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Assessment of Soil Degradation in Rice (*Oryza sativa* L) Fields under Intensive Cultivation in Kura, Kano State, Nigeria

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ABSTRACT

Soil degradation is a major threat to the sustainability of irrigated rice production in Nigeria. This study assessed the status of soils under intensive rice cultivation in Kura LGA, Kano State, by analyzing physical, chemical, and micronutrient properties from 20 composite samples (0–20 cm depth). Soil pH, electrical conductivity, organic carbon, total nitrogen, available phosphorus, exchangeable bases, and micronutrients, were analyzed to access degradation severity, while a degradation index was applied to classify severity. Results showed that soils were moderately acidic to neutral (pH 5.9-7.1) with low organic carbon (< 1%) and nitrogen (< 0.1%), indicating nutrient depletion. Micronutrients such as Cu and Zn were below critical thresholds in several locations, while high Fe (>300 mg/kg) suggested potential imbalance. Overall, 55% of sampled fields showed moderate degradation and 15% severe degradation, mainly due to nutrient mining, poor organic matter management, and salinity risks from irrigation. The findings highlight the urgent need for integrated soil fertility management, including organic amendments, micronutrient supplementation, and conservation tillage, to sustain rice productivity in the Kano River Irrigation Project area. This study delivers the first ward-level insight into soil degradation in Kura LGA, revealing spatial variability and critical nutrient threshold that inform targeted strategies to sustain rice productivity under intensive cultivation.

Keywords: Soil degradation, Rice cultivation, Soil fertility, Nutrient management, Ward-Specific Management; Sustainable agriculture

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1. INTRODUCTION

The Food and Agriculture Organization (FAO) defines soil health as the ability of soil to sustain the productivity, diversity, and environmental services of terrestrial ecosystems. However, soil health is increasingly under threat from various environmental and management pressures such as climate change, pollution, and unsustainable land use practices. These factors contribute to soil degradation, which in turn undermines soil productivity and ecosystem stability.

Soil degradation manifests in several forms, including erosion, loss of organic matter, nutrient imbalance, salinization and alkalinization, contamination, acidification, loss of biodiversity, sealing, compaction, and poor water retention. Globally, about one-third of the world's soils are moderately to severely degraded due to erosion, nutrient depletion, and salinization, posing a serious threat to agricultural productivity and ecosystem services.

In Nigeria, particularly within the Kano River Irrigation Project (KRIP) area, earlier studies have primarily emphasized salinity and irrigation-related degradation issues (Jibrin et al., 2008). However, other critical forms of degradation such as nutrient depletion, decline in organic matter, and poor management practices have received less attention. This study therefore focuses on these neglected aspects, integrating field-level evidence on soil fertility decline and management-linked degradation patterns in Kura. It aims to provide a broader understanding that goes beyond the irrigation-centered perspective of earlier KRIP assessments.

Rice production in Nigeria has expanded rapidly in response to growing demand and food security needs, with Kura Local Government Area (LGA) in Kano State serving as a key rice-producing zone. However, empirical studies in Kura have indicated that intensive irrigated farming has led to a drastic decline in soil fertility (Sule, Umar, Danlami, & Mansur, 2025).

Farmer surveys further reveal limited use of organic manure and suboptimal fertilizer management, reinforcing evidence of management-driven soil fertility stress. Consequently, while Kura remains central to Nigeria's rice supply, the sustainability of production is increasingly threatened by ongoing soil fertility decline and degradation risks associated with intensive cultivation practices. This study was therefore designed to:

- Assess the soil degradation status of fields under intensive rice cultivation in Kura LGA, Kano State;
- Analyze the relationships between soil properties and degradation indicators; and
- Recommend sustainable management practices to enhance soil health and maintain rice productivity.

By integrating chemical, physical, and management data, this study provides one of the first ward-level assessments of soil degradation in Kura LGA. It offers localized insights to support targeted strategies for sustainable soil fertility management under intensive rice production systems.

2. MATERIALS AND METHODS

2. 1. Description of the Study Area

The study was conducted in Kura Local Government Area (LGA), Kano State, Nigeria one of the major rice-producing zones within the Sudan Savanna agroecological region.

Geographically, the area lies between latitude 11°46′17″ N and longitude 8°25′49″ E. It experiences a tropical semi-arid climate with an average annual rainfall of 800-1000 mm, concentrated between May and September, and a mean annual temperature ranging from 21 °C to 34 °C. The region is characterized by high evapotranspiration rates, which accentuate moisture deficits during the dry season.

