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Peri-Urban Land Suitability Analysis for Sustainable Agriculture and Food Security Using Space Derived Data in Makurdi, Benue State

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Abstract: Soil properties in Makurdi's peri-urban areas are critical factors for sustainable food production. The increasing insecurity in rural areas in Benue State has led to widespread displacement of farmers, and the expansion of Internally Displaced Persons (IDP) camps in and around the peri-urban, thus, making it a pressure zone for intensive agricultural cultivation. The study investigates the agricultural land in Makurdi's peri-urban zone in order to promote sustainable farming. This is accomplished by determining and integrating soil parameters (soil pH, organic matter, N, P, K). Samples were collected using a stratified random sampling method based on soil variability. A total of 100 soil samples were gathered from various farmlands around the peri-urban zone and analyzed in the laboratory. The spatial analysis was performed using the inverse distance weighting interpolation (IDW) approach. The results revealed three textural classes predominantly sandy loam with spatial coverage of 1120.07 Km^2, accounting for 82.25% of the area. The soil pH ranged from less than 5 to 7.1, with slightly acidic, moderately acidic, and strongly acidic soil accounting for 32.9%, 21.2%, and 22.1%. This clearly demonstrates that acidic soil with a pH range of 5-6.1 is found in more than 80% of the whole area. The study area has a diverse spatial distribution of soil organic matter concentration, with moderate level (OM) accounting for 42.9% of the total area. Total nitrogen (N) levels varies from 0.0286 - 0.144. The IDW with low (0.06), moderate (0.076) and high levels (0.096) of available N distributed in the north, central and southern parts. These covered more than 80% of the study area with spatial coverage of 346.64, 351.37 and 396.18 Km^2 representing 25.5%, 25.8% and 29.1%. The spatial distribution of the available Phosphorus (P) showed that the soil with low and moderate content (3.996mg kg^{-1}) and (5.135 mg kg^{-1}) covered more than 61% of the total area, extending to the central parts as well as to the eastern and southern parts. The available potassium (K) concentration varies from 0.16 – 0.489 cmol (+)/kg. The distribution appears to have nearly comparable concentrations at the low, moderate, and high levels accounting for 22.7%, 25.8% and 28.2% respectively. The weighted overlay analysis of soil properties show that more than 95% of the region isp suitable, with locations ranging from moderately suitable to suitable spanning 1,360.22 Km^2 of the total area of 1,381.83 km^2. Overall, the results reveal that more than 98.36% of the land is adequately suited for food production. Despite population increase and increasing insecurity, the land has historically supported agricultural practices for food availability in cities and IDP camps. Areas with high suitability can be further investigated for the purpose of setting up large scale integrated farms that can improve the state's capacity in agriculture and contribute towards food security. The study therefore suggests a relatively large-scale cultivation of exotic crops in the peri-urban region for income generation and improved livelihood.

***Keywords**: Soil Properties, Suitability, Spatial Analysis, Peri Urban, Texture.*

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I. INTRODUCTION

Land capability for food production is a method of determining the appropriateness of land for sustainable agriculture and food security. The ability of a region's land to produce food can be improved by assessing soil qualities, fertility, topography, and climate. Food production in and around cities is an essential component of the urban and peri-urban fabric in many developing countries. The Global Food Security Index (GFS 2018) found that Nigeria's food security performance was poor. The Food and Agriculture Organization of the United Nations (2015) defined peri-urban agriculture as "agriculture practices within and around cities that compete for resources that could also serve other purposes to satisfy the needs of the urban population." Food security is considered as a condition in which all people have constant physical, social, and economic access to sufficient, safe, and nutritious food that fits their dietary needs and food preferences for an active and healthy life (Bolanle and Oluwafisayo 2018). In Africa, urban and peri-urban agriculture is critical for diversifying urban diets and delivering environmental benefits in these places. Peri-urban regions are considered as 'superficial' rural areas that are within the orbit of immediate urban hubs, or areas that surround major population concentrations (Houston, 2015). These locations are also known as 'exurban areas'. According to Anupama, & Pandey (2023), peri-urban agriculture is defined as agriculture that has been undertaken on the periphery or fringes of urban areas and dynamic interface between urban cities and rural areas. Peri-urban agriculture (UPA) has become an essential activity for sustaining urban livelihoods (Bello 2014). According to Rosenberg (2012), Rural and peri-urban agriculture supports around 55% of the world's population. The middle belt in Nigeria is well known for its intensive and extensive agricultural practices. Many of our cities have historically learned to depend on the middle belt for supply of wide variety of food such as yam, cassava, sweet and Irish potato, rice, maize, guinea corn, groundnut, soya beans etc. which are grown in the region. According to the Benue State Ministry of Agriculture and Natural Resources (Benue State Government, 2013), about 80% of the population of Benue state depends on agriculture for their sustenance and livelihood. The State is a rich agricultural region where varieties of crops grow and thrive. No wonder it is called the “Food Basket of the Nation”. To develop an effective and sustainable plan for peri-urban agriculture, its potential should be examined through land evaluation, characterization, and land use planning. Peri-urban agriculture accounts for the majority of global urban food supply and has the ability to alleviate poverty and improve food security in Makurdi's urban households. Poor data collection and documentation methods are a major restriction to peri-urban agriculture growth in Nigeria (Alina et al, 2022). Some of the main causes of the unprecedented cultivation of Makurdi town's peri-urban areas include the government policy encouraging civil servants to cultivate food crops and the growing insecurity in farming communities in Benue State. It is against this background that this study seeks to investigate or examine the soil properties in peri-urban area of Makurdi using geospatial techniques.

II. STUDY AREA

The study area is located in Makurdi, Benue state of Nigeria (Figure 1). It is specifically situated in the peri-urban fringes of about 25km round the town, which lies between Latitudes $7^0$32’27.06" N and $7^0$53’48.3" N and Longitudes $8^0$22’52.01" E and $8^0$43’ 8.6" E (Figure 1) with spatial coverage of about 1361.83km^2. The area is traversed by River Benue as a very prominent and key natural resource central to the economic growth within the sub region. The Benue River is an important river in West Africa, located in Nigeria. It is the Niger River's main tributary, measuring around 1,400 kilometers long (Agbaje et al, 2018). It is among Nigeria's most important rivers, providing water for farming, transportation, and other purposes. It serves as a major transportation route in the areas through which it flows. According to recent predictions from Nigeria's National Population Commission, Benue State's population could have reached 5.7 million by 2021 (National Population Commission, 2022). These rocks are mostly sandstone, sandstone and clay, sandstone and mudstone, clay, and alluvial sand which dominated the low-lying areas. Climate is the key factor influencing agricultural productivity in Makurdi. Given agriculture's critical role in human welfare, there have been concerns raised regarding the possible consequences of climate change on agricultural output. The area typically receives rainfall amount of about 135 millimeters to 150mm and has 160 rainy days annually. The dry season begins in November with a harmattan and ends in March with heat, whereas the wet season begins in April with high humidity and precipitation and finishes in October. The proximity to the River Benue helps to regulate temperatures, with riverfront regions significantly cooler than inland areas. Makurdi's temperature remains high throughout the year, with February and March being the hottest months, causing increasing heat stress in the area.

