



Environmental Implication of Thermal Radiation on the Physiochemical Properties of Soil around Gas Flare Sites in the Niger Delta Region of Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The effect of thermal radiation on the Physiochemical properties of soil around gas flare site in the Niger Delta region was assessed in Emuoha Local Government Area of River State, Nigeria, for a period of twelve months. Radiation profile was determined at different times (hours) – 6, 10, 14, 18 and 22, in the four seasons (early dry, early wet, late dry and late wet) of the year. Soil samples were taken at different depths (cm) (0-15 and 15-30) for physicochemical attributes at different distances (m) (0-150, 150-300, 300-450, 450-600 and 1000 -2000) from the flare site and thermal radiation was also determined at the respective distances. Results of effect of time and seasonal variations on radiation profile showed that environmental temperature ($^{\circ}\text{C}$) ranged from 29.2 ± 0.3 at 22 hours of early wet season to 33.0 ± 0.4 at 14 hours of late dry season; radiation temperature ranged from 35.4 ± 1.2 at 22 hours of late wet season to 42.0 ± 1.4 at 14 hours of late dry season, while thermal radiation (w/m^2) ranged from 490.83 ± 7.7 at 22 hours of late wet season to 535.69 ± 9.69 at 14 hours of late dry season. Results of effect of flare distance on physicochemical properties of soil showed that as the distance (m) from flare site increases from 0 – 150 to 1000 –

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2000, the radiation intensity (w/m^2) decreases from $603.84 \pm 5.7 - 428.83 \pm 0.75$, and values of pH, OC, N, P, and exchangeable cations - K^+ , Na^+ , Ca^{2+} , Mg^{2+} increases in the range {pH ($4.94 \pm 0.02 - 5.50 \pm 0.00$), OC ($1.09 \pm 0.01 - 2.05 \pm 0.00$), N ($0.07 \pm 0.01 - 0.09 \pm 0.00$), P ($10.90 \pm 0.03 - 12.10 \pm 5.19$), K^+ ($0.28 \pm 0.01 - 1.86 \pm 0.01$), Na^+ ($0.48 \pm 0.00 - 1.04 \pm 0.00$), Ca^{2+} ($1.65 \pm 0.01 - 2.85 \pm 0.00$), Mg^{2+} ($0.73 \pm 0.01 - 1.24 \pm 0.01$)}, These values seemed not to be affected by the thermal radiation and flare distance, oil and grease and THC decreases in the range $203.30 \pm 0.88 - 61.33 \pm 0.33$ and $352.90 \pm 2.08 - 10.04 \pm 0.04$ respectively. Similar trend was observed with soil samples taken at 15-30cm depth. Statistical analysis showed there is significant difference ($p < 0.001$) in soil attributes as distance from flare distance increases. Further studies should be carried out to investigate the relationship between soil around flare site and crop performance on different agro-ecological zone of Rivers State.

Keywords: Environmental impact; thermal radiation; gas flare; soil; physiochemical properties.

1. INTRODUCTION

Man in his quest to improve his standard of living has continuously introduced substances that contaminate the environment. Hence, in his pursuit for technological development, man's activities have made the environment to be subjected to one form of pollution or the other, consequently, resulting in environmental degradation on land, in water and air.

Soil is a very important component of terrestrial ecosystem. It is essential to human because, it is the top layer of the earth in which humans grow plants. This makes it play a vital role in food chain [1]. In the Niger Delta region, there is a paucity of arable agricultural land due to Oil and Gas exploration activities. Most of the region land mass has been taken over with the criss-cross of pipelines carrying crude oil and gas and in most locations you have gas flares tips which are vertical or horizontal. Accordingly, a closer look at the geographical spread of oil fields would show that the flares are located principally in the South-Eastern axis of the Nigeria Delta Zone (mainly Delta / Bayelsa / Rivers / Imo / Akwa Ibom States), where also there is a preponderance of large chemical process plants, such as existing four oil refineries (2 - Government and 2 - Private Investors), steel plant, fertilizer complex, petrochemical plant as well as the Nigeria liquefied natural gas (NLNG) with train 7 (seven) currently undergoing Detailed Engineering Design and Construction. The resulting harmful environmental heat-related effects from such haphazard field operations are obvious; "The surrounding soil get scorched, vegetation and farmlands look patched, villagers complained of an illness referred to as "internal heat" which may not be unrelated to the cumulative effect of long exposure to radiant heat from gas flares [2].

This land use types poses an environmental threat to the physiochemical properties of soil around the flare sites. According to [3], variations in soil temperature and related soil heat transfer processes are influenced by different land use types and soil management practices. In a similar study by [4], a comprehensive data on variations in soil heat transfer under different land uses is necessary for proper understanding of the variations in thermal energy transfer under diverse human activities and modifications on land.

Plant and animal communities may also be directly affected by changes in their environment through variations in water, air and soil/sediment quality and through disturbance by noise, extraneous light and changes in vegetation cover necessitated by the flaring of Gas [5]. Such changes may directly affect the ecology: for example, habitat, food and nutrient supplies, breeding areas, migration routes, vulnerable to predators or changes in herbivore grazing patterns, which may then have a secondary effect on predators. Soil disturbance (thermal effect) may have an impact on ecological integrity and may lead to indirect effects by upsetting nutrient balances and microbial activity in the soil. If not properly controlled, a potential long-term effect is loss of habitat, which affects both fauna and flora, and may induce changes in species composition and primary production cycles. It is important to consider how changes in the biological and physical environment also affect local people and indigenous population's livelihood [6].

A similar study revealed that Gas flare (thermal stress) causes some physiological changes in the cassava plant ranging from internodes shortening of apical internodes, leaf distortion and discoloration, crinkling and pebbling,

reduction in leaf size. [5]. It has also been reported that the rate of most enzymatic reactions approximately doubles for each 10⁰C rise in the temperature. This affects the body metabolism that depends on enzyme activities as well as the breeding potentials of animals [7].

Thermal radiation is also known to affect the environment by baking the soil, destroying plants, soil organism and nutrients. Continuous ejection of excessive heat into the environment has increased the desert encroachment being noticed in some parts of the Niger Delta, since the water content of the soil can no longer support the rain forest.

Thermal radiation consists of electro-magnetic waves emitted due to the agitation of the molecules of a substance. The waves are similar to light waves in that they are propagated in straight lines at the speed of light and they require no medium for propagation. Radiation striking a body can be absorbed by the body, reflected from the body, or transmitted through the body. The fractions of the radiation absorbed, reflected and transmitted are called the absorptivity (α), and the reflectivity (ρ), and the transmissivity (ψ), respectively [8].

According to [9], the soil is essential for the preservation of plant life, providing mechanical support, supplying nutrients and water. According to Adedayo, [10]. Thermal properties of soils are an important ingredient of soil physics that has found vital uses in climatology, engineering, and agriculture. Soil temperature is an important component for plant growth like air, water, and nutrients. The temperature of the soil can affect plant growths directly or indirectly by influencing moisture, aeration, structure, microbial and enzyme activities, organic matter decomposition, nutrient availability, and other soil chemical reactions.[11]

Soil heat is the most important factor that controls the intensity of biophysical, biochemical, and microbiological processes that takes place in the soil. The source of heat for soil is the solar radiation. The rate of mineralization of organic matter, the physical processes of diffusion and viscous flow, the germination of seed, root growth and its activity in terms of water and nutrients absorption and respiration are strongly temperature dependent [9,12,13].

Some researchers [14] had studied the impact of a thermal power plant located at Obra on

vegetation and soil in surrounding areas and found that pollutant concentration in the area gradually decreased along a belt in the prevailing wind direction and a gradient of structural and functional changes in plants and soil was reported. Another study [15] revealed that forest fires can disturb the evolution of plant communities and influence soil physicochemical properties.

It has been observed that most of the plants grown around flare sites are stunted and do not grow as expected. This has been a major concern to the farmers in the communities. Thus, this study was designed to investigate the environmental impact of the thermal radiation from gas flare on the soil physiochemical parameters and to establish if the soil parameters are implicated as the major cause of the poor crop yield or negative growth impart on the plant or a combination of both the thermal heat on plant and soil temperature respectively. Findings from the study will guide the villages (farmers) not only in Emuoha, but also in other parts of Rivers State and the Niger Delta Region in farming plan.

