Factorial Analysis of Soil pH as a Function of Its Moisture Content and Distance from Flare Point

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Abstract— *This paper presents a derived model which predicts the soil pH based on its soil moisture content and distance from flare point. The response coefficient of the soil pH to the distance from flare point and soil moisture content was evaluated to ascertain the viability and reliability of the highlighted dependence. Results of series of evaluations carried out indicate that the correlations between soil pH and distance from flare point & soil moisture content as evaluated from the actual and model-predicted results were all > 0.88. Standard errors incurred in obtaining results of soil pH based on distance from flare point & moisture content were 0.08 and 0.07 & 0.076 and 0.06%, as obtained from actual and model-predicted results respectively. The validity of the model;* $\xi = -0.0496\beta^2 - 1.5\,x10^{-7}\vartheta + 0.7122\beta + 0.0003\vartheta + 2.5408$ *was rooted on the insignificant maximum deviation of model-predicted values of soil pH from the corresponding actual values which was less than 1.1%. This translated into over 98.9% operational confidence level for the derived model as well as over 0.98 response coefficient of soil pH to the combined operational influence of distance from flare point and soil moisture content.*

Keywords— Analysis, soil pH, distance from flare site, and soil moisture content.

I. INTRODUCTION

Investigations [1] carried out to measure physicochemical parameters in flare sites have shown that pH of soil and rain-water samples are acidic in nature if collected at varied distances of 20, 50 and 100 m from flare points. This implies presence of acid rains and acid soils around the flare locations. The results of the investigation also reveal that soils and rain water are contaminated by heavy metals such as Cr, Cd, As, Pb, Zn, Fe. The research findings further show that higher concentration of air quality parameters (such as SO_2, NO_2, H_2S, CO, VOC, SPM etc.) exists at least distances near the flare point and lower values at distances farther away from flare point.

Research [2] has shown that apart from the fact that gas flaring activities in the Niger-Delta region pose very serious environmental implications on the host communities, it is an economic wastage of natural resource to Nigeria. For example, acid compounds are formed when NOx and SO_2 gases contained in gas flares reacts with water. This has placed gas flaring as being responsible for the acid rain syndrome often experienced in the Niger Delta region.

It has been revealed [1] that high pollution loads are imposed on gas flaring environments arising from increased pH of soil and acid rain concentrations (due to gas emissions), abnormal air temperature (due to flare radiation), heavy metal concentration and poor air quality due to flare emissions (particularly CO, NO_2, SO_2, smoke and particulate matter contents). This has impacted negatively on human habitats and as a result, no meaningful human activity can take place at gas flaring locations within radial distances < 2 km away from flare point.

Some undermining effects of gas flaring on locations and its inhabitants has been reported [3] to include poor soil fertility (due to soil pH, heavy metals and toxics pollution), health hazards (such as skin problems, cancer, reproductive health problems, respiratory disorders etc.), climate change (bringing about flooding).

Some research works [4], [5],[6] and [7] have corroborated earlier finding [3] that gas flaring is also the major cause low agricultural productivity, depleted success in fishing and hunting due to incessant acid rain. This causes impoverishment in the Niger Delta. The poor agricultural activities were observed [4] to be as a result of release of some substances which alters the surface and ground water quality, aggregate nutrient deficiencies in soils, or accelerate the soiling, weathering or corrosion of engineering and cultural materials. Furthermore, visible changes exist in soil characteristics close to a flare site.

Factors such as distance of sample from source of flare, duration of flare and height of flare stack have been observed [1] to absolutely affect the distribution (or spread) of soils physicochemical parameters in a gas flaring environments. These research outputs are in line with earlier report [8] where soil pH values changed from acidic to near neutral as soil samples were collected some distances away from flare point.

Results [9] of insitu and laboratory tests indicate that gas flare effect pH, temperature and moisture content of soils negatively. The results reveal that pH showed the least value (most acidic) of 5.12 at depth of 5cm and distance of 200m away from the flare. The soil temperature at 200m and 5cm depth, recorded the highest value (39.7^{0}C) and the least value (27^{0}C) at 35000m (control site) away. The least value for moisture content (5.83%) was recorded at 200m and the highest (15.38%) at the control site.

This work attempts to derive a model which will predict the soil pH based on its soil moisture content and distance from flare point.

