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Spatial Variability of Soil Physico-Chemical Properties and its Influence on Irish Potato Production in Bokkos and Mangu Local Government Areas, Plateau State, Nigeria

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Abstract: Irish potato (*Solanum tuberosum* L.) production in Nigeria faces significant yield constraints despite favourable climatic conditions on the Jos Plateau. This study investigates the spatial variability of soil physico-chemical properties affecting Irish potato cultivation in Bokkos and Mangu Local Government Areas of Plateau State. Using geospatial techniques and inverse distance weighting (IDW) interpolation, 240 composite soil samples were collected from randomly selected potato farms at 0-30 cm depth across a 3,329.41 km² study area. Key soil parameters analyzed included texture, pH, organic matter, total nitrogen, available phosphorus, and potassium. Results revealed predominantly sandy clay loam soils (75% in Mangu, 60% in Bokkos) with significant spatial heterogeneity in chemical properties. Soil pH ranged from 4.0-7.0, with 77% of soils classified as moderately to very strongly acidic (pH < 5.36), potentially limiting nutrient availability. Organic matter content was predominantly low to very low across 67.6% of the study area (0.2-1.19%), indicating poor soil fertility status. Total nitrogen levels were critically deficient, with 83.2% of soils showing very low to low concentrations (0.01-0.084%). Available phosphorus ranged from 3.68-23.24 mg/kg, with 55.6% of soils exhibiting very low to low levels. Potassium availability was more favourable, with 51.5% of soils showing moderate to very high concentrations (0.278-0.749 cmol/kg). The spatial analysis identified central areas of both LGAs, particularly around Kerang, Ampang, Kwatas, and Daffo, as having improved soil fertility status due to volcanic ash deposits and basaltic parent materials. These findings indicate that 45-55% of the study area possesses adequate soil conditions for potato production, while the other areas requires targeted soil amendment strategies including liming, organic matter incorporation, and balanced fertilization to optimize yields.

Keywords: *Irish Potato, Soil Fertility, Spatial Variability, Geospatial Analysis, Jos Plateau, Nigeria.*

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I. INTRODUCTION

Irish potato (*Solanum tuberosum* L.) is an annual, herbaceous, tuber crop of the family Solanaceae, representing the world's largest non-cereal crop and ranking fourth globally in importance after maize, wheat, and rice in terms of area and production (FAOSTAT, 2016). The crop is highly sensitive to temperature and rainfall, requiring cool growing seasons with moderate, well-distributed rainfall of 800-1200 mm and temperatures below 27°C for optimal tuber development.

Global potato production reached approximately 375 million tons in 2022, with China (95.5 million tons) and India (56 million tons) leading production (FAOSTAT, 2022). In Africa, potato production is estimated at 25 million metric tonnes with an average yield of 13,215.4 kg/ha and per capita consumption of 18.76 kg/capita/year (FAOSTAT, 2019). Egypt leads African production with 6,155,467 metric tonnes, followed by South Africa (2,528,946 metric tonnes) and Morocco (1,768,362 metric tonnes). Nigeria ranks as the fourth largest producer in sub-Saharan Africa and seventh in Africa, with an output of 1,216,409 metric tons and yield of 37,201 hg/ha (FAOSTAT, 2022).

Irish potato was introduced to Nigeria in the early 19th century in Plateau State, specifically on the Jos Plateau (Taiy et al., 2017; Tadesse et al., 2018). The crop has become a

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major root crop in Nigeria due to its efficiency in tuber yield and short maturity period (80-90 days), allowing multiple planting cycles annually. The Potato Research Centre at Kuru-Vom in Plateau State actively promotes improved production through seed multiplication, farmer training, research, and development of responsive varieties (Zemba et al., 2013).

However, Nigerian potato productivity remains constrained by multiple factors including pests and diseases, inadequate quality seed supply, poor storage facilities, declining soil fertility from intensive cultivation, unsuitable varieties, and high labour costs. Consequently, Nigeria records one of the world's lowest average potato yields at approximately 3.1 tons per hectare, significantly below the global average.

Soil fertility is a critical factor limiting agricultural productivity, particularly for nutrient-demanding crops like Irish potato. Understanding spatial variability in soil properties is essential for developing site-specific management strategies to optimize crop yields. This study aims to examine the spatial variability of physico-chemical soil properties and their impact on Irish potato production across Bokkos and Mangu LGAs, providing insights for targeted soil management interventions.

II. MATERIALS AND METHODS

A. Study Area Description

The research area encompasses two Local Government Areas (LGAs) in the central zone of Plateau State: Bokkos and Mangu, both significant Irish potato producers. The study area is located between latitudes 9°01'50.2"N and 9°44'6.5"N, and longitudes 8°41'27"E and 9°19'56"E, at approximately 600 meters above sea level (Figure 1). Bokkos covers approximately 1,472 km², while Mangu spans about 1,645 km², totaling 3,329.41 km².

