



Research Article

Gas Flaring and its Effects on the Physicochemical Parameters of Soils in Ebedei, Delta State

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ABSTRACT

The practice of burning off the natural gas released during petroleum extraction, known as gas flaring, has recently drawn criticism from the public due to concerns about the environmental harm and public health risks associated with its frequent occurrence in populated areas. The majority of Nigeria's oil exploration operations take place in the Niger Delta region, with a significant level of gas flaring. This study investigated changes in the physicochemical parameters of soils around the Ebedei flow station facility. The soil samples used for the investigation were collected from two different locations (50m and 100m) at the test site and 70km as control sites, at depths (Topsoil, 10 cm, and 30cm), respectively. The results revealed a noticeable trend, as some parameters considered showed a gradient away from the flare site. The soil physicochemical properties from the polluted area were significantly lower ($p < 0.05$) for moisture, pH, organic carbon, K^+ , Mg^{2+} , Ca^{2+} , Na^+ , SO_4^{2-} , PO_4^{3-} , NO_3^- and total nitrogen in comparison with samples from the unpolluted area. The soil temperature was higher in the test site compared to the control areas. The data obtained suggest that gas flaring had a negative impact on soil physicochemical properties.

Keywords: Moisture; Natural gas; Petroleum extraction; soil temperature; Total nitrogen

Citation: Okoh, F., Nwakwanogo, B.E., & Nwasiwe, A. (2026). Gas Flaring and its Effects on the Physicochemical Parameters of Soils in Ebedei, Delta State. *Sahel Journal of Life Sciences FUDMA*, 4(3): 70-80. DOI: <https://doi.org/10.33003/sajols-2026-0403-08>

INTRODUCTION

Gas flaring is the burning of natural gas and other petroleum hydrocarbons in flare stacks for the seamless disposal of the products of oil extraction. Several combustible products are formed when gas undergoes combustion. A stream of gas leaks out of the open spaces, including methane, which is largely flammable and forms explosive mixtures on exposure to air. The significant flaring process takes place usually at the top of the stack by burning of gases with the visible flame (Kalparanjan *et al.*, 2022; Onwuka & Mang, 2018).

Gas flaring is the greatest and most prominent cause of global warming. This practice promotes the venting of carbon monoxide (CO), methane (CH₄), carbon dioxide (CO₂), and nitrous oxide (N₂O), all of which have the potential to pollute the environment and

cause wanton ecological degradation (Okwagi *et al.*, 2019). These associated gases, commonly called greenhouse gases, are byproducts of the petroleum production processes that are separated from the oil at flow stations. Approximately 95% of this is made up of gases that are flared with a concomitant release of substantial greenhouse gases (CH₄, N₂O, NO₂, CO₂, volatile organic compounds) into the atmosphere. However, through a feedback process, emitted sulphur dioxide and some percentage of carbon dioxide and nitrogen oxides accelerates localized acid rain (Okwagi *et al.*, 2019; Ukhurebor *et al.*, 2024). These emissions have elicited concerns from environmentalists and the general public because of the harmful effects of acid rain, greenhouse effect and corrosion of roofing sheets (Adeoye, 2022).

There are about 200 gas flaring locations in Nigeria, where incessant flaring has continued unabated. Oil exploration in Nigeria primarily occurs in the Niger Delta region, largely due to the substantial reserves of crude oil and natural gas around the area (Nwagbara & Irondi, 2020).

The direct impact of gas flaring and venting is inimical, particularly for biodiversity and the sanctity of the ecosystem. Soils within the gas flaring vicinity are increasingly losing their nutrient retention capacity as well as the potential for long-term farming, chiefly because of the acidity of the soil caused by several contaminants associated with gas flaring. Flaring emits a variety of waste products, organic and inorganic, into the surrounding environment together with thermal pollution prompted by gas emissions (Aktar *et al.*, 2024). An investigation by Okoh & Osuji, 2019, found that gas flaring increased heavy metal content of soils, lower microbial activity, and degenerate soil parameters, highlighting environmental concerns. According to some reports, gas flare-induced temperature increases have resulted in reduced agricultural productivity and alterations to the natural habitat. Recent systemic review on the effects of climate change on the Niger Delta by Nwankwo *et al.* (2023) which emphasize the widespread ecological footprint of continuous gas flaring, revealed a decline in soil organic carbon. This underscores a critical intersection with global climate literature; sustained thermal radiation and atmospheric pollutants from flaring accelerates soil carbon mineralization, degrading the soil's capacity to act as a carbon sink and creating a dangerous climate feedback loop.

The modified environmental conditions near flare sites, characterized by changes in air and temperature, relative humidity, soil moisture content, and other soil physico-chemical parameters, not only affected maize germination but also plant growth and agricultural productivity (Odjugo & Osemwenkhae, 2009). This is evident in plants with stunted growth, scorched leaves and withered crops littering places around flare sites.

