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Geospatial Assessment of Agricultural Land Capability in Plateau State, Nigeria: A Multi-Criteria Approach to Sustainable Food Production

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Abstract:

Agricultural sustainability in Nigeria's middle belt region faced mounting challenges from population growth, soil degradation, and inadequate data infrastructure, threatening achievement of Sustainable Development Goals related to food security and sustainable land management. This study employed integrated remote sensing and Geographic Information Systems (GIS) to assess land capability for food production across 26,899 km² in Plateau State. Through systematic collection of 1,065 georeferenced soil samples and multi-criteria weighted overlay analysis, the study characterized the spatial variability in soil physicochemical properties including texture, pH, organic matter, nitrogen, phosphorus, and potassium. Results indicated predominantly clayey soils (27.16% coverage) with significant textural heterogeneity spanning nine classes. Soil acidity affected 61.54% of the study area (pH 5.1-6.5), while organic matter content remained critically low across 61.62% of surveyed lands. The weighted overlay suitability analysis revealed that 55.6% of the region exhibited moderate agricultural suitability, with 34.19% classified as suitable and 9.47% as highly to very highly suitable. Only 0.74% proved least suitable for cultivation. Spatial distribution patterns demonstrated strong geological control on soil properties, with crystalline basement rocks producing sandy-textured soils in northern zones, while sedimentary formations in southern areas generated finer textures. These findings provided crucial baseline data for precision agriculture initiatives and evidence-based policy formulation toward enhanced food security, directly supporting SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 15 (Life on Land) in north central Nigeria.

Keywords — **Land capability classification, soil suitability mapping, precision agriculture, IDW interpolation, Plateau State, sustainable development goals.**

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I. INTRODUCTION

Nigeria's agricultural sector has experienced dramatic decline from contributing over 50% to GDP pre-independence to heavy import dependence following petroleum exploitation [1]. This transformation contradicts Sustainable Development Goal 2 (Zero Hunger), which calls for ending hunger and promoting sustainable agriculture by 2030. The middle belt region, particularly Plateau State, historically served as Nigeria's breadbasket, supplying diverse crops including yam, cassava, potatoes, rice, maize, and groundnuts. However, rapid population growth coupled with declining productivity has created significant food security concerns, exacerbated by climate variability and land degradation [2, 3].

A fundamental constraint to agricultural development in Nigeria is poor data infrastructure. Traditional survey methods are time-consuming and financially prohibitive for comprehensive coverage. Remote sensing and GIS technologies offer transformative potential, enabling rapid, cost-effective spatial data acquisition across large areas [4, 5]. When integrated with ground-truthing and laboratory analysis, these technologies provide robust frameworks for land evaluation aligned with SDG targets.

This study addresses critical knowledge gaps regarding land capability for food production in Plateau State. The research aims to generate comprehensive spatial data supporting evidence-based agricultural policy formulation. Specifically, the study characterized the biophysical environment, determined spatial distribution of essential soil nutrients, classified land suitability based on soil properties, produced high-resolution land resource maps at 1:50,000 scale, and developed replicable methodology for land capability assessment. These objectives align with SDG targets 2.3 (doubling agricultural productivity) and 2.4 (sustainable food production systems).

The scarcity of reliable agricultural data in developing countries represents a critical impediment to sustainable development planning. Data-driven approaches are essential for achieving SDG targets, particularly in agriculture where spatial heterogeneity demands location-specific interventions [6]. Integration of earth observation data with ground measurements has revolutionized land capability assessment, enabling spatially explicit analyses previously impossible [7]. In Nigeria, inadequate soil information systems have resulted in blanket fertilizer recommendations ignoring spatial variability, leading to inefficient resource use and environmental degradation. Precision agriculture approaches based on detailed soil mapping can increase fertilizer efficiency by 20-30% while reducing environmental impacts [8].

