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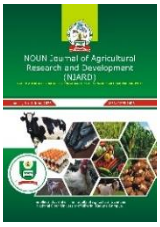

Original Article

Soil Characterization and Land Suitability Evaluation for Maize Production in the Peri-Urban Gulum Area of Jalingo, Nigeria

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ABSTRACT

Peri-urban agriculture offers a vital pathway to strengthen food security and urban resilience, yet systematic evaluations of land suitability in these transitional landscapes remain limited. This study integrated remote sensing and field-based methods to characterize soils and assess their suitability for rainfed maize cultivation in the Gulum area of North-eastern Nigeria. Cultivable land was delineated using a Random Forest classifier within Google Earth Engine, identifying 409.13 ha (about 70% of the landscape) as arable, with an overall accuracy of 91.1% (κ = 0.88) confirming the reliability of the classification. Climate parameters such as annual rainfall (1101.5 mm), dry season length (150 days), and relative humidity (43%) were derived from long-term satellite-based climatic records, and all were rated as highly suitable (S1). Morphological, physical, and chemical analyses of three representative pedons indicated deep, well-drained sandy loam profiles with moderate fertility constraints. Specifically, organic carbon (0.73–1.04%), available phosphorus (10.11–12.02 mg kg^{-1}), and cation exchange capacity (8.76–9.05 cmol kg^{-1}) were marginal, reducing overall land ratings. Suitability classification using the parametric approach categorized all three units as moderately suitable (S2–sf), with Index of Productivity (IP) values ranging from 50.0 to 70.7, suggesting maize yield potential of 60–75% under current conditions. Under improved fertility management, all sites showed potential to attain optimal suitability (S1). These findings highlight Gulum's strategic importance as a peri-urban agricultural zone and emphasize the scope for boosting food security through targeted soil fertility management and the application of geospatial tools in peri-urban planning.

Keywords: *Characterization; Google Earth Engine; Land evaluation; Maize suitability; Peri-urban agriculture*

1.0 Introduction

Rapid urbanization in developing countries, particularly across Sub-Saharan Africa, has intensified pressure on land resources, resulting in complex transformations at the rural-urban interface. These peri-urban zones are increasingly recognized as critical frontiers for food production, environmental services, and sustainable land use planning (Wahab and Abiodun, 2018; Chaminuka *et al.*, 2021). In Nigeria, as in much of West Africa, peri-urban agriculture has emerged as a key livelihood strategy for low-income households and urban food systems, offering advantages such as proximity to markets, availability of labor, and access to urban organic waste streams that can be repurposed for soil fertility (Chaminuka *et al.*, 2021).

Despite their strategic importance, peri-urban landscapes are often neglected in national agricultural policies, largely due to competing land uses and insufficient knowledge of their agroecological potential. The increasing competition for land between residential expansion and agricultural use necessitates evidence-based decision-making, particularly through systematic soil suitability assessment. Evaluating the physical and chemical characteristics of soils and matching them with crop-specific requirements provides a scientifically grounded basis for enhancing productivity, improving land management, and guiding peri-urban land-use zoning (Food and Agriculture Organization [FAO], 2022).

Several soil suitability studies have been conducted in Nigeria focusing on major food crops such as cassava, yam, rice, and maize (Usman *et al.*, 2018; Awwal, 2021; Awwal and David, 2024). These evaluations have largely applied the FAO parametric framework, integrating factors such as climate, topography, drainage, soil fertility, and physical attributes to determine land capability. However, most of these studies are situated in clearly rural environments, with limited attention to peri-urban soils that are subject to more anthropogenic pressures and changing land cover. Moreover, in rapidly growing cities like Jalingo, peri-urban soils are poorly characterized, which hinders their optimal use for intensive cropping.

The Gulum area, located on the southern fringe of Jalingo in northeastern Nigeria, exemplifies a typical peri-urban zone undergoing rapid transformation. The area experiences a tropical savanna climate with unimodal rainfall distribution and distinct wet and dry seasons (Kefas *et al.*, 2023). The soils are mainly sandy loam with moderate organic carbon levels, characteristics shaped by the tropical environment and land-use history. These properties pose both opportunities and limitations for intensive cropping. As a case crop, maize (*Zea mays* L.) is selected for this study due to its wide consumption, market value, and sensitivity to edaphic conditions, especially nutrient availability, soil depth, drainage, and structure (Reuben and Samuel, 2025).

This study evaluates the suitability of soils in the Gulum peri-urban area for maize production through land use mapping, morphological and physicochemical characterization of representative pedons, fertility assessment, and parametric land evaluation using the productivity index model of Sys *et al.* (1993). The findings aim to fill critical knowledge gaps in peri-urban land-use planning while providing data-driven guidance for sustainable intensification and policy interventions.

2.0 Materials and Methods

2.1 Study Area Description

This study was conducted in the Gulum area, Taraba State, located in northeastern Nigeria. This peri-urban fringe of the state's capital, Jalingo, hosts an intersection of rural and urban land uses, which offers a strategically relevant landscape for the study. A representative site, spanning about 586 ha, situated between latitude 8°57'21.6" N and longitude 11°23'20.26" E was delineated as shown in Figure 1.