Soils in Kura are predominantly sandy loam to sandy in texture, possessing low organic matter content and limited cation exchange capacity, typical of soils in the Sudan Savanna zone [(Issa et al., 2021)]. Rice cultivation is practiced under both rainfed and irrigated systems, with increasing intensity driven by population growth, market demand, and expansion of irrigation infrastructure. This intensification exerts mounting pressure on the soil resource base, predisposing it to nutrient depletion and degradation.

Figure 1. ESRI Satellite Map showing sampling fields clustered by sampling wards.

2. 2. Soil Sampling and Preparation

Soil samples were collected from rice fields across major wards within Kura Local Government Area (LGA). In each ward, composite soil samples were obtained at a depth of 0–20 cm using a soil auger, with five subsamples per field pooled to form a representative sample. A total of 20 composite samples were collected, air-dried at room temperature (23 °C), and prepared for subsequent laboratory analyses.

The sampling design was considered adequate for an LGA-scale assessment, with each composite representing five subsamples per field (100 point samples in total). This approach enhances spatial representativeness and minimizes small-scale variability. A similar sampling intensity was adopted by Yau (2025) in the Soil Degradation Assessment of Selected Land Uses in Kumbotso LGA, Kano State, which utilized 18 composite samples.

The selection of soil degradation indicators was guided by the frameworks of the Global Assessment of Human-Induced Soil Degradation (GLASOD, 1998) and Snakin et al. (1996). Soil pH, electrical conductivity (EC), and exchangeable sodium percentage (ESP) were measured to capture acidification, salinization, and sodicity processes consistent with the GLASOD chemical degradation categories. Organic carbon, total nitrogen, available phosphorus, and exchangeable potassium were included to assess organic matter decline and nutrient depletion, reflecting Snakin's fertility-decline indicators. Exchangeable bases, base saturation, and cation exchange capacity (CEC) were analyzed to evaluate soil structural stability and nutrient-retention capacity, while micronutrients (Mn, Cu, Zn, and Fe) were determined to identify fertility stress and potential micronutrient imbalances.

Together, these parameters operationalize the GLASOD–Snakin criteria, enabling a comprehensive assessment of physical and chemical degradation processes affecting soils under intensive rice cultivation in Kura LGA.

2. 3. Laboratory Analyses

Standard laboratory procedures were employed to determine the physical and chemical properties of the soil samples. Particle size distribution was analyzed using the hydrometer method (Gee & Or, 2002), while soil pH was measured in a 1:2.5 soil-to-water suspension using a glass electrode pH meter. Electrical conductivity (EC) was determined in the same extract with a conductivity meter.

Organic carbon (OC) was analyzed by the Walkley–Black wet oxidation method (Nelson & Sommers, 1996), and total nitrogen (TN) was determined using the Kjeldahl digestion method (Bremner & Mulvaney, 1982). Available phosphorus (P) was extracted using the Bray-1 method and quantified colorimetrically (Bray & Kurtz, 1945).

Exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) were extracted with 1 M ammonium acetate (pH 7.0) and quantified using atomic absorption spectrophotometry for Ca and Mg, and flame photometry for K and Na. Effective cation exchange capacity (ECEC) was computed as the sum of exchangeable bases and exchangeable acidity.

2. 4. Degradation Assessment

The analytical results for each sample were classified into degradation severity classes based on established land degradation indicators (Table 1).

Table1. Indicators and Criteria for Land Degradation Assessment.

Degree of Degradation				
Indicator	**1**	**2**	**3**	**4**
pH (Acidity)	6.5-7.5	5.5-6.5	5.0-5.5	5.0
pH (Alkalinity)	- - -	7.5-8.0	8.0-8.5	8.5
Content of Available N element N (%)	>0.13	0.13-0.10	0.10-0.08	>0.08

Content of Available Phosphorus Element (mg/kg)	>8	8-7	7-6	<6
Content of Potassium Element (cmol /kg)	>0.16	0.16-0.14	0.14-0.12	<0.12
Content of ESP (%)	<10	10-25	25-50	>50
Base saturation (%)	<2.5	2.5-5	5-10	>10
Excess salt (Salinization) (increase of conductivity mm ho cm^{-1} yr^{-1})	<2	2-3	3-5	>5
Content of Organic Carbon (%)	>2	1.4-2.0	1.0-1.4	<1
Content of Calcium (Cmol/kg)	>6	3-6	2-3	<2
Content of Magnesium (Cmol/kg)	>1	0.6-1	0.3-0.6	<0.3
Content of Manganese (mg/kg)	>5	2.5-5.0	1.1-2.5	<1
Content of Copper (mg/kg)	>2	1.0-2.0	0.21-1.0	<0.2
Content of Zinc (mg/kg)	>2	1.0-2.0	0.81-1.0	<0.8
Content of Iron (mg/kg)	>10	5-10	2.5-5	<2.5

Source: GLASOD, (1998); Snakin et al. (1996).