II. STUDY AREA AND THEORITICAL FRAMWORK

A. Study Area Characteristics

The investigation covered the entire Plateau State in north central Nigeria, encompassing the northern, central, and southern senatorial zones, spanning 26,899 km² (8°24'N to 10°30'N; 8°32'E to 10°38'E). The area encompasses seventeen Local Government Areas across northern (Bassa, Barkin Ladi, Jos East, Jos North, Jos South, Riyom), central (Bokkos, Kanam, Kanke, Mangu, Pankshin), and southern zones (Langtang North/South, Mikang, Qua'an Pan, Shendam, Wase).

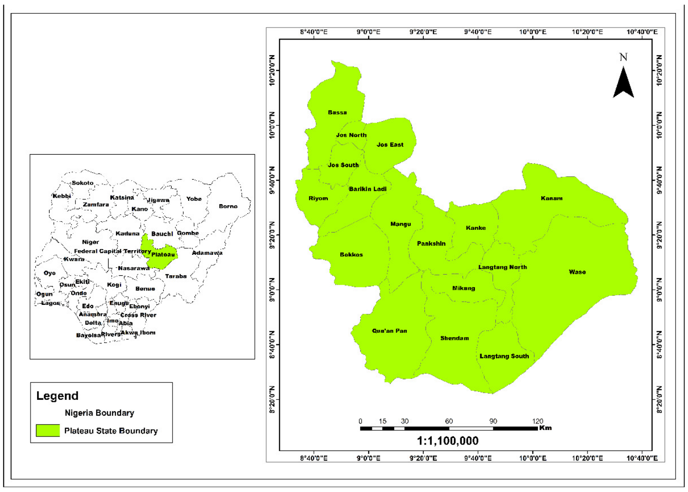

Fig 1: Map of the study area

The region exhibits tropical savannah climate with distinct wet (May-October) and dry (November-April) seasons, providing a six-month growing season. Temperature ranges between 25°C and 37°C, with rainfall averaging 146 cm annually in northern areas and 131.75cm in southern portions. The area falls within northern Guinea savannah vegetation zone. These climatic conditions, while generally favourable, are increasingly affected by climate variability, making climate-smart approaches essential for SDG 13 compliance [9].

Geological complexity significantly influences soil formation and agricultural potential [10]. The area sits within Pre-Cambrian Basement Complex, dominated by migmatite-gneiss formations. Northern zones feature younger granite ring complexes with crystalline basement rocks, older granites, and granite-gneiss. Elevations reaching 1,752 meters facilitate lateritic soil formation. Central zones contain crystalline basement rocks with Pan African granites, while southern zones feature Cretaceous to Tertiary sedimentary rocks (sandstone, limestone, shale) dominating lowland areas.

B. Conceptual Framework

Land capability classification represents systematic appraisal of physical land characteristics, originally developed by the United States Soil Conservation Service in 1939 [11]. Contemporary applications increasingly integrate this framework with sustainable development principles, recognizing that assessment must consider both productivity and environmental sustainability [12]. The FAO (1993) defines land suitability as "the fitness of a given parcel of land for specific uses." Modern interpretations emphasize that suitability must incorporate biophysical factors, socioeconomic considerations, and climate resilience [13].

Land suitability analysis serves as prerequisite for sustainable agricultural crop production. Suitability functions as the relationship between crop requirements and soil/land characteristics. Recent advances in machine learning and artificial intelligence enhance suitability assessment capabilities, enabling sophisticated modelling of complex soil-crop-climate interactions [14, 15].

Assessment approaches have evolved from qualitative methods (broad-scale potential assessment) to quantitative approaches employing parametric techniques with detailed land attributes [16]. Contemporary research combines qualitative and quantitative approaches, incorporating mathematical models, expertise, and GIS. Recent methodological advances include fuzzy logic to handle uncertainty, Bayesian approaches for probabilistic assessment, and participatory methods incorporating local knowledge [17].

