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

Abstract: This paper estimated the annual levels of sulphur dioxide (SO₂) 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 SO₂. 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 SO₂ emissions from consumption of PMS and AGO, respectively, in 2012. Between 2001 and 2014; most of the SO₂ 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 SO₂ emissions from utilization of PMS and AGO are projected to further increase over their 2014 estimates. Interim measure suggested for mitigation of SO₂ 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.
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 (SO₃) and dissolves in water readily forming acidic solution (ATSDR, 1998; Cofala et al., 2004). The emission of SO₂ 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 SO₂ 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)                |
| 0.03                 | Tijjani et al. (2012)                            | 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, vegetation 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 (FRNOD, 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.
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 SO₂ emission patterns in the country over the past decade as well as to examine the future trends of SO₂. These data were combined with reported emission factors of SO₂ 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 SO₂ was determined as:
where $E_R = \text{Emission rate (tons/year)}$, $E_F = \text{Emission factor (ton/litre)}$, $S_F = \text{Fuel sulphur content (wt %)}$, $A_{FC} = \text{Annual fuel consumption (L/year)}$.

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 SO$_2$ 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, 2005, 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
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.

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

| Location | 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| 6,353,157,990| 5,688,449,530| 5,017,535,110| 15,894,471,340| 17,399,476,630|

Source: Nigeria National Petroleum Corporation (2016).
| 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      | SO2 from PMS (ton/year) | SO2 from AGO (ton/year) | Population PMS (g/capital SO2) | AGO (g/capital SO2) | Land area (km²) PMS (g/km² SO2) | AGO (g/km² SO2) | PMS (g/km² SO2) | AGO (g/km² SO2) |
|------------|-------------------------|-------------------------|---------------------------------|--------------------|---------------------------------|-----------------|----------------|----------------|
| Abia       | 3.191264496             | 15.41274275             | 2,845,380                       | 1.121560036        | 4,900                           | 651.2784686     | 3,145.457704     |
| Adamawa    | 1.38737592              | 7.4642788               | 3,178,950                       | 0.43642583         | 38,700                          | 35.84950698     | 192.8754212      |
| Akwa Ibom  | 2.539623341             | 13.19005794             | 3,902,051                       | 0.650843195        | 6,900                           | 368.0613537     | 1,911.602599     |
| Anambra    | 2.708023248             | 13.574813               | 4,177,828                       | 0.64818926         | 4,865                           | 556.6137612     | 2,790.300328     |
| Bauchi     | 1.336921488             | 7.392174381             | 4,653,066                       | 0.287320551        | 49,119                          | 27.21801112     | 150.4952133      |
| Bayelsa    | 0.2854152               | 1.3610828               | 1,704,515                       | 0.167446576        | 9,059                           | 31.50625897     | 150.2464711      |
| Benue      | 2.079651168             | 12.22368655             | 4,253,641                       | 0.488910834        | 30,800                          | 67.5214182      | 396.87294        |
| Borno      | 1.083570113             | 6.240514016             | 4,417,104                       | 0.259780172        | 72,609                          | 14.92335816     | 85.94681877      |
| Cross River| 1.034880689             | 4.836732208             | 2,892,957                       | 0.180062952        | 21,787                          | 47.49991687     | 222.0008357      |
| Delta      | 1.673302176             | 9.437730482             | 4,112,445                       | 0.40688743         | 17,108                          | 97.80817021     | 551.6559786      |
| Ebonyi     | 0.400454863             | 2.43275677              | 2,176,947                       | 0.183952509        | 6,400                           | 62.57107238     | 380.1182454      |
| Edo        | 1.064871616             | 6.198971266             | 3,323,366                       | 0.32376892         | 19,187                          | 54.56023145     | 323.0818401      |
| Ekiti      | 0.43196328              | 2.172031164             | 2,398,957                       | 0.180062952        | 5,435                           | 79.4780644      | 399.6378407      |
| Enugu      | 1.642165862             | 9.22551579              | 3,267,837                       | 0.502523799        | 7,534                           | 217.9673298     | 1,224.517625     |
| Ewebe      | 0.679828817             | 3.54671918             | 2,365,040                       | 0.287449183        | 17,100                          | 39.7500716      | 207.3901285      |
| Imo        | 2.022777641             | 10.63519779             | 3,927,563                       | 0.515021055        | 5,288                           | 382.522467      | 2,011.19474      |
| Jigawa     | 0.560227601             | 3.514984               | 4,361,002                       | 0.128463046        | 23,287                          | 24.05765739     | 150.9418989      |
| Kaduna     | 2.387539150             | 13.81125322             | 6,113,503                       | 0.39054426         | 42,481                          | 56.2037971      | 325.1160099      |
| Kano       | 2.684000239             | 13.26308398             | 9,401,288                       | 0.285492822        | 20,280                          | 132.3471588     | 653.998217       |
| Katsina    | 0.986129777             | 5.37672461             | 5,801,584                       | 0.169975954        | 23,561                          | 41.85432608     | 228.2044315      |
| Kebbi      | 1.162729663             | 6.17556573             | 3,256,541                       | 0.35704438         | 36,985                          | 31.4378112      | 166.974844       |
| Kogi       | 0.78864865              | 4.459560926             | 3,314,043                       | 0.237971705        | 27,747                          | 28.42283724     | 160.7222736      |
| Kwara      | 1.703052072             | 9.679200018             | 2,365,353                       | 0.719887702        | 35,705                          | 47.69710326     | 271.0880834      |
| Lagos      | 5.715614016             | 24.71943027             | 9,113,605                       | 0.627151826        | 3,671                           | 1,556.963774     | 6,733.704786     |
| Nasarawa   | 0.775669759             | 4.495974498             | 1,869,377                       | 0.4149349          | 28,735                          | 26.99390149     | 156.4633547      |
| Niger      | 1.10482344              | 6.661003712             | 3,954,772                       | 0.279364636        | 76,469                          | 14.44799121     | 87.1072431      |