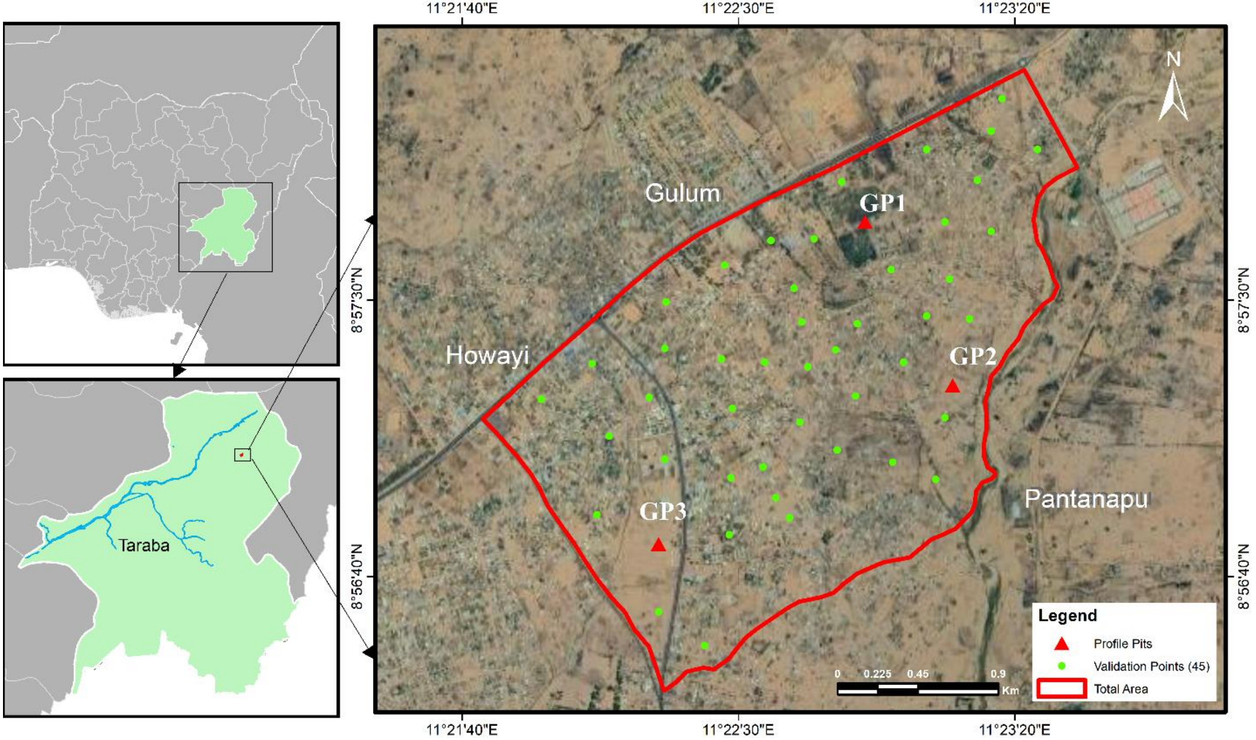

Figure 1: Map Showing Location of the Study Area and Profile Pits

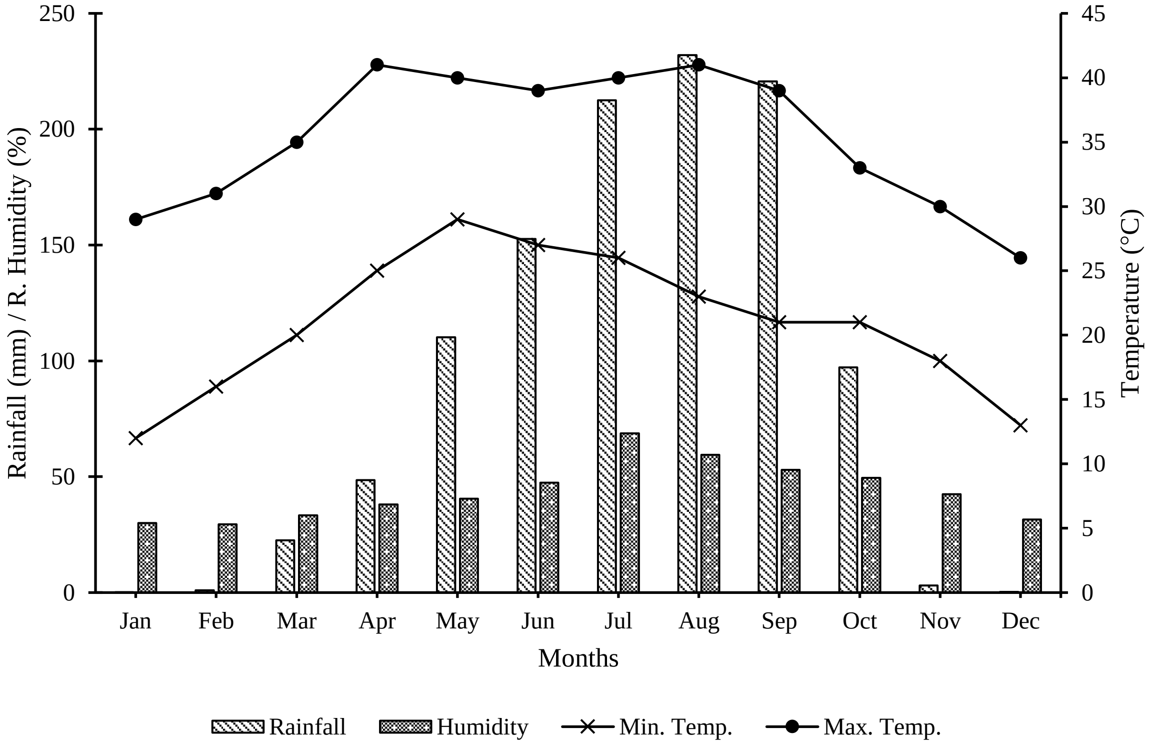

Figure 2: Monthly Variations in Climatic Variables in the Study Area (2002–2024)

2.2 Climate Data Acquisition and Analysis

Monthly climate data between 2002 – 2024 were extracted for the Gulum peri-urban region using remote sensing datasets accessed via Google Earth Engine (GEE). Rainfall data were obtained from the CHIRPS dataset, land surface temperature (LST) from MODIS (MOD11A2), and relative humidity was estimated from ERA5-Land by computing values from hourly dewpoint and air temperature. For each month, zonal means were calculated over the delineated study area, producing a multivariate climate profile suitable for agro-ecological interpretation and suitability analysis (Nwachukwu *et al.*, 2020; Keikhosravi-Kiany *et al.*, 2023). The resulting climatic variables are shown in Figure 2.