Food security has occupied international agendas since 1948's Universal Declaration of Human Rights, now central to SDG 2. The FAO (1996) defines food security as existing "when all people at all times have physical or economic access to sufficient, safe and nutritious food." Contemporary frameworks increasingly emphasize climate-resilient food systems, acknowledging that climate change threatens all dimensions of food security [18]. This integration links SDG 2 with SDG 13, emphasizing that sustainable food production must address productivity and environmental sustainability simultaneously.

III. METHODOLOGY

A. Conceptual Framework

The research employed multi-source data integration, combining primary field observations with secondary remotely sensed data. This integrated approach aligns with best practices in digital soil mapping, emphasizing the value of combining multiple data sources [19]. Systematic soil sampling occurred throughout the study area, with 1,065 samples collected from villages across seventeen LGAs, providing sampling density of approximately one sample per 25 km². Geographical positions were determined using handheld GARMIN GPSMAP 78s receivers. Four sub-samples were collected from randomly selected farm locations using soil sampling augers at 0-30 cm depths, then thoroughly mixed to create composite samples following Global Soil Partnership protocols [20].

TABLE 1: PARAMETERS AND METHODS ADOPTED FOR LABORATORY ANALYSIS

S/N	Parameters	Unit	Methods
1	Soil Texture		Hydrometer **(Bouyoucos, 1927)**
2	Soil pH		Potentiometric 1:2 (**Jackson, 1973) pH-meter**
3	Organic Matter	%	Walkely and Black, (**Walkely and Black, 1934**)
4	Total N	%	Kjeldahl (**Bremer and Mulvaney, 1982**)
5	Available P_2O_5	mg/kg	Olsen's (**Olsen et al., 1954**)
6	Available K_2O	mg/kg	Ammonium acetate (**Jackson, 1967**)

Soil samples underwent physicochemical analysis at the Centre for Dry Land Agriculture Laboratory, Bayero University Kano. Standard analytical methods ensured data quality and international comparability: soil texture (hydrometer method), pH (potentiometric 1:2 soil-water ratio), organic matter (Walkley and Black method), total nitrogen (Kjeldahl method), available phosphorus (Olsen's extraction), and available potassium (ammonium acetate extraction).

Spatial distribution of physicochemical properties was prepared using Inverse Distance

Weighting (IDW) interpolation techniques in ArcGIS 10.8. IDW proved effective for soil property mapping in data-sparse environments [27]. Soil texture classification employed the USDA Soil Textural Triangle. Thematic maps used five categories for nutrients (Very Low, Low, Medium, High, Very High) and pH categories from Very Strongly Acidic to Neutral.

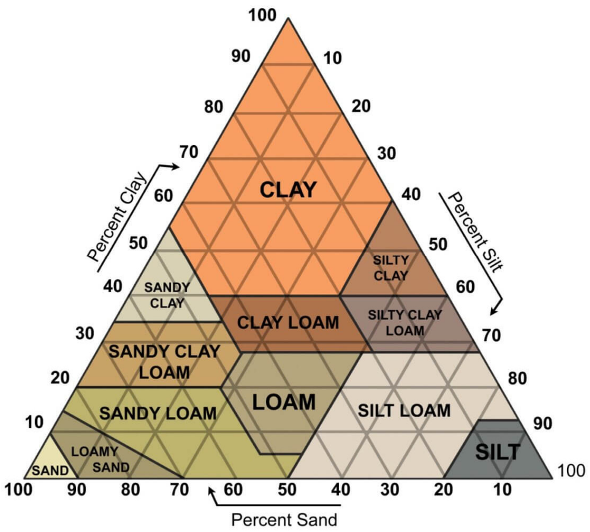

Fig 2: The USDA Soil Texture Triangle Chart. (After USDA, 2017)

B. Weighted Overlay Analysis

Each parameter received weights according to relative contribution to crop production: pH (28%), nitrogen (25%), organic matter (22%), phosphorus (16%), potassium (9%). This weighting reflects pH's fundamental influence on nutrient availability, followed by nitrogen as primary macronutrient, organic matter for multiple soil quality benefits, phosphorus for root development, and potassium for plant stress resistance [28]. Machine learning studies have validated similar weighting schemes through quantitative yield prediction assessment [14].

