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Assessment of Soil Degradation under Different Land Use Practices in Owerri, Imo State, Southeastern Nigeria: Implications for Sustainable Agricultural Development

Nnabuihe, E. C[1], Okafor, M. J[2], Nwosu, T. V[3], Onunwa, A. O[4], Chukwu, E. D[5], Ugochukwu, G. U[6], Madueke, C. O[7], Apalowo, O. A[8], Ibigweh, M. N[9], Nwaiwu, C. J[10] &Anarah, S. E[11]

[1,2,3,4,10,11] Department of Soil Science and Land Resources Management, Nnamdi Azikiwe University Awka Anambra state Nigeria.
[5] Department of Soil Science and Technology, Federal University of Technology Owerri, Imo state Nigeria.
[6]Department of Bioenvironmental Science, Morgan State University Baltimore MD, U.S.A
[7]Institute of Soil Science and Land Evaluation, University of Hohenheim, Stuttgart, Germany
[8]Department of Crop Science and Horticulture, Nnamdi Azikiwe University Awka Anambra state Nigeria.
[9]Department of Agricultural Economics and Extension, Nnamdi Azikiwe University Awka Anambra state Nigeria.

***Corresponding Author**: Nnabuihe, E. C
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Abstract

Soil degradation is a critical constraint to sustainable agricultural development, particularly in rapidly urbanizing regions of sub-Saharan Africa. This study assessed the extent of soil degradation under four land use types: oil palm plantation (OP), secondary forest (SF), industrial layout (IL), and residential layout (RL), in Owerri, Imo State, Southeastern Nigeria. Eight profile pits were dug, and 37 soil samples were collected through genetic horizons and analyzed for physical and chemical properties; and degradation indices, including dispersion ratio (DR), clay dispersion ratio (CDR), clay flocculation index (CFI), clay dispersion index (CDI), structural stability index (S), exchangeable sodium percentage (ESP), sodium adsorption ratio (SAR), and soil degradation rating (SDR). Results showed that IL soils exhibited the highest DR (0.68–0.71), lowest S (0.22–0.29), highest BD (1.64–1.70 Mg m^{-3}), and lowest SOC (0.34–0.39 g/kg), classifying IL I as severely degraded (mean RWF = 4). SF soils consistently outperformed other land uses in structural stability (S = 0.69–0.72), SOC content (1.00–1.01 g/kg), and TN (47–48%). RL soils were moderately degraded but showed worrying compaction trends (BD up to 1.73 Mg m^{-3}). All ESP (2.11–4.33%) and SAR (0.11–0.49) values were below sodicity thresholds, although variability was high for some indicators (CV > 30%). Integration of statistical and graphical outputs revealed that IL and RL land uses are the primary drivers of degradation in the area. Management interventions should prioritize organic matter enhancement, erosion control, and land use planning to prevent further decline in soil quality and maintain agricultural productivity. This study provides baseline data to guide sustainable soil management policies in Southeastern Nigeria and similar agro-ecological zones.

Keywords: *Soil degradation, land use change, soil physicochemical properties, Coastal Plain Sands, Owerri Southeastern Nigeria; sustainable land management.*

Introduction

Soil degradation is one of the most pressing global environmental challenges, with severe implications for food security, ecosystem services, and climate resilience. Globally, an estimated 33% of soils are degraded to some degree, and the situation is projected to intensify as the human population approaches 10 billion by 2050 (Meena *et al.*, 2023). In sub-Saharan Africa, soil degradation undermines agricultural productivity, exacerbates poverty, and reduces the adaptive capacity of rural communities to climate change (Tefera *et al*., 2024).

Nigeria, expected to become the third most populous country by mid-century, is already experiencing the compounded effects of land degradation and food insecurity (Pontianus & Oruonye, 2021; Yeboua & Le Roux, 2022). The problem is especially acute in regions undergoing rapid land use transformation, where fragile soils are subjected to deforestation, urban expansion, overgrazing, and intensive cultivation (Leul *et al*., 2023). These pressures accelerate the loss of organic matter, structural stability, and nutrient reserves, ultimately impairing the soil's capacity to sustain crop yields and deliver ecosystem services (Ekka *et al*., 2023).

Different land use systems exert variable impacts on soil quality. Agricultural, industrial, residential, and forested lands differ in their effects on bulk density, porosity, pH, nutrient status, and aggregate stability (Meena *et al*., 2023). In southeastern Nigeria, soils derived from Coastal Plain Sands are particularly vulnerable due to their inherently low fertility and high susceptibility to erosion. Under conditions of high rainfall and unplanned land conversion, these soils degrade rapidly, making them critical hotspots for monitoring land use effects (Nnabuihe *et al*., 2025).

Despite this vulnerability, there remains limited site-specific, quantitative information on how contrasting land uses influence degradation processes in this ecological zone. Most existing studies emphasize agricultural soils, with far fewer focusing on the effects of industrial and urban development on fragile soils. There is also a lack of integration between soil degradation indices and their implications for ecosystem services, agricultural productivity, and land use policy. Furthermore, very few studies have established thresholds at which soil physicochemical changes translate into yield decline or ecological dysfunction (Madkour, 2023).

Owerri, the capital of Imo State, exemplifies a rapidly urbanizing landscape where agricultural production competes with residential and industrial expansion. Understanding how different land uses affect soil physical and chemical properties in this setting is crucial not only for soil study but also for land use planning and sustainable development (Baquy *et al*., 2017). This study therefore assessed the extent and variability of soil degradation under four dominant land use types: oil palm plantation, secondary forest, industrial layout, and residential layout in Owerri, Southeastern Nigeria. Specifically, it quantifies key soil physicochemical properties and degradation indices, evaluates their spatial variability, and integrates these results into an overall Soil Degradation Rating (SDR). The findings provide baseline data to guide sustainable soil management, inform land use policies, and highlight critical knowledge gaps for future research in similar agro ecological contexts.

Materials and Methods

Physical Environment of the Study Area

The study was conducted in selected towns within Owerri, Imo State, Nigeria, namely: Obinze, Avu, Irete and Amakohia, located between latitude 5°28′35″ N and 5°49′5″ N, and longitude 7°1′33″ E and 7°10′5″ E of the Greenwich meridian (Fig. 1). It is 100 m (328 ft) above sea level and covers a land area of 2,973 km² (Fig. 2). The soils are derived from Coastal Plain Sands parent material, characterized by light texture and susceptible to erosion and degradation due to poor land use practices (Nnabuihe *et al*., 2025). The climate is typically humid tropics in a rainforest vegetation zone of southeastern Nigeria, with distinct wet and dry seasons, characterized by high rainfall (annual rainfall ranges between 2,500 mm and 3,000 mm) peaking during the wet season (April to November). Mean annual temperature ranges from 28°C to 31°C, with minimal seasonal variation (NIMET, 2024).

Description of Land Use Types

The summary of the description of the land use types is presented in Table 1. Four land use types were determined and selected for the study. These sites are undergoing rapid urbanization but still play a vital role in the agricultural productivity of the area (Fig. 1). They were georeferenced using Garmin etrex 20 GPS (global positioning system) to determine both coordinates and elevations. They include oil palm plantation (OP) at Obinze, secondary forest (SF) at Avu, industrial layout (IL) at Irete, and residential layout (RL) at Amakohia. Oil Palm Plantation (OP) at Obinze is located along the Obinze-Avu-Umuagwo expressway. It is situated between latitude 05° 26′ 04″ N and longitude 06° 58′ 39″ E, with an altitude of 59 m above sea level. The plantation is more than 15 years old, with species of *dura* and *tenera*. The slope is level to gentle (0 – 2 %), with a convex soil surface form, sheet erosion, close drainage spacing, depth of water below the length of description, and evidence of mechanical modifications. Secondary forest (SF) at Avu is a neighbouring town to Obinze, situated at latitude 05° 25′ 34″ N and longitude 06° 58′ 45″ E, with an altitude of 57 m above sea level. The forest is more than 25 years old, with a thick layer of partially decomposed litter; level to very gentle slope (0 – 2%), straight soil surface form; evidence of sheet erosion, close drainage spacing, and depth of water below the length of description.

