Acta Avionica
Volume XXIV, 46 – No. 1, 2022, DOI: 10.35116/aa.2022.0019

ESTIMATION OF SAFE PARTICULATES THRESHOLDS FOR BETTER RADIO SIGNAL STRENGTH USING RESPONSE SURFACE METHOD

Jimoh Olugbenga HAMED*, Wasiu Akande AHMED, Ganiyu Ishola AGBAJE, Adekunle Benjamin FALADE
African Regional Centre for Space Science and Technology Education in English, Obafemi Awolowo University Campus, Ile-Ife, Nigeria
Christopher Kenileh GBAGIE
Nigerian Army Signals, Nigerian Army, Arakan Barracks, Apapa, Lagos, Nigeria
Bisola Abigail OLANIYI
Engineering Space System, National Space Research and Development Agency, Abuja, Nigeria
Ismail Olusegun LAWAL
Advanced Aerospace Engines Laboratory, Oka-Akoko, Ondo, Nigeria
**Corresponding author.* E-mail: hamedjimoh45@yahoo.com

Abstract. The research formulated a mathematical model for evaluating the effects of particulates on radio signal strength. In the study, particulates such as oxides of nitrogen (NO_x), carbon monoxide (CO), oxides of Sulphur (SO_x), and particulate matter (PM_{10}) with corresponding meteorological parameters were obtained for Abuja, the capital territory from the Centre for Atmospheric Research (CAR). The Response Surface Method was adopted. The model was adopted to solve the formulated optimization problem for optimal levels of signal strength and analyze the results. The model calculated the corresponding signal strength at 106.3MHz of WE-FM radio station, Abuja within the period of 2001 and 2016. From the results, it was observed that the specific particulates investigated exhibited both linear and inverse relationships with signal strength. The relationship was anomalous. The coefficient of determination (R^2) for the model of NO_x, CO, SO_x, and PM_{10} in terms of radio signal strength was 0.9931 at a significant p-value of 0.0421. An optimal radio signal strength of 1.7562E+006 dB was obtained for safe particulate thresholds of NO_x, 1351.02, CO, 38342.43, SO_x, 77.92, and $PM_{10,}$ 96.95 kg/year respectively at a desirability of 0.999. It is, therefore, concluded that the mathematical model is promising, effective and efficient for predicting safe particulates thresholds for better radio signal strength.

Keywords: oxides of nitrogen; oxides of Sulphur; carbon monoxide; particulate matter; radio signal strength

1. INTRODUCTION

Wireless signals travel through the vacuum of outer space and the air [1]. The atmosphere surrounds the Earth and receives energy from the Sun. This atmosphere is unique among the planets in the Solar System. It shields Earth's surface from the harsh rays of the Sun; helps contain heat in the biosphere; and nourishes life on Earth [2]. Human activity has altered fundamental elements of the biogeochemical cycles of the Earth which atmosphere is saturated by the troposphere, stratosphere, mesosphere, and ionosphere [3]. In the earth's atmosphere, especially the troposphere there are various particles whose components are always influenced or altered the radio frequency signal transmission negatively. The previous studies and different experiments carried out on the effects of temperature and or relative humidity on radio frequency signal strength have shown categorically how signal strength was influenced by the following quantities pressure, temperature, and relative humidity even though the focus of this research is on evaluating the effects of particulates on radio signal strength.

The activities of man as mentioned above, contribute in no small measure to altering the structure of the atmosphere. This is generally referred to as air pollution. Airborne particulate matter represents a complex mixture of organic and inorganic substances. Mass and composition tend to divide into two principal groups: coarse particles mostly larger than 2.5 μm in aerodynamic diameter and fine particles mostly smaller than 2.5 μm in aerodynamic diameter ($PM_{2.5}$). The smaller particles contain the secondarily formed aerosols (gas-to-particle conversion), combustion particles, and re-condensed organic and metal vapours [4]. The larger particles usually contain Earth crust materials and fugitive dust from roads and industries. The fine fraction contains most of the acidity (hydrogen ion) and mutagenic activity of particulate matter; although, in fog, some coarse acid droplets are also present [5].

Particulate air pollution is a mixture of solid, liquid, or solid and liquid particles suspended in the air [6]. These suspended particles vary in size, composition, and origin. It is convenient to classify particles by their aerodynamic properties because: (i) they govern the transport and removal of particles from the air; (ii) they govern their deposition within the respiratory system; and (iii) they are associated with the chemical composition and sources of particles [7]. Particulate Matters (PM) can originate from natural processes (soil erosion, forest fires, and pollen dispersion) and human activities, typically from combustion processes, road transport, and vehicular traffic [5]. In developing countries, sources of air pollution range from transportation and industrial pollution, biomass burning, and coal fuel use, to suspended soil particles from unpaved roads. These sources are - to some extent different from those in many other regions. Air pollution in Africa appears to be rising with respect to key pollutants. Many studies have revealed the main cause of urban air pollution as the use of fossil fuels in almost all industrial and domestic sectors [8].

