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Setting Regulatory Limits for Sulphur Content in Premium Motor Spirit (PMS): A Case of Degraded Vehicles

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Authors' contributions

This work was carried out in collaboration between the two authors. Author TH collected the primary data and performed statistical analysis, he also wrote the protocol and first draft of the manuscript. Author ILN supervised the analysis performed and proof read the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

The need for a cleaner environment free from unhealthy levels of Sulphur IV oxide (SO_2) has prompted this study of setting regulatory limits of sulphur content in Premium Motor Spirit (PMS) especially that used in Nigeria. This study has used secondary and primary data to show the extent of damage to the environment, caused by high sulphur content in the PMS we use especially with degraded vehicles. The method adopted for this studyinvolved field monitoring at three number locations (Choba junction, Rumuokoro junction and Alakahia off the East-west road), to obtain meteorological parameters via installed weather stations, traffic count through positioned Close Circuit Television (CCTV) cameras and sampled vehicular exhaust emission of SO_2 from randomly selected vehicles. Results showed that vehicles using PMS distributed in Nigeria emits as high as 210.6 mg/m^3 and as low as 0.0 mg/m^3 SO_2 from their exhausts. For the Department of Petroleum Resources (DPR) and the Ministry of Environment (MENv) to achieve its environmental limit of

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0.15 mg/m^3 ambient level of SO_2, they need to reduce the sulphur content limit in PMS supplied to Nigeria to 0.01% weight or restrict the movement of vehicles that emit more than 30.6mg/m^3 SO_2(degraded vehicles) from their exhausts.

Keywords: PMS; exhaust; junctions; traffic; modeling; regulatory limits.

1. INTRODUCTION

The need to regulate the amount of Sulphur in Premium Motor Spirit is very important because the major source of Sulphur IV oxide in the environment is from the combustion of Sulphur containing substances [1]. One of the main environmental goals of any country is to make sure the ambient level of pollutant gases are kept below levels that can cause severe damage to the environment. As such the limits to substances that can cause high level of dangerous pollutants should be established based on all factored conditions such as the level of degraded vehicles used.

Degradability of vehicles is a very difficult parameter to measure because it is dependent on many factors such as age of vehicle, mileage of the vehicle, maintenance habit of owner (corrective, preventive or breakdown), lubricant used in servicing, terrain where vehicle is used and petrol used by vehicles. Over time the easiest parameter that has been used to judge degradability is the age of the vehicle. Cottingham stated that as vehicle engine wears off from age, it starts producing more emissions [2]. The vehicle exhaust emission Amendment of New Zealand [3] has subjected every vehicle that operates in its environment to an exhaust certified test except for vehicles manufactured from the first of January 2014 and above (approximately 4 year old cars when considered in the present).

Nigeria is a major user of PMS for most of its combustions engines as proven by the process audit information of 2004 (See Chart 1). The high level of SO_2 in Nigeria's environment has been confirmed to as a result of PMS used by combustion engines [4].

Researchers have carried out a lot of studies on air pollution monitoring and model development for pollutant dispersion [5-14], but it is time we concentrate on the main causes of these pollutants and how realistic limits can be set to help reduce their effects on the environment. This study is limited to the sulphur content in PMS and how they cause high level of SO_2 in the environment. Past researches [15-18] have recorded sulphur content in Nigeria's PMS and other countries Nigeria imports from. The range is between 0.025-0.081% weight [19]. However, the set limit of the Nigeria ministry of Environment is 0.1% (See Fig. 2).

2. MATERIALS AND METHODS

2.1 Study Area

The study area for this research is Port Harcourt which is selected as a typical urban city in Nigeria. It lies between longitudes 4.42035° N - 4.42048° N and latitudes 6.41601° E - 6.41326° E (see Fig. 3). Port Harcourt is in Rivers State in southern part of Nigeria, densely populated with over 500,000 people [20]. The presence of a refinery, some oil companies and a few oil servicing companies have made the growth of commercial activities very significant. This explains the massive traffic observed in the city with occasional long interrupted traffic. The two major junctions selected for this study are Rumuokoro junction (N 4.86706, E 4.86706) and Chobajunction (N 4.89865, E 6.90673). These junctions serve as major entry/ exit routes connecting Rivers state with neighboring States. The non-traffic point selected for this study is the Alakahia axis of East-west road (N 4.8853, E 6.93069) which is a point between the Rumuokoro and Choba junction.

2.2 Method Anddata Collected

The method adopted for this research involved field monitoring and detailed statistical analysis. The equipment used for this research are, aeroqual 500 series, a Garmin GPRS, 4 CCTV cameras, 2 Vantage Due weather station and a stop watch.

The data collected for this research included meteorological data obtained from two separate weather stations at Rumuokoro and Choba observation locations. Ambient concentration of SO_2 was also collected at Choba, Rumuokoro junctions, and Alakahia axis of the East -west road. Hourly traffic count was monitored with

CCTV cameras at Choba and Rumuokoro junctions. Concentrations of emitted SO_2 were monitored from exhaust of randomly selected vehicles within the Choba Junction. Fig. 4 shows a typical site setup of the monitoring activities which yielded the data presented in Tables 1-3.