The climate of the study area reflects a typical tropical savanna regime, marked by a distinct wet season from April to October and a dry season from November to March. Rainfall peaks between July and September, coinciding with high relative humidity levels that support optimal crop growth and soil microbial activity (Dwamena *et al.*, 2020). In contrast, the dry months receive minimal rainfall, and humidity drops below <50%. Temperature ranges are wide, with daily maxima reaching 42°C between March and May, and minima dropping below 15°C in December and January. These thermal and moisture dynamics critically influence evapotranspiration rates, germination potential, and soil biological functions.

2.3 Delineation of Cultivable Land Using Remote Sensing and GIS

To delineate available cultivable land within the peri-urban zone, we employed supervised classification of high-resolution Sentinel-2 imagery in the GEE platform. A cloud-free median composite of 2024 images was generated using red (B4), green (B3), blue (B2), and near-infrared (B8) bands. Ground-truth data were collected by digitizing training points for built-up areas, vegetation, bare soil, and farmland as described by Arpitha *et al.* (2023). Each point was assigned a numeric land use class, after which a Random Forest classifier with 20 decision trees was trained on the selected bands and applied to classify the entire area of interest. Built-up zones were then masked out to reveal only the cultivable land. Finally, the available land layer was vectorized into polygons using the “reduceToVectors” function in GEE, quantified and exported for mapping and field reconnaissance.

2.4 Soil Profile Description, Sampling and Sample Preparation

Following the identification of cultivable zones, three representative soil profile pits were excavated manually. The choice of three pedons was based on the need to capture spatial variability across the major land units within the delineated area while maintaining analytical feasibility. Each pit was described in situ following the USDA Soil Survey Manual (Soil Survey Staff, 2017). Soil samples were collected from each identified horizon of the three profile pits. Samples were air-dried, sieved through a 2 mm mesh, and prepared for laboratory analysis.

2.5 Laboratory Analysis

Particle size distribution (sand, silt, and clay fractions) was determined using the hydrometer method after dispersing the samples with sodium hexametaphosphate. Textural classes were assigned using the USDA textural triangle, while bulk density and porosity were also measured for each horizon using the core method.

Soil pH was measured in a 1:2.5 soil-to-water suspension with a pH meter. Organic carbon (OC) content was determined by the Walkley-Black dichromate oxidation method, total nitrogen (TN) was analyzed using the Kjeldahl digestion procedure, while available phosphorus (avail. P) was extracted using the Bray-1 method and quantified colorimetrically. Exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+) were extracted with 1N ammonium acetate at pH 7.0 and measured using atomic absorption spectrophotometry for Ca and Mg, and flame photometry for K and Na. Total exchangeable acidity (TEA) was determined by titration after extraction with 1N KCl, effective cation exchange capacity (ECEC) was calculated by summation and base saturation (BS) was computed as the percentage of the ECEC occupied by the sum of the exchangeable bases. All analyses were done following standard procedures as described by Soil Survey Staff (2014).

2.6 Statistical Analysis and Validation Metrics

Data derived from laboratory analysis were subjected to both descriptive and inferential statistical procedures to evaluate variability within and between the three profile pits. All analyses were conducted using Minitab 17.0, while correlation visualization was supported by a correlogram constructed in R (R Core Team, 2025). Coefficient of variation (CV) and one-way analysis of variance (ANOVA) was applied to assess significant differences in soil properties across pedons and horizons. Where differences were significant ($p < 0.05$), Tukey's HSD post-hoc test was employed to identify distinct groupings. Additionally, to ascertain the reliability of the land use/land cover classification, a total of 45 independent ground-truth points (Figure 1) were used to construct a confusion matrix. From this matrix, standard accuracy metrics were derived, including Overall Accuracy (OA), the Kappa coefficient (κ), User's Accuracy (UA), and Producer's Accuracy (PA), using the formulas described by Congalton and Green (2009).

2.7 Land Suitability Classification

To determine land suitability for maize cultivation, soil property values were compared against established agronomic benchmarks (Table 1) to determine their suitability for agricultural use.

Table 1: Land Use Requirement Ratings for Rainfed Maize Cultivation

Land Characteristic	Highly suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Not suitable (N1)
A. Climate (c)				
Mean annual temp. (°C)	24–30	20–24	15–20	<15
		30–32	32–35	>35
Annual rainfall (mm)	>800	700–800	600–700	<600
Length of Rainy Season (days)	150–220	110–130	90–110	<90
B. Topography (t)				
Slope (%)	0–2	4–8	8–16	>16
C. Wetness (w)				
Flooding	F0	F1	F3	F4
Drainage	WD	ID	PD	VPD
D. Land physical property (s)				
Vol. of coarse frag. (%)	<3	15–35	35–55	>55
Soil rooting depth (cm)	>120	75–120	30–75	<30
Soil Texture Class	CL, L	SL, LS	SCL	CS, S
E. Soil Fertility (f)				
CEC (cmol kg^{-1})	>25	13–25	6–12	<6
Base Saturation (%)	>50	35–50	20–35	<20
pH in water	6.0–6.5	5.5–6.0	5.0–5.5	<5.0
		6.5–7.0	7.0–8.0	>8.0
Available P (mg kg^{-1})	>22	7–13	3–7	<3
Organic Carbon (g kg^{-1})	>2	1–2	0.5–1	<0.5
Total Nitrogen (g kg^{-1})	0.08–0.04	0.04–0.02	<0.02	Any
Exchangeable K (cmol kg^{-1})	0.3–0.5	0.2–0.3	0.1–0.2	<0.1

