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CACCI FIELD NOTES

Spatial Distribution of Climate Risk and Vulnerability in Nigeria

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About the CACCI Field Notes

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Published on the AKADEMIYA2063 website (open access), CACCI Field Notes provide broad and timely access to significant insights and evidence from our ongoing research activities in the areas of climate adaptation and mitigation. The data made available through this publication series will provide evidence-based insights to practitioners and policymakers driving climate action in countries where the CACCI project is being implemented.

AKADEMIYA2063's work under the CACCI project contributes to the provision of technical expertise to strengthen national, regional, and continental capacity for the implementation of NDCs and NAPs.

AKADEMIYA2063 is committed to supporting African countries in their efforts against climate change through provision of data and analytics using the latest available technologies. In this Field Note, AKADEMIYA2063 scientists use remote sensing methods to describe Nigeria's context in terms of climate-related variables such as surface water, rainfall, land use and land cover, drought intensity, and soil properties at the pixel level.

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Following from its vision and mission, the main goal of AKADEMIYA2063 is to help meet Africa's needs at the continental, regional and national levels in terms of data, analytics, and mutual learning for the effective implementation of Agenda 2063 and the realization of its outcomes by a critical mass of countries. AKADEMIYA2063 strives to meet its goals through programs organized under five strategic areas—policy innovation, knowledge systems, capacity creation and deployment, operational support, and data management, digital products, and technology—as well as innovative partnerships and outreach activities. **For more information**, visit www.akademiya2063.org.

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1. Introduction

Climate change is a complex challenge that is disrupting economies, ecosystems, and societies globally. Nigeria, a West African nation with a population of over 200 million, is not immune to the effects of climate change. Despite abundant natural resources, including oil and gas, the country continues to grapple with a host of issues, including poverty, insecurity, and ecological deterioration. Nigeria has a tropical climate that is characterized by high temperatures, humidity, and rainfall. This climate is heavily influenced by factors such as location, topography, and proximity to large water bodies, resulting in significant regional differences within the country. Average temperatures in Nigeria range from 25 °C to 30 °C, with greater variations occurring between the northern and southern regions. In terms of precipitation, Nigeria has two seasons: wet (April-October) and dry (November-March), with larger amounts of rainfall experienced in the south and southeast regions of the country. Humidity is generally high throughout the year, especially during the wet season. Wind patterns are influenced by Nigeria's location and topography, largely due to the Inter-Tropical Convergence Zone (ITCZ) which brings moist winds from the Atlantic Ocean during the wet season and dry winds from the Sahara Desert during the dry season. Nigeria also receives a good amount of sunshine through both wet and dry seasons, although it is highest during the latter season.

Nigeria is already experiencing the adverse effects of climate change, with natural disasters occurring more frequently and with greater intensity. Floods, droughts, and desertification have resulted in the loss of lives, infrastructural damage, and the forced relocation of people. The agricultural sector, which is the country's economic mainstay, is also grappling with changing rainfall patterns and elevated temperatures, resulting in reduced crop productivity and heightened food insecurity.

Water bodies, rainfall, and population density are all key climatic variables that are critical to understanding the impacts of climate change. Water bodies provide essential services but are vulnerable to changes in climatic patterns. Monitoring changes in water bodies can help in understanding the impacts of climate change on the environment and human populations. Changes in rainfall patterns and population density can lead to increased water scarcity and competition for resources, affecting access to clean drinking water and sanitation facilities. Monitoring these climate variables is therefore essential. This can be accomplished through remote sensing, ground-based observations, and citizen science initiatives. Data obtained from these sources can be used to develop models that analyze the impacts of climate change, as well as to develop effective adaptation strategies.

The vulnerability of different regions or populations to climate change impacts is not uniform and can vary greatly based on a range of factors. It is therefore important to have disaggregated data to examine the differential impacts among communities. In this case, we are using remote sensing methods to describe Nigeria's context in terms of climate-related variables such as surface water, rainfall, land use and land cover, drought intensity, and soil properties at the pixel level.