The overall degree of degradation was then quantified mathematically by integrating selected physical and chemical parameters, as expressed in the equation below. This approach provided a standardized framework for evaluating and comparing degradation intensity across sampling sites.

Overal Degree of Degradation:

$$ODD\ (\%) = \frac{\sum(\,Degree\ of\ Degradation\ of\ Each\ Quality) \times\ 100}{(Maximum\ Degree\ of\ Degradation \times Numbers\ of\ Quality)}$$

Table 2. Soil Degradation Score Rating.

Class of Degradation	**Overall Degree of Degradation (%)**	**Description**
1	0-25	Non to slightly degraded soil
2	26 – 50	Moderately degraded soil
3	51 -75	Highly degraded soil
4	76 – 100	Very highly degraded

2. 5. Data Analysis

Soil characteristics and degradation score were compared across the sampling villages using one-way Analysis of Variance (ANOVA), post-hoc mean separation was conducted using Tukey's Honest Significant Difference (HSD) at a significant threshold of $p < 0.005$. Relationship between soil properties was assessed using Pearson correlation coefficients analysis. While the influence of management history on the degradation score was assessed using Classification and Regression Tree (CART) regression model analysis. All statistical analyses were carried out using JMP Version 17.0 statistical software.

3. RESULTS

3. 1. Soil Condition Across the Sampling Wards

3. 1. 1. Soil Physical and Chemical Properties

Soils in the study area were predominantly sandy (>75%), with low clay fractions, indicating limited nutrient retention, low water holding capacity and high susceptibility to leaching (Table 3). Soil pH ranged from moderately acidic in Domawa (6.1) to slightly alkaline in Kura (7.5), while EC values were generally low (<0.3 dS/m) but significantly (p <0..001) higher in Kura, this indicate prolonged irrigation and fertilizer build up which is at per to the findings of Shahid et al., (2018) and Ye et al., (2024)

Table 3. Soil Texture, pH, EC and ESP average conditions across the sampling location wards.

Ward	Sand (%)	Silt (%)	Clay (%)	pH (H_2O)	pH ($CaCl_2$)	EC (dS/m)	ESP (%)
BIGAU	75.78	19.56^a	4.66	6.8	6.0	0.18^{ab}	9.72
DOMAWA	81.78	15.06^b	3.16	6.1	5.3	0.12^b	5.95
GURAZA	80.28	15.56^b	4.16	6.7	5.6	0.16^b	4.18
KOSAWA	82.78	14.06^b	3.16	6.6	5.7	0.21^{ab}	6.37
KURA	81.78	14.56^b	3.66	7.5	6.0	0.28^a	7.26
p-value	0.1055	0.049	0.756	0.125	0.279	0.006	0.179
SE±	1.83	1.25	0.95	0.34	0.25	0.03	1.59

3. 1. 2. Micronutrients

Micronutrient status varied widely (Table 4). Manganese was significantly higher in Kura (50.42 mg/kg, while Cu was critically low across all wards (<1 mg kg^{-1}), though relatively higher in Kura (0.81 mg kg^{-1}). Zn was marginal but more adequate in Kura and Kosawa (>6 mg kg^{-1}). In contrast, Fe levels were extremely high (>300 mg kg^{-1}) in all wards, raising concerns of possible toxicity and nutrient imbalance; which may affect pollen formation, grain yield, plant resilience, seedling vigor and tillering. (Shahid et al., 2018; Blanco-Canqui & Rattan, 2022).

Table 4. Soil Micronutrients average condition across the sampling location wards.

