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Assessment of Plant Response and Tolerance to Air Pollution in Gas Flaring Locations in Ibeno, Akwa Ibom, Nigeria

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Abstract This study assessed the effect of gas flaring on the biochemical properties and air pollution tolerance of ethnomedicinal plants around two gas flaring locations (ExxonMobil's Qua Iboe Terminal and Network Exploration Limited) in Ibeno, Nigeria, during wet and dry seasons. Five perennial shrubs of ethnobotanical importance in the study area (Aframomum danielii, Alchornea cordifolia, Harungana madagascariensis, Stachytarpheta augustifolia, and Tetracera alnifolia) within a 200-meter perimeter area outside each of the flare sites were selected for the study using the quadrat method. Control samples were collected 15 kilometers away. Statistical analyses were carried out using ANOVA and an independent T-test at $P \leq 0.05$. Results of biochemical analysis indicated a significant increase in ascorbic acid (AA) and relative water content at the study sites, while total chlorophyll content and pH were significantly higher at the control site compared to the study sites. Generally, the findings of this study indicate that gas flaring-induced environmental stress on selected plants is more pronounced during the dry season. None of the plants can be considered very tolerant to air pollution from gas flaring in the study area based on APTI. However, Aframomum danelli and Stachytarpheta augustifolia could be utilized in green belt development for mitigating air pollution from gas flaring in the study area, given their very high intermediate APTI values.

Keywords: *Air pollution tolerance index, Ascorbic acid content, Chlorophyll content, Gas flaring, Leaf Ph, Relative water content*

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1. Introduction

Gas flare is a major source of greenhouse and precursor gases, particulate matter, chemical toxins, and heavy metals, among other air pollutants, in the environment. These pollutants are known to pollute the vicinity of gas flaring sites [1,2,3] and pose serious hazards to ecosystems and human health [4].

Globally, the problem of gas flaring in destroying the ecosystem of an impacted area poses a great challenge to the sustainability of the environment and human health. In Nigeria, the magnitude of gas flaring has created mass consciousness of its effects, especially among the communities living in the coastal belt, whose delicate mangrove ecosystem is frequently impacted. Anatomical and physiological changes in plant roots, shoots, and leaves may be indicative of adverse environmental impacts on plants exposed to environmental pollution [5].

In the study area and other parts of the Niger Delta, plant and animal species in all ecological units have been facing serious threats for more than fifty years due to gas flaring from the exploitation of oil and gas by multinational companies operating in these areas [6]. The toxic gases and particulate matter emitted by gas flaring have been reported to have adverse effects on both the environment and human health [7]. Abua and Ashua [8] reported a loss of plant species at the Qua Iboe flare site, Mkpanak, Ibeno, due to gas flaring in the area, while Asuoha and Osu [9] found high concentrations of carbon dioxide in the study area. Israel *et al.* [10] also reported higher concentrations of some trace elements and heavy metal contaminants from gas flares than the maximum permissible limits of the World Health Organisation (WHO) and Nigerian Standards for Drinking Water Quality (NSDWQ) in the surface waters of the study area. Their study further observed that the concentrations of heavy metals from gas flares in the surface water of the study area were higher than regulatory standards and could have negative effects on plants in the area.

Air pollutants are absorbed by plants either directly

through foliar uptake or indirectly via root uptake [11], posing a significant threat to plants and other organisms within their ecological systems. The resulting physicochemical changes in plants impact their ability to perform environmental and ethnobotanical functions. For example, Shrestha et al. [12] reported a decline in plants' physiological and morphological traits, such as chlorophyll content and leaf structure, due to air pollution. This directly affects the photosynthetic activities of plants.

The observed major problems of gas flaring in the study area include air pollution, soil pollution, and damage to biodiversity. Air pollution from gas flaring is not only an environmental issue in terms of impacts on biological organisms and possible effects on human health, in particular for those with respiratory problems but the particulate matter can also have physical effects on the plants, such as blocking and damaging their internal structures, abrasion of leaves and cuticles and triggering biochemical alterations in plants which may affect long-term survival and ethnobotanical potentials [13].

Gas flaring in the study area results from oil production by Mobil Producing Nigeria Unlimited and Network Exploration and Production Nigeria Limited, which both operate in the region. Mobil Producing Nigeria Unlimited has been involved in oil production there for over forty years, while Network Exploration and Production Nigeria Limited has operated in the area for about ten years. The increase in air pollutant concentrations caused by gas flaring, as seen in similar locations worldwide, threatens human health, natural vegetation, plant diversity, crop production, and the nutritional quality of harvested crops. In the study area, plants have shown morphological changes such as leaf and cuticle abrasion, necrosis, and stunted growth, indicating pollution stress and potential biochemical shifts. As Lui and Ding [14] observed, biochemical changes due to pollutant exposure occur before visible morphological symptoms appear.