MATERIALS AND METHOD

Study Area

Ebedei, a village in Ukwuani Local Government Area of Delta State (5°50'15.4"N 6°14'55.9"E), which is part of the Niger Delta area, was selected as the study area. The community plays host to an oil company that produces crude oil from several wells in the Umutu-Ebedei oil fields. Crude oil produced in the facility is transported via booster stations in the

Umusadege marginal oil field and Kwale/Okpai gas plant to Brass terminal, for export, and some of the associated gas is re-injected into the formation to enhance oil recovery, while a significant quantity of the gas is flared to the atmosphere. The control site Ewossa (6°25'08.4"N 6°15'50.9"E), in Igueben local government area of Edo state, which is 70km northwest of the flare site, was strategically chosen due to the claim that the impact of gas flaring on atmospheric indicators is statistically insignificant beyond 15-20km radius (Okwagi *et al.*, 2019). However, there is a significant risk of "cross-contamination" when choosing a control location that is somewhat outside the 20km radius. The control location may still be inside the plume of a nearby flare or local industrial point source at that distance. The control site at Ewossa 70km from the test site is entirely beyond the regional airshed of potential petroleum activities, providing a genuinely contamination free baseline. It is important to state that the test and control sites fall within the same climatic and soil zone, but the control site is not a crude oil production area, so any observable changes could be attributed to the effect of gas flaring.

Samples

Soil samples were collected at 50m and 100m from the flare site at different soil depths (topsoil, 10cm, and 30cm), using an auger and stored in sterile plastic containers. The last point of sample collection (70km) was considered the control sample. The soil samples were transported to a Biochemistry Laboratory in Abia State University, Uturu, Abia State, for analysis in refrigerated coolers to prevent microbial development.

Soil Analysis

Reagents: All reagents used in this research were of analytical grade

Physico-chemical parameters: Field sampling was conducted during the dry season to drastically reduce the effects of diurnal variations, such as temperature and moisture fluctuations, all sample collections were consistently carried out in the early morning. Soil samples were collected in triplicates (n=3) for each location and depth. The temperature of each sample was measured at the site by dipping the bulb of the thermometer in the soil, and the reading was taken in °C and recorded after 5 minutes. Soil pH was measured using the process described by (Umeadi *et al.*, 2017). The Soil Moisture Content of the samples were determined by the oven-dry method by (AOAC, 1999). The amount of water is determined by subtracting the dry weight from the initial weight, and the moisture content is then calculated as the

amount of water divided by the dry weight. The Organic carbon content was determined by the titration method described in (AOAC, 1999) and expressed as a percentage. Exchangeable Cations Ca, Mg, K and Na were determined by the method (AOAC, 1999). The concentrations of K, Na, and Ca were measured on a flame photometer, while Mg was determined on an atomic absorption spectrophotometer. Soil sulphates were determined by the method of (AOAC, 1999). The % transmittance and absorbance at 420nm were determined within 30 to 60 min. on a B & L Spectronic-70 electrocolorimeter. Phosphates were determined by the method of (AOAC, 2000) on a spectrophotometer at 882nm. Nitrate was determined by the method of (AOAC, 2000), and finally, the transmittance was measured at 470nm. Total nitrogen was determined by the micro-Kjeldahl method described by (AOAC, 2000), expressed in percentage.

Data Analysis

Data (n=3) from the study were analyzed using SPSS version 21 and result presented as mean $\pm$ standard deviation while comparison was carried out with Tukey's posthoc analysis and the graph plotted using Microsoft excel 2013.

RESULTS

The results of the physico-chemical analysis of soil samples are shown in Figures 1 to 12. From the data presented in Figure 1, temperature was higher in all the test samples when compared to the samples from the unpolluted site, but not significantly at $P < 0.05$. There was no significant difference observed at different soil depths in the control site at $P < 0.05$. This trend was also observed in the test samples collected at 50 & 100 m from the flare vicinity.

The soil moisture content was significantly higher in the control samples when compared with samples from the polluted site. However, there were no significant differences between samples from the polluted sites (50m & 100m) at $P < 0.05$. It was observed that moisture content increases with increasing depth in both the control and test sites.

The results for pH are shown in figure 3 were significantly higher in the control samples when compared with samples from the test site at $P < 0.05$. The data obtained revealed a lower pH at the topsoil in both the flare vicinity and the control site.

