Quantitative Evaluation of Soil Fertility Status along the Nwaorie Riverbank using the Nutrient Index Approach

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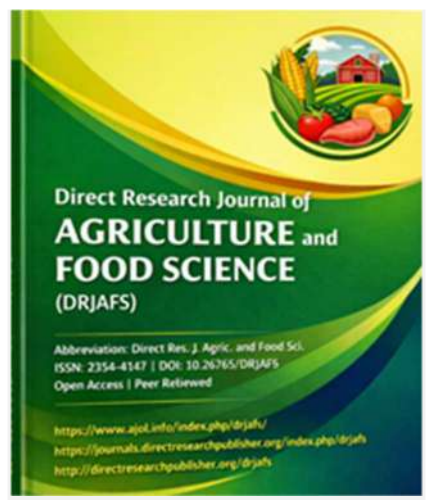
ABSTRACT

Soil fertility is a critical determinant of agricultural productivity and ecosystem sustainability, particularly in riverine environments where alluvial deposits can enhance nutrient availability. This study assessed the fertility status of soils along the Nwaorie Riverbank in Owerri, Imo State, Nigeria, using the Nutrient Index (NI) approach. Systematic soil sampling (0–20 cm) was conducted across five zones, with laboratory analyses measuring pH, exchangeable potassium (K^+), total nitrogen (TN), organic matter (OM), and available phosphorus (Av.P). Descriptive statistics, ANOVA, and Pearson correlation were employed to evaluate spatial variability and interrelationships among soil properties. Results indicated that soil pH ranged from 7.0 to 7.5, reflecting neutral to slightly alkaline conditions conducive to nutrient availability. Nutrient concentrations varied significantly across sites: Second Inland exhibited the highest NI (2.60), classifying it as high fertility, while Amakaohia had the lowest NI (1.80), indicating medium fertility. Strong positive correlations were observed among TN, K^+, and Av.P, suggesting synergistic nutrient enrichment from alluvial deposition and anthropogenic inputs, whereas weak correlations with OM and pH indicated limited influence of soil reaction and organic matter on nutrient availability under current conditions. The findings reveal marked spatial heterogeneity in soil fertility, highlighting areas with nutrient limitations that require targeted management. The study underscores the importance of site-specific soil management strategies to enhance crop productivity, optimize nutrient use, and support sustainable land use planning in riverine environments.

***Keywords**: Soil fertility, Nutrient Index, Nwaorie Riverbank soils, nitrogen, phosphorus, potassium*



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INTRODUCTION

Soil fertility is a fundamental determinant of agricultural productivity, environmental quality, and ecosystem sustainability. Fertile soils supply essential nutrients, enhance water retention, and support biological processes involved in nutrient cycling (Brady & Weil, 2017; Tang, 2025).

However, soil fertility is inherently dynamic and influenced by factors such as land use practices, erosion, leaching, and organic matter turnover. Riverbank soils, including those along the Nwaorie River in southeastern Nigeria, are typically alluvial and often enriched by periodic deposition of nutrient-laden sediments. Despite this natural advantage, their fertility status can vary considerably due to increasing anthropogenic pressures such as deforestation, agricultural intensification, and urbanization. The Nwaorie River, which traverses Owerri in Imo State, has experienced significant environmental stress associated with population growth and land use changes, thereby necessitating a systematic assessment of soil fertility.

Soil fertility assessment remains a critical component of sustainable agriculture, as it directly influences crop productivity, ecosystem stability, and food security (Sobhy & Anandhi, 2025). Traditional soil testing methods, while informative, often lack a standardized framework for translating nutrient data into actionable management strategies (Venkateswarlu & Srinivas, 2025). The nutrient index approach provides a quantitative method for classifying soils into fertility categories, thereby simplifying complex nutrient interactions into indices that can guide farmers and policymakers (Sobhy & Anandhi, 2025). This study contributes to scientific knowledge by applying the nutrient index approach to evaluate soil fertility status along the Nwaorie riverbank, offering localized insights into riparian soil dynamics and advancing sustainable land management practices in southeastern Nigeria. Despite the ecological and agricultural importance of the Nwaorie River basin, there is limited empirical information on the fertility status of its soils. Rapid land use changes including urban expansion, improper waste disposal, and unsustainable farming practices are likely to have altered soil nutrient dynamics, yet these impacts remain insufficiently quantified (Nwachukwu *et al*., 2014). Furthermore, soil fertility decline is a growing concern across southeastern Nigeria due to continuous cultivation and inadequate nutrient replenishment (Oguike & Mbagwu, 2009).