Having looked at the twin issues of the atmosphere and the nature of particulate matters, it is imperative that we consider radio waves as a type of electromagnetic radiation that is transmitted in wave or particulate forms. Radio waves are one part of the complete electromagnetic spectrum, which comprises; Gamma Rays, X-Rays, Ultraviolet Rays, Visible Light, Infrared Rays, Microwaves, and Radio Waves in descending and ascending order of their frequencies and wavelengths respectively [9]. These waves are different because they possess different properties. Their wavelengths and frequencies are the major properties that differentiate one wave from another. Both parameters are of inverse proportion, so that when one increases, the other decreases accordingly. On the electromagnetic spectrum, radio waves have the lowest frequency and highest wavelength. The radio frequency band ranges from 3 KHz to 300 GHz with a corresponding wavelength range of 100 Km to 1 mm [9].

Particles suspended in the atmosphere due to particulate matter emission can have consequences on the electromagnetic wave propagation. The electromagnetic wave signal may suffer from attenuation and cross polarization upon encounter with the suspended particles [5]. The main cause of attenuation is the conversion of electromagnetic energy into some other form of energy, such as heat. Assessing the air pollution by measuring all the compounds introduced into the air is impossible. For this reason, to evaluate the extent, it is preferred to detect only some compounds considered indicative to describe the phenomenon [10]. To estimate the attenuation in a communication system, it is necessary to take into account not only the attenuation due to the propagation medium but also all components of which the system is composed. In fact, the two mechanisms that can negatively interfere with the frequency spectrum utilization concern the signal attenuation and cross polarization. These phenomena are caused by the dispersion and absorption of the waves in the medium. These two mechanisms are at the base of signal attenuation and strongly depend on the dielectric constant and the particles' size [5].

Some researchers have indicated the presence of air pollution and the possibility of a significant cross polarization of the electromagnetic waves [5]. However, the possibility of significant attenuation due to these pollutants has received little attention. This paper examined the effects of particulates such as oxides of nitrogen (NO_x), carbon monoxide (CO), oxides of sulphur (SO_x) and particulate matter (PM_{10}) on radio signal strength. Additionally, it formulated a model for radio signal strength in terms of the mentioned particulates and then formulated and solved the optimization problem for optimal radio signal strength.

2. RESEARCH METHODOLOGY

2.1. Meteorological and particulate values

Meteorological data such as atmospheric temperature, pressure and relative humidity at the troposphere for the hosting site located in Abuja (9º 04¹ 38.64¹¹ N and 7º 23¹ 53.26¹¹ E) with corresponding particulates such as oxides of nitrogen (NO_x), oxides of sulphur (SO_x), carbon monoxide (CO) and particulate matter (PM_{10}) were obtained for gaseous pollutants in diesel combustion and gasoline combustion respectively as shown in Tab. 1. Abuja – the Federal Capital of Nigeria was considered for this study due to its reflection of variations in urban infrastructure such as the usual high traffic, large residential areas and other features. These represent typical industrial and medium residential areas, high-density residential areas and well-planned and secluded areas. The operational frequency considered was 106.3 MHz of WE-FM, located at No. 7 Rima Street, Maitama – Abuja. The samples obtained for the study site between 2001 and 2016 was based on availability of data [11]. The mathematical model was adopted to calculate the signal strength based on the atmospheric parameters [12]. Finally, samples of the particulates were modelled and optimized using Response Surface Methodology (RSM).

Table 1 Meteorological Readings with Emission Rate of Gaseous Pollutants in Diesel and Gasoline Combustion across Hosting Site

Year	NOx (Kg/yr) (N_1)	CO (Kg/yr) (N_2)	SOx (Kg/yr) (N_3)	PM10 (Kg/yr) (N_4)	Average Air Temp (˚C)	Average Pressure (Bar)	Average Relative Humidity (%)
2016	12695	333068	712	815	27.68	979	67.13
2015	17389	564296	935	1091	27.95	980	63.602
2014	10141	324746	547	637	28.07	980.7	60.383
2013	9269	306523	496	580	30.25	979	35.47
2012	6209	106940	369	411	25.58	958.7	68.61
2011	8163	82094	507	555	25.76	958	72.7
2010	1554	42846	86	99	26.37	958	71.08
2009	1351	38342	74	86	26.05	957.9	68.66
2008	57043	1367348	3247	3693	27.27	1007	79.91
2007	43528	1318911	2375	2753	27.41	1006	81.29
2006	19743	578421	1085	1254	28.75	1002	78.83
2005	14456	442848	787	913	30.72	988	70.57
2004	24156	361298	1456	1615	26.77	1005	79.57
2003	19996	339204	1190	1327	26.98	1005	79.66
2002	9138	155619	544	606	27.54	1004	78.15
2001	5606	143075	316	361	28.17	1003.7	71.25

