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Air quality impact of diesel back-up generators (BUGs) in Nigeria's mobile telecommunication base transceiver stations (BTS)

Air quality
impact of
diesel BUGs

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Abstract

Purpose – The introduction of mobile telecommunication services in Nigeria led to the development of base transceiver stations (BTS) across the country. Inadequate power supply from the national grid has led to massive use of diesel-fueled back-up generators (BUGs). The purpose of this paper is to attempt to quantify and inform relevant stakeholders about air quality implications of BTS BUGs.

Design/methodology/approach – Seven major telecommunication network operators were identified. Emission factor approach was used to estimate the quantity of important air pollutants such as NO_x, CO, SO₂, PM₁₀, PM_{2.5}, PAH and TVOC that are emitted from the use of the BUGs based on fuel consumption rate and generators' capacity. Fuel-based emission inventory and emission factor from the United States Environmental Protection Agency AP-42 and National Pollution Inventory were used to estimate pollutants emission from diesel-powered generators used in the BTS sites and amount of diesel consumed. Land distribution and per capita dose of the estimated pollutants load were calculated.

Findings – The study showed that the deployment of BUGs will lead to increase emissions of these air pollutants. The states that are most affected are Lagos, Kano and Oyo, Katsina and Akwa Ibom states with respective total air pollutants contribution of 9,539.61, 9,445.34, 8,276.46, 7,805.14 and 7,220.70 tonnes/yr.

Originality/value – This study has estimated pollutant emissions from the use of diesel-fueled BUGs in mobile telecommunications BTS sites in Nigeria. The data obtained could assist in policy making.

Keywords Emission, Air pollutants, Back-up generator, Base transceiver station, Diesel fuelled

Paper type Research paper

1. Introduction

The uses of wireless communication systems have provided access to a wide range of services including easier and faster transmission of mobile voice and internet. The telecommunication industry in Nigeria witnessed a major revolution in 2001 with the introduction of the global system for mobile telecommunication (GSM) (Taiwo, 2010) as a replacement for the code division multiple access (CDMA) networks that were introduced in December 1997 by a private company, Multilinks (Shoewu *et al.*, 2011). Since then, the use of mobile phones has become a very powerful means of communication and business transaction in the country. Mobile service has had positive impact on Nigeria's economy as it had enabled greater interaction, created employment



opportunities and brought a wide variety of services to a very large proportion of the country's population (Pyramid Research, 2010).

The telecommunications industry in Nigeria has continued to receive a major boost as the number of active subscribers rose from less than 500,000 in 2001 to about 114 million by 2013 (Hassan *et al.*, 2009; NCC, 2013a, b). This increase has necessitated the building of transmission backbones to complement the GSM operation facilities. The pace of Nigeria's telecoms growth has also created an increasing demand for high-capacity transmission infrastructure that will provide necessary support for expansion. This has resulted in the building of more base transceiver stations (BTS) across the country. There are over 20,000 BTS sites in the country at present and operators will have to deploy additional 50,000 BTS sites to meet up with the quality of service (QoS) threshold of the Nigerian Communication Commission (NCC), the regulatory arm of the industry (Adebayo, 2012). The unreliability of Nigeria's grid power to provide constant and adequate electricity has been the reason why alternative sources of energy are sought through the use of back-up generators (BUGs) (Olabiyi *et al.*, 2012; Oseni, 2012; Sonibare, 2010). BUGs have been found to be as better and stable sources of power for the growing number of BTS across the country. The use of diesel generators as back-ups during power outages from grid source satisfy the required power demand for BTS stations but with the attendant air quality and noise pollution.

It has been reported that diesel BUGs contribute to both regional and local air pollution (Gilmore *et al.*, 2010; Tong and Zhang, 2015; Zhang and Zhang, 2015). Emissions from diesel generators lead to air quality deterioration and have negative effects on human health (Gilmore *et al.*, 2010). Air pollutants emitted from the use of diesel BUGs include particulate matter (PM), NO_x, CO, SO₂, and a retinue of hydrocarbons including aldehydes, 1,3-butadiene, benzene and nitro-PAHs (Akinpelu, 2011; Calvo *et al.*, 2013; Lingren *et al.*, 2011; Shah *et al.*, 2006). Some of these pollutants are known to contribute to acid rain, global warming and ozone layer depletion (Kusakana and Vermaak, 2013).

Studies have been carried out on air quality and noise around BTSs across Nigeria. Okedere and Elehinafe (2011) investigated noise levels of diesel-powered generators around some BTS sites in Lagos and Osun States, Nigeria and concluded that the average noise levels in the residential areas around the BTS stations exceeded the WHO recommended limits. Olatunji and Olatunbosun (2013) assessed the levels of airborne pollutants and noise around some BTS sites in the city of Ibadan, Southwestern Nigeria and reported that the air pollutants levels are not a threat to the environment. Globally, there have been several attempts to reduce power consumption of BTS through infrastructure sharing between operators (Diamantoulakis and Karagiannidis, 2012; Faruk *et al.*, 2012; Idachaba, 2010; Lubritto, 2010; Lubritto *et al.*, 2011). This study investigated the air quality impact of diesel-fueled BUGs in powering BTS. The results will serve as an indicator for the relevant stakeholders and operators in respect of air quality implication of deploying BUGs to BTS sites. It will also propel the need for both the operators and the relevant government agencies to ensure sustainable development in the telecommunication industry.

2. Materials and methods

Seven major telecommunication network operators were investigated in this study (Figure 1). These are Mobile Telephone Network (MTN), Globacom (Nigeria) Limited (Glo), Bharti Airtel Nigeria Limited (Airtel) and Etisalat Nigeria (EMTS) for GSM. Others are Visafone Communications Limited (Visafone), Starcomms Nigeria Limited (Starcomms) and Multilinks Telecommunications Limited (Multilinks) for CDMA. Data on the number of BTS (Table I) were obtained from the NCC (2013a). Fuel-based emission inventory and emission factor from the United States Environmental Protection Agency AP-42 (USEPA, 1995) and National Pollution Inventory (NPI, 2008) were used to estimate air pollutants emission from diesel-powered generators used in the BTS sites (Table II) and amount of diesel consumed (Kean *et al.*, 2000).