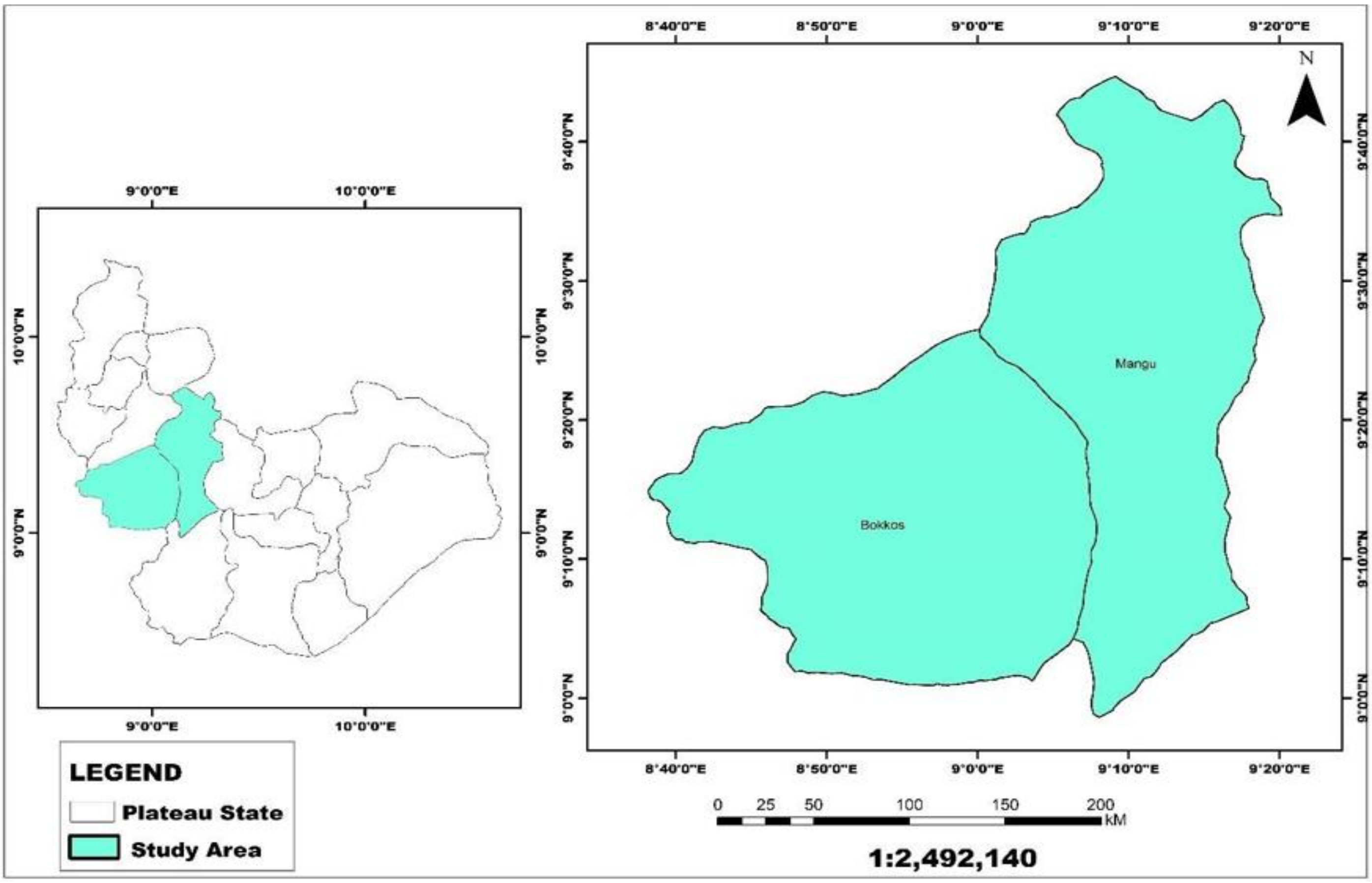

Fig 1 Location map of the study area showing Mangu and Bokkos Local Government Areas

Both LGAs experience similar climatic conditions typical of the Jos Plateau, with average maximum temperatures around 34°C and minimum temperatures of 27°C. The warmest months occur from March to May, while the coldest period is during December and January during the Harmattan season. The rainfall season extends from April to October, followed by a dry season with cold winds from November to February. This climate is conducive to Irish potato cultivation, which thrives at optimal temperatures around 27°C for tuber formation.

The study area falls within the northern guinea savannah vegetation zone and is characterized by diverse land use patterns, primarily agricultural, with Mangu LGA comprising approximately 65% and Bokkos LGA about 60% agricultural land. Various crops including Irish potatoes, maize, beans, soybeans, and other cereals are cultivated in the region.

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B. Geology

Geologically, the study area features Pre-Cambrian Basement rocks, particularly migmatite-gneiss complexes that significantly influence soil formation and fertility (Figure 2). The dominant geological formations include granitic rocks, which weather to produce sandy-clay and loamy soils rich in clay minerals. Newer basaltic rocks are found mainly in Kerang and Ampang, while older basaltic boulders occur in parts of Bokkos and Mangu. Soils derived from these basaltic rocks and volcanic ashes are particularly productive for food crops, especially at altitudes between 1,600-3,000 m around Kerang.

