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Influence of environment on sustainable crop cultivation in southern and central zone of Plateau State, North Central Nigeria

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Abstract
This study examined the influence of the environment on sustainable crop production, encompassing the central and southern Plateau in north central Nigeria. The environment had been characterized from Sentinel 2 images using Google Earth Engine. A total of 746 soil samples were collected, and soil texture variations were prepared using inverse distance weighted interpolation. Additionally, the elevation and slope of the area were derived from SRTM RADAR images. The environment was classified into various categories, including rock outcrop (1065 km^2), forest (1054 km^2), shrubland (6913 km^2), grassland (7324 km^2), agricultural land (14,252 km^2), built-up (416 km^2), bare surface (138 km^2), water bodies (37 km^2), and wetland (4 km^2).

The results of soil analysis revealed nine textural classes, ranging from sandy (571 km^2), sandy clay (3293 km^2), sandy loam (3961 km^2), sandy clay loam (4681 km^2), clay (2882 km^2), clay loam (2370 km^2), loam (1661 km^2), silty clay (1431 km^2), and silty clay loam (317 km^2). The elevation and slope of the area ranged from 95m to 1681m and 20 to 540, respectively. These thematic maps were interpreted both quantitatively and qualitatively to assess the environmental impact on sustainable agriculture.

Based on these findings, it was determined that terrain, soil properties, and climate were the environmental factors influencing the extent of crop cultivation in the area. The combination of these three factors determined the specific crops that could be grown in particular areas. The results indicated that agricultural land was the most dominant land use class, occupying approximately 14,252 km^2 (45.7%) of the total land area. Regarding terrain, the results showed that sustainable crop production could not thrive in areas with high altitudes due to the rocky nature, which primarily allowed for terrace and contour farming practices due to environmental constraints. Climate was identified as a significant factor determining the location of crops, accounting for much of the spatial differences in the types of crops grown across the area.

The study also revealed that different crops had varying requirements for the amount of light and temperature needed to thrive. Sorghum thrived well in areas with high altitudes, while rice crops required a hot and humid climate. In contrast, maize and potatoes were considered low-temperature and low-humidity crops. This study clearly demonstrated the significance of the environment on sustainable agriculture and its influence on the spatial distribution of crops in the area.

Keywords: Environment, crop cultivation, terrain, climate, soil texture

1. Introduction
The positioning of crop agriculture has been predominantly shaped by a combination of environmental, economic, and societal considerations. Environmental factors play a crucial role in determining the suitability of land for farming, encompassing terrain, climate conditions, and soil characteristics. Adequate space, ample light, warmth, and moisture are essential for crop cultivation. Moreover, soils must possess the right depth, drainage capacity, texture, and chemical composition, while also being fertile. Terrain features, such as ruggedness and elevation, play a pivotal role in accessibility, requiring a balance between gentle slopes to prevent soil erosion and steep slopes to avert flooding [1].

The spectrum of environmental conditions that favor crop production spans a wide range. Different combinations of these conditions determine the suitability of specific areas for growing particular crops. Naturally, regions characterized by steep slopes, nutrient-poor soils, and harsh climates would not be viable or economically feasible for commercial agriculture. Conversely, some regions boast ideal environmental conditions, enabling the cultivation of numerous high-yield crop varieties, leading to substantial profits. Nevertheless, the majority of agricultural lands fall within the middle ground, occupying a range of conditions between these two extremes.

The utilization of agricultural land for commercial purposes faces limitations due to factors such as elevation and slope. In the context of agricultural production, elevated areas share common restrictions with regions at high latitudes, including lower temperatures, elevated wind speeds, and suboptimal soil quality. These ancillary attributes are the primary factors that hinder the cultivation of crops, rather than the high elevation itself [2]. Terrain that is too rugged (steep slopes) is not readily accessible for mechanized agriculture. In addition, terrain indirectly effects soil formation, modifies climates, and affects water drainage and availability. Steep slopes are subject to soil and nutrient loss. In contrast, very flat terrain is prone to flooding and poorly drained soils. Most crops are grown in the area are located on land with shallow slope where the temperature, precipitation, and soils are favorable. In some areas that are too steep, wet, or dry, landscapes have been modified to allow cultivation. Some of the limitations of the environmental factors that determine the location of agriculture can be overcome through modifications, but others cannot. The study aimed at characterizing the environment and to determine the environmental factors and its influence on sustainable agriculture.

2. The study area

The study area encompasses the Southern and Central zones of Plateau state in North central Nigeria, including Bokkos, Mangu, Pankshin, Kanke, Kanam, Langtang North, Langtang South, Wase, Shendam, Mikang, and Qua'an-pan local government areas. Its geographical coordinates span from 8° 21' 50.885"N to 9° 46' 24.955"N latitude and 8° 38' 23.358 "E to 10° 38' 28.662" E longitude, covering a total land area of approximately 20,411 square kilometers.