C. Suitability Classification and Mapping

Weighted soil parameters were reclassified to a common suitability scale (1-5) and integrated using ArcGIS Weighted Overlay tool to generate composite suitability scores. Final scores were classified into five land capability categories: Least Suitable (1.0-1.8), Moderately Suitable (1.9-2.6), Suitable (2.7-3.4), Highly Suitable (3.5-4.2), and Very Highly Suitable (4.3-5.0). Classification thresholds were established through iterative analysis and expert consultation to ensure meaningful differentiation of agricultural potential across the landscape.

D. Crop Distribution Analysis

Concurrent with soil sampling, crop type surveys were conducted through structured farmer interviews and direct field observations across all seventeen LGAs. Dominant crops were documented at each sampling location, including cereals (maize, sorghum, millet, rice), legumes (soybeans, groundnuts, beans), tubers (yam, Irish potatoes, cassava), and vegetables. Crop coverage percentages were calculated for each LGA using spatial analysis tools, and distribution maps were produced to identify crop specialization zones and relate cultivation patterns to underlying soil properties and climatic conditions.

E. Statistical Analysis and Validation

Spatial statistics were computed for all thematic maps using ArcGIS zonal statistics functions. Area coverage (km²) for each parameter class was calculated by multiplying pixel counts by cell resolution (100 m²), then exported to Microsoft Excel for percentage calculations and tabular presentation. Relationships between geological formations, soil properties, and crop distribution patterns were analyzed through spatial overlay and correlation analysis. Map accuracy was assessed through cross-validation, withholding 20% of samples for independent validation. Interpolation performance was evaluated using root mean square error (RMSE) and mean absolute error (MAE), while final maps were visually inspected against field observations to ensure spatial patterns aligned with known soil-landscape relationships.

IV. RESULTS

A. Crop Distribution and Patterns

Field surveys documented diverse crop cultivation demonstrating agricultural diversification essential for food security and climate resilience. Northern zones show crop specialization favouring temperate crops due to higher elevations: maize dominates (34-49%), followed by Irish potatoes (16-21% in Riyom, Barkin Ladi, and Jos South) and vegetables (tomatoes 16-18%, cucumbers 16%) in Jos East. Southern zones focus on traditional cereals and tubers adapted to warmer conditions: sorghum (22-31%), millet (22-33%), yam (16-30%), and groundnut (11-21%) feature prominently. Central zones exhibit transitional characteristics with mixed cropping patterns. This spatial differentiation reflects adaptive agricultural strategies responding to environmental gradients, demonstrating farmer knowledge that should inform SDG 2 implementation [29].

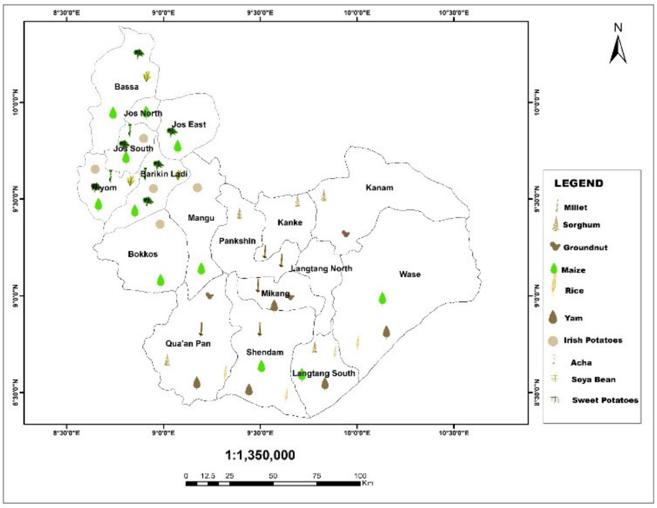

Fig 3: Crop Types Across Plateau State.