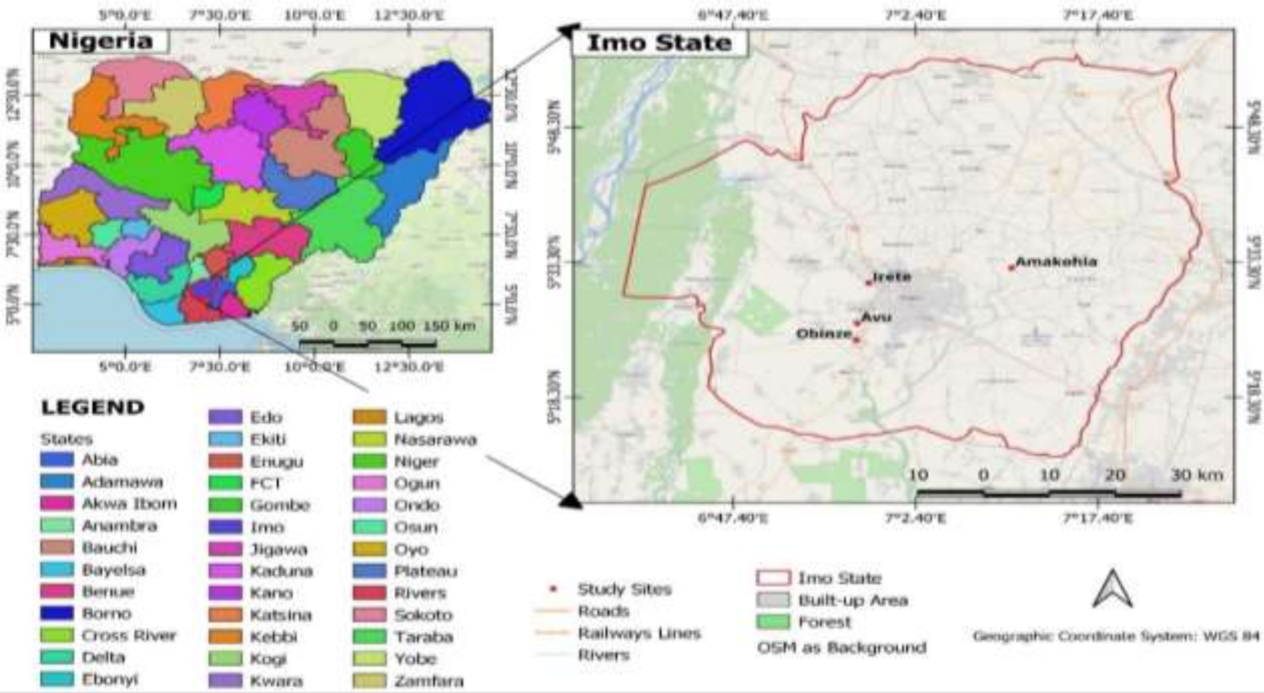


Fig. 1: Map of Imo State Showing the Study Sites

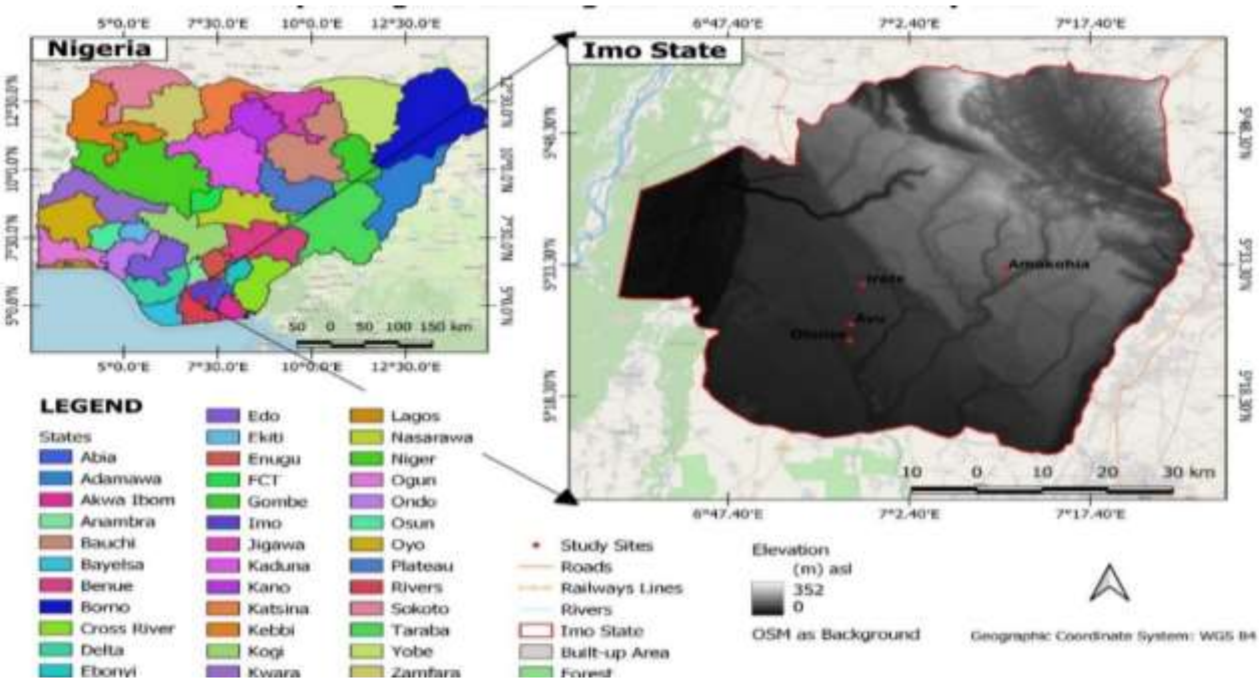


Fig. 2: Map of Imo State Showing the Spatial Variation in Altitude

The site has been significantly modified by human activities such as agriculture, urbanization, and deforestation. Industrial layout (IL) at Irete is located along the Owerri-Onitsha expressway, involving clusters of industries, mostly manufacturers of various drinks, household items, and building materials, include both not limited to Coca Cola and Vinal Aluminum companies. It is situated at latitude 05° 30′ 18″ N and longitude 06° 59′ 48″ E on an elevation of 78 m above sea level. The industrial hub has been in operation for more than 30 years; with a slope of 3 – 5%, straight soil surface form, sheet erosion, moderate drainage spacing, and depth of water below the length of description; evidence of land modification, and sewage pipeline layering. Residential layout (RL) at Amakohia is situated along the Orlu road expressway; consisting of a developed residential area; level to gentle slope, mostly straight form, with sheet erosion; moderate drainage spacing, and depth of water below the length of description. It is situated at latitude 05° 30′ 37″ N and longitude 07° 20′ 53″ E on an elevation of 145 m above sea level. The RL has been established for more than 40 years, with evidence of ongoing building construction, recent leveling and demolishing of old structures, and influx of people in the area.

Table 1: Summary of Land Use Characteristics

Land Use Type	Location	GPS Coordinates	Altitude (m)	Age (yrs)	Slope (%)	Surface Form	Human Activity
OP	Obinze	05°26′04″N, 06°58′39″E	59	15+	0–2	Convex	Plantation farming
SF	Avu	05°25′34″N, 06°58′45″E	57	25+	0–2	Straight	Logging, farming
IL	Irete	05°30′18″N, 06°59′48″E	78	30+	3–5	Straight	Industrial layout
RL	Amakohia	05°30′37″N, 07°20′53″E	145	40+	0–2	Straight	Residential buildings

Key: OP = Oil palm plantation, SF = Secondary Forest, IL = Industrial layout, RL = Residential layout

Soil Sampling

A targeted soil sampling technique was adopted, focusing on areas showing clear signs of soil degradation. Two profile pits were dug in each of the four study sites (oil palm plantation – OP, secondary forest – SF, industrial layout – IL, and residential layout – RL), giving a total of eight pits. Profile pits were described according to FAO (2006) guidelines. Thirty-seven soil samples were collected from genetic horizons, air-dried, sieved (2 mm), and analyzed for physical and chemical properties.

.