2. Surface Water Index

We used the **Global Surface Water** datasets from the European Union's Joint Research Center to estimate Nigeria's water surface index. The datasets are composed of several variables that are used to examine different aspects of the spatial and temporal distribution of surface water over the last 38 years. In this section, we will focus on two variables: ***Change*** and ***Transitions.*** We have extracted Nigeria's data related to these two variables, as well as data on rainfall anomalies. These are described below.

2.1. Water Occurrence Change

This variable also called occurrence change intensity, provides information on water occurrence in distinct locations. It shows whether the occurrence of water increased, decreased, or remained the same from 1984 to 2021. The data covers changes in water occurrence intensity for two periods (16 March 1984 to 31 December 1999, and 1 January 2000 to 31 December 2021). Consistent estimates of water occurrence change are derived from homologous pairs of months (i.e., the same months with valid observations in both periods).

Table 1: Description of water occurrence change bands

Name	Description
Change_abs	The absolute difference in the mean occurrence values between the two periods for homologous months
Change_norm	The normalized difference in the mean occurrence values between the two periods for homologous months (epoch1-epoch2 /epoch1+epoch2)

Table 2: Classification of Tiff change_norm band based on value: The values from 0 to 200 are discrete and correspond to -100 percent loss to 100 percent increase respectively.

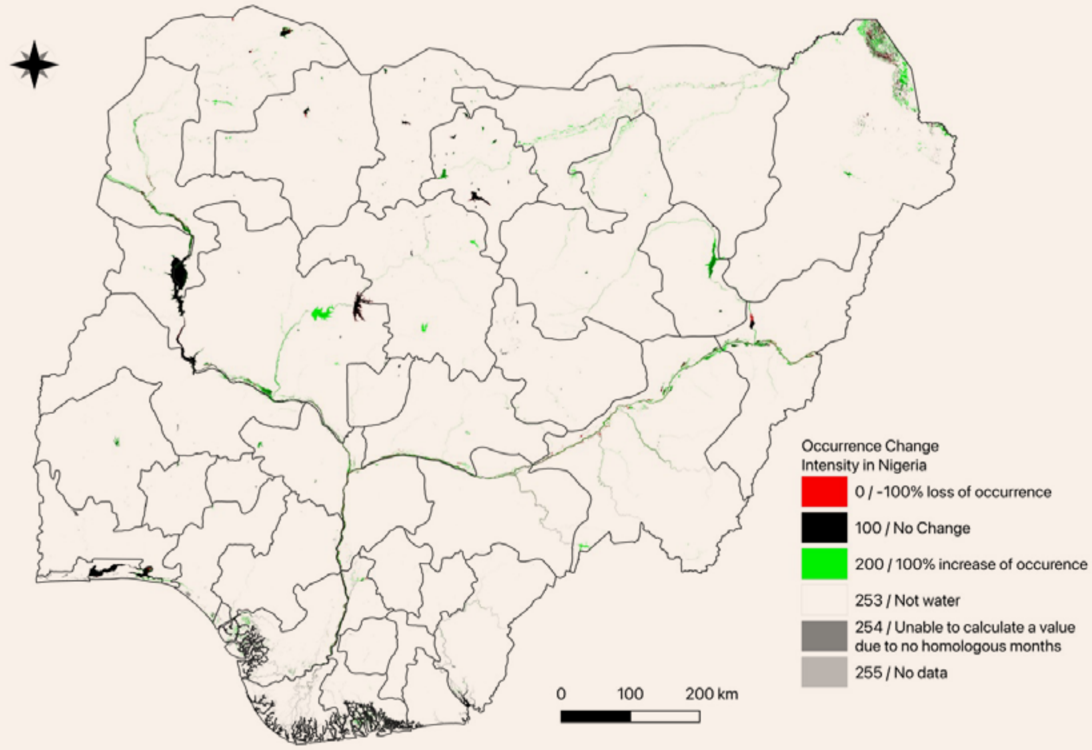
Tiff Value	Legend	Meaning
0	Red	-100% loss of occurrence
100	Black	No Change
200	Green	100% increase in occurrence
253	White	Not water
254	Dark Gray	Unable to calculate a value due to no homologous months
255	Light Gray	No data

Table 3 shows statistics on the change in surface water occurrence in Nigeria between 1984 and 2021. Significant losses in occurrence ranging from -100 to -75 percent can be observed, corresponding to 35.27 percent of the total surface land in Nigeria. However, increases in occurrence over 75 percent representing 0.27 percent of the surface are also noted, followed by losses in water occurrence ranging from -10 to 0 percent.