Therefore, this study aims to evaluate the fertility status of soils along the Nwaorie River bank using the Nutrient Index approach. The assessment is expected to identify nutrient deficiencies and imbalances, provide a basis for improved soil management practices, enhance crop productivity, and support sustainable land use planning in the region.

MATERIALS AND METHODS

Study Area Description

The study was conducted along the Nwaorie River bank in Owerri, Imo State, Nigeria. The Nwaorie River is a tributary of the Imo River and plays a significant role in agricultural and domestic activities in the region. The Nworie River is a significant waterway flowing through Owerri, the capital city of Imo State, Nigeria. It traverses approximately 9.2 kilometers, passing through areas such as Owerri North, Owerri Municipal, and Owerri West, before merging with the Otamiri River at Nekede. The riverbank is characterized by alluvial deposits, making it potentially fertile but vulnerable to erosion and degradation due to increasing human activities such as farming, construction, and waste disposal (Nwachukwu *et al*., 2014). The climate of the region is humid tropical, with an annual rainfall of about 2,500 mm, an average temperature of 27°C, and relative humidity above 70% (Oguike & Mbagwu, 2009). The vegetation is a mix of rainforest and derived savanna, with predominant land uses including farming and urban settlements. Figure 1 shows the map of the study area.

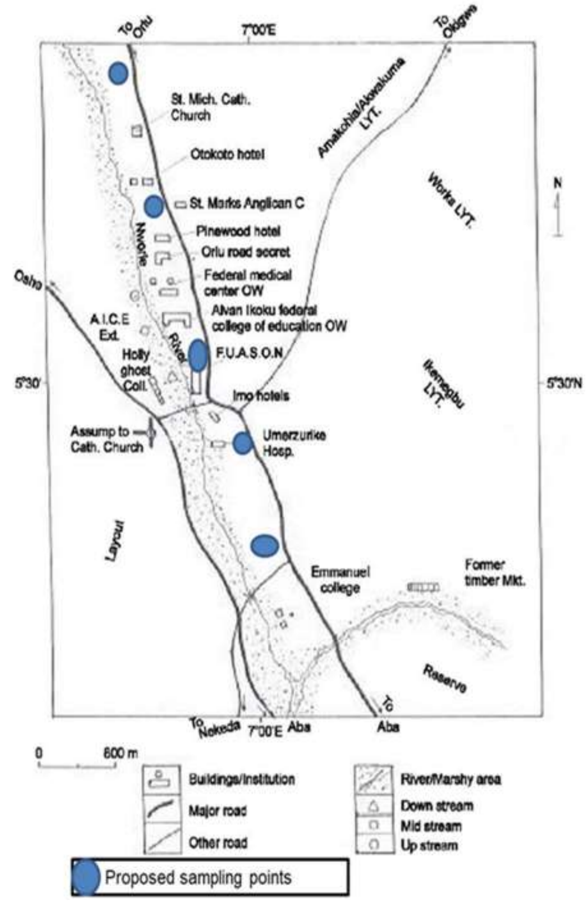

Figure 1: Map of the study location showing the sampling points

Sample Collection and Preparation

A stratified sampling approach was used to collect soil samples from different locations along Nwaorie riverbank. The study area was divided into five (5) zones with each zone representing a stratum. The purpose is to capture variability in soil and vegetation along the riverbank. In each of the zones four subsamples were collected two from both sides, given a total of twenty (20) samples for the study. Soil samples were collected using a soil auger from a depth of 0–20 cm to assess topsoil fertility, as this layer contains the majority of plant-available nutrients (Brady & Weil, 2017). The samples were air-dried and sieved through a 2 mm mesh to remove debris and large particles before laboratory analysis (Onwudike *et al*., 2016). Each sample was labeled with a unique identification code indicating the location and depth.