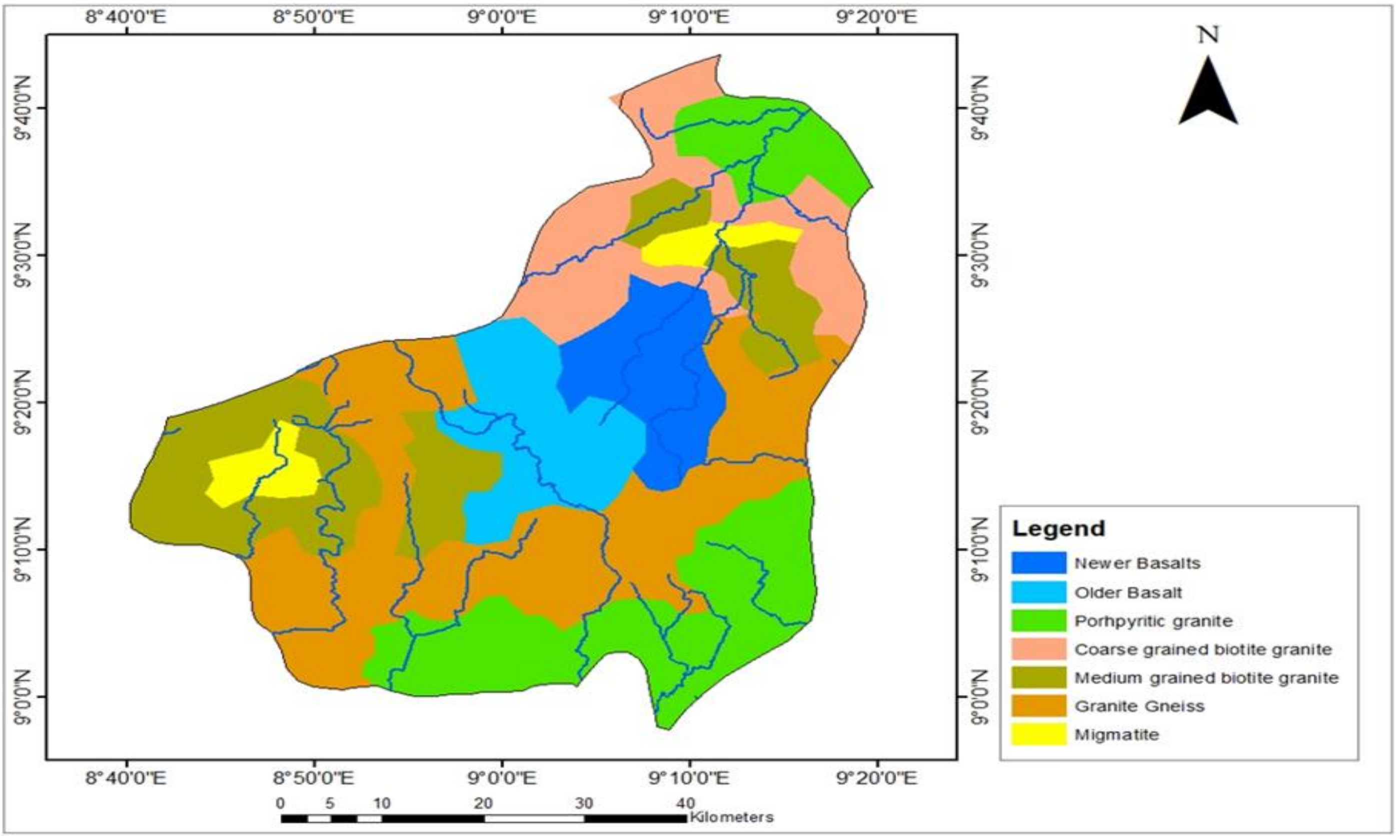

Fig 2 Geological map showing the distribution of rock types in Mangu and Bokkos LGAs

C. Data Collection and Analysis

A geospatial approach was employed to assess soil variability across selected farms in both LGAs. Nigeria Sat-2, ASTERDEM (30m resolution), and Sentinel (10m resolution) satellite imagery, along with climatic data (rainfall, temperature, and relative humidity), were acquired from the National Space Research and Development Agency (NASRDA) and online sources.

Field equipment included GPS receiver, soil auger, plastic buckets, polythene bags, hand trowel, permanent markers, masking tape, hardcover notebooks, and pens. Four sub-samples were collected from randomly selected Irish potato farms using soil sampling auger at 0-30 cm depth. The collected sub-samples were thoroughly mixed to create one composite sample per location. Exact sample locations were recorded using a handheld 78MAPCSx GPS receiver in situ.

A total of 240 composite samples were collected from different farming communities within both LGAs. Samples were stored in clean, labelled polythene bags with unique identifiers for laboratory analysis. Soil parameters tested included texture, pH, organic matter, total nitrogen, available phosphorus, and potassium.

Laboratory analyses followed standard procedures: soil texture by hydrometer method, pH by 1:2.5 soil-water ratio using a pH meter, organic matter by Walkley-Black method, total nitrogen by Kjeldahl method, available phosphorus by Bray-1 method, and exchangeable potassium by flame photometry after ammonium acetate extraction.

Spatial analysis was conducted using ArcGIS software with inverse distance weighting (IDW) interpolation to create continuous surface rasters of each soil property. Classification of soil parameters followed established international standards for agricultural soil fertility assessment.

III. RESULTS

A. Soil Texture

The study area is characterized by nine textural classes, with sandy clay loam predominating (Figure 3). In Mangu, sandy clay loam covers 75% of the area, while in Bokkos, sandy loam occupies over 60% of the total area. These soil textures are generally suitable for agricultural production, particularly for potato and maize cultivation. Silty clay loam represents the smallest proportion in both LGAs.

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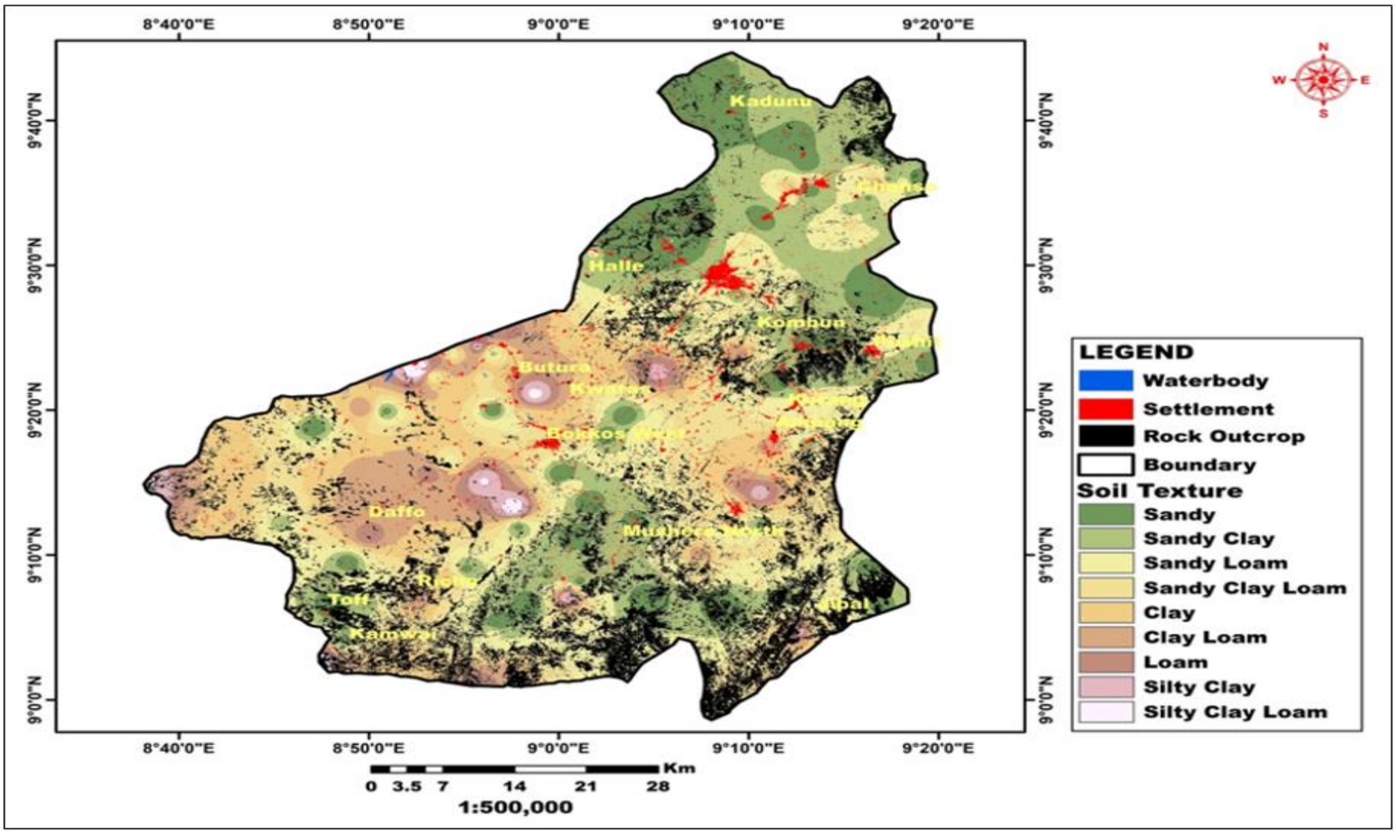

