Okedere et al., *Cogent Environmental Science* (2017), 3: 1330456
https://doi.org/10.1080/23311843.2017.1330456

cogent environmental science

ECOLOGY | RESEARCH ARTICLE

Estimation of sulphur dioxide emission from consumption of premium motor spirit and automotive gas oil in Nigeria

O.B. Okedere[1]*, J.A. Sonibare[2], O.E. Ajala[3], O.A. Adesina[4] and F. Elehinafe[2]

Received: 17 January 2017
Accepted: 13 April 2017
First Published: 17 May 2017

*Corresponding author: O.B. Okedere, Faculty of Engineering and Environmental Sciences, Osun State University, Osogbo, Nigeria
E-mail: tunjiokedere@gmail.com

Reviewing editor:
Conor Buggy, University College Dublin, Ireland

Additional information is available at the end of the article

Abstract: This paper estimated the annual levels of sulphur dioxide (SO_2) from consumption of premium motor spirit (PMS) and automotive gas oil (AGO) across the States and Regions of Nigeria. This was with a view to estimating the per capita and land distributions of emissions. Annual fuel consumption, average fuel sulphur contents and emission factors were combined to estimate the annual levels of SO_2. Per capita and land distributions of emissions were then established using population and land area, respectively. Results showed that Lagos and Ogun States had the maximum SO_2 emissions from consumption of PMS and AGO, respectively, in 2012. Between 2001 and 2014; most of the SO_2 emissions from consumption of PMS and AGO came from the South-western and South-southern regions of the country, respectively. Based on projected future fuel consumption, annual SO_2 emissions from utilization of PMS and AGO are projected to further increase over their 2014 estimates. Interim measure suggested for mitigation of SO_2 emission is the importation of refined products with highly reduced sulphur contents. Medium to long-term measures include building of more refineries locally to make use of Nigeria's crude oil which is generally low in sulphur content and a massive improvement in the country's energy generation so as to lower the demand pressure on refined petroleum products.

ABOUT THE AUTHOR

O.B. Okedere holds PhD in Chemical engineering from Obafemi Awolowo University Ile-Ife, Nigeria. He is a lecturer and researcher at Osun State University, Nigeria. His research interests are in the area of environmental pollution monitoring, modelling and control.

PUBLIC INTEREST STATEMENT

Due to insufficient local refining capacity, majority of the premium motor spirit (PMS) and automotive gas oil (AGO) consumed in Nigeria are imported. The imported PMS and AGO have been reported to have slightly higher sulphur contents than those obtained from local crudes. Following the recently reported cases of acid rain precipitations in certain parts of the country with attendant devastating impacts on vegetations and aquatic lives, the authors in this paper estimated the annual levels of sulphur dioxide owing to consumption of PMS and AGO in the country. The authors observed that SO_2 emissions into the country's air shed increased drastically between 2011 and 2014. Projected future fuel consumption data showed that by 2030, SO_2 emission from PMS and AGO consumption would have increased tremendously over their 2014 values. This is expected to further aggravate acid rain precipitation. The authors suggested some mitigation measures.

Subjects: Environment & Agriculture; Environment & Health; Environmental Change & Pollution

Keywords: PMS; AGO; sulphur; emission factor; Nigeria

1. Introduction

The demand for premium motor spirit (PMS) and automotive gas oil (AGO) in Nigeria has been on the increase and this can be attributed to a number of interconnected factors which include population increase and limited electricity generation capacity. The population of the country which was a little above 100 million in 1991 rose to over 140 million in 2006 (FRNOG, 2009). At present, it is often said to be between 170 and 180 million people considering a growth rate of 3% (FRNOG, 2009); although the last official population census in the country was still that of 2006. This growth in population has translated to greater demand for PMS and AGO which are used as energy sources for day to day business activities in the absence of reliable supply of electricity from the country's national grid. Electricity generation in the country is still very poor. The maximum reported electricity generation level in the country was only about 6,000 MW; therefore, its availability is not guaranteed. These factors put together are exerting serious pressure on the demand for PMS and AGO in the country.

In contrast to the growing demand for PMS and AGO; the country presently does not have sufficient local refining capacity to satisfy the local demand. This inability to meet local demand for PMS and AGO is largely due to lack of investment in building new petroleum refineries. There are four refineries in the country and the last one was built almost three decades ago (Odularu, 2007). Apart from insufficient refining capacity of these refineries; most of the refineries are fast becoming obsolete and are not always in operation. The inability of local refineries to meet local demand makes importation of refined petroleum products a necessity in the country. Imported refined petroleum products thus constitute a huge proportion of the refined petroleum products consumed in the Nigerian market. These imported refined petroleum products have been shown to have slightly higher sulphur contents than those of Nigerian origin (Faruq et al., 2012; Odebunmi, Ogunsakin, & Ilukhor, 2002) as summarized in Table 1. The imported refined products are constantly distributed to different States that make up Nigeria where they find their ways into different shades of combustion engine.

Among the products of combustion of sulphur containing fuels is sulphur dioxide. Sulphur dioxide is formed as an oxidation product when fuel sulphur is oxidized during combustion. It is a colourless gas with a pungent smell. It can be further oxidized to sulphur trioxide (SO_3) and dissolves in water readily forming acidic solution (ATSDR, 1998; Cofala et al., 2004). The emission of SO_2 has been known to exert various human health and environmental effects. It is one of the air pollutants considered by United States Environmental Protection as being hazardous to human health (ATSDR, 1998). Human exposure to SO_2 can be via inhalation or skin contact. When inhaled, it dissolves in the water in the nasal cavity and has been associated with damage to lungs and respiratory organs. Reported effects in animals include decreased respiration, inflammation or infection of the airways and destruction of areas of the lung (ATSDR, 1998).

Table 1. Sulphur content of refined petroleum products in Nigeria market

Sulphur in PMS (wt%)	Source	Sulphur in AGO (w%)	Source
0.041	Faruq et al. (2012)	0.160	Tijjani, Ike, Usman, Malami, and Matholo (2012)
0.081	Faruq et al. (2012)	0.101	Olatunji et al. (2015)
0.029	Faruq et al. (2012)	0.090	Olatunji et al. (2015)
0.032	Faruq et al. (2012)	0.097	Olatunji et al. (2015)
0.025	Faruq et al. (2012)	0.099	Olatunji et al. (2015)
0.03	Tijjani et al. (2012)	0.107	Olatunji et al. (2015)
		0.091	Olatunji et al. (2015)
Mean 0.040		Mean 0.11	

In the atmosphere, it readily dissolves in water vapour resulting in acid precipitation which could be detrimental to soil, soil microbes, vegetations and aquatic systems (Havens, Yan, & Keller, 1993; Savabi & Stockle, 2001). The effects on plants include sulphur and sulphur products migration between soil and the plant (Ruth-Balaganskaya & Kudrjavtseva, 2002); destruction of aesthetic and economic values of plants (Westenbarger & Frisvold, 1994).