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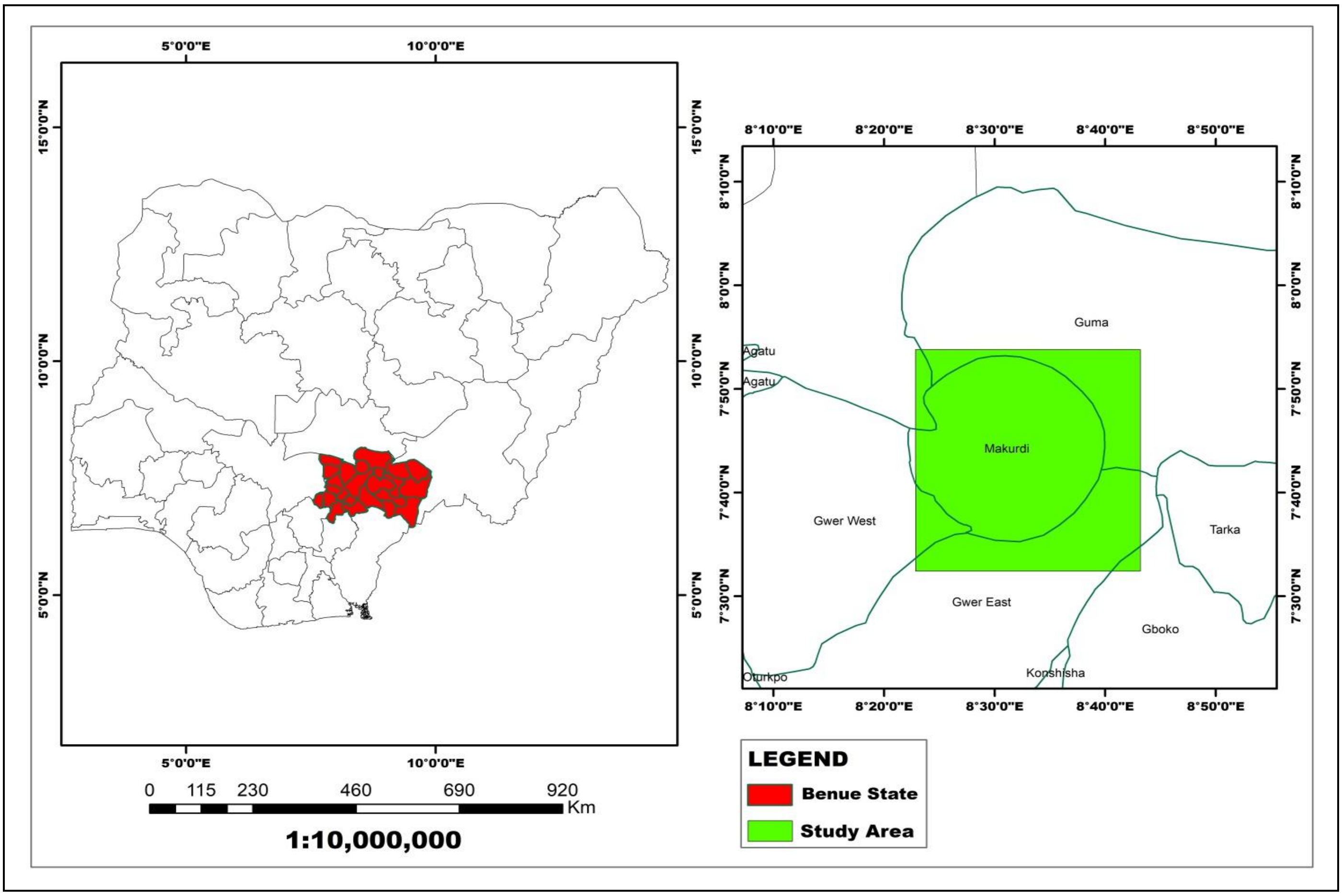

Fig 1 Map of the Study Area

III. MATERIALS AND METHOD

The materials used for the project are auger, polythene bag, permanent marker, desktop, ArcGIS 10.8, Global Positioning System (GPS map), hand trowel, plastic bucket, field map, camera. The geographical positions of all sample points were determined and recorded using a handheld GARMIN GPSMAP 78s receiver in the field. Four sub samples were collected from randomly selected farm locations using soil sampling auger at depths of 0–30cm. The sub samples collected were thoroughly mixed to have one composite. A stratified random sampling procedure was done to assign soil sampling points to the area. Subsequently, the geographical information system (GIS) was employed, and grid-based soil samplings were assigned to avoid the distance variation on the neighborhood effect. A total of 100 soil samples from different farms in the periphery of urban fringe within Makurdi town were collected and recorded for analysis. A systematic random sampling procedure was done to assign soil sampling points to the area.

- *Chemical Analysis*

The soil samples were analyzed for their physicochemical properties (N,P,K,pH,Organic Matter, Mn,Mg,Ca,Zn,Fe and Na).

- *Spatial Analysis*

The soil parameter values (N, P, K, pH, and OM) were entered into an attribute table and integrated with ArcGIS 10.8 to create a relational database. The parameters were plotted as a point map, then transformed to shapefiles and analyzed in ARCGIS 10.8 using the spatial interpolation method of inverse distance weighted analysis (IDW) in the spatial analyst extension tool. The inverse distance weighted technique of analysis was used because it is a sort of spatial moving average that estimates the value at an unsampled place using a weighted average of known observations. The weights allocated to known values are based on regional patterns and correlations that may exist. This type of analysis slices the output using the natural break technique into variable spatial extents. It has been observed that among different methods of spatial interpolation of soil properties, IDW is an optimal interpolation method. It is an advanced interpolation procedure that generates an estimated surface from a scattered set of points with Z-values. The soil parameters (pH, organic matter, N, P, K)) were compared against each other using Analytical Hierarchical Calculator (AHP) in a pair – wise comparison matrix. A numerical value expressing the level of importance of one parameter against another was assigned. Each raster was assigned a percentage of influence according to its importance derived for crop production.