Fig 3 Soil Texture for Mangu and Bokkos LGAs

B. Soil pH

Soil pH values across the study area ranged from 4.0 to 7.0, showing significant spatial variability (Figure 4, Table 1). The distribution revealed that 31%, 28%, 17%, 19%, and 4% of soils were classified as very strongly acidic, strongly acidic, moderately acidic, slightly acidic, and neutral, respectively. Mangu's spatial distribution indicated a pH range of 4.3-7.0, while Bokkos showed a more restricted range of 4.0-5.6.

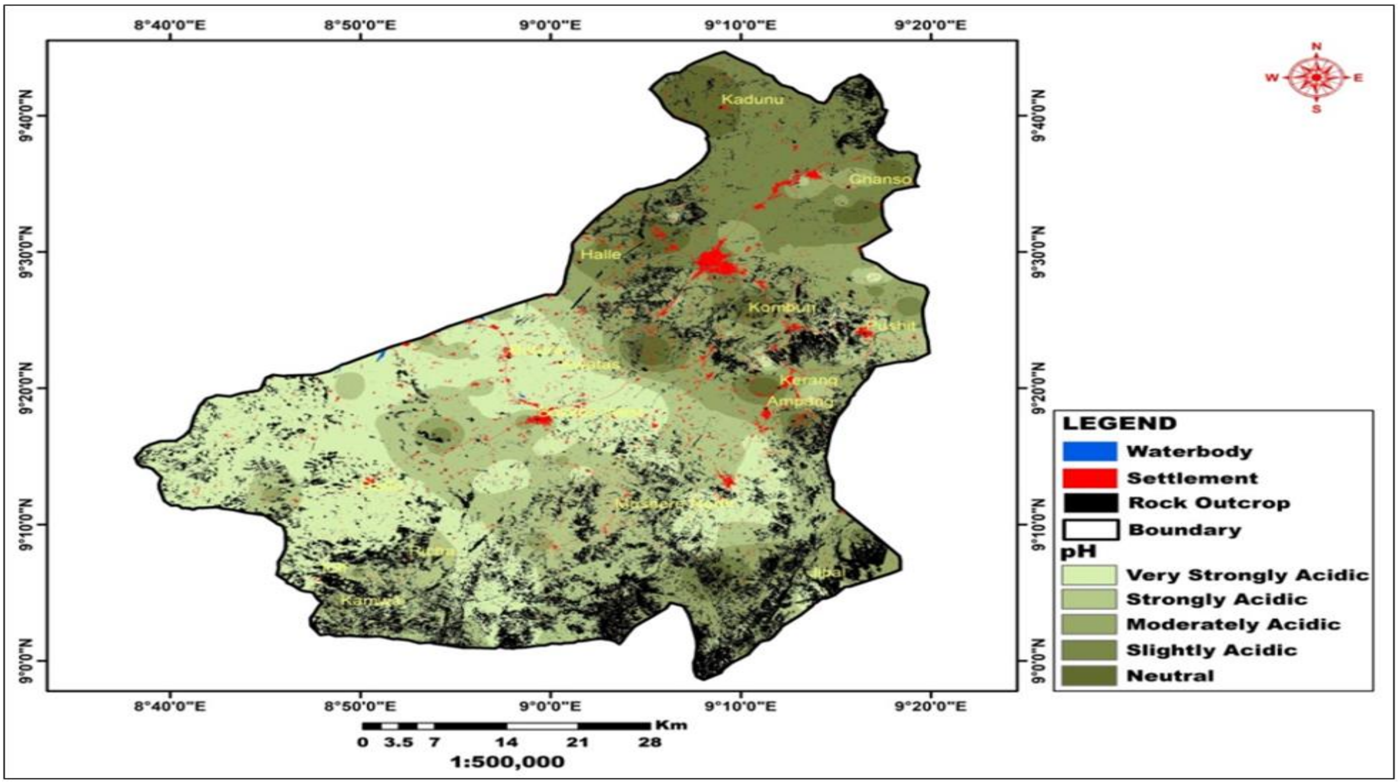

Fig 4 Spatial distributions of soil pH for Mangu & Bokkos LGAs

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Table 1 Area coverage and percentage of each soil pH category

pH Class	pH Range	Area (km²)	Percentage (%)
Very strongly Acidic	4.050 - 4.793	850.84	32.0
Strongly Acidic	4.793 - 5.065	758.58	28.6
Moderately Acidic	5.065 - 5.360	453.23	17.1
Slightly Acidic	5.360 - 5.678	477.20	18.0
Neutral	5.678 - 7.059	116.81	4.4
Total		**2656.65**	**100.0**

Approximately 77% of the study area exhibited acidic conditions (pH < 5.36), with Mangu and Bokkos showing moderately to very strongly acidic soils across 60% and 74.5% of their respective areas.

C. Soil Organic Matter

The spatial distribution of organic matter showed distinct geographical patterns (Figure 5, Table 2). Very low, low, and moderate levels covered 789.59 km² (29.7%), 1,008.15 km² (37.9%), and 542.07 km² (20.4%) respectively. Combined very low and low organic matter content accounted for 67.6% of the total area, indicating poor soil fertility status across most of the study area.

