

HYDROCARBON SEEPAGE DRIVES GRASSLAND BIODIVERSITY LOSS AND LIVELIHOOD DECLINE IN THE UGWUEME GUINEA SAVANNA, NIGERIA

***UBOCHI, K.C.,¹ OZOKOLIE, C.B.² NWANKWO, M.C.³ AND EZE C.N.⁴**

¹University of Agriculture and Environmental Sciences, Umuagwo, Faculty of Science and Computing, Department of Biotechnology, Owerri, Nigeria

²University of Nigeria, Nsukka, Faculty of Biological Sciences, Department of Plant Science and Biotechnology, Enugu, Nigeria

³Michael Okpara University of Agriculture, Umudike, College of Natural Sciences, Department of Plant Science and Biotechnology, Umuahia, Nigeria

⁴University of Agriculture and Environmental Sciences, Umuagwo, Faculty of Science and Computing, Department of Biology, Owerri, Nigeria

*Corresponding author: kingsley.ubochi@uaes.edu.ng

Abstract

Grassland ecosystems sustain biodiversity, ecosystem services, and rural livelihoods but are increasingly threatened by hydrocarbon contamination. The Ugueme Guinea savanna of southeastern Nigeria, characterized by natural oil seepages and tar sand deposits, provides a unique setting to evaluate the ecological consequences of chronic hydrocarbon exposure. This study assessed changes in floristic diversity, soil quality, and community livelihoods using vegetation surveys across three hydrocarbon exposure zones, soil physicochemical analyses, and structured questionnaires administered to 150 households. A total of 90 plant species belonging to 72 genera and 23 families were recorded. Species richness declined from 85 species in the reference zone to 54 in the moderate-exposure zone and 38 in the high-exposure zone, while the Shannon-Wiener diversity index decreased significantly from 3.45 ± 0.21 to 2.56 ± 0.18 and 1.65 ± 0.14 , respectively. Surface-soil total petroleum hydrocarbon (TPH) concentrations reached $937.33 \text{ mg kg}^{-1}$ in the highly impacted zone, approximately 18.7 times above the Department of Petroleum Resources intervention limit for agricultural soils. Hydrocarbon contamination simplified plant community structure by favouring a few disturbance-tolerant species while reducing the richness of key grassland families. Consequently, 86.7% of households reported declining crop productivity, 75.3% reduced access to medicinal plants, and 65.3% reduced livestock forage. These findings demonstrate that chronic hydrocarbon seepage drives biodiversity loss, soil degradation, and declining ecosystem services, underscoring the need for ecological restoration and community-based conservation in oil-affected grassland landscapes.

Keywords: *Grassland biodiversity, Hydrocarbon contamination Floristic diversity, Species richness, Total petroleum hydrocarbons, Ecosystem services, Southeastern Nigeria*

Introduction

Petroleum hydrocarbon contamination of terrestrial ecosystems remains one of the most persistent forms of environmental degradation globally, with vegetation systems among the ecosystems affected by long-term exposure (Adamu *et al.*, 2018; Adeniran *et al.*, 2023). Hydrocarbon contamination can alter soil properties, reduce vegetation productivity, restrict plant establishment, and influence ecosystem functions through direct toxicity, nutrient imbalance, and changes in soil biological processes.

In Nigeria, crude oil exploration and associated environmental impacts have contributed significantly to ecosystem degradation, particularly in oil-producing areas. Oil contamination has been linked with biodiversity decline, reduced agricultural productivity, and disruption of livelihoods dependent on natural resources (Ezeh *et al.*, 2024). These impacts are not restricted to coastal oil-producing regions but also occur in inland areas where natural hydrocarbon seepages exist.