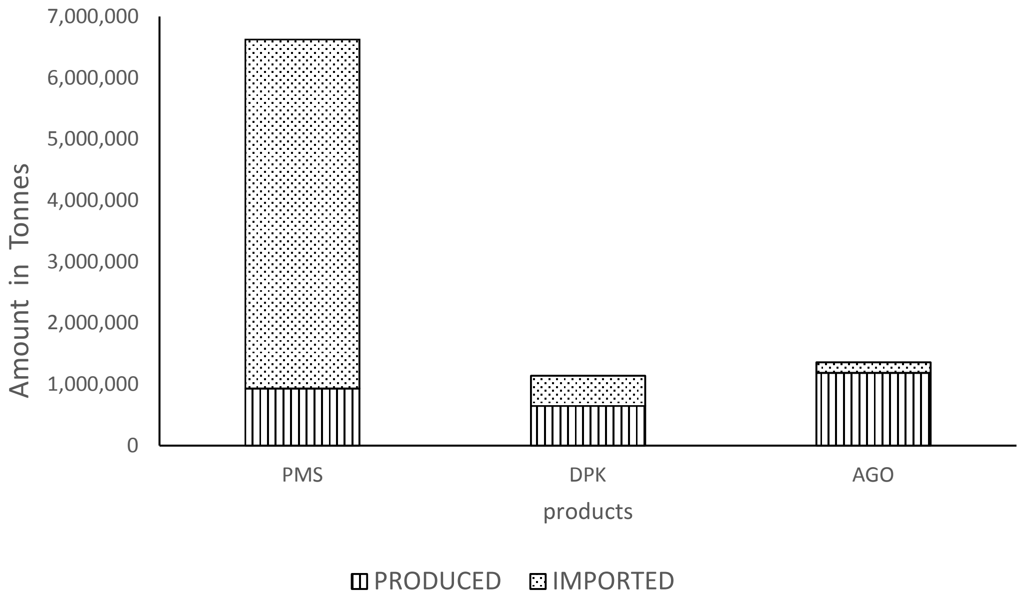

Fig. 1. Plot showing PMS produced and imported, compared to DPK and AGO

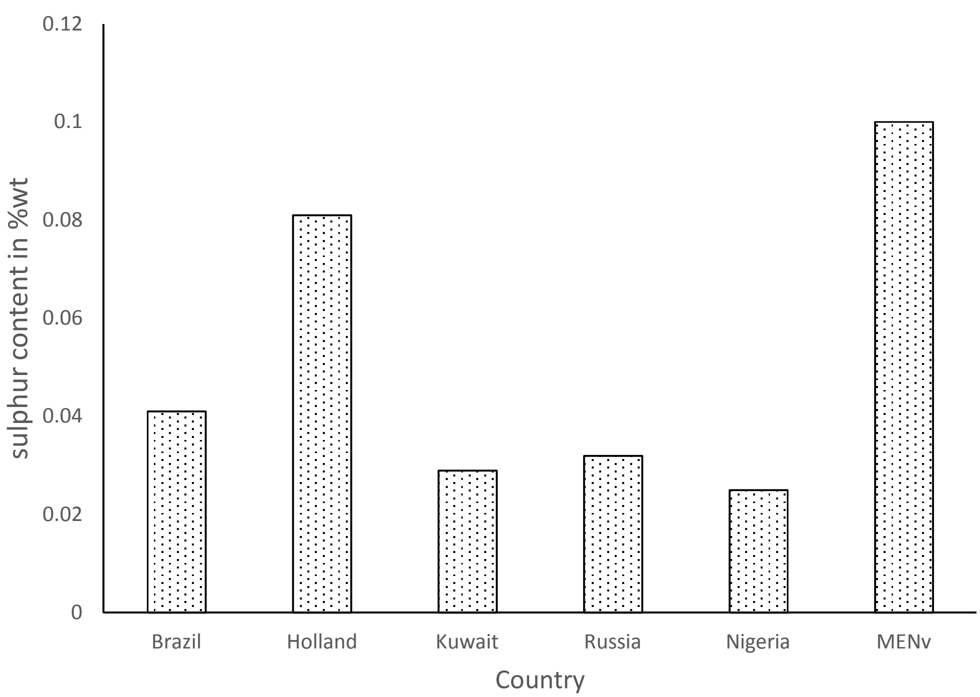

Fig. 2. Plot showing Sulphur content of different PMS used in Nigeria compared to Nigeria's set limit

Fig. 3. Map showing study area referenced on Google map and in detail

2.3 Data Analysis

From the Michigan air emission reporting system [21], Equation (1) was adopted to estimate the amount of SO_2 most likely to be emitted from a particular percentage of sulphur present in PMS.

$$ER = R \times PC \times \frac{MW_P}{MW_f} \qquad (1)$$

Where ER=pollutant emission rate; R= fuel flow rate; PC=pollutant concentration in fuel (%/100); MW_p = molecular weight of pollutant emitted which is Sulphur IV oxide in this study case (Ib/Ib-mole); MW_f = molecular weight of pollutant in fuel which is Sulphur in this study case (Ib/Ib-mole)

Using the sulphur content of 0.1% as the Nigerian Environmental limit and a KIA Picanto 2011 model of vehicle, the expected SO_2 emission is as calculated next:

To estimate fuel rate, R, Alvin [22] concept was adopted which states that a 2 Horse Power (HP) engine will consume approximately 1 Pound of fuel per hour. Translating this, a KIA Picanto of 84 HP engine will consume approximately 42Lbs/hr.

Estimating MW_p; We have SO_2= 32+ (16×2) = 64 and for MW_f; we have S = 32; thus:

$$ER = 42 \times \frac{0.1}{100} \times \frac{64}{32} = 0.084\text{Lbs of } SO_2\text{/hr}$$

The pollutant emission based on 0.1% Sulphur content is 0.084 Lbs of SO_2/hr, but we need to express the answer in mg/m^3 which will require having a knowledge of the vehicle exhaust flow.