TABLE 1
VARIATION OF SOIL PH WITH ITS MOISTURE CONTENT AND DISTANCE FROM FLARE POINT [10]

(ϑ) (m)	(β)	(ξ)
200	5.83	5.09
500	8.13	5.12
750	7.68	5.25
1000	7.11	5.27
1200	6.58	5.18
1500	6.35	5.12

II. MATERIAL AND METHOD

2.1 Model formulation

Computational analysis (using C-NIKBRAN [11]) of results in Table 1 indicates that

$$\xi - K = -Ѣ\beta^2 - S\vartheta^2 + N\beta + C\vartheta \tag{1}$$

Introducing the values of Ѣ and K into equation (1) reduces it to

$$\xi - 2.5408 = -\ 0.0496\ \beta^2 - 1.5\ \text{x}10^{-7}\vartheta + 0.7122\beta + 0.0003\vartheta \tag{2}$$

$$\xi = -\ 0.0496\ \beta^2 - 1.5\ \text{x}10^{-7}\vartheta + 0.7122\beta + 0.0003\vartheta + 2.5408 \tag{3}$$

Where

(ϑ) = Distance from flare point (m)

(ξ) = Soil pH at distance ϑ from flare point (%)

(β) = Soil moisture content at distance ɣ where the soil pH was evaluated

K , Ѣ, S, N and C are equalizing constants; 2.5408, 0.0496, 1.5 X10^{-7}, 0.7122 and 0.0003 respectively.

III. BOUNDARY AND INITIAL CONDITIONS

The ranges of distance from flare site, soil pH and soil moisture content are 200 -1500m, 5.09- 5.27, and 5.83 – 8.13(%) respectively.

IV. RESULTS AND DISCUSSION

4.1 Model validation

Validation of the model was carried out by statistical, graphical and deviational methods.

TABLE 2
VARIATION OF $\xi - 2.5408$ with $- 0.0496\beta^2 - 1.5 \times 10^{-7}\vartheta + 0.7122\beta + 0.0003\vartheta$

$\xi - 2.5408$	$- 0.0496\beta^2 - 1.5\times10^{-7}\vartheta + 0.7122\beta + 0.0003\vartheta$
2.5492	2.5203
2.5792	2.6243
2.7092	2.6848
2.7292	2.7063
2.6392	2.6794
2.5792	2.635

The derived model was rooted in equation (2). Equation (2) agrees with Table 2 following the values of $\xi - 2.5408$ and $- 0.0496\beta^2 - 1.5 \times 10^{-7}\vartheta + 0.7122\beta + 0.0003\vartheta$ evaluated from Table 1.

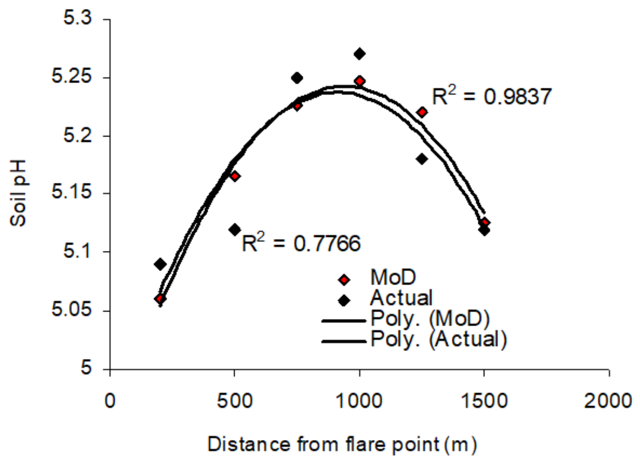

FIGURE 1: Comparison of the correlations of the actual and model-predicted soil pHs (relative to distance from flare point)

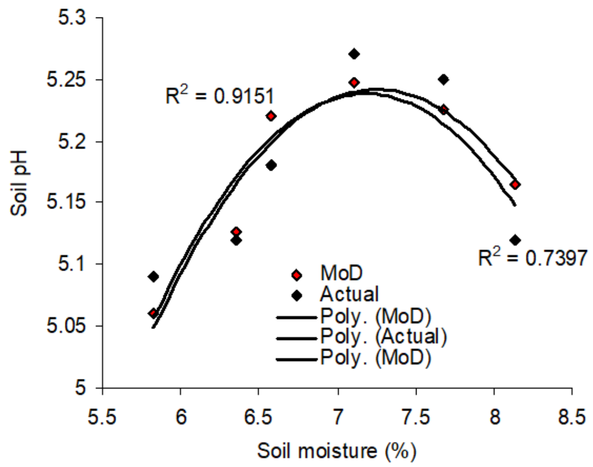

FIGURE 2: Comparison of the correlations of the actual and model-predicted soil pHs (relative to soil moisture)

4.2 Statistical Analysis

4.2.1 Standard Error (STEYX)

The standard errors incurred in predicting the soil pH for each value of the distance from flare point & soil moisture content considered as obtained from actual and derived model were 0.08 and 0.07 & 0.076 and 0.06 % respectively. The standard error was evaluated using Microsoft Excel version 2003.