B. Soil Physical and Chemical Properties

Soil Texture: Analysis identified nine textural classes with wide spatial variation. Clayey soil dominates (7,194.19 km², 27.16%), followed by sandy clay loam (4,688.88 km², 17.70%), sandy loam (3,473.00 km², 13.11%), clay loam (3,588.68 km², 13.55%), and sandy clay (2,685.44 km², 10.14%). Loam covers 2,184.70 km² (8.25%), silty clay 1,776.30 km² (6.71%), sandy soils 548.76 km² (2.07%), while silty clay loam represents least coverage (351.12 km², 1.33%). Sandy textures predominate in northern zones reflecting crystalline basement rock weathering, while finer textures (clay, silty clay) dominate southern zones derived from sedimentary formations. This textural diversity reflects complex geological history. Clay-dominated soils, while potentially productive due to high nutrient retention, may present management challenges including poor drainage and difficult tillage [30].

Soil pH: Soil pH ranged from <5.0 to 7.3, with strongly acidic soils (pH 5.1-5.5) most prevalent (8,758.83 km², 33.06%), particularly in northern and central zones (Bassa, Barkin Ladi, Jos North/South, Riyom, Bokkos, Mangu). Moderately acidic soils (pH 5.6-6.0) covered 7,544.48 km² (28.48%), while slightly acidic (pH 6.1-6.5) comprised 6,251.57 km² (23.60%). Very strongly acidic soils (<5.0) affected 2,645.58 km² (9.99%), concentrated in high-elevation volcanic areas. Only 1,290.60 km² (4.87%) exhibited neutral pH (6.6-7.3), primarily in southern zones with carbonate-rich sedimentary rocks. The dominance of acidic conditions (71.53% below pH 6.0) represents significant constraint, as low pH reduces nutrient availability while increasing aluminium and manganese to potentially toxic levels [31]. However, 61.54% falling within pH 5.5-6.5 indicates general suitability for most crops with appropriate management.

Soil Fertility Status: Analysis of soil organic matter, nitrogen, phosphorus, and potassium reveals critical nutrient deficiencies across the study area (Table 2). Organic matter status shows 61.62% of land with critically low levels (very low: 4,971.47 km², 18.77%; low: 11,351.97 km², 42.85%), while only 15.19% exhibits high to very high OM content. Nitrogen distribution follows similar patterns, with 54.64% classified as low to very low (very low: 5,702.00 km², 21.52%; low: 8,772.72 km², 33.12%), reflecting the close relationship between OM and N. Phosphorus shows more balanced distribution, with moderate levels dominating (9,152.66 km², 34.55%), though 35.81% still exhibits low to very low P availability concentrated in acidic northern zones. Potassium presents the most severe deficiency, with 53.69% of area classified as low to very low (very low: 6,176.28 km², 23.31%; low: 8,048.42 km², 30.38%). These widespread deficiencies reflect intensive cultivation without adequate organic inputs, erosion on sloping lands, and rapid nutrient depletion typical of tropical environments [32].

TABLE 2: Comprehensive Soil Properties Summary Showing Distribution Across the Study Area