Table 2: Rating scheme for soil degradation rating (SDR)

Limitation	RWF	Texture	BD (Mg m^{-3})	pH	TP (%)	SOC (g/kg)	T. N (%)	Avail. Pa (mg kg^{-1})	CEC (cmol/kg)	Ca: Mg	Al. Sat (%)	B. Sat (%)	ESP (%)
None	1	Loam	< 1.3	7 – 8	> 50	5- 10	> 0.15	> 19	> 15	> 6:1	< 5	> 60	< 5
Slight	2	Silt `Loam, Silt Clay	1.3-1.4	6-7 or 8-9	45 – 50	3 – 5	0.10-0.15	15-19	10=15	4:1 - 6:1	5-10	50-60	5 -10
Moderate	3	Clay Loam, Sandy Loam	1.4-1.5	5.5-5.9 or 9-9.5	40 – 45	1.0 – 3	0.05-0.10	10 -15	5-10	2:1 - 4:1	10-15	40-50	10-15
Severe	4	Silt Clay, Loamy Sand	1.5-1.6	5.0-5.4 or >9.5	35 – 40	0.5-1.0	0.02-0.05	5-10	3-5	1:1 - 2:1	15-25	20-40	15-25
Extreme	5	Clay, Sand	> 1.6	< 5 and > 9.5	< 35	< 0.5	<0.02	< 5	< 3	< 1.1	> 25	< 20	>25

RWF: Relative weight factor; BD: Bulk density, TP = total porosity, SOC: Soil Organic Carbon; TN: Total Nitrogen; Avail. P: Available Phosphorus, CEC: Cation Exchange Capacity, Ca: Mg: Calcium Magnesium ratio, Al. Sat: Aluminum Saturation, B. Sat: Base Saturation, ESP: Exchangeable Sodium Percent (Source: Lal,1994)

Laboratory Analyses

Standard procedures were followed: particle size distribution by the hydrometer method (Gee & Or, 2002), bulk density by the core method (Grossman & Reinsch, 2002), moisture content by oven drying (Obi, 1990), pH in a 1:2.5 soil-to-water suspension (Thomas, 1996), total nitrogen by the micro-Kjeldahl method (Bremner, 1996), organic carbon by wet oxidation (Nelson & Sommers, 1982), available phosphorus by Bray I (Bray & Kurtz, 1945), exchangeable acidity (Mclean, 1982), exchangeable bases by NH_4OAc extraction (Jackson, 1962), and CEC by aluminum acetate leaching (Blackmore *et al.*, 1987). Organic matter was organic carbon (OC) multiplied by 1.724 (Van Bermelen factor). The following soil degradation indices were calculated using standard procedures:

Exchangeable sodium percentage $(ESP) = \frac{\text{Exchangeable Na+}}{\text{CEC}}\ x\ 100$ ………. (1) (Richards 1954)

Sodium adsorption ratio $(SAR) = \text{Na} + / \frac{\sqrt{(Ca+Mg)}}{2}$ …………………. (2) (Richards, 1954)

The clay-dispersion indices were calculated as follows;

Dispersion ratio $DR = \frac{\text{(WDSi +WDC)}}{(Silt+Clay)}$ …………... (3) (Middleton 1930)

Clay dispersion ratio $(CDR) = \frac{\text{WDC}}{\text{Clay}}$ …………… (4)

Clay flocculation index $CFI = \frac{\text{(TC−WDC)}}{\text{TC}}$ ………… (5)

Clay dispersion Index $CDI = \frac{\text{WDC}}{\text{TC}}$ ……………… (6)

Soil structural stability index $(S) = \frac{\text{Organic matter content (\%)}}{\text{Clay (\%)+ Silt (\%)}} \times 100$ … (7) (Pieri, 1989)

For equation 7, if S < 5 indicates severe degradation, 5 –7 indicates high hazard, 7–9 indicates low hazard, and S > 9 indicates no degradation. Other indices of soil degradation include the scheme for soil degradation rating (SDR) (Lal, 1994) (Table 2).

Data Analysis

Descriptive statistics (mean, SD, range) were computed. Coefficient of variation (CV) was calculated following Wilding (1994) (<15% = low, 16–30% = moderate, >30% = high variability). Figures (bar charts, box plots, scatter plots, radar chart and heatmaps) were produced to illustrate relationships between properties and degradation indices.

Results and Discussion

Soil Degradation Indices Across Land Uses

Soil degradation indices exhibited marked variation across the different land use types and profile horizons (Table 4; Fig. 3a – h, Fig. 4a – h, and Fig. 5a - h). The DR showed a range of 0.46 to 0.85 across all land uses and depths. The lowest value was observed in RL I (DR = 0.46), while the highest was in SF I (DR = 0.85). Mean values across land uses ranged from 0.58 (RL II) to 0.77 (OP I), with most sites showing values above 0.65, indicative of moderate to high dispersion potential (Hamad & Surucu, 2024). The coefficient of variation (CV) ranged from 3.11% (OP I) to 23.81% (RL I), reflecting relatively low variability within natural systems (e.g., OP I) and high variability in disturbed sites (e.g., RL I). The DR provide insight into the ease with which soil particles disperse in water, and indicates the degree of clay dispersion and hence the potential for erosion, across soil horizons. DR values > 0.3 indicate vulnerability to slaking and soil detachment. Higher DR values indicate greater susceptibility to structural breakdown and erosion (Panda, 2022). DR generally declined with depth but remained relatively stable in oil palm and industrial sites, resulting in vertical structural consistency (Zhang *et al*., 2024). Residential areas had the highest DR variability (CV = 23.81%), resulting in greater spatial inconsistency in degradation levels due to anthropogenic disturbances (Fig. 4a). Conversely, OP I and OP II showed more uniform DR (CV = 3.11% and 6.51%, respectively), indicating relative structural stability under consistent management practices like mulching and litter deposition. The CDR values ranged from 0.38 (RL II) to 0.83 (IL I), showing a generally moderate to high dispersion tendency across profiles. Mean CDR values ranged from

0.48 (RL I) to 0.71 (IL II). CV values for CDR ranged between 3.91% (IL II) and 22.60% (RL I), resulting in better internal consistency in industrial and oil palm sites. CDR was consistently high in Bt horizons, particularly in industrial areas, resulting in greater susceptibility to subsoil structural breakdown (Rengasamy *et al*., 2016; 2002). The CFI values ranged from 0.55 (IL I) to 0.73 (RL II), with most values between 0.58 and 0.67. Mean CFI values were quite uniform, ranging from 0.59 (IL I & IL II) to 0.68 (RL I). CVs were consistently low (2–7%), indicating limited variability in flocculation capacity across depths and land uses. This reflects the degree to which clays are aggregated or flocculated, with higher values indicating better structure. Bt horizons generally exhibited slightly reduced CFI, reflecting lower structural integrity deeper in the profile (Udom *et al*., 2024). Clay flocculation index (CFI), which inversely relates to dispersion, was notably higher in RL II and RL I (0.67 and 0.68, respectively), but the residential lands also showed higher variability (CV = 7%). The high CFI in these zones suggests increased input of materials that may temporarily enhance flocculation (e.g., concrete debris, waste ash) **(**Abbaslou *et al*., 2020**)**. The CDI ranged from 0.27 (RL II) to 0.45 (IL I) (Table 4; Fig. 4d). Mean CDI values varied from 0.32 (RL I) to 0.41 (IL I & IL II), resulting in more clay dispersion in industrial layouts. CVs for CDI ranged from 1% (SF I) to 14% (RL I), and is inversely related to soil aggregation, as higher values indicate more dispersion and degradation. Bt horizons generally displayed high CDI, highlighting potential problems with subsoil permeability and structure (Belarbi *et al*., 2013). This is visualized in Figure 3, where IL consistently shows higher bars across depths. SF generally performed better than industrial layout (IL) and residential layout (RL) soils, reflecting reduced anthropogenic disturbance. The highest CFI in RL I (0.68) and lowest in IL I (0.59), suggests that industrial activities may have reduced aggregation. Figure 4 (box plots) further confirms these trends, showing narrower interquartile ranges for OP and SF soils, indicating lower variability, and wider spreads for IL soils, reflecting greater heterogeneity likely caused by land disturbance. IL I, IL II, and OP II recorded the highest CDI values, which implies increased risk of structural breakdown, likely from compaction and exposure of subsoils due to construction activities (Hamad and Surucu, 2024). Residential layouts had slightly lower CDI (mean = 0.32–0.33), possibly reflecting higher organic inputs from waste but also suffered high spatial variability (CV = 10–14%). The S Values ranged from 0.16 (IL II) to 1.15 (SF II). Mean S values ranged between 0.22 (IL II) and 0.72 (SF I), resulting in best stability in secondary forests and poorest in industrial layouts. CVs ranged from 21% to 39%, with highest variation in residential and forested areas, resulting in surface processes and organic matter largely influence stability. The S index quantifies the stability of soil aggregates. Values above 0.6 are indicative of structurally stable soils. Notably, surface Ap horizons generally had the highest S values, confirming the influence of organic inputs on aggregation. All land uses had S < 5 (Table 4), indicating severe structural degradation (Pieri, 1989)**.** The lowest S values were in IL II (0.22), while SF I (0.72) had a higher value. Figure 5 shows a negative relationship between DR and S, especially in IL soils. The structural stability index (S) ranged from 0.22 in IL II to 0.72 in SF I. According to Pieri's (1989) classification, values below 5 indicate severe physical degradation. All land uses recorded mean S values well below 5, pointing to a general decline in physical condition across the study area. Figure 5 (scatter plots) reveals a negative relationship between S and DR, particularly pronounced in IL soils, indicating that soils with lower stability were more prone to dispersion. Secondary forests recorded the highest S values (mean = 0.72 and 0.69), consistent with natural vegetative cover that promotes organic matter accumulation and microaggregate formation (Bronick and Lal, 2005). In contrast, IL II and RL II had the lowest values (0.22 and 0.27), reflecting poor aggregation and high degradation. ESP values ranged widely from 0.86% (OP II) to 8.47% (SF II). Mean ESP values ranged from 2.11% (OP II) to 4.33% (SF II). No profile exceeded the critical sodicity threshold, though SF II and RL I showed high values, indicating incipient sodic degradation (Singer *et al.,* 1982). CVs ranged from 0.42% (OP II) to 48.46% (SF II), with highest variability in forested profiles due to depth and natural heterogeneity. It measures the sodium proportion on the cation exchange complex and is a key indicator of sodicity. An ESP >15% typically signifies sodic soils. ESP tends to increase with depth in forest and residential sites, likely due to leaching and subsoil sodium accumulation. Exchangeable sodium percentage (ESP) ranged from 0.86% in OP II to as high as 8.47% in SF II (Bt1 horizon), a notably unexpected observation (Fig. 4f). This distinction in the forest could suggest lithological influence or subsurface sodicity accumulation, possibly due to perched water tables or atmospheric deposition, as reported in similar studies from humid zones (Esu, 2010). The highest mean ESP was found in SF II (4.33%), followed by RL I and IL II, resulting in higher sodium saturation and risk of dispersion in these areas. These patterns align with the observed low structural stability indices (S) in IL II and RL I. SAR values ranged from 0.05 (OP II) to 0.49 (SF II). Mean SAR values varied from 0.11 (OP II) to 0.24 (SF II). Although all values were well below the critical threshold of 13 for sodicity **(**Choudhary & Kharche, 2018**)**, some profiles, notably in SF II and RL I, displayed relatively higher SAR in deeper Bt horizons. CVs ranged from 9.30% (RL II) to 52.15% (SF II), reflecting high subsoil variability and potential accumulation of Na+ ions. This reflects the relative concentration of Na+ to Ca^{2+} and Mg^{2+} and is a predictor of sodicity effects on soil physical properties. These values fall below the conventional sodicity threshold (ESP ≥ 15; SAR ≥ 13) (Richards, 1954), noting that sodium-related dispersion is currently minimal. However, sustained land disturbance could elevate these levels over time. Overall, SAR values are low enough to rule out serious sodicity risks, but rising values in deeper horizons warrant continued monitoring, especially under forest and residential land uses. SAR followed a similar trend, with the highest mean value in SF II (0.24) and lowest in OP II (0.11) and IL I (0.15) (Fig. 4g). SAR values above 0.2 in several sub horizons (e.g., Bt4 in SF II, Bt1 in RL I) point to sodicity effects capable of disrupting soil hydraulic conductivity and physical condition (Dikinya *et al*., 2007).

