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Impact of Horizontal Gas Flaring on the Physico-chemical Properties of Surrounding Arable Soils in Owaza, Southeastern Nigeria

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Abstract: *Horizontal gas flaring and its impact on surrounding arable soil have not been given the deserved attention in Nigeria. This study evaluated this process using the status of selected soil physico-chemical properties within the vicinity of a horizontal gas flaring site in Owaza, Abia State, Southeastern Nigeria. Fibrous tape was used to mark distances of 50, 100 and 200 m in the active flare direction and 50 m interval distances to the left and right of it as well as 50 and 100 m behind it, all within the flare bond wall. Other sampling points (400, 600, 800, 1000, 2000, 3000 and 4000 m) were located away from the bond wall. All data were taken from georeferenced points at 0 – 15 cm and 15 – 30 cm sampling depths. Soil temperature was taken in situ using a hand held mercury-in-glass thermometer at each sampling point. Core samplers were driven into each point for bulk density and soil moisture determination. A total of 28 disturbed samples from each sampling point were collected, bagged and labeled for analysis of the selected properties using standard procedures. The data were further analyzed using descriptive and inferential statistics. Results showed Soil temperature, Bulk Density and Percentage Sand content increasing at decreasing distance towards the flare point ranging from 23.5 - 45 °C, 1.42 - 2.50 g/cm^3, and 77.77 - 87.35 % respectively, whereas Percentage Total Porosity, Gravimetric Moisture Content, Hydraulic Conductivity, Percentage Silt and clay content increased at increasing distances away ranging from 6 - 46 %, 5.25 - 29.73 %, 0.10 - 7.84 cm^3/hr, 5.80 - 9.69 % and 6.85 - 12.54 % respectively. All chemical properties except Percentage Organic Carbon and Percentage Organic Matter decreased towards the flare point and increase away. The alterations in the soil physico-chemical properties around the gas flaring site convey negative implications for sustained soil ecosystem functions.*

Keywords: *Horizontal gas flaring, arable soils, soil temperature, physico-chemical properties*

INTRODUCTION

Nigeria has an estimated two million barrels of crude oil output per day, which represent about 22 billion standard cubic feet (SCF), about 75% of this quantity is been flared as waste gas [1]. She tops the list of ten countries responsible for 74% of gas flaring emissions in the world, which represent 16% of the associated gases, flared globally, the highest in any country in the world [2]. Gas flaring is the controlled burning of natural gases associated with oil production. It involves the use of vertical or horizontal flare to burn off unwanted associated gas that are extracted from the earth along with the crude [3]; [4]. There are over 200 gas flaring sites in Nigeria, some of which have been on continuously for over 20 years [5]. The Niger Delta region is the heart of this tremendous oil exploration, exploitation and gas flaring over the years. This is largely due to the huge deposits of crude oil and natural gas within the region [6]. The widespread use of the 'open pipe flare' method in Nigeria, with close ground contact which is almost obsolete in some developed countries compound the problem [7]. Tremendous heat is generated within the vicinity of gas flare sites thereby causing thermal pollution. Temperature produced at flare sites could be as high as 1,600^{o}C [8]. It is known that gas flaring in Nigeria has raised the average global temperature by about 0.5^{0}C [9]. High temperature creates physical, chemical, and biological conditions which are harmful to human health, plant and soil micro-organisms. The heat, toxins and particulates from gas flaring adversely affect vegetation, soil, water, humans, and livelihoods of the host communities [2]. Increased soil temperature by 12.6 and 23.4^{o}C and reduced soil moisture at 5cm by 18.6% and 2.8% from gas flaring have been reported [10]. There is a great physiological impact of the high temperature on crops planted in the vicinity of the flare [11] – [14. Soils at very close distance to gas flare sites are impoverished because the heat from the gas flare hinders the process of eluviation and hydrolysis which could have enhanced the formation of clay minerals needed for plants [15]. For instance, the heat from gas flared falls on the soil thereby heating it up, which hinders some plants and crops from surviving hence rendering such land unsuitable for cultivation. The physico–chemical properties of soil, air and soil temperatures, rainfall, vegetation and relative humidity around some flare sites in Niger Delta area have been reported to show disruptions in many studies [12]; [11]; [17] and [18]. The obvious signs of this can be noticed in the poor vegetation growth and scorched soil around gas flare locations [19]. Almost no vegetation can grow in the area directly surrounding the flare due to the prevailing heat [20].

Typical gas flare in Nigeria oil fields are located at ground level (horizontal flaring) (Plate 1), and is usually surrounded by vegetation, farmlands and village huts 20 – 30m away from the flare and the heat radiation is a function of the flare temperature; gas flow rate and geometrical design of flare jet. The free disposal of gas through flaring generates tremendous heat, which is felt over an average radius of 0.5 km thereby causing soil thermal pollution [21]. This study therefore examined the amount and variability of soil physico-chemical properties of the study site.