Existing studies on the impacts of gas flaring in the study area have focused on soil quality [15], surface water [10], galvanized roofing sheets [16], air quality [9], and plant diversity [8]. Biochemical status and air pollution tolerance of medicinal plants due to gas flaring in the Ibeno area have not been evaluated.

This study, therefore, aimed to assess the physicochemical properties of selected medicinal plants in the Mkpanak gas flaring area in Ibeno. The results will help to evaluate the effects of gas flare on the plants, determine the tolerance of the plants to air pollution with a view to identifying those plants that are most suitable for green belt development in the study area.

2. Materials and Methods

2.1. Study area

The study area, Mkpanak, is in Ibeno Local Government Area, Akwa Ibom State (Figure 1) located in the Niger Delta region of Nigeria. The area is within a stretch of coastal area along the Bight of Bonny on the Atlantic Ocean. It is polygonal and bordered on latitude 4˚33'47"N and longitude 7˚59'15"E, latitude 4˚33'57"N and longitude 8˚00'10"E, latitude 4˚32'27"N and longitude 7˚59'22"E, and latitude 4˚32'53"N and longitude (Figure 1).

The study area is a crude oil-producing community. The major oil mining company is Exxon Mobil, which has a large terminal at Qua Iboe in the study area. The operational bases of Mobil Producing Nigeria Unlimited and Network Exploration and Producing Nigeria Limited, where pumping, treatment, transportation of crude oil, and flaring of associated gas take place daily, are located there. These activities result in pollution of the land, air, and water bodies in the study area.

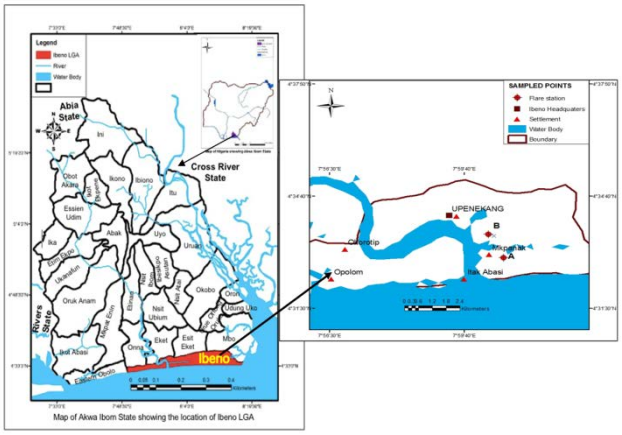

Figure 1. Ibeno Local Government Area showing Study Locations

2.2. Sampling Procedure

The study population consisted of plant species of known medicinal importance within the study area. The purposive sampling method was used in selecting plant samples for analysis. Samples were collected from a 200m perimeter area located approximately 250m away from each of the gas flare locations –Exxon Mobil Qua Iboe terminal flare area (study site A) and Network Exploration flare location (study site B) in Mkpanak community in Ibeno Local Government Area An inventory and distribution of medicinal plants, excluding grasses and lower plants, within a 200-meter transect of each study site was taken by free listing. Only perennial shrubs of ethnobotanical importance in the study area were selected for the study. Study site B is approximately one kilometer from study site A, while both sites are approximately fifteen (15) kilometers from the control location.

Out of twenty-five plants encountered, five (*Aframomum daniellii*- AD, *Alchornea cordifolia* - AC, *Harungunamadagascariesis* - HM, *Stachytarpheta augustifolia* - SA, and *Tetracera alnifolia*- TA) were selected for the study based on their percentage frequency distribution scores. This was calculated using the quadrat method. Percentage frequency was calculated following Mahajan and Fatima [17] as shown in equation 1:

$$\%\,fequency = \frac{number\ of\ plots\ in\ which\ species\ occurred}{total\ number\ of\ plots(6)} \times 100 \quad (1)$$

2.3. Data Collection Procedure

Leaf samples were collected during the early part of the dry season (November) and early wet season (May). Leaf samples were collected from the upper part of each selected plant species, facing the flare from the study sites.

Physical measurements of plant breadth were used to estimate the age of the selected plants at the study area and the control site, as described by Sean *et al.* (1995). The leaf samples were stored in clean, unused paper bags and labeled properly before they were sent to the laboratory for analysis.