Key: Flooding: F0- no flooding, F1 - seasonal flooding, F3 = aeric, F4 = mostly flooded; Drainage: W – well, I – imperfectly, P – poorly, VP – very poorly, D – drained; Texture: CL - clay loam, L - loam, SL - sandy loam, LS - loamy sand, SCL - sandy clay loam, CS - clay sand, S – sand.

Adapted from Fatihu *et al.* (2020)

Suitability ratings were derived through qualitative matching with crop-specific requirements, after which the Index of Productivity (IP) was computed using the formula:

$$Index\ of\ Productivity\ (IP) = A\ \times \sqrt{\prod_{i=4}^{4} \frac{S_i}{100}}$$

Where A denotes the dominant climatic factor and S_i represents limiting factor ratings for topography, wetness, soil physical characteristics, and fertility. Current suitability classes ranging from S1 (highly suitable) to N1 (not suitable) were defined based on IP thresholds as proposed by Udoh *et al.* (2006), while adjustments were made to account for fertility limitations typically managed through supplementation in tropical agricultural systems to determine potential suitability.

3.0 Results and Discussion

3.1 Cultivable Land in the Peri-Urban Area

The spatial delineation of cultivable land within the Gulum peri-urban region enabled the differentiation of built-up areas from areas such as vegetation surfaces, arable fields, and bare soils with potential for crop use (Figure 3). The analysis identified 409.13 hectares, or approximately 70% of the total 586-hectare study area, as potentially cultivable. The reliability of this delineation was confirmed through an accuracy assessment based on independent ground-truth points, which produced an overall accuracy of 91.1% and a Kappa coefficient of 0.88. User's accuracy ranged from 80% (vegetation) to 100% (built-up areas), while producer's accuracy ranged from 88.9% (vegetation) to 92.9% (bare soil) (Table 2). These values indicate strong agreement between the classified map and reference data, thereby strengthening confidence in the derived estimates of cultivable land. This emphasizes the often-underappreciated agricultural potential of peri-urban landscapes.

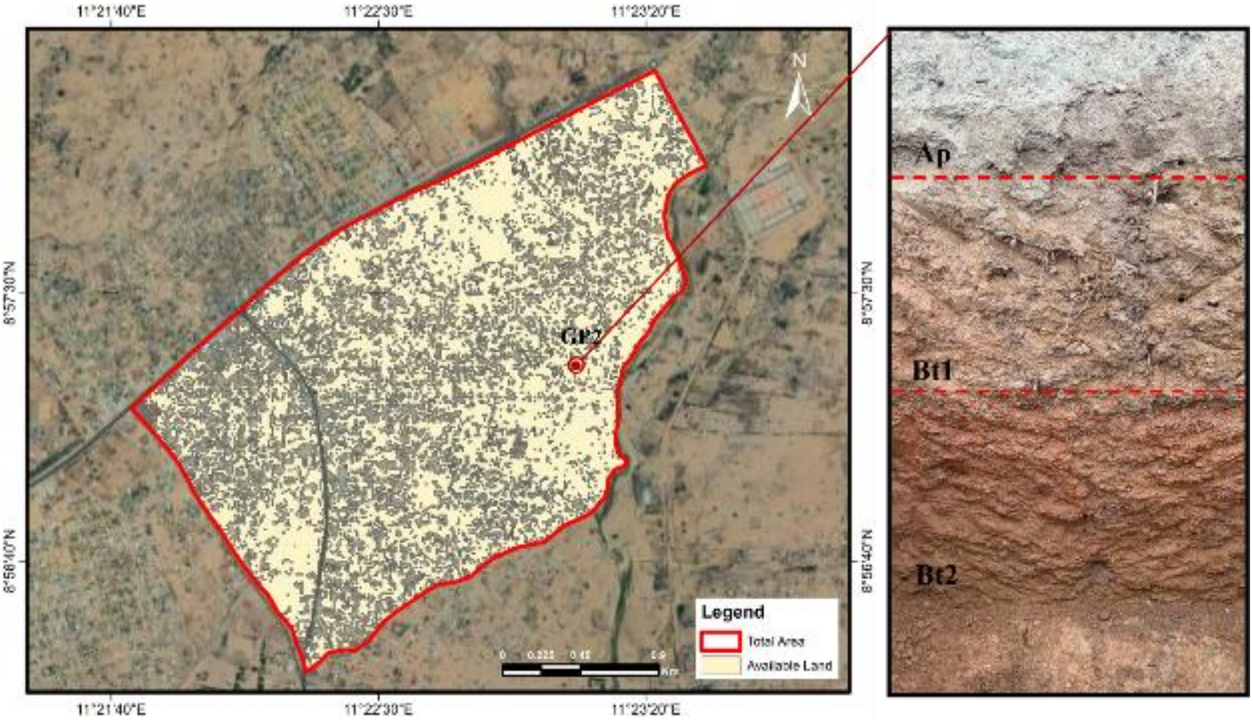

Figure 3: Supervised classification of the Gulum peri-urban showing Land Delineation and Morphological Profile of a Typical Pedon within the Study Area

Table 2: Confusion Matrix

		Actual				
		Built-up	Farmland	Vegetation	Bare soil	PA (%)
Predicted	Built-up	11	0	0	1	91.7
	Farmland	0	9	1	0	90.0
	Vegetation	0	1	8	0	88.9
	Bare soil	0	0	1	13	92.9
	UA (%)	100.0	90.0	80.0	92.9	

Note: UA = User's accuracy; PA = Producer's accuracy; Overall Accuracy (OA): 91.1%; Kappa (κ) = 0.88.

