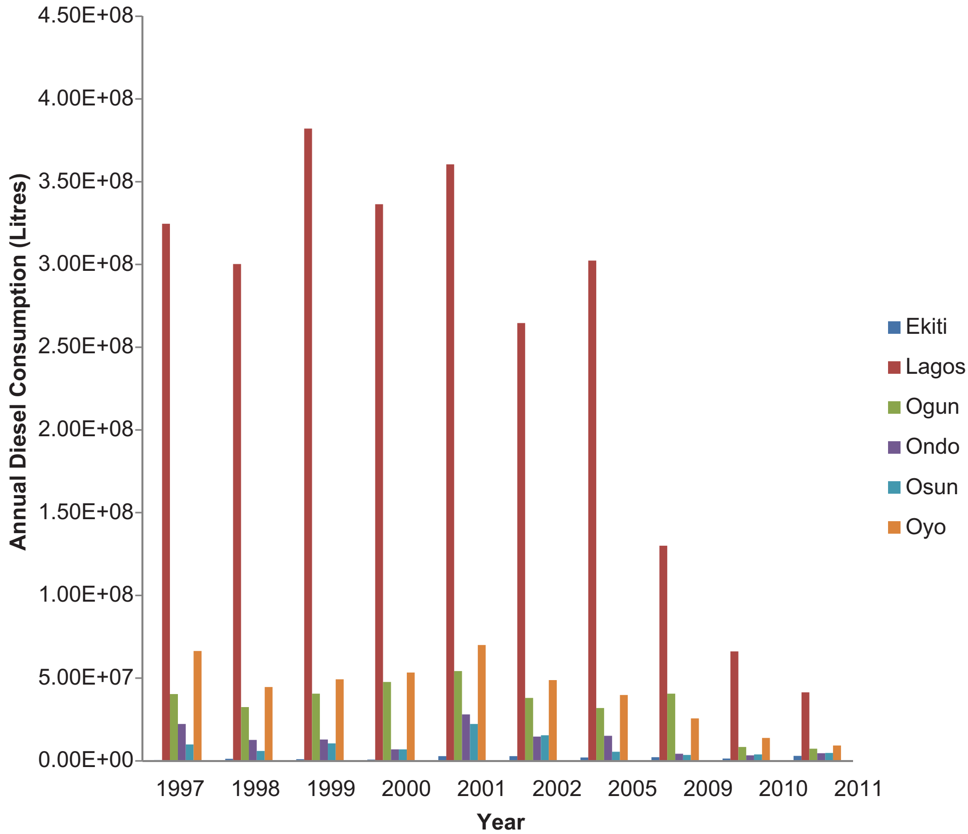

FIGURE 3 Diesel consumption in the six states of Southwestern Nigeria for 10 selected years.

located between 7° 00′N and 3° 35′E. Ondo state is located between 7° 10′N and 5° 05′E with a population of 3,460,877 and land area of 15,820 km^2. Ekiti state has land area of 5,435 km^2 with a population of 2,398,957 located between 7° 40′N and 5° 15′E (NBS, 2010). Southwestern Nigeria receives the highest percentage of 41% out of the total volume of refined petroleum products distributed across the country annually (Nigerian National Petroleum Corporation, 2011). Figure 1 shows the study areas in Nigeria.

2.2 Estimation of Sulphur Dioxide Emission

The annual SO_2 emission from consumption of refined petroleum products was estimated using a combination of annual domestic consumption of refined petroleum products data from Nigerian National Petroleum Corporation annual statistical bulletin (Figures 2 and 3) and an uncontrolled emission factor approach (National Bureau of Statistics, 2010). Table 1 shows emission factors for SO_2 in uncontrolled gasoline and diesel engines used in the study. It was generally assumed in this study that the sulphur content of the fuel was constant for the 10 selected years. The average sulphur content of gasoline and diesel from southwestern states in Nigeria is presented in Table 2. The average densities of the gasoline and diesel fuel considered in this study are 0.739 kg/L and 0.844 kg/L, respectively. The total annual emissions of sulphur dioxide from gasoline and diesel

TABLE 1
Emission Factors for SO_2 in Uncontrolled Gasoline and Diesel Engines

Fuel	Fuel Input	
	lb/MMBtu[a]	*g/L*[b]
Gasoline	0.084	1.26
Diesel	0.29	4.72

[a]Source: U.S. Environmental Protection Agency (1996). [b]Source: Calculated in the present study.

consumption in the Southwestern Nigeria were calculated by summing the annual average sulphur dioxide emissions of all its six states.