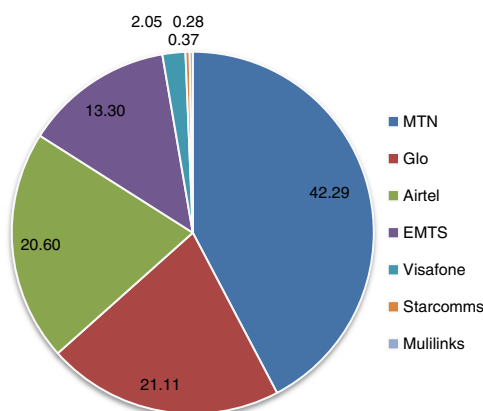


Figure 1.
Market share of
mobile telecoms
operators in Nigeria

SNo.	Operator	Number of BTS	No. of diesel BUGs	Installed generator capacity (kW)
1	MTN	7,100	8,250	88
2	Glo	6,060	6,500	88
3	Airtel	5,000	5,400	88
4	EMTS	2,100	2,150	88
5	Visafone	1,150	1,200	88
6	Starcomms	460	500	88
7	Multilinks	350	350	88

Source: NCC (2013a, b)

Table I.
Base transceiver
stations and diesel
BUGs used by
telecoms operators
in Nigeria

Pollutants	Emission factor (kg/kW-hr) (energy output)	Emission factor Kg/m ³ (fuel based)
NO _x	1.900E-02	7.200E + 01
CO	4.100E-03	1.600E + 01
SO ₂	4.300E-06	1.700E-02
PM ₁₀	1.300E-03	5.100E + 00
PM _{2.5}	1.300E-03	5.000E + 00
PAH	6.000E-11	2.400E-07
TVOC	1.400E-03	5.300E + 00

Source: USEPA (1995)

Table II.
Emission factors used
in pollutants emission
estimation

Stuver *et al.* (2015) posited that estimation is the preferred method for creating emission inventories since direct measurement of diesel engine exhaust is often cost prohibitive. Direct emission measurement of all emission sources in the air can be limited by funding, time or staff size; hence, estimation is typically used to determine the air quality impact (USEPA, 2016). AP-42 emission factor has been previously used to estimate SO₂ emission from gasoline and diesel fuel consumption in Nigeria (Olatunji *et al.*, 2015). Other inputs are the generators capacity, daily operating hours and the quantity of fuel consumed. It has been established that a heavy duty generator consumes an average of eight liters of diesel per hour and a generator is assumed to run for at least 18 hours daily (NCC, 2013a). In the worst case scenario, the generators could be operated for 300 days per annum. All diesel generators used in the BTS sites are less than

450 kW (88 kW) and the distribution of BTS in all the states across the country is presented in Table III.

To estimate individual BUG contribution to pollution emission, it was assumed that one generator is used at a time (Agyeman, 2007), and the emission estimate is based on the generator capacity of 88 kW (NCC, 2013a). Population and land size data were obtained from the Nigerian National Population Commission (NPC, 2010). Population projection for 2012 was made using the information provided for the population growth rate for each state of the federation (NPC, 2010). The land size and per capita distributions of the air pollutants were computed using the method reported in Sonibare (2010).

The emission of air pollutants was calculated using the quantity of fuel consumed as (NPI, 2008):

$$E_i = Q_f \times EF_i \times \left(\frac{100 - ER_i}{100} \right), \tag{1}$$

SNo.	State	MTN	Glo	Airtel	EMTS	State total
1	Abia	155	137	105	37	434
2	Adamawa	190	155	126	47	518
3	Akwa Ibom	270	241	188	67	766
4	Anambra	184	171	122	46	523
5	Bauchi	178	165	115	60	518
6	Bayelsa	75	80	61	21	237
7	Benue	207	185	134	52	578
8	Bornu	230	227	160	59	676
9	Cross River	162	145	109	41	457
10	Delta	225	200	149	70	644
11	Ebonyi	120	107	100	31	358
12	Edo	168	140	130	60	498
13	Ekiti	145	125	110	47	427
14	Enugu	155	135	118	39	447
15	FCT	105	80	70	70	325
16	Gombe	100	80	65	27	272
17	Imo	244	230	175	61	710
18	Jigawa	243	215	155	60	673
19	Kaduna	210	180	131	51	572
20	Kano	339	282	243	138	1,002
21	Katsina	300	267	188	73	828
22	Kebbi	189	161	126	47	523
23	Kogi	194	180	102	47	523
24	Kwara	157	134	102	37	430
25	Lagos	280	230	362	140	1,012
26	Nassarawa	120	127	80	36	363
27	Niger	225	104	154	60	543
28	Ogun	179	179	151	50	559
29	Ondo	165	132	120	45	462
30	Osun	269	200	200	71	740
31	Oyo	307	270	206	95	878
32	Plateau	155	88	95	44	382
33	Rivers	226	200	141	92	659
34	Sokoto	207	150	124	55	536
35	Taraba	144	125	97	42	408
36	Yobe	153	123	101	44	421
37	Zamfara	125	110	85	38	358
	Total	7,100	6,060	5,000	2,100	20,260

Table III.
Distribution of GSM
BTS across Nigeria

where E_i is the emission of substance i (kg/y); Q_f the activity rate (quantity of fuel combusted in the reporting period) (m^3/y); EF_i the emission factor of substance i (kg/kL) and ER_i the emission reduction efficiency for substance i (percent).

The total emission of a substance i is given by (NPI, 2008):

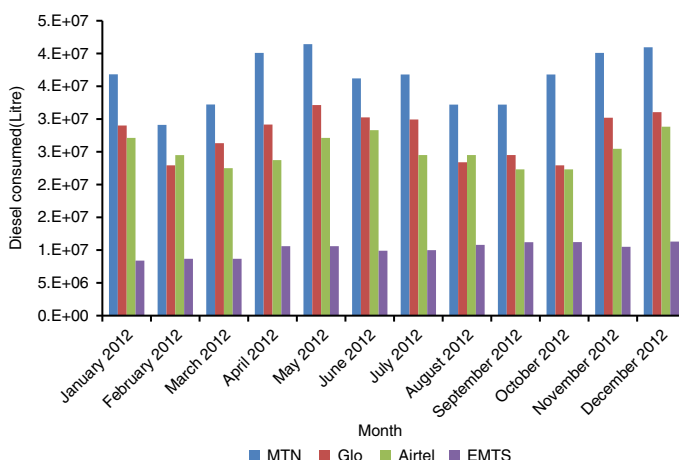
$$E_i = P \times \text{OpHrs} \times EF_i \times \left(\frac{100 - ER_i}{100} \right), \quad (2)$$

where E_i is the total emission of substance i from a stationary combustion engine for the reporting year (kg/y); P the engine power capacity rating (kW); OpHrs the operating hours of engine during the reporting year (h/y); EF_i the emission factor of substance i (kg/kWh); ER_i the emission reduction efficiency for substance i (percent) and i the substance i (CO, NO_x , SO_2 , PAH, TVOC). Power factor is assumed to be 0.8 (Olson, 2009). Emission reduction efficiency was assumed to be zero (worst case scenario).

3. Results and discussion

The emission factor methodology based on fuel consumption and generator capacities was used to estimate the air pollutants emission from diesel BUGs used in mobile telecommunication BTS. The market share of mobile telecommunication service operators in the country is shown in Figure 1 with MTN having the largest market share of about 42 percent. This is followed by Glo and Airtel with close shares of 21.10 and 20.6 percent, respectively. CDMA networks have the lowest share of between 0.27 and 2.04 percent. The distribution of BTS across the nation is shown in Table III. Total fuel consumed by the GSM BUGs is shown in Figure 2. MTN, the largest market share holder (Tables I and III, Figure 1) and the owner of the highest number of BTS and BUGs (7,100 and 8,250, respectively), is the highest consumer of diesel and largest contributor of air pollutants (Figures 2 and 3). This is followed by Glo, Airtel and Etisalat. CDMA networks are the least contributors with a total number of 1,960 BTS and 2,050 BUGs.