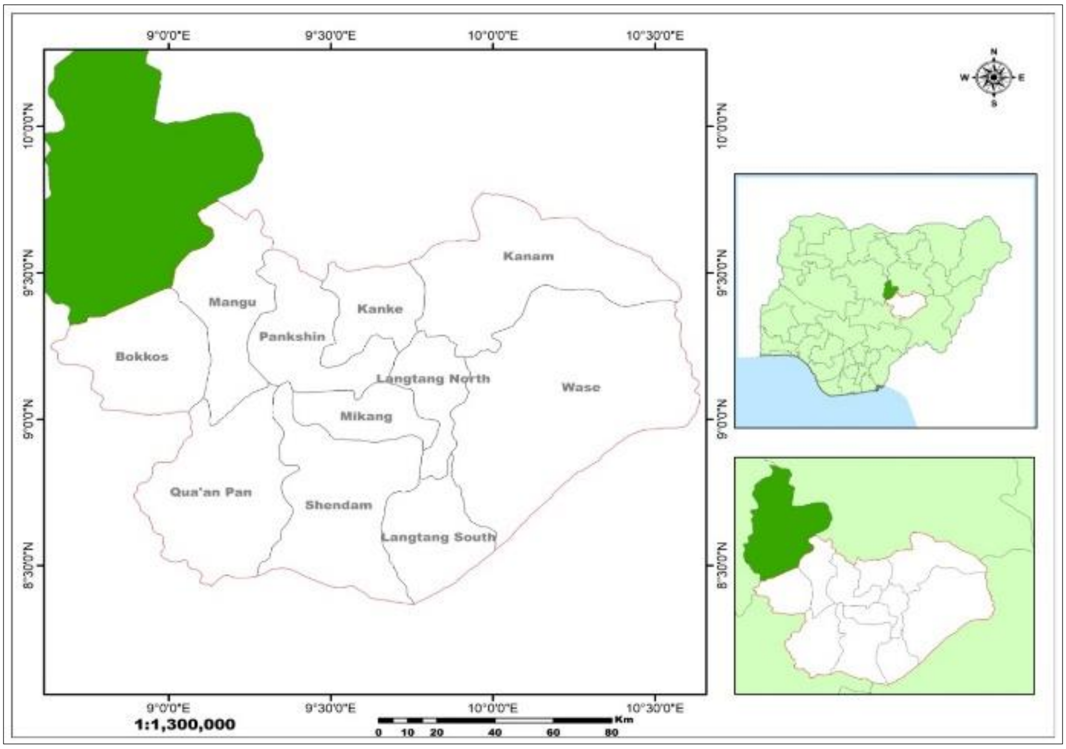

Fig 1: The Study area (Source: Settlement map of Nigeria)

The region experiences a tropical savannah climate characterized by pronounced wet and dry periods, accompanied by elevated humidity levels in its southern sector. Typically, the dry phase spans from November through April, while the wet season prevails from May to October. This alternation provides a six-month window for agricultural cultivation. Temperature fluctuations within this area range from 25 °C to 38 °C, with an annual precipitation average of approximately 1,500 mm [3]. The area experiences an average humidity level of approximately 80%, which increases to over 85% during July and August, when the entire area falls under the influence of the Maritime Air mass. Conversely, in January, when the area is impacted by the Tropical Continental Air mass, the humidity drops to around 60%. The area features a hot and humid climate, characterized by two distinct seasons: the Rainy season spanning from April to October, and the Dry season from November to February [4]. The wet season is relatively warmer while the Dry season is much colder. However, the upland area of the zones particularly the Central zone which is marked by higher altitude makes the area to have a near temperate climate with an average temperature of about 18 °C to 22 °C. The mean annual rainfall varies from 132cm (52 in) in the southern part to 146 cm (57 in) on the Jos-Plateau due to the influence of relief which induces orographic rainfall. The highest rainfall is recorded during the wet season months of July and August.

The geographical region under investigation typically receives an average yearly precipitation of 131.75 centimeters (equivalent to 52 inches), with notable occurrences during the months of July and August. In contrast, the Jos Plateau, located within the same area, registers a higher annual rainfall of 146.01 centimeters (approximately 57 inches). Rainfall in this region is predominantly observed between the months of April and September. In terms of its meteorological characteristics, the type of rainfall commonly observed in this study area is categorized as Convectional precipitation [5].

Again, the region situated in the northern Guinea savannah, characterized by its distinctive vegetation zone of the same name. The majority of the population in this area primarily engages in farming activities, benefiting from a climate that is conducive to the cultivation of a diverse range of crops. These crops include maize, Irish potatoes, rice, cowpeas, groundnuts, soybeans, as well as various cereals like millet and guinea corn. Additionally, yam and cassava are also prevalent in this agricultural landscape.

Soil in the central and southern zone of Plateau State are not homogenous in nature, soil properties vary in spatial and temporal direction and such variation depicts systematic changes as a function of the geology and derived landforms [6]. The consistent denudation effect of erosion and deposition leads to a complex in the formation of the soil with the southern zone predominantly occupied by sandy clay, sandy loam, and clay soils while the central zone is overlaid by sandy clay, sandy loam and loamy soils respectively [7].