2.4. Laboratory Analysis

Determination of ascorbic acid content

This was performed according to the method described by Iqbal *et al.* [18]. One gram of the leaf sample was extracted with 4 ml of oxalic acid -acid-acid-ethylenediamine tetra-acetic acid (EDTA) solution. To a test tube containing the extract, 1 ml of 5% H_2SO_4, 2 ml of ammonium molybdate, and 3 ml of water were added successively to the test tube containing the extract, and allowed to settle for 15 minutes. The absorbance was measured at 760 nm, and the concentration of ascorbic acid was calculated from a standard curve [18].

Determination of chlorophyll content

This was done according to the method of Singh *et al.* [19]. Three (3) grams of the leaf sample were macerated with 10 ml of 80 % acetone, and the liquid portion was decanted after allowing it to settle for 15 minutes, then centrifuged at 2,500 rpm for 3 minutes. The absorbance of the supernatant was measured at 663 nm using a UV-Vis spectrophotometer.

Determination of leaf pH

Leaf samples were macerated with de-ionized water and filtered through an ashless filter paper. The filtrate was read for pH with the aid of a digital pH meter (Singh and Rao, 1983).

Determination of relative water content (RWC)

This was done following Das and Prasad [20]. Fresh leaf samples were weighed, and the fresh mass (FM) was recorded. The same samples were floated in distilled water inside a closed petri dish at room temperature for 24 hours. At the end of the incubation period, the leaf samples were wiped dry gently with blotted paper and re-weighed to obtain the turgid mass (TM). They were then placed in a pre-heated oven at 80 ºC for 48 hours. Thereafter, the leaf samples were weighed to obtain the Dry Mass.

RWC was calculated using the formula:

$$RWC = \frac{(FM - DM)}{(TM - DM)} \times \frac{100}{1} \quad (2)$$

where, RWC = Relative water content (%), FM = Fresh mass of leaf sample (g), DM = Dry mass of leaf sample (g) and TM = Turgid mass of leaf sample (g)

2.5. Determination of Air Pollution Tolerance Index (APTI)

By synthesizing these parameters (ascorbic acid content, chlorophyll content, leaf pH, and percentage relative water content), the air pollution tolerance index was computed as described by Lalitha, Dhanam, and Sankar-Ganesh (2013) using the equation:

$$APTI = \frac{[A(T + P)] + R}{10} \quad (3)$$

where,

A = Ascorbic acid (mg/g) of leaf sample; T = Total chlorophyll (mg/g) of leaf sample; P = Leaf extract PH of leaf sample; R = Relative water content (%) of leaf sample.

Based on APTI values, selected plants were rated as follows;

APTI 30 – 100 is considered a tolerant plant species.

APTI 17 – 29 is considered an intermediate plant species.

APTI 1 – 16 is considered a sensitive plant species.

APTI < 1 is considered a very sensitive plant species.

2.6. Data Analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 20. Analysis of variance was used to test for differences in physicochemical properties, phytochemical properties, foliar characteristics, and heavy metal content of plants at $p \leq 0.05$. Post hoc analysis (Duncan's multiple test range) was used for the separation of means. Values were expressed as mean ± standard error of mean. Student's t-test was used to test for differences in plant properties between wet and dry seasons.

3. Results

3.1. Biochemical Status of the Plants in Wet Season

The biochemical status of the samples at study sites A and B, and the control site during the wet season is shown in Table 1. The results indicate that for *A. daniellii*, there was a significant decrease in total chlorophyll content at sites A and B in comparison to the control site, which had a mean total chlorophyll content of 18.18mg/g ± 0.06. Ascorbic acid content was significantly higher at study sites A and B, with site B having the highest ascorbic acid content (16.18mg/g ± 0.04). pH level was significantly higher at the control site (8.25mg/g ± 0.25) compared to the two study sites. Relative water content (RWC) was significantly lower at the control sites in comparison to flare locations A and B (Table 1).

Total chlorophyll content of *A. cordifolia* ranged from 4.20mg/g at study site B to 11.25mg/g at the control site. Total chlorophyll content was significantly higher at the control site in comparison with the study sites. Ascorbic acid content was higher at study site B (12.84mg/g ± 0.45) and lowest at the control site (11.52mg/g ± 0.41). However, a significant difference was not found in the ascorbic acid content of plants from the three locations. pH varied significantly across the different locations, with the control site having the highest pH, followed by plants at site A and site B, respectively. Study sites A and B had higher relative water content compared to the control site (Table 2).