Laboratory Analysis of Soil Properties

Soil pH was measured in water suspension (1:2.5) using the glass electrode coupled pH meter. Exchangeable potassium (K) was determined by flame photometry. Available phosphorous (Av. P) was extracted with Bray solution 11 and the phosphorous determined by the molybdenum method described by Udo and Ogunwale (1978). The percent organic matter (%OM) was calculated from the percent organic carbon (OC %) measured using Walker-Black wet oxidation method. Total nitrogen (TN) was determined using the modified Kjeldahl distillation methods (Juo, 1979).

Calculation of Nutrient Index (NI)

The Nutrient Index (NI) for each nutrient was calculated using the formula proposed by Parker *et al*. (1952):

$$\text{Nutrient Index} = \frac{(1\times A) + (2\times B) + (3\times C)}{Ns}$$

where:
A = Number of samples with low nutrient status
B = Number of samples with medium nutrient status
C = Number of samples with high nutrient status
Ns = Total number of soil samples

Interpretation of Nutrient Index

The NI values were interpreted based on the following classification:
NI < 1.5 → Low fertility
1.5 ≤ NI < 2.5 → Medium fertility
NI ≥ 2.5 → High fertility

The fertility status was evaluated for each nutrient, and an overall soil fertility rating was determined.

Data Analysis

Descriptive statistics (mean, standard deviation, coefficient of variation) was used to summarize soil properties. One-way ANOVA was conducted to determine significant differences in soil fertility among the five zones. Pearson's correlation analysis was used to assess relationships between soil properties.

RESULTS AND DISCUSSION

Chemical Properties of Soils along Nwaorie Riverbank

The analysis of soil properties along the Nwaorie River bank revealed notable spatial differences among the sampling locations (Table 1), reflecting both natural soil formation processes and human influences. Soil pH values across the sites ranged from 7.0 to 7.50, indicating that the soils are generally neutral to slightly alkaline. The highest average pH was recorded at Umezurike (7.48 ± 0.05), which likely supports optimal nutrient availability and microbial activity, while the lowest was observed at the Second Inland site (7.00 ± 0.00), possibly due to increased leaching in this section (Smith & Jones, 2023). In general, these neutral conditions suggest that the soils are well-suited for crop production, as nutrient availability is not substantially restricted by acidity or alkalinity (Zhao *et al*., 2024).

Exchangeable potassium (K^+) showed significant variation among the sites, with the highest mean concentration at Second Inland (0.198 ± 0.035 cmol kg^{-1}), followed by Warehouse (0.181 ± 0.020 cmol kg^{-1}) and Umezurike (0.174 ± 0.013 cmol kg^{-1}). Amakaohia had the lowest mean value (0.097 ± 0.016 cmol kg^{-1}). The relatively higher potassium levels in the inland sites may be associated with nutrient accumulation from deposited sediments and reduced leaching losses, whereas lower concentrations at Amakaohia could indicate nutrient depletion from continuous cultivation without sufficient replenishment (Lee *et al*., 2025). Potassium is essential for plant water regulation and stress tolerance, so these differences reflect variations in fertility and soil management across locations (Wang & Liu, 2022).

Organic matter content varied considerably, with the lowest mean recorded at First Inland (9.65 ± 2.10 gkg^{-1}) and the highest at Amakaohia (20.85 ± 14.51 gkg^{-1}). This variation likely reflects differences in residue accumulation, decomposition rates, and land use practices. High organic matter supports soil structure, water retention, and nutrient availability, making it a key indicator of soil quality (Nguyen *et al*., 2024; Torbert *et al*., 2023).