2. MATERIALS AND METHODS

2.1 Study Location

The experimental plots were sited on an agro-ecological zone. The coastal plain sands of Emuoha Local Government Area of River state hosting flow station of a multinational oil exploration company was selected. Emuoha is a humid tropical area. The rainfall pattern is bimodal with peaks in June and September, and the period of low precipitation in August. The long rainy season is between April and early August, while the short rainy season is between late August and October. The dry season is from November to March interrupted occasionally by sporadic down pour. Emuoha has an annual rainfall of between 2000 mm and 2453 mm, while the annual temperature is between 22.6⁰C and 31.2⁰C. Emuoha, is located within N 4⁰53'2" and E6⁰52'36". The experiment was conducted for a period of 12 months starting from July to June using the seasonal variations shown in Table 1.

2.2 Measurement of Thermal Radiation

Heat radiation was measured with a pyranometer (Serial No: SOL 5256 100224922) equipped with an automatic logging system. The sensor was

focused on the direction of flare for ten minutes interval to record radiation every ten seconds interval. The mean reading taken over the ten minutes for a period of 1hr (one hour) exposure time was then recorded as the thermal radiation value at 0-150 m, 150-300m, 300-450m, 450-600m and 1000-2000m, respectively. Raytek, non-contact MT4 – (MiniTemp Thermometer) was placed near the Pyranometer in an open air, also at one meter above the ground to measure

the ambient temperature. For the soil Temperature, the method [16] using Soil thermometers that was buried in the ground carefully, so that the surrounding soil was left undisturbed at the particular location. In each station, the measurement was started at 6.00 a.m. to 10p.m (6.00a.m, 10.00a.m, 2.00p.m, 6.00p.m and 10.00 p.m.), covering 0-150m, 150-300m, 300-450m, 450-600m and 1000-2000m, respectively.

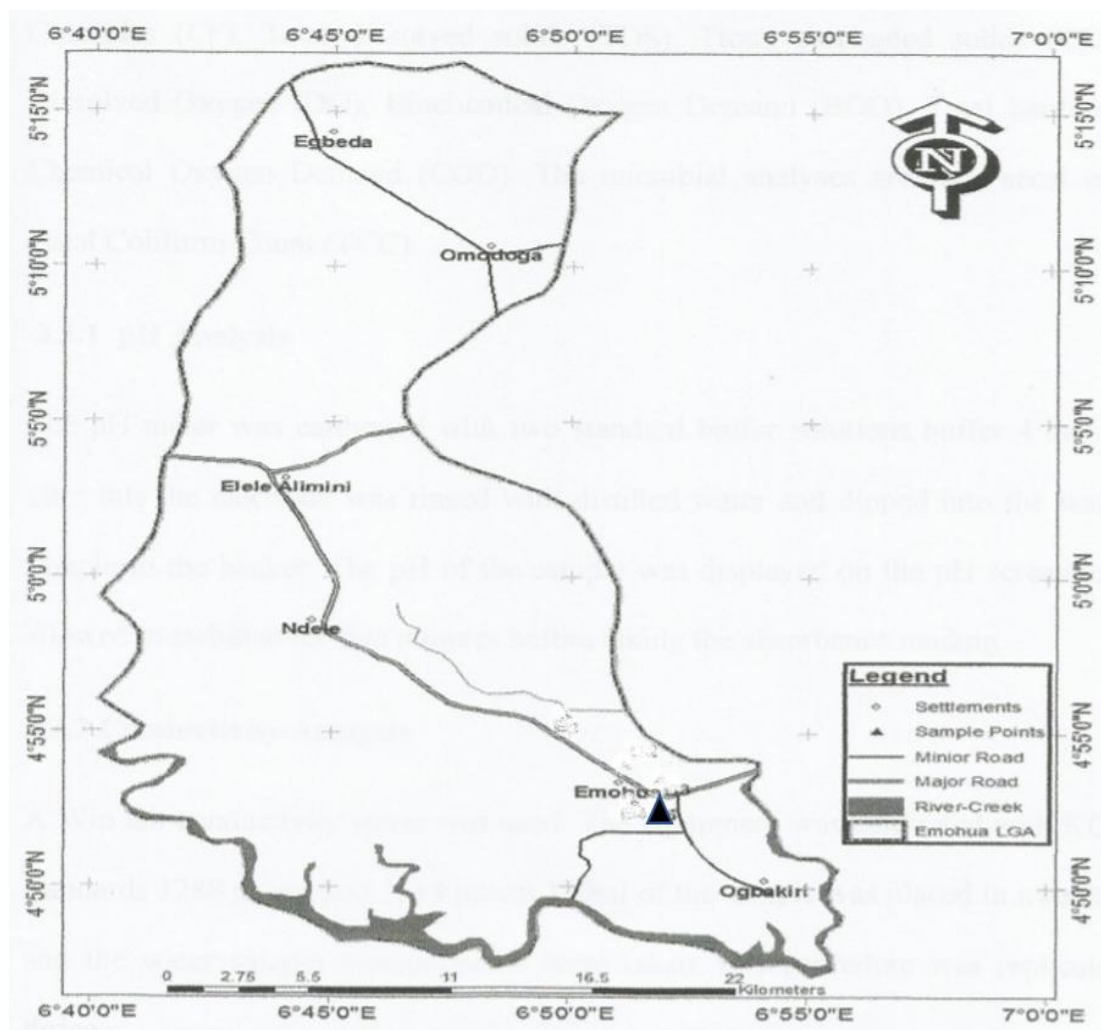


Fig. 1. Map of Rivers State, showing the study area- Emuoha

Table 1. Seasonal Variations

Seasons	Months		
Late Wet	July	August	September
Early Dry	October	November	December
Late Dry	January	February	March
Early Wet	April	May	June

2.3 Soil Sample Collection and Analysis

Soil samples were collected at different intervals at a depth of 0 – 15 cm and 15-30 cm using soil auger. The sample collected in dry season were air dried for 2 days at room temperature and those collected in wet season were air dried for 7 days at room temperature and sieved through 2mm sieve and stored for analysis at the Institute of pollution Studies, Rivers State University, Port-Harcourt.

2.4 Procedure for Soil Analysis

2.4.1 Soil organic carbon

Organic carbon determination was carried out by the methods described by [17]. This was done by taking 1g of air-dried soil sample passed through a 0.5mm mesh sieve and treated with 10 ml 0.167 $K_2Cr_2O_7$ and 20ml of conc. H_2SO_4 in 500ml conical flasks and immediately swirl the flask gently until soil and reagents are mixed, then more vigorously for one minute. After a 30-min rest 200 mL of distilled water, 10 mL of concentrated H_3PO_4 and 1 mL of 0.16 % diphenylamine were added. The excess dichromate that was not reduced in the reaction was determined by volumetric titration using ammonium ferrous sulfate $[Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O]$ (Mohr's salt).

2.4.2 Soil pH

In the determination of soil pH, 20 g of air-dried soil sample was weighed into a 50ml beaker and 50 ml of distilled water was added. The mixture was allowed to stand for one (1) hour stirring occasionally with a glass rod. A pH meter (1:2.5/v) with a glass electrode was then used to measure the pH [18].

2.4.3 Available phosphorus

Available phosphorus in the soil sample was determined using the method in [19]. 2g of air-dried soil was weighed into a clean extraction flask. Absorbance of the sample containing the soil extract was measured. Phosphorus concentrations were then calculated from a standard curve.

2.4.4 Exchangeable cations

The exchangeable bases sodium (Na) and potassium (K) were determined using a flame photometer, as described by [20]. Whereas calcium (Ca) and magnesium (Mg) were

determined using the EDTA titration method as in [21].

2.4.5 Total Nitrogen

Total nitrogen was determined by micro-kjeldahl digestion method as described by [22].

2.4.6 Oil and Grease /THC

Oil and grease and THC were determined using the EPA method 9071A and the extract was analyzed using GC/FID in accordance with EPA 8015B as described by [23].