Total chlorophyll content of *H. madagascariensis* at the three sites ranged from 5.43mg/g to 13.33mg/g, with plants from the control site having significantly higher chlorophyll content during wet season. Ascorbic acid content was significantly higher at study sites A and B compared to the control location. pH was significantly lower in plants at the two study sites compared to the control site. Relative water content was high at site B

(76.42% ± 0.0) and site A (75.52% ± 0.19). Both values were significantly higher than the relative water content at the control (Table 2).

The total chlorophyll content of S. angustifolia was significantly lower at both study sites during the wet season compared to the control site, which had a mean value of 16.01 mg/g ± 0.11 (Table 1). However, ascorbic acid content was higher at site B (14.98mg/g ± 0.15) and lowest at the control site (10.93mg/g ± 0.34) but did not significantly vary between sites A and B. pH level of *S. angustifolia* at the control site was significantly higher (8.10 ± 0.20) relative to the two study sites. Relative water content was high at site B (79.43% ± 0.78) and site A (73.02% ± 0.19). Both values were significantly higher than the relative water content at the control site (Table 1).

Table 1. Biochemical Status of Leaf Samples in Wet Season

Parameter	Sample	Control Site	Site A	Site B
Total chlorophyll (mg/g)	AD	18.18 ± 0.06^{a}	7.73 ± 0.11^{b}	6.86 ± 0.02^{c}
	AC	11.25 ± 0.04^{a}	4.27 ± 0.04^{b}	4.20 ± 0.04^{b}
	HM	13.33 ± 0.11^{a}	5.52 ± 0.50^{b}	5.43 ± 0.12^{b}
	SA	16.01 ± 0.11^{a}	7.87 ± 0.16^{b}	6.82 ± 0.11^{c}
	TA	13.21 ± 0.00^{a}	6.59 ± 0.13^{b}	6.22 ± 0.00^{c}
Ascorbic acid (mg/g)	AD	12.93 ± 0.29^{c}	15.13 ± 0.12^{b}	16.18 ± 0.04^{a}
	AC	11.52 ± 0.41^{a}	11.71 ± 0.45^{a}	12.84 ± 0.45^{a}
	HM	9.74 ± 0.08^{c}	11.16 ± 0.05^{b}	13.84 ± 0.02^{a}
	SA	10.93 ± 0.34^{b}	14.62 ± 0.00^{a}	14.98 ± 0.15^{a}
	TA	8.15 ± 0.17^{b}	8.33 ± 0.11^{b}	8.88 ± 0.04^{a}
pH	AD	8.25 ± 0.25^{a}	6.25 ± 0.25^{b}	5.75 ± 0.25^{b}
	AC	8.00 ± 0.00^{a}	6.75 ± 0.25^{b}	6.00 ± 0.00^{c}
	HM	8.25 ± 0.25^{a}	6.25 ± 0.25^{b}	6.50 ± 0.00^{b}
	SA	8.10 ± 0.20^{a}	6.65 ± 0.15^{b}	6.10 ± 0.10^{b}
	TA	8.10 ± 0.30^{a}	6.05 ± 0.25^{b}	6.65 ± 0.15^{b}
RWC (%)	AD	46.95 ± 1.72^{b}	76.32 ± 2.02^{a}	77.40 ± 0.95^{a}
	AC	48.16 ± 1.90^{b}	67.86 ± 0.54^{a}	69.74 ± 1.39^{a}
	HM	50.59 ± 0.04^{c}	75.52 ± 0.19^{b}	76.42 ± 0.04^{a}
	SA	55.01 ± 1.68^{c}	73.02 ± 0.19^{b}	79.43 ± 0.78^{a}
	TA	63.36 ± 0.00^{a}	63.36 ± 0.00^{a}	63.36 ± 0.00^{a}

Data are presented with mean ± standard error.
Means with different alphabets along each column are significantly different, separated using Duncan New Multiple Range Test (DNMRT) at $P < 0.05$

During the wet season, total chlorophyll content of *T. alnifolia* ranged from 6.22mg/g ± 0.00 at site B to 13.21mg/g ± 0.00 at the control site, which also had a significantly higher value. Ascorbic acid content was significantly higher at site B (8.88mg/g ± 0.04) and lowest at the control site (8.15mg/g ± 0.17). However, a significant difference was not found in ascorbic acid content between the control site and site A. pH had significant variation across the three sampling locations. The highest pH was obtained at the control site, followed by site B and site A, respectively. The results showed that pH did not vary significantly between site A and site B (Table 1).