- *Thematic Maps*

Thematic Maps were produced using point data of the soil parameters which were interpolated across the study area. Their classes were defined as Very low, Low, Medium, High and Very High for soil macro and micro-nutrients such as

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Organic matter, total Nitrogen, available Phosphorus and available Potassium, others are Manganese, Calcium, Sodium, Magnesium, Zinc and Iron. For soil pH, Strongly Acidic, Moderately Acidic, Slightly Acidic, Very Slightly Acidic and Neutral were considered.

➢ *Weighted Overlay*

The weighted overlay incorporated several rasters using a common measurement scale and weights each parameter according to its importance. The suitability map was determined; all the parameters were compared against each other using Analytical Hierarchical Calculator (AHP) in a pair – wise comparison matrix which was a measure of the relationship between the parameters in order to rule out bias. Subsequently, a numerical value expressing the level of importance of one parameter against another was assigned. Each raster was assigned a percentage of influence according to its importance derived for crop production. Therefore, the weights used for the overlay were relative percentages vertically compared for each parameter, and the sum of the percentage weights of influence added up to 100% for each soil parameter.

IV. RESULTS AND DISCUSSION

A. *Soil Texture*

The results revealed that Makurdi sandy loam and sandy clay loam are the most common soil textures in the area, accounting for more than 70% of the total (Figure 3 and Table1). These are generated from the parent materials, sandstone and limestone, which occur in more than half of the area, demonstrating a spatial link between lithological units and soil textures. These soils are favourable for the cultivation of crops such as rice, cassava, yam, cocoyam, soybean, fruits and vegetables.

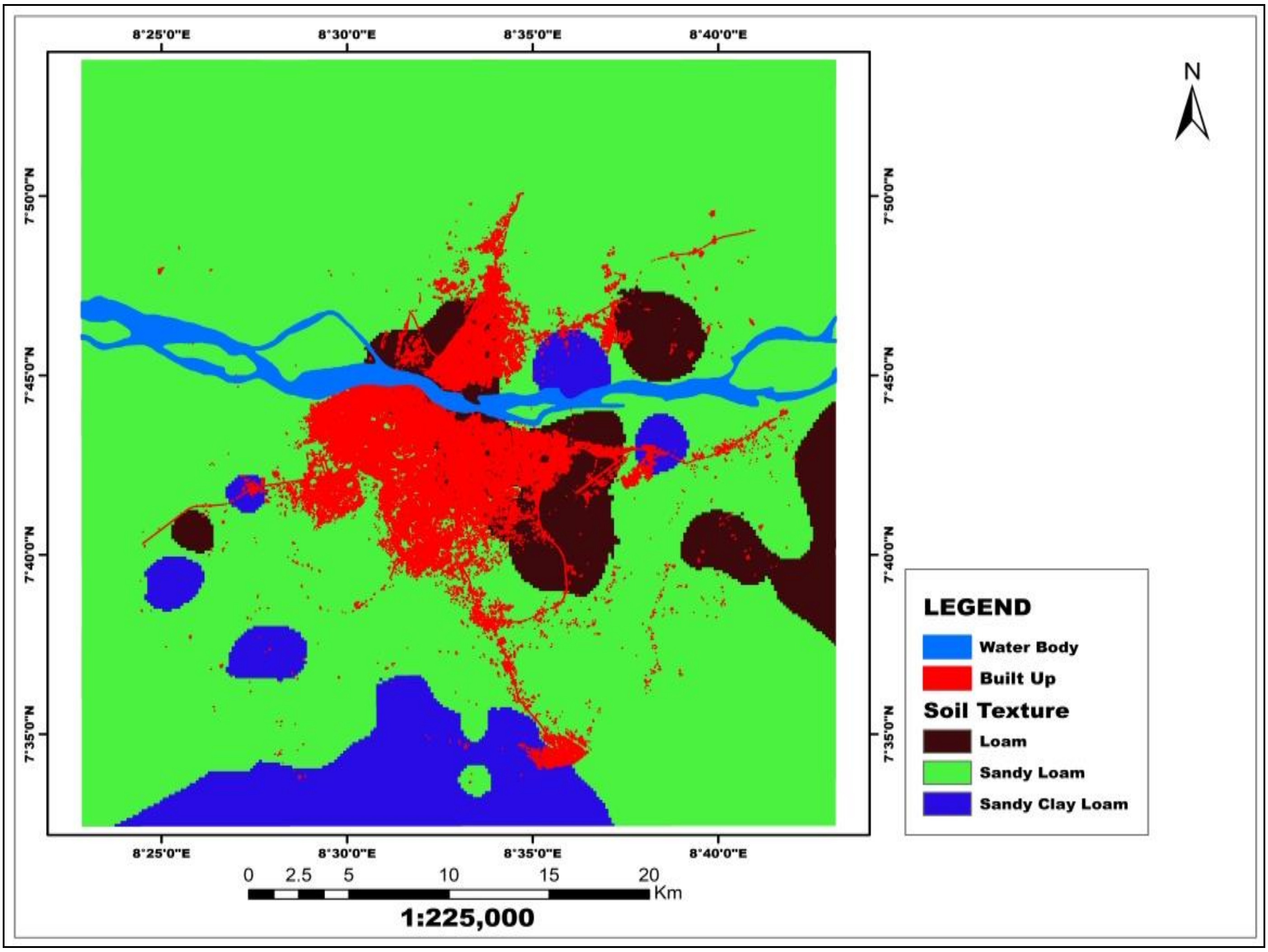

Fig 2 Soil Texture Status

Table 1 Area (Km^2) Coverage and Percentage of each Soil Class

Class Name	Area (km^2)	Percentage (%)
Sandy Clay Loam	126.6475	9.30
Sandy Loam	1120.0778	82.25
Loam	115.1085	8.45
Total	**1361.83**	**100**

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B. Soil pH

The pH value distribution in the study region ranged from less than 5 to 7.1, with slightly acidic, moderately acidic, and strongly acidic soil accounting for 32.9%, 21.2%, and 22.1% (Figure 5 and Table2). This clearly demonstrates that acidic soil with a pH range of 5-6.1 occupies more than 80% of the whole area. The implication is that the soil pH influences nutrient availability by altering the form of the nutrient inside the soil. Plants often grow effectively at pH levels over 5.5. A soil pH of 6.5 is generally regarded optimal for nutrient availability. Most micronutrients are less readily available at high pH. Extreme pH values reduce or alter the availability of most nutrients, as well as microbial activity. It was discovered that a substantial portion (76.1%) of the research region falls between 5.6 and 6.4. This implies that a large portion of the land is suitable for most crops. This clearly explains the prevalence of farming activities in these peri-urban areas.