Table 1. Meteorological and Sulphur IV oxide pollutant data collected from Rumuokoro and Choba observation sites

Days	Time	RUMUOKORO					CHOBA				
		SO_2 concentration (mg/m^3)	Solar radiation (w/m2)	Wind speed (m/s)	Traffic count (number/ 2 hours)	Hold time (mins)	SO_2 concentration (mg/m^3)	Solar radiation (w/m2)	Wind speed (m/s)	Traffic count (number/ 2 hours	Hold time (mins)
Mon day 1	6:00	0.72	0	0	560	0	0.61	0	0	723	0
	8:00	0.9	100	0	1795	13	0.57	280	4.8	6162	4
	10:00	0	195.1	6.4	2518	9	0.46	350.9	9.7	6735	6
	12:00	0	473.1	4.8	2864	7	0	413.8	8	6978	0
	14:00	0	237.2	3.2	3555	28	0	1220	11.3	7199	0
	16:00	0	111.8	9.7	3541	0	0.17	600	12.9	7104	9
	18:00	0	8.5	8	3134	18	3.37	14	4.8	6387	7
	20:00	0.09	0	8	3017	10	0.77	0	1.6	4827	7
	22:00	0.026	0	9.7	2708	6	0.14	0	1.6	2139	0
Tues day 2	6:00	0.22	0	0	432	0	1.35	0	1.6	633	0
	8:00	0	123	0	1998	21	1.05	240.6	4.8	5964	3
	10:00	0	221.7	3.2	2380	7	0	151.2	4.8	6798	7
	12:00	0	505.1	3.2	2991	7	0.3	1025	6.4	6975	0
	14:00	0	161.6	3.2	3688	13	0	83	12.9	7010	1
	16:00	0.45	234.8	4.8	3541	4	1.12	37.8	6.4	6397	11
	18:00	0	46	4.8	2598	36	2.29	12.4	1.6	6337	6
	20:00	0.87		9.7	2894	15	1.41	0	0	5423	8
	22:00	0.69		1.6	2939	6	0.44	0	0	2444	2
Weds day 3	6:00	0.27	2.8	0	432	0	1.19	0	0	548	0
	8:00	0	147.6	0	2321	7	2.26	14.1	0	5778	5
	10:00	0	538.5	1.6	2694	8	0.4	21.9	1.6	6776	8
	12:00	0	650.5	4.8	2937	6	0.33	102	0	6878	1
	14:00	0	491.3	3.2	3642	13	0.76	250	4.8	6994	1
	16:00	0	400.6	3.2	3891	3	1.44	170.1	3.2	6587	5
	18:00	0	28.9	4.8	3607	11	1.76	16	1.6	6580	4
	20:00	0	0	3.2	3102	13	0.69	0	0	5072	5
	22:00	0	0	1.6	3074	3	0.32	0	1.6	2382	2
Thurs day 4	6:00	1.67		0	453	0	0	0	0	433	0
	8:00	0.15	98.5	0	2343	10	0.64	60.2	0	6245	5
	10:00	0	205.9	3.2	2880	6	0	341	1.6	7639	9
	12:00	0	406.9	3.2	3319	3	0.05	1092	4.8	7409	2
	14:00	0.07	404,4	1.6	1446	3	0.17	639	3.2	7346	1
	16:00	0.01	194.2	4.8	4313	2	0	422.5	11.3	7312	6
	18:00	0.23	22.2	6.4	4001	15	0	79.2	4.8	7030	4

Fig. 4. A typical site set up for the monitoring activities in this study

Table 2. Observed traffic count for model of vehicles from 2012 and above

	Day 2					
Time	**RUMUOKORO**			**CHOBA**		
	Traffic Count (Number/ 2 Hours)	**Model of vehicles from 2012**	**% Model of vehicles from 2012**	**Traffic Count (Number/ 2 Hours)**	**Model of vehicles from 2012**	**% Model of vehicles from 2012**
6:00	432	98	22.69	633	44	6.95
8:00	1998	499	24.98	5964	393	6.58
10:00	2380	893	37.52	6798	659	9.69
12:00	2991	655	21.89	6975	350	5.01
14:00	3688	546	14.80	7010	420	5.99
16:00	3541	892	25.19	6397	626	9.78
18:00	2598	654	25.17	6337	648	10.22
20:00	2894	722	24.94	5423	515	9.49
22:00	2939	411	13.98	2444	214	8.75

Table 3. Observed concentration of Sulphur IV oxide (maximum exhaust temperature of 1200°F)

S/N	Vehicle model	Actual exhaust SO_2 concentration (mg/m^3)	Total distance by vehicle (Km)
1	KIA Picanto, 2011 Model (84 HP)	126.10	38,110
2	Toyota Corolla 2012 Model (132 HP)	3.58	45,039
3	Honda Civic 2014 Model (205 HP)	1.16	1020
4	Land Cruiser 2015 Model (351 HP)	0.00	9731
5	Toyota 4Runner 2004 Model (245 HP)	210.60	207,150
6	Mazda bus 1991 Model (commercial) (150 HP)	126.80	N/A
7	Mitsubishi Montero 2003 Model (215 HP)	210.60	289,400
8	Toyota Corolla 2012 Model (132 HP)	28.19	73,546
9	Toyota Camry 1995 Model (133 HP)	53.18	225,971
10	Mitsubishi Bus 1991 Model (commercial) (150 HP)	210.60	N/A
11	Mazda 625 1991 Model Commercial (150 HP)	166.40	N/A
12	Toyota corolla 1999 model Commercial(120 HP)	145.50	N/A

Table 4. Observed Sulphur IV oxide concentrations (maximum exhaust temperature of 1200^0 F)