Plate 1: A typical horizontal/ground gas flaring jet [22]

RESEARCH METHODOLOGY

Study Area

The study was carried out within the vicinity of horizontal gas flaring site of Shell BP gas flare station in Owaza, Abia State, Southeastern Nigeria (Figure 1). The area is located about latitude 4° 55'N and longitude 7° 11'E. Farming is the main socio-economic activity of the rural population with the growing of cassava (*Manihot esculenta*), maize (*Zea mays*), vegetables (fluted pumpkin) etc. Oil exploration started in the area in early eighties with its resultant gas flaring. Soil type of the area are ultisols (USDA Soil Classification) derived from coastal plain sand. The geological material is coastal plain sand (Benin Formation) with a low land geomorphology of 50m above sea level. There are two distinct seasons in the study area, the dry and rainy season. These seasons are usually influence by the tropical maritime air mass and the tropical continental air mass. The rainy season usually begins in March and is interrupted by a dry season in October. Annual rainfall ranges from 2000 – 2500mm and annual mean temperature range of 28.5 – 30°C [23]; [24].

Field Studies and Sample Collection

Field reconnaissance survey was first carried out to determine the feasibility of the study and appropriate contacts and clarifications were given by the host community and Shell BP Oil Servicing Company prior to the several field trips to the gas flare study site. The study was carried out in September 2016 when the soil was wet representing typical rainy season condition in the study area in order to ascertain the extent of variability of soil physico-chemical properties (soil temperature, Bulk Density (BD), Percentage Sand content (% sand), Percentage Total Porosity (% TP), Gravimetric Moisture Content (GMC), Hydraulic Conductivity (K-sat), Percentage Silt content (% silt), Percentage clay content (% clay), Percentage Organic Carbon (% OC), Percentage Organic Matter (% OM), Total Nitrogen (TN), Available Phosphorus (AP), Electrical conductivity (EC), Exchangeable acidity (EA), Effective cation exchange capacity (ECEC) and % base saturation (BS), pH (H_20), Ca, Mg, K, and Na. All data were taken when the gas flare jet was on during noon between 1.00 and 3.00 pm local time, i.e. 13.00 and 15.00 Hours, GMT + 1. Sampling technique involved the use of a fibrous measuring tape (starting from the active point of the horizontal gas flaring jet), to mark out sampling points at 50, 100, 200 m parallel to the active flaring point (sampling points 1, 2 and 3), 50 m interval distances to the left and right sides from the active flare point (sampling points 4 and 5). Sampling points 6 and 7 were taken behind the active gas flaring point at 50 and 100 m respectively all within the bond wall of the gas flaring site whereas other sampling points (sampling points 8 through 14), were located outside the bond wall of the active flare point at varying distances (i.e. 400, 600, 800, 1000, 2000, 3000 and 4000 m) away from the active gas flaring point (see plate 3 and 4).

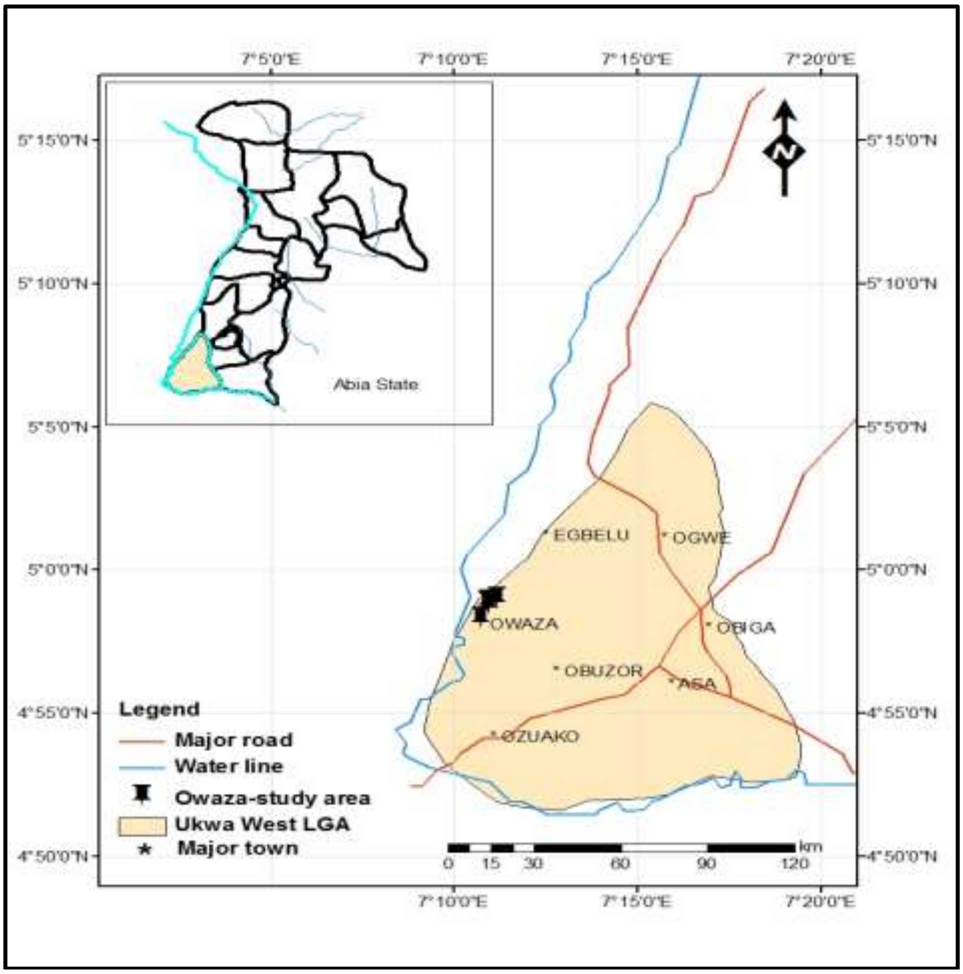

Figure 1: Georeferenced map showing the location of the gas flare point in the study area

These distances were taken to observe better the spatial scale variations of soil physico-chemical properties of the soils. All sampling points were geo-referenced using a hand Garmin GPS (Global Positioning System).