3.2. Biochemical Status of the Plants in Dry Season

During the dry season, total chlorophyll content of *A. daniellii* ranged from 6.57mg/g ± 0.02 at site B to 16.27mg/g ± 0.03 in the control site. Total chlorophyll content was significantly higher at study site B. Ascorbic acid was significantly higher at site B (16.01mg/g ± 0.12) and lowest at the control site (13.35mg/g ± 0.11). The control site had the highest pH (7.50 ± 0.10), while the pH value was lowest at site B (5.35 ± 0.05). However, no significant difference was observed in the ascorbic acid content across the three locations. Relative water content was significantly higher in samples from polluted site A (79.56%± 0.68) and polluted site B (79.23% ± 0.39) compared to the control site.

Alchornea cordifolia had significantly higher total chlorophyll content at the control site (10.81mg/g) in comparison with the study site. Ascorbic acid content was, however, higher in plants at site B (14.67mg/g ± 0.05) and lowest in plants at the control site (11.97mg/g ± 0.15). The pH level of samples from the control site was significantly higher (8.00 ± 0.20) than what was obtained at the study sites A and B. However, relative water content was significantly high at site B (71.81% ± 0.05) and had the lowest value at the control site (Table 2).

Total chlorophyll content of *H. madagascariensis* ranged from 5.61mg/g at study site B to 12.88mg/g at the control site, with the control site having significantly higher chlorophyll content. Ascorbic acid was significantly higher at sites A and B compared to the control site. pH was significantly lower at sites A and B compared to the control site. Relative water content was high in plants at study site B (78.08% ± 0.13) and site A (77.79% ± 0.34), and was significantly higher than relative water content at the control site (Table 2).

Total chlorophyll content of *S. angustifolia* ranged from 6.03mg/g at study site B to 14.13mg/g at the control site. Total chlorophyll content was significantly higher at the control (Table 2). Ascorbic acid content was highest at study site A (15.14mg/g ± 0.28) and lowest at the control site (12.29mg/g ± 0.06). However, a significant difference was not found in ascorbic acid content between sites A and B. pH varied significantly among the three locations. pH was highest at the control site, followed by site A. Site B had the lowest pH value (5.90 ± 0.10). The results indicate that the study sites had higher relative water content than the control site (Table 2).

During the dry season, total chlorophyll content was significantly lower at the study sites compared to the control site, which had a mean total chlorophyll content of 11.93mg/g ± 0.11 (Table 5). Ascorbic acid content was significantly higher at the study sites, with site B having the highest ascorbic acid content (9.54mg/g ± 0.01). pH level of *T. alnifolia* was significantly higher at the control site (8.15 ± 0.05) in comparison with the study sites. Relative water content was significantly lower at the

control site compared to the study sites (Table 2).

Table 2. Biochemical Status of Leaf Samples in Dry Season

Parameter	Sample	Control Site	Site A	Site B
Total chlorophyll (mg/g)	AD	16.27 ± 0.03^{a}	7.03 ± 0.19^{b}	6.57 ± 0.02^{b}
	AC	10.81 ± 0.03^{a}	3.43 ± 0.09^{b}	2.88 ± 0.01^{c}
	HM	12.88 ± 0.24^{a}	6.02 ± 0.20^{b}	5.61 ± 0.03^{b}
	SA	14.13 ± 0.14^{a}	7.27 ± 0.04^{b}	6.03 ± 0.19^{c}
	TA	11.93 ± 0.11^{a}	5.76 ± 0.02^{b}	4.53 ± 0.03^{c}
Ascorbic acid (mg/g)	AD	13.35 ± 0.11^{c}	15.40 ± 0.02^{b}	16.01 ± 0.12^{a}
	AC	11.97 ± 0.15^{c}	13.72 ± 0.10^{b}	14.67 ± 0.05^{a*}
	HM	10.21 ± 0.03^{c}	12.02 ± 0.13^{b}	14.05 ± 0.17^{a}
	SA	12.29 ± 0.06^{b}	15.14 ± 0.28^{a}	14.69 ± 0.04^{a}
	TA	8.39 ± 0.03^{c}	9.13 ± 0.02^{b}	9.54 ± 0.01^{a}
pH	AD	7.50 ± 0.10^{a}	5.60 ± 0.20^{b}	5.35 ± 0.05^{b}
	AC	8.00 ± 0.20^{a}	6.65 ± 0.05^{b}	5.70 ± 0.10^{c}
	HM	8.15 ± 0.05^{a}	6.25 ± 0.15^{b}	5.90 ± 0.10^{b}
	SA	8.25 ± 0.15^{a}	6.15 ± 0.05^{b}	6.00 ± 0.00^{b}
	TA	8.15 ± 0.05^{a}	6.05 ± 0.05^{b}	5.90 ± 0.10^{b}
RWC (%)	AD	51.03 ± 0.20^{b}	79.56 ± 0.68^{a}	79.23 ± 0.39^{a}
	AC	51.02 ± 0.40^{c}	69.61 ± 0.63^{b}	71.81 ± 0.05^{a}
	HM	53.04 ± 0.17^{b}	77.79 ± 0.34^{a}	78.08 ± 0.13^{a}
	SA	55.01 ± 1.68^{c}	73.02 ± 0.19^{b}	79.43 ± 0.78^{a}
	TA	63.36 ± 0.00^{a}	63.36 ± 0.00^{a}	63.36 ± 0.00^{a}