ID±	Sulphur content	0.1	0.041	0.081	0.029	0.032	0.025	Actual exhaust SO_2 concentration	Total distance moved (Km)
	Vehicle model		Exhaust concentration of SO_2						
A	KIA Picanto, 2011 Model (84 HP)	34.71	14.05	28.1	10.07	11.11	8.68	126.1	38,110
B	Toyota Corolla 2012 Model (132 HP)	34.74	14.24	28.1	10.07	11.05	8.68	3.58	45,039
C	Honda Civic 2014 Model (205 HP)	34.73	14.24	28.1	10.08	11.05	8.68	1.16	1020
D	Land Cruiser 2015 Model (351 HP)	34.73	14.24	28.1	10.08	11.05	8.68	0.00	9731
E	Toyota 4Runner 2004 Model (245 HP)	34.73	14.24	28.1	10.08	11.05	8.68	210.6	207,150
F	Mazda bus 1991 MODEL (commercial) (150 HP)	34.73	14.24	28.1	10.08	11.05	8.68	126.8	N/A
G	Mitsubishi Montero 2003 Model (215 HP)	34.73	14.24	28.1	10.08	11.05	8.68	210.6	289,400
H	Toyota Corolla 2012 Model (132 HP)	34.73	14.24	28.1	10.08	11.05	8.68	28.19	73,546
I	Toyota Camry 1995 MODEL (133 HP)	34.73	14.24	28.1	10.08	11.05	8.68	53.18	225,971
J	Mitsubishi Bus 1991 MODEL (commercial) (150 HP)	34.73	14.24	28.1	10.08	11.05	8.68	210.6	N/A
K	Mazda 625 1991 MODEL Commercial (150 HP)	34.73	14.24	28.1	10.08	11.05	8.68	166.4	N/A
L	Toyota corolla 1999 model Commercial(120 HP)	34.73	14.24	28.1	10.08	11.05	8.68	145.5	N/A

±identification for vehicle model (See also Fig. 5)

From Donaldson [23] it is shown that the average exhaust temperature of a petrol engine gets as high as 1200^0 F and the amount of air intake into the engine is 2.5 multiplied by the horse power (HP) of the engine. Equation (2) is for the estimate of the amount of exhaust flow.

$$Exhuast\ flow\ (cfc) = \left(\frac{exhaust\ temp+460}{540}\right) \times intake\ air \quad (2)$$

For the KIA picanto of 84 HP, the exhaust flow is given as;

$$Exhuast\ flow\ (cfc) = \left(\frac{1200+460}{540}\right) \times (84 \times 2.5) = 646\ \text{CFM}$$

Converting 0.084 SO_2Lbs/hr to mg/m^3 requires the use of Equation (3)

$$C\ mg/m^3 = \frac{\frac{453.6gram}{lb} \times \frac{1000mg}{gram} \times Clbs/hr}{V_{dscfm} \times 60min/hr \times 0.02832m^3/ft^3} \quad (3)$$

$$= \frac{\frac{453.6gram}{lb} \times \frac{1000mg}{gram} \times 0.084lbs/hr}{646_{dscfm} \times 60min/hr \times 0.02832m^3/ft^3} = 34.71\ \text{mg/m}^3$$

From the foregoing prediction, the KIA Picanto of 84 HP engine is to emit 34.71 mg/m^3 of SO_2 if the Sulphur content in the PMS used is 0.1%. Table 4 shows other vehicles sampled and their expected actual emission of SO_2 observed. Fig. 5 shows SO_2 predicted for all Sulphur amounts and that observed from sampled vehicles. Fig. 6 shows Model of vehicles plotted against observed SO_2 exhaust level and total distance traveled.

From Table 1 the daily mean values of all the observed parameters were computed and presented as Table 5. A comparison of parameters between Choba and Rumuokoro was carried out to identify any differences. Sample t-test results of the comparison of average daily traffic count between Choba and Rumuokoro junctions (See Table 6) and that of other parameters (See Table 7) were made.

Table 5. Means of observed parameters

Days	RUMUOKORO					CHOBA				
	SO_2 (mg/m^3)	Solar W/m^2	Wind m/s	Hold time (mins)	Traffic (number/2 hours)	SO_2 (mg/m^3)	Solar W/m^2	Wind m/s	Hold time (mins)	Traffic (number/2 hours)
1	0.19	125.08	5.53	10.11	2632	0.68	319.90	6.08	3.67	5362
2	0.25	184.60	3.39	12.11	2606	0.88	172.20	4.28	4.22	5331
3	0.03	251.13	2.49	7.11	2856	1.02	63.79	1.42	3.44	5288
4	0.30	185.54	2.74	5.57	2679	0.12	376.30	3.21	3.85	6202

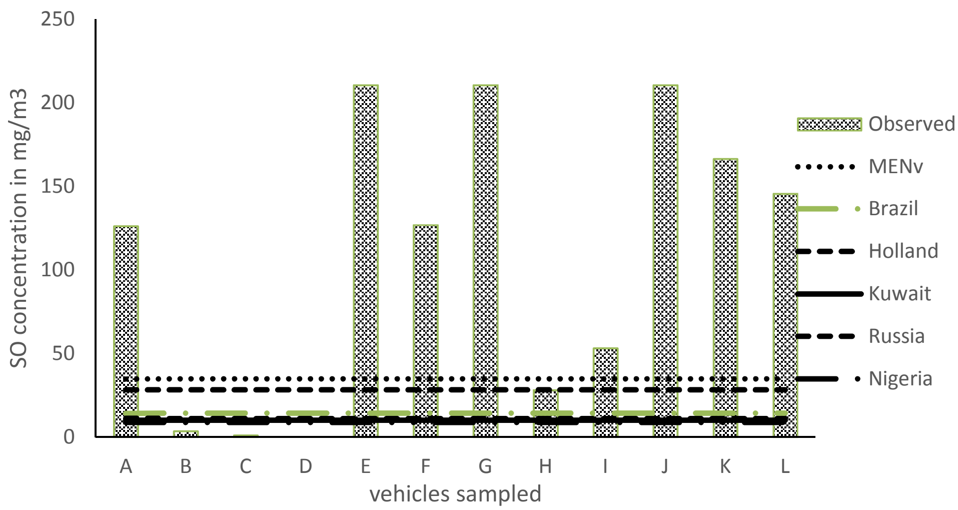

Fig. 5. Plot showing Sulphur IV oxide predicted for different Sulphur content and Sulphur IV oxide observed from sampled vehicles