The number of BTS sites is proportional to the quantity of diesel consumed using the emission factor approach on fuel consumption. The calculated air pollutants from the use of BUGs at the BTS sites, based on an estimated generators' capacity of 88 kW, are presented in Tables IV and V, respectively. Table IV shows the estimated quantity of air pollutants



Source: NCC (2013b)

Figure 2.
Diesel consumption
of GSM BTS BUGs
for 2012

Figure 3.
Operators contribution
of air pollutants
from BTS BUGs

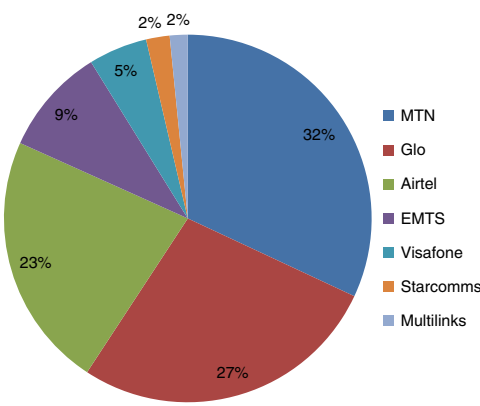


Table IV.
Calculated air
pollutants from BTS
BUGs for year 2012
based on fuel
consumption

Operator	Fuel consumption m ³ /year	NO _x	Pollutants emission (tonnes/annum)					
			CO	SO ₂	PM ₁₀	PM _{2.5}	PAH	TVOC
MTN	434,937	31,315.46	6,958.99	7.40	2,218.18	2,174.69	0.000104	2,305.17
Glo	331,832.8	23,891.96	5,309.33	5.64	1,692.35	1,659.16	7.96E-05	1,758.71
Airtel	301,194.2	21,685.98	4,819.11	5.12	1,536.09	1,505.97	7.23E-05	1,596.33
EMTS	121,851.8	8,773.33	1,949.63	2.07	621.44	609.26	2.92E-05	645.81
Visafone	60,444	4,351.97	967.10	1.03	308.26	302.22	1.45E-05	320.35
Starcomms	24,177.6	1,740.79	386.84	0.41	123.31	120.89	5.8E-06	128.14
Multilinks	18,396	1,324.51	294.34	0.31	93.82	91.98	4.42E-06	97.50
Total	1,292,833	93,084.01	20,685.33	21.98	6,593.45	6,464.17	0.00031	6,852.02

Table V.
Calculated air
pollutants from BTS
BUGs for year 2012
based BUGs estimated
capacity of 88 kW

Operator	No. of BTS	NO _x	Pollutants emission (tonnes/annum)					
			CO	SO ₂	PM ₁₀	PM _{2.5}	PAH	TVOC
MTN	7,100	77,993.79	16,830.24	17.65	5,336.42	5,336.42	2.46E-04	5,746.91
Glo	6,060	66,569.34	14,364.96	15.07	4,554.74	4,554.74	2.10E-04	4,905.11
Airtel	5,000	54,925.20	11,852.28	12.43	3,758.04	3,758.04	1.73E-04	4,047.12
EMTS	2,100	23,068.58	4,977.96	5.22	1,578.38	1,578.38	7.28E-05	1,699.79
Visafone	1,150	12,632.80	2,726.02	2.86	864.35	864.35	3.99E-05	930.84
Starcomms	460	5,053.12	1,090.41	1.14	345.74	345.74	1.60E-05	372.34
Multilinks	350	3,844.76	829.66	0.87	263.06	263.06	1.21E-05	283.30
Total	22,220	2.44E + 05	52,671.53	55.24	16,700.73	16,700.73	7.71E-04	17,985.40

emission based on diesel consumption while Table V indicates the expected air pollutants contribution based on the estimated capacity of generators.

Air pollutants emission from the GSM – operated BTS are more significant than those from the CDMA. GSM operators are in control of the market as their networks signals are strong and more consistent in the rural and urban areas of the country. The estimated emission ranges are between 46,542.00-1.22E + 05; 20,685.34-52,671.53; 21.98-55.24; 3,296.73-8,350.36; 3,232.08-8,350.36; 3.10E-04-7.71E-04 and 6,852.02-17,985.4 tonnes/year for NO_x, CO, SO₂, PM₁₀, PM_{2.5}, PAH and TVOC, respectively. Air pollutants being emitted from BUGs are products of fuel combustion. Other sources of these air pollutants include transportation sources, forest fires, cooking and industries. Sonibare and Jimoda (2009) reported that a significant proportion of electricity consumed in Nigeria is from gasoline (PMS)-fueled and

diesel (AGO)-fueled private electric generators. It was estimated that about 97 percent of firms operating in the country use BUGs (Tyler, 2002).

The country exhibits the typical tropical climate characterized with dry and wet seasons associated with the movement of the Inter-Tropical Convergence Zone north and south of the equator. When it is to the south of the equator, the north-east winds prevail producing the dry-season condition and whenever it moves into the Northern Hemisphere, the south westerly wind prevails to bring rainfall and the wet season thus giving the country both the dry and wet seasons. Air pollutants emitted from BUGs may in addition undergo photochemical reaction with free radicals in the atmosphere to form secondary organic air pollutants which could be more harmful. Microclimatic parameters such as temperature and relative humidity could have effect on the photochemical reaction (Folberth *et al.*, 2003). Variation in microclimatic parameters and seasons could have effect on the formation of the secondary products. Wind speed and directions also affect the dispersion of emitted air pollutants. Concentrations of air pollutants decrease with the lapse in time and distance away from the source in the direction of wind movement (Berret and Britter, 2009).

The air masses during the dry seasons are often laden with huge particulate matter mass while particulate pollution levels are often low during the wet season due to rain wash out. High temperatures observable during the dry seasons may enhance the formation of high concentration levels of secondary pollutants such as ozone especially in states with high human and industrial population like Lagos and Kano.

Emission of gaseous pollutants such as NO_x, CO, SO₂, PAH and TVOC may largely depend on the emission sources other than the country's climate. However, exposure period and emitted concentrations of these pollutants may be the major factors influencing their environmental impacts.

The implications of air pollution for all the states in Nigeria and the Federal Capital Territory (FCT) are presented in the supplementary figures. The states mostly affected are Lagos, Kano and Oyo, Katsina and Akwa Ibom States with respective total pollutant contribution of 9,539.61/yr, 9,445.34/yr, 8,276.46/yr, 7,805.14/yr and 7,220.70 tonnes/yr. The least polluted states are Zamfara, Ebonyi, FCT, Gombe and Bayelsa states with total contributions of 3,374.69, 3,374.69, 3,063.61, 2,564.01 and 2,234.08 tonnes/yr, respectively. It should be noted that states with the estimated high air pollutants concentrations have high population. In a bid to satisfy customers and improve QoS thresholds in these states, service providers site more BTS in these states.

