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GAS FLARING AND SOIL QUALITY DYNAMICS IN LOWLAND RAINFOREST ENVIRONMENT OF DELTA STATE, NIGERIA

ODIETE, AMANDA OKEFE AND NDAKARA, OFUDJAYE EMMANUEL
Email: ndascoemma@yahoo.com
ORCID: 0000-0001-8622-7342

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ABSTRACT

This study examined gas flaring and soil quality dynamics within the lowland rainforest environment of Delta State in south-southern Nigeria. This study adopted both experimental and quasi experimental design approaches; while the study area was divided into 5 (Ebedei, Okpai/Kwale, Erhoike/Kokori, Otu-Jeremi, Ekpan/Ubeji) using stratified random sampling technique. From each gas flaring site, 4 sampling spots were established at 0 - 0.1km, 0.5km, 1km, and rainforest control site to make a total of 20 sampling spots, from which soil samples were collected from the topsoil (0-15 cm) and subsoil (15-30 cm). Standard approaches were adopted in the field samples collection. Soil samples collected were put into labelled polythene bags and taken to laboratory for analysis on some physical and chemical properties. All data generated were statistically analysed using descriptive and inferential statistics. Results of statistical tests showed that: there was no significant difference in soil properties between the topsoil and subsoil at the distances away from gas flaring sites and adjacent rainforest; there was no significant variation in topsoil properties amongst the different established distances away from gas flaring sites and the adjacent rainforest; there is no significant variation in subsoil properties amongst the different established distances from gas flaring sites and the adjacent rainforest; distance decay does not significantly influence soil properties to vary within gas flaring sites and adjacent rainforest. The impact of gas flaring does not significantly differ with distance away from flaring site within the rainforest environment. Therefore, control of temperature effects on crop productivities and plants adaptation within gas flaring area is recommended.

KEYWORDS: Degradation, distance decay, gas flaring, rainforest environment, soil quality dynamics.

INTRODUCTION

Attention towards the investigation of gas flaring impact has become of paramount importance because of its role in the degradation of the environment and its components (Obi and Ndakara, 2020).

The emitted gases such as ethylene, propylene, propane, butadiene and butane are expelled as waste gases and released into the atmosphere, thereby reacting with the oxygen present in the atmosphere to form carbon dioxide and water (Adamu and Umar, 2013).

Odiete, Amanda Okefe, Department of Geography and Regional Planning, Delta State University, Abraka, Nigeria
Ndakara, Ofudjaye Emmanuel, Department of Geography and Regional Planning, Delta State University, Abraka, Nigeria

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This process contributes significantly to the increase in emission of greenhouse gases such as carbon dioxide, methane, Sulphur dioxide, nitrogen oxide, which have adverse effect on the environment. Carbon monoxide is also released due to the incomplete combustion of carbon compounds, with particulate matter in form of black carbon or soot (Ovuakporaye, et al., 2012; Uzoekwe and Ajayi, 2018). The major gas released in high quantity is carbon dioxide. The harmful effect of greenhouse gases emission has negatively contributed to climate change on Earth. To this end, the practice of gas flaring, which is a major concern and contributor to global warming and climate change, needs to be put to proper check (Egwurugwu and Nwafor, 2013; Nriagu, et al., 2016).

According to Olukoya (2015), gas flaring is the burning of natural gas that is associated with crude oil when it is pumped up from the ground. In petroleum-producing areas where insufficient investment was made in infrastructure to utilize natural gas, flaring is employed to dispose of this associated gas (Nwaogu and Onyeze, 2010; Aigberua, et al., 2016; Yakubu, 2018). The practice of gas flaring is common to oil production processes from the crude form, and it is not restricted to Nigeria (Uzoekwe, 2019). It is important, to state here that gas flaring has been the subject of much controversy in Nigeria, due to its wasteful nature and negative impact on the environment and it contributes significantly to destroying the soil (Ndakara and Ohwo, 2022a).