In many rapidly expanding urban centers across sub-Saharan Africa, peri-urban land is caught in a state of flux, and frequently excluded from long-term planning frameworks (Wahab and Abiodun, 2018). Yet, as demonstrated here, such zones can boast of arable land, which may serve as strategic buffers for sustainable food production (Salem *et al.*, 2025). These lands can leverage on its spatial advantages which affords it proximity to markets, reduced transport costs, and labor accessibility, to boost food security in communities. Moreover, with increasing competition for rural agricultural land due to population growth and urban encroachment, peri-urban regions like Gulum offer a viable alternative for controlled, intensive, and technologically integrated agriculture.

3.2 Soil Characterization

3.2.1 Morphological Characterization

The morphological description of the three representative pedons in the cultivable peri-urban area of Gulum is presented in Table 3. All three pedons were classified as very deep (>150 cm), which is a favorable characteristic for root development and moisture retention (Licida *et al.*, 2024). The surface horizons in all pedons exhibited a sandy loam texture, indicative of moderate water holding capacity and good drainage (Weil and Brady, 2017). In GP1, the Ap and B horizons presented light brown (7.5YR 6/4) and reddish yellow (7.5YR 6/8) colors, with moderate crumb and subangular blocky structures, respectively.

Table 3: Morphological Properties of the Pedons

Horizon	Depth (cm)	Color (moist)	Texture	Structure	Consistence	Boundary
GP 1: (8°57′46.8″N, 11°22′51.6″E)						
Ap	0–40	7.5YR 6/4 (light brown)	SL	2MCR	Hard	d
B	40–80	7.5YR 6/8 (reddish yellow)	SL	2MSBK	Slightly hard	d
Bt1	80–120	2.5YR 6/4 (light reddish brown)	SCL	2MSBK	Very hard	d
Bt2	120–170	2.5YR 4/4 (Reddish brown)	SCL	2MSBK	Very hard	
GP 2: (8°57′14.4″N, 11°23′6.0″E)						
Ap	0-50	2.5YR 6/4 (light reddish brown)	SL	2MG	Firm	d
Bt1	50-110	2.5YR 6/8 (light red)	SL	2MSBK	Firm	d
Bt2	110-170	5YR 5/6 (Yellowish red)	SCL	2MSBK	Very firm	
GP 3: (8°56′45.6″N, 11°22′15.6″E)						
A	0-40	2.5YR 4/3 (Olive brown)	SL	2MCR	Very firm	d
AB	40-100	2.5YR 3/6 (Dark red)	SL	2MSBK	Hard	d
B	100-200	5YR 5/6 (Yellowish red)	SL	2MSBK	Very Hard	

Keys: Texture = SL - sandy loam, SCL - sandy clay loam; Structure = 2 - moderate, M - massive, CR – crumb, SBK - subangular blocky, G – granular; Boundary = d – diffuse.

Subsurface horizons in most pedons revealed textural transitions to sandy clay loam, particularly in Bt horizons of GP1 and GP2, and maintained sandy loam in GP3, though with increased consistence from firm to very hard. All pedons had diffuse horizon boundaries and lacked mottles, suggesting gradual transitions and stable, well-drained conditions across the landscape (Figure 3) (Awwal, 2021). Morphologically, the soils reflect moderate development, suitable for sustainable cultivation, particularly under the semi-humid climate and land-use dynamics.

3.2.2 Variability in Physicochemical Properties among Pedons in the Study Area

The comparison of soil properties across the pedons (Table 4) reveals generally consistent characteristics, with no statistically significant differences ($p > 0.05$) observed for the measured parameters. Sand content varied modestly (CV = 7.28%), with GP2 exhibiting the highest proportion (71.0%) and GP1 the lowest (67.2%). Silt showed the greatest variation (CV = 27.94%), with GP2 markedly lower than the others. Bulk density (BD) was similar across all pedons (1.3–1.4 Mg m^{-3}), resulting in minor differences in porosity (CV = 7.18%), with GP2 having slightly lower porosity, possibly linked to higher compaction.

Note: Soil parameter values represent means ± standard deviation. CV = coefficient of variation.

Soil reaction was slightly acidic (pH 6.4–6.6), with minimal variability (CV = 1.91%), suggesting a stable chemical environment. Soil OC and TN showed moderate variation (CVs > 22%), with GP2 registering slightly lower values, indicating some organic matter depletion. Av. P ranged from 9.0 to 10.4 mg kg^{-1}, while base-forming cations showed low variability and consistent distribution across pedons.

However, depth analysis reveals statistically significant differences between surface and sub-surface horizons for several soil parameters (Table 5). Sand content was significantly higher at the surface (75.1%) compared to the sub-surface (66.6%) ($p = 0.004$), indicating a clear trend of increasing fineness with depth as supported by the corresponding increase in clay (14.3% to 18.6%) and silt (from 10.6% to

14.8%), although the latter was not statistically significant. This particle size redistribution aligns with clay illuviation processes typical of argillic horizon development (Silva *et al.*, 2021). Similarly, BD increased significantly from surface to sub-surface (1.3 to 1.4 Mg m^{-3}, $p = 0.017$), reflecting compaction with depth, while porosity declined correspondingly (44.5% to 40.1%, $p = 0.024$), which is a regular trend reported by previous researchers on tropical soils (Osujieke *et al.*, 2018; Awwal, 2021).