The interest in SO_2 estimation has gained the attention of both private researchers and governments worldwide. It was reported by Obioh, Oluwole, Akeredolu, and Asubiojo (1994) that SO_2 level from all activities in the country was about 85,920 tons/year. Intergovernmental Panel on Climate Change (IPCC) in its account on SO_2 emissions from all activities, reported national (Nigeria) and global SO_2 levels in terms of land distributions as 190,000 tons/km^2 and 1,561,100 tons/km^2 reported a land distribution of 190,000 tons/km^2 for SO_2 from all activities in Nigeria (IPCC, 2005).

Among the known leading sources of SO_2 emission are pyrite ore conversion, petroleum refining and consumption of refined petroleum products. In Nigeria, the ore extractive industry is not fully developed and cannot be said to contribute to SO_2 level in any significant manner. However, there has been a rapid rise in demand for refined petroleum products in the country which calls for frequent and continuous estimation of SO_2 given the fact that it is a pollutant of great concern to human and environmental health (IPCC, 2005). Also, observation of acid rains occasioned by increasing levels of acid anhydrides including SO_2 in the country in recent years (Amadi, 2014; Efe, 2011; Efe & Mogborukor, 2012; Osu and Ekpo, 2013); necessitates the continuous study of this criteria air pollutant in relation to the activities responsible for it. The Niger Delta Region (South-South) and Lagos axis of the country have especially been reported to have experienced acid rains. The economic impacts of acid rains on vegetation, housing and aquatic life have been reported by Amadi (2014).

While some studies have been conducted on annual levels of SO_2 in some parts of the country (Obioh et al., 1994; Olatunji, Fakinle, Jimoda, Adeniran, & Adesanmi, 2015), the rapid rise in demand for refined petroleum products in the recent time calls for frequent and continuous estimation of the contribution of key activities to the annual levels of this pollutant in the entire country. It is also important to have a forecast about its future level based on projected fuel consumption. An understanding of the extent of SO_2 emission in relation to fuel consumption could assist in planning for its reduction.

Among several techniques, emission factor presents a simplified technique for estimation of pollutant emission associated with an activity and has been widely used to quantify the amount of pollutants released from an activity (Sonibare, 2010; Sonibare, Akeredolu, Obanijesu, & Adebiyi, 2007). It is a representative value that attempts to relate the quantity of pollutant that is released to the atmosphere with the activity associated with the release of that pollutant.

In the present study, estimation of annual SO_2 levels from petroleum products consumption for each State in the country was achieved with year 2012 refined petroleum products consumption data from Department of Petroleum Resources (2012). Similar computations of SO_2 level in each of the six regions were achieved with 2001–2014 refined petroleum products consumption data obtained from Nigeria National Petroleum Corporation (Nigeria National Petroleum Corporation, 2016). SO_2 trends from consumption of refined petroleum products (PMS and AGO) in the entire country were also established based on available petroleum product consumption data (Nigeria National Petroleum Corporation, 2016). Due to perceived human health and ecological impacts of SO_2 emissions, 2006 population figures (FRNOG, 2009) and land mass (Ley, Gaines, & Gaines, 2015) were used to establish the per capita and land distributions of SO_2 for each state and region of the country.

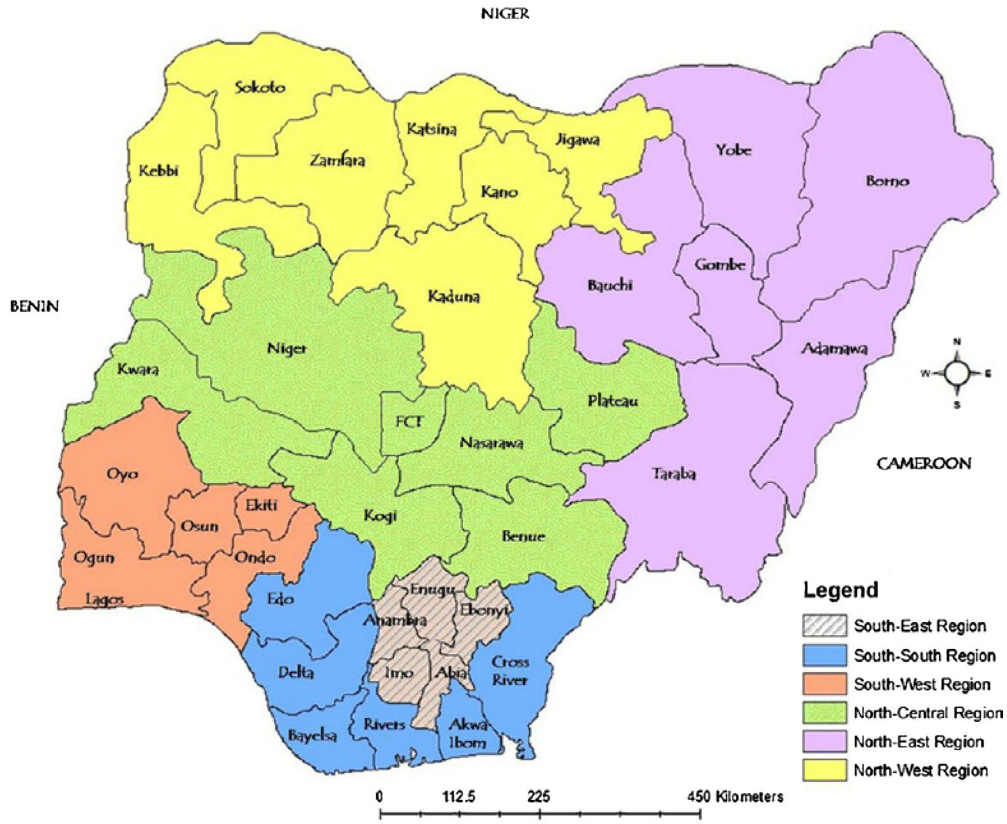


Figure 1. Map of Nigeria showing the states and the regions. Available at https://www.google.com/search?.q=map+of+nigeria+showing+the+six+geopolitical+zones&ie=utf-8&0e=utf-8&client=firefox-b.