The signal strength model formulated adopted as given in equation (1) [12].

$$y = 40754 - 2.120X_1 - 6.87X_2 + 5.57X_3 + 5.22X_1^2 - 2.72X_2^2 - 2.47X_3^2 - 3.2X_1X_2 - 1.46X_1X_3 + 7.58X_2X_3 \quad (1)$$

where y is signal strength; X_1, atmospheric temperature; X_2, atmospheric pressure and X_3, relative humidity.

2.2. Designed model development

The model was developed using a Response Surface Methodology (RSM). Generally, RSM is a combination of statistical and mathematical techniques used for developing, improving and optimizing systems. It also finds application in the design, development and improvement of existing product models [13]. Additionally, it relates product properties by using a regression equation that describes the interrelationship between input parameters and product properties [13]. In this study, the input parameters were particulates and the output variable considered was radio signal strength. Principally, as stated above, RSM adopts both mathematical and statistical techniques which are useful for the modelling and analysis of problems in which a response of interest is influenced by several independent variables and the objective is to optimize the response [14]. The objective of quality improvement, including reduction of variability and improved process and product performance could often be accomplished directly using the mathematical approach. In this methodology, the quantitative interrelationship between the desired response and independent input variables is represented as shown in equation (2):

$$y = f(N_i) \tag{2}$$

where f is the response function and N_i represents oxides of nitrogen, oxides of sulphur, carbon monoxide and particulate matter in gasoline and gaseous pollutants in diesel combustion across the hosting site. In order to study the effects of the particulates on radio signal strength, a second order polynomial response surface was fitted into the following equation (3):

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i N_i + \sum_{i=1}^{k} \beta_i N_i^2 + \sum{}_i \sum{}_j \beta_{ij} N_i N_j + \varepsilon \tag{3}$$

where y is the corresponding response, N_i are the values of input parameters, β are regression coefficients and ε is the residual measure resulting from the experimental error in the observations. Using Analysis of Variance (ANOVA), the significance of the input parameters was evaluated. Design-Expert software Version 6.0.8 was used to establish the design matrix, to analyse the meteorological data and to fit it into the second order polynomial. Sequential F test and adequacy test were used to check and observe the model's performance.

2.3. Optimization model for signal strength

An optimization problem was formulated to maximize signal strength subject to particulate parameters from gaseous pollutants in diesel and gasoline combustions such as oxides of sulphur and nitrogen, carbon monoxide and particulate matters as given in equation (4):

$$\text{Maximize } y = f(N_i),\ (i = 1,2,3.....) \text{ Subject to: } -1 \le N_i \le 1 \tag{4}$$

where N_i are coded variables for particulates (oxides of sulphur, oxides of nitrogen, carbon monoxide and particulate matters) and y is the response variable for signal strength.

3. RESULT AND DISCUSSION

3.1 Effect of particulates on radio signal strength

The results of the calculation obtained from the model adopted are presented in Tab. 2. The table shows the combined effects of the emission rate in gasoline combustion and gaseous pollutants in diesel combustion within a period of 16 years in Abuja, Nigeria. As could be observed from the table, there exists an inconsistent pattern of correlation between particulates and signal strength. This research examines the patterns accordingly.

3.2 Performance model for signal strength

In developing the mathematical model for signal strength, regression analysis was conducted. The effects of model orders such as main, linear, quadratic and interaction were calculated for the model. The regression coefficient as well as correlation coefficient are depicted in the model equation for signal strength. Using Design-Expert software Version 6.0.8, a quadratic model was fitted to the experimental results. The best model was fitted according to the following main criteria: high *F*-value, low *P*-value (<0.05), insignificant lack of fit, high R^2 (>0.90), low standard deviation, a randomly scattered plot, and whether it is able to predict well the validation set [14]. The correlation coefficient for signal strength response was 0.9931 (R^2 = 0.9931). This is quite high for response surface and indicates that the fitted quadratic model accounts for more than 99% of the variance in the experimental data. This was found to be highly significant. Based on t-test, the regression coefficients that were not significant at 95% were discarded while only those that were significant were selected for developing the signal strength model equation represented as equation (5):

Table 2 Effect of Particulates on Radio Signal Strength (WE-FM 106.3 MHz, Abuja)