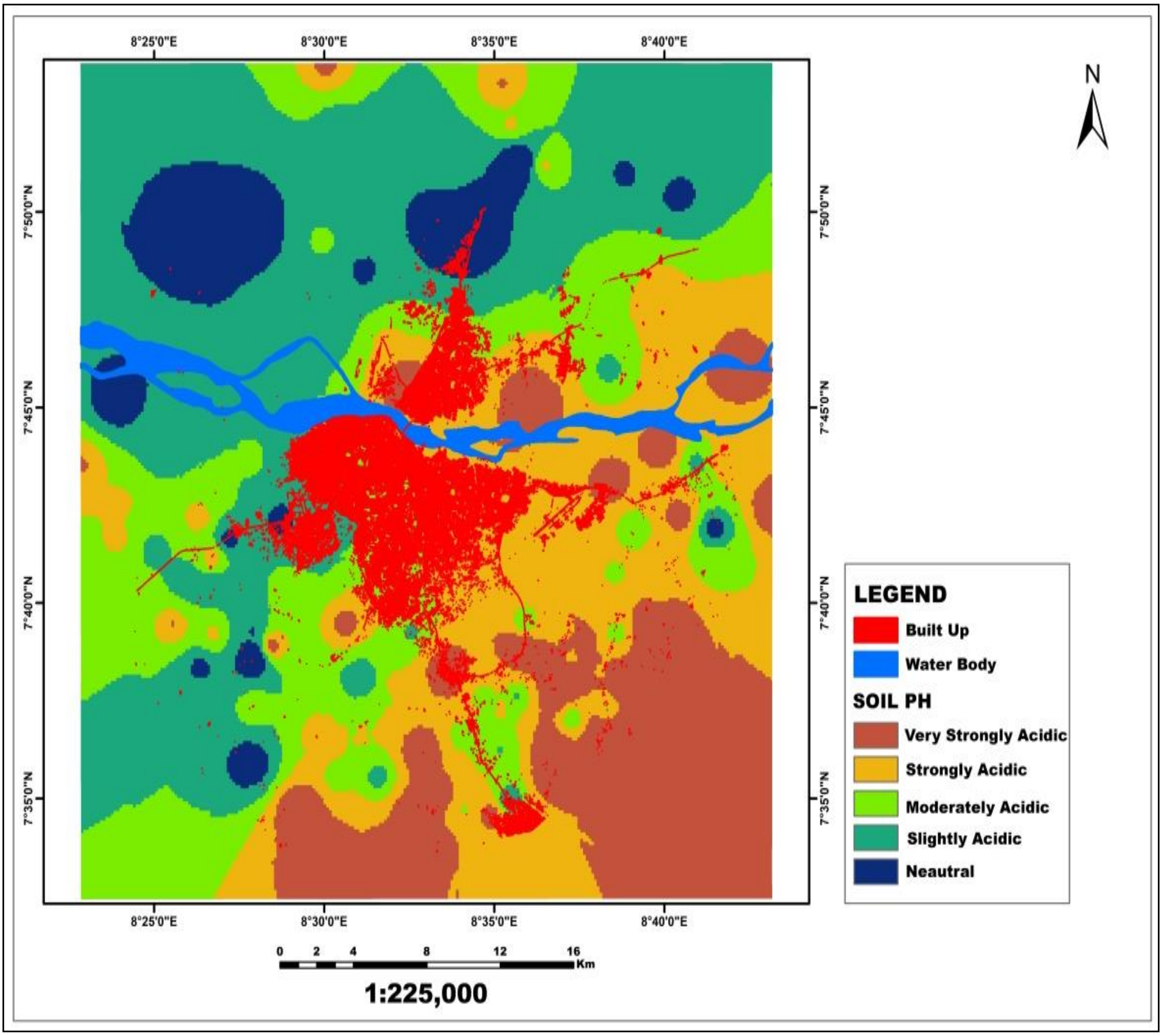

Fig 3 Spatial Distributions of Soil pH

Table 2 Area (km^2) coverage and percentage of each category of Soil pH

pH		Area (km^2)	Percentage (%)
< 5.0	Very Strongly Acidic	233.73	17.16
5.6–5.9	Strongly Acidic	299.76	22.01
5.9-6.1	Moderately Acidic	288.13	21.16
6.1-6.4	Slightly Acidic	448.51	32.93
6.4-7.1	Neutral	91.69	6.74
Total		**1361.82**	**100**

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C. Organic Matter

They revealed a diverse spatial distribution of soil organic matter concentration, with low-level (OM) accounting for 42.9% of the total area (Table 3). The result of the analysis indicates that much of the area is dominated by low and moderate organic matter concentration ranges (Figure 6). The moderate and higher concentrations in the area are likely as the result of soil management (the use of animal dung). Animal dung increased soil nutrient (NPK by 2.8, 0.6 and 2.4 percent respectively) as reported by Thomas (2022). Areas with moderate levels accounted for 26.8%. Because the research area is characterized by tropical forest and other flora, organic matter is the primary source of nitrogen in the soils, with plant and animal residues accounting for the majority of this. Thomas (2022) asserted that most soil fertility experts believe that higher amounts of soil organic matter are related to increased productivity because of its contribution to water holding capacity, improved soil structure, and supply of nutrients.