Physicochemical Properties and Their Implications

Table 5 highlights the mean values of soil physicochemical properties across land uses. All soils were classified as sandy clay loam (SCL), indicating moderate to good structural condition, with potential to improve drainage and moisture. The uniform texture provides a consistent basis for comparing degradation indices across land uses without the confounding effect of textural variability. Bulk Density ranged from 1.39 Mg/m³ (SF I) to 1.73 Mg/m³ (RL II). Lower BD in forest areas (SF I & SF II: ~1.39–1.40) implies less compaction and better soil structure, likely due to organic matter input and minimal disturbance. In contrast, higher BD in RL IL areas (up to 1.73 Mg/m³) reflects compaction from anthropogenic activities (Reichert *et al*., 2009). Total Porosity (TP) showed an inverse relationship with BD, ranging from 35.16% (RL II) to 47.70% (SF I). TP values above 45% (in OP I, OP II, SF I, SF II) implies adequate aeration and water infiltration, while values below 40% (IL and RL sites) are indicative of restricted pore space, likely impeding root growth and water movement (Reynolds *et al*., 2009). High BD and low TP values in IL and RL sites indicate compaction, which restricts root growth and water infiltration (Logsdon & Karlen, 2004). Soil pH values across land uses ranged from 4.50 (OP I) to 5.34 (RL II). The lowest pH in OP and SF areas reflects natural acidity or leaching, while slightly higher pH in RL and IL zones may result from construction debris, liming, or anthropogenic alteration. This acidity, along with low base saturation (B. Sat) and high aluminum saturation (Al. Sat) in industrial and oil palm lands, suggests soil fertility constraints (Johnston, 2004). Soil Organic Carbon (SOC) ranged from 0.34 g/kg (IL II) to 1.01 g/kg (SF I). Forest areas (SF I and SF II) had the highest SOC (which could be due to litter input and less mineralization) while IL sites had the lowest (Poeplau *et al*., 2023). The low SOC in IL and RL soils aligns with their high degradation ratings (Table 6) and reduced stability (Figure 6a). Total nitrogen (TN) followed a similar trend, with the highest value of 0.13% in SF II and lowest (0.03–0.04%) in RL and IL areas. These results underscore the importance of vegetation cover and organic inputs in maintaining soil fertility (Salo & Turtola, 2006). Available P ranged from 0.27 mg/kg (IL I) to 0.60 mg/kg (SF I). Although relatively low across the board, SF and OP plantations had higher values, possibly due to mineralization of organic matter and moderate use of phosphorus fertilizers Industrial and residential areas were notably deficient, indicating poor nutrient cycling and possible P fixation under acidic conditions (Kleinman *et al*., 2000; Jalali *et al*., 2025). Cation exchange capacity (CEC) values ranged from 4.57 cmol/kg (RL II) to 5.92 cmol/kg (OP I). Though not highly variable, slightly higher CEC in OP and SF could mean better nutrient-holding capacity, linked to higher organic matter and clay content. Lower CEC in RL and IL soils may result from OM loss and structural breakdown, reducing the soil's ability to retain nutrients (Baquy *et al*., 2018). Notably, CEC values were below 6 cmol/kg across most land uses, reflecting low nutrient retention potential, except in OP I (5.92 cmol/kg). Calcium to magnesium ratios (Ca: Mg) ranged from 1.47 (OP I) to 3.10 (RL II). Values around 2.0–3.0 are typical of well-balanced soils; however, very high ratios (e.g., 3.10 in RL II) may indicate mg^{2+} deficiency, which can affect soil aggregation and nutrient uptake. OP I had the lowest ratio (1.47), which could be due to dominance of Mg^{2+} or relative Ca^{2+} depletion (Hansen *et al*., 2007). The Ca: Mg ratios, which were consistently below 6:1, indicate potential antagonistic effects on calcium uptake. Aluminum saturation (Al. Sat) ranged from 5.25% (OP II) to 23.89% (RL II) (Haby, 1990). Values above 20% (seen in RL II, RL I, IL II) are generally toxic to plant roots, inhibiting nutrient uptake. Forest (SF) and oil palm (OP) sites recorded significantly lower Al. Sat, reflecting less acidification stress and more favorable conditions for root development (dos Santos Rheinheimer *et al*., 2024). High Al saturation, particularly in IL I (24.06%) and RL II (23.89%), closely approaches critical toxicity thresholds (>25%) that impair root elongation and nutrient uptake (Esu, 2010). Base saturation ranged from 34.54% (OP I) to 45.09% (SF II). All sites had moderate base saturation (BS), with SF and RL areas showing slightly higher values. This pattern suggests some level of cation replacement by acidic ions (Al^{3+}, H^+), but the soils retain a reasonable balance of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, Na^+) (Johnston & Karamanos 2005; Gaspar & Laboski 2016). ESP values ranged from 2.11% (OP II) to 4.33% (SF II). All values were well below the sodicity threshold of 15%, indicating no sodic soil conditions (Cameron *et al*., 2003). However, high ESP in SF II (4.33%) and RL I (4.14%) may suggest incipient Na^+ accumulation, warranting periodic monitoring to prevent long-term structural degradation. Exchangeable Sodium Percentage (ESP) was below the sodicity threshold (5%) in all samples, indicating no sodic hazard but not negating the overall degradation trend (Van de Graaff & Patterson, 2001).