2.4.7 Data Analysis

The statistical differences were analyzed by analysis of variance and least significant difference as described by [24] Using mean of three determinations. Also, descriptive analysis and two-way analysis of variance (ANOVA) were performed to determine the general trend of experimental data. Mean separation was performed on the analyzed data using Duncan's multiple test with the aid of SAS version 9.1 software (SAS 2003)

3. RESULTS AND DISCUSSION

3.1 Results

Table 2 showed the effects of time and seasonal variations on thermal radiation profile. The effects of flare distance on the physicochemical properties of soil were presented in Table 3. Highlighted in Table 4. is the effect of interaction between flare distance and depth on soil physicochemical properties. Correlation matrix between flare distance (Thermal radiation), Environmental and Soil Temperature was shown in table 5.0. Influence of interaction between flare distances, seasonal variations, radiation temperature on thermal radiation profile are presented in Figs. 2, 3 and 4. respectively. The effect of flare distance and seasonal variations on the environmental and soil temperature was presented in Figs 5 and 6 respectively.

3.2 Discussion

3.2.1 Effect of time and seasonal variation on radiation profile

The effect of time and seasonal variations on radiation intensity shows that, the highest environmental and radiation temperatures were recorded during late dry season respectively. Thus, the radiation intensity was highest during

early dry season. The radiation profile decreased with increasing distance from the flare. This agrees with the work of [2] that the radiation intensity increased with increasing distance to the flare. This increase in radiation intensity and environmental temperature are implicated for the poor performance of crops around the flare site. According to [25], the seasonal variations affecting the solar inclination also cause variations in soil temperature. It was also reported that as the in-coming energy available at the soil surface varies with the position of the sun, the soil profile experiences diurnal as well as annual variations in temperature. This also affects the environment by baking the soil, destroying plants and soil organisms and nutrients, which agreed with the work of [9]. Soil temperature exercises a major influence on the growth and development of plants through its effect on germination, emergence, and early growth. The effect being more critical during germination and early seedling development than at any other growth stage. Unfavorable soil temperature at seeding time not only affect germination and seed emergence but also result in poor crop stand and reduce yields because of a lower plant population and delayed maturity. A similar study by [11] highlighted the effects of Soil Temperature on some Soil Properties and Plant Growth. According to [3], variations in soil temperature and related soil heat transfer processes are influenced by different land use types and soil management practices. In this study, the thermal heat from the continuous gas flaring activities is implicated. According to [10]. The results obtained showed that the soil temperature decreased with depth. This can be attributed to the fact that temperature functions are greatest at the surface than at the subsoil. Other researchers [25] had recorded variations between the temperatures of various farm sites around the flare site with highest temperature value of 47°C at 1200hr, which compares favourably with these results. More so, [26] had reported that the peak of radiation intensity occurs between 1130hr and 1430hr each day. Radiation intensity is generally low during the late wet season at all selected time of sampling as compared to other seasons with highest value 513.32 w/m² at 1400hr and lowest value 490.83w/m² at 2200hr. Correlation matrix showed that significant relationships existed between the radiation and the ambient temperature during dry and wet season. Similarly, significant relationships existed for thermal radiation. However, the findings further showed a significant positive relationship

between flare distance, environmental and soil temperature. The relationship showed an increase in soil temperature as the environmental temperature increased. The effect of interaction, between flare distance and seasonal variations on radiation and soil profile shows significant difference (P<0.05).

3.2.2 Effect of flare distance on the physicochemical properties of soil

The study highlighted the effects of flare distance on the physicochemical properties of soil. From Table 3, at 0-150m flare distance, the highest radiation intensity of 603.84 ± 5.7w/m² was recorded, while the least radiation value of 428.83 ± 0.75w/m² was recorded at 1500-2000m flare distance. According to [2] that radiation intensity increased with decreasing distance to the flare. The study also showed that as the distance is decreasing towards the flare site, pH is also decreasing from 5.50 (at 1000 – 2000 m) to 4.94 (at 0-150 m). This showed that the soils that are very close to the flare site were slightly acidic. In contrast, to flare site [27] recorded a pH of 4.9 to 5.0 around a river. According to [28] that the degree of acidity and /or alkalinity is considered a master variable that affects nearly all soil properties-chemical, physical, and biological.

The same trend was observed with percentage organic carbon, total nitrogen and available phosphorous as the values decreased from 2.05 % to 1.09 %, 0.09 mg/kg to 0.07 mg/kg and 12.1 mg/kg to 10.9 mg/kg respectively as the distance decreases from 1000-2000 m to 0-150 m respectively. Exchangeable cations K⁺, Na⁺, Ca²⁺ and Mg²⁺ also show similar behavior as their highest values (meq/100g) of 1.86, 1.04, 2.85 and 1.24 were recorded respectively at 1000 – 2000m, while their lowest values (meq/100g) of 1.28, 0.48, 1.65 and 0.73 were recorded respectively at 0-150m flare distance. Oil and grease and total hydrocarbon have their highest values (ppm) of 203.3 and 352.9 respectively at 0-150m and their least values (ppm) of 61.33 and 10.04 respectively at 1000-2000m. This could be because of possible oil seepage from the flare bund wall into the surrounding environment.

3.2.3 Effect of interaction between flare distance and depth on soil physicochemical properties of Soil

Table 4 showed results of the effect of interaction between flare distance and depth on soil physicochemical properties. it showed that at all

distances from the flare site, soil pH values were generally higher at the 0-15cm than at 15-30cm, and the pH values increases as the distance from the flare increases with the least value 4.94 (0-15 cm) and 4.41 (15-30 cm) at 0-150 m distance, and at 1000 – 2000m, the pH values were 5.50 (0-15 cm) and 4.68 (15-30 cm) respectively. These results compare favorably with similar research on Izombe flow station [29] where pH range of 4.3 to 5.6 for soils around the flow station was reported and concluded that flare does not affect the soil physical condition and pH characteristics. In a similar study by [30] who demonstrated the effect of the power plant(thermal) emissions on soil and eco-physiological characteristics such as pH, organic matter and N, P, K and S concentrations in soil; leaf injury symptoms, number, and distribution of plant species; chlorophyll content in leaves, percentages of photosynthetically active leaf area; accumulation of N, P, K, and S in leaves etc. seemed to be a function of the pollutant gradient existing in the soil environment. A study by [31] revealed that Forest fires can disturb the evolution of plant communities and influence both organic matter (SOM) and soil physicochemical properties. The increase in soil acidity in the area may cause cation-anion imbalance and microbe population reduction to

affect soil fertility [31]. According to [10]. the exchange of heat in the soil is very essential for the redistribution of moisture and nutrients in the soil. Increase in soil temperature decreases organic matter [32], through combustion. This decrease in organic matter and reduction in clay size clay fraction as a result of high temperature leads to a decrease in the cation exchange capacity of the soil [33] Increase in soil temperature leads to a decrease in the cation exchange capacity of the soil [34]. The trend is not different for percentage organic carbon, total nitrogen and available phosphorous with organic carbon percentage (%) having higher values (1.09, 1.25, 1.95, 2.01 and 2.05) at 0-15cm depth at 0-150 m, 150-300 m, 300-450 m, 450-600 and 1000-2000 m respectively and lower values (0.80, 0.88, 0.78, 0.81 and 0.86) at 15-30 cm depth at 0-150 m, 150-300 m, 300-450 m, 450-600 and 1000-2000 m respectively. Except for Na^+ where the values were lower at 0-15 cm depth, the exchangeable cations showed similar trend. The absolute quantity and pattern of occurrence of nitrogen, available phosphorus, and exchangeable cations in the soils do not appear to be influenced by the flare irrespective of the distance of the soil to the flare, which agreed with the work of [25].