Parameter	Category	Area (km²)	%
Texture	Clay	7,194.19	27.16
	Sandy Clay Loam	4,688.88	17.70
	Sandy Loam	3,473.00	13.11
	Clay Loam	3,588.68	13.55
	Sandy Clay	2,685.44	10.14
	Loam	2,184.70	8.25
	Silty Clay	1,776.30	6.71
	Sandy	548.76	2.07
	Silty Clay Loam	351.12	1.33
pH	Strongly Acidic (5.1-5.5)	8,758.83	33.06
	Moderately Acidic (5.6-6.0)	7,544.48	28.48
	Slightly Acidic (6.1-6.5)	6,251.57	23.60
	Very Strongly Acidic (<5.0)	2,645.58	9.99
	Neutral (6.6-7.3)	1,290.60	4.87
Organic Matter	Low	11,351.97	42.85
	Moderate	6,145.87	23.20
	Very Low	4,971.47	18.77
	High	3,273.20	12.36
	Very High	748.55	2.83
Nitrogen	Low	8,772.72	33.12
	Moderate	6,833.20	25.79
	Very Low	5,702.00	21.52
	High	3,972.08	14.99
	Very High	1,211.07	4.57
Phosphorus	Moderate	9,152.66	34.55
	Low	6,117.09	23.09
	High	5,723.02	21.60
	Very Low	3,370.91	12.72
	Very High	2,127.38	8.03
Potassium	Low	8,048.42	30.38
	Moderate	6,762.78	25.53
	Very Low	6,176.28	23.31
	High	3,858.67	14.57
	Very High	1,644.92	6.21

C. *Integrated Land Suitability Assessment*

Weighted overlay analysis integrating pH (28% weight), nitrogen (25%), organic matter (22%), phosphorus (16%), and potassium (9%) produced comprehensive suitability classification. Moderately suitable lands dominated at 55.60% (14,728.35 km²), distributed across all zones but concentrated in central areas with balanced soil properties. Suitable lands covered 34.19% (9,057.15 km²), primarily in northern zones despite acidity challenges, due to higher organic matter and better nutrient status. Highly suitable areas comprised 9.16% (2,425.85 km²), concentrated in central Mangu, Bokkos, and parts of southern Langtang with optimal pH and nutrient levels. Very highly suitable lands covered only 0.31% (81.55 km²), limited to specific locations with exceptional soil conditions. Least suitable areas represented only 0.74% (198.14 km²), restricted to severely degraded or extremely acidic sites.

Results demonstrate 99.26% of the study area exhibits at least suitable conditions for agriculture, with 65.07% falling in moderately suitable to very highly suitable categories. This high proportion of agriculturally viable land represents significant opportunity for enhancing food production to meet SDG 2 targets, provided that appropriate soil management strategies address identified constraints [32]. The spatial distribution of suitability classes provides basis for differentiated management strategies, with highly suitable areas serving as priority zones for intensive production systems, while moderately suitable areas benefit from targeted soil improvement before intensification.

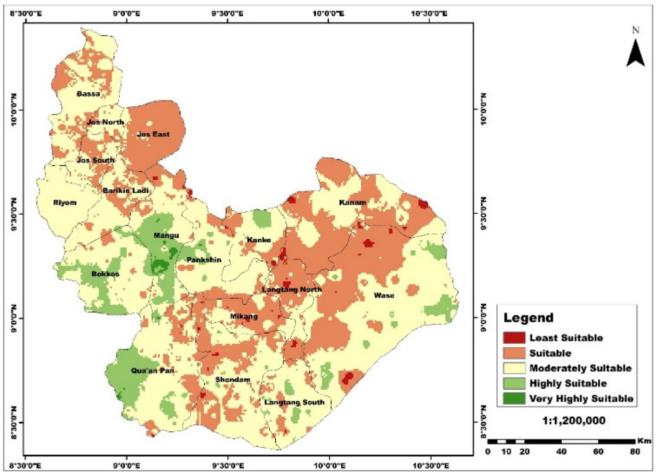

Fig 4: Soil Suitability Map (Weighted Overlay)

V. RESULTS

A. *Geological and Environmental Controls*

Strong correlation exists between lithological units and soil characteristics, demonstrating parent material's fundamental importance in pedogenesis. Northern and central portions dominated by crystalline basement rocks produce characteristic weathering products: quartz yields sandy textures, while feldspar residues generate clay. This mineralogical control on texture has been extensively documented in similar West African settings [10]. Southern zone sedimentary rocks produce sandy clay loam, sandy clay, sandy loam, and silty clay. Soil texture influences organic matter and nitrogen stabilization, with coarser soils containing less nitrogen due to reduced retention capacity. Clay content strongly influences organic matter stabilization through mineral-organic associations protecting organic compounds from microbial decomposition [33].