Table 4: Selected soil degradation indices under different land use

Horizon	Depth (cm)	DR	CDR	CFI	CDI	S	ESP	SAR
							←%→	
OIL PALM PLANTATION I (OP I)								
Ap	0-16	0.80	0.74	0.58	0.42	0.65	1.05	0.07
AB	16-41	0.79	0.53	0.65	0.35	0.58	2.69	0.18
Bt1	41-70	0.77	0.53	0.66	0.34	0.46	2.76	0.16
Bt2	70-122	0.73	0.54	0.65	0.35	0.40	3.36	0.19
Bt3	122-200	0.77	0.49	0.67	0.33	0.19	2.19	0.12
	Mean	0.77	0.56	0.64	0.36	0.45	2.41	0.14
	% CV	3.11	15.84	5.00	9.00	34.58	32.15	30.96
OIL PALM PLANTATION II (OP II)								
Ap	0-19	0.81	0.79	0.56	0.44	0.56	0.86	0.05
AB	19-46	0.77	0.55	0.65	0.35	0.56	2.05	0.12
Bt1	46-75	0.67	0.60	0.62	0.38	0.40	2.21	0.09
Bt2	75-128	0.74	0.62	0.62	0.38	0.27	2.50	0.12
Bt3	128-200	0.71	0.66	0.60	0.40	0.20	2.59	0.14
	Mean	0.74	0.63	0.61	0.39	0.40	2.11	0.11
	% CV	6.51	12.88	5.00	8.00	37.10	0.42	29.66
SECONDARY FOREST I (SF I)								
Ap	0-17	0.69	0.49	0.67	0.33	0.98	2.48	0.14
AB	17-53	0.84	0.75	0.57	0.43	0.92	3.44	0.18
Bt1	53-88	0.61	0.53	0.65	0.35	0.68	2.55	0.14
Bt2	88-134	0.85	0.66	0.60	0.40	0.56	2.80	0.15
Bt3	134-200	0.77	0.53	0.65	0.35	0.44	3.43	0.20
	Mean	0.75	0.59	0.63	0.37	0.72	2.94	0.16
	% CV	12.17	16.55	6.00	1.00	29.00	14.22	15.78
SECONDARY FOREST II (SF II)								
Ap	0-14	0.66	0.53	0.65	0.35	1.15	1.99	0.11
AB	14-36	0.72	0.53	0.65	0.35	0.89	2.58	0.13
Bt1	36-67	0.59	0.53	0.65	0.35	0.67	8.47	0.49
Bt2	67-94	0.74	0.62	0.62	0.38	0.62	3.65	0.21
Bt3	94-148	0.76	0.65	0.61	0.39	0.47	4.83	0.27
Bt4	148-200	0.64	0.49	0.67	0.33	0.34	4.48	0.23
	Mean	0.68	0.56	0.64	0.36	0.69	4.33	0.24
	% CV	8.81	10.12	4.00	6.00	39.05	48.46	52.15
INDUSTRIAL LAYOUT I (IL I)								
Ap	0-60	0.65	0.54	0.65	0.35	0.38	2.25	0.15
AB	60-122	0.76	0.63	0.61	0.39	0.31	3.05	0.16
Bt1	122-166	0.78	0.71	0.59	0.41	0.27	1.84	0.10
Bt2	166-200	0.83	0.83	0.55	0.45	0.21	3.35	0.19
	Mean	0.76	0.68	0.59	0.41	0.29	2.62	0.15
	% CV	8.65	15.68	6.00	8.00	21.38	23.08	20.25

Table 4: Selected soil degradation indices under different land use (continued)

Horizon	Depth (cm)	DR	CDR	CFI	CDI	S	ESP ←%→	SAR
				INDUSTRIAL LAYOUT II (IL II)				
Ap	0 – 56	0.69	0.72	0.58	0.42	0.30	3.40	0.18
AB	56 – 130	0.72	0.72	0.58	0.42	0.21	3.26	0.18
Bt1	130 – 170	0.84	0.66	0.60	0.40	0.19	2.62	0.14
Bt2	170 – 200	0.79	0.73	0.58	0.42	0.16	4.32	0.26
	Mean	0.76	0.71	0.59	0.41	0.22	3.40	0.19
	% CV	7.73	3.91	2.00	3.00	24.32	17.86	21.59
				RESIDENTIAL LAYOUT I (RL I)				
Ap	0-29	0.84	0.68	0.59	0.41	0.50	4.00	0.20
AB	29-68	0.46	0.39	0.72	0.28	0.25	3.30	0.16
Bt1	68-141	0.52	0.45	0.69	0.31	0.28	4.97	0.28
Bt2	141-200	0.70	0.49	0.67	0.33	0.25	4.23	0.22
	Mean	0.63	0.48	0.68	0.32	0.32	4.14	0.21
	% CV	23.81	22.60	7.00	14.00	32,97	14.40	21.02
				RESIDENTIAL LAYOUT II (RL II)				
Ap	0 -25	0.55	0.52	0.66	0.34	0.44	2.41	0.12
AB	25 – 76	0.51	0.38	0.73	0.27	0.25	2.97	0.14
Bt1	76 – 153	0.65	0.47	0.68	0.32	0.23	2.47	0.12
Bt2	153 – 200	0.60	0.58	0.63	0.37	0.17	3.07	0.15
	Mean	0.58	0.49	0.67	0.33	0.27	2.73	0.14
	% CV	9.07	14.95	5.00	10.00	37.31	29.29	9.30

Key: DR= dispersion ratio, CDR=Clay dispersion ratio, CFI = Clay flocculation index, CDI = Clay dispersion index, S = Soil structural stability index, ESP = Exchangeable sodium percentage, SAR = Sodium adsorption ratio

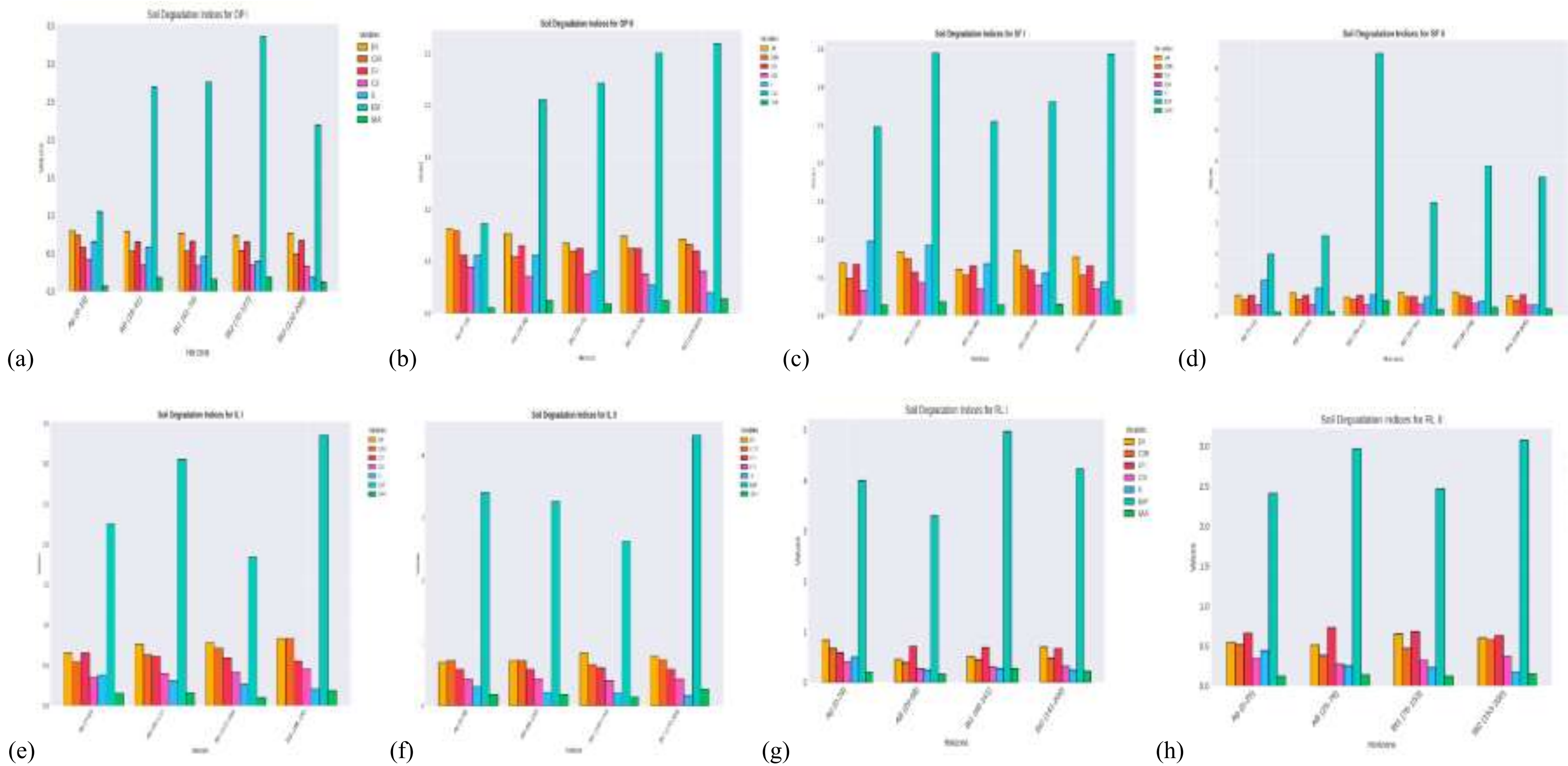


Fig.3 (a - h): Bar charts of selected soil degradation indices across different horizons and depths under different land use types