Table 2. Effect of time and seasonal variations on radiation profile

Time (Hrs.)	Seasonal effect	Envi. Temp (°C) Mean ± SEM	Radiation temp. (°C) Mean ± SEM	Thermal radiation (w/m ²) Mean ± SEM
600	Early Dry	30.4 ± 0.3 ^{cdef}	38.0 ± 1.1 ^{abc}	507.03 ± 7.19 ^{abc}
	Early Wet	30.0 ± 0.2 ^{ef}	37.0 ± 1.1 ^{abc}	500.07 ± 6.80 ^{bc}
	Late Dry	29.7 ± 0.3 ^{efg}	38.1 ± 1.2 ^{abc}	507.69 ± 7.47 ^{abc}
1000	Late Wet	29.5 ± 0.3 ^{efg}	35.9 ± 1.0 ^{bc}	492.89 ± 6.59 ^c
	Early Dry	30.9 ± 0.3 ^{cde}	39.0 ± 1.2 ^{abc}	573.71 ± 7.88 ^{abc}
	Early Wet	30.3 ± 0.2 ^{def}	38.5 ± 1.1 ^{abc}	509.99 ± 7.32 ^{abc}
1400	Late Dry	30.2 ± 0.2 ^{def}	38.8 ± 1.2 ^{abc}	512.58 ± 7.65 ^{abc}
	Late Wet	29.8 ± 0.2 ^{efg}	37.4 ± 1.1 ^{abc}	503.37 ± 7.45 ^{abc}
	Early Dry	32.7 ± 0.4 ^{ab}	40.2 ± 1.2 ^{abc}	521.77 ± 8.19 ^{abc}
1800	Early Wet	31.7 ± 0.3 ^{bc}	41.2 ± 1.3 ^{ab}	529.01 ± 8.78 ^{ab}
	Late Dry	33.0 ± 0.4 ^a	42.0 ± 1.4 ^a	535.69 ± 9.69 ^a
	Late Wet	30.8 ± 0.5 ^{cde}	38.8 ± 1.3 ^{abc}	513.32 ± 8.23 ^{abc}
2200	Early Dry	31.5 ± 0.4 ^{cd}	38.3 ± 1.2 ^{abc}	509.47 ± 7.80 ^{abc}
	Early Wet	30.4 ± 0.3 ^{cdef}	39.7 ± 1.3 ^{abc}	519.00 ± 8.63 ^{abc}
	Late Dry	30.9 ± 0.4 ^{cde}	40.2 ± 1.4 ^{abc}	523.31 ± 9.25 ^{abc}
2200	Late Wet	29.6 ± 0.3 ^{efg}	37.2 ± 1.2 ^{abc}	502.04 ± 7.68 ^{abc}
	Early Dry	30.1 ± 0.3 ^{def}	37.1 ± 1.2 ^{abc}	501.14 ± 7.48 ^{abc}
	Early Wet	29.2 ± 0.3 ^{fg}	38.4 ± 1.3 ^{abc}	510.79 ± 8.71 ^{abc}
2200	Late Dry	29.3 ± 0.3 ^{fg}	37.6 ± 1.2 ^{abc}	504.90 ± 8.02 ^{abc}
	Late Wet	28.5 ± 0.5 ^{gh}	35.4 ± 1.2 ^c	490.83 ± 7.70 ^c

Within column, mean ± SEM with different superscript are significantly different at P<0.05). Mean of 3 determinations

Table 3. Effect of flare distance on the physiochemical properties of soil

Distance Flare	Thermal Radiation (W/M2) Mean ±SEM	PH Mean±SE M	%organic carbon Mean ±SEM	Total nitrogen Mean ±SEM	Avail. Magnesium /kg Mean ±SEM	Exchangeable cations (Meq/100g)				Oil and grease (ppm) Mean ±SEM	THC (ppm) Mean ±SEM	% Composition		
						K+ Mean ±SEM	Na+ Mean ±SEM	Ca ²⁺ Mean ±SEM	Mg ²⁺ Mean			Sand	Silt	Clay
0-150	603.84±5.7	4.94±0.02 _d	1.09±0.01 ^e	0.07±0.01 ^d	10.9±0.03 ^{ab}	1.28±0.01 ^e	0.48±0.00 ^g	1.65±0.01 ^d	0.73±0.01 ^d	203.3±0.88 _b	352.9±2.08 ^a _{6^c}	75.10±0.0 _{0^b}	15.20±0.1 _{0^b}	10.10±0.1 _{0^g}
150-300	588.40±4.0	4.81±0.01 _e	1.25±0.01 ^d	0.08±0.00 ^{cd}	8.71±0.00 ^{ab}	0.95±0.00 ^h	0.32±0.00 ^h	1.48±0.01 ^e	0.25±0.00 ^h	186.0±0.00 ^c	140.2±57.73 _{bc}	68.01±0.0 _{0^g}	10.10±0.1 _{0^e}	22.1±0.00 ^b
300-450	557.29±1.4 ₉	4.92±0.01 _d	1.95±0.00 ^c	0.12±0.01 ^a	15.7±0.00 ^{ab}	1.76±0.00 ^c	0.76±0.01 ^e	2.91±0.00 ^b	0.48±0.01 ^f	70.61±0.01 ^f	80.13±0.01 ^{bc} _d	79.01±0.0 _{0^a}	7.20±0.00 ^g	14.1±0.10 ^f
450-600	448.91±5.3	5.41±0.01 _c	2.01±0.01 ^b	0.10±0.00 ^{ab}	16.7±0.00 ^a	1.81±0.01 ^b	0.92±0.01 ^c	2.95±0.00 ^a	1.01±0.01 ^b	15.01±0.01 ⁱ	48.44±13.33 _{cd}	78.01±0.0 _{0^b}	14.2±0.10 ^c	8.1 ±0.10 ^h
1000-2000	428.83±0.7 ₅	5.50±0.00 _b	2.05±0.00 ^a	0.09±0.00 ^b _c	12.1±5.19 ^{ab}	1.86±001 ^a	1.04±0.00 ^a	2.85±0.00 ^c	1.24±0.01 ^a	61.33±0.33 _g	10.04±0.04 ^d	73.23±0.1 _{5^d}	22.10±0.0 _{9^a}	5.10±0.00 ⁱ

Within column, mean ±SEM with different superscript are significantly different at P<0.05

Table 4. Effect of interaction between flare distance and depth on soil physiochemical properties

Distance Flare (M)	Depth of soil (cm)	PH Mean± SEM	%organic Mean±SEM	Total nitrogen Mean±SEM	Avail. Mg/kg Mean±SEM	Exchangeable cations (Meq/100g)			Oil and grease (ppm) Mean±SEM	THC (ppm) Mean±SEM	% Composition Mean ± SEM			
						K+ Mg ²⁺ Mean±SEM	Na+ Mean±SEM	Ca ²⁺ Mean±SEM			Sand Clay	Silt		
0-150	0-15	4.94±0.02 ^d	1.09±0.01 ^e	0.07±0.01 ^d	10.9±0.03 ^{ab}	1.28±0.01 _e	0.48±0.00 ^g	1.65±0.01 _d	0.73±0.01 _d	203.3±0.88 ^b	352.9±2.08 ^a	75.10±0.06 _c	15.20±0.10 ^b	10.10±0.10 ^g
	15-30	4.41±0.01 ^h	0.80±0.00 ^{gh}	0.07±0.00 ^{de}	6.44±0.00 ^b	1.48±0.00 _d	0.69±0.00 ^f	0.68±0.00 _h	0.61±0.01 _e	230.1±0.00 ^a	360.4±0.00 ^a	72.02±0.01 _e	13.10±0.00 ^d	15.10±0.10 ^{0^e}
150-300	0-15	4.81±0.01 ^e	1.25±0.01 ^d	0.08±0.00 ^{cd}	8.71±0.00 ^{ab}	0.95±0.00 _h	0.32±0.00 ^h	1.48±0.01 _e	0.25±0.00 _h	186.0±0.00 ^c	140.2±57.73 ^{bc}	68.01±0.00 _g	10.10±0.10 ^e	22.1±0.00 ^b
	15-30	4.52±0.02 ^g	0.88±0.00 ^f	0.05±0.00 ^e	12.4±0.00 ^{ab}	0.68±0.00 ⁱ	0.46±0.00 ^g	0.61±0.01 ⁱ	0.46±0.00 ^f	130.5±0.03 ^d	180.1±0.00 ^b	67.02±0.00 _h	8.10±0.10 ^f	25.2±0.10 ^a
300-450	0-15	4.92±0.01 ^d	1.95±0.00 ^c	0.12±0.01 ^a	15.7±0.00 ^{ab}	1.76±0.00 _c	0.76±0.01 ^e	2.91±0.00 _b	0.48±0.01 ^f	70.61±0.01 ^f	80.13±0.01 ^{bcd}	79.01±0.00 _a	7.20±0.00 ^g	14.1±0.10 ^f
	15-30	4.51±0.01 ^g	0.78±0.01 ^h	0.06±0.00 ^{de}	10.4±0.00 ^b	1.26±0.01 _e	0.97±0.00 ^b	1.25±0.01 ^f	0.36±0.00 _g	80.67±0.01 ^e	90.25±0.00 ^{bcd}	75.01±0.00 _c	3.10±0.10 ^h	22.2±0.10 ^b
450-600	0-15	5.41±0.01 ^c	2.01±0.01 ^b	0.10±0.00 ^{ab}	16.7±0.00 ^a	1.81±0.01 _b	0.92±0.01 ^c	2.95±0.00 _a	1.01±0.01 _b	15.01±0.01 ⁱ	48.44±13.33 ^{cd}	78.01±0.00 _b	14.2±0.10 ^c	8.1 ±0.10 ^h
	15-30	5.81±0.01 ^a	0.81±0.01 ^g	0.06±0.00 ^{de}	10.2±0.00 ^{ab}	1.10±0.00 ^f	0.81±0.01 ^d	1.11±0.01 _g	0.70±0.00 _d	20.03±0.02 ^h	40.51±0.01 ^{cd}	70.13±0.15 ^f	10.2±0.10 ^e	20.1±.10 ^d
1000-2000	0-15	5.50±0.00 ^b	2.05±0.00 ^a	0.09±0.00 ^{bc}	12.1±5.19 ^{ab}	1.86±001 ^a	1.04±0.00 ^a	2.85±0.00 _c	1.24±0.01 _a	61.33±0.33 ^g	10.04±0.04 ^d	73.23±0.15 _d	22.10±0.09 ^a	5.10±0.00 ⁱ
	15-30	4.68±0.0 [†]	0.86±0.00 [†]	0.07±0.00 ^{de}	9.38±0.00 ^{ab}	1.02±0.01 _g	0.79±0.00 ^{de}	1.09±0.01 _g	0.87±0.01 _c	10.10±0.06 ⁱ	20.23±0.03 ^d	64.05±0.03 ⁱ	15.10±0.00 ^b	21.10±0.10 ^c