Data are presented with mean ± standard error.
Means with different alphabets along each column are significantly different, separated using Duncan New Multiple Range Test (DNMRT) at P < 0.0

In terms of seasonal variation, *A. daniellii* varied significantly in total chlorophyll content at the control site and study site B, both having higher chlorophyll content during the wet season. Total chlorophyll content was significantly higher at the control site relative to study sites A and B during both wet and dry seasons. Significant differences were not found in the value of total chlorophyll content between study sites A and B during the dry season. Similarly, total chlorophyll content of *A. cordifolia* was significantly higher during the wet season when compared with dry season values across the three study sites. Ascorbic acid content of *A. cordifolia* was significantly higher during the dry season at the study sites. *H. madagascariensis* varied significantly in ascorbic acid content and relative water content during both wet and dry seasons. Ascorbic acid content and relative water content were significantly higher during the dry season at the three study locations. However, there was significant seasonal variation in total chlorophyll content and ascorbic acid content at the control site for *S. angustifolia*. In *T. alnifolia*, chlorophyll content was significantly higher during the wet season across the three study sites. Ascorbic acid content was significantly higher during the dry season at sites A and B (Table 3).

3.3. Air Pollution Tolerance Indices of Plants in Dry Season

Results of air pollution tolerance indices (APTI) of selected plants at the two study sites and the control site during the wet and dry seasons are presented in Figure 2 and Figure 3.

During the wet season, APTI of *A. daniellii* ranged from 28.13 for study site B to 38.88 for the control site. APTI of study site B was significantly higher compared to study site A and the control site.

APTI of A. *cordifolia* was significantly higher at the control site (26.97) and lowest at study site A (19.68). *H. madagascariensis* had significant variation in APTI across the three sites. APTI was highest (26.08) at the control site, followed by site B and study site A, respectively. The results showed variation in APTI for *S. indica* at the two study sites, with the control site having the highest APTI. For *T. alnifolia*, APTI was highest at the control site and lowest at study site A. Air pollution tolerance during the wet season followed the order: *A. daniellii*> *S. indica* > *A. cordifolia* > *H. madagascariensis* > *T. alnifolia*.

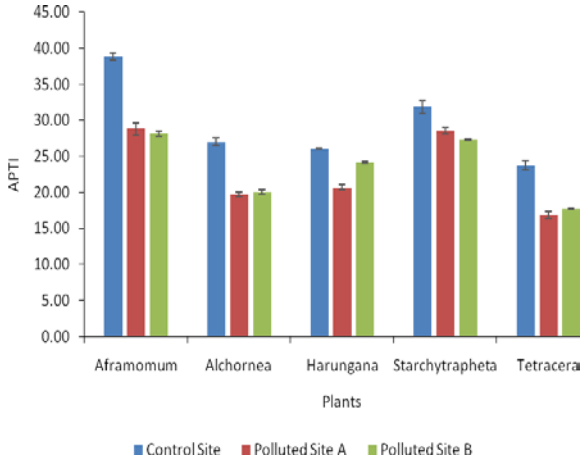

Figure 2. Air Pollution Tolerance Indices of Plants in Wet Season

During the dry season, APTI of *A. daniellii* ranged from 26.99 for study site B to 36.84 for the control site. APTI of *A. daniellii* was significantly higher at the control site. APTI of *A. cordifolia* was significantly higher at the control site (27.62) and lowest at study site B (19.76). There was significant variation in APTI of *H. madagascariensis* at the three sites. APTI ranged from (22.85) at study site A to (26.76) at the control site. The results showed variation in APTI of *S. angustifolia* at the two study sites, with the control site having the highest APTI. For *T. alnifolia*, APTI was highest at the control site and lowest at study site B (Figure 3).