Year	NO_x (Kg/yr) (N_1)	CO (Kg/yr) (N_2)	SO_x (Kg/yr) (N_3)	PM_{10} (Kg/yr) (N_4)	Signal Strength (dB)
2016	12695	333068	712	815	-2211729.859
2015	17389	564296	935	1091	-2242384.149
2014	10141	324746	547	637	-2269029.474
2013	9269	306523	496	580	-2444959.238
2012	6209	106940	369	411	-2096849.084
2011	8163	82094	507	555	-2065882.095
2010	1554	42846	86	99	-2078787.347
2009	1351	38342	74	86	-2094041.254
2008	57043	1367348	3247	3693	-2257692.490
2007	43528	1318911	2375	2753	-2243229.915
2006	19743	578421	1085	1254	-2245156.500
2005	14456	442848	787	913	-2240693.184
2004	24156	361298	1456	1615	-2248688.787
2003	19996	339204	1190	1327	-2248682.898
2002	9138	155619	544	606	-2256285.842
2001	5606	143075	316	361	-2306414.183

$$y = -2.19584E + 006 + 61096.51088N_1 - 409.15357N_2 - 1.32887E + 006N_3 + 3.76179E + 005N_4 - 5721.95043N_1^2 - 0.19025N_2^2 - 1.36542E + 006N_3^2 + 1.67090E + 005N_4^2 + 66.81714N_1N_2 + 1.89394E + 005N_1N_3 - 14567.94346N_1N_4 - 1043.49146N_2N_3 + 26.80192N_2N_4 - 1.36204E + 005N_3N_4 \quad (5)$$

$$R^2 = 0.9931 \quad (6)$$

where y is signal strenghth, N_1, N_2, N_3 and N_4 represent NO_x, CO, SO_x and PM_{10} respectively. Generally, the constant variable in the model is the intercept and represents the average of all n observations. The generated model contains quadratic terms, which explains the nonlinear nature of the responses and multiple factor terms explaining interaction effects between factors. It could be observed from the model that the oxides of nitrogen (NO_x) and particulate matter (PM_{10}) have negative linear effects while the oxides of sulphur (SO_x) and carbon monoxide (CO) have positive linear effects on signal strength. Also, NO_x, SO_x and CO have negative quadratic effects while PM_{10} has a positive quadratic effect on signal strength. Consequently, it was observed that the interaction effect in particulates was statistically significant on signal strength. In addition, the interactive effect between the parameters was more substantial on the signal strength than the linear and quadratic effects.

The model was tested for goodness of fit and coefficient of determination *(R^2)*. Fig. 1 shows the predicted radio signal strength values (derived from the model) versus actual radio signal strength values (obtained from the historical data). This figure shows that the model was successful in capturing the correlation between the mixture components with R^2 of 0.9931.

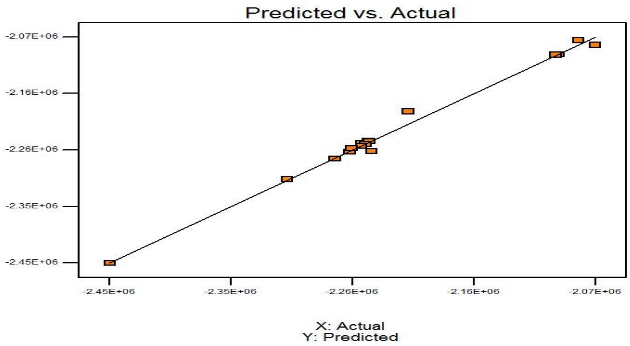

Figure 1. Scatter Plot of Predicted Radio Signal Strength versus Actual Radio Signal Strength from Response Surface Experimental Design

3.3 Adequacy test of signal strength model

The fitted model was tested for adequacy and consistency by analysis of variance (ANOVA). The details of ANOVA for the model equation are presented in Tab. 3. It was used to assess how well the model represent the design data. The result from the statistical analysis revealed that the "Model F-value" for signal strength was 10.21 and the adjusted R Square (adj. R^2) value was 0.8958. Values of "Prob > F" less than 0.0500 indicate that model terms are significant. In this design, there is a significant model term p-value of 0.0421. On these bases, it can be ascertained that the selected model was suitable for the analysis and could adequately represent the data for signal strength.

Table 3 Analysis of Variance (ANOVA) of the Fitted Linear/Quadratic Equation for Signal Strength

Source of Variation	Sum of Squares	DF	P-Values	Adjusted R-Squared	F-values	Mean Square
Model	1.407E+011	14	0.0421	0.8958	10.21	1.005E+010
Residual	9.844E+008	1				9.844E+008
Total	1.417E+011	15				

*Significant level at $p < 0.05$

3.4 Response surface plots

The response surfaces were plotted for the relationship between the independent and dependent variables for the selected model equation. Given that there are four variables in this experiment, each response surface was plotted for signal strength with different combinations of two variables at a time while maintaining the other variables at constant levels. The convex response surfaces suggest that there are well-defined optimal variables. If the surfaces are rather symmetrical and flat near the optimum, the optimized values may not vary widely from the single variable conditions [12]. The 3-D and interactions graph representation of response surface shown in Fig. 2 helps to visualize the effects of oxides of nitrogen and carbon monoxide on radio signal strength. The figures show the effects of combining both variables in relation to signal strength. It was observed that at low values of NO_x and CO, signal strength was at around -4.32057E+012. However, the signal strength increased with an increase in the value of NO_x and reached its optimum level when NO_x was at 0.00 levels. Simultaneously, the signal strength dropped as CO increased, until it got to its minimum value of -5.76111E+012.