Within column, mean ±SEM with different superscript are significantly different at P<0.05

Table 5. Correlation matrix between flare distance and environmental and soil temperature

	S-150	E-150	S-300	E-300	S-450	E-450	S-600	E-600	S-2000	E-2000
S-150		0.97***	0.94***	0.91***	0.67***	0.90***	0.91***	0.82***	0.85***	0.85***
E-150	0.97***		0.90***	0.82***	0.61***	0.82***	0.87***	0.71***	0.82***	0.80***
S-300	0.94***	0.90***		0.90***	0.65***	0.93***	0.82***	0.80***	0.85***	0.86***
E-300	0.91***	0.82***	0.90***		0.68***	0.93***	0.78***	0.88***	0.75***	0.78***
S-450	0.67***	0.61***	0.65***	0.68***		0.64***	0.59***	0.61***	0.54***	0.57***
E-450	0.90***	0.82***	0.93***	0.93***	0.64***		0.81***	0.91***	0.81***	0.82***
S-600	0.91***	0.87***	0.82***	0.78***	0.59***	0.81***		0.82***	0.77***	0.76***
E-600	0.82***	0.71***	0.79***	0.88***	0.61***	0.91***	0.82***		0.69***	0.74***
S-2000	0.85***	0.82***	0.85***	0.75***	0.54***	0.81***	0.77***	0.69***		0.96***
E-2000	0.85***	0.79***	0.86***	0.78***	0.57***	0.82***	0.76***	0.74***	0.96***	

*= $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$; N.S = Not significant

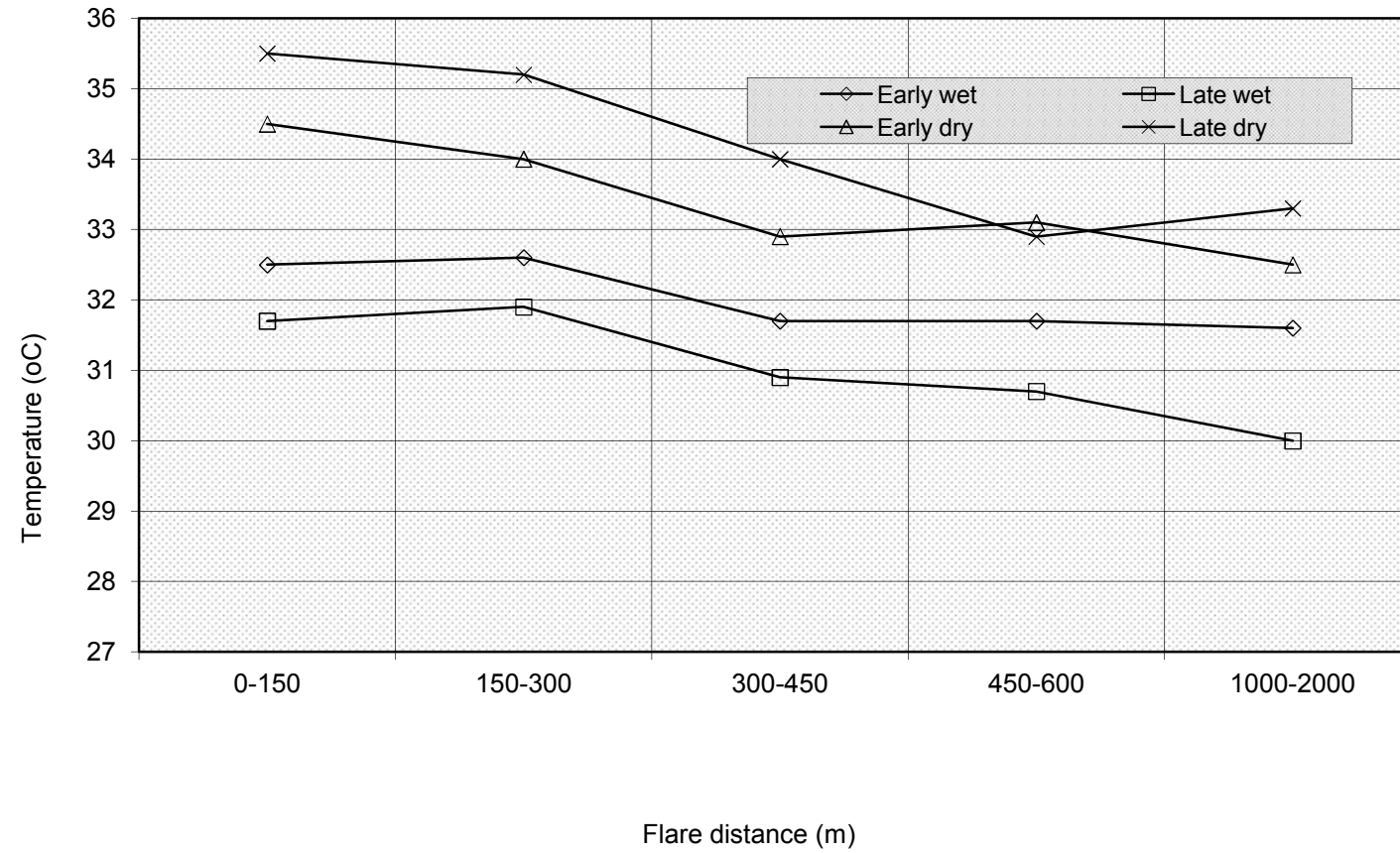


Fig. 2. Effect of flare distance and seasonal variations on the soil temperature

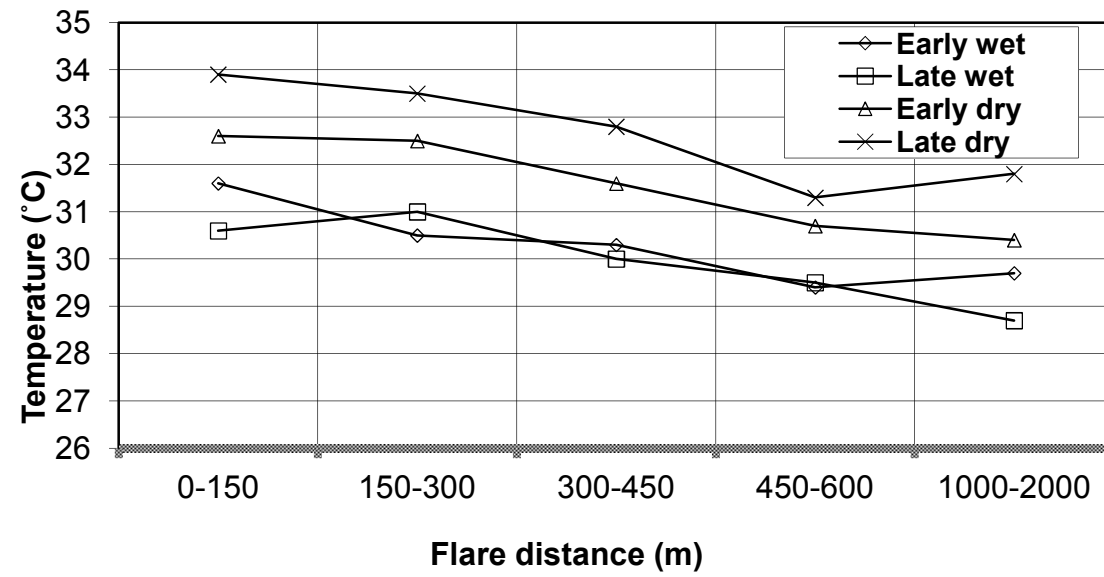


Fig. 3. Effect of Flare distance and Seasonal variations on the environmental temperature