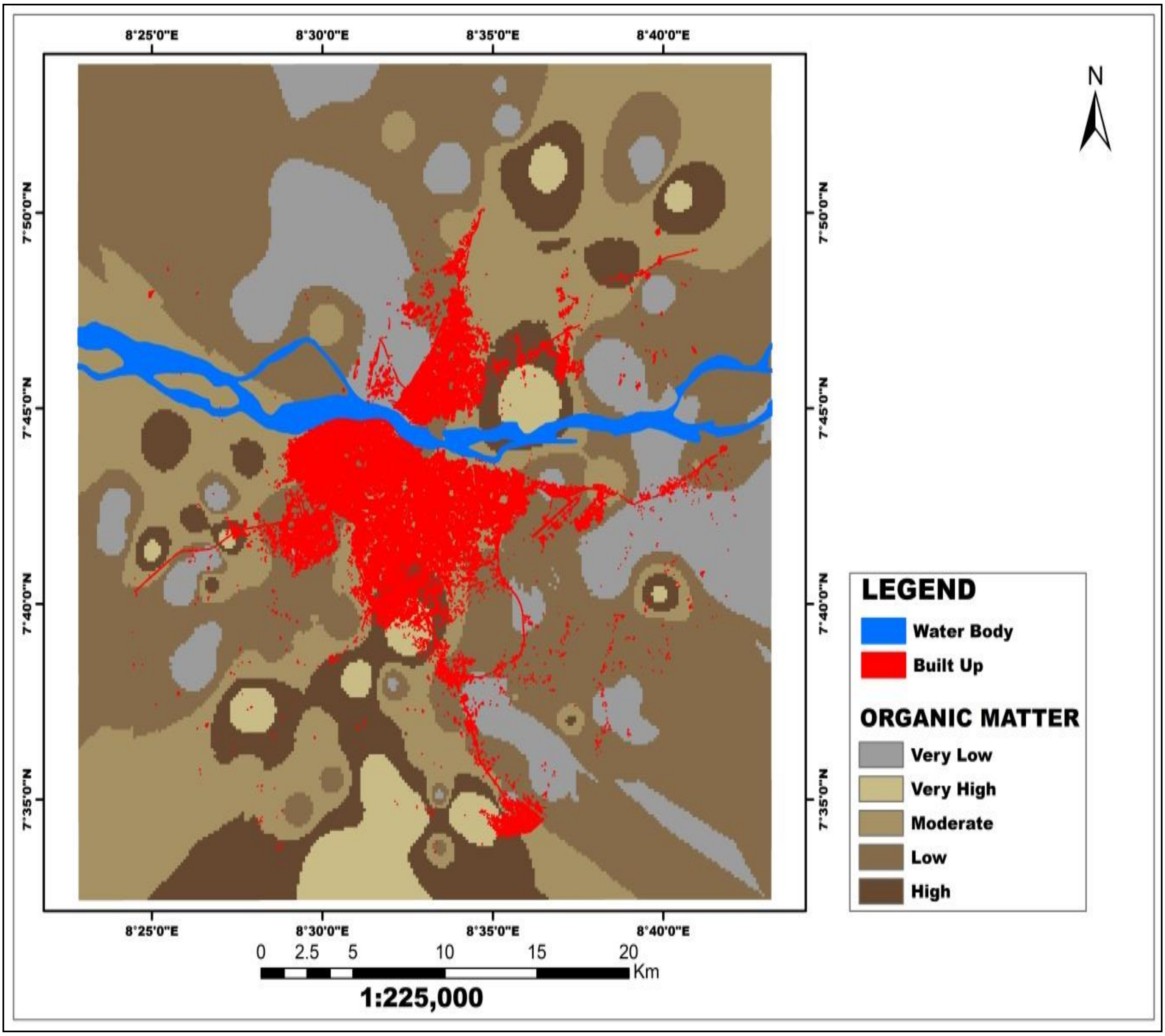

Fig 4 Spatial Distributions of Soil Organic Matter

Table 3 Area (km^2) Coverage and Percentage of each Category of Soil Organic Matter (OM)

Class	Area (km^2)	Percentage (%)
Very low	207.66	15.25
Low	583.52	42.85
Moderate	365.28	26.82
High	143.75	10.56
Very High	61.62	4.52
Total	**1361.83**	**100**

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D. Total Nitrogen (N)

The spatial distribution of nitrogen (N) levels in the study area varies from 0.0286 - 0.144 (Table 4). The IDW map showed low (0.06), moderate (0.076) and high levels (0.096) of available N distributed in the north, central and southern parts. These occupy more than 80% of the study area with spatial coverage of 346.64, 351.37 and 396.18 Km^2 representing 25.5%, 25.8% and 29.1% (Figure 7 and Table 4). While very low and very high appears to be the least coverage occupying 182.64 and 84.9 Km^2 of the study, accounting for 13.4% and 6.2% of the total area respectively (Table 4). It was observed that high concentration of nitrogen coincides with the occurrences of sandstone in the study area, indicating spatial relationship. This is especially true of the alluvial sands lining the river Benue.

Nitrogen is essential for plant development, since it plays a fundamental role in energy metabolism and protein synthesis. Nitrogen is absorbed by the plant in the form of a nitrate. This macronutrient is directly related to plant growth. It is indispensable for photosynthesis activity and chlorophyll formation. The organic matter content and total nitrogen were quite low in some places and has been attributed to poor vegetative growth, fast rate of decomposition, and the high temperature of the ecological zone as asserted by Abah (2016). However, the low content of nitrogen in the study area could be attributed to burning of bush and plant residue during the farming season, leaching and the high rate of organic matter decomposition by micro-organisms, as well as adsorption of nitrogen due to continuous farming. The low levels of organic matter and total nitrogen cannot sustain intensive cropping, and the application of fertilizers is necessary. The presence of higher concentration of organic matter could be due to incorporation of organic matter on the upper layer of the soil, through roots and other plant residues and manures. Singh et al., (2014) and Shrivas et al., (2020) reported almost similar result.