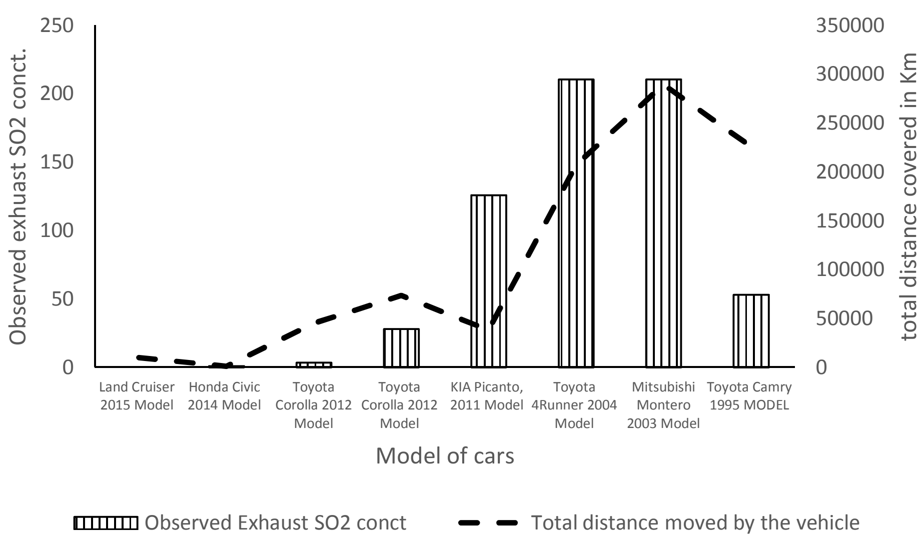

Fig. 6. Plot showing observed model of cars and millage

Table 6. Result of t-test for the comparison of Traffic between Choba and Rumuokoro junctions

Difference	-2852.2619
t (Observed value)	-12.6034
|t| (Critical value)	2.4476
DF	6
p-value (Two-tailed)	< 0.0001
alpha	0.05

Test interpretation:

H_0: The difference between the means is equal to zero.
H_a: The difference between the means is different from zero.

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H_0, and accept the alternative hypothesis H_a.

The risk to reject the null hypothesis H_0 while it is true is lower than 0.01%.

A linear regression model based on Equation (4) is developed to show the relationship of the parameters in Table 5. For the Rumuokoro junction a maximum of 25% of the total traffic is used for 2012 model and above that ply the road and 11% is used for Choba (See Table 2).

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 \quad (4)$$

Where: y= SO_2 ambient concentration, a_0, a_1, .a_5= site specific constants; x_1= mean daily solar radiation, x_2 = mean daily wind speed, x_3= mean daily Hold time, x_4= mean daily Traffic count, x_5= maximum number of 2012 and above vehicles.

The result of the regression analysis is presented as Table 8 and the developed model is presented as Equation (5)

$$y = 5.108061 - 0.00045x_1 - 0.03722x_2 - 0.02773x_3 - 0.000015x_4 - 0.00656x_5 \quad (5)$$

2.4 Model Verification

The verification of the model was carried out by regressing the predicted SO_2 concentrations of Equation (5) and the observed values which attained a goodness of fit, R^2 of 0.9824 (See Fig. 8).

Table 7. T-test results for all the observed parameters from Choba and Rumuokoro junctions

S/N	Comparison between Rumuokoro and Choba junctions	Risk in rejecting the Null hypothesis H_0	Remark
1	Traffic	0.01%	There is significant difference
2	SO_2 ambient concentration	5.78%	There is significant difference
3	Solar radiation	56.09%	No significant difference
4	Wind speed	86.71%	No significant difference
5	Hold time	1.58%	There is significant difference
6	% of 2012 model vehicles and above	0.01%	There is significant difference

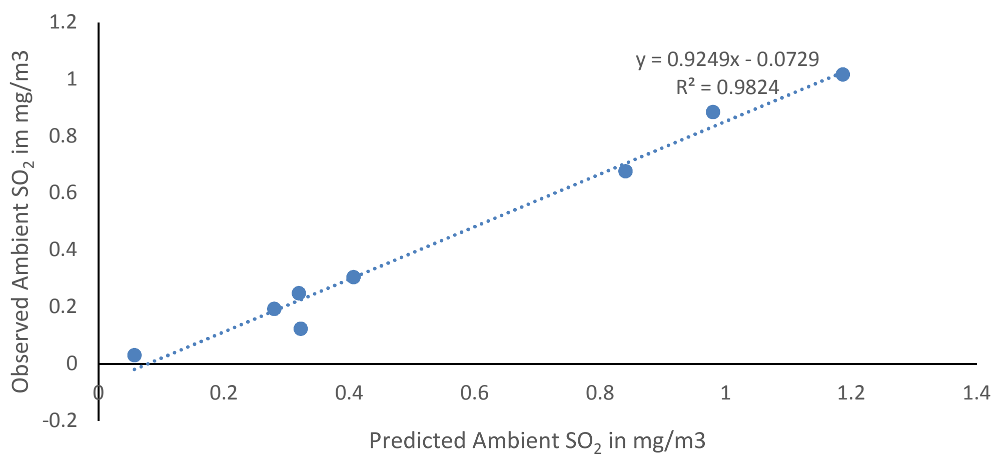

Fig. 8. Plot of observed and Predicted SO_2

Table 8. Result of regression analysis

Summary output								
Regression statistics								
Multiple R	0.995952							
R Square	0.991921							
Adjusted R Square	0.971725							
Standard Error	0.062626							
Observations	8							
ANOVA								
Significance								
	df	***SS***	***MS***	***F***	***F***			
Regression	5	0.963107	0.192621	49.11308	0.020074			
Residual	2	0.007844	0.003922					
Total	7	0.970951						
	Coefficients	**Standard error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**	**Lower 95.0%**	**Upper 95.0%**
Intercept	5.108061	0.765462	6.673171	0.021727	1.814543	8.401579	1.814543	8.401579
Solar	-0.00045	0.000483	-0.92453	0.452811	-0.00252	0.001631	-0.00252	0.001631
wind	-0.03722	0.022262	-1.67176	0.236535	-0.133	0.058569	-0.133	0.058569
Hold time	-0.02773	0.012931	-2.14467	0.165164	-0.08337	0.027904	-0.08337	0.027904
Traffic	-1.5E-05	3.65E-05	-0.42077	0.714825	-0.00017	0.000142	-0.00017	0.000142
2012 models	-0.00656	0.001071	-6.11994	0.025676	-0.01117	-0.00195	-0.01117	-0.00195