Table 4: Variability in Physicochemical Properties between Studied Pedons

Soil Parameters	GP1	GP2	GP3	CV (%)	P-value
Sand (%)	67.2 ± 4.76	71.0 ± 6.15	70.1 ± 5.30	7.28	0.626
Silt (%)	15.5 ± 0.61	9.5 ± 3.56	15.0 ± 4.02	27.94	0.065
Clay (%)	17.4 ± 4.23	19.5 ± 2.72	14.9 ± 1.36	19.64	0.278
BD (Mg m^{-3})	1.3 ± 0.07	1.3 ± 0.02	1.4 ± 0.04	3.61	0.623
Porosity (%)	42.7 ± 3.05	39.4 ± 2.87	41.7 ± 2.87	7.18	0.387
pH	6.6 ± 0.13	6.6 ± 0.10	6.4 ± 0.10	1.91	0.242
OC (%)	0.8 ± 0.19	0.6 ± 0.08	0.8 ± 0.18	22.17	0.327
TN (g kg^{-1})	1.4 ± 0.32	1.1 ± 0.14	1.4 ± 0.32	22.12	0.331
AvP (mg kg^{-1})	9.0 ± 0.85	9.4 ± 1.53	10.4 ± 1.50	13.46	0.383
Ca (cmol kg^{-1})	4.8 ± 0.62	4.6 ± 0.26	4.6 ± 0.36	9.26	0.736
Mg (cmol kg^{-1})	1.9 ± 0.60	2.0 ± 0.56	2.4 ± 0.04	23.59	0.446
Na (cmol kg^{-1})	0.2 ± 0.02	0.2 ± 0.03	0.2 ± 0.03	12.94	0.366
K (cmol kg^{-1})	1.3 ± 0.28	1.1 ± 0.07	1.0 ± 0.18	19.95	0.204
TEA (cmol kg^{-1})	1.4 ± 0.44	1.5 ± 0.60	1.3 ± 0.08	28.23	0.906
ECEC (cmol kg^{-1})	9.6 ± 1.08	9.3 ± 0.31	9.5 ± 0.40	7.17	0.896
BS (%)	85.6 ± 5.81	84.1 ± 7.14	86.1 ± 1.41	5.72	0.896

Table 5: Variability in Physicochemical Properties between Surface and Sub-surface soils

Soil Parameters	Surface	Sub-surface	P-value
Sand (%)	75.1^{a} ± 2.51	66.6^{b} ± 3.26	0.004
Silt (%)	10.6 ± 4.78	14.8 ± 2.75	0.107
Clay (%)	14.3 ± 2.38	18.6 ± 3.00	0.061
BD (Mg m^{-3})	1.3^{b} ± 0.06	1.4^{a} ± 0.03	0.017
Porosity (%)	44.5^{a} ± 2.22	40.1^{b} ± 2.26	0.024
pH	6.5 ± 0.13	6.5 ± 0.13	0.781
OC (%)	0.9^{a} ± 0.17	0.7^{b} ± 0.11	0.027
TN (g kg^{-1})	1.6^{a} ± 0.30	1.2^{b} ± 0.19	0.026
AvP (mg kg^{-1})	11.0^{a} ± 0.96	8.9^{b} ± 0.77	0.006
Ca (cmol kg^{-1})	4.2^{b} ± 0.06	4.9^{a} ± 0.37	0.022
Mg (cmol kg^{-1})	1.7 ± 0.62	2.2 ± 0.38	0.141
Na (cmol kg^{-1})	0.2 ± 0.02	0.2 ± 0.02	0.104
K (cmol kg^{-1})	1.0 ± 0.06	1.2 ± 0.22	0.058
TEA (cmol kg^{-1})	1.9^{a} ± 0.40	1.2^{b} ± 0.11	0.002
ECEC (cmol kg^{-1})	8.9 ± 0.15	9.7 ± 0.68	0.093
BS (%)	79.2^{b} ± 4.63	87.9^{a} ± 1.53	0.002

Note: Soil parameter values represent means ± standard deviation. Means followed by different alphabet notations in rows are statistically different at $P < 0.05$. CV = coefficient of variation.

In terms of chemical properties, the pH remained stable across depths, however, OC and TN declined significantly with depth, perhaps due to reduced biological activity and organic matter accumulation (Osujieke *et al.*, 2018). Available P also decreased notably ($P<0.05$), highlighting surface enrichment likely due to litter input, which is common in peri-urban environments. Exchangeable Ca increased slightly with depth (4.2 to 4.9 cmol(+)kg^{-1}), possibly due to leaching, while Mg and Na levels showed no significant variation. Base saturation rose significantly from 79.2% to 87.9% (p = 0.002), further confirming the relatively higher fertility status of subsoil exchange sites.