All data were collected from geo-referenced points at 0 – 15 and 15 – 30 cm sampling depths from each sample point distance. These depths were chosen because they represent the moisture control section in the soil [25]. Also, these depths form the main root zone of most crops [26]. Soil temperatures were estimated in situ using mercury-in-glass thermometer at each sample point. Soil temperature data estimation involves immersing the bulb of the mercury thermometer 2-3 cm into 0 - 15 and 15 – 30 cm soil depths for five minutes each and readings (in ^{o}C) taken appropriately. Bulked soil samples from every sample point were collected using a cylindrical core sampler 3.5cm in diameter and 6cm in length. This involved driven the core samplers into the soil to collect undisturbed samples for soil moisture and bulk density determination. Disturbed samples were also collected from these points for analysis of selected physico-chemical properties of the soil using a hand held auger. A total of twenty eight (28) soil samples from both sampling depths (0 – 15 and 15 – 30 cm) were collected for laboratory analysis. All samples were bagged in a polythene bag and properly labelled against each sample point location.

Laboratory Analysis

Samples were air dried, ground, and sieved through a 2 mm screen prior to analysis. Prepared samples were subjected to various analysis using standard procedures as described in the USDA Soil Survey Staff [27] at soil physics laboratory of National Root Crop Research Institute (NRCRI) Umudike. Particle size analysis was determined using the pipette method [28]. Bulk density was analyzed by the core sample method according to Blake and Hartage [29]. Total porosity was calculated from the result of bulk density using the procedure of Hillel [30]. The moisture content was determined by gravimetric method according to APHA [31](1985). Soil pH was determined in duplicate both in distilled water and in 0.1N KCl, using Bechman's zeromatic pH meter, in a soil: liquid ratio of 1:2.5 [32]. Soil organic carbon was determined by the method of wet oxidation according to Nelson and Sommers [33]. Organic matter was determined by multiplying organic carbon with Van Bemmelen factor of 1.724. Total nitrogen was determined using the modified micro-Kjedahl digestion method [34]. Exchangeable bases were determined from ammonium acetate (NH4OAc) leachate of the soil. Exchangeable calcium and magnesium were determined by the EDTA (Ethylene Di Amine Tetra-acetic Acid) versanate titration method. Exchangeable sodium and potassium were determined by the flame photometer method [35]. Exchangeable acidity was determined by leaching the soil with 1.0 N KCl and titrating with 0.05 N NaOH [36]. Effective Cation Exchange Capacity (ECEC) was determined by the summation of the total exchangeable bases (TEB) and total exchangeable acidity (TEA). It is expressed in meq/100g soil according to Blank [37]. Percentage base saturation was calculated by dividing the TEB by ECEC multiplied by 100.The electrical conductivity was determined by the method described by Corwin and Lesch [38]. Hydraulic conductivity of the soils was estimated using a filtration column as described by Sobieraj *et al.* [39]. The percentage base saturation was calculated by multiplying the quotient obtained after dividing TEB by ECEC by 100. Data collected were analyzed and presented in tables and charts.

Data Analysis

Descriptive statistics of mean, standard deviation were used to characterize the soil physico-chemical properties using Micrsoft Excel spreadsheet (version 2013) software package according to Cruz [40]. Correlation analysis (correlation coefficient) was employed to assess the degree of relationship between selected soil properties.

RESULTS AND DISCUSSION

Results of the soil physical parameters are shown in Table 1 and the variability trend of the particle size distribution and selected soil physical properties are shown in Figure 2. The soil temperature ranged from 23.5 – 45 ^{o}C increasing from the closest sampling point (50 m) to the flare point and descending in values away at increasing distance from the flare. The bulk density (BD) varied from 1.42 – 2.50 g/cm^3, showing abnormal increase in values within the flare vicinity and decreased away. The total porosity (TP) and moisture content followed dissimilar pattern of decrease towards the flaring site and increased outside it. They ranged from 6 - 46 % and 5.25 - 29.73 % respectively from sample points 50 m though 4 km. The hydraulic conductivity (K-sat) decreased within the flare sample points and increased with increasing distances after the flare and varied from 0.10 cm^3/hr – 7.84 cm^3/hr. For the particle size distribution, the percentage sand content increased at decreasing distance towards the flare point and ranged from 77.77 - 87.35 % whereas the percentage silt and clay (% clay) decreased at decreasing distances towards the flare and varied from 5.80 - 9.69 % and 6.85 - 12.54 % respectively. This was evident in the textural class, which was predominantly sand within the flare sample points and loamy sand at increase distances away from the flare point.