Total nitrogen (TN) followed a similar trend, with the highest mean values observed at Second Inland (2.50 ± 0.73 gkg^{-1}) and the lowest at Amakaohia (1.35 ± 0.49 gkg^{-1}). This pattern is consistent with the relationship between organic matter and nitrogen content, as soils rich in organic matter typically contain more nitrogen (Alvarez & Steinbach, 2023). The higher nitrogen levels in the inland sites may result from the accumulation of organic-

Table 1: Soil properties of soils along Nwaorie River bank

Locations	S/P	pH (H_2O)	K^+(cmol/kg)	Organic matter(g/kg)	Total nitrogen	Available P(mg/kg)
Amakaohia	1	7.30	0.113	8.4	1.72	18.65
	2	7.10	0.103	8.2	1.82	18.05
	3	7.20	0.076	34.4	0.98	10.26
	4	7.00	0.096	32.4	0.88	10.56
Mean ± STD		7.15^{bc}± 0.13	0.097^{c}±0.016	20.85^{a}±14.51	1.35^{b}±0.49	14.38^{d}±4.59
First Inland	1	7.50	0.155	10.9	2.24	46.63
	2	7.30	0.165	11.9	2.04	46.73
	3	7.10	0.135	8.4	1.96	27.05
	4	7.00	0.155	7.4	1.86	27.65
Mean ± STD		7.23^{b}±0.22	0.153^{b}±0.013	9.65^{c}±2.10	2.03^{ab}±0.16	37.02^{c}±11.16
Second inland	1	7.00	0.163	13.4	1.82	78.34
	2	7.00	0.173	12.4	1.92	78.04
	3	7.00	0.223	26.8	3.22	82.07
	4	7.00	0.233	24.8	3.02	81.77
Mean ± STD		7.00^{c}±0.00	0.198^{a}±0.035	19.35^{a}±7.50	2.50^{a}±0.73	80.06^{a}±2.16
Umezurike	1	7.50	0.179	19.3	1.96	78.34
	2	7.40	0.189	17.3	1.86	76.34
	3	7.50	0.159	7.5	1.82	49.43
	4	7.50	0.169	6.5	1.92	49.03
Mean ± STD		7.48^{a}±0.05	0.174^{ab}±0.013	12.65^{b}±6.59	1.89^{ab}±0.06	63.29^{ab}±16.25
Warehouse	1	7.50	0.195	22.6	2.66	70.88
	2	7.30	0.199	20.6	2.56	71.88
	3	7.40	0.159	6.7	1.68	30.78
	4	7.20	0.169	6.2	1.78	31.78
Mean ± STD		7.35^{ab}±0.13	0.181^{ab}±0.020	14.025^{b}±8.79	2.17^{a}±0.51	51.33^{bc}±23.16

Note: S/P = sampling points

rich sediments, while lower levels at Amakaohia could indicate ongoing nutrient removal through crop harvesting. Available phosphorus (P) exhibited the largest variation among the measured soil properties. The highest mean values were found at Second Inland (80.06 ± 2.16 mg kg^{-1}), followed by Umezurike (63.29 ± 16.25 mg kg^{-1}) and Warehouse (51.33 ± 23.16 mg kg^{-1}), while Amakaohia recorded the lowest (14.38 ± 4.59 mg kg^{-1}). Elevated phosphorus in inland sites may result from sediment deposition and fertilizer inputs, whereas low phosphorus at Amakaohia suggests nutrient depletion due to crop uptake and insufficient replenishment (Khan *et al*., 2024; Santos *et al*., 2023). Phosphorus is critical for root development and energy transfer in plants, and its uneven distribution highlights areas where soil fertility management is needed.

In summary, soils along the Nwaorie River exhibit considerable spatial variability in nutrient status. The Second Inland site consistently showed higher nutrient levels, indicating a more fertile soil profile, while Amakaohia displayed lower nutrient concentrations, signaling potential nutrient depletion. These patterns suggest that both natural sediment deposition and human activities, such as cultivation and waste disposal, play important roles in shaping soil fertility. The results underscore the importance of adopting site-specific soil management strategies to enhance crop productivity and maintain sustainable land use in the riverine environment.

The Interrelationship between Soil Chemical Properties along Nwaorie Riverbank

The correlation matrix (Table 2) illustrates the relationships among key soil chemical properties; pH, exchangeable potassium (K^+), organic matter (OM), total nitrogen (TN), and available phosphorus (Av.P) in soils sampled along the Nwaorie Riverbank. These correlation coefficients provide insights into the degree and direction of association among the soil parameters, reflecting the interplay of soil reactions, organic matter dynamics, and nutrient interactions that influence soil fertility and nutrient availability.