During the dry season, APTI of the samples was significantly higher in study site A than study site B, except for *H. madagascariensis*, which had a higher APTI in study site B (23.97).

Dry season APTI followed the order: S. angustifolia =A. daniellii>H. madagascariensis > A. cordifolia > T. alnifolia.

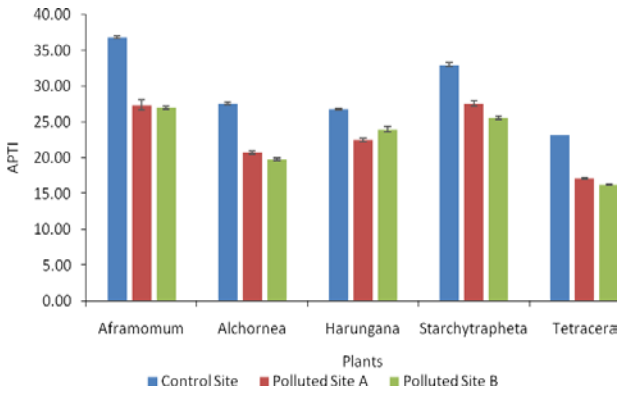

Figure 3. Air Pollution Tolerance Indices of Plants During the Dry Season

4. Discussion

Biochemical Properties of Selected Plants

Pandit). In this study, a significant reduction in chlorophyll at the study sites across all the plant species studied was observed, which is indicative of air pollution. This corroborates the findings of Shrestha *et al.* [12], Akande *et al.* [21], Uchenna *et al.* [22], Jyothi and Jaya [23], Mir *et al.* [24], and Tripathi and Gautam [25], who reported that high levels of air pollution decreased the chlorophyll content in plants in and around gas flare locations and other polluted environments. Similarly, Pandit *et al.* [26] and Walia *et al.* [27] reported a reduction of chlorophyll content of plants in polluted sites. Gupta et *al.* [28] noted that pollutant accumulation on the leaves of plants caused severe damage to their photosynthetic pigment. Further, Set [29] observed that pollutant accumulation on leaf surfaces may also reduce the chlorophyll synthesis due to shading effects. In addition to the reduction and gradual disappearance of chlorophyll in plants due to pollution, concomitant yellowing of leaves, which may be associated with a consequent decrease in the carotenoids that are critical for the photosynthesis process, has also been recorded by Bui *et al.* [30]. Given these outcomes, it is obvious to state that the observed reduction in chlorophyll content in plants at the gas flaring sites can be attributed to the degradation of their photosynthetic pigment.

Ascorbic acid content at sites A and B was higher compared to the control site. Such high ascorbic content on plant leaves has been reported in the study by Antil, Kumari, and Singh [31] in India. Other researchers, such as Shahrukh *et al.* [32], Walia *et al.* [33], Pandit *et al.* [26], and Rai and Panda [34] have also reported a noticeable increase in ascorbic acid in plants within polluted environments. Such an increase in ascorbic acid in plants was attributed to enhanced levels of reactive oxygen species (ROS) generation during the process of photo-oxidation [32,35] of SO_2, where sulphites are generated from SO_2 absorbed. Studies by Shahrukh *et al.* [32], Jasmin *et al.* (2020), and Sadia et a [36] have also reported a decline in ascorbic acid content in polluted locations, especially for *Magnifera Indica and Polyalthia longifolia* species. The reported decrease in ascorbic content of plants was attributed by Randhi and Reddy [37] to the high sensitivity of such plants to air pollutants. It has been noted that plant species having high ascorbic acid content under polluted conditions are considered to be tolerant to air pollution stress [38,39]. All the evaluated plant species showed higher ascorbic acid content in the polluted sites than in the control, except *Tetracera alnifolia.* However, the reduction observed in *T. alnifolia is* the result of an impaired ascorbic acid biosynthesis pathway by the pollutant.

The study observed a reduction in pH in all the plants evaluated at the two gas flaring locations. This agrees with the findings of Shakeel *et al.* [40], Akande *et al.* [21], and Rai and Panda [41], who reported low pH values or observed slightly acidic conditions in polluted sites. They attributed the acidic condition to the presence of acidic pollutants, which shift the cell sap pH towards the acidic side. Singh and Verma [42] and Rai *et al.* [43] had noted that in the presence of an acidic pollutant, which may be due to the presence of SO_2 and NO_2 in ambient air, leaf pH is reduced, and the decline is greater in sensitive than in tolerant plants. Generally, it can be summarized based on the findings of Bui *et al.* [44] and Shahrukh *et al.* [32] that the degree of reduction in leaf extract pH depends on the tolerance level of the plants.