Grasslands of the derived Guinea savanna zone of southeastern Nigeria support diverse assemblages of grasses, herbaceous plants, and legumes that contribute to soil protection, livestock feeding, medicinal resources, and local livelihoods (Adeleke *et al.*, 2020; Enwelu *et al.*, 2021; Greksa *et al.* 2024). A greater variety of plant species expands the range of ecological niches and supports more associated species (Bulleri *et al.* 2016; Carscadden *et al.* 2020). Additionally, trees deliver vital ecosystem services, including species conservation, soil erosion control, and habitat preservation for plants and animals (Armenteras *et al.*, 2009; Barrios *et al.*, 2018). Reduction in grassland vegetation diversity can therefore affect ecosystem stability and the availability of important biological resources for rural

communities (Camarretta *et al.*, 2020; Sahoo *et al.*, 2023; Baskent, 2024).

Ugwueme, a highland community in Awgu Local Government Area of Enugu State, southeastern Nigeria, represents a unique inland hydrocarbon-affected landscape outside the Niger Delta region. The area contains tar sand deposits and natural hydrocarbon seepage zones. According to the National Population Commission (2006), Ugwueme has an estimated population of 15,000 people. The people of Ugwueme are mostly farmers, who cultivate food and cash crops such as yam, cassava, cocoyam and maize (Okeke and Enoh, 2016; Enoh *et al.*, 2019). The zone comprises of Guinea savanna vegetation with hydrocarbon seepage (Enoh *et al.*, 2021; Ubochi *et al.*, 2022; Enoh *et al.*, 2022; Enoh *et al.*, 2024). The once-thriving vegetation has reduced to grassland due to hydrocarbon pollution and rampant human activities such as unregulated farming, deforestation, and urban encroachment (Onyena and Sam, 2020; Akani *et al.*, 2022; Aransiola *et al.*, 2024). Okeke and Enoh (2016) assessed vegetation response to hydrocarbon seepage in Ugwueme using Normalized Difference Vegetation Index (NDVI) threshold classification and reported changes in vegetation condition associated with seepage influence.

Further geospatial investigations have assessed vegetation trends and future changes in Ugwueme. Enoh *et al.* (2022) evaluated the influence of hydrocarbon micro-seepage on vegetation dynamics using leaf area index (LAI) analysis and Markov chain modelling, demonstrating continued vegetation change associated with hydrocarbon influence. Despite previous remote sensing assessments of hydrocarbon contamination in Ugwueme grasslands, information on plant species composition, diversity patterns, and species-specific responses to hydrocarbon exposure

remains scarce. This knowledge gap limits understanding of the ecological consequences of contamination and its effects on vegetation-dependent livelihoods. Therefore, this study aimed to evaluate the floristic composition and diversity of Ugwueme grasslands across hydrocarbon exposure gradients, determine the relationship between soil hydrocarbon concentration and vegetation diversity, and assess the community-level implications of grassland species loss.

Materials and Methods

Description of Study Area

The study was carried out in a crude oil seep site at Ugwueme in Awgu Local

Government Area of Enugu State, Nigeria (Figure 1). Ugwueme is situated at longitude 7°25'00" E and 7°35'00" E, and latitude 6°00'00" N and 6°15'00" N. It consists of roughly elevated topography (hills) with steep slopes and could attain an altitude of about 400–850 m above sea level. The area often experiences heavy rainfall during the rainy season with a rainfall record of 1,800 mm (Ubochi *et al.*, 2022) annually which aids heavy flooding, soil leaching, erosion, extensive outwash, ground water infiltration and percolation and high temperature during the dry season with an annual temperature average of 26.6 °C.