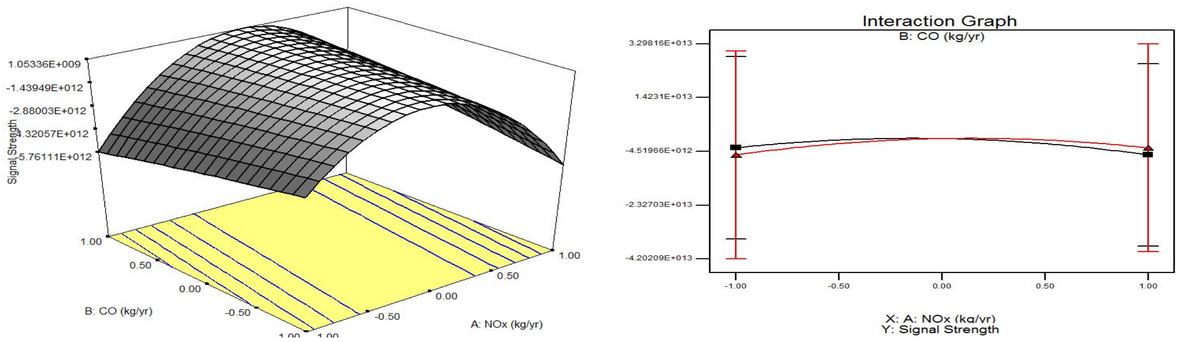

Figure 2. 3-D and Interaction Response Surface Plot showing the effect of Oxides of Nitrogen and Carbon Monoxide on Radio Signal Strength

Similarly, Fig. 3 shows the effects of combining NO_x and SO_x in relation to signal strength. Like before, the highest value of signal strength (5.01043E+011 dB) was attained when both independent variables were at their least levels. Consequently, the signal strength decreased to its least value of around -1.62481+013 dB as the values of the particulates increased from -1.00 to 1.00. Furthermore, Fig. 4 shows the interaction of NO_x and PM_{10} with respect to the signal strength. In this case, the signal strength improved to an optimal value when NO_x was at 0.00 in the coded process factors on the plot. Initially, signal strength was at its weakest value when both particulates were at -1.00.

However, after the optimal point, the signal strength decreased with an increase in particulates. It is imperative to note that the effect of the particulates of the signal strength after the optimal point is insignificant.

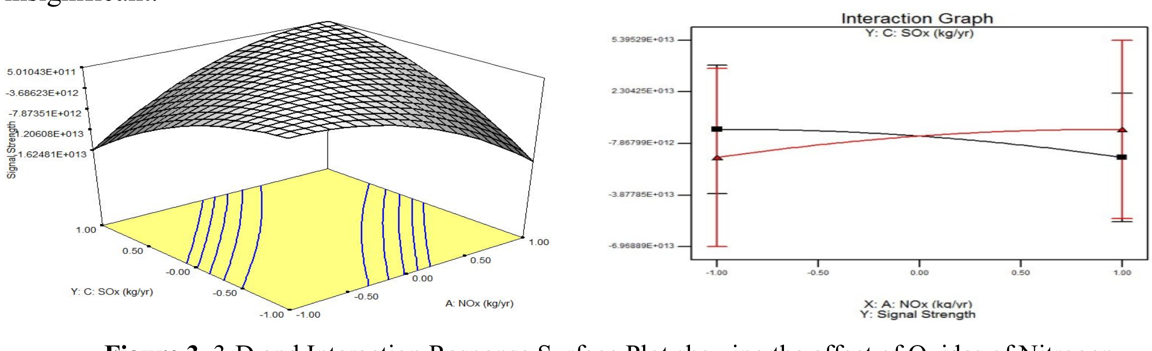

Figure 3. 3-D and Interaction Response Surface Plot showing the effect of Oxides of Nitrogen and Sulphur on Radio Signal Strength

The situation in Fig. 5 is similar to Fig. 4, though with a slight twist. The signal strength was observed to be at its minimum when both SO_x and CO were at their lowest levels. As they increased from -1.00 to 1.00, signal strength also increased to an optimum level but declined to -2.3123E+012 dB with respect to SO_x. However, the signal strength reached the same level with respect to CO in an incremental mode. Fig. 6 shows the interaction between CO and PM_{10} with respect to signal strength. Its response is uniquely different from the previous cases. At their least values, depicted as -1.00, the signal strength was relatively high at about 3.898E+011 dB, but not at its peak level. As both parameters increased, the signal strength also decreased and got to its minimum value when PM_{10} was at 0.00 level. However, simultaneously, it attained an optimal value with respect to CO at 0.00 before declining to 3.898E+011 dB with the continual increase in CO.