Figure 2 clearly conveyed the variability trend of the soil particle size distribution and selected soil physical properties. As earlier stated from the results, % sand content increase towards the flare point whereas the % content of silt and clay increased outside the flare bond wall. The high soil temperature and bulk density values from sample points closer the flare location could be attributed to the tremendous near ground heat generated from the horizontal flaring jet. Heat induces increase in bulk density through its influence on mineralization, caking of soil and infiltration of heavy metals. Similarly, the high bulk density values at decrease distance away from the flare location. This may have contributed to the absence of vegetation and bare scorched soil around the flare location. This is in good agreement with literatures as high bulk density interferes with root penetration and seedling emergence. The decreased porosity towards the flare points could be attributed to the high bulk density and reduced infiltration rate within the flare vicinity. The increase sand content within the flare site could be attributed to decreased microbial activities as well as low clay minerals at close proximity to the flare point. This result supports previous findings of Alakpodia [15] and Akpobome [41]. In all the soil physical parameters (BD, TP, GMC, K-sat, % sand, silt and clay), only BD and % Sand increased at a decreased distance to the flare point whereas other parameters (TP, GMC and K-sat) increased at an increasing distance away from the flare location (Table 1). This trend agrees with previous assertions that the high TP and low GMC close the flaring point is a direct effect of the tremendous heat emission [42]. Low moisture content experienced within the flare vicinity will lead to reduction in the rate of translocation of nutrients within the plant system and also affect soil temperature and microbial activities. Figures 2A – B display the variability trend of the soil particle size distribution and other selected physical properties. The % sand content increased towards the flare point whereas, % silt and % clay content increased with an increasing distance away from the flare location. The increase sand content within the flare site could be attributed to decreased microbial activities as well as low clay minerals at close proximity to the flare point. The variability pattern was similar to previous findings of Alakpodia [15] and Akpobome [41]. They stated that heat from the gas flare hinders the process of eluviation and hydrolysis which enhances the formation of clay minerals needed for plants growth.

The soil pH (H_20), organic carbon (OC), organic matter (OM), total nitrogen (TN) and available phosphorus (AP) mean values ranged from 4.5 - 6.3 %, 0.91 - 2.8 1 %, 1.67 - 4.84 %, 0.20 - 1.48 % and 15.2 - 37.6 mg/kg, respectively. The electrical conductivity (EC) values varied from 0.16 - 1.15 mS/cm. The mean values of Ca, Mg, K and Na ranged from 0.60 - 3.60 cmolkg-1, 0.30 - 2.80 cmolkg-1, 0.07 - 0.31 cmolkg-1 and 0.06 - 0.20 cmolkg-1, respectively. The exchangeable acidity (EA), exchangeable cation exchange capacity (ECEC) and % base saturation (BS) varied from 0.42 - 3.48 cmolkg^{-1}, 4.03 - 7.33 cmolkg^{-1} and 20.36 - 94.27 % respectively from sampling point 1 through to 14 at 0 – 30 cm depth (Table 2). All exchangeable bases (i.e. Ca, Mg, K and Na) and % BS increased in values with an increasing distance away from the flare point and decreased towards the flare bond wall sample points whereas OC, OM, TN and EA increased at a decreasing distance towards the gas flaring point. That is, the closer the sampling points are to the flare the higher their values. The results were in agreement with some works. For example, [43] – [45], stated that low pH values around a flare station could be attributed to acidic precipitation. Also, [46] – [49] stated that gas flaring increased the acidity of the soil and high soil acidity creates chemical and biological which may be harmful to plants and soil microorganisms. Also, microbial activities and recycling of basic plant nutrients are seriously affected at low pH. Similarly, [50] observed that strongly acidic soils inhibited nutrient release and consequently, reduction in fertility status of soils. The results of OM and TN and EC were not in agreement with assertions of Alakpodia [15] and Ogidiolu [51] that organic matter and total nitrogen declined in gas flaring sites. Similarly, they showed in their works that exchangeable bases (Ca, Mg, K and Na) in soils under gas flaring were low. The observed increased in organic matter content at decreasing distance towards the flare site could be attributed to the release and prolonged accumulation of organic carbon compounds released as oxides of carbon from the flaring [52]. Carbon is a rich source of organic matter. Visual observations of very dark carbon-rich soil samples within the flare area support this inference. Generally, soil chemical parameters decreased towards the flare point and the result of these soil properties is a clear indication that the excessive heat emitted by the flare did not only modify the microclimate but also the soil nutrient resource. The excessive heat either kills or induces micro and macro organisms' migration that would have participated in organic matter decomposition [52].

Figure 3 shows the variability trend of selected soil chemical properties and exchangeable bases from different sample points away from the flare point. The pH (H_20) and TN decreased at closer distances towards the flare point whereas OC and Exchangeable Acidity (EA) increased at a decrease distance towards the flare point (Figure 3). This trend agrees with the findings of Hewitt *et al.* [43] and Botkin and Keller [44] that low soil pH around flare location could be attributed to acidic precipitation. Figure 4 showed the variation of selected soil properties from varying distances away from the flare site. Figure 4 displays variations of soil temperature, organic carbon and total nitrogen which decreased at increasing distances away from the flare, whereas soil moisture increased at increasing distances away from the flare site (Figure 4B). These observations agreed with previous findings. Figure 5 shows plots of selected physical properties with their chemical counterparts. It could be observed there is strong and very strong positive correlation between temperature and organic carbon, and clay content and base saturation with $r^2 = 0.85$ and 0.92, respectively; whereas that of moisture content and organic matter observed strong negative correlation with $r^2 = -0.86$. The relationship between pH(H_2O) and total nitrogen, and exchangeable acidity and base saturation exhibited very strong negative correlation with $r^2 = -0.96$ and - 0.99 (Figure 6) whereas there was strong positive correlation between saturated hydraulic conductivity and electrical conductivity with $r^2 = 0.78$ (Figure 6C). In all the plots, the relationship of clay and base saturation showed the highest positive correlation whereas the relationship of exchangeable acidity and base saturation observed highest negative correlation.