2.1 Drainage Pattern

The research focuses on a dendritic network system, primarily emptying into the River Benue, with a few flowing northward. Notable rivers in this network include River Wase (located in Wase L.G.A.), River Shimankar (found in Shendam L.G.A.), and River Dep (situated in Qua'an Pan L.G.A.). To elaborate, River Wase originates from the elevated terrain of Tafawa Balewa in Bauchi State, traverses Langtang North and Wase L.G.A.s, eventually merging with the River Benue. River Wase's principal tributaries are River Pilgani, River Bapkwai, and River Zamko, all located within Langtang North L.G.A. Parts of Langtang North and Mikang LGAs exhibit significant relief, with elevations ranging from 200 m to 1000 m above sea level, particularly in the north. These areas serve as hydrological hubs for numerous small rivers in the region. River Shimankar meanders through the Southern Plateau region and discharges its waters into the River Benue, constituting a significant tributary. Its source lies in the Jibam Hills in Pankshin L.G.A., flowing southwards until it joins the River Benue at Ibi L.G.A. in Taraba State. River Ankwai, situated in Shendam L.G.A., plays a vital role as a boundary between Plateau and Nassarawa States. Originating from the Jos Plateau, it eventually merges with the River Benue at Tunga in Nassarawa State. Additional noteworthy rivers in the study area include Dep, Lee, and Ntireem, all within Qua'anpan L.G.A. Consequently, the study area boasts efficient drainage, presenting opportunities for dam construction to enhance irrigation agriculture.

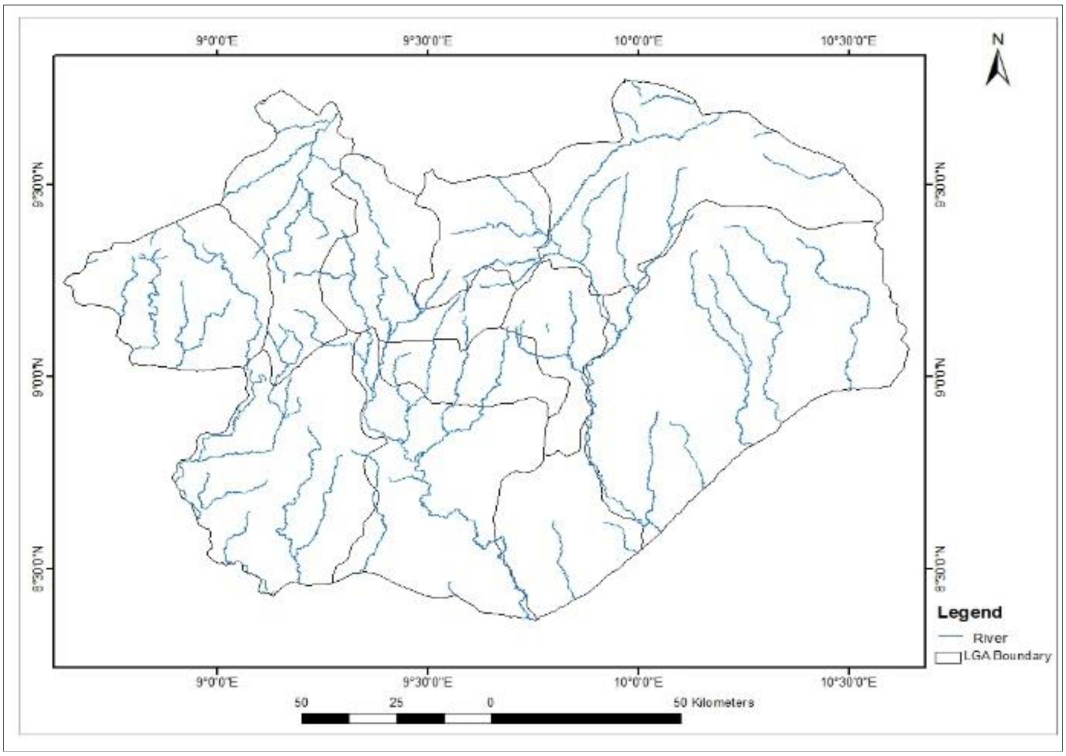

Fig 2: Drainage map of the study area (Source: SRTM Radar image)

3. Geology of the study area

The geological composition of the southern and central regions of the Plateau is situated within the Pre-Cambrian Basement rock formation. This predominantly consists of the migmatite-gneiss complex, which is thought to have been thrust into place over 600 million years ago [8]. Roughly 50% of the designated research region is characterized by the presence of these rock formations (refer to Figure 3). Within this geological complex, certain areas have experienced intrusion by Pre-Cambrian to Late Paleozoic Pan-Africa Granite, commonly referred to as Older Granite. This intrusive formation comprises various rock types, including biotite granites, Hornblende biotite granite, syenite, and medium to coarse-grained biotite granites [9]. The ancient granitic formations, dating back in time, are predominantly found as isolated hill-like formations known as inselbergs, primarily situated within the central region of the project area. Within this geological context, there exists a geological feature called the Jurassic orogeny, characterized by alkali Younger Granite, which intrudes into the older Basement Complex rocks. Alongside this, there is a presence of volcanic rocks like basalts and rhyolites associated with the Younger Granite. These volcanic rocks are either superimposed upon the existing formations or intersect with both the Basement rocks and the Younger Granite, adding to the geological complexity of the region [10]. In the study region, the southern portions are covered by sedimentary layers dating from the Cretaceous period to more recent times. In contrast, pockets of elevated terrain in the southern area are composed of crystalline basement rocks, specifically Granite gneiss and older granites. Meanwhile, low-lying regions in the southern part are predominantly characterized by Cretaceous sedimentary rocks. These rocks consist primarily of quartz, feldspars, mica, biotite, and hornblende as their mineral components. Over time, varying degrees of weathering have affected these rock formations, ultimately resulting in the development of soils with different textures that are distributed across the area in a spatially diverse manner [11].