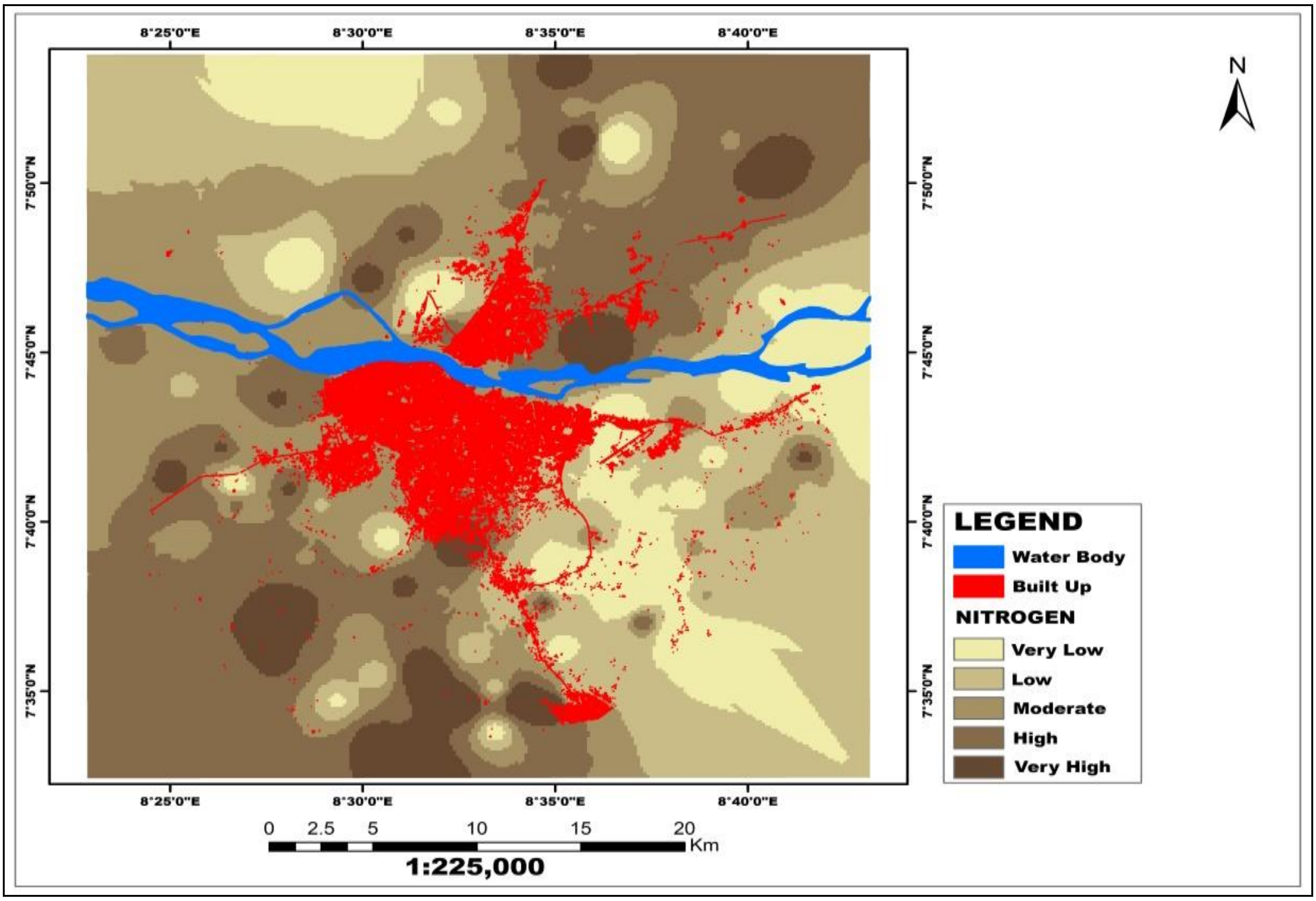

Fig 5 Spatial Distributions of Total Nitrogen (N)

Table 4 Area (km^2) Coverage and Percentage of each Category of Soil Organic Matter (OM)

Class	Area (km^2)	Percentage (%)
Very low	182.64	13.41
Low	346.64	25.45
Moderate	351.37	25.80
High	396.18	29.09
Very High	84.9	6.24
Total	**1361.83**	**100**

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E. Available Phosphorus

The spatial distribution of the available Phosphorus showed that the soil with low and moderate content of P (between 3.996mg kg^{-1} and 5.135 mg kg^{-1}) covered more than 61% of the total area and occupies the central parts of the area, extending to the eastern and southern parts of Makurdi town (Figure 8 and Table 5). The primary source of phosphorus inputs in soils is from the application of chemical fertilizers and organic manure. According to Well (2017), Most of the P in the soil is tied up chemically in a form that is unavailable to a crop in any given growing season. Indeed, the amount of P available to plants is very low compared to its total amount in the soil. The temperature of the soil and the amount of soil moisture can also influence the availability of soil P and its rate of uptake by plants.

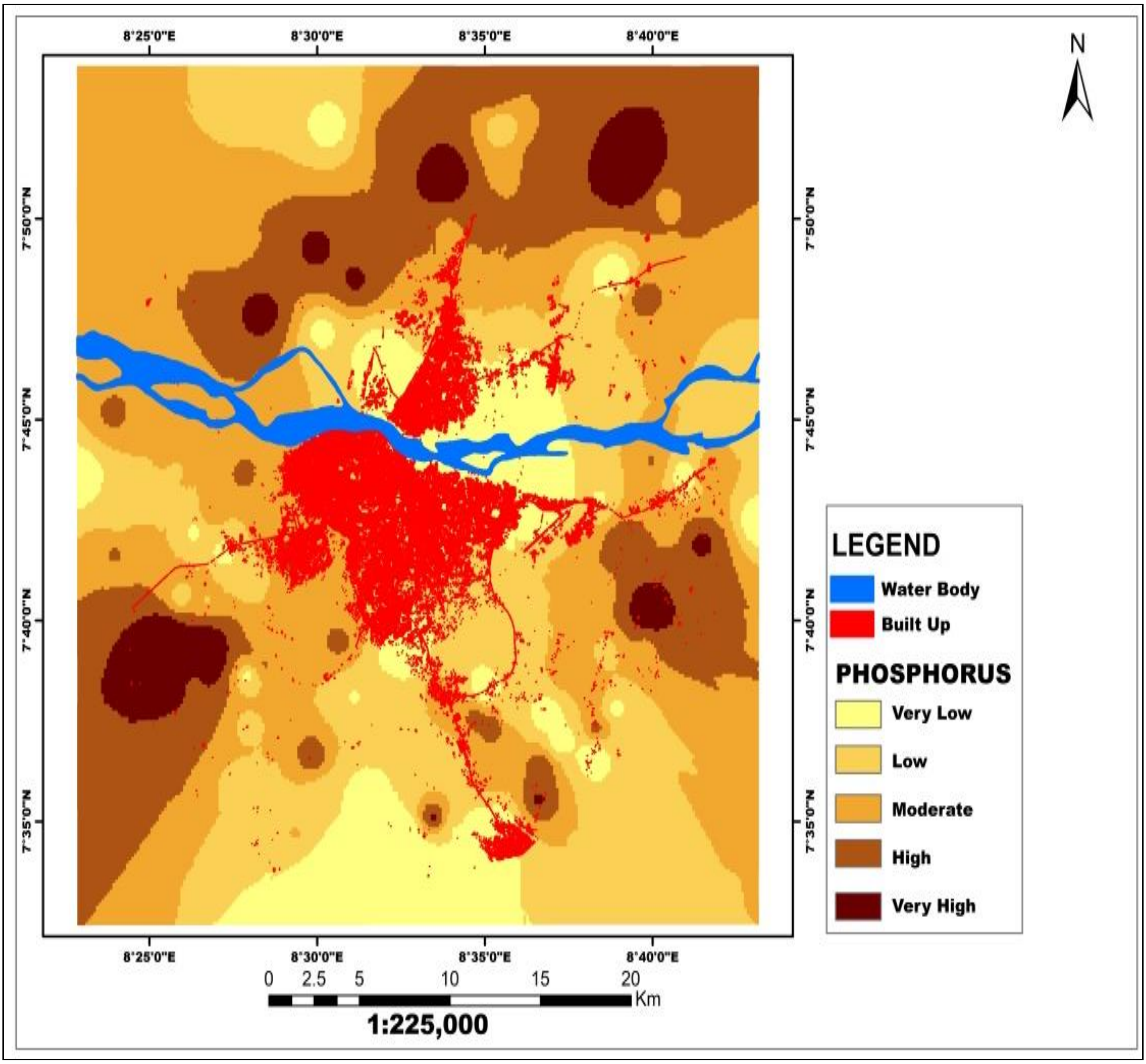

Fig 6 Spatial Distributions of Phosphorus (P)