Ward	Mn	Cu	Zn	Fe
	(mg kg^{-1})			
BIGAU	22.65	0.51	2.34	366.01
DOMAWA	14.95	0.56	2.87	334.47
GURAZA	20.53	0.53	3.69	415.81
KOSAWA	19.89	0.45	6.23	331.17
KURA	50.42	0.81	6.78	383.99
p-value	0.005	0.012	0.081	0.923
SE±	5.79	0.06	1.25	75.47

3. 1. 3. Degradation score

Highly significant difference degradation score across all wards were observed (Table 5), where bigau and domawa were having the highest degradation score (41.07 and 41.96) which was due to high OC, Ca, Cu, and ESP were observed, and Kura having the lowest degradation score (35.30). this stress the need for ward specific management response rather than a blanket management practice. As recommended by (Khallah et al., 2025 and Wahab et al., 2024)

Table 5. Average Soil Degradation Scores across the sampling location wards.

Indicator	BIGAU	DOMAWA	GURAZA	KOSAWA	KURA	SE±	P-value
pH (H_2O)	2	2	1	2	2	-	-
EC (dS/m)	1	1	1	1	1	-	-
Organic C (%)	4	4	4	4	3	-	-
P (mg/kg)	1	1	2	1	1	-	-
N (%)	2	1	1	1	1	-	-
Ca (cmol/kg)	3	4	3	3	2	-	-

Mg (cmol/kg)	1	1	1	1	1	-	-
K (cmol/kg)	1	1	1	1	1	-	-
Mn (mg/kg)	1	1	1	1	1	-	-
Cu (mg/kg)	3	3	3	3	3	-	-
Zn (mg/kg)	1	1	1	1	1	-	-
Fe (mg/kg)	1	1	1	1	1	-	-
Base Saturt. (%)	1	1	1	1	1	-	-
ESP (%)	2	2	1	1	1	-	-
Degradation Score (%)	41.07	41.96	37.50	38.39	35.30	1.14	0.006

3. 2. Correlation Coefficient between Soil Properties and Degradation Score

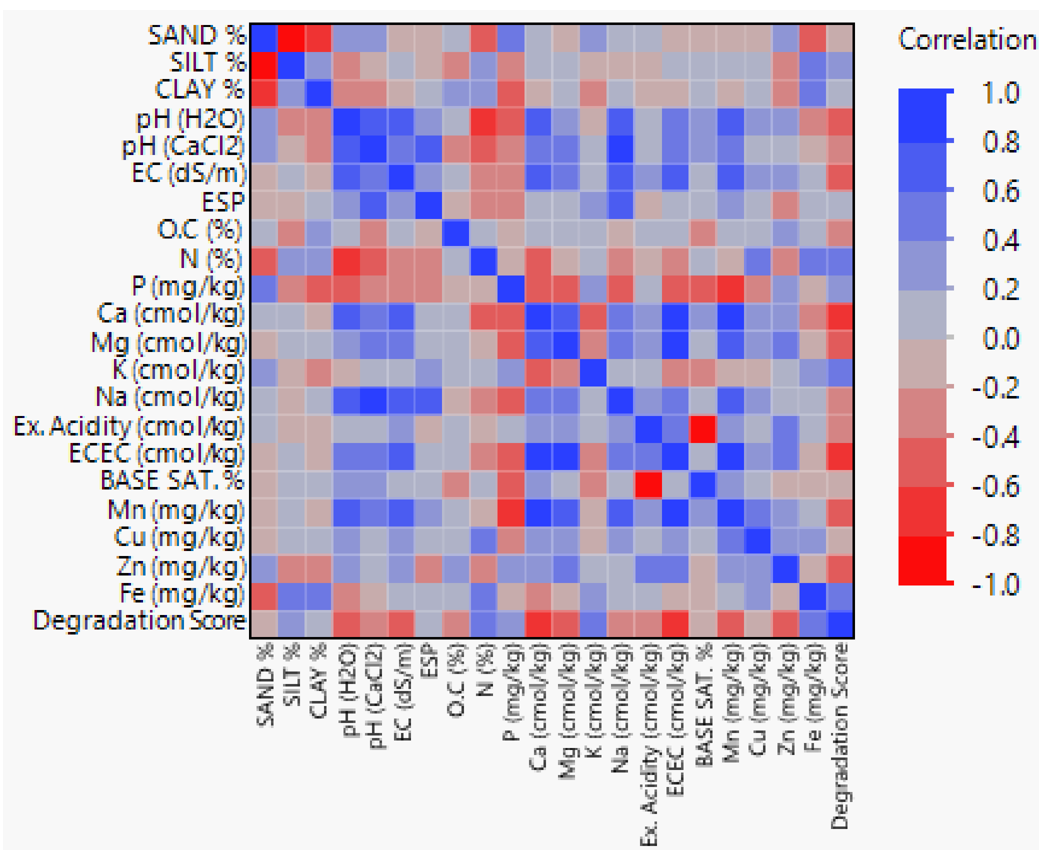

Figure 2. Correlation Coefficient between Soil Properties and Degradation Score. The colors range from blue (positive correlations) +1 to red (negative correlations) -1, with varying intensities indicating the strength of the correlation.