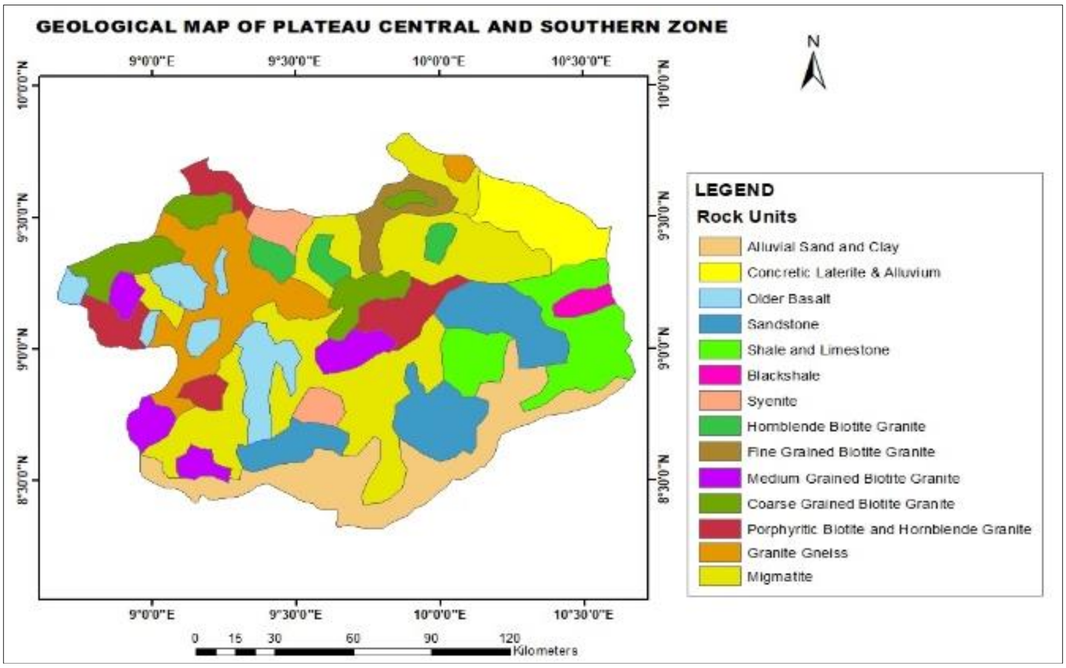

Fig 3: Geology of the study area (Source: Geological Survey of Nigeria 2005)

The central zone is characterized by the crystalline basement rock which comprises of the Migmatite and Granite-gneiss and the Pan African granites (Older granites) [8]. These rocks are found in various regions, including Mangu, Pankshin, Bokkos, Kanam, and Kanke areas (see Fig. 3). Specifically, Mangu and Bokkos share similar geological formations containing granitic rocks. These granitic rocks are present as elongated and large intrusive formations distributed throughout the central area. They primarily consist of quartz as the predominant mineral, with additional components such as feldspars and biotites. Over time, these rocks undergo weathering, resulting in the formation of sandy-clay and loamy soil, often enriched with a significant clay content [12]. The feldspars composed of Potassium (K-feldspars) weathers to clay. Therefore, rock forming minerals attributed to the soil composition and its textural variation in the project area. The Newer basaltic rocks occur mostly in parts of Mangu while the Older Basalt occur as boulders in parts of Bokkos. The soils derived from the basaltic rocks and volcanic ashes in parts of Mangu and Bokkos are extensively used for food crop productions like potatoes and maize than their granitic equivalents. The reddish basaltic soils occur over a wide range of altitudes of about 1600 m to 3000 m above sea level around Kerang in Mangu LGA [13]. Such soils are highly prolific for the production of agricultural activities in this region. There are also sizeable pockets of loamy soil of volcanic origin in such areas too.

In the southern region is characterized predominantly by the Cretaceous to Tertiary sedimentary rocks, consisting mainly of sandstone, limestone, shale, and alluvial sand. These types of rocks dominate the lower-lying regions of Wase, Langtang South, and portions of Shendam and Langtang North. On the other hand, in the northern areas of Langtang North, Mikang, and Quanpan, you'll encounter crystalline basement rocks like migmatite and granite-gneiss. Additionally, there are occasional occurrences of younger granite and older granite intrusions within the basement unit, which manifest as inselbergs. These rock formations cover approximately 40% of the Quanpan and Mikang areas. The majority of the silts, sandy soils, and clay soils in this region are a result of weathering and erosion from the sedimentary rocks [14].