The quantities of air pollutants emitted were found to be proportional to the quantity of fuel consumed (Table IV) as well as the number of BUGs operated at the BTS sites (Table V). MTN, the operator with the highest number of BTS sites and BUGs is the highest contributor of air pollutants into the atmosphere while Multilinks which has the lowest number of BTS and BUGs is the least emitting operator. The operator's contributions of air pollutants from BTS BUGs are presented in Figure 3. The air pollution contribution of the two operators from the use of BUGs is estimated to be between 32-33.64 percent for MTN and 1.42-1.58 percent for Multilinks.

Over 22,000 BTS are currently serving a population of over 150 million people and it is expected that the proposed additional 50,000 BTS sites building will be completed by 2017 (Adebayo, 2012; Ajanaku, 2013). This is an average increase of 10,000 BTS per year. The expected number of BUGs expected to power the purported increase in BTS sites is shown in Table AI. The expected increase in the air pollutants concentration levels associated with these would be in multiples of 1.45, 1.90, 2.35, 2.8 and 3.25 of the present air pollutants level for 2013, 2014, 2015, 2016 and 2017, respectively.

The present distribution of BTS across the different states of the country is characterized by uneven air pollutants emission distribution across the land (Table AII; Figures A1-A7) and per capita distribution (Table AIII). Emissions from BTS BUGs constitute a

considerable share of anthropogenic emissions of air pollutants into the Nigerian airshed. Lagos, Imo, Akwa Ibom, Anambra and Abia states are the states with the highest air pollutants per land size distribution while Taraba, Niger, Borno, Zamfara and Bauchi states have the lowest air pollutants per land distribution. Lagos state has the highest land distribution of air pollutants (g/km^2) of about 13.35 times the national average per land distribution. Taraba state has the lowest pollutant distribution with about 3.1 percent of the national level. Similarly, in terms of population distribution of air pollutants per capita, 21 states and the FCT exceeded the national level of 671.23 g/capita while the remaining 15 states had emission levels lower than the national average. Cross River State has the highest value of 1,041.99 g/capita while Kaduna State has the lowest level of 433.96 g/capita.

These results indicate that the resulting air pollutants emitted from the diesel BUGs could have a significant effect on air quality (as evident from the land distribution) and human health as shown in Table AIII. The national per capita air pollutants distribution estimate presented in this study are about 1.53, 1.10, 4.55 and 32.67 multiples of what was obtainable for power supply from the national grid thermal plants, for NO_x , CO, PM and TVOC, respectively, and 6 percent for SO_2 (Sonibare, 2010). Also, in terms of area coverage, the estimated results are in respective multiples of 1.76, 0.64, 53.5, 0.034 and 18.66 of the estimated concentration levels obtained in a previous study for NO_x , CO, PM, SO_2 and TVOC (Sonibare, 2010). This implies that the continuous engagement of BUGs would emit more pollutants into the Nigerian airshed as compared to national grid sources.

Air pollutants emissions into the atmosphere from BTS BUGs are through stacks. People are at high risk of exposure to the emitted air pollutants in developing countries like Nigeria where environmental regulations are not adequate. Moreover, some of these BTS are located within the residential areas. The emitted air pollutants are known to have serious health effect on people (Sonibare and Jimoda, 2009). Diesel particulate matter emitted from diesel BUGs have been linked with an array of carcinogenic ailments (Gilmore *et al.*, 2010). Persistent emission of these air pollutants into the environment may cause visibility reduction and fog formation (Gilmore *et al.*, 2010). The environmental impact of the use of BUGs calls for concern especially in the densely populated areas where per capita and per land distribution are high. Densely populated cities like Lagos and Kano could be heavily polluted as contributions from other sources like transportation and industrial processes will further aggravate air quality. The major regulator of the telecommunication industry (NCC) should encourage and enforce the use of hybrid power sources and the largely untapped renewable energy sources like biomass and solar sources in providing the required energy for BTS.

4. Conclusions

This study has estimated the types, quantity and distribution of air pollutants emission from diesel BUGs employed as sustainable alternatives to national grid power supply in powering mobile telecommunications BTS in Nigeria using the emission factor approach. The estimated emission of NO_x , CO, SO_2 , PM_{10} , $\text{PM}_{2.5}$, PAH and TVOC ranges were 46,542.00-1.22E+05; 20,685.34-52,671.53; 21.98-55.24; 3,296.73-8,350.36; 3,232.08-8,350.36; 3.10E-04-7.71E-04 and 6,852.02-17,985.4 tonnes/year, respectively. Lagos State has the highest land distribution of air pollutants (g/km^2) of about 13.35 times the national average per land distribution while Cross River State has the highest value of 1,041.99 g/capita per capita distribution. The environmental impacts of these air pollutants emissions are sharp indicators for the regulators and policy makers in the industry.

To address this alarming trend, concerted efforts will be required from the operators, investors and the government. Efforts should be geared toward the proper monitoring and adequate environmental impact assessment of BTS sites on the part of the regulator and all other relevant agencies. The pollutants emission limits must be set by the relevant

environmental protection agency especially for the BUGs. Permits should be issued for all the BTS sites and it should contain information on the maximum allowable emission rates and air quality monitoring by the operators and concerned individuals. This is to ensure that air quality meets up with the required standards around BTS facilities. Efforts should be made to improve on energy generation from the national grid as this could totally eradicate the use of BUGs at BTS sites. The major regulator of the telecommunication industry (NCC) should encourage the use of hybrid power sources and the largely untapped renewable energy sources in providing the required energy for BTS. The use of diesel particulate filters and diesel oxidation catalyst in BUGs will drastically reduce air pollutants emission and should be enforced. Operators and government could collaborate with the local and foreign energy investors to provide facilities that will be required to achieve pollution free development in the telecommunication sector.

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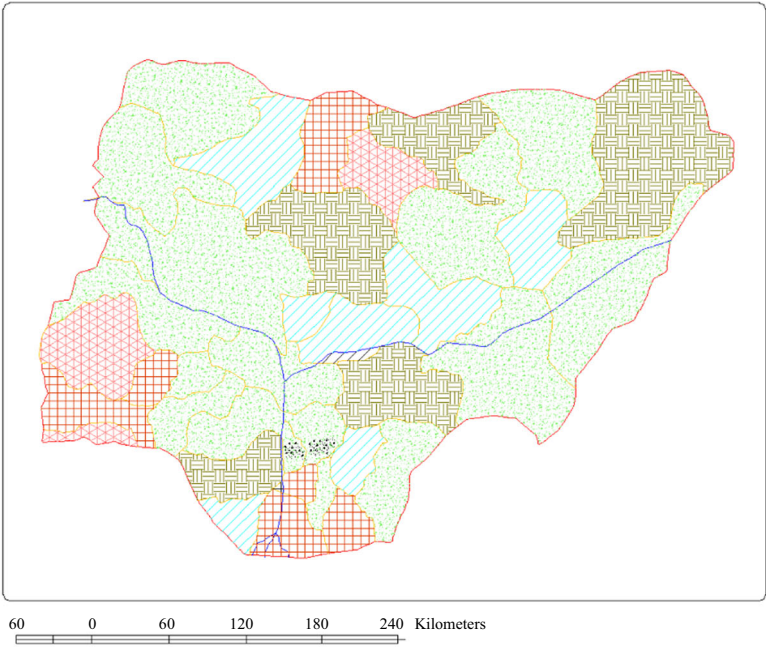
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(The Appendix follows overleaf.)