2.5 Sensitivity Analysis of Regression Model

Detailed sensitivity analyses on individual parameters of Equation (4) were carried out to evaluate the contributing effect of each of them to the prediction of ambient concentration of SO_2. Table 9 shows the ranking of the parameters in order of importance with respect to R^2

Table 9. t-statistics values

S/N	Parameter	Model	R^2	Ranking
1	Solar radiation	$Y=f(X_1)$	0.19	4
2	Wind speed	$Y=f(X_2)$	0.001	5
3	Traffic hold time	$Y=f(X_3)$	0.31	2
4	Traffic count	$Y=f(X_4)$	0.300	3
5	=>2012 models	$Y=f(X_5)$	0.91	1

Redeveloping Equation (5) with the significant parameters led to the production of Equation (6)

$SO_{2\ (cont.)}$ = 4.765 –hold time (0.021) - Number of vehicles models produced from 2012 (0.0066) (6)

Equation (6) attained high correlation coefficients of 0.9347. Equation (6) was used to develop a design chart as presented on Fig. 9.

2.6 Risk Analysis

This research has identified two major hazards in the use of both PMS with high Sulphur content and the degraded vehicles around major junctions in Port Harcourt. Table 10 shows a summary of the itemized hazards and possible risks. From this research the hazards that have been identified would be used to estimate the possible risks they can cause. The OSHAH 18001: 2007 [24] method of risk scoring was adopted for this purpose (See Equation 7, Tables A-1, A-2, A-3 and A-4).

$$R = S \times E \times P \qquad (7)$$

Where R = the estimated risk; E = assessment to exposure to hazard; and P = assessment of the likelihood and S=Potential hazard consequence.

Estimating the Risk number based on the hazards of using degraded vehicles and high Sulphur content in PMS, we assume the following: Potential hazard consequence (S) =100 given that this hazard leads to loss of life or properties and it takes the highest coefficient (See Table A-1);Exposure to this hazard (E) =10 given that this hazard is continuous, as long as degraded vehicles ply the roads and we use high Sulphur PMS (See Table A-2);the likelihood of this hazard (P) =10 because as long as this hazard exist, it is very likely that there would be continuous loss of lives and properties (See Table A-3); and

$$R = 100*10*10 = 10,000$$

Fig. 10 shows the hazards in this research plotted against the maximum accepted high Risk (See Table A-4). It also represents the estimated risk score for the identified hazards compared with OSHAH 18001:2007 [24].

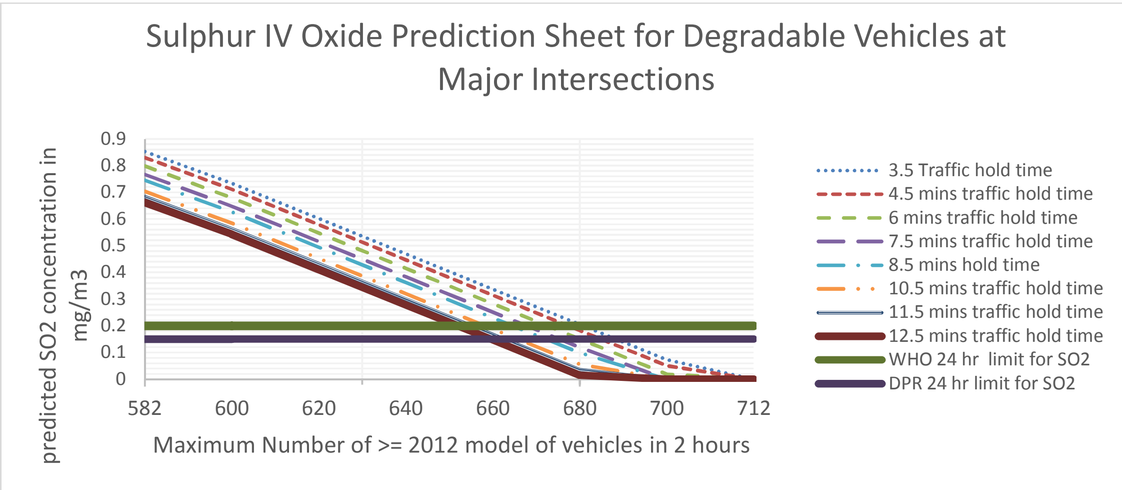

Fig. 9. Design chart to predict the amount of ambient SO2 in major intersections (traffic hold time)