Table 1: Result of in-situ and laboratory soil physical analysis from different sampling points at 0 – 30cm sampling depth

Sampling	Soil Temp	BD	TP	GMC	K-sat	← Mechanical Analysis →			USDA Soil
Points	(^{o}C)	(g/cm^3)	(%)	(%)	(cm^3/hr)	Sand	Silt	Clay	Tex. Class
						%			
50m	45.0 ± (0.50)	2.50 ± (0.06)	6.0 ± (1.30)	5.25 ± (0.50)	0.10 ± (0.05)	87.35± (1.00)	5.80± (0.40)	6.85± (0.10)	S
100m	43.5 ± (0.30)	2.45 ± (0.05)	8.0 ± (0.75)	5.35 ± (0.65)	0.13 ± (0.03)	87.17± (0.07)	6.47± (0.20)	6.35± (0.20)	-
200m	42.5 ± (0.40)	2.38 ± (0.05)	11 ± (0.55)	5.60 ± (0.60)	1.46 ± (0.07)	86.75± (1.00)	6.90± (0.15)	6.35± (1.00)	-
50m-R	40.5 ± (0.50)	2.15 ± (0.05)	15 ± (0.52)	7.82 ± (1.40)	1.55 ± (0.10)	86.60± (2.00)	6.15± (0.10)	7.25± (2.00)	-
50m-L	39.5 ± (0.50)	2.07 ± (0.14)	22 ± (1.10)	8.53 ± (1.10)	2.14 ± (0.07)	85.53± (0.61)	6.63± (0.20)	7.85± (0.13)	-
50m-B	34.0 ± (0.50)	1.59 ± (0.07)	37 ± (1.33)	13.41 ± (1.22)	5.34 ± (0.06)	83.97± (0.20)	7.17± (0.10)	8.85± (0.10)	LS
100m-B	32.5 ± (0.30)	1.57 ± (0.07)	36 ± (0.54)	15.54 ± (2.05)	5.33 ± (0.08)	84.30± (0.25)	6.75± (0.35)	8.95± (0.05)	-
400m	35.5 ± (0.40)	1.55 ± (0.08)	34 ± (0.73)	19.69 ± (2.05)	5.55 ± (0.07)	84.30± (2.05)	6.15± (2.00)	9.63± (0.10)	-
600m	31.0 ± (2.00)	1.54 ± (0.16)	36 ± (1.33)	21.93 ± (2.00)	6.75 ± (0.15)	81.37± (1.53)	5.17± (0.05)	10.05± (0.04)	-
800m	31.0 ± (0.50)	1.54 ± (0.06)	42 ± (1.75)	21.85 ± (2.15)	7.04 ± (0.40)	78.73± (1.00)	9.80± (0.17)	9.98± (0.30)	LS
1km	28.5 ± (1.00)	1.45 ± (0.06)	45 ± (1.15)	23.56 ± (1.50)	7.40 ± (0.40)	75.70± (0.50)	13.32± (0.10)	11.46± (1.00)	-
2km	26.5 ± (1.50)	1.42 ± (0.08)	46 ± (1.30)	25.79 ± (1.52)	7.35 ± (0.10)	72.60± (0.30)	15.48± (0.20)	11.92± (0.20)	-
3km	25.5 ± (1.50)	1.44 ± (0.05)	46 ± (2.04)	26.79 ± (0.58)	7.75 ± (0.45)	77.30± (0.25)	10.70± (0.30)	12.0± (2.00)	-
4km	23.5 ± (0.50)	1.42 ± (0.04)	46 ± (1.51)	29.73 ± (2.00)	7.84 ± (0.04)	77.77± (0.10)	9.69± (0.10)	12.54± (0.10)	-

Key: 50m-R and 50m-L = 50m interval distance points to the right and left from the active flare point, 50m-B1 and 100m-B2 = 50m and 100m distance points behind the active flare point, BD = Bulk density, TP = Total porosity, GMC = Grav. Moisture content, K-sat = Hydraulic conductivity. Means are values of three replicates.