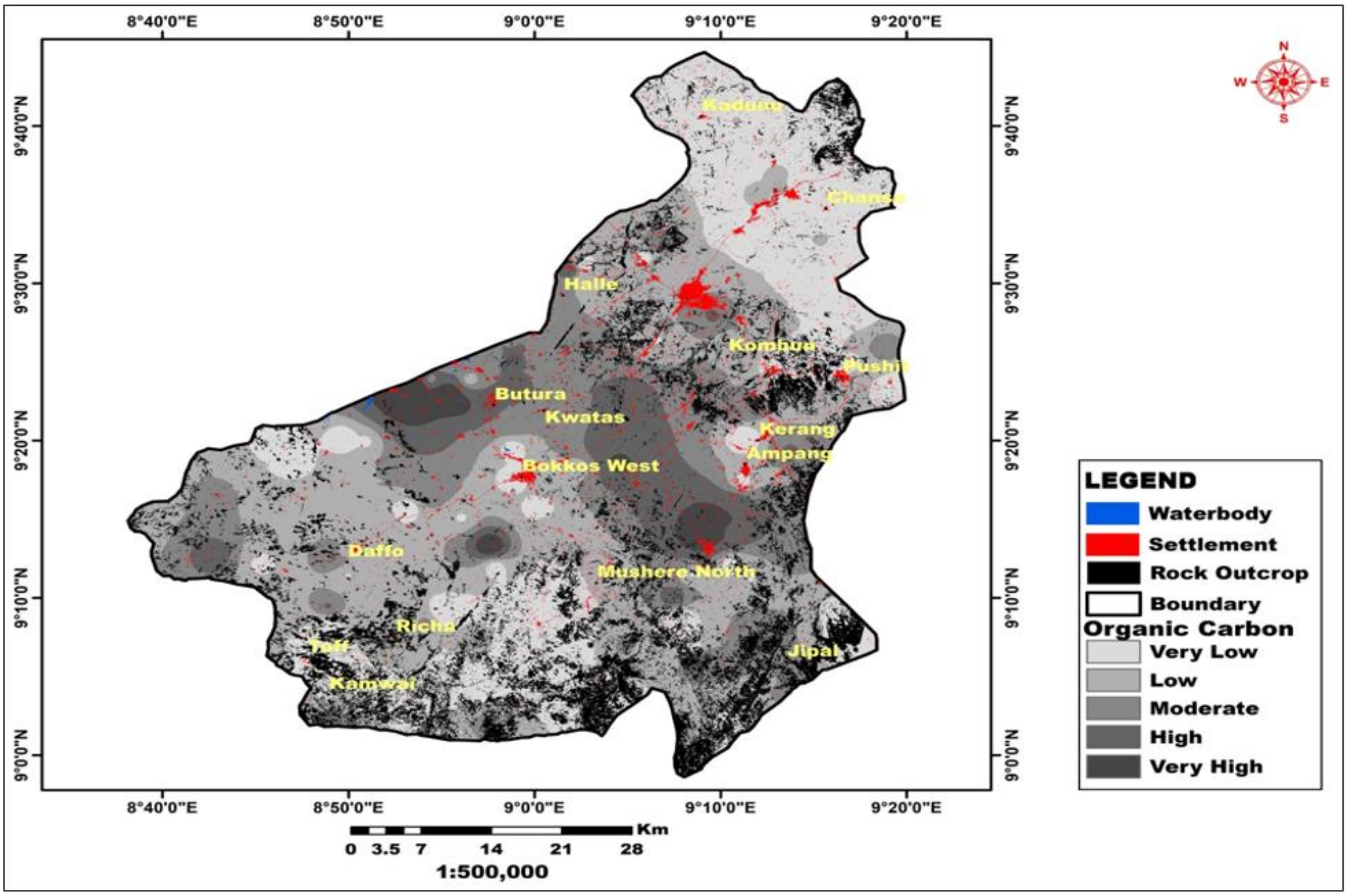

Fig 5 Spatial distributions of Organic Matter (%) for Mangu & Bokkos LGAs

Table 2 Area coverage and percentage of each organic matter category

Class	Concentration Range (%)	Area (km²)	Percentage (%)
Very Low	0.200 - 0.892	789.59	29.7
Low	0.892 - 1.187	1008.15	37.9
Moderate	1.187 - 1.520	542.08	20.4
High	1.520 - 2.059	251.98	9.5
Very High	2.059 - 3.469	64.86	2.4
Total		**2656.65**	**100.0**

Higher organic matter concentrations were observed in central areas of both LGAs, particularly around Kerang, Ampang, Kwatas, and Daffo, associated with basaltic soils and volcanic ash deposits.

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D. Total Nitrogen

Total nitrogen distribution showed critical deficiency across most of the study area (Figure 6, Table 3). Very low and low nitrogen levels covered 1,132.49 km² (42.6%) and 1,078.12 km² (40.6%) respectively, totalling 83.2% of the area. Higher nitrogen concentrations were concentrated in central portions of both LGAs, particularly in areas with basaltic parent materials.