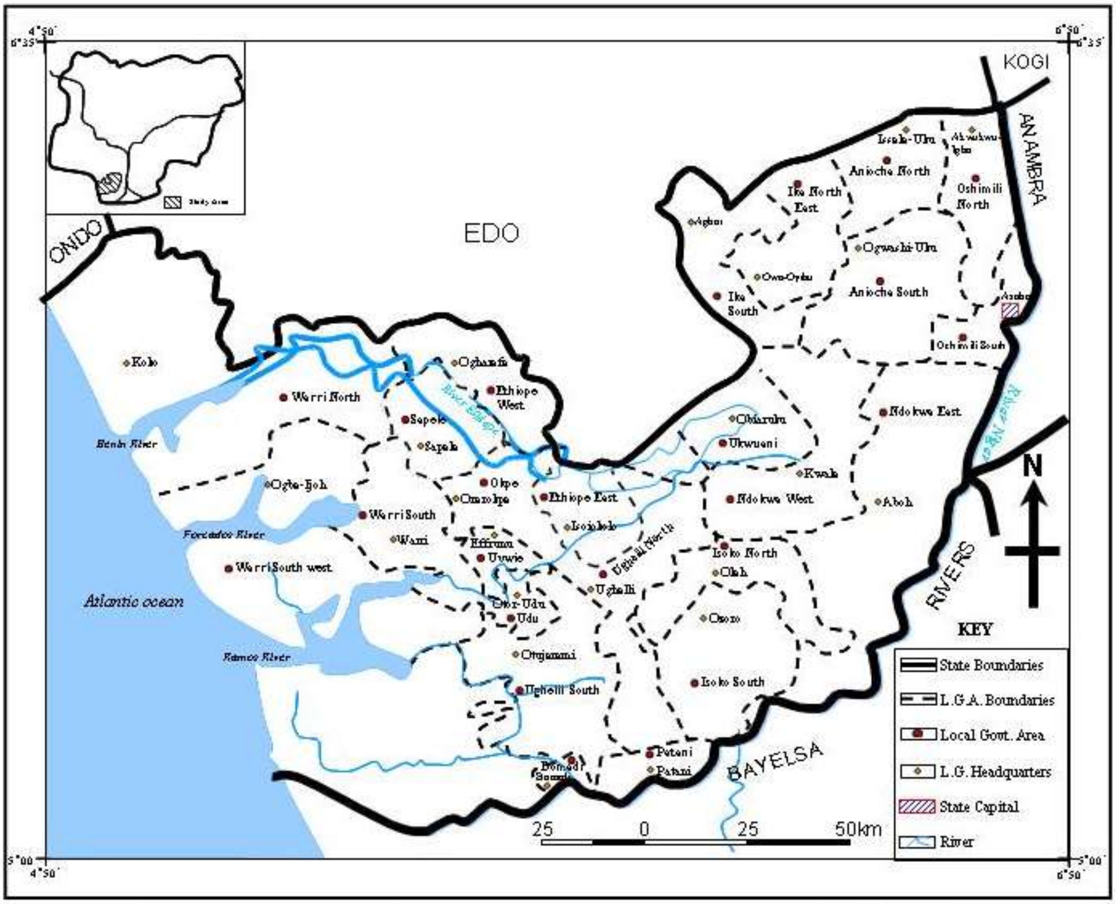
Within the Delta State region of southern Nigeria, the adverse effects of flaring has devastating effects on the soil and soil fauna, water bodies, agricultural crops, tree plants, forest development, ecosystems functions, and the general environment within gas flare areas. Since soil fertility comprises of the presence of chemical elements, the activities of soil organisms is essential in the actualisation of soil organic carbon from the humus organic matter on the topsoil layers. Thus, the death of microbial organism caused by gas flaring can be of negative impact to the soil and major components of the ecosystem near gas flaring sites (Egwurugwu and Nwafor, 2013; Seiyeboh and Izah, 2017).

Several studies as carried out by Adamu and Umar (2013) examined the occurrence and chemistry of co-contamination of nitrate and hydrocarbon pollutants in gas-flared areas of the Niger-Delta of Nigeria. Donwa, et al. (2015) carried out an assessment of selected heavy metals and their pollution indices in oil spill contaminated soil in the Niger Delta. Environmental impact analysis of gas flaring in the Niger Delta region of Nigeria was carried out by Ubani and Onyejekwe (2013). Aigberua et al. (2016) evaluated total hydrocarbon content and polycyclic aromatic hydrocarbon in an oil spill contaminated soil in Rumuolukwu, Niger Delta.