The general equation used for estimating the annual uncontrolled emissions of SO_2 from gasoline and diesel consumption is given in Eq. (1).

$$\text{Annual } SO_2 \text{ Emission} = \text{Annual fuel Consumption} * (\text{Emission Factor} * \text{Sulphur Content}) \quad (1)$$

3. RESULTS AND DISCUSSION

The results of the annual SO_2 emissions from gasoline and diesel consumed in the six Southwestern States of Nigeria and the total annual SO_2 emissions in Southwestern region are presented in Tables 3 and 4 respectively. The highest SO_2 emission of 0.928 tons/year was obtained in 2009 due to the volume of gasoline consumed in the year, while the lowest SO_2 emission of 0.045 tons/year was recorded in 1997 from Ekiti state. Annual SO_2 emission from diesel consumed in Ekiti state was at its peak in 2011 with 1.503 tons/year and was at minimal level of 0.262 tons/year in 1997.

The respective maximum and minimum annual SO_2 emissions of 26.91 tons/year and 0.734 tons/year from gasoline consumption in Lagos state were experienced in 2005 and 2011. The lowest SO_2 emission of 19.39 tons/year was recorded in 2011 while the highest SO_2 emission of 179 tons/year was obtained in 2001 from diesel consumed in Lagos state. The highest quantity of SO_2 is emitted from gasoline and diesel consumed in Lagos state when compared to other states of Southwestern Nigeria as result of the population and high rate of petroleum products consumption in the state.

In Ogun state, annual SO_2 emission from gasoline consumption was at its peak in 2001 with 3.318 tons/year and was at minimal level of 0.904 tons/year in 2011. The maximum and minimum annual SO_2 emissions of 24.77 tons/year and 3.367 tons/year from diesel consumption in Ogun state

TABLE 2
Average Sulphur Content of Gasoline and Diesel From Southwestern States in Nigeria

Gasoline Sample Location	*Average Sulphur Content, wt%*	*Diesel Sample Location*	*Average Sulphur Content, wt%*
Osun State	0.0063	Osun State	0.101
Oyo State	0.0134	Oyo State	0.090
Ogun State	0.0087	Ogun State	0.097
Lagos State	0.0142	Lagos State	0.099
Ekiti State	0.0136	Ekiti State	0.107
Ondo State	0.0076	Ondo State	0.091

TABLE 3
Total Annual Emission of Sulphur Dioxide from Gasoline Consumption in Southwestern Nigeria

	Average Emission of SO_2, tons/annum						
Year	*Ekiti*	*Lagos*	*Ogun*	*Ondo*	*Osun*	*Oyo*	*SW*
1997	0.045	17.1	2.08	0.739	0.456	2.852	23.27
1998	0.142	21.1	2.547	0.496	0.384	2.396	27.07
1999	0.186	22.61	1.964	0.647	0.542	2.95	28.9
2000	0.159	15.94	1.856	0.497	0.405	2.613	21.47
2001	0.254	26.77	3.318	0.908	0.741	4.361	36.35
2002	0.43	24.44	2.721	1.187	0.893	4.197	33.87
2005	0.642	26.91	3.033	1.094	0.697	5.001	37.38
2009	0.928	26.01	3.143	1.051	0.987	5.343	37.46
2010	0.558	11.4	1.547	0.768	0.796	2.876	17.95
2011	0.561	8.734	0.904	0.714	0.416	2.358	13.69

were obtained in 2001 and 2011, respectively. The minimum value recorded in 2011 was as result of inaccurate reported data for the annual petroleum products consumed in the year (Nigerian National Petroleum Corporation, 2011).