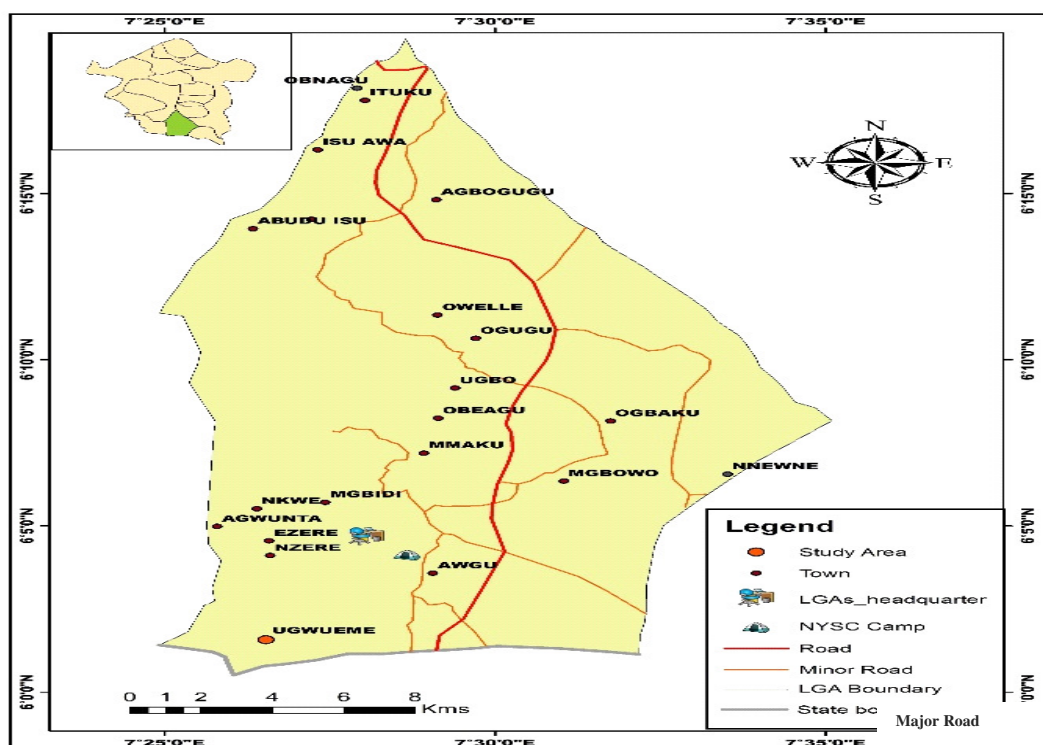


Fig. 1: Map of Awgu L.G.A. showing Ugwueme, the study area

Sampling Design

A stratified random sampling design was adopted for vegetation assessment. The study area was divided into three sampling zones: Zone A (high-exposure),

grassland areas within 0–200 m of active hydrocarbon seepage points, characterized by visible vegetation stress, bare soil patches and surface hydrocarbon staining; Zone B (moderate-exposure),

grassland areas 200–500 m from seepage locations, showing intermediate vegetation conditions; and Zone C (reference), grassland areas beyond 1,000 m from known seepage sites, representing relatively undisturbed vegetation. Twenty sampling plots were established in each zone, giving a total of 60 plots. Within each plot, all plant species were identified, counted and recorded. Grass species were sampled using quadrat methods, and density was expressed as the number of individuals per square metre (plants m⁻²). A 10 m × 10 m quadrat was used for plant species assessment.

Vegetation Survey Techniques

Field surveys were conducted during both the wet season (August-September 2024) and dry season (January-February 2025) to capture seasonal variations in vegetation composition and structure. Vegetation parameters recorded included species identity, family, life form, Percentage Frequency = $\frac{\text{Number of quadrats in which the species occurred}}{\text{Total number of quadrats thrown}} \times 100$

Percentage Cover (Braun-Blanquet Approach)

Percentage cover is visually evaluated within each plot using the traditional Braun-Blanquet cover-abundance scale (Braun-Blanquet, 1932; Furman *et al.*, 2018; Ricotta and Feoli, 2013) where each species was assigned an ordinal alphanumeric score based on its combined abundance and spatial coverage (Ricotta and Feoli, 2013):

- r: Solitary/rare individuals, negligible cover
- +: Few individuals, minor cover (<1%)
- 1: Plentiful, but covering <5% of the area
- 2: Covering 5% - 25% of the area
- 3: Covering 25% - 50% of the area
- 4: Covering 50% - 75% of the area
- 5: Covering >75% of the area

abundance, frequency, and percentage cover.

Species Identity, Family, and Life Form

Individual plants within designated sampling plots are observed to note their structural life form (e.g., tree, shrub, herb, liana). Plant species are initially identified morphologically following the keys in the *Flora of West Tropical Africa* (Hutchinson and Dalziel, 1972). Plant identification followed *Flora of West Tropical Africa* (Hutchinson and Dalziel, 1972), and species names were cross-checked using Plants of the World Online database (Royal Botanic Gardens, Kew, 2024).