Soil pH critically affects nutrient availability by altering nutrient forms and microbial activity. Carbonate rock occurrence around Wase contributes to relatively high pH, while volcanic and intrusive rocks around northern LGAs generate acidic soils. Climate influences pH through rainfall-induced leaching. On Jos Plateau, intense rainfall leaches topsoil, producing acidic soils losing base cations [31]. Continuous cultivation practices combined with excessive precipitation reduce pH in middle and upper elevation areas. Farmers continuously apply UREA and NPK fertilizers with blanket recommendations without soil testing. Nitrogen-containing fertilizers release hydrogen ions through nitrification, decreasing soil pH. This continuous fertilizer application without pH management threatens long-term soil health, potentially creating a downward spiral of increasing acidity and declining productivity [34]. However, organic manure application increases pH long-term, suggesting integrated soil fertility management combining organic and inorganic inputs could provide sustainable solutions [35].

B. Nutrient Dynamics and Management Implications

High nitrogen concentrations coincide with sedimentary rock occurrence at southern edges, especially alluvial sands and clays. Widespread low organic matter and nitrogen levels represent critical constraints. Generally low OM levels reduce soil buffering capacity, elevating exchangeable acids. Beyond pH regulation, OM improves soil quality through enhanced aggregate stability, water holding capacity, cation exchange capacity, microbial diversity, and nutrient availability [36]. Multiple ecosystem services provided by soil organic matter extend beyond crop production to include carbon sequestration, water filtration, and biodiversity support, aligning with SDG 15 objectives.

Intensive cultivation without adequate organic inputs has caused serious soil erosion across undulating terrain. Conservation agriculture practices incorporating residue retention, reduced tillage, and cover cropping can significantly increase organic matter while reducing erosion [37]. Spatial phosphorus distribution partially reflects phosphorus content within limestone, sandstones, and shale in southern areas, with higher concentrations in northern and central zones resulting from fertilizer application. Potassium spatial variation closely links with potassium feldspar occurrence in crystalline rocks, with basalt occurrences noticeably influencing high concentration areas.

C. Land Suitability and SDG Alignment

Findings reveal Plateau State lands generally prove highly viable for agricultural purposes, with 99.26% exhibiting at least suitable conditions. Despite population growth and inorganic fertilizer use, land continues supporting agricultural practices, demonstrating the area's critical role in regional food security. The dominance of moderately suitable lands (55.6%) indicates substantial potential for productivity enhancement through targeted interventions, aligning with SDG 2.3 calling for doubling agricultural productivity and incomes of small-scale food producers. Spatial variation in suitability classes provides basis for differentiated management strategies, with highly suitable areas potentially serving as priority zones for intensive production systems.

Sustainable crop production requires urgent land capability improvement, smallholder farmer support, and indigenous farming knowledge enhancement. Identification of specific limiting factors enables targeted interventions addressing constraints efficiently. Acidic soils require liming programs, low OM areas need organic matter management, and nutrient-deficient zones require balanced fertilization. This precision approach optimizes resource use while minimizing environmental impacts, supporting SDG 12

(Responsible Consumption and Production) alongside food security objectives.

The research also contributes to SDG 13 (Climate Action) by providing baseline data for monitoring land degradation and soil carbon stocks. Widespread organic matter deficiency suggests substantial potential for carbon sequestration through improved management, offering climate change mitigation co-benefits alongside productivity improvements. Healthy soils with adequate organic matter exhibit greater resilience to climate stresses including drought and flooding, supporting climate adaptation objectives [38].