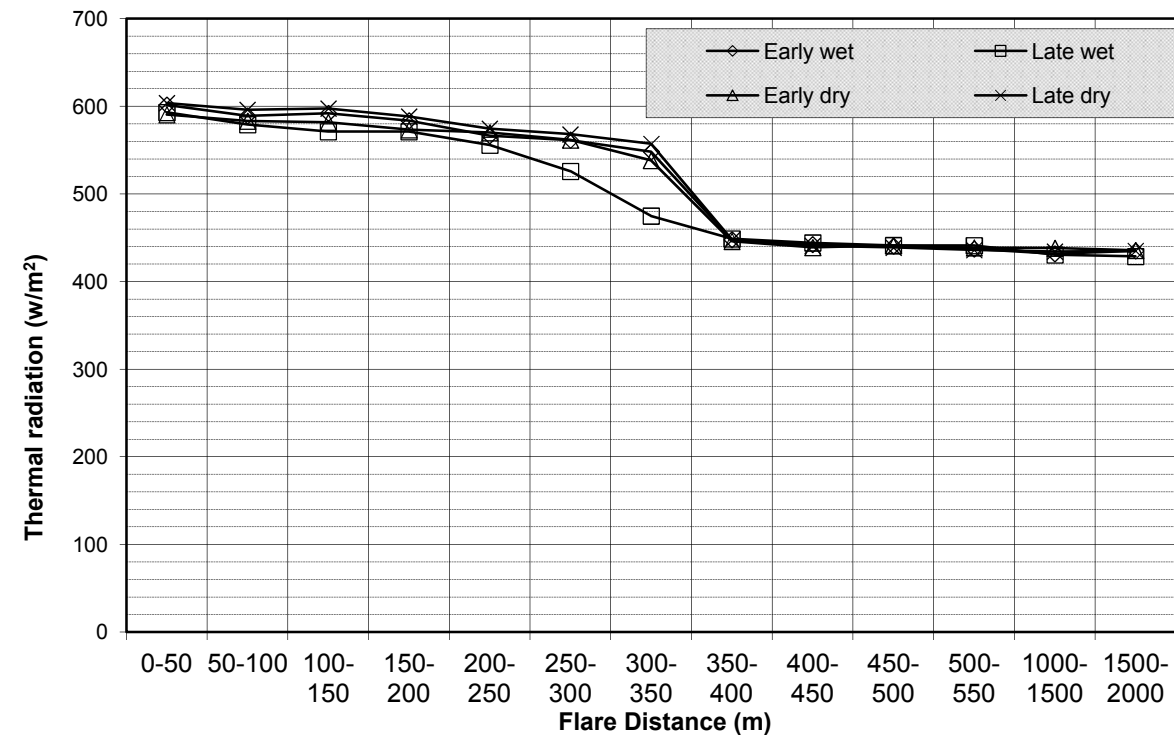


Fig. 4. Influence of interaction between flare distance and seasonal variation on thermal radiation profile

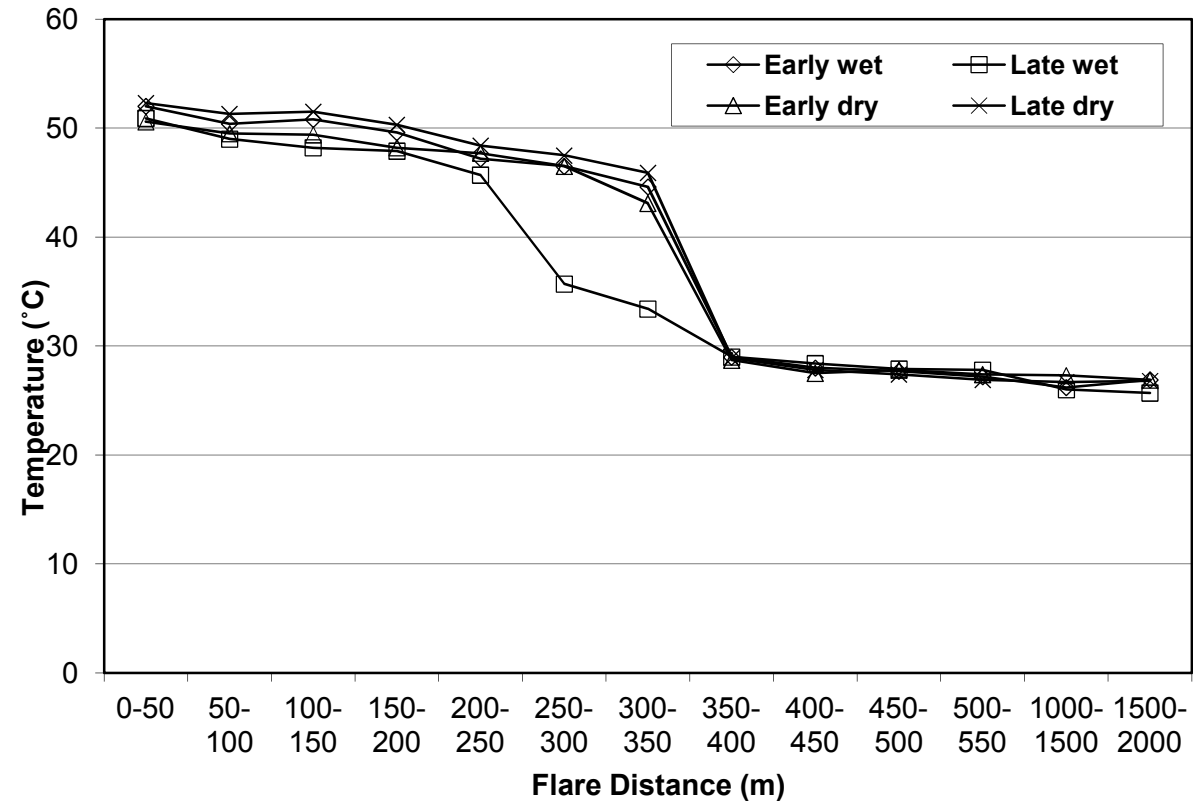


Fig. 5. Effect of interaction between flare distance and seasonal variation on radiation temperature (°C)

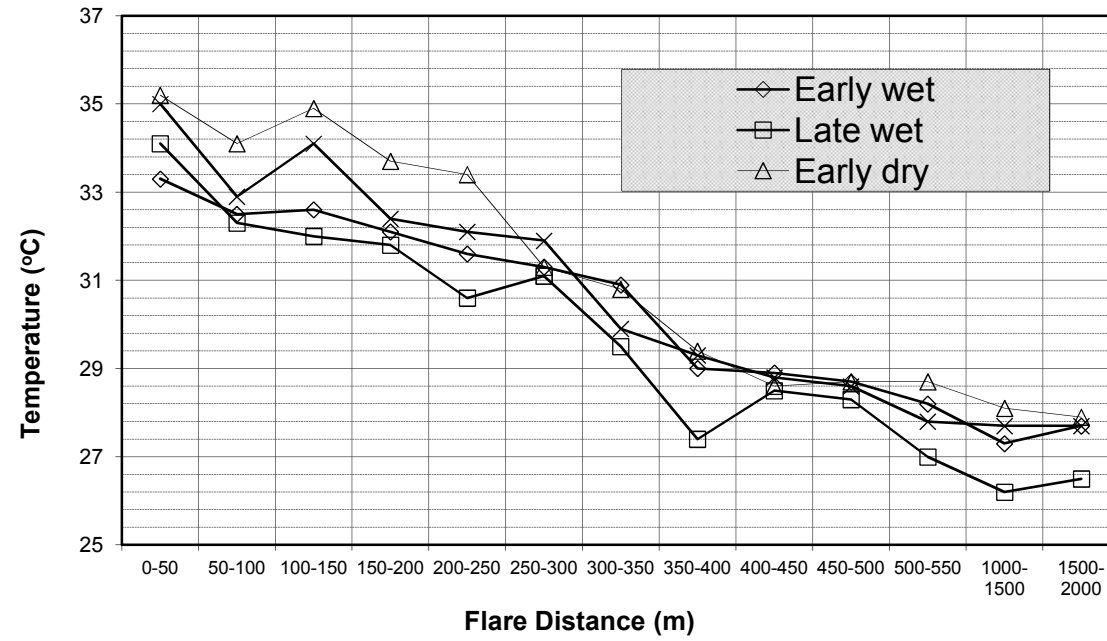


Fig. 6. Influence of Interaction between flare distance and seasonal variations on environmental temperature (oC)