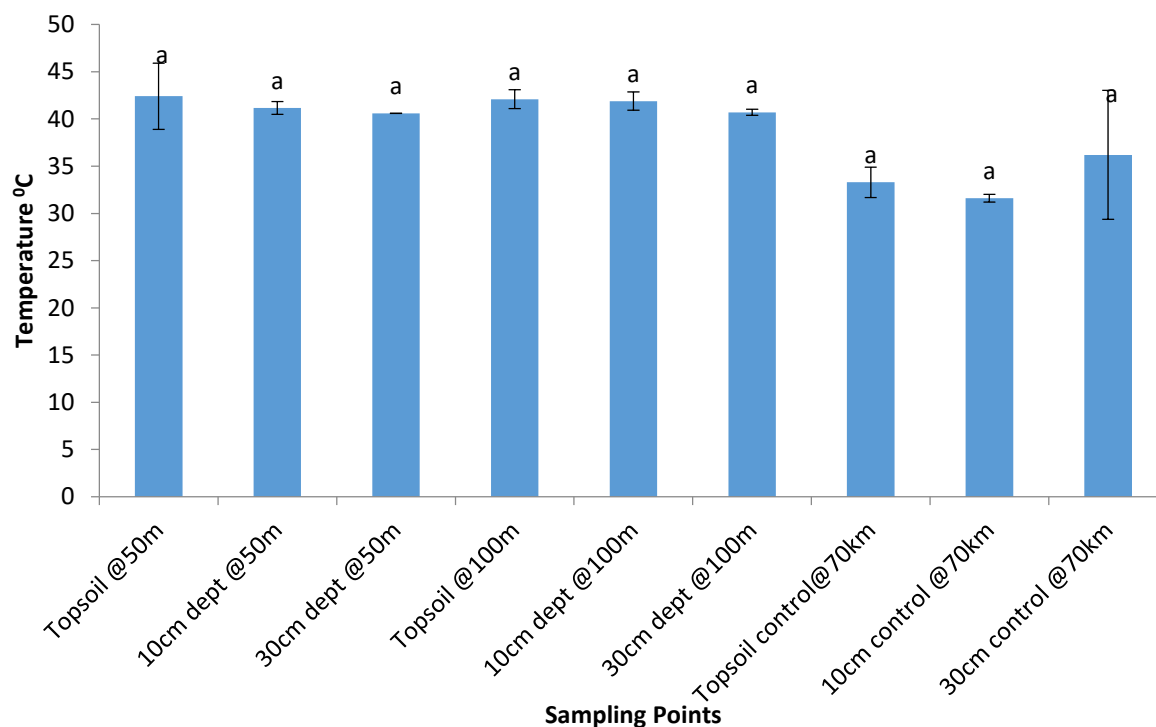


Figure 1: Soil Temperature (°C)

Values are presented as Mean $\pm$ SD, where bars with different superscripts (a, b, c, d & e) show significant difference at $P < 0.05$

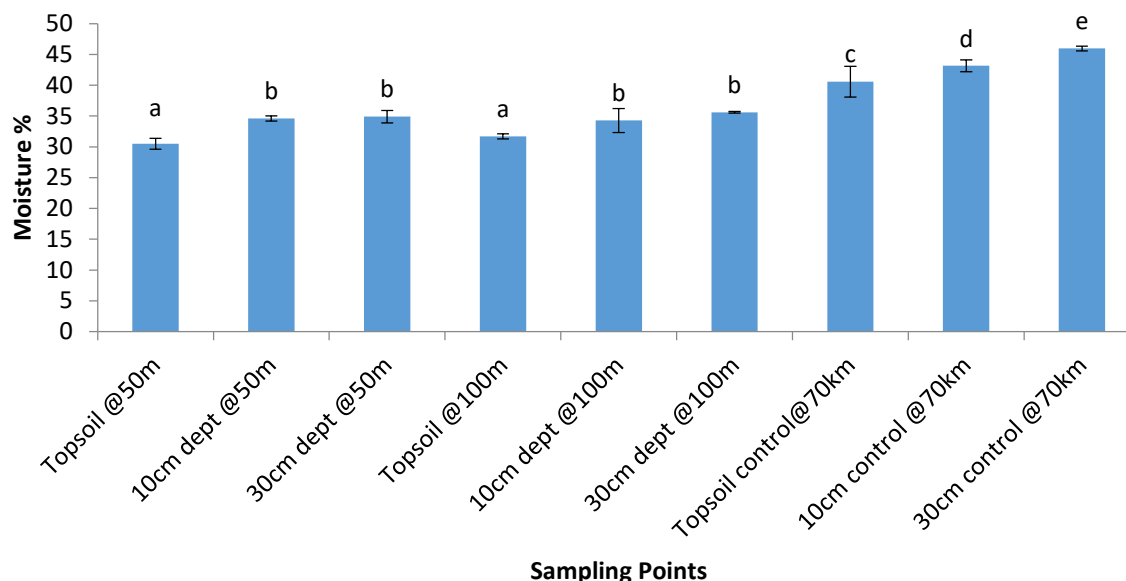


Figure 2: Soil Moisture (%)

Values are presented as mean $\pm$ SD, where bars with different superscripts (a, b, c, d, & e) show significant difference at $P < 0.05$

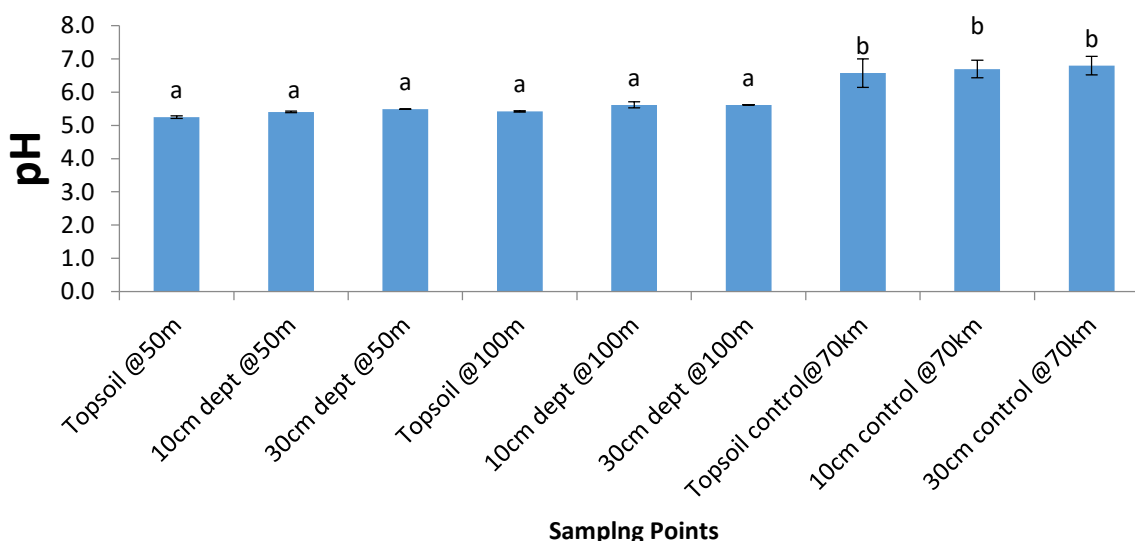


Figure 3: Soil pH

Values are presented as mean $\pm$ SD, where bars with different superscripts (a, b, c, d & e) show significant difference at $P < 0.05$

The concentration of organic carbon is shown in figure 4. The concentration was significantly higher in the control samples when compared with the samples from the test site at $P < 0.05$. The results for soil potassium concentration, as shown in Figure 5, was significantly higher in the samples from the control site when compared to samples from the test site at $P < 0.05$.