Table 3: Occurrence of change values and their corresponding classes

Class Name	Occurrence Change (%)
-100 to -75	35.27297
-75 to -50	0.024682
-50 to -25	0.03222
-25 to -10	0.031129
-10 to 0	0.196392
1 to 10	0.058989
10 to 25	0.03974
25 to 50	0.071908
50 to 75	0.078624
75 to 100	0.272763
Not Water	63.73616
Unable to calculate	0.184423

Figure 1: Water occurrence change intensity in Nigeria.



Data source: Surface Water Body dataset; Data processing and mapping: Authors.

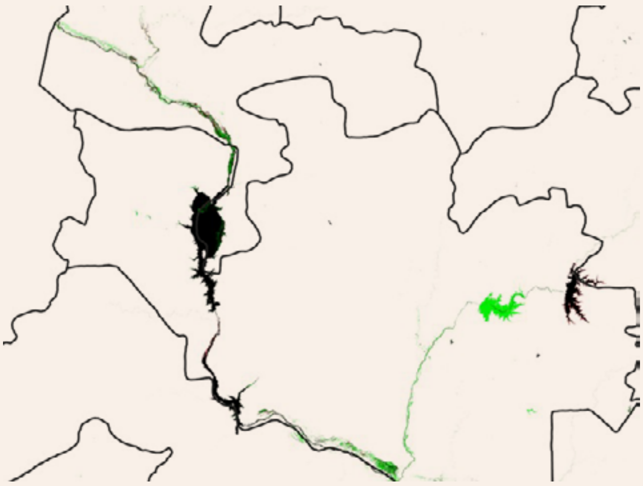


Figure 2: Occurrence change intensity in Nigeria/Niger River. **Data source:** Surface Water Body dataset; Data processing and mapping: Authors.

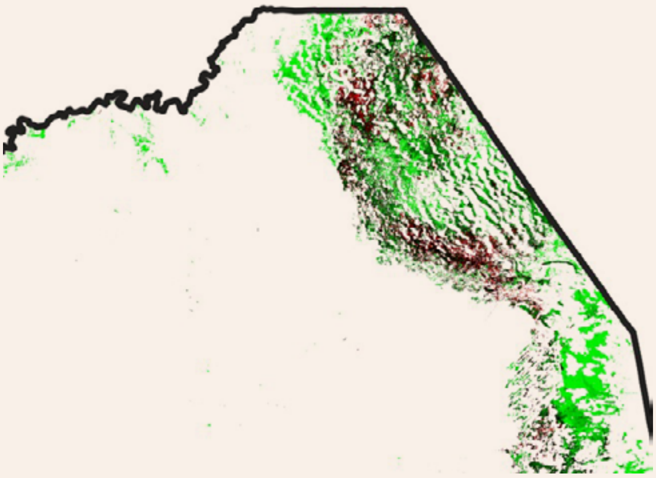


Figure 3: Occurrence change intensity in Nigeria/Lake Chad. **Data source:** Surface Water Body dataset; Data processing and mapping: Authors.

Figure 1 shows the occurrence of surface water in Nigeria. Detailed examples of water occurrence changes are also shown in Figure 2 which illustrates the Niger River in the western part of the country and Figure 3 representing Lake Chad in the north. Increases in water occurrence are shown in green and decreases in red. The intensity of the color represents the degree of change (in percentage), for example, the bright red areas show a greater loss of water than the light red areas.

Figure 1 shows significant increases in surface water occurrence in the extreme north and southern parts of the Niger River as well as in scattered areas around Lake Chad. In contrast, a loss of occurrence can be observed at various locations around Lake Chad, especially in the western parts of the lake. An increase can also be noted in the northern and southern parts of the Lake. The black areas are those where there was no meaningful change in water occurrence during the 1984-2021 period. However, there were no significant changes between the observation years in the central part of the river.