However, researches on the dynamics of soil qualities within the lowland rainforest environment of southern Nigeria have not been adequately documented. The studies which investigated soil qualities within gas flaring areas focused on a single sites and cultivated land area, without reference to uncultivated mature rainforest soils as control to account for the extent of impact made by gas flaring on soils within the rainforest environment. Therefore, this study researched on gas flaring and soil quality dynamics in lowland rainforest environment of Delta State in southern Nigeria, with a view to ascertain the impact of gas flaring on soil physical and chemical properties at different distant points away from gas flaring sites and adjoining mature rainforest sites within Delta State.

STUDY AREA

This study was carried out in the Delta State region of Southern Nigeria. This region is located between latitudes 5^0 00'N and 6^0 30'N and also between longitudes $5^0$00'E and 6^0 45'E (See map of Delta State showing L.G.A and Headquarters).



MAP OF DELTA STATE SHOWING L.G.A. AND HEADQUARTERS

Source: Ministry of Lands, Survey and Urban Development, Asaba (2023)

The area coverage of Delta State is approximately 16,986 km^2 (Ndakara, 2011). The climate of the area is characterised with the tropical equatorial type, which is typically influenced by two seasonal air-masses {the tropical maritime (MT) and tropical continental (CT)} respectively. According to Ndakara and Eyefia (2021), this region experiences annual rainfall ranging between 2000mm and 4000mm, with mean temperature ranging between 31^0C and 31.5^0C (Ndakara, 2014). The study area is located within the tropical rainforest belt, which is evergreen forest and consist of three canopies of trees (upper, middle and lower). The influence of man through developmental strides and population increase has reduced the forests mainly to secondary growth. According to Ndakara (2014), the vegetation of this region comprises the rainforest, fresh water forest, mangrove forest, and derived savannah landscape. The study area consists mainly of sedimentary rock formations deposited in three cycles of marine transgressions. According to Ndakara (2011), the surficial geology comprises the Sombreiro-Warri Deltaic plain formation. The Sombreiro-Warri formation covers much of the Deltaic plain. The lithologies of these surficial materials show evidence of a variety of depositional environments that include deltaic, fluvial and ages that range from Miocene through Pleistocene to the recent (Ndakara and Osokpor, 2023). The primary source rocks for petroleum in this region are the inter-bedded marine shale facies of Agbada and Akata formations. The terrain is characteristically lowland with mixed anticlines and synclines features that define areas with respect to elevations above or below sea levels. Geologically, the basin comprises three formations which are the Agbada, Akata, and

Benin (Ndakara and Ohwo, 2022b). The soil order can be classified under the oxisols, following the United States Department of Agriculture (U.S.D.A.) soil classification taxonomy. They have the characteristics of soils in the lowland rainforest ecosystems of the tropical region (Ndakara and Atuma, 2024). The soil within this region has been tampered with owing to centuries of anthropogenic disturbances which includes gas flaring.

METHODOLOGY

This study adopted both experimental and quasi experimental design approaches. This design was appropriate to this study where mature rainforest covers that are meaningfully far away from gas flaring sites, were examined as control sites, to under-study areas at different distance intervals away from gas flaring sites.