For further characterization, a correlation matrix (Figure 4) was constructed to identify interdependencies among soil properties in relation to fertility and pedogenic processes. Soil OC exhibited a strong positive correlation with TN (r = 0.9), which aligns with the established linkage between organic matter (OM) and nitrogen reserves in tropical soils (Silva *et al.*, 2021; Awwal and David, 2024). This relationship reflects the role of organic matter as a key nutrient reservoir, particularly in surface horizons where biological activity and organic inputs are concentrated (Thomas *et al.*, 2016). Similarly, the negative correlation between OC and BD (r = –0.7) is consistent with the structural benefits conferred by OM, where higher OC levels contribute to lower compaction and improved porosity (Awwal, 2021)
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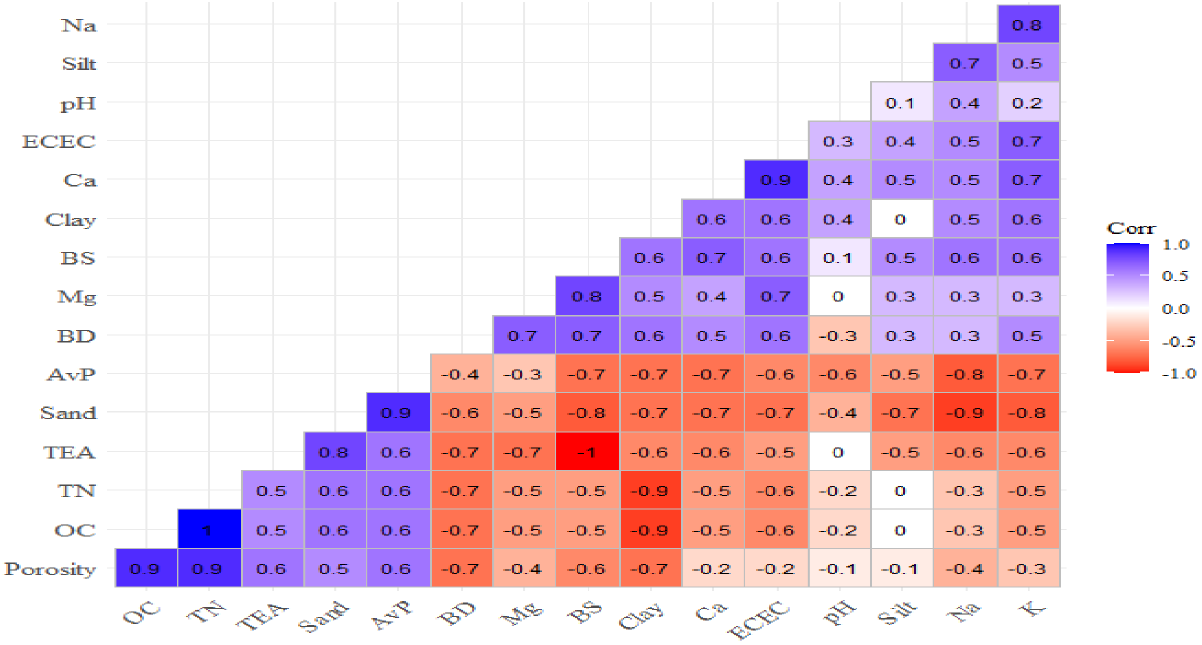

Figure 4: Pearson Correlation Matrix of Selected Physicochemical Soil Properties in the Study Area

The association between clay content and exchangeable bases, notably Ca (r = 0.6) and Mg (r = 0.8), reflects the higher cation retention capacity of fine-textured subsoils as reported by Parewa *et al.* (2023). Clay also correlated positively with BS (r = 0.6), reinforcing its role in maintaining nutrient reservoirs. These relationships are characteristic of argillic horizons, where clay illuviation enhances the soil's capacity to retain essential cations through increased surface area and charge density.

3.3 Soil Suitability for Maize Cultivation

The land parameters across the three pedons relevant for maize cultivation are summarized in Table 6, while the criteria matching against FAO ratings are presented in Table 7. Climatically, all three pedons experienced an annual rainfall of 1101.5 mm, a 150-day dry season, mean annual maximum temperature of 28°C, and relative humidity of 43%. These values are highly suitable (rated S1) for maize cultivation class based on FAO criteria (Sys *et al.*, 1993).

Topographic and wetness-related characteristics further affirm this trend. The slope in all pedons remained at a minimal 2%, categorizing them as highly suitable (S1) terrains due to reduced erosion risk and better mechanization potential. Similarly, the absence of flooding (F0) and well-drained profiles in all pedons confer strong hydrological suitability, minimizing concerns of seasonal waterlogging that could compromise root development or microbial balance.

The physical attributes of the soils reveal a uniformly sandy loam (SL) texture across all pedons, placing them in the moderately suitable (S2) class. While sandy loam benefits drainage and tillage, it limits nutrient retention compared to more clayey textures (Samuel & Dines, 2023). The absence of coarse fragments grants a perfect S1 score for mechanical suitability.

Fertility characteristics, however, present a more nuanced picture. While BS and ex. K were consistently rated as S1 across all pedons, other fertility indicators varied in suitability levels. The CEC in all soil units fell below the >13 cmol kg^{-1} threshold for moderate suitability, hence it was rated marginal (S3). Similarly, av. P values ranged between 10.11 and 12.02 mg kg^{-1}, also rated S3 due to suboptimal P availability for maize requirements.