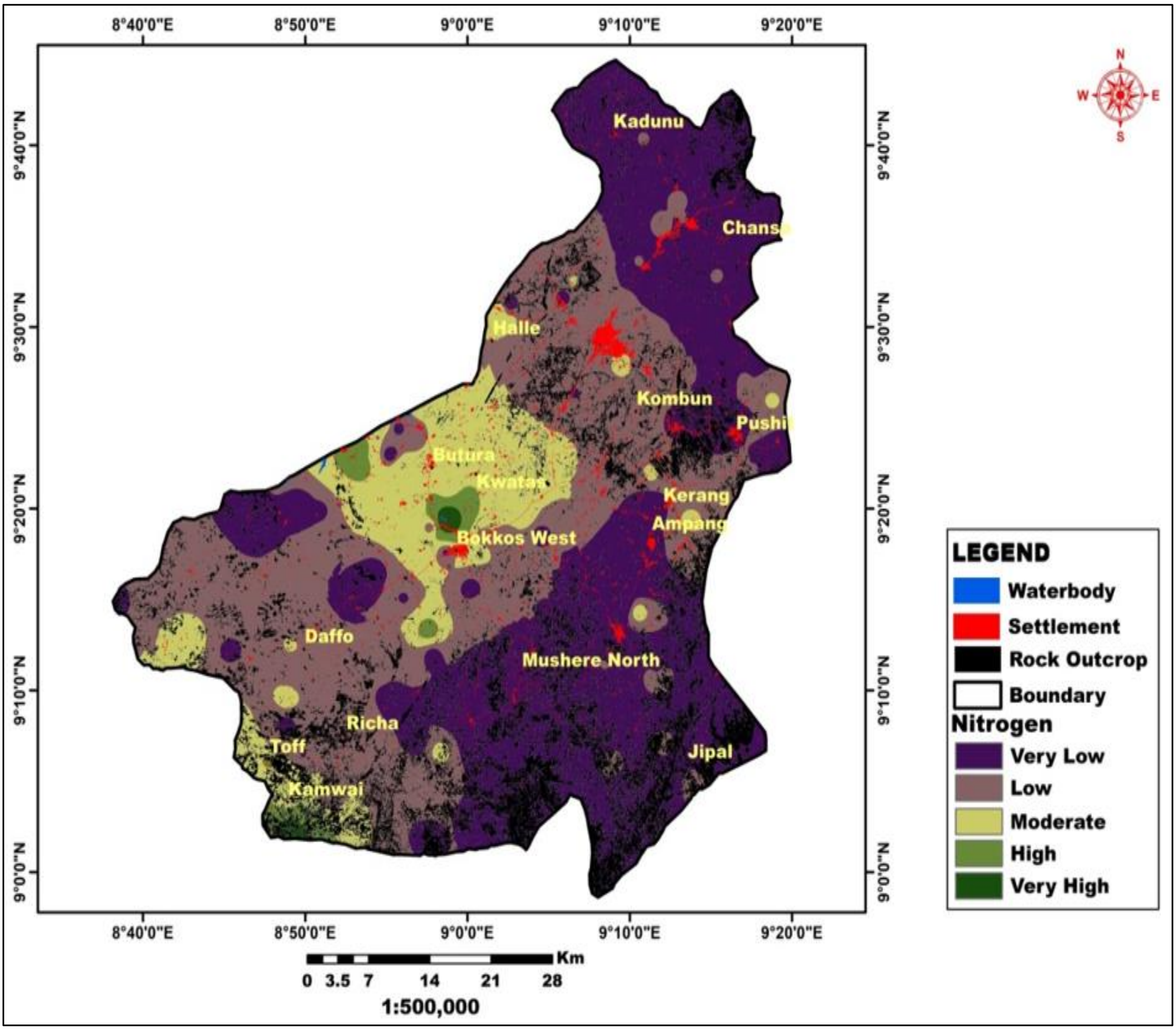

Fig 6 Spatial distributions of Total Nitrogen (%) for Mangu & Bokkos LGAs

Table 3 Area coverage and percentage of each total nitrogen category

Class	Concentration Range (%)	Area (km²)	Percentage (%)
Very Low	0.010 - 0.055	1132.49	42.6
Low	0.055 - 0.084	1078.12	40.6
Moderate	0.084 - 0.137	394.14	14.8
High	0.137 - 0.285	43.55	1.6
Very High	0.285 - 0.579	8.35	0.3
Total		**2656.65**	**100.0**

E. Available Phosphorus

Available phosphorus content ranged from 3.68 to 23.24 mg/kg (Figure 7, Table 4). Very low and low phosphorus levels were distributed across 734.25 km² (27.6%) and 744.39 km² (28.0%) respectively, totalling 55.6% of the study area. Higher phosphorus concentrations were conspicuous in central areas, particularly around Kerang, Ampang, Kwatas, and Daffo.

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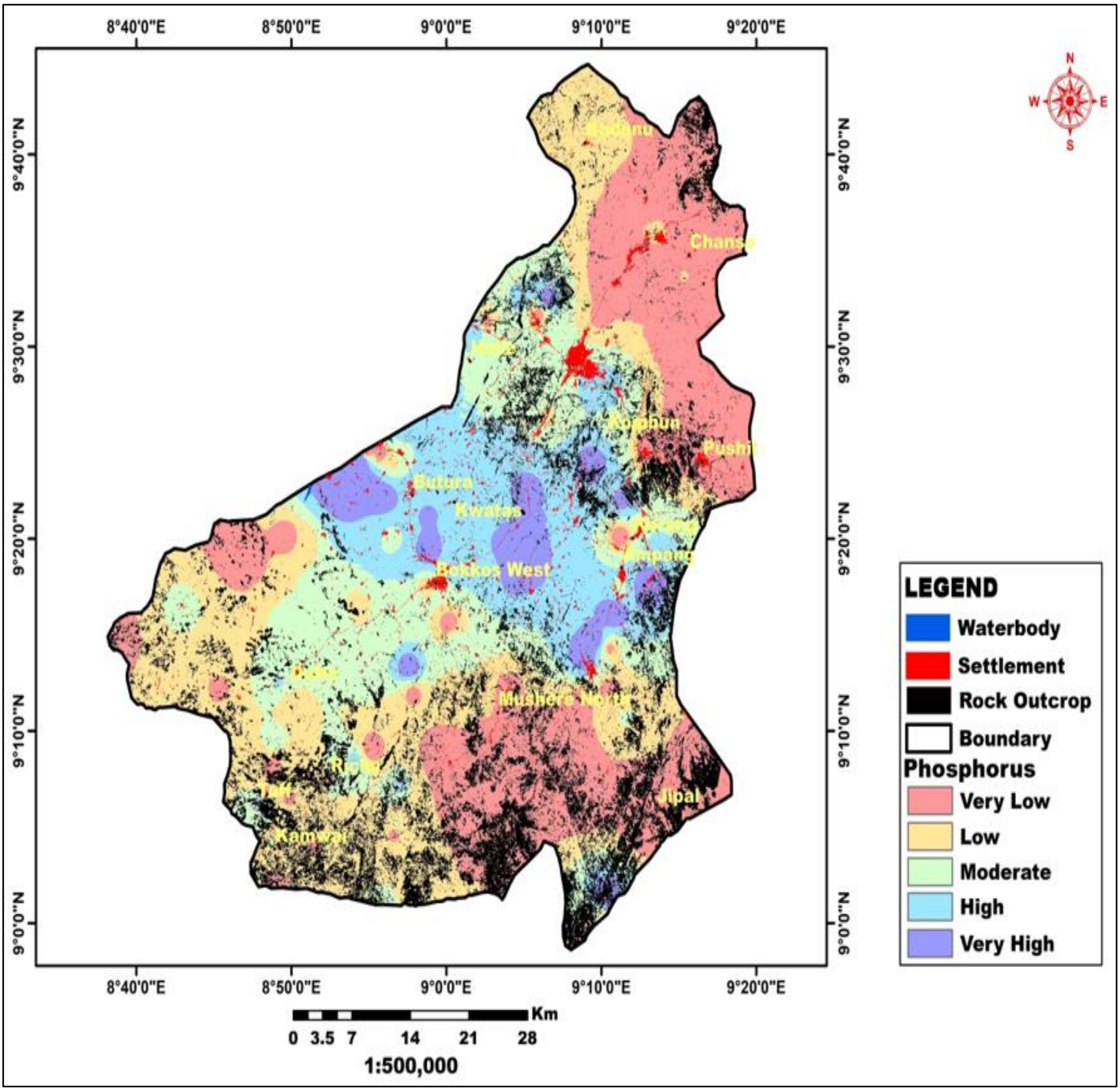