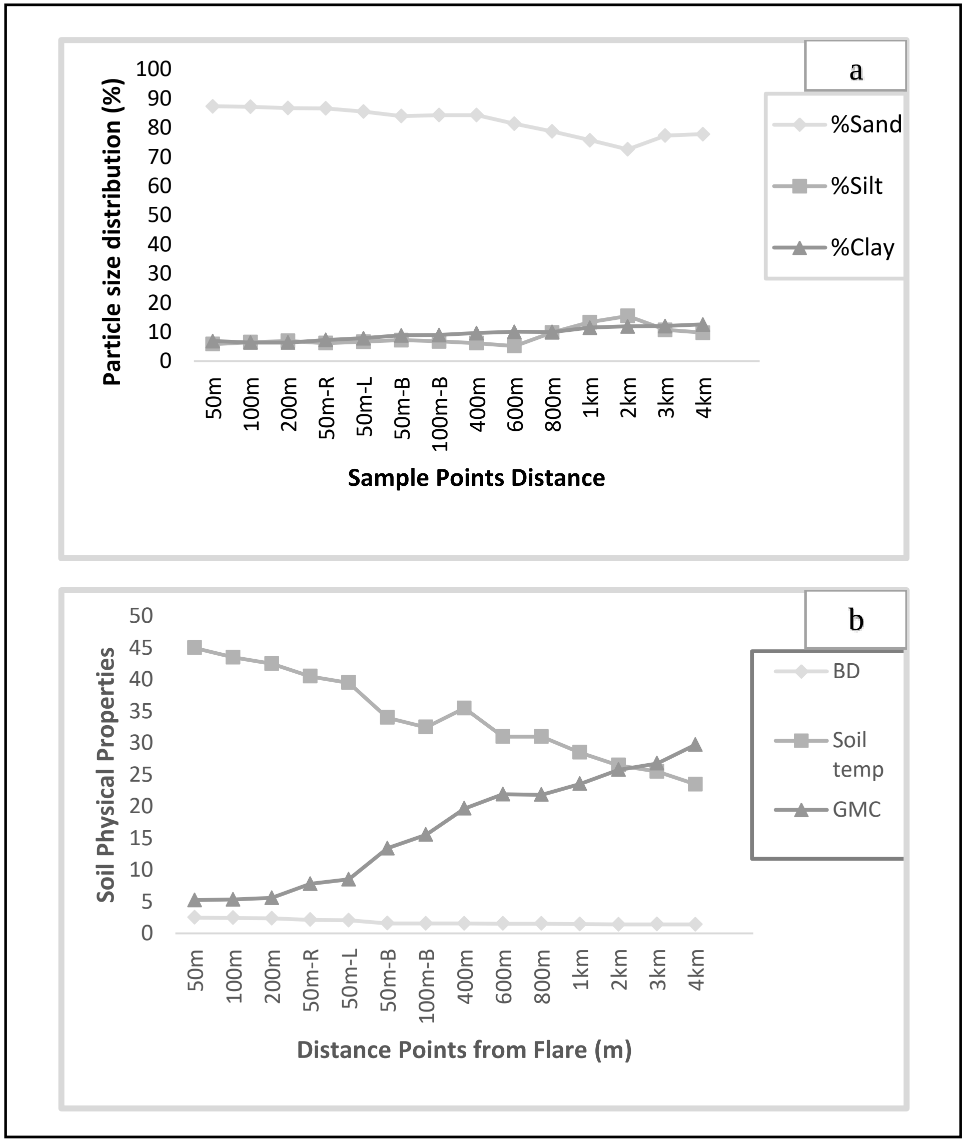

Figure 2: Variability trend of between (a) soil particle size distribution and (b) selected physical properties at 0 – 30 cm sampling depth from different sample distance points away from a horizontal gas flaring site

Table 2: Mean values of soil chemical properties on different sampling points at 0 – 30cm sampling depth

Sampling	pH		OC	OM	TN	AP	EC	←		cmolkg-1			→	BS
Distance	H_20	Kcl	(%)	(%)	(%)	(mg/kg)	(mS/cm)	Ca	Mg	K	Na	EA	ECEC	(%)
50m	4.5	3.9	2.81	4.84	1.48	15.2	0.16	0.60	0.30	0.07	0.06	3.48	4.37	20.36
100m	4.7	4.0	2.62	4.52	1.26	15.8	0.37	0.80	0.40	0.08	0.07	3.22	4.57	29.54
200m	4.6	3.9	2.72	4.68	1.12	15.5	0.26	0.70	0.35	0.07	0.06	2.85	4.03	29.28
50m-R	4.8	4.2	2.58	4.45	1.08	15.6	0.18	0.80	0.40	0.08	0.07	2.43	3.78	35.71
50m-L	5.3	4.3	2.21	3.81	0.80	18.7	0.38	1.20	0.80	0.09	0.09	2.04	4.22	51.65
50m-B	5.6	4.4	1.65	2.85	0.40	23.5	0.21	1.40	0.90	0.12	0.07	2.00	4.49	55.45
100mB	5.9	4.5	1.01	1.74	0.12	39.4	0.48	1.45	1.60	0.14	0.14	0.86	5.19	79.47
400m	6.2	5.0	1.53	2.64	0.15	39.8	1.15	2.50	1.80	0.15	0.15	0.65	5.25	87.62
600m	5.8	4.5	0.91	1.67	0.09	34.2	0.48	2.60	1.90	0.18	0.17	0.68	5.53	87.70
800m	6.1	4.6	1.22	2.15	0.12	37.0	0.82	2.65	2.10	0.21	0.17	0.52	5.65	90.79
1km	5.9	5.7	1.31	2.26	0.16	37.2	0.94	3.00	2.25	0.22	0.16	0.54	6.17	91.25
2km	6.3	4.7	1.34	2.27	0.14	32.6	1.12	3.40	2.40	0.28	0.18	0.55	6.81	91.92
3km	5.7	4.3	1.40	2.41	0.18	36.6	1.15	3.45	2.42	0.29	0.17	0.48	6.81	92.95
4km	5.9	4.8	1.44	2.28	0.20	37.6	1.15	3.60	2.80	0.31	0.20	0.42	7.33	94.27