The design of samples was based on stratified random sampling technique, where the study area was stratified into 5 (Ebedei, Okpai/Kwale, Erhoike/Kokori, Otu-Jeremi, Ekpan/Ubeji) based on the conditions that all strata falls within the same ecological zone, with homogenous environmental characteristics, presence of gas flaring sites, and presence of mature adjoining rainforest at minimum distance of 3 km away from gas flaring sites. From each gas flaring site, 4 sampling spots were established at 0 - 0.1 km, 0.5 km, 1 km, and rainforest site to make a total of 40 sampling spots thus, a total of 40 soil samples were collected (20 each from the 0-15 cm and 15-30 cm depths of the soil profiles), at each established sampling spot within the gas flaring area and the control sites respectively, using the distance decay approach, while quadrants of 1m x 1m were established at each sampling spot (Ndakara, 2011). The soil samples collected by the use of core sampler, were put into labelled polythene bags and conveyed to the laboratory for analysis on the soil particle size distribution, bulk density, total porosity, water holding capacity, exchangeable potassium, total nitrogen, available phosphorus, and total organic carbon respectively. Laboratory analysis of samples adopted the methods used in a study by Ndakara (2014), where the hydrometer method was used in the analysis of particle size distribution; Soil bulk density was determined using the core method (Blake, 1965); Total porosity was determined by the core method using the assumed value of 2.65/cubic cm for the soil particle density; The soil water holding capacity was determined by saturation; Exchangeable potassium (K) was determined with a flame photometer; Total nitrogen (N) was determined with an auto-analyzer; Available phosphorus was determined colorimetrically with a “spectronic 20” spectrophotometer after the colour had been developed with Murphey and Riley reagent (Ndakara, 2016). Total organic carbon (TOC) was determined by the Walkley-Black wet oxidation method, and the figures obtained were converted into total organic matter by multiplying TOC with a fraction of 1.724. Data from the laboratory analysis of soil samples were analysed using the descriptive and inferential statistical techniques.

RESULTS AND DISCUSSION

Soil Properties in Topsoil Layers of Distances Away from Gas Flaring Sites and Adjacent Rainforest

The topsoil properties varied among the different sampling spots at the established distances away from the gas flaring sites. Figure 1 shows the concentrations of the topsoil properties at established distances away from gas flaring sites and the adjacent rainforest.

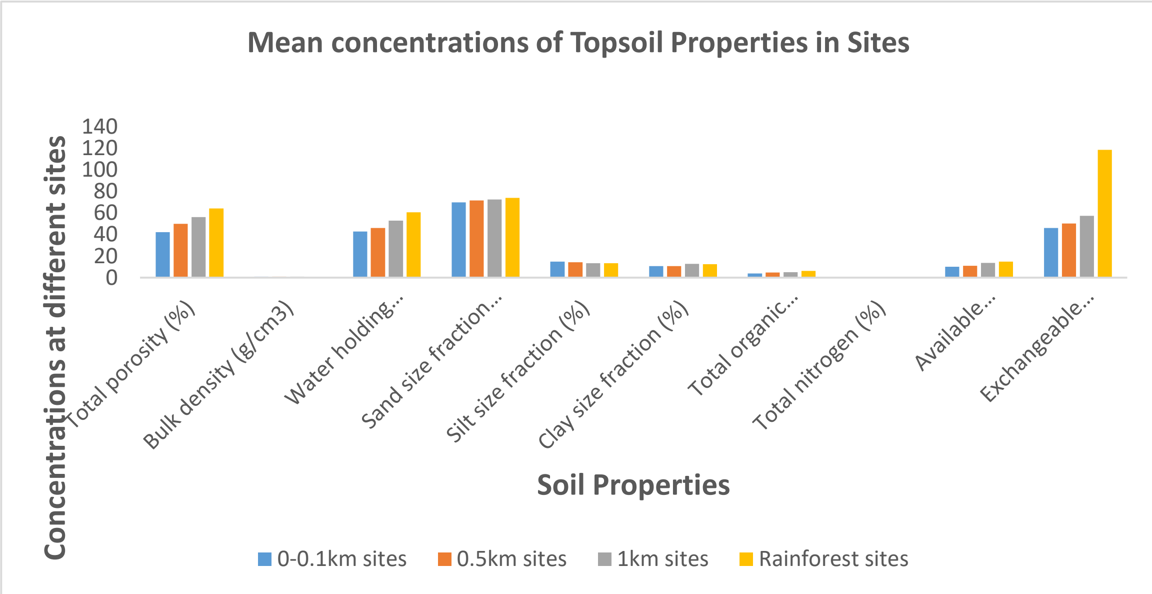


Fig. 1: Mean Concentrations of Topsoil Properties at Established Distances Away from Gas Flaring Sites and Adjacent Rainforest