The correlation heatmap (Figure 2) corroborates the statistical relationships presented in Table 5. Both analyses consistently indicate that sand content, soil acidity (pH), electrical conductivity (EC), and exchangeable sodium are positively correlated with the soil degradation index. In contrast, organic carbon, clay, silt, exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}), and base saturation exhibit negative correlations with degradation severity.

The strong concordance between the regression outputs and the correlation matrix underscores the robustness and reliability of these findings. Collectively, the results suggest that soil degradation in the study area is primarily driven by nutrient depletion, salinity buildup, and poor soil structural stability. These observations align with the findings of Ye et al. (2024), who reported that sandy paddy soils limit nutrient retention and rice nutrient uptake, highlighting that nutrient depletion poses a greater threat to soil productivity than salinity or sodicity alone.

3. 3. Impact of Management History on Soil Degradation Score

Impact of Phosphorus (P_2O_5) Application

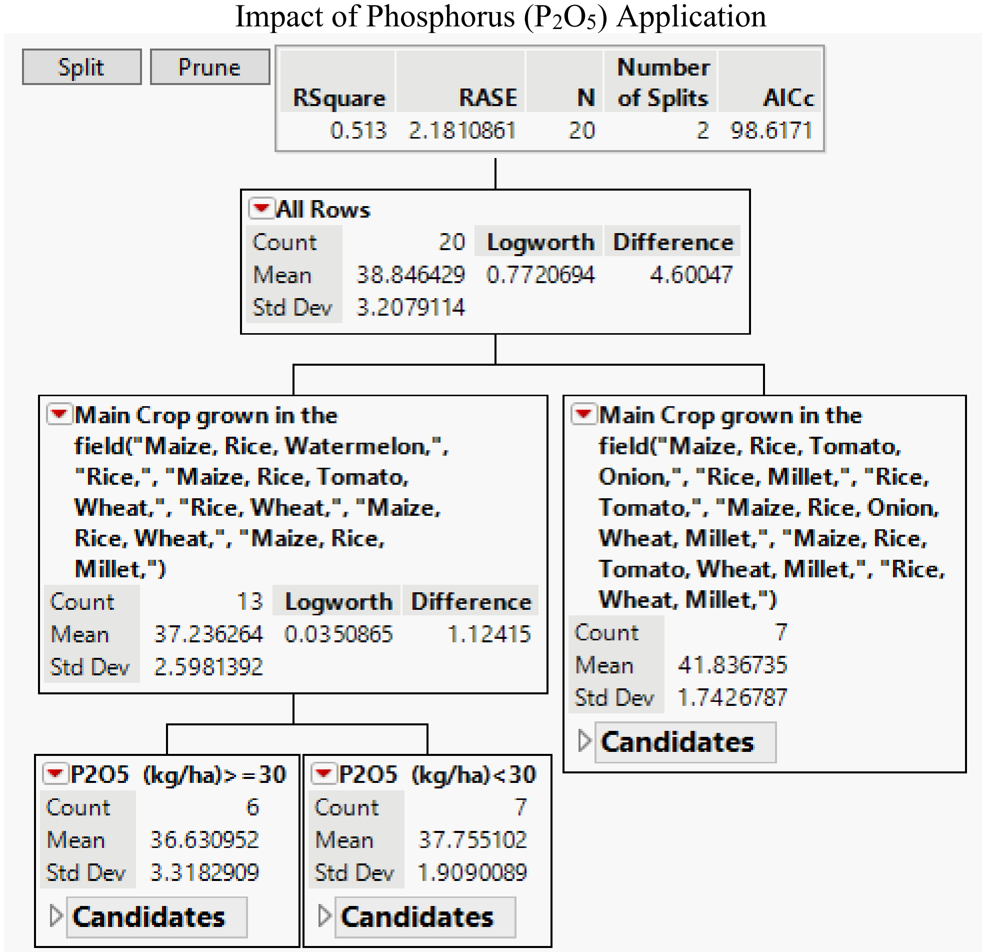

Figure 3. Presents a Classification and Regression Tree (CART) model, which illustrates the impact of field management history on soil degradation scores. The model partitions data into different groups based on key variables, with each split representing a significant factor influencing soil degradation.