Abundance and Frequency

Abundance (n): Determined by directly counting the total number of individual stems of a specific species across all sampled plots.

Frequency (F): Calculated as the percentage of sample plots in which a specific species occurs, using the formula:

Species Diversity and Richness Analyses

All of the following alpha-diversity metrics are calculated programmatically using the raw abundance data input into the PAST (PAleontological Statistics) software version 4.0 (Hammer *et al.*, 2001).

Species Richness (S): This was represented simply as the absolute count of unique, distinct species observed within a given zone or community sample (S).

Margalef's Richness Index (SR): This index was used to adjust absolute species richness by factoring in the total number of individual organisms collected, correcting for sample size effects (Kumar *et al.*, 2022).

$$\text{Formula: } SR = \frac{\{S - 1\}}{\ln(N)}$$

Where:

S = { Total number of species recorded }

N = { Total number of individuals of all species combined }

ln = { Natural logarithm }

Shannon-Wiener Diversity Index (\$H'\$):

This method was used to determine both species richness and the relative evenness of individual distribution among those species (Kumar *et al.*, 2022).

Using the formula:

$H = -\sum P_i \ln p_i \dots \dots \dots$ Shannon-Weiner index

Where

H = Shannon-Wiener diversity index

$\sum$ = Summation

Pi = Proportion of species (S/N)

S = Number of individuals of one species

N= Total number of individuals in the sample

ln= Natural log to base e.

Pielou's Evenness Index (J): It was used to determine how equally distributed individual organisms are among the species present in the sample, standardizing the value on a scale from 0 to 1 (Kumar *et al.*, 2022).

Formula:

$$J = \frac{H'}{H'_{\max}} = \frac{H'}{\ln(S)}$$

H' = { Calculated Shannon-Wiener index value }

S = { Total number of species in the sample }

Sørensen Similarity Coefficient: It was used to perform beta-diversity assessment by measuring the floristic similarity and species overlap between different ecological zones. It ranges from 0 (no shared species) to 1 (identical species composition) (Diserud and Ødegaard, 2006).

Formula: $C = \frac{2c}{\{a + b\}}$

Where:

c = { Number of species common to (shared by) both zones }

a = { Total number of species recorded in Zone A }

b = { Total number of species recorded in Zone B }

Soil Physicochemical Analysis

Composite soil samples were collected from 0–20 cm depth in each sampling zone. Samples were air-dried, sieved using a 2 mm mesh, and analysed for soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable cations, and total petroleum hydrocarbons (TPH).

TPH analysis was conducted using gas chromatography-flame ionization detector (GC-FID) following petroleum industry analytical procedures (Department of Petroleum Resources, 2002). Heavy metals including Pb, Cd, Cr and As were determined using atomic absorption spectrophotometry after aqua regia digestion

Community Socioeconomic Survey

A structured questionnaire was administered to 150 randomly selected household heads across the four residential quarters of Ugwueme. The questionnaire assessed perceived changes in grassland resources, crop productivity, livestock forage availability, medicinal plant access, and cultural plant resources. Twenty key informant interviews were also conducted with farmers, herbalists, elders, and traditional leaders.

Data Analysis

Vegetation diversity indices were analysed using PAST version 4.0. Differences among zones were tested using one-way analysis of variance (ANOVA), followed by Tukey's HSD test.

Data from community socioeconomic survey were analysed using descriptive statistics and chi-square tests in IBM SPSS version 27, with significance considered at $p < 0.05$.