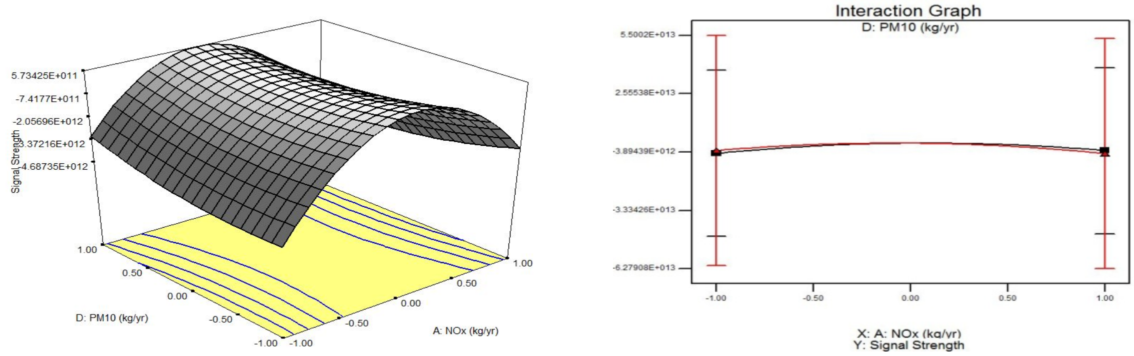

Figure 4. 3-D and Interaction Response Surface Plot showing the effect of Oxides of Nitrogen and Particulate Matters on Radio Signal Strength

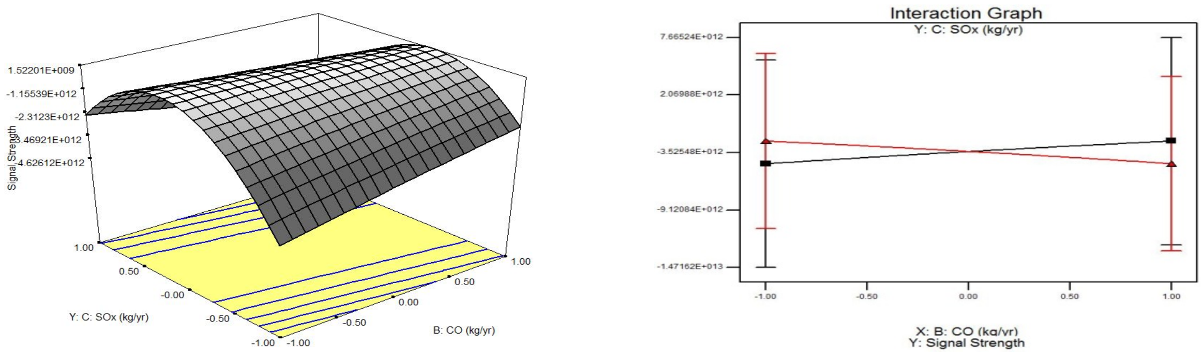

Figure 5. 3-D and Interaction Response Surface Plot showing the effect of Carbon Monoxide and Oxides of Sulphur on Radio Signal Strength

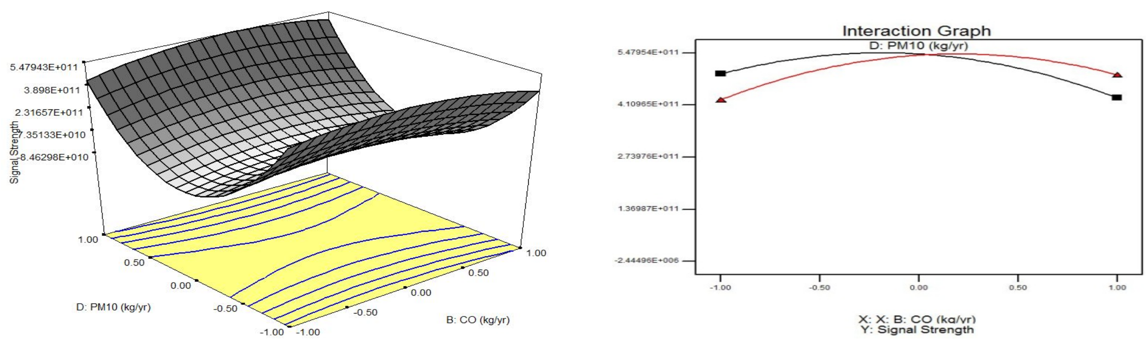

Figure 6. 3-D and Interaction Response Surface Plot showing the effect of Carbon Monoxide and Particulate Matter on Radio Signal Strength

Finally, Fig. 7 represents a correlation between SO_x and PM_{10} with respect to signal strength. It was observed that at the least values of the particulates, signal strength was at its minimum (somewhere around -3.50968E+012 dB). Incidentally, the signal strength improved with an increase in the value of SO_x and PM_{10}, reaching its peak level when SO_x was at 0.00 levels. However, the signal strength decreased as the particulates increased further.