The results for oil and grease and THC were somewhat erratic. However, a trend is still discernible at distances closer to the flare site (0-150m) there were higher results of 230.1ppm and 360.4ppm for oil and grease and THC respectively at 15-30cm depth, and lower results of 203.3ppm and 352.9ppm for oil and grease and THC respectively at 0-15cm depth. And as the distance from flare site increases, the values became higher at the top (0-15cm depth) than below (15-30cm depth). It is important to state that, the high level of hydrocarbons within 0-300m flaring distances could be attributed to seepage of crude oil from the bund pit through the bund wall foundation, especially within the 250m circumference. This most probably could not be due to flare, although particulate matter may be deposited on topsoil and plant leaves [2].

The soil textural attribute showed a higher percentage of sand ranging from 68% to 79%, followed by silt in a range of 7% to 22% and then clay ranging from 5% to 22%. The soil is essentially loamy sand. The result of the study showed that all the soil physico-chemical properties are not significantly affected by the effect of thermal radiation. Fig. 2 showed the effect of flare distance and seasonal variations on soil temperature. Generally during all seasons, the soil temperature decreases with increasing distance from flare site, with its highest value of 35.5°C in late dry season at 0-150m and its lowest value of 30°C in late wet season at 1000-2000m. In a similar study, Soil temperature also affects nutrient uptake by changing soil water viscosity and root nutrient transport [35,36] observed that at low soil temperature, nutrient uptake by plants reduces because of high soil water viscosity and low activity of root nutrient transport. A study [29], had reported that the seasonal variations affecting the solar inclination also cause variations in soil temperature. Same study also reported that as the in-coming energy available at the soil surface varies with the position of the sun, the soil profile experiences diurnal as well as annual variations in temperature. This also affects the environment by baking the soil, destroying plants and soil organisms and nutrients, this was also reported by another researcher [9]. Soil temperature exercises a major influence on the growth and development of plants through its effect on germination, emergence, and early growth. The effect being more critical during germination and early seedling development than at any other growth stage. Unfavorable soil temperature at seeding

time not only affect germination and seed emergence but also result in poor crop stand and reduce yields because of a lower plant population and delayed maturity. The effects of soil temperature on some soil properties and plant growth had also been reported in a similar study [11]. This account further collaborated the response of plant population losses observed in the study area. Thus, the high temperature and radiation intensity characteristics of the farm closest to the flare accounted for the high population loss and no yield situation of crops cultivated in these areas [37]. The effect of interaction, between flare distance and seasonal variations on radiation and soil profile shows significant difference ($P < 0.05$). Fig. 3 showed the effect of flare distance and seasonal variations on the environmental temperature, the environmental temperature also decreases with increasing distance from flare site, with its highest value of 33.8°C in the late dry season at 0-150m and lowest value of 28.6°C in the late wet season at 1000-2000m. Increase in soil temperature causes temperature induced dehydration of 2:1 clay minerals in the soil leading to strong interactions among the clay particles which in turn yield less clay and more silt-sized particles in the soil [38].

Further assessment carried out on the influence of flare distance on radiation profile (Fig. 4) and radiation temperature (Fig. 5) showed that during all seasons, the radiation intensity and temperature dropped sharply between 300m to 400m from flare site. At 0-50m flare distance, the highest radiation intensity of $603.84 \pm 5.26 \text{w/m}^2$ was observed during the late dry season, while the least radiation value of $428.83 \pm 0.79 \text{w/m}^2$ was recorded at 1500-2000m flaring distance during the late wet season. The radiation profile decreased with increasing distance from the flare. This compares favourably with the work of other researchers [2] who observed intensities of about 613w/m^2 at 200m distances in February and March. Another researcher [25] had established that the dry season contributions were higher than in the rainy season, this is also reflected in the results obtained in this study. Furthermore, research carried out in other part of the Niger Delta [29] also concluded that excessive heat released during gas flaring has far reaching effect and the levels of radiation intensity decreased away from the flare. Fig. 5 further indicated that radiation temperature of 52.3°C was recorded for late dry season at 0-50m and 25.7°C (late wet) season at 1500-2000m flaring distance. Fig. 6 showed the

influence of interaction between flare distance and seasonal variation on environmental temperature. At 0-50m flaring distance the value of environmental temperature recorded was 35.2°C during early dry season and 26.2°C (late wet) at 1000-1500m. The trend shows a downward environmental temperature to normal ambient temperature at 1000-2000m. comparative evaluation of the soil temperature (Fig. 2) and environmental temperature (Fig. 3) appeared to be similar, however, the soil temperature became higher than the environmental temperature. The effect of a higher soil temperature is more critical during germination and early seedling development than at any other growth stage. High soil temperature also leads to heat-induced cracks in the sand-sized particles that eventually lead to breakdown and consequently a reduced amount of sand-sized particles in the soil [39]. The defects of high soil temperature had been studied by other researchers and had concluded that unfavorable soil temperature at seeding time not only affect germination but also result in poor crop stand and reduce yields because of a lower plant population and delayed maturity [25]. According to [3], variations in soil temperature and related soil heat transfer processes are influenced by different land use types and soil management practices. In this study, the thermal heat from the continuous gas flaring activities is implicated. Increase in soil temperature lowers the clay sand contents and increases the silt content [40]. The correlation matrix between thermal radiation and physico-chemical characteristics of soils at various flaring distances showed that significant negative correlation existed at 0-600m. Flare distance except for 1000-2000m showed no positive significant relationship as the radiation intensity decreased with increased distance to the flare point and gradually results in normal environmental earth radiation level.

4. CONCLUSION

The study showed that the effect of environmental implication of thermal radiation on the Physio-chemical properties of soil around gas flare site in Emouha LGA in the Niger Delta have been established. The effect of interaction between flare distance, seasonal variations, radiation profile on soil was observed. The result showed higher radiation profile on soil during dry season than lower radiation profile recorded during early wet season. The result highlighted the higher effects of flare distance and seasonal variations on the environmental and soil

temperature. The environment and soil temperature decreased as the distance from the flare increased. Generally, the study further revealed that the mineral elements in the soil were available and increased as the distance from the thermal source increased. Finally, the result of the study showed that all the soil physio-chemical properties were not significantly affected by the effect of thermal radiation, except for higher thermal stress for soil closer to the flare site and this suggest that the soil outside the flare zone can support the growth of plant. This research work is recommended as a reference document for Agricultural extension officer in providing resource information to local farmers on the environmental implication of heat from gas flare site on soil viability.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Audu P, Oyet GI, Chibor BS. Assessment of Levels and Ecological Risks of Some Selected Potentially Toxic Metals in Soils around Onne Dumpsite, Rivers State, Nigeria. *International Journal of Plant & Soil Science*. 2021;33(4):49-62. Article no.IJPSS.67089 ISSN: 2320-7035.
2. Atuma MI, Ojeh VN. Effect of gas flaring on soil and cassava productivity in Ebedei, Ukwuani Local government Area, Delta State, Nigeria. *Journal of Environmental Protection*. 2013;4(10). DOI: 10.4236/jep.2013.410121.
3. Wang R, Sun Q, Wang Y, Zhing W, Yao, L, Hu Y, Guo S, Contrasting responses of Soil Respiration and Temperature Sensitivity to Land use types; Cropland Vs Apple Orchard on the Chinese Loess Plateau. *Science of the Total Environment*. 2018;621:425-433.
4. Brown Mang Onwuka, Paul C. Oguike, Emmanuel Adeboye Adesemuyi. Variations in soil heat transfer under different land use types in Abia State, South eastern Nigeria. *Eurasian Journal Of Soil Science*. 2021;10(1):1-8
5. Oyet GI, Achinewhu S.C, Sigalo, F.B, Audu P. Effect of Thermal Radiation On Viability Of Cassava Plant Population Cultivated Around Flare. *Journal of Environmental Science, Toxicology and Food Technology*. 2016;10(8 II):61-69