Figure 1 shows the mean concentrations of topsoil properties at established distances away from gas flaring sites and adjacent rainforest. The concentrations of both physical and chemical properties were highest in the adjacent rainforest, with highest observed difference in the concentration of exchangeable potassium. The concentration of soil bulk density and proportion of soil total nitrogen were less than the value of 1 thus, their bars were not observed in the graph like other soil properties. The observed level of total nitrogen value in the rainforest is in line with the results reported in the studies carried out by Uzoekwe (2019), and Ndakara and Ofuoku (2020).

Although the soil properties varied among the different established distances and the rainforest, the extent to which they varied did not reveal whether there was a significant variation observed or not. Therefore, test of hypothesis 2 revealed the extent to which the topsoil properties varied across the different distances away from the gas flaring sites and the adjacent rainforest at 0.05 level of confidence.

Soil Properties in Subsoil Layers of Distances Away from Gas Flaring Sites and Adjacent Rainforest

Subsoil properties varied across the different distances away from the gas flaring sites and the adjacent rainforest. In this study, the subsoil physical and chemical properties varied among the different sampling spots at the established distances away from the gas flaring sites. Figure 2 shows the concentrations of subsoil properties at established distances away from gas flaring sites and adjacent rainforest.

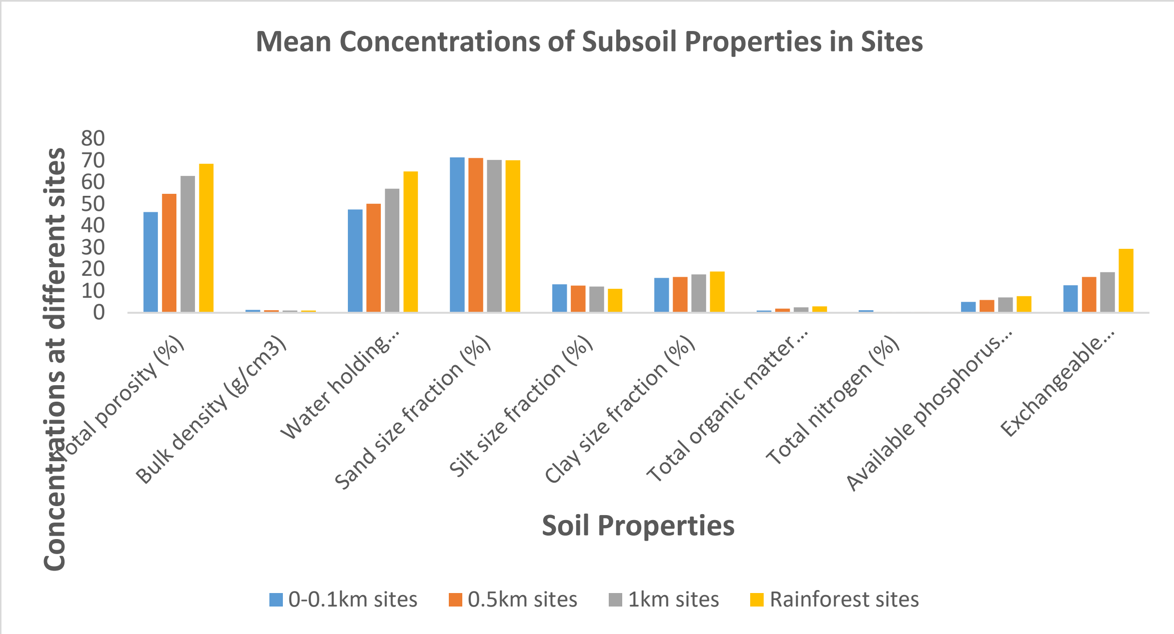


Fig. 2: Mean Concentrations of Subsoil Properties at Established Distances Away from Gas Flaring Sites and Adjacent Rainforest

Figure 2 shows the mean concentrations of subsoil properties at established distances away from gas flaring sites and adjacent rainforest. The concentrations of both physical and nutrient properties were highest in the adjacent rainforest, with highest observed difference in the concentration of total porosity, water holding capacity, and sand size fractions. The concentrations of soil total nitrogen at the 0.5 km, 1 km, and adjacent rainforest were less than the value of 1 thus, their bars were not observed in the graph like other soil properties. The observed level of total nitrogen value in the rainforest is in line with the results reported in the studies carried out by Atuma and Ojeh (2013), Ndakara (2014), and Uzoekwe (2019).