Among the management history factors examined, only the type of crop grown and phosphorus (P) fertilizer application showed a statistically significant effect on the soil degradation score. Fields cultivated with a diverse crop combination of maize, rice, watermelon, wheat, and millet recorded a lower mean degradation score (37.23), indicating relatively better soil condition. In contrast, fields dominated by rice, tomato, onion, and millet exhibited a higher mean degradation score (41.83), suggesting that these cropping patterns may accelerate soil nutrient depletion and degradation intensity (Figure 3).

3. 4. Soil Fertility Indicators

Among the soil indicators, Organic Carbon, Available Phosphorus, and Exchangeable Calcium showed significant ward-level differences. Wards with lower OC and Ca corresponded with higher degradation scores, implying poorer soil structure, reduced nutrient cycling, and weaker root environments, all of which constrain rice performance. Likewise, wards with lower available P face stronger yield limitations since P deficiency is a well-documented bottleneck in tropical paddy systems.

These results echo recent findings from northern Nigerian rice soils, where low OC and P availability were identified as the principal constraints to yield sustainability (Mesele et al., 2024; Oni et al., 2024). Together, this confirms that rice productivity in Kura cannot be sustained under uniform input regimes, but instead requires ward-specific strategies to address variable OC, P, and Ca status.

While these findings provide valuable war-level insight into degradation patterns, certain limitation should be acknowledged.

Table 6. Soil Organic Carbon, Macronutrients, Cation Exchange Capacity (CEC) and Base Saturation average condition across the sampling location wards.

Ward	Organic C (%)	N (%)	P (mg/kg)	Ca (cmol/kg)	Mg (cmol/kg)	K (cmol/kg)	Na (cmol/kg)	Ex. Acidity (cmol/kg)	ECEC (cmol/kg)	Base Saturation (%)
BIGAU	0.59	0.19	9.53	2.30	2.25	0.27	0.56	0.24	5.62	95.77
DOMAWA	0.81	0.23	29.12	1.35	2.09	0.33	0.30	0.52	4.59	87.84
GURAZA	1.02	0.19	16.75	3.60	3.24	0.30	0.31	0.69	8.14	90.54
KOSAWA	0.75	0.18	19.56	2.24	2.40	0.57	0.41	0.85	6.47[ab]	86.63
KURA	1.08	0.18	10.29	5.13[a]	3.30	0.26	0.75	0.67	10.11	93.89
SE±	0.15	0.03	4.43	0.71	0.39	0.09	0.14	0.14	1.08	2.69
p-value	0.197	0.682	0.042	0.017	0.129	0.108	0.151	0.074	0.019	0.134

4. LIMITATIONS OF THE STUDY

This study covered a single cropping season, and was based on 20 samples. In addition, the study only focusses on chemical, physical indicators, and management practice, excluding biological parameters which also influence soil health. Future work should integrate this aspect for a more comprehensive understanding of the degradation dynamics.

5. CONCLUSIONS

This study provides the first ward-level assessment of soil degradation in Kura LGA, integrating statistical modelling (ANOVA, Correlation, CART) with soil-rice productivity analyses. Unlike prior KRIP survey that generalized soil conditions, we reveal marked spatial variability in fertility and degradation, identifying critical nutrient thresholds (OC <1.5%, P < 30KG/ha) that limit productivity. These findings offer actionable, wads-specific strategies to sustain rice yields under intensive cultivation. The study demonstrates that soil degradation varies heterogeneously across wards, with Bigau (41.07%) and Domawa (41.96%) most severely affected, while Kura (35.30%) shows comparatively lower deterioration. CART analysis highlights crop type and phosphorus fertilizer application as key management factors influencing soil degradation.

In order to mitigate degradation, ward specific management practice is recommended i.e., the use of organic amendments and copper supplements are suggested to balance high Fe levels and prevent toxicity. Conservation tillage should be sustained in less degraded areas (e.g., Kura and Kosawa), complemented by regular soil testing for adaptive management. Farmers are further encouraged to align crop selection with nutrient requirements and apply appropriate fertilizers, particularly phosphorus, to sustain soil fertility and reduce degradation.

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