Map Showing State Contribution of Air Pollutants From GSM BTS BUGs
in Nigeria

CO Emission (Tonnes/Annum)

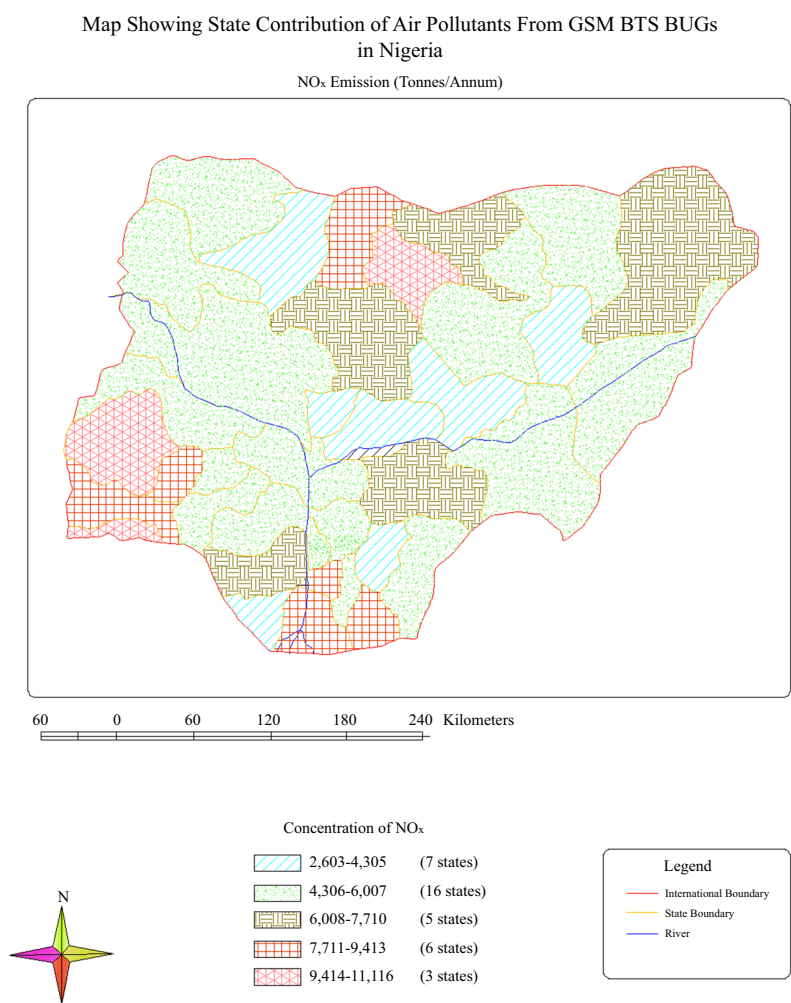


Concentration of CO

561-928	(7 states)
929-1,295	(16 states)
1,296-1,663	(5 states)
1,664-2,030	(6 states)
2,031-2,398	(3 states)

Legend	
International Boundary	
State Boundary	
River	

Figure A1.
Contribution of CO
from GSM BUGs

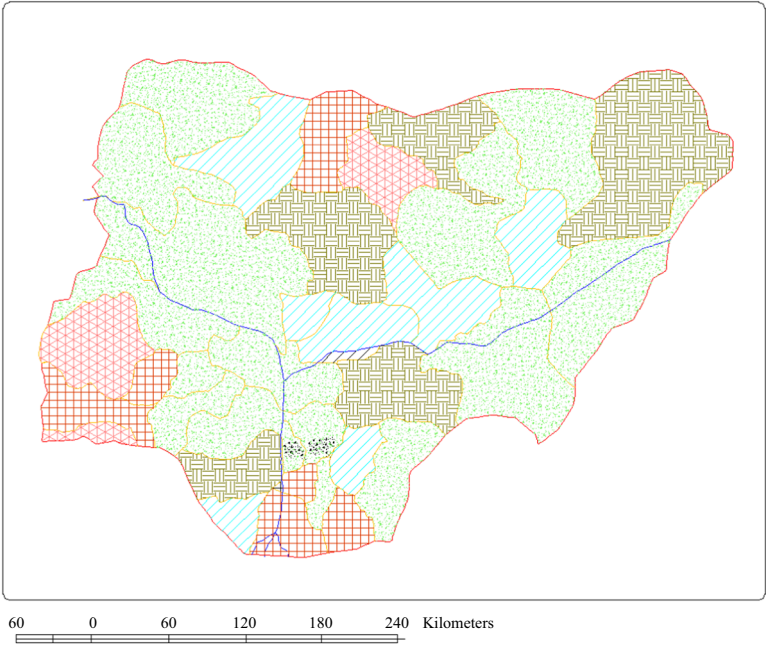


Air quality
impact of
diesel BUGs

Figure A2.
Contribution of NO₂
from GSM BUGs

Map Showing State Contribution of Air Pollutants From GSM BTS BUGs
in Nigeria

PAH Emission (Tonnes/Annum)



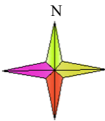
Concentration of PAH

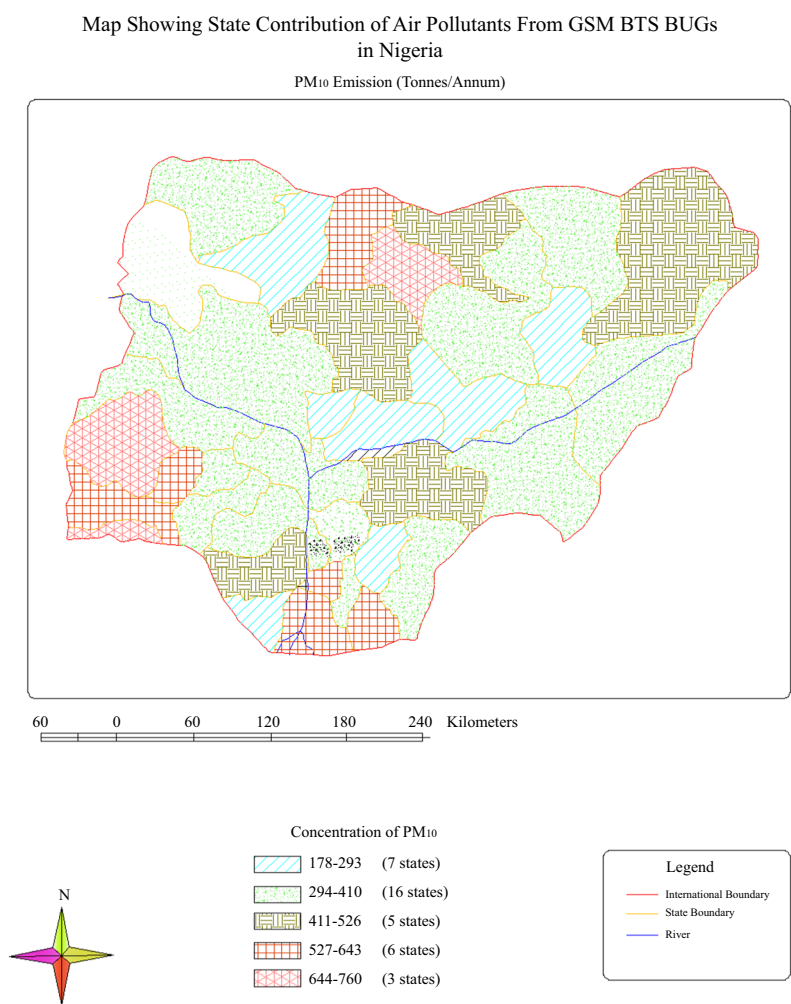
	8.22E-05-1.34E-04	(7 states)
	1.35E-04-1.88E-04	(16 states)
	1.89E-04-2.42E-04	(5 states)
	2.43E-04-2.96E-04	(6 states)
	2.97E-04-3.51E-04	(3 states)