Although the soil properties varied among the different established distances and the rainforest, the extent to which they varied did not reveal whether there was a significant variation observed or not. Therefore, test of hypothesis 3 revealed the extent to which the subsoil properties varied across the different distances away from the gas flaring sites and the adjacent rainforest at 0.05 level of confidence.

Differences in Soil Properties Between the Topsoil and Subsoil of the Distances Away From Gas Flaring Sites and Adjacent Rainforest

The mean concentrations and values of soil properties varied between the topsoil and subsoil at the different distances away from gas flaring sites and adjacent rainforest. Table 1 presents the results of paired samples t-test to ascertain whether the mean concentrations and values of soil properties varied significantly between the topsoil and subsoil at the different established distances away from the gas flaring sites and the adjacent rainforest.

Table 1: Paired Samples T-Test Output for the Differences Between the Topsoil and Subsoil Properties at Different Established Distances Away from Gas Flaring Sites and Adjacent Rainforest.

Site/Distance	Paired Samples	Paired S.E.M	Paired Differences (95% Confidence Interval)		t-value	df	Sig (2-tailed)
			Lower Differences	Upper Differences			
0-0.1km	Topsoil Subsoil	3.56567	-5.32911	10.80311	0.768	9	0.462
0.5km	Topsoil Subsoil	3.58441	-5.04449	11.17249	0.855	9	0.415
1km	Topsoil Subsoil	4.09413	-5.53557	12.98757	0.910	9	0.387
Rainforest	Topsoil Subsoil	9.00494	-11.20058	29.54058	1.018	9	0.335

Source: SPSS Output, 2024

Generally, the mean concentrations and values of soil properties varied between the topsoil and subsoil at every sampling spot. This observed differences in soil properties between topsoil and subsoil corroborates findings in studies by Ndakara and Ohwo (2023), and Osokpor and Ndakara (2023).

At the sites closest to the gas flaring area (0-0.1 km distance), the t-value is 0.768 with p-value of 0.462 > 0.05. The observed difference in the mean concentrations and values of the topsoil and subsoil is therefore not significant at the 0.05 level of confidence. Therefore, the stated hypothesis that “there is no significant difference in soil properties between the topsoil and subsoil at the distances away from gas flaring sites and adjacent rainforest” at the 0.05 level of confidence is accepted. This result is in line with findings reported in the study by Okeke and Okpala (2014), and Uzoekwe (2019).

At the 0.5 km distance, the t-value is 0.855 with p-value of 0.415 > 0.05. The observed difference in the mean concentrations and values of the topsoil and subsoil is therefore not significant at the 0.05 level of confidence. At the 1 km distance, the t-value is 0.910 with p-value of 0.387 > 0.05. The observed difference in the mean concentrations and values of the topsoil and subsoil is therefore not significant at the 0.05 level of confidence. At the adjacent rainforest, the t-value is 1.018 with p-value of 0.335 > 0.05. The observed difference in the mean concentrations and values of the topsoil and subsoil is therefore not significant at the 0.05 level of confidence. Therefore, there is no significant difference between the topsoil and subsoil properties at the different established distances and the rainforest. These findings are in line with the result reported in the study by Ndakara and Osokpor (2023). Soil properties may vary but the level of variation between the topsoil and subsoil may not differ in all parts of the environment (Ndakara and Ohwo, 2023).

Variation in Topsoil Properties Among Distances Away from Gas Flaring Sites and Adjacent Rainforest

Soil properties vary at different sampling spots within the environment. This study showed that the concentrations and values of the topsoil properties varied across the different established distances away from the gas flaring sites and the adjacent rainforest. Table 2 presents the ANOVA test output for the differences in mean concentrations of topsoil properties amongst the distances from gas flaring sites and the adjacent rainforest at the 0.05 level of confidence.