2. Materials and Methods

2.1. Study area description

The study area is entire Nigeria which is a country in West Africa. The population of the country is about 140 million people according to 2006 population figures which was the last official head count in the country. The country has over 250 distinct ethnic nationalities occupying a total land mass of approximately 923,768 square kilometre. Nigeria lies between latitudes 4°–14°N and longitude 2°–15°E and is bounded by Niger Republic in the North and Atlantic Ocean in the South. To the west and east of Nigeria are Republic of Benin and Cameroun, respectively. There are 36 federating states in the country and the capital territory is Abuja. The federating States are further grouped into six regions popularly regarded as six geo-political zones. These include the North-West (NW), North-Central (NC), North-East (NE), South-West (SW), South-East (SE) and the South-South (SS) geo-political zones. Figure 1 shows the map of Nigeria illustrating the states and the regions.

2.2. Estimation of sulphur dioxide

Information on annual domestic consumption of refined petroleum products for 10 selected years between 2001 and 2014 were obtained from the Annual Statistical Bulletin of Nigeria National Petroleum Corporation (2016) and 2012 Annual Statistical Bulletin of the DPR (Tables 2–4). In addition, expected 2020, 2025 and 2030 PMS and AGO consumption data were obtained from Energy Commission of Nigeria (ECN, 2009). These extensive data are to allow the study of SO_2 emission patterns in the country over the past decade as well as to examine the future trends of SO_2. These data were combined with reported emission factors of SO_2 from PMS and AGO for internal combustion engines reported by Olatunji et al. (2015). Other inputs included the mean sulphur contents of PMS and AGO found in Nigeria's market (Table 1). The emission rate of SO_2 was determined as:

$$E_R = E_F \times A_{FC} \times S_F \quad (1)$$

where E_R = Emission rate (tons/year), E_F = Emission factor (ton/litre), S_F = Fuel sulphur content (wt %), A_{FC} = Annual fuel consumption (L/year).

Although, there may be variations in sulphur contents of refined petroleum products in the country from time to time because of the numerous sources from which they are imported; a particular level of sulphur content cannot be tied to a particular state or region of the country. The sulphur content of refined petroleum products found in Nigerian markets as reported in literatures were harvested, averaged (Table 1) and used in this paper to compute estimated levels of sulphur dioxide for each State, Region and the country at large. Also, the mean sulphur content was assumed to be constant for the years investigated. The population (per capita) distributions of SO_2 were obtained by dividing the estimated annual SO_2 by the population of any State or Region using the 2006 population figures (FRNOG, 2009). Similar computations for land distributions estimates were achieved by diving SO_2 levels by appropriate land mass obtained from (Ley et al., 2015).

3. Results and discussion

3.1. Annual SO_2 emission by states

Annual emission of SO_2 on state basis using year 2012 refined petroleum products consumption data (Table 2) are summarized in Table 5. SO_2 emission from PMS consumption among states in the country in year 2012 ranged between 0.2854152 and 5.715614016 ton/annum, while the corresponding SO_2 emission from AGO from the states ranged between 1.3610828 and 29.62412576 ton/annum. During that year, the minimum and maximum SO_2 emissions from consumption of PMS were from Bayelsa and Lagos States, respectively. Bayelsa State also recorded the least SO2 emission from consumption of AGO in 2012 but the maximum emission was recorded in Ogun State.

Two key factors that may be attributed to the observed emission patterns. One was the population of the State and the other was the amount of PMS and AGO consumed in a particular year which was a function of how much money people had. The consumptions of PMS in Bayelsa and Lagos States are logical considering the fact that they represent two extremes of population distribution in Nigeria. Bayelsa State had a population figure of about 1.8 million people while Lagos had above 9 million people according to 2006 population census figures. In addition, Lagos was the Federal Capital of Nigeria until 1991 when it was moved to Abuja. Nevertheless, it remains the commercial nerve centre of the country most especially because of the deep sea ports.

However, the maximum emissions of SO_2 from AGO consumption in Ogun, may appear illogical considering its population figures with respect to Lagos State. It must however be pointed out that Ogun State shares boundary with Lagos and most industrial sites in Nigeria are actually within Ogun State land area. Industrial consumption of AGO might have accounted for the maximum emission of SO_2 from AGO that was estimated for Ogun State.

3.2. Annual regional SO_2 emissions

The emission of SO_2 from PMS and AGO consumption over 10 selected years between 2001 and 2014 from the six regions are presented in Figures 2 and 3, respectively. The emission of SO_2 from PMS from the regions ranged between 10.6856568–158.14638, 16.2050112–166.3629912, 7.1559936–204.05927, 9.6083568–183.43392, 18.470653–213.28991, 9.5369415–158.63435, 8.7971164–136.95192, 9.6778609–114.14762, 51.215859–267.96726 and 60.074333–301.67334 ton/year in 2001, 2002, 2003, 3005, 2009, 2010, 2011, 2012, 2013 and 2014, respectively.

The minimum regional SO_2 emission from PMS consumption between years 2001 and 2005 was from the North-East region, while the minimum between years 2009 and 2014 were from the South-East region. Although, the population of the North-East region is huge; there are no heavy industries cogent • environmental science