The concentration of calcium was significantly higher ($P < 0.05$) in samples from the control site in comparison with samples from the test site. However, the result also revealed a significant difference between the samples at 50m and 100m.

The results for sodium concentration is shown in Figure 7. The control was significantly higher in comparison with the samples from the test site.

However, no significant difference ($P < 0.05$) existed among samples from the test site. Results for soil magnesium concentration as shown in Figure 8, was significantly higher ($P < 0.05$) in the samples from the control site. However, no significant difference existed between samples from the test site. At the test and control sites, the concentration was lower at 30cm depth.

The results for sulphate concentration is shown in the figure 9. The control was significantly higher ($P < 0.05$) when compared to samples from the test site. However, no significant difference existed between the two points (50m & 100m) at the flare site.

Figure 10 showed that soil phosphate concentration in samples from the control site was significantly

higher ($P < 0.05$) compared to samples from the polluted site. However, there was no marked difference between samples from the test vicinity.

Figure 11 showed that nitrate concentration in samples from the control site was significantly higher ($P < 0.05$) than that in samples from the test site. The difference between samples from the test site was not significant.

The result for total nitrogen concentration is shown in the figure 12 were significantly higher ($P < 0.05$) in the control samples when compared to samples from the test sites. However, the result also shows an increase in the aforementioned parameters from 50m to 100m in the polluted samples, but not at a significant level.

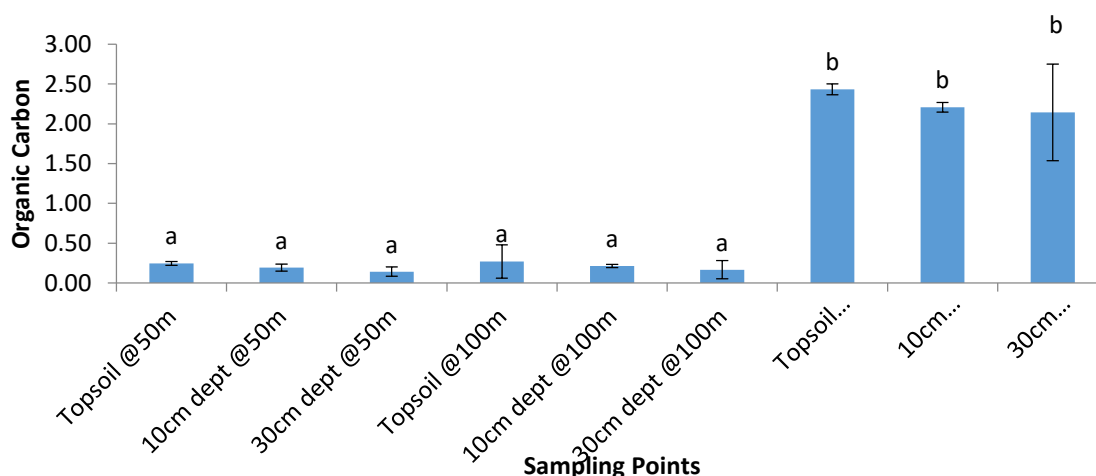


Figure 4: Soil Organic Carbon (%)

Values are presented as mean $\pm$ SD, where bars superscripts (a, b, c, d, & e) show significant difference at $P < 0.05$

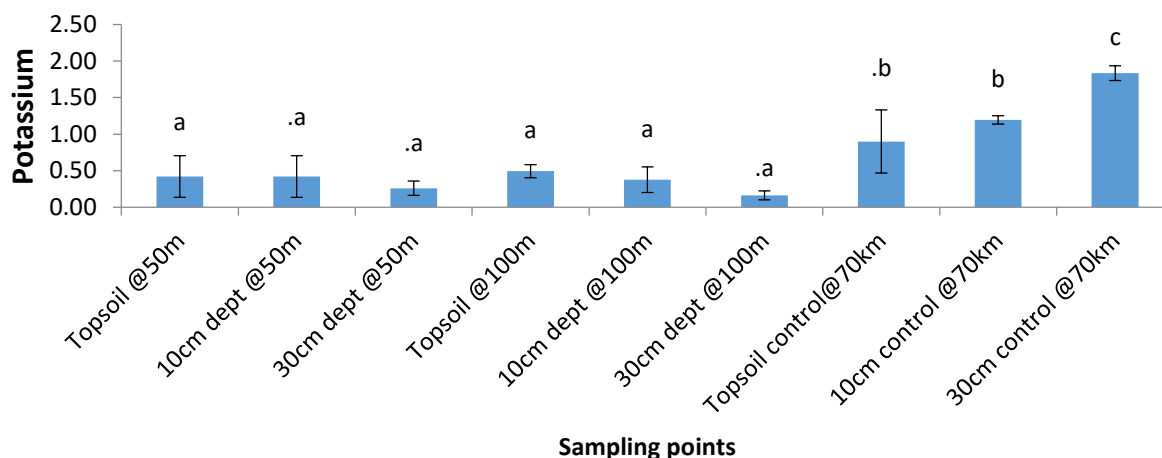


Figure 5: Soil Potassium (K^+) Conc. in (mg/L)