Table 5 Area (km^2) Coverage and Percentage of each Category of Available Phosphorus (P)

Class	**Area (km^2)**	**Percentage (%)**
Very low	154.42	11.34
Low	379.86	27.89
Moderate	474.61	34.85
High	296.69	21.79
Very High	56.23	4.13
Total	**1361.83**	**100**

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F. Available Potassium (K)

The spatial distribution of available potassium varies from 0.16 – 0.489 cmol (+)/kg. The distribution ranges from very low, low, moderate, high, very high (Figure 9). The low, moderate and high levels peaking at 0.277, 3.28 and 0.387 cmol (+)/kg of available potassium respectively occupies more than 72% of study area with spatial coverage of 352.45, 25.28 and 22.70 Km^2 (22.7% 25.86% and 25.28%) (Table 6). While very low and very high concentrations of available potassium presented the least areal coverage with 12.34% and 13.81% of the total area. It was observed that the spatial distribution of K corresponds to P at the low, moderate, and high levels (Table 8 and Table 9). The spatial distribution of Potassium (K) appears to have nearly comparable concentrations at the low, moderate, and high levels accounting for 22.7%, 25.8% and 28.2% respectively. The variation of potassium in the soils within the area could be associated with the occurrence of potassium feldspars (K-Feldspar) in the underlying sedimentary rocks, with high and very high concentration in places with the occurrence of sandstone. Also, bush burning activities in most places may also contribute to significant concentration of potassium in the area. The periodic application of chemical fertilizers (NPK) in some parts of Gwer and Agan could also have some effect on the concentration of potassium.

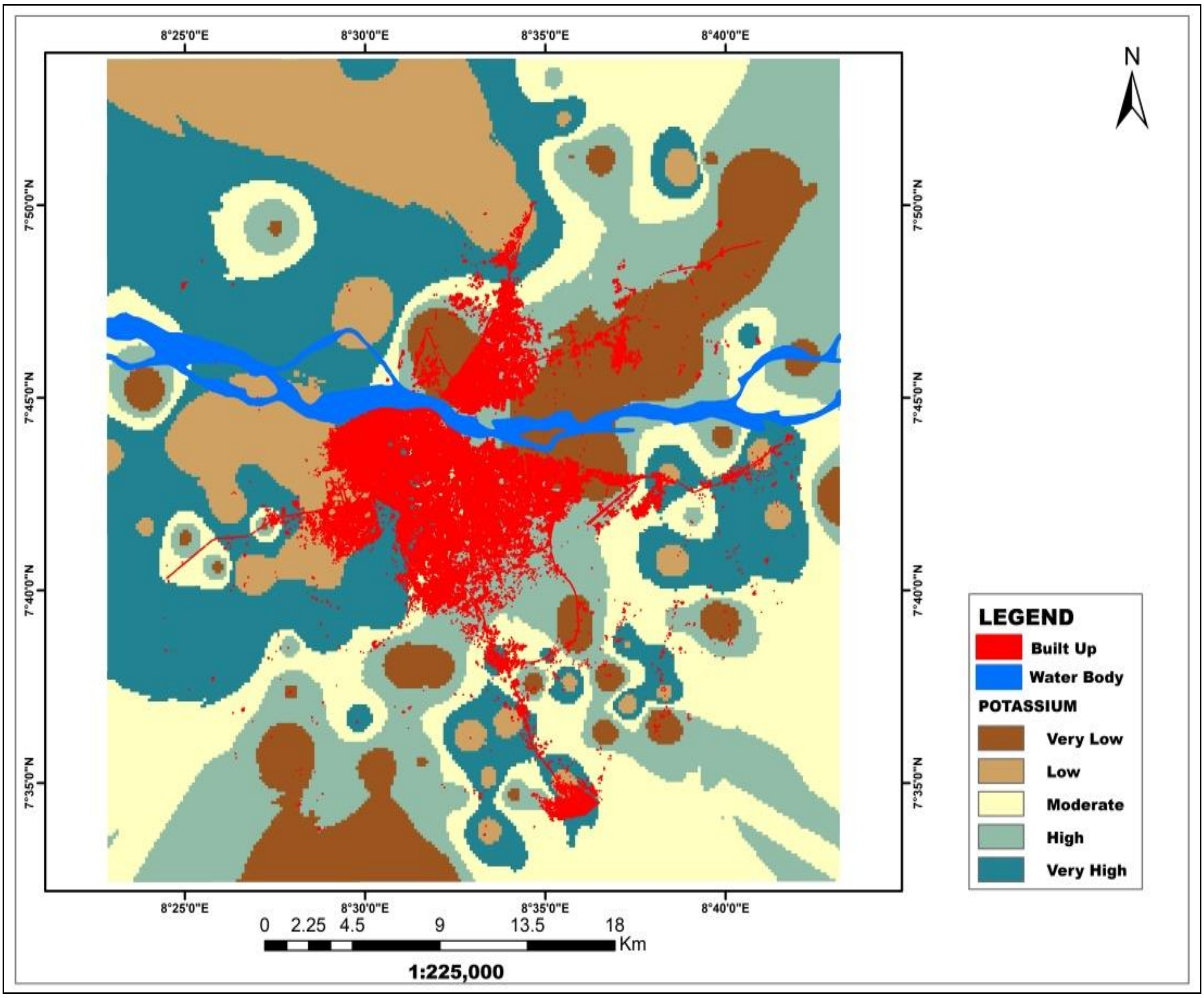

Fig 7 Spatial Distributions of Potassium (K)

Table 6 Area (km^2) Coverage and Percentage of each Category of Potassium (K)

Class	Area (km^2)	Percentage (%)
Very low	167.93	12.34
Low	309.11	22.70
Moderate	352.45	25.86
High	344.29	25.28
Very High	188.04	13.81
Total	**1361.83**	**100**

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G. Soil Suitability Based on Macro-Nutrients (N, P, K), pH and OM

The suitability map produced by a weighted overlay operation in ArcGIS that combined phosphorus, potassium, nitrogen, pH, and organic matter IDW layers resulted in the area being classified as least suitable, suitable, moderately suitable, and highly suitable (Figure 10 and Table 7). The results showed that more than half of the area (76.9%) is reasonably suitable, while the lowest is least suitable (0.11%), covering 1,046.9 Km^2 and 1.611 Km^2, respectively. The findings indicate that more than 95% of the region is reasonably suitable, with locations that are moderately suitable to suitable covering 1,360.22 Km^2 out of the total area 1,381.83 Km^2. The soil qualities in the research area were discovered to be ideal for growing a variety of crops, including roots and tuber crops.