Results and Discussion

Floristic Composition and Species

Richness

A total of 90 plant species belonging to 23 families and 72 genera were recorded across the three survey zones (Tables 1 and 2). The family Poaceae had the highest number of species (20 species; 22.2%), followed by Asteraceae (13 species; 14.4%), Euphorbiaceae (10 species; 11.1%), Fabaceae (9 species; 10.0%), and Araceae (5 species; 5.6%). Grasses and herbs constituted the dominant life forms, accounting for approximately 52% of the recorded species. The dominance of Poaceae and Asteraceae is characteristic of grass-dominated vegetation in

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Species richness declined markedly along the hydrocarbon exposure gradient, with Zone C recording 85 species, Zone B 54 species, and Zone A only 38 species. This progressive decline indicates a strong association between hydrocarbon exposure and vegetation degradation, suggesting that prolonged contamination may have eliminated sensitive species while favouring disturbance-tolerant plants. Similar

reductions in plant diversity and community structure have been reported in contaminated and otherwise disturbed ecosystems (Kuppusamy *et al.*, 2019; Gao *et al.*, 2022; Agrawal and Agrawal, 2023).

The Shannon-Wiener diversity index increased from 1.65 ± 0.14 in Zone A to 2.56 ± 0.18 in Zone B and 3.45 ± 0.21 in Zone C ($F = 52.36$, $p < 0.001$). Margalef richness index increased from 5.31 ± 0.39 to 8.04 ± 0.47 and 12.14 ± 0.68 , respectively ($F = 41.72$, $p < 0.001$), while Pielou's evenness increased from 0.44 ± 0.03 to 0.66 ± 0.05 and 0.82 ± 0.04 ($F = 31.85$, $p < 0.001$). These results demonstrate that hydrocarbon exposure affected both species number and the relative distribution of individuals. The low diversity and evenness in Zone A indicate a simplified community dominated by tolerant species, whereas the higher values in Zone C reflect a more complex and evenly distributed plant community (Magurran, 2004). Similar patterns have been reported in disturbed vegetation systems in Nigeria (Enwelu *et al.*, 2021; Moshood, 2024).

The Sørensen similarity index showed substantial differences in floristic composition. Zone A had a similarity value of 0.42 with Zone C, while Zone B showed 0.65. The low similarity between Zones A and C indicates considerable species turnover along the hydrocarbon exposure gradient. The replacement of vegetation components by disturbance-associated species, including *Imperata cylindrica*, *Chromolaena odorata*, *Tridax procumbens*, and *Cynodon dactylon*, suggests that environmental stress has favoured species capable of surviving under contaminated conditions. Similar shifts towards disturbance-tolerant vegetation have been reported in hydrocarbon-impacted landscapes (Okeke and Enoh, 2016; Abayomi *et al.*, 2021; Usiobaifo *et al.*, 2023).

Table 1: Composition and distribution of plant families

S/N	Family	No. of species	Percentage (%)
1.	Araceae	5	5.56
2.	Amaranthaceae	4	4.44
3.	Asteraceae	13	14.44
4.	Anacardiaceae	1	1.11
5.	Apocynaceae	1	1.11
6.	Arecaceae	4	4.44
7.	Costaceae	3	3.33
8.	Dioscoreaceae	2	2.22
9.	Euphorbiaceae	10	11.11
10.	Fabaceae	9	10.00
11.	Irvingiaceae	1	1.11
12.	Moraceae	2	2.22
13.	Malvaceae	1	1.11
14.	Olacaceae	1	1.11
15.	Lamiaceae	1	1.11
16.	Phyllanthaceae	1	1.11
17.	Poaceae	20	22.22
18.	Rutaceae	1	1.11
19.	Rubiaceae	2	2.22
20.	Sapindaceae	1	1.11
21.	Solanaceae	2	2.22
22.	Talinaceae	2	2.22
23.	Verbenaceae	3	3.33
	Total	90	100.00

Table 2: Summary of floristic composition and vegetation diversity indices across survey zones in Ugueme grassland