6. Scherr SJ. People and Environment: what is the relationship between exploration and natural resources and population growth in the south? *Forum for development studies* No 1997;1:32 – 50.
7. Awiri GO, Nte F. Environmental sound quality of some selected flow stations in the Niger Delta of Nigeria. *Journal of Applied Science and Environmental Management*. 2003;7(2):75-77.
8. Ajugwo AO. Negative effects of gas flaring: the Nigerian experience. *Journal of Environment Pollution and Human Health*. 2013;1(1):6-8.
Doi: 10.12691/jephh-1-1-2
9. Folland CK, Karl TR, Salinger MJ. Observed climate variability and change. *Weather*. 2006; 57:269.
Doi: 10.1256/004316502320517353.
10. Adedayo KD. Effect of Physico-chemical Parameters on the Thermal Diffusivity and Soil Heat Flux over Ayadi, Ondo State, Nigeria. *Nigeria Journal of Pure and Applied Physics*. 2019; 9(1):1–5
11. Onwuka B, Mang B. Effects of Soil Temperature on Some Soil Properties and Plant Growth. *Advances in Plants and Agricultural Research*. 2018;8(1):00288.
DOI: 10.15406/apar.2018.08.00288.
12. Shahsafia A, Roneya P, Zhou Y, Zhang Z, Xiaoa Y, Wana C, Wambolda R, Salmana J, Yua Z, Li J, Sadowski JT, Comin R, Ramanathan S, Kats MA. Temperature-independent thermal radiation. *Proceedings and the National Academy of Sciences*. 2019;116(52):26402–26406
13. Davidson EA., Janssens IA. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. *Nature*. 2006;440(7081):165-173.
14. Alli AA, Omofunmi OE. A review of soil temperature under a controlled irrigation system. *Journal of Research in Forestry, Wildlife and Environment*. 2021;13(1):50-59
15. Chiang, Po-Neng, Zhuang, Shun-Yao, Wang, Ya-Nan, Wang, Wei, Wang Ming-Kuang, Lin, Shu-Tzong. Soil organic matter and soil physicochemical properties associated with forest fires in central Taiwan. *Soil Science*. 2008;173(11): 768-778.
16. Nwaokoro, E, Nymphas EF. Temperature variations and soil thermal properties at the Nigeria mesoscale experiment site, Ibadan, Nigeria. *International Research Journal of Pure and Applied Physics*. 2019;6(2):34-43.
17. Nelson DW, Sommers LE Total carbon, organic carbon and organic matter. In *Methods of Soil Analysis, Part 2. Chem. And Microbiological Properties- Agronomy Monograph no.9 2nd edition* –edited by A.L Page, R.H. Miller and D.R Keeney, 1982;539-574.
18. Mclean EO. Soil PH and Lime requirement, Chapter 12 in *Methods of Soil Analysis, Part 2. Chem. And Microbiological Properties- Agronomy Monograph no.9 2nd edition* –edited by A.L Page, R.H. Miller and D.R Keeney. 1982;199-200.
19. Olsen SR, LE Sommers. Phosphorus. Chapter 24 in *Methods of Soil Analysis, Part 2. Chem. And Microbiological Properties- Agronomy Monograph no.9 2nd edition* –edited by A.L Page, R.H. Miller and D.R Keeney. 1982;404-407
20. Knudsen D, GA Peterson, PF Pratt. Exchangeable and Soluble Potassium and Sodium Chapter 13 In. *Methods of Soil Analysis, Part 2. Chem. And Microbiological Properties- Agronomy Monograph no.9 2nd edition* –edited by A.L Page, R.H. Miller and D.R Keeney,1982;225-238.
21. Evans LJ., Kay BD, Thomas, RL. *Soil Science, 1987 – 2000: A Study Guide and Laboratory Exercise Manual*. Department of Land Resource Sciences. University of Guelph, Ontario, Canada; 1987.
22. Pauwels JM, Ranst VE, Verloo M, Mvondo-Ze AD *Manuel de Laboratoire de pédologie*. Publications Agricoles N°28. Bruxelles AGCD.1992; 265
23. Current RW, Tilotta DC. Determination of total petroleum hydrocarbons in soil by on-line supercritical fluid extraction-infrared spectroscopy using a fiber optic transmission cell and a simple filter spectrometer. *Journal of Chromatography*. 1997;A(785):269–277.
DOI: 10.1016/s0021- 9673(97)00466-4.
24. Wahua TAT. *Applied Statistics for Scientific Studies*. Reprinted by Transparent Earth Nigeria Limited, Port Harcourt, 2nd floor, Kings Plaza, 11B Benjamin Opara Street Off Olu Obasanjo Road, GRA Phase II, PH; 2010.
25. Okezie DU. Okeke AO. Flaring of Associated Gas in the oil Industry, Impact on Growth, Productivity and Yield of selected farm crops. *Proceedings of the*

- Petroleum Industry and the Nigerian Environment. 1987;302-309.
26. Sigalo FB. Technical report on thermal radiation measurement at Olo Flow station and Rumuekpe metering station of Elf Nigeria Ltd., June – July; 1997.
 27. Norbert NF, Aaron ST, George BC, Kenneth M, Godswill A, Asongwe Vivian B. Selected physicochemical properties and quality of soils around some rivers of Cameroon. *Journal of Soil Science and Environmental management*. 2018;9(5):68-80
 28. Hazelton P, Murphy B Interpreting soil test results. What do all the numbers mean? CSIRO Publishing, Victoria. *Sustainable Agriculture Factsheet* 2007;3. www.wineaustralia.com/getmedia/. Accessed on 20th June 2017.
 29. Sigalo FB. Thermal radiation profiles at Mobil (BRT) Bonny. A Technical report submitted for Mobil, Bonny; 1997.
 30. Pandey SN. Impact of thermal power plant emissions on vegetation and soil. *Water Air Soil Pollution*. 1983;19:87–100. <https://doi.org/10.1007/BF00176798>
 31. Giovannini, G, Lucchesi, S. Modifications induced in soil physico-chemical parameters by experimental fires at different intensities. *Soil Science*: 1997;162(7):479-486
 32. Ubeda X, Pereira P, Outeiro L, et al. Effects of fire temperature on the physical and chemical characteristics of the ash from two plot of cork oak (*Quercus suber*). *Land degradation development*. 2009;20(6):589–608.
 33. Certini G. Effects of fire in properties of forest soils: A review. *Oecologia*. 2005;143(1):1–10.
 34. Rengasmy P, Churchman GJ. Cation exchange capacity, exchangeable cations and solidity. In: Pevrilli KI, et al. editors. *Soil analysis. Australia: an interpretation manual* CSIRO publishing; 2009.
 35. Grossnickle SC. Ecophysiology of Northern spruce species in the performance of planted seedlings. NRC–CNRC, NRC, Ottawa Ont, Canada: Research press; 2000;325–407.
 36. Lahti M, Aphalo PJ, Finer L, et al. Soil temperature, gas exchange and nitrogen status of 5–year old Norway spruce seedlings. *Tree physiol*. 2002;22(18):1311–1316.
 37. Oyet, GI, Audu P, Achinewhu SC, Sigalo FB Evaluation of the Effect of Thermal Radiation on the Physicochemical Properties of Improved Cassava Cultivars (*Esculenta Crantz*) and Roasted Gari in South-South Nigeria. *American Journal of Engineering Research*. 2016b;5(2):244-254.
 38. Arocena J, Opio C. Prescribed fire–induced changes in properties of sub-boreal forest soil. *Geoderma*. 2003;113(1–2):1–16.
 39. Pardini G, Gispert M, Dunjo G. Relative influence of wildlife in properties and erosion processes in different Mediterranean environments in NE Spain. *Sci Total environment*. 2004;328(1–3):237–246.
 40. Assaf I, Marcos L, Marcelo S, et al. Forest fire effects on soil chemical and physiochemical properties, infiltration, runoff and erosion in a semi–arid Mediterranean region. *Geoderma*. 2004;221(222):131–138.

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