Table 10. Summary of the risk analysis

No.	What are the hazards?	Who might be harmed and how?	What controls do we propose?	Risk	What further action is necessary to reduce the risk?	Action by whom?
1.	Use of PMS with high Sulphur content	Humans and Property. The Sulphur content in PMS is converted to SO_2 during combustion and this is emitted into the environment where it is dangerous to Humans that inhale it and when it combines with water it forms a weak acid which causes major corrosion.	The DPR and MENv. Should put the limit to Sulphur content in PMS imported into the country to 0.01% weight (Maximum).	The loss of Human lives and Property.	The use of less degraded vehicles can lower the risk in terms of the amount of SO_2 emitted into the environment.	The Government of Nigeria
2.	The use of Degraded vehicles (Vehicles more than 4 years and those that emit more than 30.6 of SO_2 from their exhaust.	Humans and Property. Degraded vehicles burns PMS less efficiently than new vehicles and this leads to more production of $SO_2$when the same quality of PMS is used.	Government should put some controls on the use of vehicles in Nigeria; Vehicles that are more than four years old should be restricted from plying the roads and if they should, they will undergo an exhaust test which will check if the SO_2 emitted from the exhaust is more than 30.2 mg/m^3.	The loss of Human lives and Property.	The use of PMS with maximum Sulphur content of 0.01% weight will reduce the risk.	The Government of Nigeria

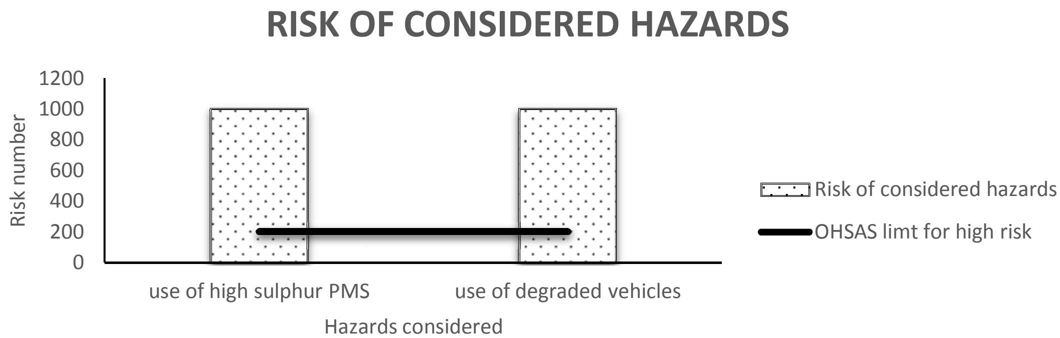

Fig. 10. Comparing Risk estimated with the OSHAH 18001: 2007 high risk limit

3. ESTIMATED SUPHUR LIMIT TO SATISFY REGULATORY LIMIT OF 0.15 mg/m^3

From Table 5, analysis for Sulphur content that would attain SO_2 prescribed limit of 0.15 mg/m^3

Assuming linearity of the amount of Sulphur that produces SO_2

0.081% of Sulphur in PMS (Max) ≡ 1.02 mg/m^3 ambient SO_2 monitored ≡ 210.6mg/m^3 of exhaust SO_2

X_1 Value of Sulphur % in PMS ≡ 0.150 mg/m^3 (DPR ambient limit) ≡ X_2 (Exhaust amount required)

From the above X_1= 0.01% and X_2= 30.19 mg/m^3

Thus, the analysis to meet the level of 0.15 mg/m^3 ambient level of SO_2needsSulphur content of 0.01% maximum in the local PMS and a maximum of 30.19 mg/m^3 SO_2 level from vehicle exhaust.

4. DISCUSSION

4.1 Analysis of Observed Sulphur Dioxide at Intersections

The Department of Petroleum Resources (DPR) and Ministry of Environment (MENv) have failed to achieve its environmental goal as it concerns the limit on ambient level of SO_2 expected in the Nigerian Environment, especially at major intersections. Its limit of 0.1% on Sulphur content in PMS has resulted in producing high unhealthy level of ambient SO_2 measured in the environment. The question that arises from this is; If the Sulphur content limit of PMS is reduced beyond the recorded ranges distributed for use to Nigerian vehicles, would the ambient level of SO_2 reduce significantly. This research has shown that the DPR will need to reduce the Sulphur content in PMS used in Nigeria to approximately 0.01% to achieve its stated limit of 0.15 mg/m^3 concentration of ambient SO_2. From Table 5 we have estimated daily mean concentration of SO_2 at 0.03 mg/m^3 which falls below DPR's limit and what this means is that there are set of conditions that if met the present sulphur content (0.025-0.081) in PMS could achieve DPR's limit on ambient concentration of SO_2. From the data collected (See Table 2) it is seen that the two junctions compared have significantly different level of ambient SO_2 (Table 7) and yet their meteorological parameters (wind speed and solar radiation) are not significantly different. The significant difference between the SO_2 ambient level in Choba and Rumuokoro junctions are based on their daily traffic and hold times because they are significantly different.

Twelve random vehicles that use PMS distributed within Nigeria were sampled to measure the amount of SO_2 emitted from their exhaust (See Table 4). This activity showed a maximum exhaust SO_2 emission of 210.6 mg/m^3 from a 2004 model Toyota 4runner and minimum of 0.0mg/m^3 from a 2015 land cruiser. Linear calculations from section 3 showed that for DPR and MENv to achieve its environmental goal on ambient level of SO_2, it needs to reduce the sulphur content in PMS imported to a maximum of 0.01% and the exhaust emission on SO_2 should be limited to a maximum of 30.6 mg/m^3 which from the analysis in this work can be achieved by models of vehicles from 2012 and beyond (See Fig. 3).