Table 2. States consumption of PMS and AGO in 2012

State	Premium motor spirit (L)	Automotive gas oil (L)
Abia	63,318,740	29,685,560
Adamawa	27,527,300	14,376,500
Akwa Ibom	50,389,352	25,404,580
Anambra	53,730,620	26,145,630
Bauchi	26,526,220	14,237,624
Bayelsa	5,663,000	2,621,500
Benue	41,262,920	23,543,310
Borno	21,499,407	12,019,480
Cross River	20,533,347	9,315,740
Delta	33,200,440	18,177,447
Ebonyi	7,945,533	4,685,587
Edo	20,770,777	11,939,467
Ekiti	8,570,700	4,183,420
Enugu	32,582,656	17,768,713
Gombe	13,488,667	6,830,453
Imo	40,134,477	20,483,817
Jigawa	11,115,627	6,770,000
Kaduna	47,372,887	26,601,027
Kano	53,253,973	25,545,231
Katsina	19,566,067	10,355,787
Kebbi	23,070,033	11,894,387
Kogi	15,647,787	8,589,293
Kwara	33,790,180	18,642,527
Lagos	113,405,040	47,610,613
Nasarawa	15,390,273	8,659,427
Niger	21,921,100	12,829,360
Ogun	103,091,467	57,057,253
Ondo	28,020,513	12,980,460
Osun	38,524,880	20,108,040
Oyo	68,909,373	3,679,907
Plateau	26,491,705	13,318,794
Rivers	40,094,748	19,246,773
Sokoto	15,632,000	8,056,667
Taraba	14,405,543	8,293,741
Yobe	10,571,400	6,327,800
Zamfara	9,675,273	4,616,333

and the volume of commercial activities is low. The southeastern region on the order hand has the least population in the country and this might have accounted for the low SO_2 emission estimates recorded for the region between 2009 and 2014. For the period of 10 years investigated, however, South-West region of the country had the maximum emission of SO_2 from PMS consumption. This is not unconnected with a number of factors such as huge population, concentration of industries and high volume of commercial activities.

cogent • environmental science

Table 3. Annual national and regional consumptions of PMS in Nigeria

Location	PMS (L)									
	2001	**2002**	**2003**	**2005**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
NW	335,708,000	518,116,000	313,618,000	388,136,000	819,552,520	419,228,770	465,027,750	304,149,290	2,675,672,740	2,433,049,150
NC	993,393,000	1,298,977,000	1,100,309,000	1,685,342,000	1,263,958,300	869,471,380	781,746,670	909,890,830	1,679,284,560	1,455,407,390
NE	212,017,000	321,528,000	141,984,000	190,642,000	494,304,550	302,454,110	331,233,880	205,185,130	1,788,128,080	1,650,900,940
SW	3,137,825,000	3,300,853,000	4,048,795,000	3,639,562,000	4,231,942,590	3,147,506,980	2,717,300,080	2,264,833,670	5,316,810,650	5,985,582,050
SE	475,220,000	650,169,000	582,536,000	604,812,000	366,481,210	189,225,030	174,545,960	192,021,050	1,016,187,670	1,191,951,060
SS	1,651,386,000	2,282,149,000	2,052,408,000	1,770,637,000	1,709,092,920	1,068,698,890	881,619,520	928,193,050	2,147,835,180	3,076,045,990
FCT	337,166,000	315,803,000	486,288,000	365,133,000	620,283,460	356,932,830	336,975,670	213,262,090	1,270,552,460	1,606,540,050
National	7,142,715,000	8,687,595,000	8,725,938,000	8,644,264,000	9,505,615,550	6,353,517,990	5,688,449,530	5,017,535,110	15,894,471,340	17,399,476,630

Source: Nigeria National Petroleum Corporation (2016).

Table 4. Annual national and regional consumptions of AGO in Nigeria

Location	AGO (L)									
	2001	2002	2003	2005	2009	2010	2011	2012	2013	2014
NW	136,485,000	147,706,000	84,516,000	121,327,000	91,400,210	46,050,070	51,220,070	29,678,760	341,696,380	157,671,490
NC	337,111,000	479,601,000	356,173,000	593,341,000	115,616,750	214,975,440	237,060,000	265,834,260	139,097,690	121,368,930
NE	130,144,000	132,561,000	74,970,000	49,483,000	39,661,640	43,154,550	32,202,960	21,013,920	60,777,290	44,147,770
SW	782,818,000	530,650,000	619,015,000	413,203,000	208,414,710	144,958,110	180,919,290	43,667,510	1,414,932,420	1,749,449,620
SE	308,518,000	254,764,000	502,811,000	228,677,000	119,531,380	26,974,080	26,099,060	24,311,510	146,710,560	116,334,840
SS	773,871,000	1,057,160,000	684,828,000	905,313,000	517,584,060	379,366,490	432,089,450	282,901,730	654,568,330	981,514,290
FCT	49,491,000	43,533,000	53,398,000	56,770,000	38,235,870	23,888,810	18,300,920	9,319,970	72,974,120	48,676,790

Source: Nigeria National Petroleum Corporation (2016).

Table 5. Annual SO2, per capita and land distribution from consumption of PMS and AGO by Nigerian States in year 2012

State	SO_2 from PMS (ton/year)	SO_2 from AGO (ton/year)	Population	PMS (g/capital SO_2)	AGO (g/capital SO_2)	Land area (km^2)	PMS (g/km^2 SO_2)	AGO (g/km^2 SO_2)
Abia	3.191264496	15.41274275	2,845,380	1.121560036	5.416760767	4,900	651.2784686	3,145.457704
Adamawa	1.38737592	7.4642788	3,178,950	0.436425839	2.348032778	38,700	35.84950698	192.8754212
Akwa Ibom	2.539623341	13.19005794	3,902,051	0.650843195	3.380288452	6,900	368.0613537	1,911.602599
Anambra	2.708023248	13.5748111	4,177,828	0.648189262	3.24925083	4,865	556.6337612	2,790.300328
Bauchi	1.336921488	7.392174381	4,653,066	0.287320551	1.588667425	49,119	27.21801112	150.4952133
Bayelsa	0.2854152	1.3610828	1,704,515	0.167446576	0.798516176	9,059	31.50625897	150.2464731
Benue	2.079651168	12.22368655	4,253,641	0.488910834	2.873699626	30,800	67.52114182	396.87294
Borno	1.083570113	6.240514016	4,171,104	0.259780172	1.496130045	72,609	14.92335816	85.94683877
Cross River	1.034880689	4.836732208	2,892,988	0.357720353	1.671881186	21,787	47.49991687	222.0008357
Delta	1.673302176	9.437730482	4,112,445	0.40688743	2.294919563	17,108	97.80817021	551.6559786
Ebonyi	0.400454863	2.43275677	2,176,947	0.183952509	1.117508497	6,400	62.57107238	380.1182454
Edo	1.046847161	6.198971266	3,233,366	0.323763892	1.917188239	19,187	54.56023145	323.0818401
Ekiti	0.43196328	2.172031664	2,398,957	0.180062952	0.905406668	5,435	79.4780644	399.6378407
Enugu	1.642165862	9.22551579	3,267,837	0.502523799	2.823126058	7,534	217.9673298	1,224.517625
Gombe	0.679828817	3.546371198	2,365,040	0.287449183	1.499497344	17,100	39.75607116	207.3901285
Imo	2.022777641	10.63519779	3,927,563	0.515021055	2.707836332	5,288	382.5222467	2,011.19474
Jigawa	0.560227601	3.514984	4,361,002	0.128463046	0.806003758	23,287	24.05752569	150.9418989
Kaduna	2.387593505	13.81125322	6,113,503	0.39054426	2.259139027	42,481	56.2037971	325.1160099
Kano	2.684000239	13.26308394	9,401,288	0.285492822	1.41077307	20,280	132.3471518	653.9982217
Katsina	0.986129777	5.37672461	5,801,584	0.169975954	0.926768381	23,561	41.85432608	228.2044315
Kebbi	1.162729663	6.17556573	3,256,541	0.35704438	1.896357433	36,985	31.43787112	166.9748744
Kogi	0.788648465	4.459560926	3,314,043	0.237971705	1.345655722	27,747	28.42283724	160.7222736
Kwara	1.703025072	9.679200018	2,365,353	0.719987702	4.092074214	35,705	47.69710326	271.0880834
Lagos	5.715614016	24.71943027	9,113,605	0.627151826	2.712365773	3,671	1,556.963774	6,733.704786
Nasarawa	0.775669759	4.495974498	1,869,377	0.4149349	2.405065698	28,735	26.99390149	156.4633547
Niger	1.10482344	6.661003712	3,954,772	0.279364636	1.684295254	76,469	14.44799121	87.10724231