Fig 7 Spatial Distributions of soil Phosphorus (mg/kg) for Mangu &Bokkos LGAs

Table 4 Area coverage and percentage of each phosphorus category

Class	Concentration Range (mg/kg)	Area (km²)	Percentage (%)
Very Low	3.690 - 6.834	734.25	27.6
Low	6.834 - 8.905	744.39	28.0
Moderate	8.905 - 11.283	578.40	21.8
High	11.283 - 14.045	443.82	16.7
Very High	14.045 - 23.249	155.78	5.9
Total		**2656.65**	**100.0**

F. Available Potassium

Potassium showed the most favourable distribution among nutrients analyzed (Figure 8, Table 5). Moderate levels occupied 891.21 km² (33.5%), while low levels covered 868.09 km² (32.7%). Combined moderate to very high potassium levels accounted for 51.5% of the study area, indicating relatively better potassium availability compared to other nutrients.

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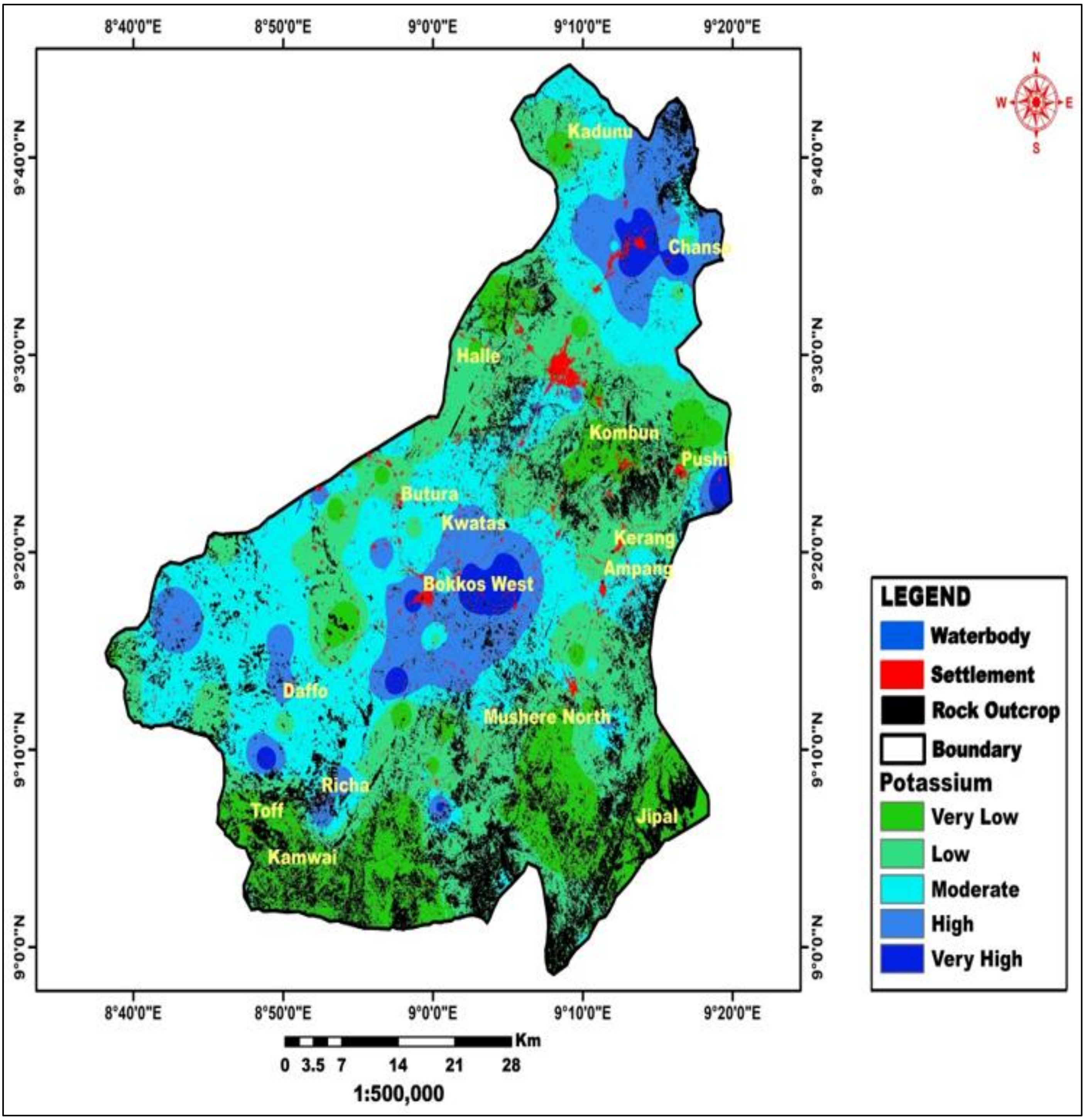

Fig 8 Spatial distributions of Potassium (cmol (+)/kg) for Mangu and Bokkos LGAs

Table 5 Area Coverage and Percentage of each Potassium Category

Class	Concentration Range (cmol/kg)	Area (km²)	Percentage (%)
Very Low	0.100 - 0.222	419.49	15.8
Low	0.222 - 0.278	868.09	32.7
Moderate	0.278 - 0.334	891.21	33.5
High	0.334 - 0.426	395.81	14.9
Very High	0.426 - 0.749	82.05	3.1
Total		**2656.65**	**100.0**

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IV. DISCUSSION

➤ *Soil Texture Suitability for Irish Potato Production*

The predominance of sandy clay loam and sandy loam textures across the study area provides generally favourable conditions for Irish potato cultivation. These textures offer optimal drainage while maintaining adequate moisture retention capacity essential for tuber development. The notable absence of purely sandy soils suggests that extremely well-drained conditions may not support optimal potato production in this region.