3. Methods and Materials

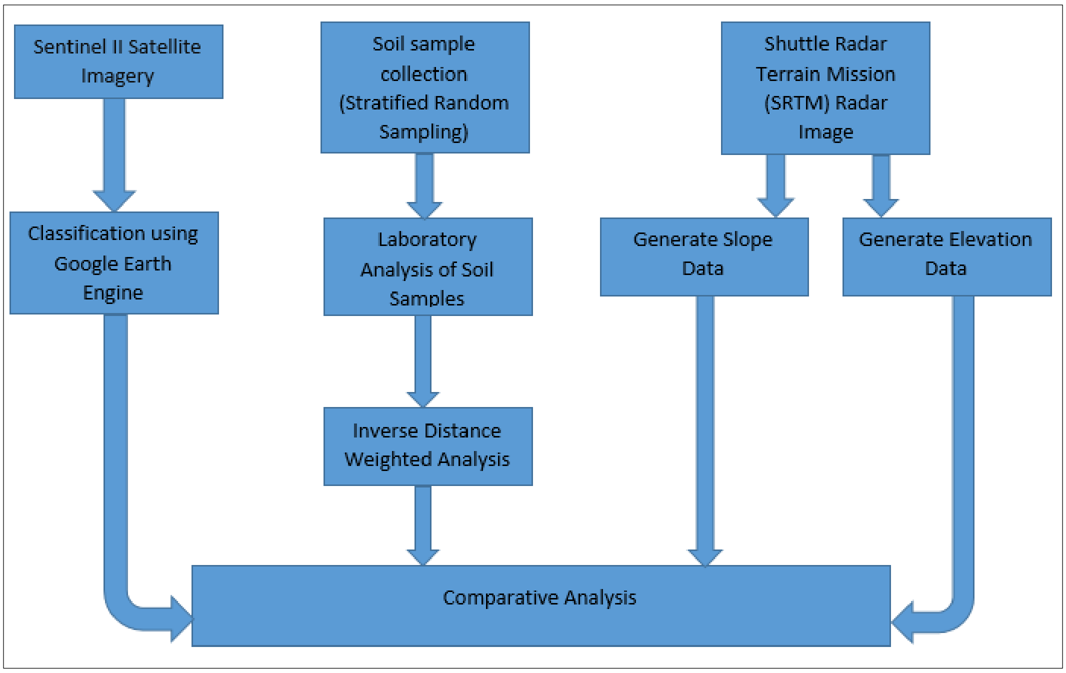

Fig 4: Flowchart of the study

This research relied on a crucial set of data sources, which encompassed soil samples, Global Positioning System (GPS) coordinates, Shuttle RADAR Terrain Mission (SRTM) data, and land use/land cover information derived from Sentinel II satellite imagery. The fieldwork phase spanned a four-week duration, commencing on April 3, 2021, and concluding on May 4, 2021. Soil sample locations were pinpointed utilizing a handheld GARMIN GPSMAP 78s receiver, and samples were diligently collected from designated farms at depths ranging from 0 to 30 centimeters. These collected samples were meticulously blended together in a plastic container to create a single composite soil sample. The soil sampling process was guided by the stratified random sampling method, which took into consideration the diverse soil characteristics present in the study area. In total, a noteworthy 738 soil samples were procured from various farmlands spanning across 525 villages situated within eleven Local Government Areas (LGAs), specifically Langtang North, Langtang South, Mikang, Qua'anpan, Shendam, and Wase in the southern zone, as well as Bokkos, Kanam, Kanke, Mangu, and Pankshin in the central zone.

Soil samples underwent laboratory analysis at the Centre for Dry Land Agriculture, situated within Bayero University in Kano, Nigeria. The determination of total soil organic carbon (referred to as total C) was accomplished through a modified procedure involving chromic acid wet chemical oxidation and spectrophotometric techniques, following the Walkley & Black method [15]. Total nitrogen (total N) was determined using a micro-Kjeldahl digestion method [16]. Soil pH in water (S/W ratio of 1:1) was measured using a glass electrode pH meter and the particle size distribution following the hydrometer method [17]. Furthermore, the analysis of various soil properties, including available phosphorus (P), exchangeable cations such as potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na), as well as micronutrients like zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), and boron (B) was carried out. These measurements were conducted using the Mehlich-3 extraction method, followed by analysis with inductively coupled plasma optical emission spectroscopy (MP-AES 4200, Agilent Inc., Waltham, MA, USA). Additionally, the determination of exchangeable acidity (H + Al) was carried out by subjecting the soil to a 1N KCl extraction and subsequently titrating the resulting supernatant with 0.5M NaOH [18]. The calculation of the Effective Cation Exchange Capacity (ECEC) involved summing up the exchangeable cations (including K, Ca, Mg, and Na) along with exchangeable acidity (H + Al).

The subsequent phase of the research involved the preparation and organization of field data for spatial analysis. Initially, meticulous arrangement of the coordinates from the collected field data was carried out within an Excel spreadsheet, followed by saving it in the ".csv (comma delimited)" format. To enable more extensive and thorough spatial analysis, the data was imported into ArcGIS 10.8 software, where it underwent conversion into the shape file format. This transformation allowed for a more detailed and comprehensive spatial analysis of the data. The primary technique employed for this spatial analysis was the utilization of the Inverse Distance Weighted (IDW) interpolation extension found within the Spatial Analyst tool in ArcGIS. This interpolation method proved to be highly valuable for estimating values at locations that had not been directly measured, relying instead on a set of known data points.

To construct a relational database, the soil parameter values were incorporated into the attribute table of ArcGIS 10.8 software and appropriately linked. This database greatly facilitated an in-depth analysis of the spatial distribution of the physicochemical properties under investigation. In particular, the Inverse Distance Weighting interpolation method was utilized to delineate and depict the spatial variations of the soil parameters across the study area. This resulted in the creation of thematic maps that illustrated the distribution patterns of the selected soil parameters, derived from the point data acquired in the field, utilizing the IDW technique.

Subsequently, the Sentinel II imagery was classified using Google Earth Engine, and elevation as well as slope data were generated utilizing SRTM RADAR imagery. Lastly, a comparative analysis was conducted, examining all these components to identify areas of agreement and divergence within the region of interest.