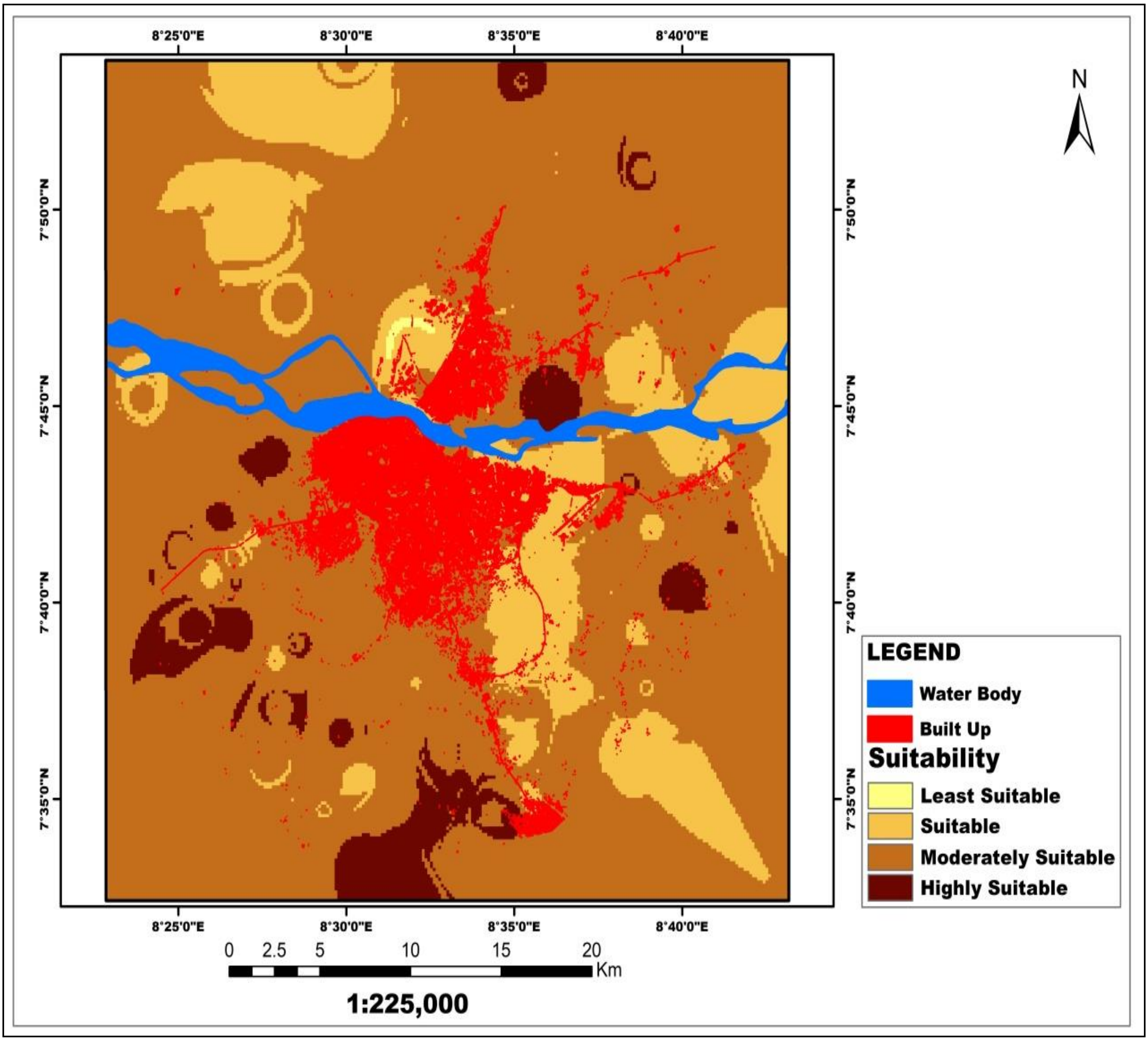

Fig 8 Soil Suitability Map (Macro-Nutrients) of the Study Area

Table 7 Area (km^2) Coverage and Percentage of each Category of Suitability

Class	Area (km^2)	Percentage (%)
Least Suitable	1.611	0.11
Suitable	237.71	17.46
Moderately suitable	1046.94	76.88
Highly Suitable	75.57	5.55
Total	**1361.83**	**100**

V. SUMMARY OF FINDINGS

- Findings revealed that soil textures are highly favorable to support the cultivation of crops with predominantly sandy loam with spatial coverage of 1120.07 Km^2, accounting for 82.25% of the area.
- A substantial portion (76.1%) of the research region falls between 5.6 and 6.4 pH levels. This implies that a large portion of the land is suitable for most crops. This clearly explains the prevalence of farming activities in peri-urban areas.
- The total Nitrogen in the area appears to have nearly comparable concentrations at the low, moderate, and high levels.
- The regional variation in organic matter corresponds to nitrogen distribution, indicating a spatial link.
- The distribution of phosphorus conforms to that of potassium at low, moderate, and high levels, indicating a spatial relationship.
- The spatial variation of magnesium in the area is almost equal at the very low, low, moderate and high concentration levels
- According to the findings, more than half of the area has low to very high concentration of exchangeable cations like Calcium (Ca), Magnesium (Mg), and Sodium (Na).
- The geographical distribution of Fe shows almost identical concentrations at low, moderate and high levels.
- Macro-elements (N,P,K), pH and organic matter indicates that more than 95% of the region is reasonably suitable with places that are moderately suitable to suitable covering 1,360.22Km^2 out of the total area 1381.83 Km^2

VI. CONCLUSION

The status of soils within the study area is generally rich enough to support crop cultivation. Over the years, the soils have benefited immensely from the nutrient laden detritus that the Benue deposits on its flood plains and, as such, makes it suitable for the cultivation of a variety of crops. The study also makes available data that can guide in the choice of both crops to cultivate and farming practices to engage. Furthermore, knowledge of the characteristics of the soil can help in the decision of which new crops can be introduced and where they can be cultivated. The study therefore, recommends possible commercial cultivation of agricultural produce within the peri urban. And also, the identification of possible agricultural hubs within the region.

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