Values are presented as mean $\pm$ SD, where bars with different superscripts (a, b, c, d, & e) show significant difference at $P < 0.05$

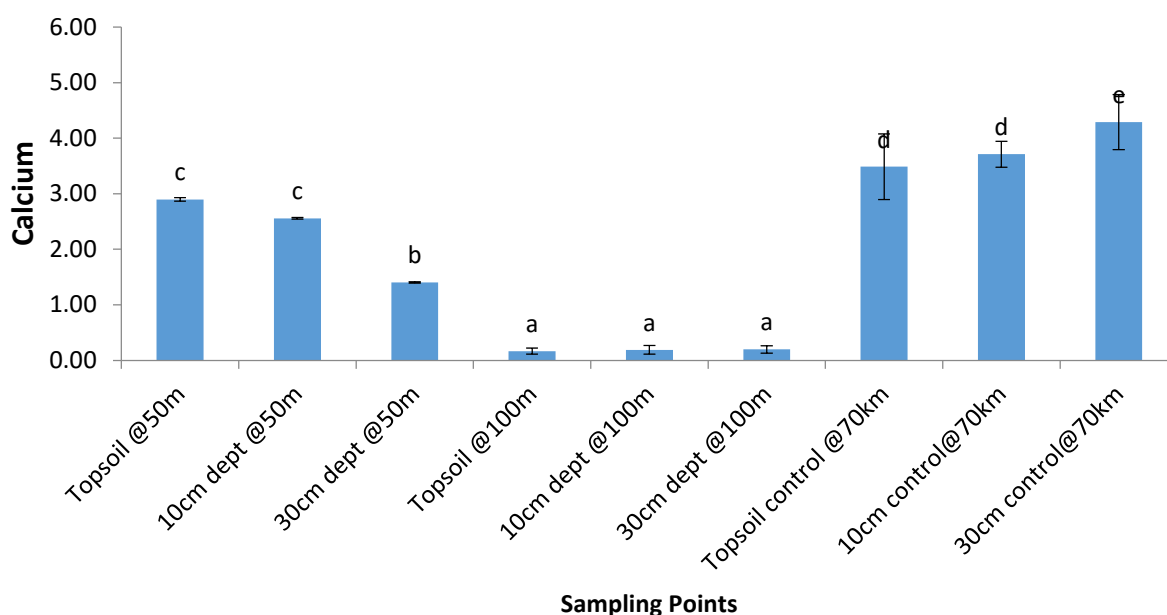


Figure 6: Soil Calcium (Ca^{2+}) conc. in (mg/L)

Values are presented as mean $\pm$ SD, where bars with different superscripts (a, b, c, d, & e) show significant difference at $P < 0.05$

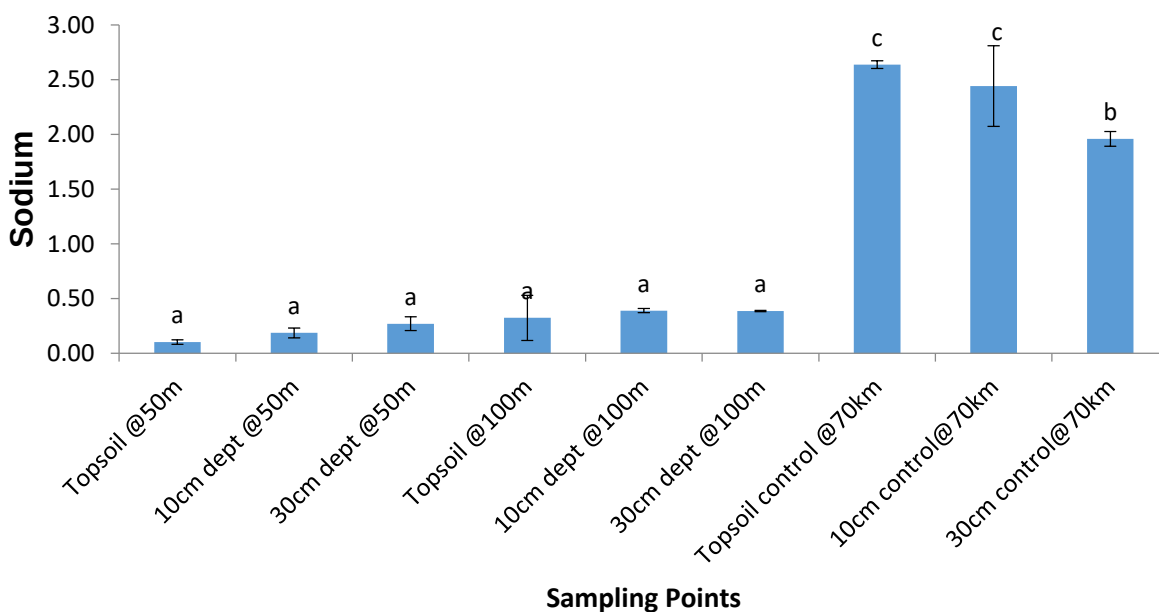


Figure 7: Soil Sodium (Na^+) Conc. in (mg/L)

Values are presented as mean $\pm$ SD, where bars with different superscripts (a, b, c, d, & e) show significant difference at $P < 0.05$