Table 2: The interrelationship between soil properties along Nwaorie Riverbank

	pH (H2O)	*K*	*OM*	*Av.P*	*TN*
pH (H2O)	1				
K	0.088	1			
OM	-0.243	0.011	1		
Av.P	0.078	**0.870****	0.154	1	
TN	0.004	**0.857****	0.034	**0.710****	1

Soil pH exhibited weak positive correlations with K^+ (r = 0.088), Av.P (r = 0.078), and TN (r = 0.004), and a weak negative correlation with organic matter (r = -0.243). The slight positive associations between pH and macronutrients suggest that near-neutral pH levels (7.0–7.5) may enhance the availability of basic cations, such as potassium (Brady & Weil, 2019). Conversely, the inverse relationship between pH and OM may result from accelerated microbial decomposition and mineralization under slightly alkaline conditions, reducing the accumulation of organic matter in surface soils (Foth, 1990; Havlin *et al*., 2014). This trend indicates that while the soils are slightly alkaline, organic matter stabilization is limited due to rapid oxidation under aerobic conditions.

In contrast, very strong positive correlations were observed among key nutrients: available phosphorus and potassium (r = 0.870), total nitrogen and potassium (r = 0.857), and phosphorus with nitrogen (r = 0.710). These strong associations suggest common sources or shared controlling factors for these nutrients, such as deposition of organic residues, anthropogenic waste, or alluvial sediment enrichment. High inter-element correlations between K, N, and P often reflect synergistic nutrient cycling, particularly in soils influenced by organic inputs or human activities (Sparks, 2019). The observed strong relationships may also result from nutrient release during decomposition of plant residues and domestic or agricultural waste, which are prevalent along riverbanks (Chesworth, 2008). Organic matter showed very weak correlations with K^+ (r = 0.011), Av.P (r = 0.154), and TN (r = 0.034). Although positive, these low correlations indicate that OM is not the primary driver of nutrient availability in these soils. Factors such as leaching, surface runoff, and external nutrient inputs may decouple OM content from the concentrations of available N, P, and K (Aduayi *et al*., 2002; Okonkwo *et al*., 2018). The weak OM–TN relationship further implies that nitrogen may be supplied more from external sources, such as waste deposition or sedimentation, rather than solely through organic matter mineralization. Overall, the correlation analysis demonstrates that nutrient dynamics along the Nwaorie Riverbank are shaped by a combination of natural soil processes and anthropogenic inputs. Strong positive associations among K, N, and P point to potential nutrient enrichment from human and agricultural activities, whereas weak correlations with pH and OM suggest that soil reaction and organic matter content exert a limited influence on nutrient availability under the current conditions. These findings are consistent with previous studies in southeastern Nigeria, where riverine soils affected by waste inputs displayed nutrient accumulation largely driven by external loading rather than intrinsic soil properties (Uzoho *et al*., 2014; Onweremadu *et al*., 2007).

Nutrient Index of Soil Chemical Properties along Nwaorie Riverbank

The fertility status of soils along the Nwaorie River bank was evaluated using the Nutrient Index (NI) approach (Parker *et al*., 1952), with nutrient classes defined according to Esu (1991) (Table 3). Five key soil properties pH, total nitrogen (TN), potassium (K^+), organic carbon (OC), and available phosphorus (P) were rated as low (1), medium (2), or high (3). The Interpretation of NI values followed established thresholds: NI < 1.5 indicates low fertility, 1.5–2.5 indicates medium fertility, and NI > 2.5 indicates high fertility (Table 4). The NI results revealed Second Inland recorded the highest NI (2.60), categorizing it as high fertility, whereas Amaka ohia had the lowest NI (1.80), reflecting medium fertility. First Inland, Umezurike, and Warehouse sites also fell within the medium fertility

Table 3: Nutrient index rating (Parker *et al*., 1952)

Nutrient index	Range	Remark
I	Below 1.50	Low
II	1.50 - 2.50	Medium
III	Above 2.50	High