4.2 Effect of Degradable Vehicles and Exhaust Test

The 0.01% Sulphur content attained by our calculations agree with New Zealand's proposed value for its sulphur content in PMS which it is working towards attaining in the nearest future (VEEA, 2016). Countries like New Zealand have seen that without proper policies to control degradable vehicles their set sulphur limits may not be effective in meeting their environmental goals and for this reason vehicles produced before the 1st of January 2014 are passed through compulsory exhaust test to see if the emissions from these vehicle exhausts are within allowable limits(VEEA, 2016). Degradability in vehicles is very deceptive most times because most vehicles that look new have either no catalytic converters or efficient one. A catalytic converter is a component within the exhaust line that helps to convert harmful gases emitted from the engine as a result of combustion, to less harmful substances. This method of treating exhaust gases is called the post combustion technique because it starts after the combustion has occurred [25]. It is for such reason that sampled vehicles such as the Toyota Land cruiser Prado 2015 model recorded zero mg/m^3 of SO_2though it uses the same PMS other sampled vehicles used. However, this is not to say sulphur in PMS is satisfactory but a good catalytic converter contains the harmful substance and converts it to something else within the exhaust line. This process basically tries to complete the combustion process by burning the remaining unburnt gases as a result of inefficiency of the engine. A good example is seen when we steam a very healthy engine such as the sampled Land cruiser, the SO_2 produced is converted to a weak acid which comes out as steam from the exhaust. With time this weak acid can also cause corrosion within the exhaust line. The number of vehicles for 2012 models and above were monitored and were used to approximate the percentage of these categories passing through the two junctions. Rumuokoro junction showed a maximum 25% of these categories passing through the junction in 2 hours while Choba junction showed a maximum of 11%.

4.3 Regression Modelling and Sensitivity Analysis

With the parameters in Tables 4 and 5, Equation (5) was developed and the goodness of fit of 0.99 was attained and in verification of the model a goodness of fit of 0.98 was attained. Sensitivity analysis carried out showed that the most significant parameters in the model were the traffic hold time and the number of 2012 vehicle models and above (See Table 7). Equations (6) was developed and used to produce design charts that can be used to read the value of predicted SO_2 based on traffic hold time. Equation (6) and chart on Fig. 8 can be used if the listed conditions are met;

Condition 1: Traffic hold time in the range of 3.4 – 12.4 minutes

Condition 2: Number of vehicles of 4 years old from current year in the range of 582 – 714

If the conditions above are satisfied then Fig. 9 can be used to predict SO_2 concentration at any major intersection. The scope to which the chart can handle can be widened when more intersections are analyzed based on the analysis proposed in this research.

Rumuokoro junction has more interrupted traffic than Choba junction, yet the ambient level of SO_2 at Choba junction is much higher than that of Rumuokoro junction. From monitoring activities within the Alakahia axis of East- West road on day 2, we recorded a daily average ambient level of SO_2 at 0.0mg/m^{3}and this point was selected because there was no traffic hold time. The minimum average daily speed measured was 30km/h. This research has shown that though traffic hold time is a major criterion to have traces of SO_2on our high ways, but the percentage of degradable vehicles that ply the highway within this interrupted period play a major role in the level of ambient SO_2.

4.4 Environmental Goal(s) on Emission and Related Risk

A country that is environmentally conscious towards its environment should define its degradability based on its proposed environmental goals and from this research, to satisfy Nigeria's set goal, a maximum of 30.6 mg/m^3 on the emission of SO_2 from any vehicle exhaust operating the highways should be set. This can be put as an act and enforced so vehicle owners will go for compulsory exhaust test as practiced in New Zealand. The hazards of using PMS with high sulphur content and the usage of degraded vehicles in our environment has a very high risk as shown with the calculations from OHSAS 18000: 2007 [24] method. If nothing is done soon these risks will manifest as incidence of deaths and illnesses given symptoms related to high ambient SO_2.

5. CONCLUSION

The following conclusions can be made from this research:

1. The SO_2 ambient level at major intersections in Nigeria is majorly contributed by vehicular emission as a result of the Sulphur content in PMS.
2. More vehicles of models from 2012 ply the Rumuokoro junction than the Choba junction and that was the major reason for the observed difference in ambient SO_2 concentration level between them.
3. The major variables that could reduce ambient level of SO_2 in intersections to meet DPR limits are sulphur content in PMS and the control of degradable vehicles that ply the roads.
4. To attain the DPR limit on ambient level of SO_2 the maximum exhaust emission of SO_2 should be limited to 30.2 mg/m^3 and this could be attained by allowing only vehicles that are 4 years old or less.
5. A design chart has been developed in this study and it is used to predict the concentration of ambient level of SO_2 given that they satisfy the listed conditions.
   i) **Condition 1**: Traffic hold time in the range of 3.4 – 12.4 minutes
   ii) **Condition 2**: Number of vehicles of 4 years old from current year in the range of 582 - 714
6. The hazards of using PMS with high sulphur content and the usage of degraded vehicles in the environment have a very high risk which were higher than that of OHSAS 18000:2007 limit.

6. RECOMMENDATION

The following are recommendations based on the findings in this research;

1. The Federal Ministry of Environment (FMEv) and Department of Petroleum Resources (DPR) should ensure and coordinate intensive vehicle exhaust test with the limit of the exhaust emission for SO_2 set at 30.2 mg/m^3.
2. If the point above is difficult for the DPR and FMEv.to achieve, then option 2 is to ensure that the PMS imported into the country has its sulphur content at 0.01% wt.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX-A

Table A-1. Potential hazard consequences (S)

S value	Loss	Description Human loss
100	Major accident	Many casualties
40	Significant accident	A few casualties
15	Very high	A casualty
7	high	Serious injuries
3	medium	Absenteeism
1	low	First aid treatment

Table A-2. Assessment of the likelihood (P)

P value	Description	% of chance
10	Very likely	50
6	Likely	10
3	Not likely but possible	1
1	Only sporadically possible	0.1
0.5	Possible to think of	0.01
0.2	Practically impossible	0.001
0.1	Only theoretically possible	0.0001

Table A-3. Assessment of exposure to hazard (E)

E value	Exposure description
10	Continuous exposure to hazard
6	Frequent (every day)
3	Sporadic (once a week)
2	Occasional (once a month)
1	Minimum (a few times per year)
0.5	Isolated (once a year)
0	Never

Table A-4. Reference quality assessment risk (R)

Risk category	Value
Slight	Below 20
Low	20-70
Medium	70-200
High	200-400
Very high	0ver 400

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