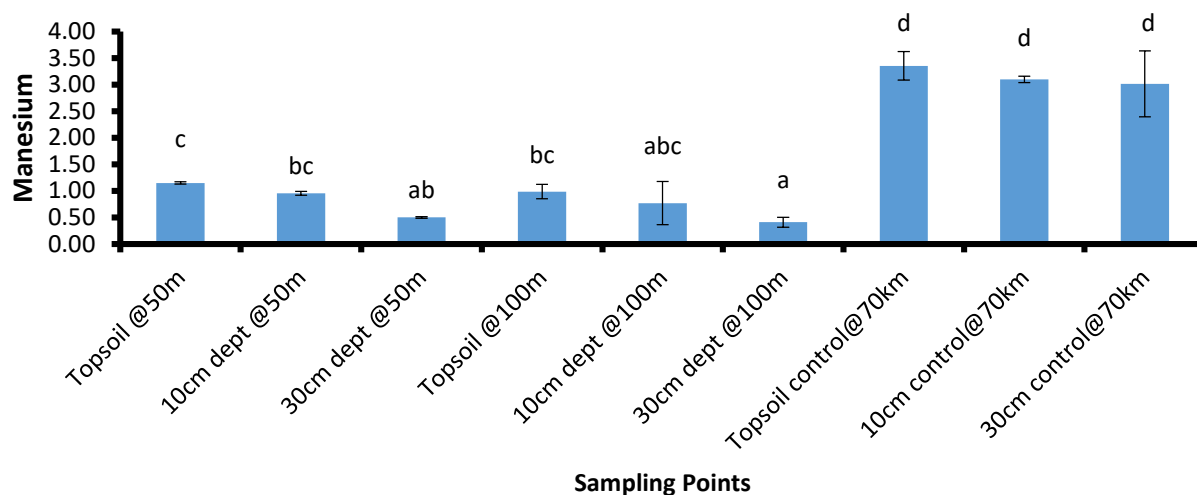


Figure 8: Soil Magnesium (Mg^{2+}) Conc. in (mg/L)

Values are presented as mean $\pm$ SD, where bars with different superscripts (a, b, c, d, & e) show significant difference at $P < 0.05$

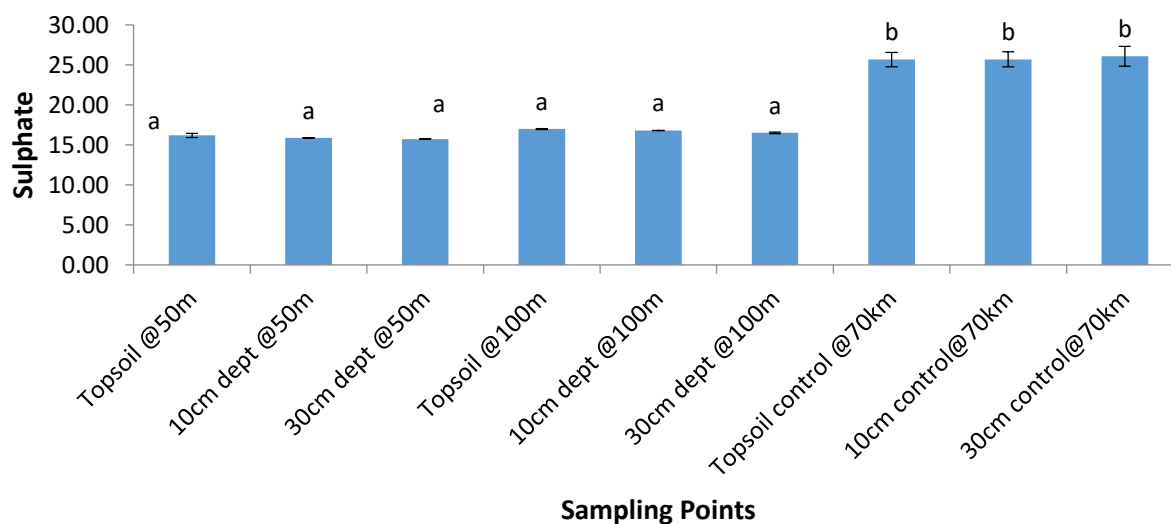


Figure 9: Soil Sulphate (SO_4^{2-}) Conc. in (mg/kg)

Values are presented as mean $\pm$ SD, where bars with different superscripts (a, b, c, d & e) show significant difference at $P < 0.05$.