VI. CONCLUSION AND RECOMMENDATION

This comprehensive geospatial assessment provides crucial baseline data supporting evidence-based approaches to achieving Sustainable Development Goals in Plateau State. Soil parameters exhibit marked spatial variability reflecting complex interactions among geology, climate, topography, and anthropogenic factors, necessitating site-specific management rather than blanket recommendations. Strong relationships between lithological units and soil properties provide predictive capacity for extrapolating findings to unmapped areas.

Over 60% exhibits acidic conditions, while low organic matter affects 61.62% and low nitrogen dominates 33.12% of surveyed lands. Despite these challenges, 99.26% exhibits at least suitable conditions for agriculture, with 55.6% moderately suitable, indicating substantial potential for productivity enhancement. Integration of remote sensing, GIS, and ground-truthing proved effective for large-scale assessment, with methodology replicable across other regions.

Key Recommendations:

Soil-Specific Management: Develop comprehensive training programs on soil-type specific fertilizer application utilizing spatial data generated. Site-specific nutrient management programs could optimize fertilizer efficiency by 20-30% while reducing costs by 15-25% [8]. Extension services should be equipped with digital tools displaying soil suitability maps accessible via mobile devices.

Targeted Liming Programs: Implement liming programs in strongly acidic zones (northern and central areas). Limestone applications could raise pH to optimal ranges, improving nutrient availability and crop yields by 15-30% [39]. Priority areas include Bassa, Barkin Ladi, Jos North/South, Riyom, Bokkos, and Mangu. Application rates should be determined based on soil testing, with typical requirements ranging from 2-5 tons per hectare.

Integrated Organic Matter Management: Address critical deficiencies through crop residue incorporation, composting programs, leguminous cover crops, organic manure support, and agroforestry initiatives. Increasing soil organic matter from 1% to 3% can increase water holding capacity by 40-60% and improve nutrient retention substantially [36]. These interventions provide multiple co-benefits including carbon sequestration (supporting SDG 13) and enhanced soil biodiversity (supporting SDG 15).

Climate-Smart Agriculture: Promote climate-resilient practices including drought-resistant crop varieties, water conservation techniques (mulching, conservation tillage, rainwater harvesting), weather information services, and crop diversification. Spatial suitability data can guide climate adaptation planning by identifying areas vulnerable to specific stresses and matching climate-resilient crops to appropriate zones [9].

Youth Engagement: Create enabling environments encouraging youth participation through access to credit and farm inputs, modern agricultural technology, market linkages and value-addition infrastructure, agricultural entrepreneurship training, and land tenure security. Technology-intensive precision agriculture may particularly appeal to youth, potentially reversing rural-urban migration while modernizing the sector.

Continuous Monitoring: Establish permanent monitoring sites tracking soil health indicators. Regular assessment (every 3-5 years) would track fertility trends, evaluate intervention effectiveness, provide early warning of degradation, and support adaptive management. Digital soil mapping approaches using machine learning can update maps more frequently using remote sensing data calibrated with ground observations [7].

This research directly contributes to SDG 2 (enhanced productivity through soil-informed management), SDG 13 (carbon sequestration and climate-resilient practices), and SDG 15 (sustainable land management preventing degradation). The integrated approach demonstrated—combining scientific assessment, policy recommendations, and practical implementation strategies—provides a model for evidence-based agricultural development supporting multiple SDG objectives. Success requires coordinated action across government, research institutions, private sector, and farming communities working toward sustainable, productive agricultural systems.

The challenge is not lack of land but optimizing land use through science-based management. With 99.26% of surveyed lands exhibiting at least suitable conditions, the opportunity space is substantial. Realizing this potential requires commitment to precision agriculture principles, investment in soil health improvement, support for smallholder farmers, and continuous learning through monitoring and adaptation. This research represents a foundation upon which evidence-based agricultural transformation can be built, offering pathways toward sustainable agricultural intensification that meets human needs while protecting natural resources for future generations.

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