The textural preferences observed align with the geological influence of parent materials. Soils derived from granitic rocks contain substantial clay content generated from feldspar breakdown and other clay-forming minerals. The volcanic activities around Kerang, particularly near Pidong crater lake, have contributed fine-grained materials that enrich soil silt content, potentially explaining higher potato yields in Mangu compared to Bokkos. Volcanic ash deposits from previous volcanic activities around Kerang and Ampang have further enhanced soil physical properties, creating highly productive agricultural soils.

➤ *Soil Acidity Constraints*

The widespread soil acidity across 77% of the study area represents a significant constraint to Irish potato production. Extreme pH values below 5.0 can severely limit nutrient availability, particularly phosphorus, calcium, and magnesium, while potentially increasing aluminum and manganese toxicity. The spatial distribution shows that 59% of soils classified as strongly to moderately acidic could significantly reduce potato growth and yield without intervention.

The acidic conditions likely result from intensive cultivation practices, high rainfall causing base cation leaching, and the inherent acidic nature of granitic parent materials. Areas with higher pH values, particularly around volcanic deposits, benefit from the buffering capacity of basaltic materials rich in basic cations.

➤ *Organic Matter and Nitrogen Deficiency*

The critical deficiency in soil organic matter (67.6% very low to low) and total nitrogen (83.2% very low to low) represents the most severe limitation to potato production across the study area. Low organic matter content directly impacts soil fertility through reduced nutrient availability, poor soil structure, decreased water holding capacity, and limited microbial activity.

The spatial pattern of organic matter distribution correlates strongly with geological parent materials, with higher concentrations observed in areas with basaltic soils around Kerang, Ampang, Kwatas, and Daffo. The low organic matter content in other areas may be attributed to high decomposition rates under tropical conditions, intensive cultivation without adequate organic inputs, and soil erosion removing surface organic layers.

Nitrogen deficiency across 83.2% of the study area severely limits potato production potential. Nitrogen is essential for vegetative growth, leaf development, and photosynthesis, directly affecting tuber formation and yield. The deficiency likely results from organic matter decomposition, leaching under high rainfall conditions, and inadequate nitrogen fertilization practices.

➤ *Phosphorus Availability Challenges*

Available phosphorus levels below optimal ranges across 55.6% of the study area present significant challenges for potato production. Phosphorus is critical for root development, energy transfer, and tuber formation. The low phosphorus availability is likely due to soil acidity, which reduces phosphorus solubility and increases fixation by iron and aluminum oxides common in tropical soils.

The spatial distribution shows higher phosphorus concentrations in central areas with basaltic parent materials, suggesting that volcanic ash and basaltic rock weathering provide more available phosphorus compared to granitic materials.

➤ *Favorable Potassium Status*

Potassium availability presents the most favorable nutrient status, with 51.5% of the study area showing moderate to very high levels. This is advantageous for potato production, as potassium is essential for tuber development, water regulation, disease resistance, and overall plant health. The relatively better potassium status may be attributed to the abundance of potassium-bearing minerals in both granitic and basaltic parent materials.

➤ *Spatial Patterns and Soil Management Implications*

The spatial analysis reveals distinct patterns of soil fertility, with central areas of both LGAs, particularly around Kerang, Ampang, Kwatas, and Daffo, showing superior soil conditions. These areas benefit from basaltic parent materials and volcanic ash deposits that provide better nutrient availability and soil buffering capacity.

The findings indicate that approximately 45-55% of the study area possesses adequate soil conditions for potato production, while the remainder requires targeted interventions. Priority management strategies should include:

- **Lime application** in acidic soils to raise pH and improve nutrient availability
- **Organic matter incorporation** through compost, manure, or cover crops to address organic matter and nitrogen deficiencies
- **Phosphorus fertilization** particularly in areas with very low to low phosphorus levels
- **Balanced fertilization programs** based on soil test recommendations
- **Soil conservation practices** to prevent erosion and maintain soil organic matter

➤ *Implications for Sustainable Potato Production*

The spatial variability in soil properties necessitates site-specific management approaches rather than blanket recommendations. Areas with favourable soil conditions can support intensive potato production with minimal inputs, while degraded areas require substantial soil improvement investments.

The concentration of favourable soil conditions around volcanic deposits suggests that similar geological environments should be prioritized for potato production expansion. However, sustainable intensification of existing productive areas while rehabilitating degraded soils represents the most viable approach for increasing overall potato production in the region.

V. CONCLUSIONS

This study demonstrates significant spatial variability in soil physico-chemical properties across the Irish potato production areas of Bokkos and Mangu LGAs. The predominant sandy clay loam textures provide suitable physical conditions for potato cultivation, but widespread soil acidity (77% of area) and critical deficiencies in organic matter (67.6%) and nitrogen (83.2%) severely limit production potential.

The spatial analysis identified central areas of both LGAs, particularly around Kerang, Ampang, Kwatas, and Daffo, as having superior soil fertility due to basaltic parent materials and volcanic ash deposits. These areas represent 45-55% of the study area with adequate soil conditions for optimal potato production.

The findings highlight the need for targeted soil management strategies including liming acidic soils, incorporating organic matter, balanced fertilization, and soil conservation practices. Site-specific management approaches based on the spatial patterns identified in this study can significantly improve potato yields and production sustainability in the region.

Future research should focus on validating these soil fertility maps through field trials, developing economic models for soil improvement interventions, and investigating the long-term impacts of different management practices on soil quality and potato productivity.

ACKNOWLEDGMENTS

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