2.2. Transitions

Data on transitions provide information **on the change in surface water seasonality** between the **first** and **last observation years** (between 1984 and 2021). The data also captures **changes** between the **three classes** of **not water**, **seasonal water**, and **permanent water,** with the two last classes divided into sub-classes. This enables the depiction of changes in the first and last years that the data was observed, but not in the intermediate years.

We mapped the following transitions:

- Unchanging **permanent water** surfaces;
- **New permanent** water surfaces (conversion of land into permanent water);
- **Lost permanent** water surfaces (conversion of permanent water into land);
- Unchanging **seasonal water** surfaces;
- **New seasonal water** surfaces (conversion of land into seasonal water);
- **Lost seasonal water** surfaces (conversion of a seasonal water into land);
- Conversion of **permanent water into seasonal water**;
- Conversion of **seasonal water into permanent water**;
- **Ephemeral permanent** water (land replaced by permanent water that subsequently disappears);
- **Ephemeral seasonal** water (land replaced by seasonal water that subsequently disappears).

An unchanging water surface means that the seasonality at that point was the same in the first and last observation years, and not necessarily that it was stable throughout the years.

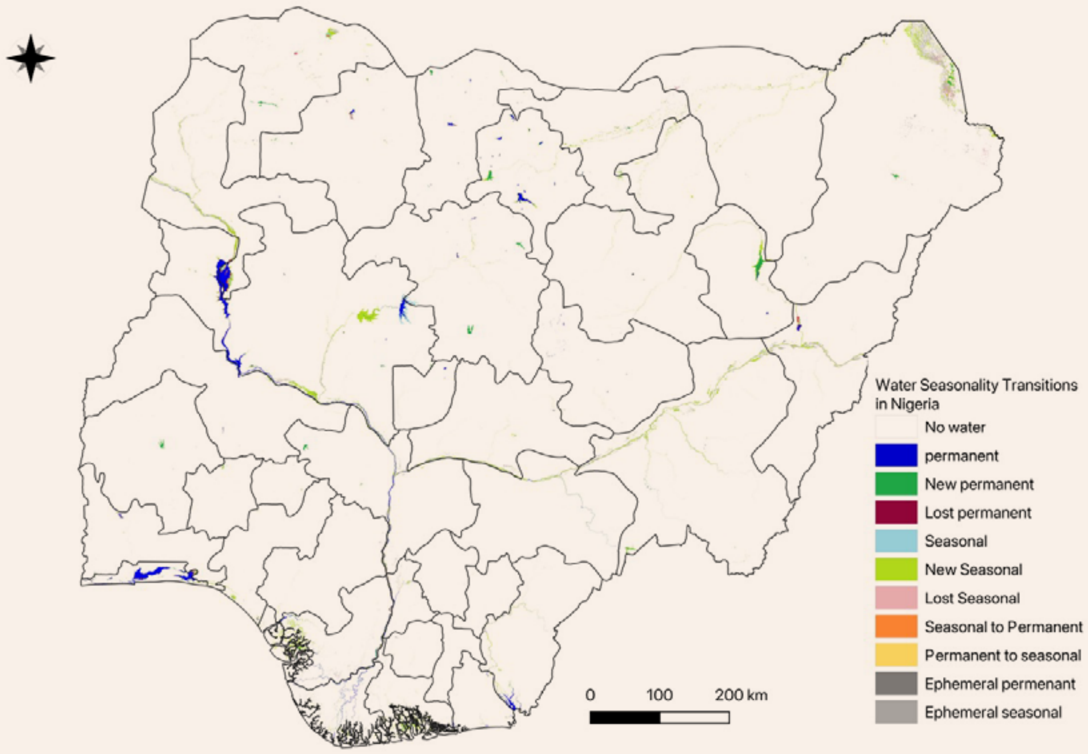
There are instances where water is not present at the beginning or the end of the observation period but is present in some of the intervening years. By tracking the inter-annual patterns of such **"ephemeral"** events and their intra-annual characteristics, each pixel can be classified as either ephemeral permanent water (land replaced by permanent water that subsequently disappears) or ephemeral seasonal water (land replaced by seasonal water that subsequently disappears), depending on duration of the observed seasonality during the period of water presence.