(*Continued*)

Table 5. (*Continued*)

State	SO_2 from PMS (ton/year)	SO_2 from AGO (ton/year)	Population	PMS (g/capital SO_2)	AGO (g/capital SO_2)	Land area (km^2)	PMS (g/km^2 SO_2)	AGO (g/km^2 SO_2)
Ogun	5.195809937	29.62412576	3,751,140	1.385128237	7.897366069	16,400	316.8176791	1,806.349132
Ondo	1.412233855	6.739454832	3,460,877	0.408056644	1.94732573	15,820	89.26889097	426.0085229
Osun	1.941653952	10.44009437	3,416,959	0.568240342	3.055375955	9,026	215.1178764	1,156.668997
Oyo	3.473032399	1.910607714	5,580,899	0.622306979	0.34234766	26,500	131.0578264	72.09840432
Plateau	1.335181932	6.915117845	3,206,531	0.416394519	2.156572896	27,147	49.18340634	254.7286199
Rivers	2.020775299	9.992924542	5,198,716	0.388706615	1.922190891	10,575	191.0898628	944.9574035
Sokoto	0.7878528	4.183021506	3,702,676	0.212779298	1.129729284	27,825	28.31456604	150.3332078
Taraba	0.726039367	4.306110327	2,294,800	0.316384594	1.876464322	56,282	12.90002785	76.50954705
Yobe	0.53279856	3.28539376	2,321,339	0.229522082	1.415301152	46,609	11.43123774	70.48839838
Zamfara	0.487633759	2.396800094	3,278,873	0.148719929	0.7309829	37,931	12.85581079	63.18842355

Figure 2. Annual SO_2 emissions from consumption of PMS in the six regions of Nigeria.

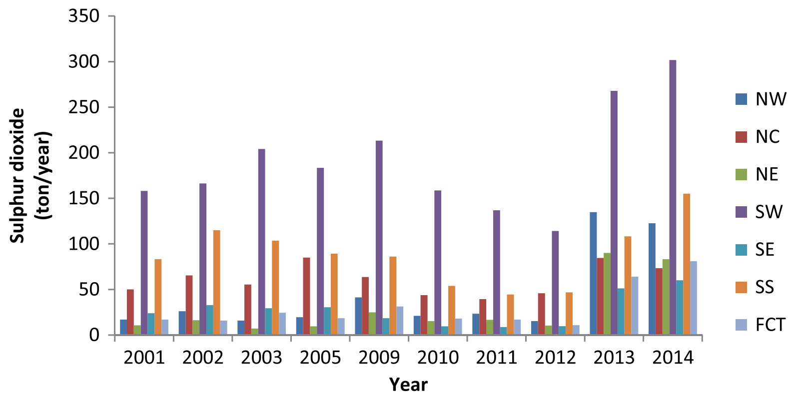
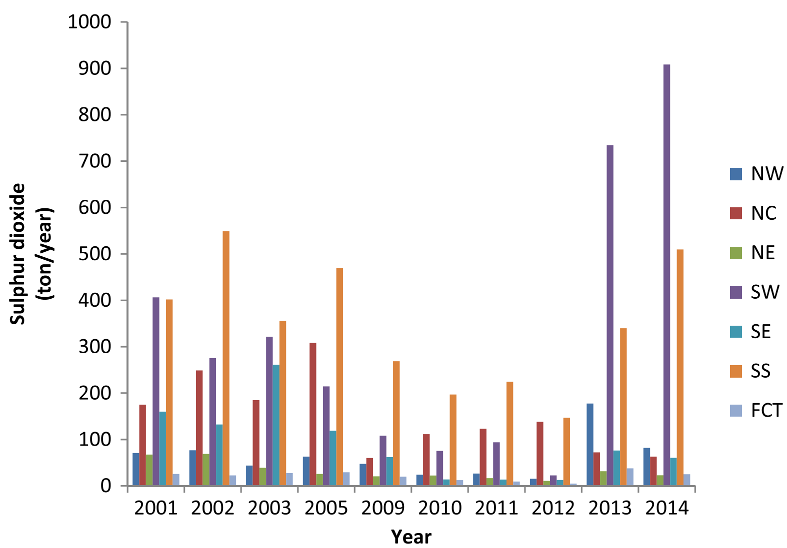


Figure 3. Annual SO_2 emissions from consumption of AGO in the six regions of Nigeria.



With the exception of years 2009 and 2010 when the minimum SO_2 emissions were from the South-East region of the country, minimum regional emissions of SO_2 over the selected 10 year period were generally from the North-East region of the country. Also, maximum SO_2 emissions were generally from the South-South region of the country with the exception of years 2013 and 2014. These observations are in agreement with the regional AGO consumptions.