Table 6: Agro-Environmental Characteristics of the Soil Units

Land Parameter	GP 1	GP 2	GP 3
A. Climate			
Annual rainfall (mm)	1101.5	1101.5	1101.5
Length of dry season (days)	150	150	150
Mean annual max temp. (C)	28	28	28
Relative humidity (%)	43	43	43
B. Topography			
Slope	2	2	2
C. Wetness			
Flooding (class)	F0	F0	F0
Drainage (class)	Well drained	Well drained	Well drained
D. Soil physical Characteristics			
Texture (class)	SL	SL	SL
Coarse fragments	0	0	0
E. Fertility			
CEC (cmol kg^{-1})	8.76	8.95	9.05
BS (%)	77.21	75.98	84.53
pH	6.65	6.5	6.4
OC (g kg^{-1})	1.04	0.73	1.02
Av. P (mg kg^{-1})	10.11	11.01	12.02
Total N (g kg^{-1})	0.17	0.13	0.17
Extr. K (cmol kg^{-1})	0.99	0.98	0.89

Soil OC showed the greatest inter-unit variability. Pedons GP1 and GP3 recorded 1.04 and 1.02 g kg^{-1} respectively, both rated S3. However, GP2 (0.73 g kg^{-1}) was rated rated not suitable (N1) for this property. This depletion could indicate more rapid mineralization or less organic matter accumulation in that zone. Total nitrogen (TN), a direct correlate of OC, followed a similar trend, with Units 1 and 3 rated as S1 and GP2 dropping to S2 (Table 7). These limitations yielded actual IP scores of 70.7 in GP1/GP3 and 50.0 in GP2; translating into about 70% and 50% of optimum maize yield, respectively. The potential IP of 95.0 (S1) suggests yields could reach approximately 95% of optimum under improved fertility management.

These findings are consistent with comparable peri urban maize suitability studies in Nigeria. In Makurdi, Abagyeh *et al.* (2016) found predominantly S2 suitability for maize, attributed to low nutrient levels, even under favorable climatic conditions which otherwise support high crop yield. In another study by Odoemena & Igomu (2017), it was found that soils in the peri-urban region of Makurdi ranged from N1 to S2 due to inadequate fertility, despite loamy textures and neutral pH. A broader assessment in Benue State by Ali *et al.* (2021) reported severe phosphorus depletion, Furthermore, at Abeokuta, Anthony (2023) used GIS-parametric methods and observed only 1.9% of the area classified as S1 for maize, with the majority rated marginal or not suitable due to slope, moisture deficits, and fertility deficits.

Table 7: Land Criteria Matching for Maize Cultivation in the Pedons

Land Parameter	GP 1	GP 2	GP 3
A. Climate (c)			
Annual rainfall (mm)	S1 (100)	S1 (100)	S1 (100)
Length of dry season (days)	S1 (100)	S1 (100)	S1 (100)
Mean annual max temp. (C)	S1 (100)	S1 (100)	S1 (100)
Relative humidity (%)	S1 (100)	S1 (100)	S1 (100)
B. Topography (t)			
Slope	S1 (100)	S1 (100)	S1 (100)
C. Wetness (w)			
Flooding (class)	S1 (100)	S1 (100)	S1 (100)
Drainage (class)	S1 (100)	S1 (100)	S1 (100)
D. Soil physical Characteristics (s)			
Texture (class)	S2 (70)	S2 (70)	S2 (70)
Coarse fragments	S1 (100)	S1 (100)	S1 (100)
E. Fertility (f)			
CEC (cmol kg^{-1})	S3 (50)	S3 (50)	S3 (50)
BS (%)	S1 (100)	S1 (100)	S1 (100)
pH	S2 (75)	S1 (100)	S1 (100)
OC (g kg^{-1})	S3 (50)	N1 (25)	S3 (50)
Av. P (mg kg^{-1})	S3 (50)	S3 (50)	S3 (50)
Total N (g kg^{-1})	S1 (100)	S2 (75)	S1 (100)
Extr. K (cmol kg^{-1})	S1 (100)	S1 (100)	S1 (100)
Index of Productivity (Actual)	70.71	50.00	70.71
Actual Suitability Class	S2 - sf	S2 - sf	S2 - sf
Index of Productivity (Potential)	95.00	95.00	95.00
Potential Suitability Class	S1	S1	S1

Thus, the suitability pattern observed in Gulum, featuring climatic and structural suitability counterbalanced by nutrient limitations is a recurring theme in both Nigerian rural and peri urban maize studies. This suggests the critical role of targeted soil fertility interventions to elevate actual land class from S2 to S1 and unlock yield potential across transitional agroecological zones.

4.0 Conclusion

The study revealed that approximately 70% of the peri-urban landscape in the Gulum area (≈409 ha) is cultivable, as confirmed by classification validation using independent ground-truth samples, which achieved an overall accuracy of 91.1% and a Kappa coefficient of 0.88. This high performance underscores the reliability of Random Forest within Google Earth Engine for land use/land cover mapping in peri-urban contexts, where heterogeneous land features often pose challenges to conventional approaches. Analysis of the three representative pedons indicated only minimal variation in key soil properties across the study area. While climatic, topographic, and drainage conditions were highly suitable, overall land suitability for rainfed maize production was constrained by suboptimal fertility indicators such as CEC, available P, and low to moderate OC. Under current conditions, all soil units were classified as moderately suitable (S2-sf), with Index of Productivity (IP) scores ranging from 50.0 to 70.7. According to the parametric evaluation model of Sys *et al.* (1993), these ratings correspond to yield potentials of approximately 60–75% of the crop's optimum under ideal management.

Nonetheless, the projected increase to maximum suitability (IP = 95.0) under improved fertility management highlights considerable opportunity for productivity gains. The findings advocate for targeted fertility interventions, particularly organic matter amendment and nutrient-specific supplementation, as essential strategies to unlock the land's agronomic potential. Given the favorable climate, well-drained soils, and proximity to Jalingo markets, Gulum emerges as a promising peri-urban agricultural hub for maize intensification. However, this study was limited to a single season and one crop; future research should validate suitability across multiple seasons and extend the framework to other key staples to strengthen recommendations for sustainable peri-urban agriculture.

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