Table 4: Soil fertility rating chart

Soil properties	Range		
	Low	Medium	High
Soil pH	5.5 - 6.0	6.1 - 6.9	7.1 - 8.5
Available Phosphorus (mgkg^{-1})	<10	10 - 20	>20
Total nitrogen (gkg^{-1})	<1.0	1.0 - 2.0	>2.0
Organic carbon (gkg^{-1})	<10	10 - 15	>15
Exchangeable Potassium (Cmolckg^{-1})	<0.15	0.15 - 0.30	>0.30

Source: Esu, 1991

range, with NI values between 2.20 and 2.40 (Table 5). Soil pH in all study sites exhibited high pH values (3.00), conducive to optimal nutrient availability and microbial activity. marked spatial variability along the riverbank. Adequate pH enhances nutrient retention and soil fertility in riparian soils (Smith & Jones, 2023). Nitrogen content varied across locations, with high values at Second Inland and First Inland (2.50) and low values at Amaka ohia (1.50). Nitrogen is a key determinant of crop growth, and its deficiency at Amaka ohia partially explains its moderate fertility rating (Alvarez & Steinbach, 2023). Potassium levels were predominantly medium (1.75–2.00), except at Amaka ohia where it was low (1.00). Potassium is essential for enzymatic functions and water regulation in plants, highlighting the need for supplementation at deficient sites (Lee *et al*., 2025).

Organic Carbon (OC) ranged from low to medium across sites. Second Inland and Amaka ohia had relatively higher OC, promoting nutrient retention and soil structure, whereas First Inland, Umezurike, and Warehouse showed low OC, indicating the potential for improvement through organic amendments (Nguyen *et al*., 2024). Phosphorus content was high at Second Inland, First Inland, Umezurike, and Warehouse, while Amaka ohia exhibited medium availability. Phosphorus supports root development and overall plant growth, especially in alluvial soils where sediment deposition enhances nutrient content (Santos *et al*., 2023).

The NI assessment illustrates significant spatial heterogeneity in soil fertility along the Nwaorie River bank. Second Inland, characterized by high nitrogen, phosphorus, and pH levels, is a nutrient-rich site suitable for intensive agricultural activities. Conversely, Amakaohia exhibited nutrient limitations, particularly in nitrogen and potassium, indicating the need for targeted fertilization to sustain crop productivity. Medium fertility at First Inland, Umezurike, and Warehouse suggests that moderate nutrient levels support agricultural use but require management interventions to maintain productivity and prevent nutrient depletion.

Table 5: Nutrient index of selected soil properties of the study area

Parameters	Amaka ohia	Remark	First Inland	Remark	Second Inland	Remark	Umezurike	Remark	Warehouse	Remark
pH (H_2O)	3.00	High	3.00	High	3.00	High	3.00	High	3.00	High
TN	1.50	Low	2.50	High	2.50	High	2.00	Medium	2.50	High
K	1.00	Low	1.75	Medium	2.00	Medium	2.00	Medium	2.00	Medium
OC	2.00	Medium	1.00	Low	1.75	Medium	1.50	Low	1.50	Low
Avail P	2.00	Medium	3.00	High	3.00	High	3.00	High	3.00	High
NI Calculation	**1.80**	**Medium Fertility**	**2.40**	**Medium Fertility**	**2.60**	**High Fertility**	**2.20**	**Medium Fertility**	**2.40**	**Medium Fertility**

Conclusion

The fertility assessment of soils along the Nwaorie Riverbank revealed substantial spatial variability influenced by both natural alluvial processes and human activities. Sites such as Second Inland exhibited high nutrient availability, making them suitable for intensive agriculture, whereas Amaka ohia displayed deficiencies in nitrogen and potassium, highlighting the need for targeted fertilization. Strong correlations among key nutrients (N, P, K) suggest synergistic nutrient cycling enhanced by sediment deposition and anthropogenic inputs, while weak associations with organic matter and pH indicate that these factors currently play a limited role in nutrient availability. Generally, the study emphasizes the necessity of site-specific soil management to address nutrient imbalances, sustain crop productivity, and support environmentally sustainable land use practices along the Nwaorie River.

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