Legend

- International Boundary
- State Boundary
- River

Figure A3.
Contribution of PAHs
from GSM BUGs





Air quality
impact of
diesel BUGs

737

Figure A4.
Contribution of PM_{2.5}
from GSM BUGs

Map Showing State Contribution of Air Pollutants From GSM BTS BUGs
in Nigeria

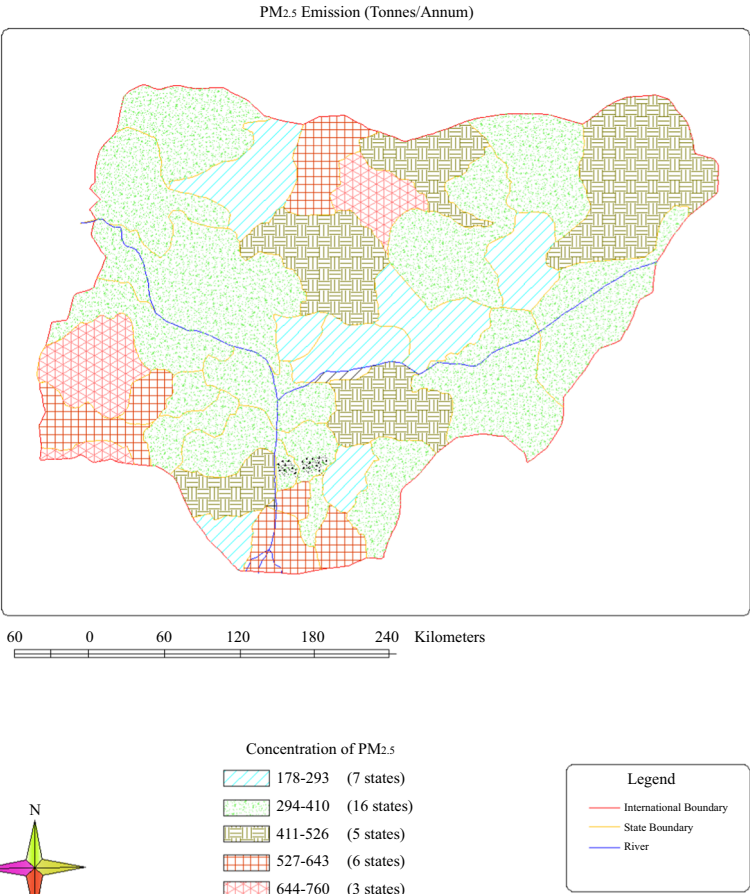
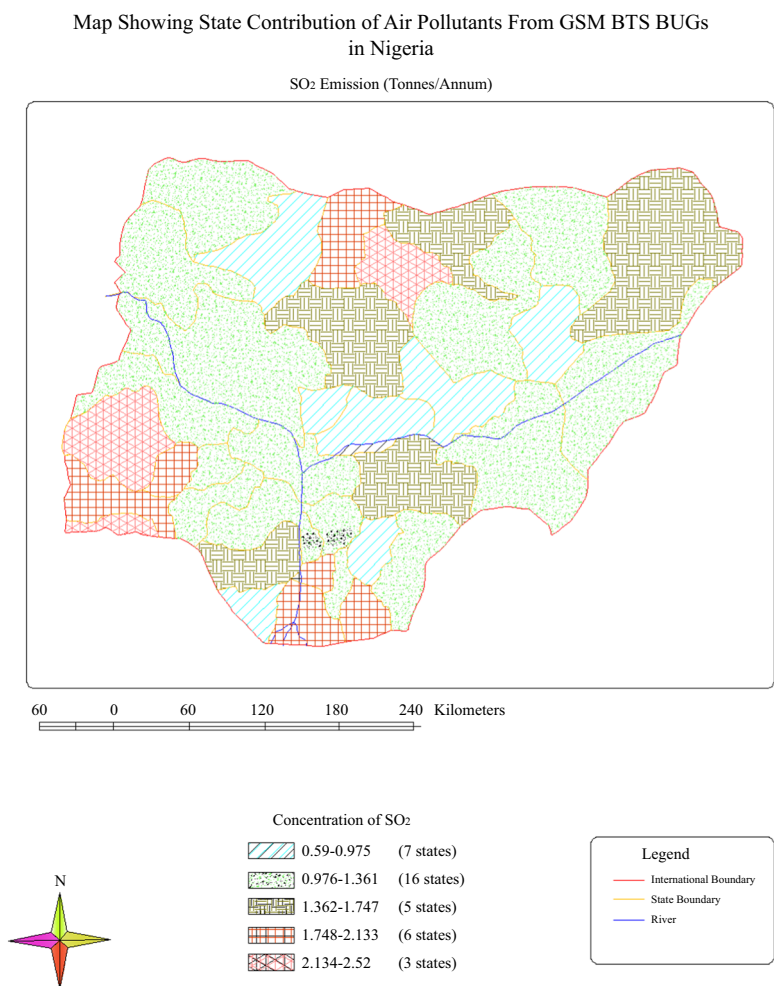