3.3. Annual national SO_2 emissions

Figure 4 shows the National trend of SO_2 emissions from the two refined petroleum products investigated for 13 selected years. The portion of the graph between 2001 and 2014 represented SO_2 emission pattern over the past decade while the rest is an attempt to predict future trend of SO_2 emissions. Sulphur dioxide emissions from consumption of both PMS and AGO initially rose gradually between 2001 and 2002; however, there was a decline in emissions between 2005 and 2012. This could be attributed to decrease in the consumption of PMS and AGO occasioned by relatively stable supply of electricity from the National grid over those periods. Figure 4 also reveals that emissions of SO_2 from PMS and AGO consumptions are presently on the increase. SO_2 emissions from PMS and AGO leaped from 252.88377 to 876.93362 ton/annum and 351.3570011 to 1,671.389809 ton/annum, respectively between 2012 and 2014.

Future trend of SO_2 emission (Figure 4) based on projected fuel consumption data (ECN, 2009), further reveals that its emission from PMS and AGO consumption will further witness an astronomical increase. Although, the present work did not include actual field measurements of SO_2; there are,

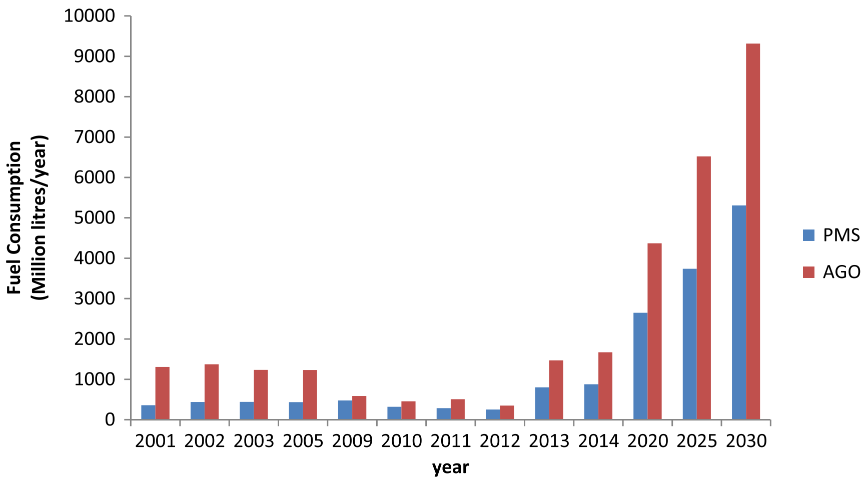


Figure 4. Past trend and future projection of SO_2 emissions from PMS and AGO consumption for Nigeria.

however, evidences that emission of acid anhydrides including SO_2 are on the increase in the country. It is a well-established fact that acid rains are traceable to elevated levels of SO_2 and other acid anhydrides in air. Measurements of acid rains occasioned by increasing levels of acid anhydrides in the country's airshed have been reported (Amadi, 2014; Efe, 2011; Efe & Mogborukor, 2012; Osu and Ekpo, 2013). The Niger Delta Region (South-South) and Lagos-Ogun axes of the country have especially been reported to have experienced acid rains. The economic impacts of acid rains on vegetation, housing and aquatic life have been reported by Amadi (2014).

3.4. Per capita and land emission distributions

The per capita distribution is a measure of the amount of pollutant per person in a given population while land distribution is a measure of pollutant per square kilometre of land. These two parameters were evaluated in order to further compare the impacts of pollutants among states and regions of Nigeria. The year 2012 per capita and land distributions of SO_2 from consumption of PMS and AGO from the States are already presented in Table 5. The regional and national population distributions of SO_2 from PMS and AGO are summarized in Tables 6 and 7 while their corresponding land distributions are summarized in Tables 8 and 9.

Table 6. Per capita distribution of SO_2 from PMS across the regions and FCT

Region	Population	Sulphur dioxide (g/capita)					
		2009	2010	2011	2012	2013	2014
NW	35,915,467	1.1500741	0.5883017	0.6525712	0.4268112	3.7547585	3.414286
NC	18,963,717	3.3592306	2.3108	2.0776535	2.4182231	4.463046	3.8680461
NE	18,509,061	1.3459867	0.8235797	0.9019468	0.5587172	4.869056	4.4953878
SW	27,722,432	7.6937661	5.7222379	4.9401122	4.1175182	9.6660804	10.881922
SE	16,395,555	1.1265647	0.5816785	0.536555	0.5902735	3.1237649	3.6640622
SS	21,044,081	4.0932309	2.5595047	2.1114547	2.222997	5.1440067	7.3670462
FCT	1,406,239	22.231133	12.792573	12.077302	7.6433731	45.536956	57.578846

Table 7. Per capita distribution of SO_2 from AGO across the regions and FCT

	Population	Sulphur dioxide (g/capita)					
		2009	2010	2011	2012	2013	2014
NW	35,915,467	1.3212967	0.6657075	0.7404459	0.4290411	4.93962	2.2793254
NC	18,963,717	3.1654246	5.8857263	6.4903706	7.2781696	3.8082999	3.3229112
NE	18,509,061	1.1125537	1.2105337	0.9033293	0.5894641	1.7048714	1.2383947
SW	27,722,432	3.9032981	2.7148502	3.3883497	0.8178276	26.499584	32.764594
SE	16,395,555	3.7852145	0.8541914	0.8264821	0.7698755	4.6459008	3.6839893
SS	21,044,081	12.769845	9.3597379	10.66052	6.9797573	16.149523	24.215941
FCT	1,406,239	14.117134	8.82003	6.7569152	3.4410427	26.942905	17.972044

The per capita distributions of SO_2 from PMS and AGO consumption among the States (Table 5) for year 2012 ranged between 0.128463046–1.385128237 g/capita and 0.34234766–7.897366069 g/capita, respectively with Jigawa and Oyo States having the least per capita emissions. In both cases, Ogun State had the maximum value of per capita emissions in year 2012. The corresponding land distributions of SO_2 from PMS and AGO for the same year ranged between 11.43123774–1,556.963774 g/km^2 and 63.18842355–6,733.704786 g/km^2, respectively. The minimum land distributions of emissions were from Yobe and Zamfara States while maximum land distributions were from Lagos State.