The high relative water content of the plants, observed in this study for both seasons, indicates that the sampled plant species have an increased chance of not being susceptible to stress conditions [32]. Relative water content has been linked to the increase in the survival rate of plants in hostile environments [44], being an adaptation mechanism by plant species [32]. This position was maintained by Sadia *et al.* [36], who noted that plants with high relative water content were tolerant of polluted environments. Relative water content is related to several leaf physiological variables, such as leaf turgor, growth, stomatal conductance, transpiration, photosynthesis, and respiration, ensuring physiological balance [30].

Season-wise, chlorophyll was observed to be significantly higher during the wet season compared to the dry season. This could be associated with the long photoperiod and low temperatures typical of the wet season in the study area. Similar results were obtained by Eno et al [45] and [28], who also reported higher chlorophyll content in plants during the rainy season than in other seasons. The higher chlorophyll content in the wet season may be due to the washout of dust particles from the leaf surface, low levels of pollution in the atmosphere, and sufficient moisture in the soil. Low chlorophyll content in the dry season may be due to the high pollution level, temperature stress, low sunlight intensity caused by winter, and short photoperiod [33]. The higher production of ascorbic acid in the leaves of selected plant species might be due to relatively more stressful conditions during the dry season.

Air Pollution Tolerance Indices of Selected Plants

The usefulness of APTI as an index for assessing the tolerance level of plants to air pollution has been shown in studies. Uka *et al.* [46] reported that plants with increased APTI in a polluted scenario show a higher tolerance level to air pollution than those with low APTI. This implies that plants with low APTI are sensitive to pollution. Antil *et al.* [31] opined, given the outcome of their study, that increased APTI values for plants in a polluted

environment point to enhanced defense mechanisms against air pollutants. The air pollution tolerance indices (APTI) recorded in our study were lower at the study sites compared to the control site in both wet and dry seasons. Such low APTI further indicates that plants at the gas flaring sites were under stress. Similar low APTI was reported by Sadia *et al*. [36], who stated that low APTI also indicates that pollution stress in the polluted area may have increased so high that plants had lost their tolerance. More so, seasonal variations in APTI were recorded in the study by Antil et al [31]. The outcome of APTI has been attributed to variations in the RWC, pH, total chlorophyll, and ascorbic acid properties, which govern the computation of the index [46,47,48]. APTI was also shown to vary across the different plants. Such variation in APTI based on plant species agrees with studies like Shakeel *et al.* [40] that sensitivity towards air pollution in plants is species-specific, with some plants being tolerant and manifesting minimal symptoms even with an increase in air pollution levels. This study shows that none of the plants met the threshold value of thirty (30) to be considered very tolerant to air pollution from gas flaring in the study area. However, *Aframomumdanielli* and *Stachytarpheta augustifolia* had high intermediate APTI values of up to twenty-seven (27) and can be used in green belt development for the mitigation of air pollution from gas flaring. *Tetracera alnifolia* is the only sensitive plant to air pollution from gas flaring, given its low APTI score of less than 17, suggesting therefore that it can be used only as a bioindicator of air pollution from gas flaring in the study area.

Conclusion and Recommendation

This study evaluated the effect of gas flaring on the physicochemical properties and APTI of five plants in Ibeno, Nigeria. The results indicate that gas flaring had adverse effects on plant physicochemical properties and influenced air pollution tolerance. The significant reduction in chlorophyll in all plants at both gas flaring sites is an indication of air pollution due to the degradation of photosynthetic pigment. Ascorbic acid content of plants at the gas flaring sites was higher compared to the control site. All the evaluated plant species showed higher ascorbic acid content at the sites than in the control, except *Tetracera alnifolia*, indicating that the plant was sensitive to air pollution. The study also observed a reduction in pH in plants at the study site, suggesting acidity-induced stress. The high relative water content observed in plants at the gas flaring sites, though resulting from stomata occlusion, indicated the species were not susceptible to water stress.

Considering their high intermediate APTI values at the two gas flaring sites, *Aframomum danielli* and *Stachytarpheta augustifolia* may be used in green belt development for the mitigation of air pollution from gas flaring. In addition, those plant species that proved to be more tolerant to pollution should be introduced and allowed to dominate the gas flaring sites for biomitigation and greenbelt development.

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Statement of Competing Interests

The authors declare that no known conflict of interest exists that could have influenced the outcome of this research paper.

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