Parameter	Zone A (High Hydrocarbon Exposure)	Zone B (Moderate Hydrocarbon Exposure)	Zone C (Reference Zone)	F-value	p-value
Total species richness (S)	38	54	85	—	—
Total families	10	15	22	—	—
Total genera	30	39	51	—	—
Shannon–Wiener diversity index (H')	1.65 ± 0.14 ^c	2.56 ± 0.18 ^b	3.45 ± 0.21 ^a	52.36	<0.001
Margalef richness index (d)	5.31 ± 0.39 ^c	8.04 ± 0.47 ^b	12.14 ± 0.68 ^a	41.72	<0.001
Pielou's evenness index (J')	0.44 ± 0.03 ^c	0.66 ± 0.05 ^b	0.82 ± 0.04 ^a	31.85	<0.001
Sørensen similarity index (relative to Zone C)	0.42	0.65	1.00	—	—
Dominant families	Poaceae, Asteraceae, Fabaceae	Poaceae, Fabaceae, Asteraceae	Poaceae, Fabaceae, Asteraceae	—	—

Values are mean ± SD across 20 plots per zone. Different superscript letters indicate significant differences at $p < 0.05$.

Soil Physicochemical Properties and TPH Concentrations

The analysis revealed significant differences among the three exposure zones for all measured soil parameters ($p < 0.05$) (Table 3). Soil pH ranged from 4.75 ± 0.06 in Zone A to 6.42 ± 0.03 in Zone C, while organic carbon varied from $0.98 \pm 0.03\%$ in Zone C to $2.31 \pm 0.06\%$ in Zone A. Available nitrogen and phosphorus were lowest in Zone A (9.33 ± 2.52 mg/kg and 6.23 ± 0.68 mg/kg) and highest in Zone C (25.33 ± 5.51 mg/kg and 16.17 ± 0.76 mg/kg).

Total petroleum hydrocarbons (TPH) were highest in Zone A (937.33 ± 37.63 mg/kg), followed by Zone B (472.00 ± 6.24 mg/kg) and Zone C (34.00 ± 6.56 mg/kg). Chromium, lead, cadmium, and arsenic were similarly highest in Zone A and lowest in Zone C. The highest F-values were recorded for cadmium (1618.34), lead (1118.52), and TPH (893.46). TPH concentrations in Zones A and B exceeded the DPR limit of 50

mg/kg, while Zone C was below this threshold. The Zone A value was broadly consistent with TPH values reported from chronically impacted Ogoniland soils, where concentrations reached 40,645 mg/kg (Idam *et al.*, 2023).

The low soil pH in Zone A revealed acid generation from anaerobic hydrocarbon degradation pathways and sulphate reduction (Adeniran *et al.*, 2023). Elevated organic carbon in Zone A was attributable to the crude oil carbon load rather than biological productivity, as reported in oil-contaminated soils of Kokori, Delta State (Olabode, 2023). Available nitrogen and phosphorus were severely depleted, reflecting microbial immobilisation during hydrocarbon mineralisation and the inhibitory effect of phytotoxic PAHs on microbial nitrogen cycling (Adeniran *et al.*, 2023). These conditions collectively create an edaphic environment hostile to most native grassland plant species.

Table 3. Soil physicochemical properties across survey zones in Ugwueme grassland

Soil Parameter	Zone A (High-Exposure)	Zone B (Moderate-Exposure)	Zone C (Reference)	F-value	p-value	DPR Limit
pH (1:2.5 H ₂ O)	4.75 ± 0.06^c	5.72 ± 0.11^b	6.42 ± 0.03^a	225.61	<0.001	—
Organic carbon (%)	2.31 ± 0.06^a	1.21 ± 0.03^b	0.98 ± 0.03^c	702.83	<0.001	—
Available N (mg/kg)	9.33 ± 2.52^c	15.00 ± 1.00^b	25.33 ± 5.51^a	17.42	0.004	—
Available P (mg/kg)	6.23 ± 0.68^c	13.43 ± 0.93^b	16.17 ± 0.76^a	108.75	<0.001	—
TPH (mg/kg)	937.33 ± 37.63^a	472.00 ± 6.24^b	34.00 ± 6.56^c	893.46	<0.001	50
Chromium Cr (mg/kg)	1.27 ± 0.21^a	0.72 ± 0.06^b	0.11 ± 0.08^c	57.88	<0.001	100
Lead Pb (mg/kg)	2.62 ± 0.08^a	0.86 ± 0.06^b	0.10 ± 0.01^c	1118.52	<0.001	85
Cadmium Cd (mg/kg)	1.93 ± 0.06^a	0.38 ± 0.02^b	0.09 ± 0.02^c	1618.34	<0.001	3
Arsenic As (mg/kg)	1.67 ± 0.15^a	0.25 ± 0.05^b	0.05 ± 0.04^b	159.63	<0.001	—