4. Results and Discussion

4.1 Environmental Characterization

The environmental characterization in the study area involved nine (9) classes as presented in figure5. The most prominent of these classes is agricultural land with over 14000 square kilometers. Naturally, the savannah landcovers, shrubland and grassland, are also important based on their areal coverages of around 7000-kilometer square each. Rock outcrops make a significant impact (bearing in mind the rocky nature of the terrain) with slightly over a thousand-kilometer square. The importance of built-up areas cannot be over emphasized vis-à-vis its influence on other landuses like agriculture and bare surfaces.

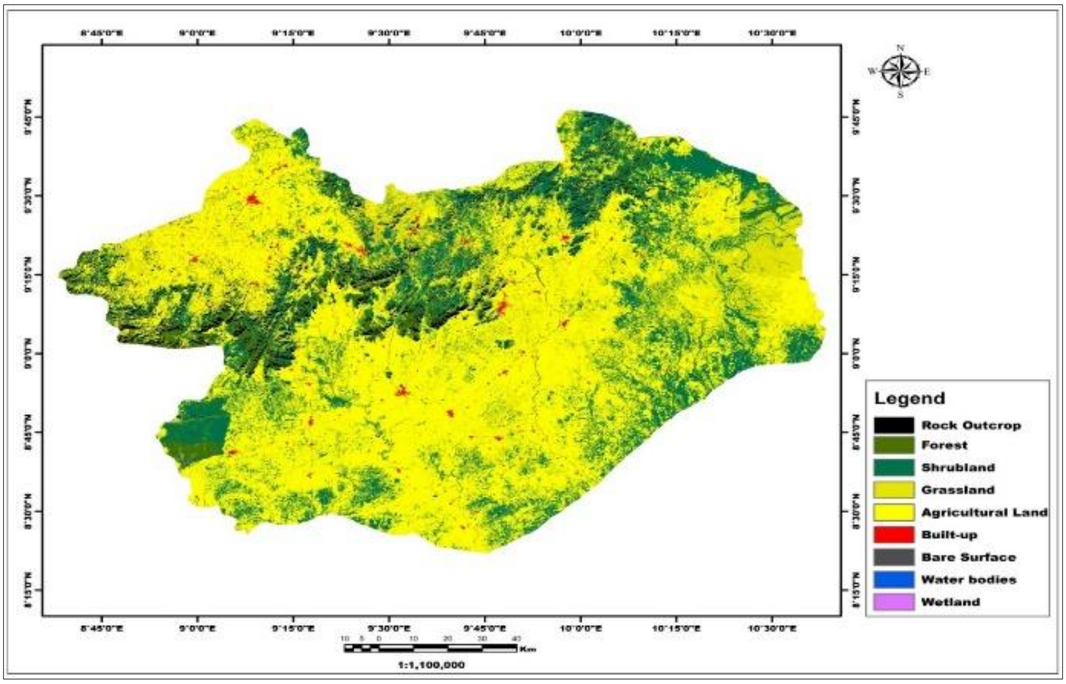

Fig 5: Land use/cover map of the area (Source: Sentinel 2 Image)

Table 1: Landuse classes in the study area

Landuse Classes	Area (Km^2)
Agricultural Land	14252.12
Bare Surface	138.49
Built-up	416.94
Forest	1054.65
Rock Outcrop	1065.94
Grassland	7324.72
Shrubland	6913.29
Water bodies	37.029
Wetland	4.05
Total	31207.26

Agricultural cropland occupies about 14,252km^2 (45.7%) of the total land area (Fig. 3), rock outcrops occupy 6.8 percent and are mostly found in Kanke and Pankshin areas. Wase has vast land with shrubland and grassland that can be modified for commercial and sustainable agriculture. About 37 km^2 is covered by water bodies and plants take water from the soil. In natural landscapes, soil water largely comes from precipitation that has infiltrated into the soil. The quantity of precipitation that falls on any given location has a strong influence on what kinds of plants thrive. Different plants have different requirements for the amount of water they need to develop to maturity. The amount of water that is needed for some plant can be different because of air temperature and humidity throughout the growing season. Wetland in the area is about 4.0541 km^2, the amount of water in soil that is available to plants is controlled by terrain, climate, and soil characteristics. Soil water availability is the limiting factor for the location of crop agriculture in many areas. The water in soil comes largely from precipitation. In some locations, soil water can also come via groundwater or surface-water flow paths. Crop agriculture is highly dependent upon the amount and seasonal patterns of available soil water from precipitation

4.2 Soil Texture

The analysis revealed that nine textural classes were identified. The Inverse Distance Weighted (IDW) maps showed a wide textural variation of the soil. This ranges from sandy, sandy clay, sandy loam, sandy clay loam, clay, clay loam, loam, silty clay and silty clay loam (Table 2). The spatial distribution map of the soil texture (Fig 6.) indicates that sandy clay loam soil was found in most parts of the study area covering 4681.8 km^2 (22.1%) of the total area mapped. On the other hand, silty clay loam covers the least area (317.1 km^2) which is less than 2% of the total area.