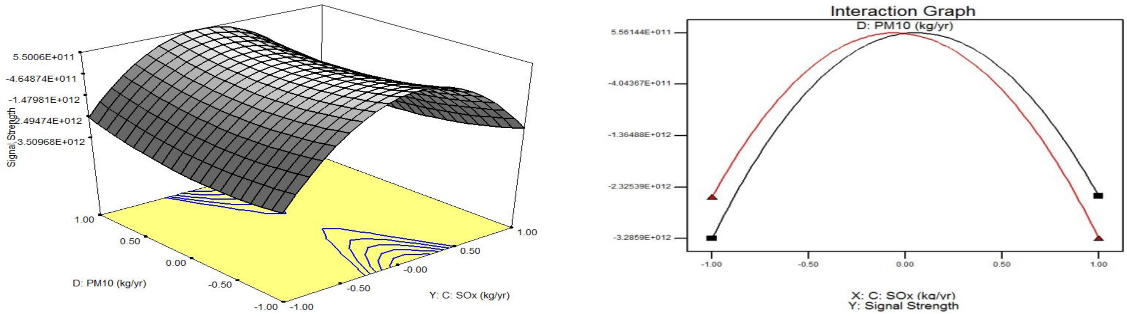

Figure 7. 3-D and Interaction Response Surface Plot showing the effect of Oxides of Sulphur and Particulate Matter on Radio Signal Strength

Based on the analysis carried out on the effect of particulates on signal strength, it could be observed that there exists an anomalous relationship between the former and the latter. This, however, is consistent with the result obtained by a similar work on an investigation into the effect of Atmospheric Particulate Matter ($PM_{2.5}$ and PM_{10}) concentrations on GPS signals. It was observed that there was no any significant impact of high $PM_{2.5}/PM_{10}$ concentration on GPS signal propagation with the presented empirical method for the six data sets collected [13]. In addition, the study carried out on air pollution effects over the intensity of the received signal in the 3G/4G mobile terminal shows that there were no significant variations in the Received Signal Levels [5]. Consequent upon the foregoing, the study agreed with the literature.

3.5 Optimization of signal strength

The response surface methodology was used for the optimization for understanding the factors affecting signal strength. The model was useful for indicating the direction in which to change variables in order to maximise signal strength. The regression equation was solved for maximum signal strength. The optimum signal strength obtained was -1.7562E+006 dB. The actual particulates at the optimum value were 1351.02, 38342.43, 77.92 and 96.95 kg/yr for NO_x, CO, SO_x and PM_{10} respectively. The optimum particulates (coded) predicted for corresponding response are presented in Tab. 4. As shown in the Table, the coded level lies within the experimental range and this indicated the validity of the variables' range.

In the optimization process, the target criteria (signal strength) was set at maximum value while the particulates were set at minimum values. The main aim was to find the optimum process parameters that favoured improved radio signal strength. Therefore, the desirability function was applied using Design-Expert Software version 6.0.8. Consequently, Fig. 8 shows the ramp of numerical optimization in response surface methodology for NO_x, CO, SO_x and PM_{10} with radio signal strength of 1.7562E+006 dB. Thus, the optimum operating conditions for radio signal strength, as shown in the Figure were NO_x 1351.02, CO, 38342.43, SO_x, 77.92 and PM_{10}, 96.95 kg/yr respectively at a desirability of 0.999.

Table 4. Optimal Particulates for Signal Strength

Particulates (Coded)				Optimal Signal Strength	
N1	N2	N3	N4	Actual Value (dB)	Desirability
-0.999	-0.999	-0.998	-0.994	1.7562E+006	0.999

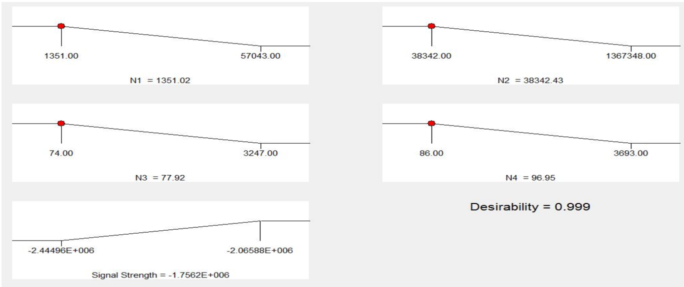

Figure 8. Ramp of Numerical Optimization in Response Surface Methodology for NOx, CO, SOx and PM_{10} of Radio Signal Strength