4.2.2 Correlation (CORREL)

Comparison of the correlations of the actual and model-predicted soil pHs relative to both distance from flare point and soil moisture content were evaluated (using Microsoft Excel Version 2003) from results of the actual and derived model. These evaluations were based on the coefficients of determination R^2 shown in Figs. 1 and 2.

$$R = \sqrt{R^2} \tag{4}$$

These correlations are 0.9918 & 0.8812 and 0.9566 & 0.8601 respectively. These evaluated results indicate that the derived model predictions are significantly reliable and hence valid considering its proximate agreement with results from actual experiment.

4.3 Graphical Analysis

Analysis of Figs 3 and 4 shows close alignment of the curves of model-predicted soil pH (relative to distance from flare point and soil moisture content) and those from the actual results.

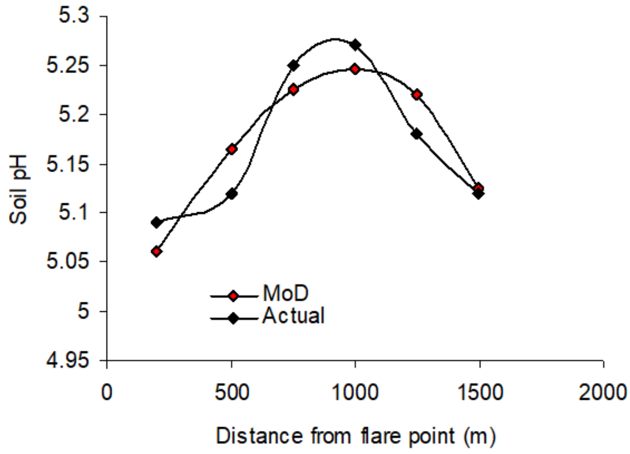

FIGURE 3: Comparison of the soil pHs (relative to distance from flare point) as obtained from actual and model-predicted results

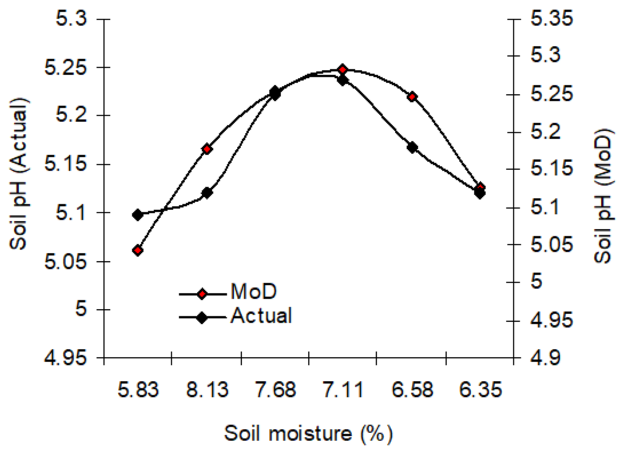

FIGURE 4: Comparison of the soil pHs (relative to soil moisture content) as obtained from actual and model-predicted results

Figs.3-4 strongly indicates that the degree of alignment of curves is indicative of the proximate agreement between both actual and model-predicted values of soil pH. This also indicates that the derived model is valid, reliable and of very high operation confidence.

4.4 Deviational Analysis

Analysis of soil pH as obtained from actual and derived model show deviation of model-predicted values from those of the actual. This is believed to be due to the fact that some considered assumptions and experiment-oriented conditions which prevailed during the actual field work were not considered during the model formulation. This necessitated the introduction of correction factor, to bring the model-predicted values to those of the actual.

Deviation (Dv) (%) of the model-predicted soil pH from that of the actual is given by

$$Dv = \frac{\xi p - \xi a}{\xi a} \times 100 \tag{5}$$

Where

ξp = Model-predicted soil pH

ξa = Soil pH evaluated from actual results

Table 3 shows that the least and highest deviations of model-predicted results (from actual results) are – 0.43 and + 1.09%. These deviations correspond to model-predicted soil pHs: 5.2471 & 5.1758; distance from flare points: 1000 & 1500m, and soil moisture content: 7.11 & 6.35% respectively.