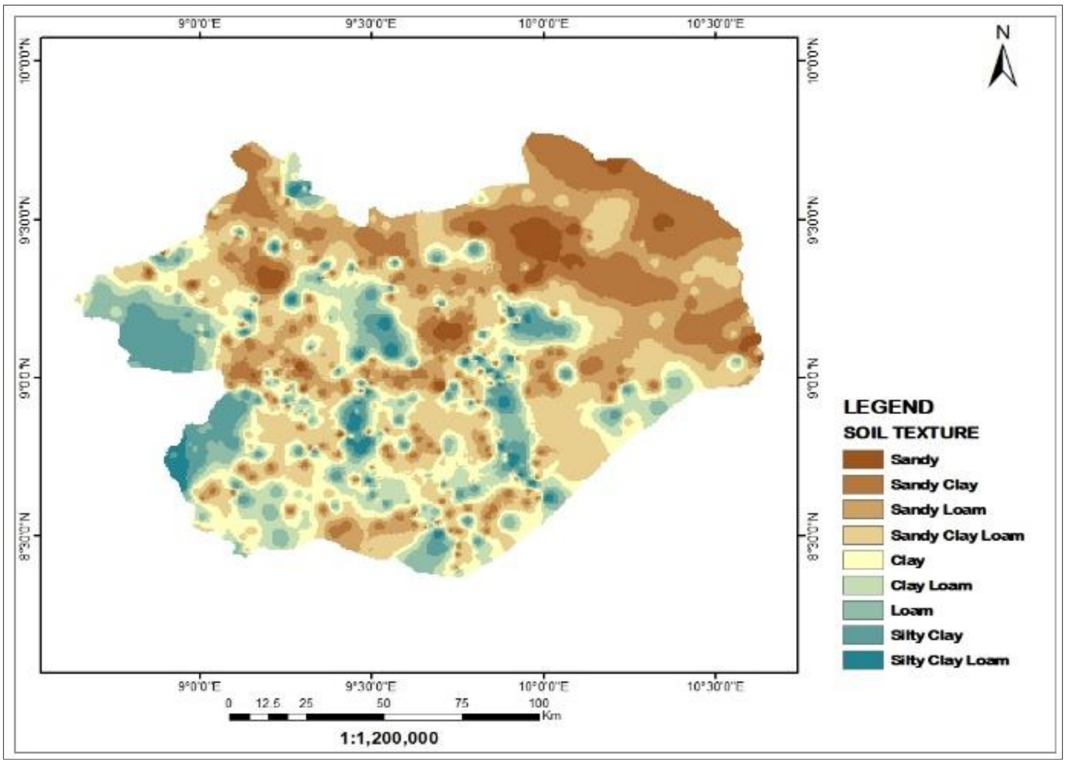

Fig 6: Soil texture of the study area

4.3 Elevation and Slope

The elevation and slope constraints food crop production in some parts of the area mostly in Panksin and Kanke local government areas (Figure 7 & 8). The terrain the study area is generally undulating with most of the area having relatively shallow topography and gentle slope that is highly suitable for crop production. The environmental factors that influence the extent of crop cultivation in the area are terrain with steep slope and rock areas most noticeable in Kanke and Pankshin and some parts of Qua'anpan. It is the combination of these factors that allow specific crops to be grown in certain areas. Most crops are grown on land where slope soils are favorable. In Kanke and Pankshin areas, terrain that are too steep, landscapes have been modified to allow for terrace method of cultivation. The range of environmental conditions conducive to the production of crops is wide, and particular combinations of these environmental conditions allow specific crops to be grown in certain areas. Obviously, in areas like Kanke and Pankshin with rugged terrain, with limited soils, commercial and sustainable agriculture would not be profitable or perhaps even possible. In other areas having relatively flat topography like Langtang South, Wase, Quanpan and Shendam with most parts of Langtang north, commercial agriculture is very profitable, and environmental conditions are such that many types of high-yielding crops can be grown. For instance, low lying areas tend to holds water with significant amount of clay and could be best suited for rice cultivation. Agricultural practices could be sustainable in such places.