The highest SO_2 emission of 1.187 tons/year was obtained in 2002 while the lowest SO_2 emission of 0.496 tons/year was recorded in 1998 from Ondo state. The lowest SO_2 emission of 1.445 tons/year was recorded in 2010 while the highest SO_2 emission of 12.03 tons/year was obtained in 2001 from diesel consumed in Ondo state due to the volume of gasoline consumed in the year.

In Osun state, the quantity of SO_2 emitted from gasoline and diesel consumed reached maximum levels of 0.987 tons/year and 10.62 tons/y in 2009 and 2001, respectively, while it attained respective minimum values of 0.384 tons/year and 1.687 tons/year in 1998 and 2009, respectively.

Oyo state, which is the second highest SO_2 emitter in Southwestern Nigeria due to its high population and high rate of petroleum product consumption, released as high as 5.343 tons/year and 29.75 tons/year of SO_2 from gasoline and diesel consumed in 2009 and 2001, respectively. Also, the lowest SO_2 emissions of 2.358 tons/year and 3.946 tons/year from gasoline and diesel consumed were respectively obtained from the state in 2011.

In Tables 3 and 4, the total annual SO_2 emissions from gasoline and diesel were respectively at the peak in 2001 and 2009 and at the lowest levels in 2011. As constant sulphur content was assumed

TABLE 4
Total Annual Emission of Sulphur Dioxide from Diesel Consumption in Southwestern Nigeria

	Average Emission of SO_2, tons/annum						
Year	*Ekiti*	*Lagos*	*Ogun*	*Ondo*	*Osun*	*Oyo*	*SW*
1997	0.262	152.1	18.42	9.559	4.717	28.23	213.3
1998	0.639	140.6	14.84	5.405	2.839	18.98	183.3
1999	0.515	179	18.53	5.529	5.033	20.95	229.6
2000	0.381	157.6	21.75	2.979	3.31	22.7	208.7
2001	1.43	168.9	24.77	12.03	10.62	29.75	247.5
2002	1.43	124	17.37	6.267	7.377	20.74	177.2
2005	1.049	141.6	14.58	6.467	2.624	16.92	183.2
2009	1.114	60.89	18.53	1.825	1.689	10.9	94.95
2010	0.693	31	3.851	1.445	1.874	5.897	44.76
2011	1.503	19.39	3.367	1.963	2.28	3.946	32.45

for the selected years in this study for each of the six states in Southwestern Nigeria, several factors (e.g., population, economic boost or meltdown, and irregular power supply, which leads to increase or decrease in petroleum products consumption rate) could have affected the total SO_2 emission between 1997 and 2011.

4. CONCLUSION

In this study air emission of sulphur dioxides from gasoline and diesel consumption in the six states of Southwestern Nigeria were investigated. The contribution of sulphur dioxide emissions from gasoline and diesel consumption in the zone to her national emission levels was also established. It was generally assumed in this study that the sulphur content of the fuel was constant for the 10 selected years between 1997 and 2011. The unavailability of data for the volume of domestic petroleum products consumption was the reason for the unselected years between 1997 and 2011.

Lagos state as the highest consumer of gasoline and diesel in Southwestern Nigeria and emitted the highest quantity of SO_2 while Ekiti state had the lowest gasoline and diesel consumer and emitted the lowest quantity of SO_2 in all the selected years except in 2011 when Osun state emitted the lowest quantity of SO_2 from diesel consumed. The estimated total contribution of sulphur dioxide emissions from gasoline and diesel consumed in Southwestern Nigeria to the national airshed was found to be minimal.

The air emissions of sulphur dioxide (SO_2) and its environmental and health impacts from the consumption of refined petroleum products with nonuniformity in sulphur contents in Nigeria could be mitigated, provided there is proper and consistence investigation. The study concluded that to mitigate the air emissions of sulphur dioxide, a cleaner technology control approach should be adopted in the form of fuel modification or fuel change since sulphur dioxide emissions are proportional to the sulphur contents of the fuel, the use of low or near-zero sulphur fuel must be imposed.

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