(Continued)
| State   | SO₂ from PMS (ton/year) | SO₂ from AGO (ton/year) | Population | PMS (g/capital SO₂) | AGO (g/capital SO₂) | Land area (km²) | PMS (g/km² SO₂) | AGO (g/km² SO₂) |
|---------|-------------------------|-------------------------|------------|---------------------|---------------------|------------------|----------------|----------------|
| 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           | 89.26859097    | 426.0085229     |
| Osun    | 1.941653952             | 10.44009437             | 3,416,959  | 0.568240342         | 3.05375955         | 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    | 150.332078      |
| Taraba  | 0.726039367             | 4.306110327             | 2,294,800  | 0.316384594         | 1.876464322        | 56,282           | 12.90002785    | 76.50954075     |
| Yobe    | 0.53279856              | 3.285339376             | 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     |

Table 5. (Continued)
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,
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     |
The per capita distributions of SO\textsubscript{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\textsubscript{2} from PMS and AGO for the same year ranged between 11.43123774–1,556.963774 g/km\textsuperscript{2} and 63.18842355–6,733.704786 g/km\textsuperscript{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\textsubscript{2} from PMS (Table 6) ranged between 1.1265647–7.6937661, 0.5816785–7.897366069 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\textsubscript{2} from PMS and AGO for the same year ranged between 11.43123774–1,556.963774 g/km\textsuperscript{2} and 63.18842355–6,733.704786 g/km\textsuperscript{2}, respectively. The minimum land distributions of emissions were from Yobe and Zamfara States while maximum land distributions were from Lagos State.

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The corresponding per capita emissions of SO\textsubscript{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\textsubscript{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\textsubscript{2} (25.518933 and 38.907589 g/km\textsuperscript{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\textsubscript{2} emission in the country. The Southern part of the country with least land area and lesser population is experiencing more SO\textsubscript{2} emission than the Northern region.

Table 7. Per capita distribution of SO\textsubscript{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 | 26.215941 |
| FCT        | 1,406,239  | 14.117134 | 8.82003 | 6.7569152 | 3.4410427 | 26.942905 | 17.972044 |
Table 8. Land distributions of sulphur dioxide from PMS across the six regions of Nigeria and FCT during selected 10 years

| Region | Land area (km²) | 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        | 38.116037 | 57.788564 | 25.518933 | 34.264286 | 88.841873 | 54.360393 | 59.533012 | 36.878138 | 321.38213 | 296.71815 |
| SW     | 76,852         | 2.0578044 | 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 | 1064.093 |
## 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     | 589.03051     | 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     | 43.545507     | 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 SO2 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 SO2 among States. Lagos and Ogun States had the maximum amount of SO2 from PMS and AGO consumption in year 2012, respectively.

The maximum regional SO2 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 SO2 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 SO2 for year 2012. The per capita distributions also pointed to South-West as the region where the impacts of SO2 from PMS consumption were felt the most. The national trend of emission revealed that SO2 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, SO2 emission is expected to further experience increase. Suggested mitigation measures for the impacts of SO2 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.

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