Figure A5.
Contribution of PM₁₀
from GSM BUGs



Air quality
impact of
diesel BUGs

Figure A6.
Contribution of SO₂
from GSM BUGs

Map Showing State Contribution of Air Pollutants From GSM BTS BUGs
in Nigeria

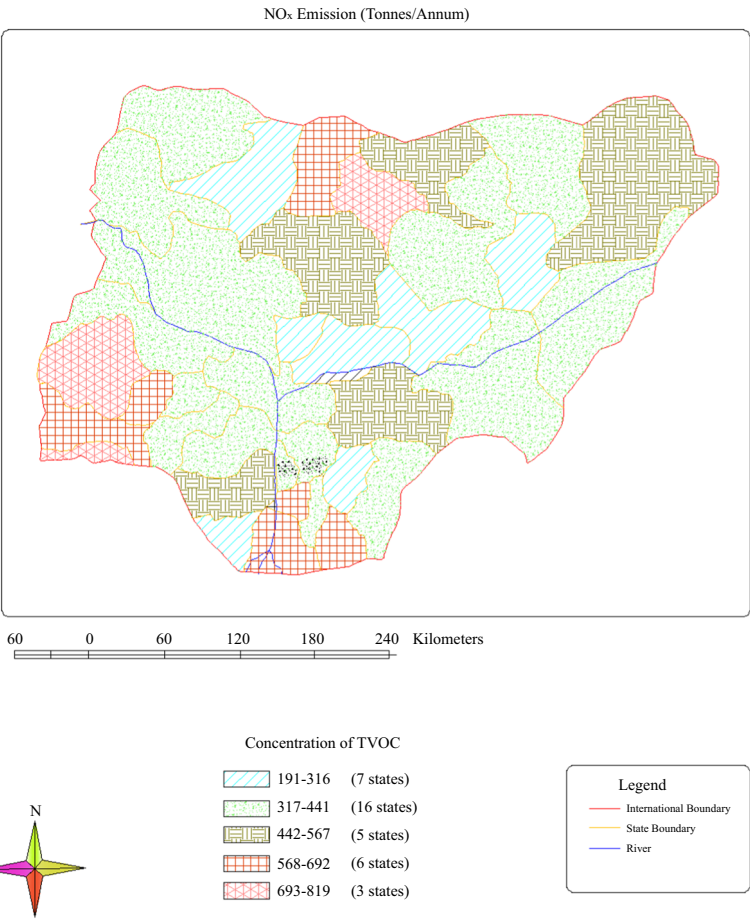


Figure A7.
Contribution of
TVOCs from
GSM BUGs

Table AI.
States contribution to
air pollutants from
GSM BTS BUGs

State	NO _x	CO	Pollutants emission (tonnes/annum)			PAH	TVOC
			SO ₂	PM ₁₀	PM _{2.5}		
Abia	4,767.51	1,028.78	1.08	326.20	326.20	1.51E-04	351.29
Adamawa	5,690.25	1,227.90	1.29	389.33	389.33	1.80E-04	419.28
Akwa Ibom	8,414.54	1,815.77	1.90	575.73	575.73	2.66E-04	620.02
Anambra	5,745.18	1,239.75	1.30	393.09	393.09	1.81E-04	423.33
Bauchi	5,690.25	1,227.90	1.29	389.33	389.33	1.80E-04	419.28
Bayelsa	2,603.45	561.80	0.59	178.13	178.13	8.22E-05	191.83
Benue	6,349.35	1,370.12	1.44	434.43	434.43	2.01E-04	467.85
Borno	7,425.89	1,602.43	1.68	508.09	508.09	2.35E-04	547.17
Cross River	5,020.16	1,083.30	1.14	343.48	343.48	1.59E-04	369.91
Delta	7,074.37	1,526.57	1.60	484.04	484.04	2.23E-04	521.27
Ebonyi	3,932.64	848.62	0.89	269.08	269.08	1.24E-04	289.77
Edo	5,470.55	1,180.49	1.24	374.30	374.30	1.73E-04	403.09
Ekiti	4,690.61	1,012.19	1.06	320.94	320.94	1.48E-04	345.62
Enugu	4,910.31	1,059.59	1.11	335.97	335.97	1.55E-04	361.81
FCT	3,570.14	770.40	0.81	244.27	244.27	1.13E-04	263.06
Gombe	2,987.93	644.76	0.68	204.44	204.44	9.44E-05	220.16
Imo	7,799.38	1,683.02	1.77	533.64	533.64	2.46E-04	574.69
Jigawa	7,392.93	1,595.32	1.67	505.83	505.83	2.33E-04	544.74
Kaduna	6,283.44	1,355.90	1.42	429.92	429.92	1.98E-04	462.99
Kano	11,007.01	2,375.20	2.49	753.11	753.11	3.48E-04	811.04
Katsina	9,095.61	1,962.74	2.06	622.33	622.33	2.87E-04	670.20
Kebbi	5,745.18	1,239.75	1.30	393.09	393.09	1.81E-04	423.33
Kogi	5,745.18	1,239.75	1.30	393.09	393.09	1.81E-04	423.33
Kwara	4,723.57	1,019.30	1.07	323.19	323.19	1.49E-04	348.05
Lagos	11,116.86	2,398.90	2.52	760.63	760.63	3.51E-04	819.14
Nassarawa	3,987.57	860.48	0.90	272.83	272.83	1.26E-04	293.82
Niger	5,964.88	1,287.16	1.35	408.12	408.12	1.88E-04	439.52
Ogun	6,140.64	1,325.09	1.39	420.15	420.15	1.94E-04	452.47
Ondo	5,075.09	1,095.15	1.15	347.24	347.24	1.60E-04	373.95
Osun	8,128.93	1,754.14	1.84	556.19	556.19	2.57E-04	598.97
Oyo	9,644.87	2,081.26	2.18	659.91	659.91	3.05E-04	710.67
Plateau	4,196.29	905.51	0.95	287.11	287.11	1.33E-04	309.20
Rivers	7,239.14	1,562.13	1.64	495.31	495.31	2.29E-04	533.41
Sokoto	5,887.98	1,270.56	1.33	402.86	402.86	1.86E-04	433.85
Taraba	4,481.90	967.15	1.01	306.66	306.66	1.42E-04	330.25
Yobe	4,624.70	997.96	1.05	316.43	316.43	1.46E-04	340.77
Zamfara	3,932.64	848.62	0.89	269.08	269.08	1.24E-04	289.77