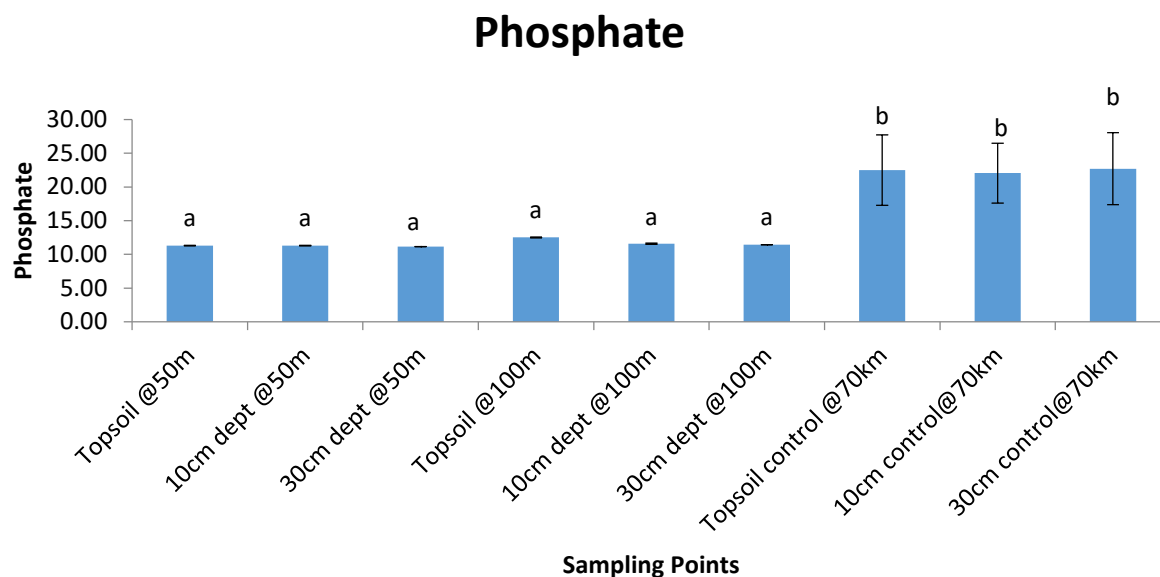


Figure 10: Soil Phosphate (PO_4^{2-}) conc. in (mg/kg)

Values are presented as mean $\pm$ SD, where bars with superscripts (a, b, c, d, & e) show significant difference at $P < 0.05$

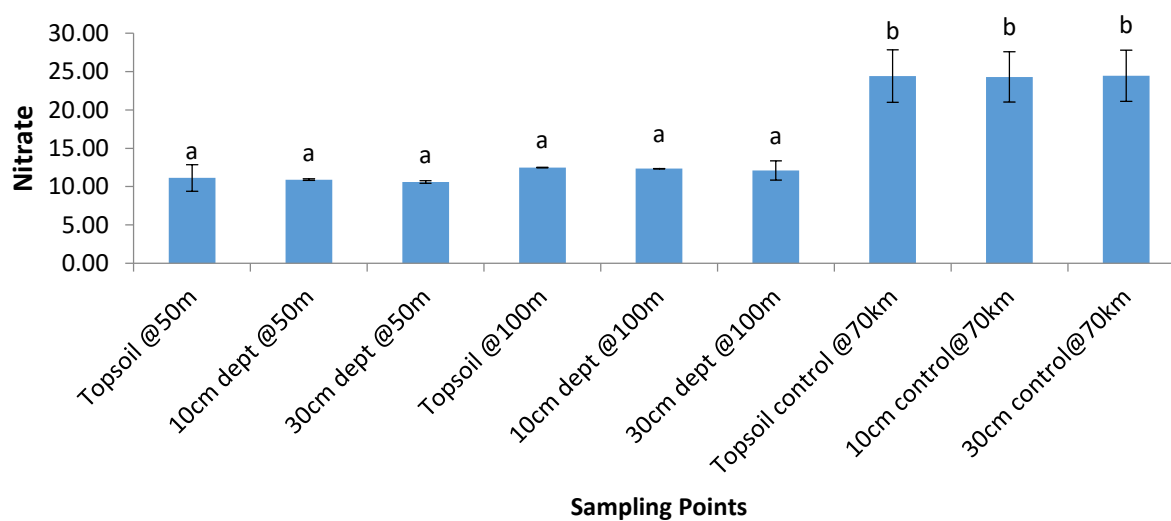


Figure 11: Soil Nitrate (NO_3^-) Conc. in (mg/kg)

Values are presented as mean $\pm$ SD, where bars with different superscripts (a, b, c, d, & e) show significant difference at $P < 0.05$

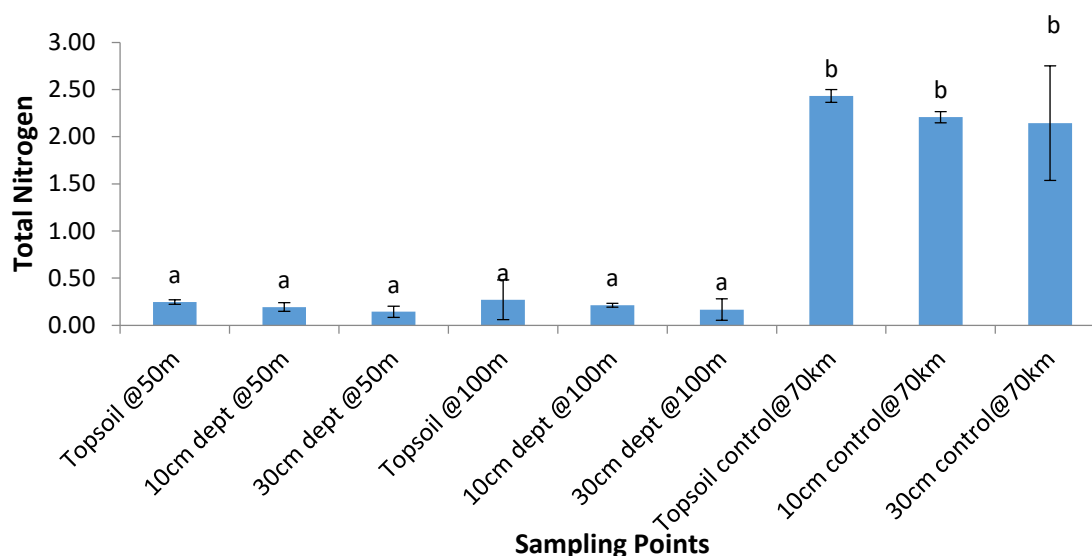


Figure 12: Soil Total Nitrogen (%)