The last official census figures in Nigeria were those of 2006; hence, per capita emissions from the regions were calculated only for years 2009 to 2014. Regional per capita emissions of SO_2 from PMS (Table 6) ranged between 1.1265647–7.6937661, 0.5816785–5.7222379, 0.536555–4.9401122, 0.4268112–4.1175182, 3.1237649–9.6660804 and 3.414286–10.881922 g/capita in years 2009, 2010, 2011, 2012, 2013 and 2014, respectively. Except for 2012 and 2014 when the minimum per capita emissions of SO_2 from PMS were from the North-West region, the South-East region generally has the minimum per capita emissions during the rest of the years. The maximum per capita emissions however were from the South-West region of the country for all the years.

The corresponding per capita emissions of SO_2 from AGO (Table 7) during the same periods ranged between 1.1125537–12.769845, 0.6657075–9.3597379, 0.7404459–10.66052, 0.4290411–7.2781696, 1.7048714–26.499584 and 1.2383947–32.764594 g/capita. The minimum per capita SO_2 from consumption of AGO alternated between the North-West and the North-East while maximum emissions were from the South-South region until 2013 when the trend shifted to the South-West.

Results (Tables 8 and 9) showed that the minimum land distributions of SO_2 (25.518933 and 38.907589 g/km^2) from consumptions of PMS and AGO between 2001 and 2014 were experienced in 2003 and 2012, respectively; and these were from the North-East region of the country. The implication of this is that there is a skew distribution of SO_2 emission in the country. The Southern part of the country with least land area and lesser population is experiencing more SO_2 emission than the Northern region.

Table 8. Land distributions of sulphur dioxide from PMS across the six regions of Nigeria and FCT during selected 10 years

Region	Land area (km^2)	Sulphur dioxide (g/km^2)									
		2001	2002	2003	2005	2009	2010	2011	2012	2013	2014
NW	211,810	79.881418	123.28524	74.625123	92.356614	195.01179	99.755111	110.65294	72.372051	636.67393	578.94187
NC	234,210	213.76972	279.5288	236.77714	362.67126	271.99308	187.10285	168.22523	195.80077	361.36775	313.19129
NE	280,419	38.106037	57.788564	25.518933	34.264286	88.841873	54.360393	59.533012	36.878138	321.38213	296.71815
SW	76,852	2,057.8044	2,164.7191	2,655.2239	2,386.8465	2,775.3332	2,064.1539	1,782.0216	1,485.2914	3,486.7961	3,925.3804
SE	28,987	826.26998	1,130.4556	1,012.8614	1,051.5929	637.20471	329.00754	303.48489	333.86901	1,766.8561	2,072.4578
SS	76,852	1,082.9888	1,496.6469	1,345.9814	1,161.1943	1,120.8333	700.85911	578.17134	608.71454	1,408.5631	2,017.2893
FCT	7,607	2,233.8854	2,092.3454	3,221.8897	2,419.1801	4,109.6735	2,364.8501	2,232.6244	1,412.963	8,418.0155	10644.093

https://doi.org/10.1080/23311843.2017.1330456

Table 9. Land distributions of SO_2 from AGO across the six regions and FCT

Region	Land area (km^2)	Sulphur dioxide (g/km^2)									
		2001	2002	2003	2005	2009	2010	2011	2012	2013	2014
NW	211,810	334.55933	362.06485	207.17014	297.40323	224.04508	112.88039	125.55337	72.750164	837.58444	386.49279
NC	234,210	747.31237	1,063.1862	789.56928	1,315.3266	256.30083	476.56056	525.51792	589.3051	308.3537	269.05234
NE	280,419	240.96358	245.43869	138.80808	91.618519	73.434124	79.901299	59.624265	38.907589	112.53007	81.740261
SW	76,852	5,288.595	3,584.9878	4,181.9678	2,791.5343	1,408.0169	979.31415	1,222.2622	295.01082	9,559.0604	11819.006
SE	28,987	5,526.0132	4,563.1997	9,006.0879	4,095.943	2,140.9836	483.14563	467.47273	435.45507	2,627.8029	2,083.7289
SS	76,852	5,228.1505	7,142.0063	4,626.59	6,116.1519	3,496.7163	2,562.9402	2,919.1282	1,911.2395	4,422.1605	6,630.9559
FCT	7,607	3,377.9055	2,971.2546	3,644.5697	3,874.7185	2,609.71	1,630.4812	1,249.0913	636.11521	4,980.6971	3,322.3333

4. Conclusion

The emissions of sulphur dioxide from consumption of PMS and AGO between 2001 and 2014 in states and regions of Nigeria were investigated using emission factor approach. The per capita and land distributions of emitted SO_2 were established because of the human health and ecological impacts of the air pollutant. Results from 2012 consumption data of PMS showed that, Bayelsa contributed the least annual amount of SO_2 among States. Lagos and Ogun States had the maximum amount of SO_2 from PMS and AGO consumption in year 2012, respectively.

The maximum regional SO_2 emissions from PMS consumption between 2001 and 2014 were generally from the South-West region of the country with its peak value in 2014. Although, the maximum SO_2 emissions from AGO consumption came from the South-South region of the country for majority of the years investigated, its peak value recorded in 2014 was still from the South-West region of the country. Among the states, Ogun had the largest per capita SO_2 for year 2012. The per capita distributions also pointed to South-West as the region where the impacts of SO_2 from PMS consumption were felt the most. The national trend of emission revealed that SO_2 emission was its minimum in 2012, but there has been a rapid rise since then.

Based on expected future consumption of PMS and AGO in the country, SO_2 emission is expected to further experience increase. Suggested mitigation measures for the impacts of SO_2 emissions in the interim include importation of refined products that have highly reduced sulphur contents. Medium to long-term measures include building of more refineries locally to make use of Nigeria's crude oil which is generally low in sulphur content and improvement in the country's energy generation so as to lower the demand pressure on refined petroleum products.

Funding
The authors received no direct funding for this research.

Author details
O.B. Okedere[1]
E-mail: tunjiokedere@gmail.com
J.A. Sonibare[2]
E-mail: asonibar@yahoo.com
O.E. Ajala[3]
E-mail: ajala.oe@unilorin.edu.ng
O.A. Adesina[4]
E-mail: adesinaolusola50@yahoo.com
F. Elehinafe[2]
E-mail: elehinafe79@yahoo.com
[1] Faculty of Engineering and Environmental Sciences, Osun State University, Osogbo, Nigeria.
[2] Department of Chemical Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria.
[3] Department of Chemical Engineering, University of Ilorin, Ilorin, Nigeria.
[4] Department of Chemical and Petroleum Engineering, Afebabalola University, Ado-Ekiti, Nigeria.