Table 2: ANOVA Test Output for the variation in topsoil properties amongst the different established distances away from gas flaring sites and the adjacent rainforest

Concentrations at different distance	Sum of Squares	Degree of freedom	Mean Square	F	Sig.
Between Groups	894.620	3	298.207	0.329	0.805
Within Groups	32652.579	36	907.016		
Total	33547.199	39			

Source: SPSS Output, 2024

Table 2 presents the ANOVA test results for the variation in topsoil properties among the different established distance away from the gas flaring sites and the adjacent rainforest. With F-value of 0.329 and P-value of 0.805 > 0.05, the mean concentrations and values of soil properties did not vary significantly. Therefore, the stated hypothesis that "there is no significant variation in topsoil properties amongst the different established distances away from gas flaring sites and the adjacent rainforest" is not significant at the 0.05 level of confidence. This result revealed that, although the mean concentrations and values of topsoil properties varied across the different established distances away from the gas flaring sites, the level of variation is not significant. Therefore, the stated hypothesis that "there is no significant variation in topsoil properties amongst the different established distances away from gas flaring sites and the adjacent rainforest" at the 0.05 level of confidence is accepted. Variation in soil properties may not be significant, but their levels of support to crop productivities would vary due to other environmental factors that affect plants growth and productivities (Egwurugwu and Nwafor, 2013; Ndakara, 2024). This result revealed that, topsoils within the rainforest environment did not vary significantly as reported in other studies by (Atuma and Ojeh, 2013; Okeke and Okpala, 2014).

Variation in Subsoil Properties Within Distances Away from Gas Flaring Sites and Adjacent Rainforest

Subsoil properties, like the topsoil properties, varied at different sampling spots within the environment. This study showed that the concentrations and values of the subsoil properties varied across the different established distances away from the gas flaring sites and the adjacent rainforest. Table 3 presents the ANOVA test output for the differences in mean concentrations of subsoil properties amongst the distances from gas flaring sites and the adjacent rainforest at the 0.05 level of confidence.

Table 3: ANOVA Test Output for the variation in Subsoil properties amongst the different established distances away from gas flaring sites and the adjacent rainforest

Concentrations at different distance	Sum of Squares	Degree of freedom	Mean Square	F	Sig.
Between Groups	197.397	3	65.799	.091	.964
Within Groups	25939.789	36	720.550		
Total	26137.187	39			

Source: SPSS Output, 2024

Table 3 presents the ANOVA test results for the variation in subsoil properties among the different established distance away from the gas flaring sites and the adjacent rainforest. With F-value of 0.091 and P-value of 0.964 > 0.05, the mean concentrations and values of subsoil properties did not vary significantly. Therefore, the stated hypothesis which states that "there is no significant variation in subsoil properties amongst the different established distances away from gas flaring sites and the adjacent rainforest" is not significant at the 0.05 level of confidence, and therefore accepted. This result revealed that, although the mean concentrations and values of subsoil properties varied across the different established distances away from the gas flaring sites, the level of variation is not significant. Variation in subsoil properties may not be significant, but their levels of support to crop productivities would vary due to other environmental factors that affect plants growth and productivities (Ndakara, 2024). This result revealed that, subsoils within the rainforest environment did not vary significantly as reported in other studies by (Atuma and Ojeh, 2013; Okeke and Okpala, 2014).

Comparative Analysis of Soil Quality Dynamics in Response to Distance Decay

As distance increased away from the gas flaring sites, mean concentrations and values of soil properties at the topsoil and subsoil increased to the adjacent rainforest. This revealed that areas closest to the gas flaring sites recorded reduced soil qualities than the areas farther from the gas flaring sites and the adjacent rainforest. The extent to which the soil properties varied at the different established distances away from the gas flaring sites were tested with multiple comparison using the LSD method for the topsoil and subsoil layers respectively. Tables 4 and 5 present the Post hoc test output using LSD, to carry out pair-wise multiple comparison of the mean differences in topsoil and subsoil properties respectively at the different established distances away from the gas flaring sites.