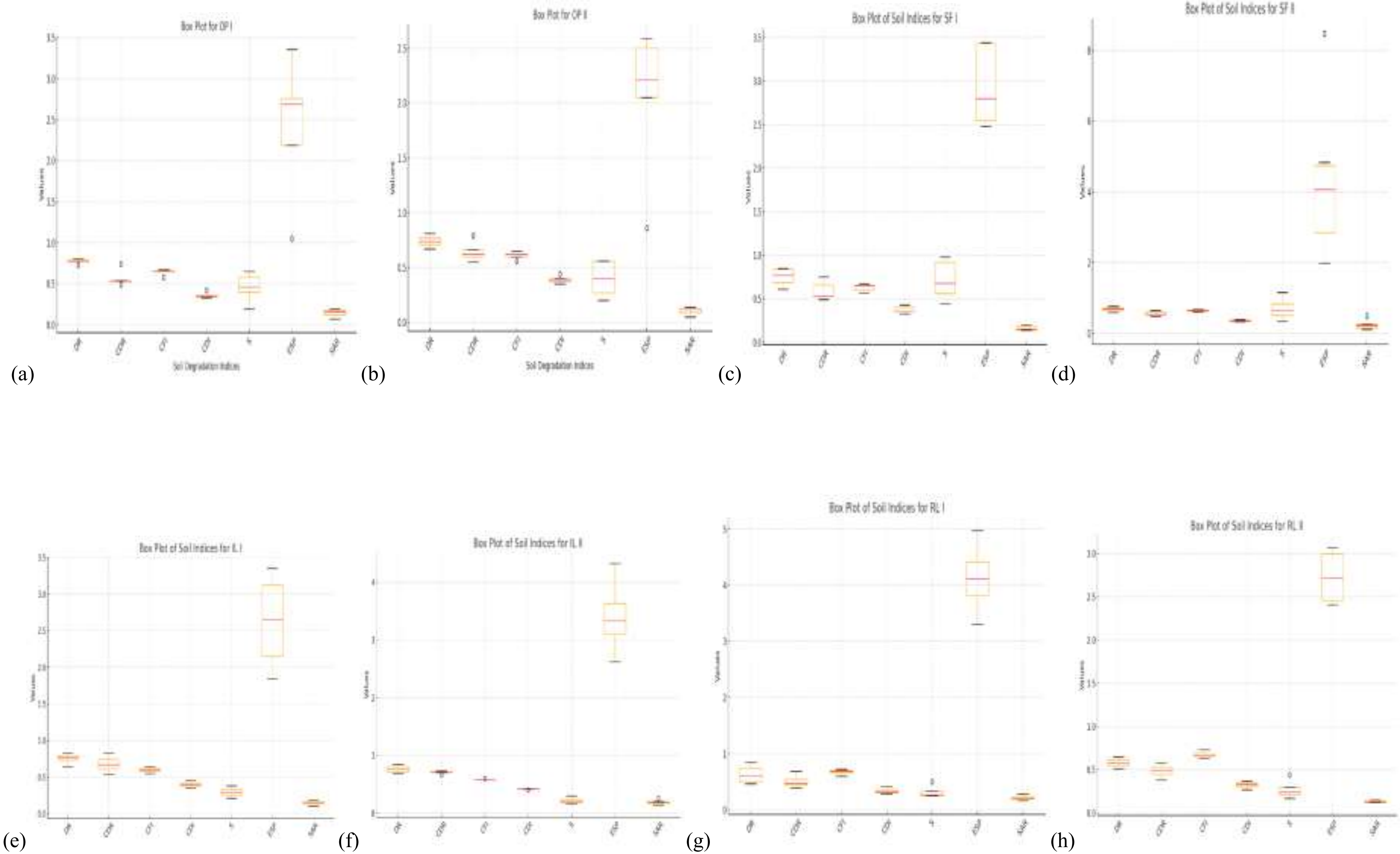


Fig.4 (a - h): Box plots of selected soil degradation indices under different land use types

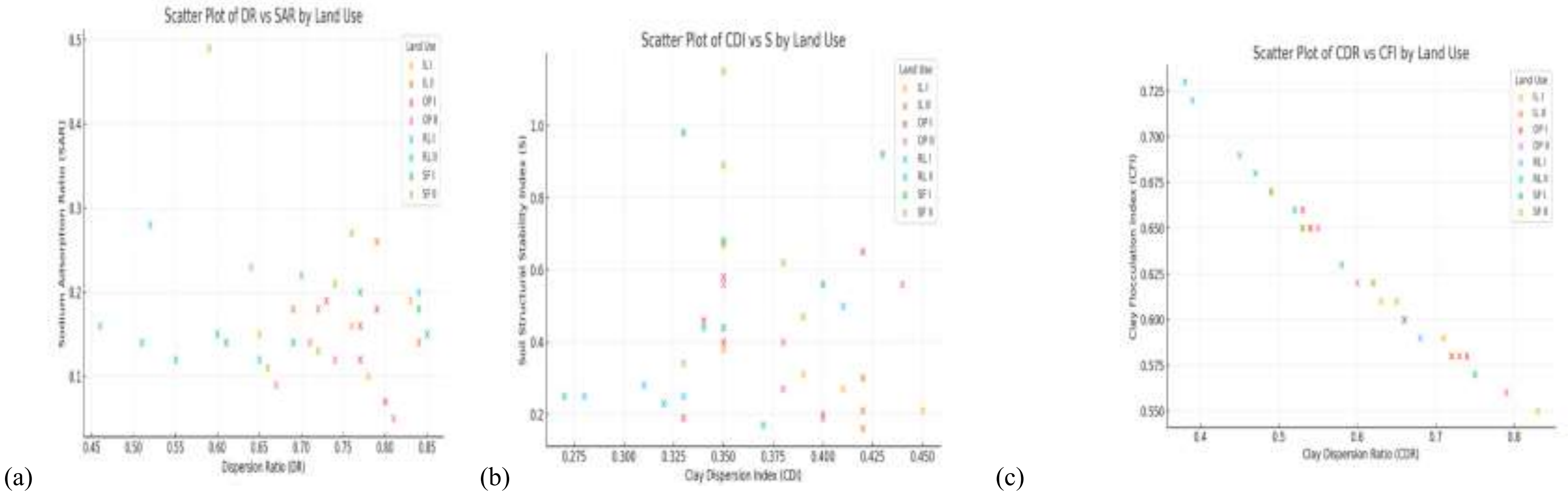


Fig. 5 (a - c) Scatter Plots of Soil Degradation Indices under Different Land use Types