Key: 50m-R and 50m-L = 50m interval distance points to the right and left from the active flare point, 50m-B1 and 100m-B2 = 50m and 100m distance points behind the active flare point, OC: Organic carbon, OM: Organic matter, TN: Total Nitrogen, AP: Avail. Phosphorus, EC = Electrical conductivity. Means are values of three replicates.

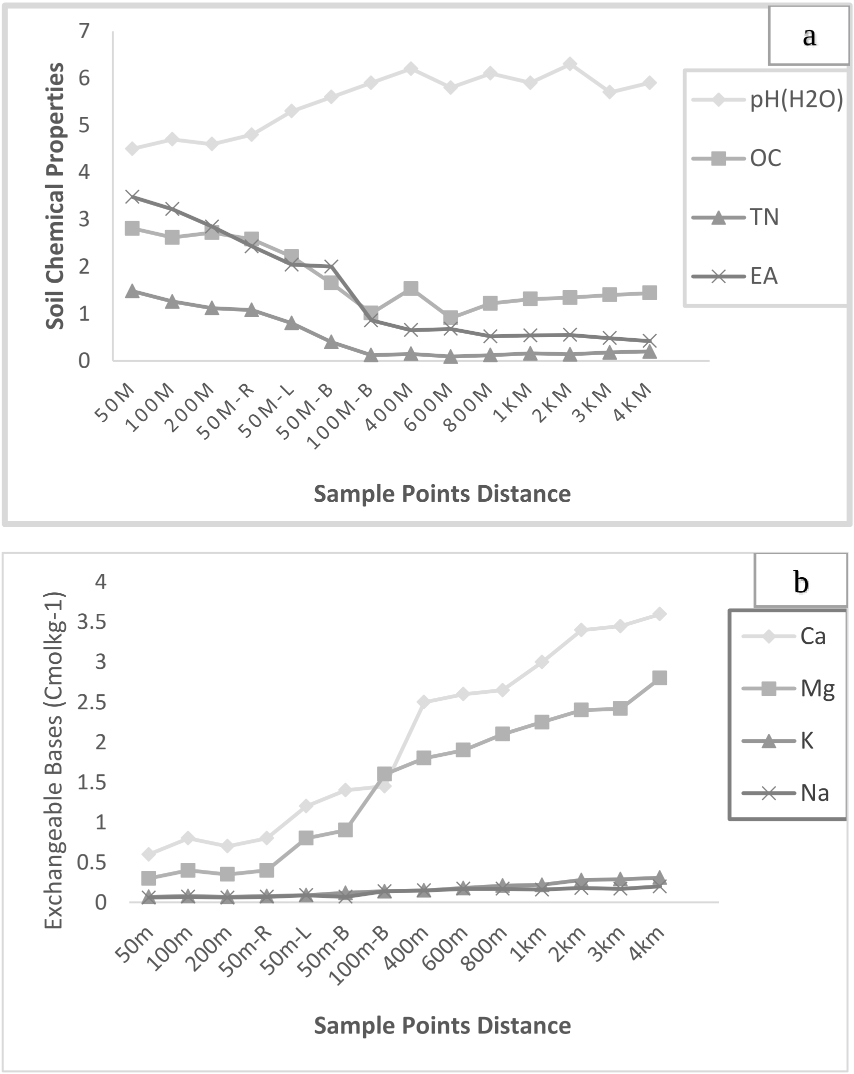

Figure 3: Variability trend of selected soil chemical properties from different sample distance points at 0 – 15 cm and 15 – 30 cm depths from different sample distance points away from a horizontal gas flaring site