TABLE 3
ACTUAL SOIL PH AND CORRESPONDING PERCENT DEVIATION OF MODEL-PREDICTED RESULTS

(ξ)	Dv (%)	Cf(%)
5.09	-0.57	0.57
5.12	0.88	-0.88
5.25	-0.46	0.46
5.27	-0.43	0.43
5.18	0.78	-0.78
5.12	1.09	-1.09

Correction factor (Cr) is the negative of the deviation i.e

$$Cr = - Dv \tag{6}$$

Therefore

$$Cr = -100 \left\{\frac{\xi p - \xi a}{\xi a}\right\} \times 100 \quad (7)$$

Introduction of the corresponding values of Cf from equation (7) into the model gives exactly the corresponding actual values.

Equations (6) and (7) show that correction factor is the negative of the deviation. It is strongly believed that the correction factor takes care of the assumptions made and experimental condition prevailing during the field works which were not considered during the model formulation.

Table 3 also revealed that the least and highest deviations of model-predicted results (from actual results) are + 0.43 and -1.09%. These deviations also correspond to model-predicted soil pHs: 5.2471 & 5.1758; distance from flare points: 1000 & 1500m, and soil moisture content: 7.11 & 6.35% respectively.

The deviation of model predicted results from that of the actual is just the magnitude of the value. The associated sign preceding the value signifies that the deviation is deficit (negative sign) or surplus (positive sign).

V. CONCLUSION

Following derivation of a model for prediction of the soil pH based on its soil moisture content and distance from flare point, the correlations between soil pH and distance from flare point & soil moisture content as evaluated from the actual and model-predicted results were all > 0.88. Standard errors incurred in obtaining results of soil pH based on distance from flare point & moisture content were 0.08 and 0.07 & 0.076 and 0.06%, as obtained from actual and model-predicted results respectively. The validity of the model; $\xi = - 0.0496\ \beta^2 - 1.5 \times 10^{-7}\vartheta + 0.7122\beta + 0.0003\vartheta + 2.5408$ was rooted on the insignificant maximum deviation of model-predicted values of soil pH from the corresponding actual values which was less than 1.1%. This translated into over 98.9% operational confidence level for the derived model as well as over 0.98 response coefficient of soil pH to the combined operational influence of distance from flare point and soil moisture content.

REFERENCES

[1] Uyigue L, and Enujekwu F. M.(2017). Physicochemical Analysis of Gas Flaring Impact on the Environment of Host Communities in the Niger-delta. Journal of Environment Pollution and Human Health, 5(1): 22-29. doi: 10.12691/jephh-5-1-4.

[2] Sonibare, J. A. and Akeredolu, F. A. (2004). A review of the usefulness of gas flares in air pollution control. Management of environmental quality: An international journal, 15(6): 574-583.

[3] Ajugwo, A. O. (2013). Negative effects of gas flaring: The Nigerian Experience. Journal of Environmental Pollution and Human Health. 1(1), 6-8.

[4] Alakpodia. I.J, Soil characteristics under gas flare in the Niger Delta, Southern Nigeria. Geo-studies forum.1 (1 and 2): 2000, 1-10.

[5] Dauda. O.D, Socio-economic and Environmental problems associated with oil spillage in the Niger Delta,(M.Sc. Thesis), 2001, School of Environmental sciences, Imo State University. Owerri, Nigeria

[6] Odjugo. P.A.O, Health Safety and Environment: Challenges of the Environmental Health. Officers in the present democratic dispensation. Paper presented at the 3rd Delta State Triennial delegates conference/NEC meeting held at Asaba, Delta State, Nigeria, 13- 15 June, 2002.

[7] Akudo, E.O, Fezighe, I.O and Ossai-Abeh, E (2012). The Impact of Distance on Soil Temperature and Moisture Content in a Gas Flare Site., African Journal of Physical Sciences, 5(2)

[8] Ubani, E. C. and Onyejekwe, I. M. (2013). Environmental impact analyses of gas flaring in the Niger-Delta region of Nigeria. American Journal of Scientific and Industrial Research.4(2), 246-252.

[9] Ernest A. Orji, Boniface C.E. Egboka , Asheshe U.S and Dio B.A(2015). Influence of Gas Flaring on some physical Properties of Soils in Kwale, Delta State. IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT) Ver. I, 9(8):52-57

[10] E. A. Orji, B. C. E. Egboka, U. S. Asheshe and B. A. Dio (2015). Influence of Gas Flaring on Some Physical Properties of Soils in Kwale, Delta State. IOSR Journal of Environmental Science, Toxicology and Food Technology, 9(8) 52-57.

[11] Nwoye, C. I. (2008). Data Analytical Memory; C-NIKBRAN.