Table 5: Mean values of selected soil physicochemical properties

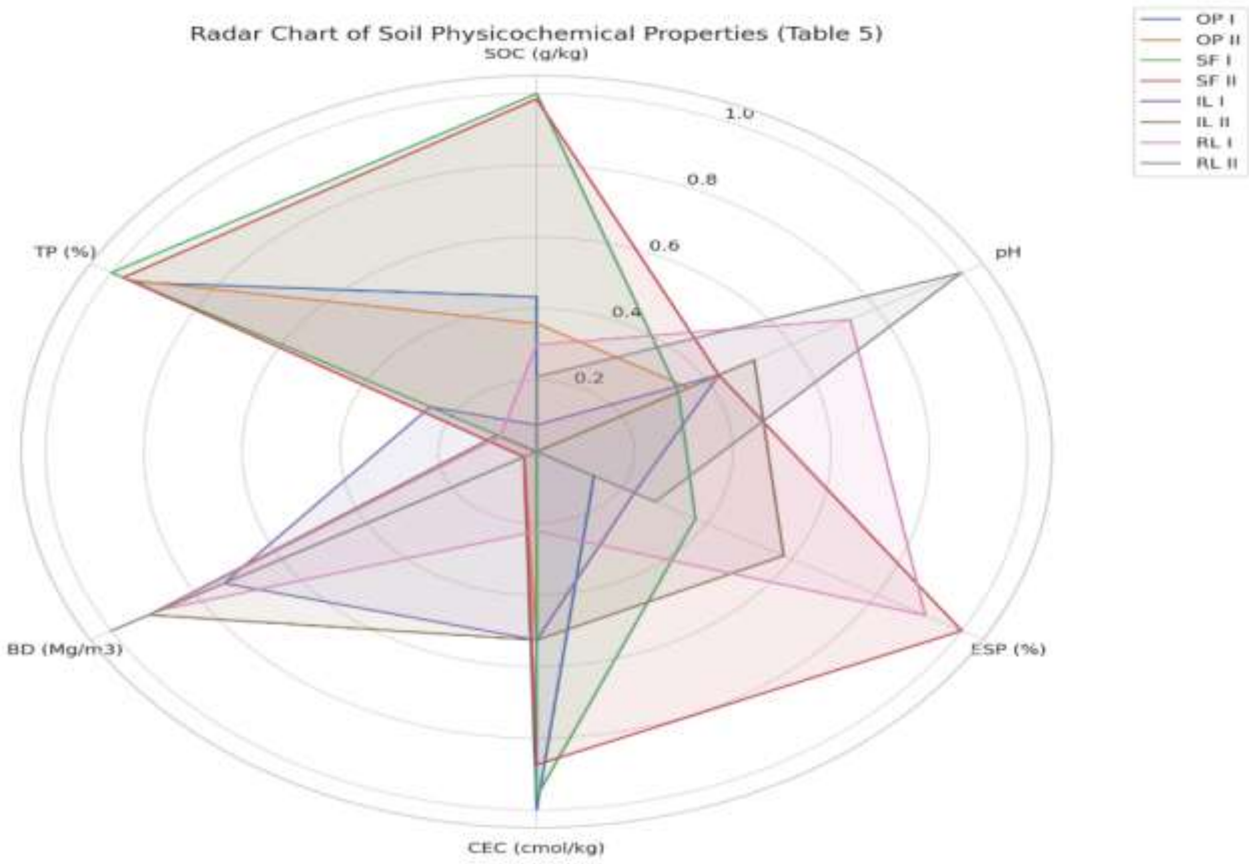
Land use	Texture	BD (Mg/m3)	TP (%)	pH	SOC (g/kg)	T. N (%)	Avail. P (mg/kg)	CEC (cmol/kg)	Ca: Mg	Al. Sat (%)	BS (%)	ESP (%)
OP I	SCL	1.40	47.02	4.50	0.63	0.08	0.59	5.92	1.47	5.30	34.54	2.41
OP II	SCL	1.41	47.17	4.80	0.58	0.06	0.53	5.31	1.96	5.25	42.61	2.11
SF I	SCL	1.39	47.70	4.78	1.01	0.10	0.60	5.87	2.76	17.36	44.22	2.94
SF II	SCL	1.40	47.36	4.86	1.00	0.13	0.54	5.75	2.29	19.92	45.09	4.33
IL I	SCL	1.64	38.30	4.86	0.39	0.04	0.27	5.28	1.85	24.06	37.89	2.62
IL II	SCL	1.70	36.32	4.93	0.34	0.05	0.37	5.28	2.09	21.32	40.59	3.40
RL I	SCL	1.69	36.23	5.12	0.54	0.03	0.38	4.87	2.31	22.66	44.53	4.14
RL II	SCL	1.73	35.16	5.34	0.48	0.04	0.43	4.57	3.10	23.89	44.95	2.73

Key: BD = bulk density, TP = total porosity, S = soil structural index, SOC = soil organic carbon, T.N = total nitrogen, CEC= cation exchange capacity, Al. Sat = aluminum saturation, BS = base saturation, ESP = exchangeable sodium percent

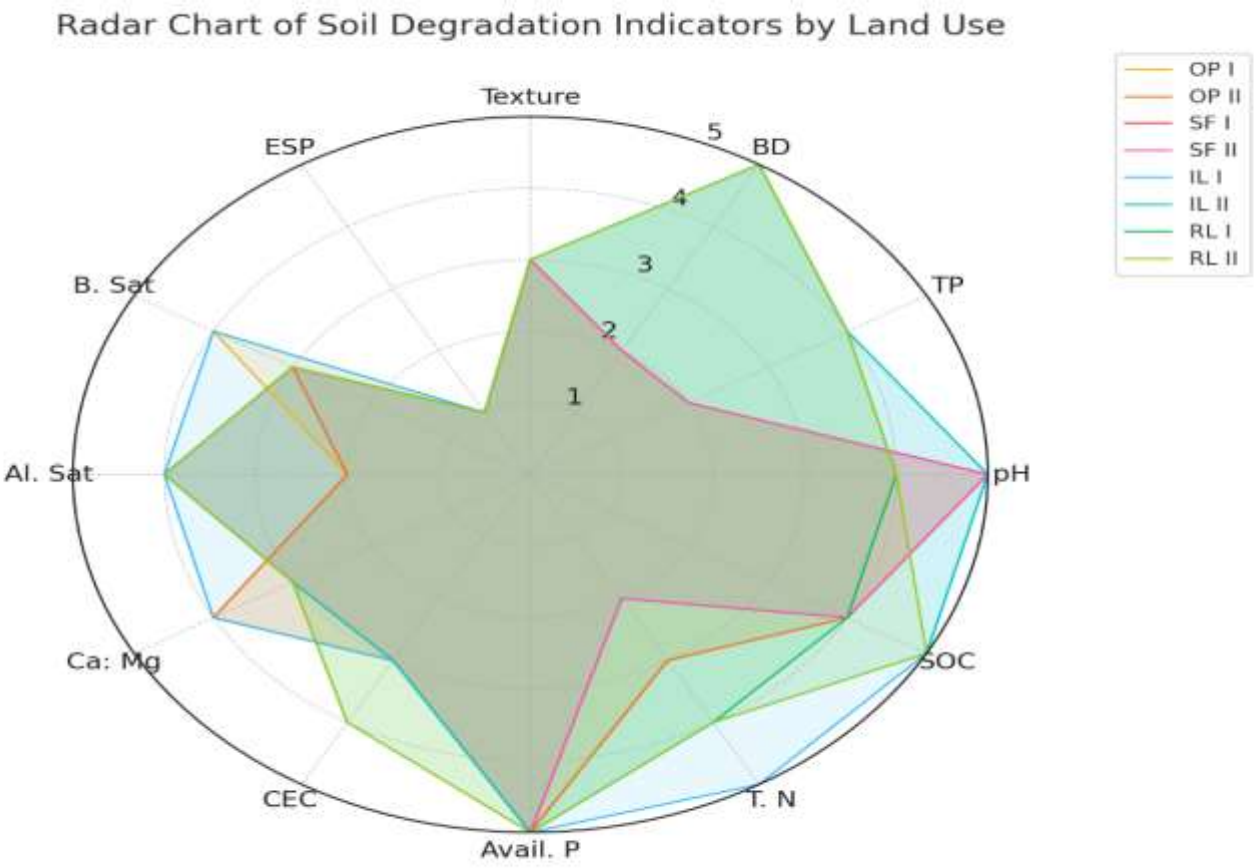
Table 6: Soil degradation rating (SDR) for different land use

Land use	Texture	BD (Mg/m3)	TP (%)	pH	SOC (g/kg)	T. N (%)	Avail. P (mg/kg)	CEC (cmol/kg)	Ca: Mg	Al. Sat (%)	BS (%)	ESP (%)	Mean RWF	SDR
OP I	3	2	2	5	4	3	5	3	4	2	4	1	3	Moderate
OP II	3	2	2	5	4	3	5	3	4	2	3	1	3	moderate
SF I	3	2	2	5	4	2	5	3	3	4	3	1	3	Moderate
SF II	3	2	2	5	4	2	5	3	3	4	3	1	3	Moderate
IL I	3	5	4	5	5	5	5	3	4	4	4	1	4	Severe
IL II	3	5	4	5	5	4	5	3	3	4	3	1	3	Moderate
RL I	3	5	4	4	4	4	5	4	3	4	3	1	3	moderate
RL II	3	5	4	4	5	4	5	4	3	4	3	1	3	moderate