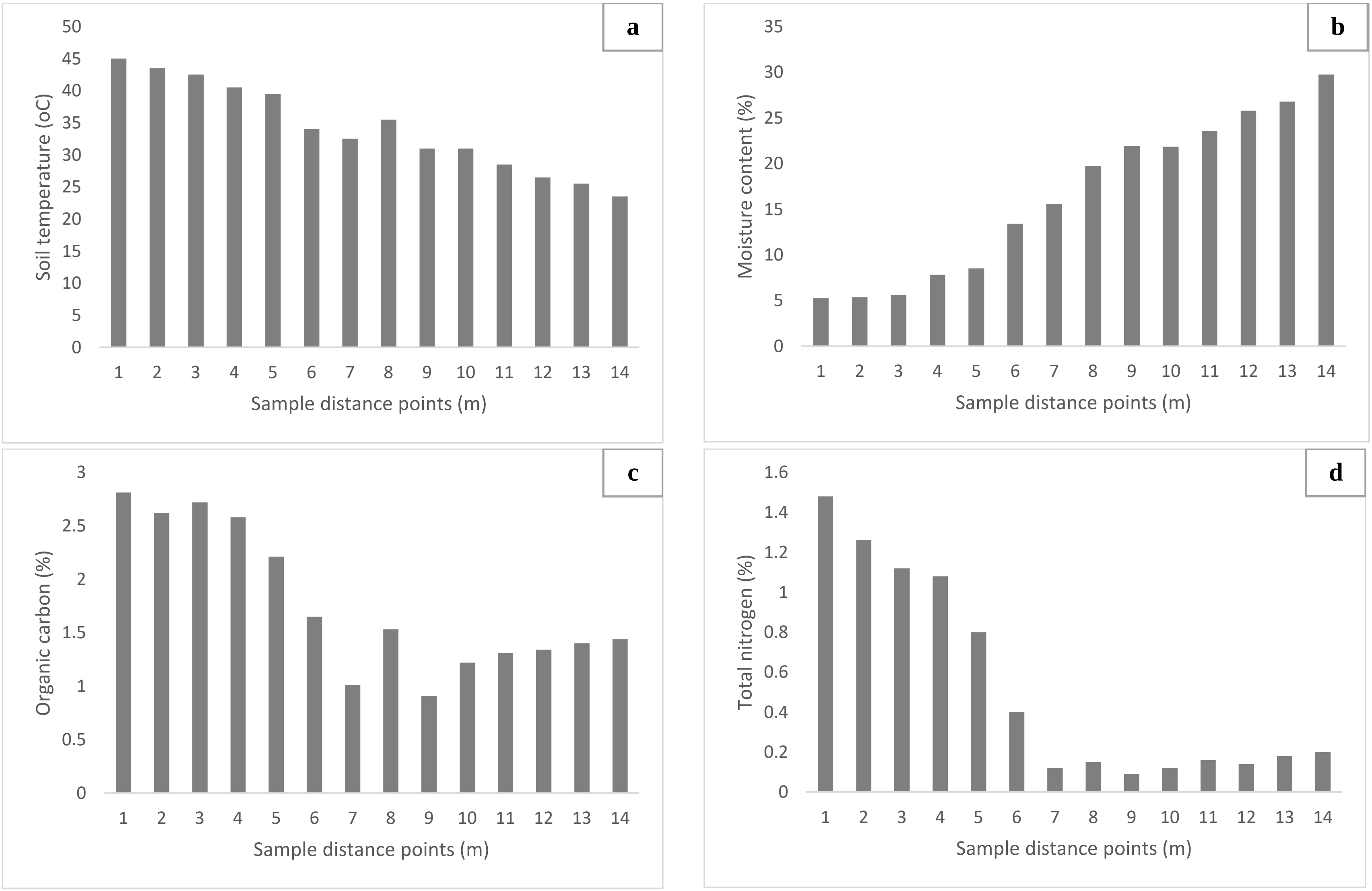

Figure 4: Variation of (a) soil temperature, (b) moisture content, (c) organic carbon and (d) total nitrogen from different sample distance points away from the flare site

CONCLUSION AND RECOMMENDATION

The study has shown glaring negative disruptions of soil physico-chemical properties within the vicinity of a horizontal gas flaring in the study area. The impact correlated strongly with distances away from the flare location. For example, among the physical properties, soil temperature, BD and % sand increased at decreasing distance towards the flare point, ranging from 23.5 - 45 ^oC, 1.42 - 2.50 g/cm^3, and 77.77 - 87.35 % respectively; whereas % TP, GMC, K-sat, % silt and % clay increased at increasing distances away from the flare point, ranging from 6 - 46 %, 5.25 - 29.73 %, 0.10 - 7.84 cm^3/hr, 5.80 - 9.69 % and 6.85 - 12.54 % respectively. The moisture content followed dissimilar pattern of decrease towards the flare sampling points and increase outside the flaring site. It ranged from 5.25 - 29.73 % from sample points 50 m though 4 km. All chemical properties except % OC and % OM decreased towards the flare point and increase away. Soil pH (H_20), TN and AP mean values ranged from 4.5 - 6.3 %, 0.20 - 1.48 % and 15.2 - 37.6 mg/kg, respectively. EC, Ca, Mg, K and Na values ranged from 0.16 - 1.15 mS/cm, 0.60 - 3.60 cmolkg-1, 0.30 - 2.80 cmolkg-1, 0.07 - 0.31 cmolkg-1 and 0.06 - 0.20 cmolkg-1, respectively. EA, ECEC and % BS varied from 0.42 - 3.48 cmolkg^{-1}, 4.03 - 7.33 cmolkg^{-1} and 20.36 - 94.27 % respectively from sampling point 1 through to 14 at 0 – 30 cm depth. OC and OM ranged from 0.91 - 2.8 1 %, 1.67 - 4.84 % respectively. This deleterious act of horizontal gas flaring, as seen in the results of this work, has negative implications for soil quality and fertility status of the arable soil, and by extension food security as a result of enormous thermal pollution and heat from the flaring. These can serve as soil quality and fertility indicators for land use management decisions.

Therefore, it is compelling to recommend the stop of this environment-unfriendly act of horizontal/ground flaring which impacts and degrades arable soils used for farming by the resource poor farmers that abound in the area. Also, the present government of Nigeria should enforce already promulgated laws of zero flaring policies by previous administrations in order to curb this menace. This is expedient in order to preserve and sustain the soil ecosystem.

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