Values are presented as mean $\pm$ SD, where bars with different superscripts (a, b, c, d, & e) show significant difference at $P < 0.05$

DISCUSSION

The results of this research show the effect of gas flaring on selected soil physico-chemical parameters. The results revealed that the closer a sampling point was to the flare site, the higher the soil temperature. This study implicated the thermal heat around the flare vicinity from the steady gas flaring activities. The increased temperature in the gas flared area may be due to climatic changes in the environment, as observed by (Osegi, 2011), who noted an increase in temperature in the gas flared community in Nigeria and also high-impact ground heat liberated from the flaring stack. This is consistent with other literature that suggests that gas flaring increases soil temperature within flare sites (Wang, 2018). The results obtained equally showed that the soil temperature decreased with depth (Adedayo, 2019). This could stem from the surface being significantly more sensitive to temperature shifts than deeper soil layers.

The percentage soil moisture content obtained from this study ranged from 30.5 - 35.60% at 50m to 100m distance, while the moisture content for the control sample ranged from 41.50 - 46.00% (Figure 2). Consequently, heat stress degrades soil moisture and creates conditions unfavorable for floral development and fruit production (Botkin & Keller, 1995). This agrees with other studies by (Nwagbara & Ironi, 2020) that shows moisture content observed

within the flare vicinity reduced. However, other site-specific factors (for example, potential crude oil spills, waste disposal, vehicular emissions) may have contributed to observable reduction in moisture content and as such "closer to flare site does not directly imply lower moisture content." The pH of the soil samples collected from the oil flow station exhibited significantly higher acidity levels (5.25–5.62) than the control baseline (pH 6.47–6.92) (Figure 3). These results are consistent with prior research (Achiche *et al.*, 2020; Nwagbara & Ironi, 2020; Nwaogu & Onyeze, 2020) demonstrating that gas flaring enhances soil acidification through precipitation. The observed acidity in the Ebedei soil samples may be hypothesized to result from flaring activities, which are known to produce acidic oxides of nitrogen (NO_x), carbon (CO_x), and sulphur (SO_x). These oxides, when released into the atmosphere, can dissolve in rainwater to form acid rain, which introduces a high concentration of hydrogen ions (H^+) into the soil. The resulting acidic runoff subsequently leaches basic minerals from the soil and lowers its pH upon deposition (Atuma & Ojeh, 2013). Furthermore, low pH values, as discovered in the flare site, may be due to some cations which may combine to form insoluble compounds which tend to negatively impact the solubility of nutrient, hence causing their unavailability to plants (Coscione *et al.*, 2009). Elevated levels of soil acidity result in chemical and biological conditions which may be deleterious to

plants and soil microorganisms (Nwaogu & Onyeze, 2010), notably by inhibiting uptake of essential cations by plants. The result also reveals that the organic carbon around the oil flow station was significantly lower when compared with the control sites (Figure 4). This could be attributed to a decline in return of plant residues into soil closer to the flare stack, impacting the return of nutrients to the soil, ultimately impoverishing soil nutrients (Ejiogu *et al.*, 2019). This finding is in agreement with (Oyet *et al.*, 2021), who found that % organic carbon decreased at a closer distance towards the flare site. An observable trend worthy of note is that Organic carbon content is higher in topsoil and decreases with increasing depth corroborated by the investigation by (Jobbágy & Jackson, 2000). The availability of exchangeable bases potassium, calcium, magnesium and sodium was highest at the control site (Figure 5 to 8). This is in agreement with findings by (Odjugo & Osemwenkhae, 2009) that investigated the effect of climate change on soil parameters in Nigeria. However, calcium concentration dipped significantly at 100m from the flare site. This observed decrease in soil cations might be attributed to a heat-induced effect leading to volatilization of exchangeable bases in the flare pit vicinity. The concentrations of sulphate, phosphate and nitrate revealed in the result were markedly lower in areas close to the test site (Figure 9 to 11). These results align with previous studies by Egwurugwu *et al.* (2013) that investigated the impact of prolonged gas flaring on water quality. Environmental mechanisms such as leaching and pollutant deposition near flare sites likely contribute to the observed depletion of these soil nutrients. Total nitrogen also showed a gradient away from the flow station (Figure 12), which is consistent with the findings by (Kalita *et al.*, 2012) that studied the impact of gas flaring on soil health. Heat stress is implicated in either killing or inducing the migration of micro and macro-organisms essential for nitrogen cycling, which directly impacts the retention and availability of total nitrogen (Nwagbara & Ironi, 2020).

CONCLUSION

This study has revealed the deleterious effects of gas flaring on the physico-chemical parameters of the soil around gas flare sites in Ebedei community, Ukwuani Local Government Area, Delta State. Notably, the degradation of these soil parameters represents a critical breach of established environmental standards stipulated by the Department of Petroleum Resources (DPR) and the Federal Ministry of Environment (FMEEnv). Consequently, this damage

severely undermines local agricultural livelihoods by degrading soil fertility, reducing crop yields, and eroding the long-term ecological resilience of the region.

Conflicts of Interest

The authors have declared that there are no competing interests exist.

Funding

No specific grant from governmental, private, or nonprofit funding organizations was obtained in the course of this study.

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