Values are presented as mean $\pm$ SD. Different superscript letters within rows indicate significant differences among zones according to Tukey's HSD test at $p < 0.05$. TPH = Total Petroleum Hydrocarbons. DPR = Department of Petroleum Resources intervention limits

Community Impacts of Grassland Species Loss

The household survey revealed substantial socioeconomic and livelihood consequences associated with grassland species loss (Table 4). Decline in crop productivity was the most frequently reported impact, affecting 130 of the 150 surveyed households (86.7%) and recording the highest severity score (4.33 ± 0.42). This was followed by increased soil erosion, reported by 120 households (80.0%), with a severity score of 4.00 ± 0.47 . The high prevalence and severity of reduced crop productivity suggest that vegetation degradation may have important implications for local agricultural productivity. Loss of vegetation cover can expose soil to erosion, reduce soil structural stability and interfere with nutrient cycling. Similar relationships between vegetation loss, soil degradation and reduced agricultural productivity have been documented in oil-impacted communities (Adeleke *et al.*, 2020; Diyaolu *et al.*, 2022).

Reduced access to medicinal plants was reported by 113 households (75.3%) and recorded a severity score of 3.77 ± 0.51 , while 91 households (60.7%)

reported loss of traditional and cultural plant resources. Decline in food sufficiency was reported by 105 households (70.0%), while decreased livestock forage availability affected 98 households (65.3%). Increased distance travelled to collect wild vegetables was reported by 85 households (56.7%), while income decline from livestock affected 73 households (48.7%), with a severity score of 2.43 ± 0.72 . These findings indicate that biodiversity loss extends beyond ecological indicators to affect plant resources used for healthcare and cultural activities, as well as crop-based and livestock-based livelihood systems.

The observed community-level impacts are consistent with reports that oil pollution can reduce access to productive agricultural land and natural resources, thereby affecting food security and rural livelihoods (Osuagwu and Olaifa, 2018; Sam *et al.*, 2024). Thus, grassland species loss at Ugueme is not solely an ecological concern but also has implications for agricultural productivity, food security, traditional plant use, livestock production and household wellbeing.

Table 4. Reported community impacts of grassland species loss based on household survey

Impact Indicator	Households Affected (n)	Percentage (%)	Severity Score (Mean $\pm$ SD)
Decline in crop productivity	130	86.7	4.33 ± 0.42
Reduced access to medicinal plants	113	75.3	3.77 ± 0.51
Decreased livestock forage availability	98	65.3	3.27 ± 0.58
Increased soil erosion observed	120	80.0	4.00 ± 0.47
Decline in food sufficiency	105	70.0	3.50 ± 0.55
Loss of traditional/cultural plant resources	91	60.7	3.03 ± 0.61
Increased distance to collect wild vegetables	85	56.7	2.83 ± 0.65
Reported income decline from livestock	73	48.7	2.43 ± 0.72

Severity scale: 1 = not severe; 5 = extremely severe. Values are mean $\pm$ SD.

Conclusion

This study demonstrates that hydrocarbon contamination is a major driver of grassland biodiversity decline in Ugwueme, resulting in reduced species richness, altered plant community structure, and loss of valuable ecosystem resources. The strong association between elevated soil TPH levels and declining vegetation diversity highlights the ecological vulnerability of hydrocarbon-affected landscapes. Beyond biodiversity loss, these changes threaten agricultural productivity, livestock resources, medicinal plant availability, and community livelihoods. The findings emphasize the urgent need for integrated restoration strategies that combine ecological monitoring, soil rehabilitation, vegetation recovery, and community participation to restore and sustain degraded grassland ecosystems.

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