Table 4: Post Hoc Test Output for the variation in topsoil properties amongst the different established distances away from gas flaring sites and the adjacent rainforest

Multiple Comparisons

Dependent Variable: Concentrations

LSD

(I) Sites	(J) Sites	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1.00	2.00	-1.81000	13.46860	.894	-29.1256	25.5056
	3.00	-4.36100	13.46860	.748	-31.6766	22.9546
	4.00	-12.37600	13.46860	.364	-39.6916	14.9396
2.00	1.00	1.81000	13.46860	.894	-25.5056	29.1256
	3.00	-2.55100	13.46860	.851	-29.8666	24.7646
	4.00	-10.56600	13.46860	.438	-37.8816	16.7496
3.00	1.00	4.36100	13.46860	.748	-22.9546	31.6766
	2.00	2.55100	13.46860	.851	-24.7646	29.8666
	4.00	-8.01500	13.46860	.556	-35.3306	19.3006
4.00	1.00	12.37600	13.46860	.364	-14.9396	39.6916
	2.00	10.56600	13.46860	.438	-16.7496	37.8816
	3.00	8.01500	13.46860	.556	-19.3006	35.3306

Source: SPSS Output, 2024

Table 4 presents the post hoc test output for the multiple comparisons of the mean differences in the topsoil properties at the different established distances away from the gas flaring sites and the adjacent rainforest. The results showed that no pair of the compared mean values is significant at the 0.05 level of confidence. Therefore, the stated hypothesis that “Distance decay does not significantly influence soil properties to vary within gas flaring sites and adjacent rainforest” is accepted. This further buttress the fact that the concentration and values of topsoil properties may differ, but the difference may not be significant at the 0.05 level of confidence.

Post hoc test was carried out using the Least Square Deviation (LSD), to carry out pair-wise multiple comparison of the mean differences in the subsoil properties at the different established distances away from the gas flaring sites. The result are as shown below.

Table 5: Post Hoc Test Output for the variation in subsoil properties amongst the different established distances away from gas flaring sites and the adjacent rainforest

Multiple Comparisons

Dependent Variable: Concentrations

LSD

(I) Sites	(J) Sites	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-1.48300	12.00458	.902	-25.8294	22.8634
	3.00	-3.37200	12.00458	.780	-27.7184	20.9744
	4.00	-5.94300	12.00458	.624	-30.2894	18.4034
2.00	1.00	1.48300	12.00458	.902	-22.8634	25.8294
	3.00	-1.88900	12.00458	.876	-26.2354	22.4574
	4.00	-4.46000	12.00458	.712	-28.8064	19.8864
3.00	1.00	3.37200	12.00458	.780	-20.9744	27.7184
	2.00	1.88900	12.00458	.876	-22.4574	26.2354
	4.00	-2.57100	12.00458	.832	-26.9174	21.7754
4.00	1.00	5.94300	12.00458	.624	-18.4034	30.2894
	2.00	4.46000	12.00458	.712	-19.8864	28.8064
	3.00	2.57100	12.00458	.832	-21.7754	26.9174

Source: SPSS Output, 2024

Table 5 presents the post hoc test output for the multiple comparisons of the mean differences in the subsoil properties at the different established distances away from the gas flaring sites and the adjacent rainforest. The results showed that no pair of the compared mean values is significant at the 0.05 level of confidence. This further buttress the fact that the concentration and values of subsoil properties may differ, but the difference may not be significant at the 0.05 level of confidence.

CONCLUSION

This study showed that distance decay does not significantly influence soil properties to vary within gas flaring sites and adjacent rainforest. From the statistical test results, there was no significant difference in soil properties between the topsoil and subsoil at the distances away from gas flaring sites and adjacent rainforest.

There was no significant variation in topsoil properties amongst the different established distances away from gas flaring sites and the adjacent rainforest. There was no significant variation in Subsoil properties amongst the different established distances from gas flaring sites and the adjacent rainforest. From these results, other factors may be responsible for poor crop yields and productivities within gas flaring areas.

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