MEQ 28,5								
	State	NO _x	CO	SO ₂	PM ₁₀	PM _{2.5}	PAH	TVOC
742	Abia	972,516.50	209,858.82	220.10	66,540.60	66,540.60	0.0307	71,659.11
	Adamawa	146,567.90	31,627.81	33.17	10,028.33	10,028.33	0.0046	10,799.74
	Akwa Ibom	1,242,532.49	268,125.43	281.20	85,015.38	85,015.38	0.0392	91,555.03
	Anambra	1,192,882.19	257,411.42	269.97	81,618.26	81,618.26	0.0377	87,896.58
	Bauchi	113,955.73	24,590.45	25.79	7,796.97	7,796.97	0.0036	8,396.74
	Bayelsa	276,499.78	59,665.74	62.58	18,918.41	18,918.41	0.0087	20,373.67
	Benue	203,005.79	43,806.51	45.94	13,889.87	13,889.87	0.0064	14,958.32
	Borno	98,381.00	21,229.58	22.27	6,731.33	6,731.33	0.0031	7,249.13
	Cross River	232,021.86	50,067.88	52.51	15,875.18	15,875.18	0.0073	17,096.35
	Delta	410,364.13	88,552.26	92.87	28,077.55	28,077.55	0.0130	30,237.36
	Ebonyi	612,444.08	132,158.99	138.61	41,904.07	41,904.07	0.0193	45,127.46
	Edo	276,021.67	59,562.57	62.47	18,885.69	18,885.69	0.0087	20,338.44
	Ekiti	796,654.16	171,909.58	180.30	54,507.92	54,507.92	0.0252	58,700.83
	Enugu	641,019.12	138,325.18	145.07	43,859.20	43,859.20	0.0202	47,232.99
	FCT	460,434.06	99,356.82	104.20	31,503.38	31,503.38	0.0145	33,926.72
	Gombe	166,162.01	35,856.01	37.61	11,368.98	11,368.98	0.0052	12,243.52
	Imo	1,504,852.84	324,731.40	340.57	102,963.62	102,963.62	0.0475	110,883.89
	Jigawa	301,560.06	65,073.49	68.25	20,633.06	20,633.06	0.0095	22,220.22
	Kaduna	137,459.63	29,662.34	31.11	9,405.13	9,405.13	0.0043	10,128.60
	Kano	517,322.76	111,632.81	117.08	35,395.77	35,395.77	0.0163	38,118.52
	Katsina	364,243.92	78,600.00	82.43	24,921.95	24,921.95	0.0115	26,839.03
	Kebbi	152,278.98	32,860.20	34.46	10,419.09	10,419.09	0.0048	11,220.56
	Kogi	194,212.64	41,909.04	43.95	13,288.23	13,288.23	0.0061	14,310.40
	Kwara	137,043.95	29,572.64	31.02	9,376.69	9,376.69	0.0043	10,097.98
	Lagos	3,179,471.65	686,096.51	719.56	217,542.80	217,542.80	0.1004	234,276.86
	Nassarawa	146,217.48	31,552.19	33.09	10,004.35	10,004.35	0.0046	10,773.92
	Niger	80,488.34	17,368.54	18.22	5,507.10	5,507.10	0.0025	5,930.72
	Ogun	361,627.71	78,035.45	81.84	24,742.95	24,742.95	0.0114	26,646.25
	Ondo	333,993.38	72,072.26	75.59	22,852.18	22,852.18	0.0105	24,610.04
	Osun	934,377.34	201,628.79	211.46	63,931.08	63,931.08	0.0295	68,848.86
	Oyo	341,468.40	73,685.29	77.28	23,363.63	23,363.63	0.0108	25,160.83
	Plateau	154,179.13	33,270.23	34.89	10,549.10	10,549.10	0.0049	11,360.57
	Rivers	693,917.41	149,740.07	157.04	47,478.56	47,478.56	0.0219	51,130.76
	Sokoto	174,319.84	37,616.39	39.45	11,927.15	11,927.15	0.0055	12,844.62
	Taraba	74,336.72	16,041.08	16.82	5,086.20	5,086.20	0.0023	5,477.44
	Yobe	98,587.20	21,274.08	22.31	6,745.44	6,745.44	0.0031	7,264.32
	Zamfara	111,816.15	24,128.75	25.31	7,650.58	7,650.58	0.0035	8,239.08
	National	237,507.50	51,251.62	53.75	16,250.51	16,250.51	0.0075	17,500.55

Table AII.
Land distribution
of air pollutants
from BTS BUGs
by State (g/km²)

State	NO _x	CO	SO ₂	PM ₁₀	PM _{2.5}	PAH	TVOC
Abia	1,436.74	620.07	0.65	98.30	98.30	9.07E-05	211.73
Adamawa	1,525.46	658.36	0.69	104.37	104.37	9.63E-05	224.81
Akwa Ibom	1,794.64	774.53	0.81	122.79	122.79	1.13E-04	264.47
Anambra	1,177.36	508.12	0.53	80.56	80.56	7.44E-05	173.51
Bauchi	1,016.21	438.57	0.46	69.53	69.53	6.42E-05	149.76
Bayelsa	1,299.68	560.92	0.59	88.93	88.93	8.21E-05	191.53
Benue	1,262.42	544.83	0.57	86.38	86.38	7.97E-05	186.04
Borno	1,473.53	635.94	0.67	100.82	100.82	9.31E-05	217.15
Cross River	2,083.99	638.24	0.67	101.18	101.18	9.34E-05	217.94
Delta	1,441.70	622.21	0.65	98.64	98.64	9.11E-05	212.46
Ebonyi	1,545.07	666.82	0.70	105.72	105.72	9.76E-05	227.69
Edo	1,450.04	625.81	0.66	99.21	99.21	9.16E-05	213.69
Ekiti	1,647.79	711.15	0.75	112.74	112.74	1.04E-04	242.83
Enugu	1,273.41	549.58	0.58	87.13	87.13	8.04E-05	187.66
FCT	1,630.77	703.81	0.74	111.58	111.58	1.03E-04	240.32
Gombe	1,058.28	456.73	0.48	72.41	72.41	6.68E-05	155.96
Imo	1,666.78	719.35	0.75	114.04	114.04	1.05E-04	245.63
Jigawa	1,443.25	622.87	0.65	98.75	98.75	9.12E-05	212.69
Kaduna	867.93	374.58	0.39	59.38	59.38	5.48E-05	127.90
Kano	974.37	420.52	0.44	66.67	66.67	6.15E-05	143.59
Katsina	1,325.93	572.24	0.60	90.72	90.72	8.37E-05	195.40
Kebbi	1,482.27	639.72	0.67	101.42	101.42	9.36E-05	218.44
Kogi	1,466.90	633.08	0.66	100.37	100.37	9.26E-05	216.18
Kwara	1,695.81	731.87	0.77	116.03	116.03	1.07E-04	249.91
Lagos	1,021.27	440.76	0.46	69.88	69.88	6.45E-05	150.50
Nassarawa	1,803.13	778.19	0.82	123.37	123.37	1.14E-04	265.72
Niger	1,251.47	540.11	0.57	85.63	85.63	7.90E-05	184.43
Ogun	1,365.76	589.44	0.62	93.45	93.45	8.63E-05	201.27
Ondo	1,242.09	536.06	0.56	84.99	84.99	7.84E-05	183.05
Osun	1,994.80	860.91	0.90	136.49	136.49	1.26E-04	293.97
Oyo	1,438.96	621.03	0.65	98.46	98.46	9.09E-05	212.06
Plateau	1,112.43	480.10	0.50	76.11	76.11	7.03E-05	163.94
Rivers	1,155.97	498.89	0.52	79.09	79.09	7.30E-05	170.35
Sokoto	1,345.57	580.72	0.61	92.07	92.07	8.50E-05	198.29
Taraba	1,662.75	717.61	0.75	113.77	113.77	1.05E-04	245.04
Yobe	1,729.69	746.50	0.78	118.35	118.35	1.09E-04	254.90
Zamfara	1,006.20	434.25	0.46	68.85	68.85	6.35E-05	148.28
National	1,342.49	574.09	0.60	91.01	91.01	8.40E-05	196.03

Table AIII.
Population
distribution of air
pollutants from
BTS BUGs in
Nigeria (g/capita)

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