Key: BD = bulk density, TP = total porosity, SOC = soil organic carbon, T.N = total nitrogen, CEC= cation exchange capacity, Al. Sat = aluminum saturation, BS = base saturation, ESP = exchangeable sodium percent, RWF: Relative weight factor, SDR rating: 1 = none, 2 = slight, 3 = moderate, 4 = severe, 5 = extreme

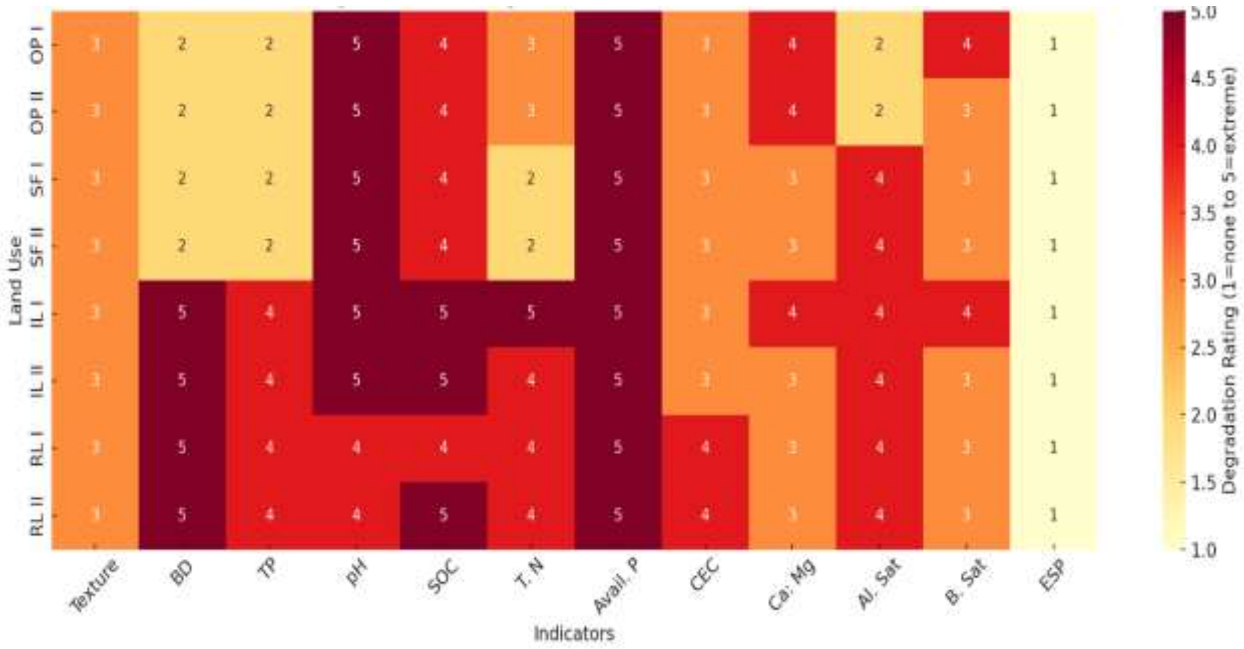

Radar Chart of Soil Physicochemical Properties (Table 5)
SOC (g/kg)
pH
ESP (%)
CEC (cmol/kg)
BD (Mg/m3)
TP (%)
0.2
0.4
0.6
0.8
1.0
OP I
OP II
SF I
SF II
IL I
IL II
RL I
RL II

(a)

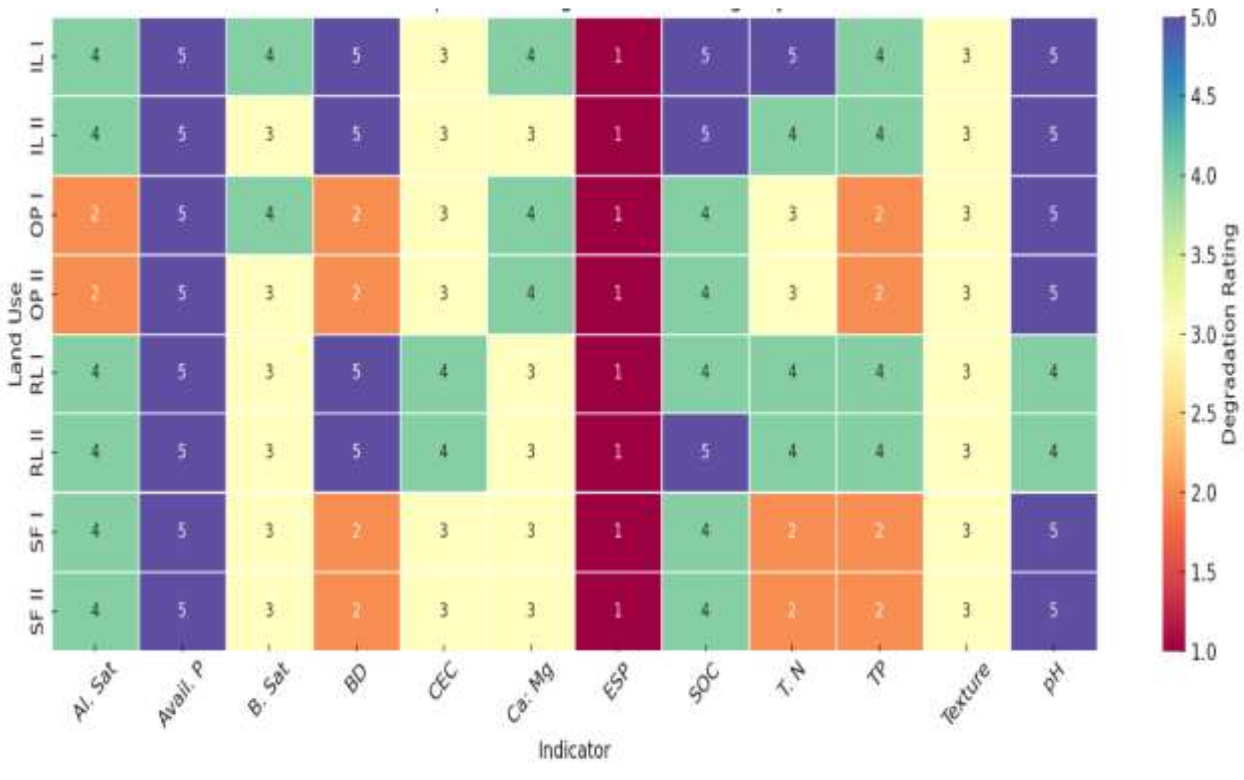

Radar Chart of Soil Degradation Indicators by Land Use
Texture
BD
TP
pH
SOC
T. N
Avail. P
CEC
Ca: Mg
Al. Sat
B. Sat
ESP
1
2
3
4
5
OP I
OP II
SF I
SF II
IL I
IL II
RL I
RL II

(b)

Fig. 6: Radar Chart of (a) Mean values of Soil Physicochemical Properties (b) Soil Degradation Indicators by Land Use



(a)



(b)

Fig. 7: Categorical (a) and Stacked (b) Heatmaps of Soil degradation rating (SDR) by land use

Recommendations

Secondary forest soils demonstrated structural stability with higher CFI and SOC, while industrial and residential soils showed severe degradation due to compaction, low organic matter, and poor structure. To address these issues, land-use-specific strategies are needed. Conservation practices such as minimum tillage, organic residue incorporation, mulching, and cover cropping should be prioritized in industrial and residential areas to rebuild SOC and improve structural indices. Liming is recommended for acidic soils with high aluminum saturation, particularly in oil palm and industrial sites. Targeted nutrient management, especially phosphorus supplementation, is essential where deficiencies were recorded. Regular monitoring using composite indices such as the Structural Stability Index (S) and Soil Degradation Rating (SDR) will enable early detection of degradation and timely interventions. Land-use zoning and soil monitoring policies should be implemented to limit urban sprawl and protect fertile soils, aligning with global sustainability frameworks and Nigeria's Land Degradation Neutrality targets.

Conclusion

This study confirms that land use significantly influences soil physicochemical properties and degradation processes in Owerri. Secondary forests maintained higher stability and fertility, while industrial lands were the most degraded and residential soils showed worrying compaction. The SDR placed industrial soils in the severe category, with others moderately degraded. Despite providing valuable baseline data, the study highlights research gaps: weak linkage between degradation indices and agricultural productivity, limited integration of biological indicators, and absence of long-term monitoring systems. Addressing these gaps, alongside implementing soil conservation and organic matter restoration practices, will prevent further decline and enhance sustainable agricultural development in Southeastern Nigeria.

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