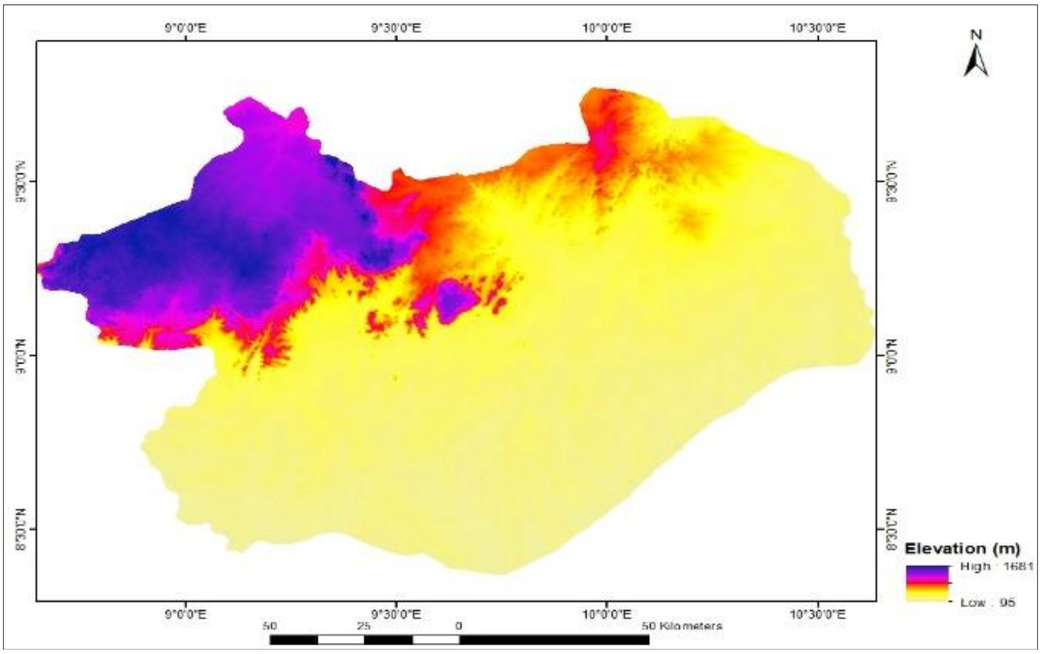

Fig 7: The Elevation of the study area

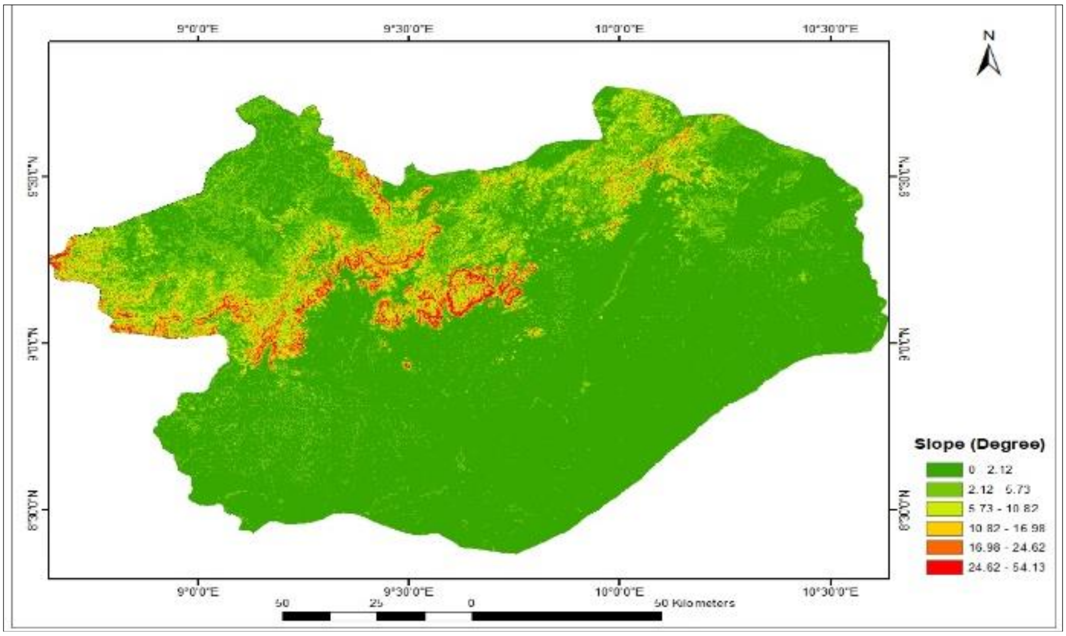

Fig 8: Slope map of the area

Fig 9: Terrace farming practices at Amper (Kanke LGA)

Agricultural land used for commercial production is constrained by both elevation and slope. For agricultural production, high elevations have similar constraints as high latitudes, including decreased temperature, increased wind velocity, and poor soil. It is these secondary characteristics that constrain crop cultivation rather than high elevation itself [2]. Terrain that is too rugged (steep slopes) is not readily accessible for mechanized agriculture. In addition, terrain indirectly effects soil formation, modifies climates, and affects water drainage and availability. Steep slopes are subject to soil and nutrient loss. In contrast, very flat terrain like the extreme southern part of Shendam and Langtang South are prone to flooding that could leads to poorly drained soils.

Climate is an important factor for determining the location of crops, and it accounts for much of the spatial differences in the types of crops grown across the area. The climate of a location is a function of precipitation and sunlight (solar radiation that determines light intensity and temperature). Climate is largely determined by latitude, altitude, and proximity to water bodies. According to [19], the intensity, quantity, and duration of solar radiation that falls on the Earth at any given place determine local temperature and light and these are essential for the formation of chlorophyll and for the process of photosynthesis in plants. Different plants have different requirements for the amount of light and heat needed to reach maturity. For many plants, the growth rate from emergence to maturity depends upon the accumulation of specific quantities of heat. Each plant has its own low-temperature threshold for development. For instance, the low temperature threshold for corn is 50 °F [20]. That is why sorghum thrives well in the high altitude of Kanke and Pankshin. Rice crop needs a hot and humid climate. It is best suited to regions which have high humidity, prolonged sunshine and an assured supply of water. Maize and potatoes thrive well in Mangu and Bokkos and are temperate or cool season crops with lower temperature, less humidity, less windy and bright sunny days [21].

4.4 Terrace Farming Practice

Terrace agricultural is usually practice by rearranging farmlands or turning hills into farmlands by constructing specific ridged platforms. The essential (and distinguishing) feature of terracing agriculture is excavating and moving topsoil to form farmed areas and ridges. This practice involves tilling slope land along lines of consistent elevation in order to conserve rainwater and to reduce soil losses from erosion. These farming practices are noticeable in Kanke and Pankshin local government areas (Fig. 9).

5. Conclusion

The study shows that environmental features influence the spatial variation of food crop production and soil textural classes. The topography of the area is generally undulating with most of the area having relatively shallow and gentle slope that is highly suitable for crop production. Therefore, most crops are grown in the area are located on land with shallow slope where the temperature, precipitation, and soils are favorable. In some areas that are too steep, wet, or dry, landscapes have been modified to allow cultivation.

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