4. CONCLUSION

This research focused, specifically, on the effects of oxides of nitrogen and sulphur (NO_x and SO_x), carbon monoxide (CO) and particulate matter (PM_{10}) on radio signal strength. The various measured parameters, which include the particulate matter, have been shown to affect the signal strength. Generally, unlike atmospheric parameters – temperature, pressure and relative humidity – which have a consistent and well-defined inverse relationship with radio signals, particulates have been observed to exhibit inverse, as well as, linear relationships with radio signals. The consequence of this is that, at times radio signal strength increased with a corresponding decrease in the concentration of particulates while at other instances, radio signal strength increased with increase in particulates in the atmosphere. The correlation between the particulates is not proportionate, reason being that the agents that produce the pollutants vary from place to place. Therefore, the research establishes an optimization approach for predicting safe thresholds below which pollutants must be maintained to curtail signal attenuation and engender better radio signal propagation. This study results allow the designers of communication links and a network engineer to improve their model such that the effects of these parameters measured will be minimal on radio signal strength especially in the study area considered for the research.

References

[1] Nagaraja, M.P. Anatomy of an Electromagnetic Wave. NASA Publication. Available at: https://science. nasa.gov/ems/02 anatomy. Accessed on 19 September 2019.

[2] Moskowitz, C. What Makes Earth Special Compared to Other Planets. Online Publication on Science and Astronomy. Available at: https://www.space. com/5595-earth-special-compared-planets. html. Accessed on 19 September 2019.

[3] Godish, T., Wayne T.D. and Joshua S.F. Air Quality Published by CRC Press – Taylor & Francis Group, 6000 Broken Sound Parkway - New York, Suite 300 Boca Raton, FL 33487-2742. ISBN- 13:978-1-4665-8444-0 (Hardback). 2015; 11-12.

[4] Dietrich, S. and Olivier, Z. Urban Traffic Pollution. Publishers: E & FN Spon, an inprint of Routledge, 11 New Fetter Lane, London EC4P 4EE. ISBN- 0 419 237208. 1999; 24.

[5] Grazia, L. S. Air Pollution Effects on the Intensity of Received Signal in 3G/4G Mobile Terminal. International Journal of Energy and Environmental Engineering. 2019; 10: 221–229.

[6] Yi-Yang, J., Wang, Q., and Liu, T. Toxicity Research of $PM_{2.5}$ Compositions in Vitro. International Journal of Environmental Research and Public Health. Publisher: National Centre for Biotechnology Information, U.S. National Library of Medicine, 8600 Rockville Pike, Bethesda MD, 20894 USA. 2017.

[7] WHO. Particulate Matter. Air Quality Guidelines - Second Edition, WHO Regional Office for Europe, Copenhagen, Denmark, 2000. Chapter 7.3, pp 1–2.

[8] Munoz, L., Delgado, J. and Rodriguez, V. Measurement of air pollution with low-cost technology, *2018 13th Iberian Conference on Information Systems and Technologies (CISTI)*, 2018; pp. 1-5, doi: 10.23919/CISTI.2018.8399368.

[9] Abramowitz, M., Thomas, J.F. and Michael, W.D. The Nature of Electromagnetic Radiation. Online Publication by the Florida State University. Available at https://micro.magnet.fsu.edu/primer/lightandcolor/electromagintro.html. Accessed on 19 September 2019.

[10] Kodali, R. K., Pathuri, S. and Rajnarayanan, S. C. Smart Indoor Air Pollution Monitoring Station, *2020 International Conference on Computer Communication and Informatics (ICCCI)*, 2020; pp. 1-5, doi: 10.1109/ICCCI48352.2020.9104080.

[11] Ezeh, G.C., et al. Trace Metals and Source Identification of Air-Borne Particulate Matter Pollution in a Nigerian Megacity. Journal of Environmental & Analytical Toxicology, 2017; volume 7, issue 3. ISSN: 2161-0525. pp 1.

[12] Hamed, J. O., et al. Estimation of Optimal Atmospheric Condition for WE-FM Radio Station in Abuja. Anale. Seria Informatică. 2019; Vol. XVII fasc. 2. pp 109 – 120.

[13] Raymond, H.M., Douglas, C.M., and Christine, M.A. Response Surface Method: Process and Product Optimization using Designed Experiments. Third Edition. Hoboken, New Jersey: John Wiley and Sons Inc., 2009.

[14] Montgomery D.C. Design and Analysis of Experiments. New York: Wiley, 2001.

Received 03, 2022, accepted 07, 2022