Citation information
Cite this article as: Estimation of sulphur dioxide emission from consumption of premium motor spirit and automotive gas oil in Nigeria, O.B. Okedere, J.A. Sonibare, O.E. Ajala, O.A. Adesina & F. Elehinafe, *Cogent Environmental Science* (2017), 3: 1330456.

References

Amadi, A. N. (2014). Impact of gas-flaring on the quality of rain water, groundwater and surface water in parts of Eastern Niger Delta, Nigeria. *Journal of Geosciences and Geomatics, 2*, 114–119.

ATSDR. (1998). *Public health statement for sulphur dioxide*. Retrieved July 2016, from www.atsdr.cdc.gov/phs/phs.asp?id=25i&tid=46

Cofala, J., Amann, M., Gyarfas, F., Schoepp, W., Boudri, J. C., Hordijk, L., … Gupta, S. (2004). Cost-effective control of SO_2 emissions in Asia. *Journal of Environmental Management, 72*, 149–161. https://doi.org/10.1016/j.jenvman.2004.04.009

Department of Petroleum Resources. (2012). *Nigerian oil industry statistical bulletin*. Lagos: Department of Petroleum Resources, Ministry of Petroleum Resources.

Energy Commission of Nigeria. (2009). *Energy options for climate change mitigations in Nigeria 2009–2035* (Report No. ECN/EPA/09). Abuja: Federal Ministry of Energy, Federal Republic of Nigeria.

Efe, S. I. (2011). Spatial variation of acid rain and its ecological effect in Nigeria. In *Proceedings of the Environmental Management Conference, Federal University of Agriculture, Abeokuta, Nigeria* (pp. 381–396). Retrieved October 3, 2016, from http://www.unaab.edu.ng

Efe, S. I., & Mogborukor, J. O. A. (2012). Acid rain in Niger Delta Region: Implication on water resources quality and crisis. *An International Journal of Science and Technology, 1*, 17–46. Retrieved October 3, 2016, from www.afrrevjo.net/afrrevstech

Faruq, U. Z., Runde, M., Danshehu, B. G., Yahaya, H. N., Zuru, A. A., & Muhammad, A. B. (2012). Comparative studies of gasoline samples used in Nigeria. *Nigeria Journal of Basic and Applied Science, 20*, 87–92.

FRNOG. (2009, February). Legal notice on publication of 2006 census final results. *Federal Republic of Nigeria Official Gazette, 96*, B1–42.

Havens, K. E., Yan, N. D., & Keller, W. (1993). Lake acidification: Effects on crustacean zooplankton populations. *Environmental Science and Technology, 27*, 1621–1624. https://doi.org/10.1021/es00045a019

Intergovernmental Panel on Climate Change. (2005). *SO_2 emission per populated area by country* (Special Report on Emission Scenarios). Retrieved November 2016, from https://www.nationmaster.com/country-info/stat/Environment/SO2-emissions-per-populatedarea

Ley, K., Gaines, J., & Gaines, A. (2015, June). *The Nigerian energy sector—An overview with special emphasis on renewable energy, energy efficiency and rural electrification* (2nd ed.). Bad Homburg: GOPA – International Energy Consultant.
Nigeria National Petroleum Corporation. (2016). *Annual statistical bulletin*. Abuja: Nigeria National Petroleum Corporation. Retrieved August, from www.nnpcgroup.com/PublicRelations/monthlyPerformance.aspx
Obioh, I. B., Oluwole, A. F., Akeredolu, F. A., & Asubiojo, O. I. (1994). *National inventory of air pollutants in Nigeria emissions for 1988*. Benin City: Ilupeju Press.
Odebunmi, E. O., Ogunsakin, E. A., & Ilukhor, P. E. P. (2002). Characterization of crude oils and petroleum products: (I) Elution liquid chromatographic separation and gas chromatographic analysis of crude oils and petroleum products. *Bulletin of Chemical Society of Ethiopia, 16*, 115–132.
Odularu, G. O. (2007). Crude oil and the Nigeria economic performance. *Oil and Gas Business*, 1–29. Retrieved July 2016, from http://www.ogbus.ru/eng/
Olatunji, S. O., Fakinle, B. S., Jimoda, L. A., Adeniran, J. A., & Adesanmi, A. J. (2015). Air emissions of sulphur dioxide from gasoline and diesel consumption in the southwestern states of Nigeria. *Petroleum Science and Technology, 33*, 678–685. https://doi.org/10.1080/10916466.2014.1002929
Osu, O. R., & Ekpo, M. O. (2013). Acid rain and environmental problems: Implications for the teaching of biology in schools in riverine communities. *Academic Journal of Interdisciplinary Studies, 2*, 101–108.
Ruth-Balaganskaya, E., & Kudrjavtseva, O. (2002). Sulphur migration in the soil–Plant system contaminated by deposits from nickel industry: A field manipulation. *Environmental Pollution, 117*, 287–293. https://doi.org/10.1016/S0269-7491(01)00194-4
Savabi, M. R., & Stockle, C. O. (2001). Modeling possible impact of increased CO_2 and water temperature on water balance, crop yield and soil erosion. *Environmental Modelling & Software, 16*, 631–640. https://doi.org/10.1016/S1364-8152(01)00038-X
Sonibare, J. A., Akeredolu, F. A., Obanijesu, E. O. O., & Adebiyi, F. M. (2007). Contribution of volatile organic compound to Nigeria's airshed by petroleum refineries. *Petroleum Science and Technology, 25*, 503–516. https://doi.org/10.1080/10916460500295397
Sonibare, J. A. (2010). Air pollution implications of Nigeria's present strategy on improved electricity generation. *Energy Policy, 38*, 5783–5789. https://doi.org/10.1016/j.enpol.2010.05.029
Tijjani, N., Ike, P. O., Usman, B. B., Malami, D. I., & Matholo, A. (2012). Trace elemental analysis of Nigeria petroleum products using AAS method. *International Journal of Scientific and Engineering Research, 3*(2), 1–5.
Westenbarger, D. A., & Frisvold, G. B. (1994). Agricultural exposure to ozone and acid precipitation. *Atmospheric Environment, 28*, 2895–2907. https://doi.org/10.1016/1352-2310(94)90338-7