Table 4: Surface water seasonality transition statistics by classes. Data Source: Surface Water Body dataset; Data processing and computation: Authors.

Class Name	Covered area (%)
Not Water	98.9559245
Permanent	0.1933939
New Permanent	0.06722958
Lost Permanent	0.0055183
Seasonal	0.0879257
New Seasonal	0.36679144
Lost Seasonal	0.04633353
Seasonal to Permanent	0.02240185
Permanent to Seasonal	0.02065624
Ephemeral Permanent	0.00392433
Ephemeral Seasonal	0.2299006

Table 4 shows the statistics on surface water seasonality transitions in Nigeria between 1984 and 2021. It shows that Nigeria is dominated by non-water surfaces which cover 98.9 percent of the country. The dominant surface water transitions are new seasonal water bodies (0.36 percent), ephemeral seasonal water surfaces (0.22 percent), and permanent water bodies (0.19 percent). Other surface water transitions are seasonal water bodies (0.087 percent), new permanent (0.067 percent), lost seasonal (0.046 percent), seasonal to permanent water bodies (0.022 percent), permanent to seasonal (0.020 percent), lost permanent water bodies (0.005 percent), and ephemeral permanent water bodies (0.003 percent).

Figure 4: Transitions in water seasonality in Nigeria.



Data source: Surface Water Body dataset; Data processing and mapping: Authors.

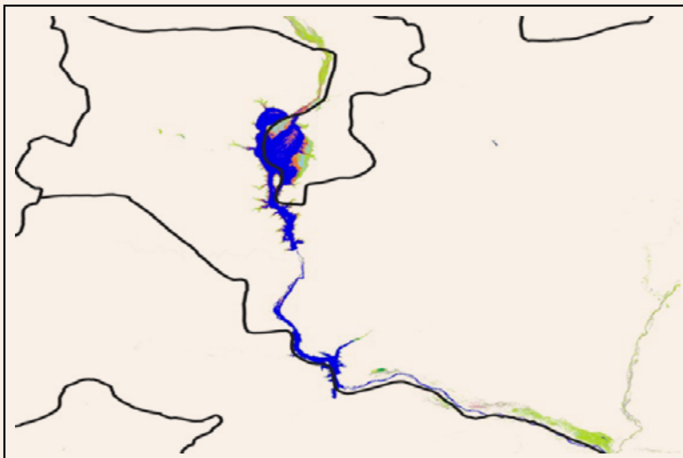


Figure 5: Transitions in water seasonality in Nigeria/Niger River. **Data source:** Surface Water Body dataset; Data processing and mapping: Authors.

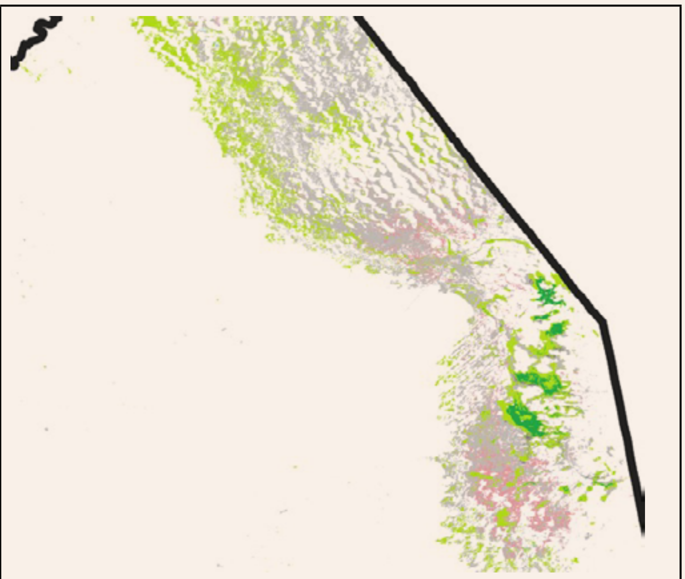
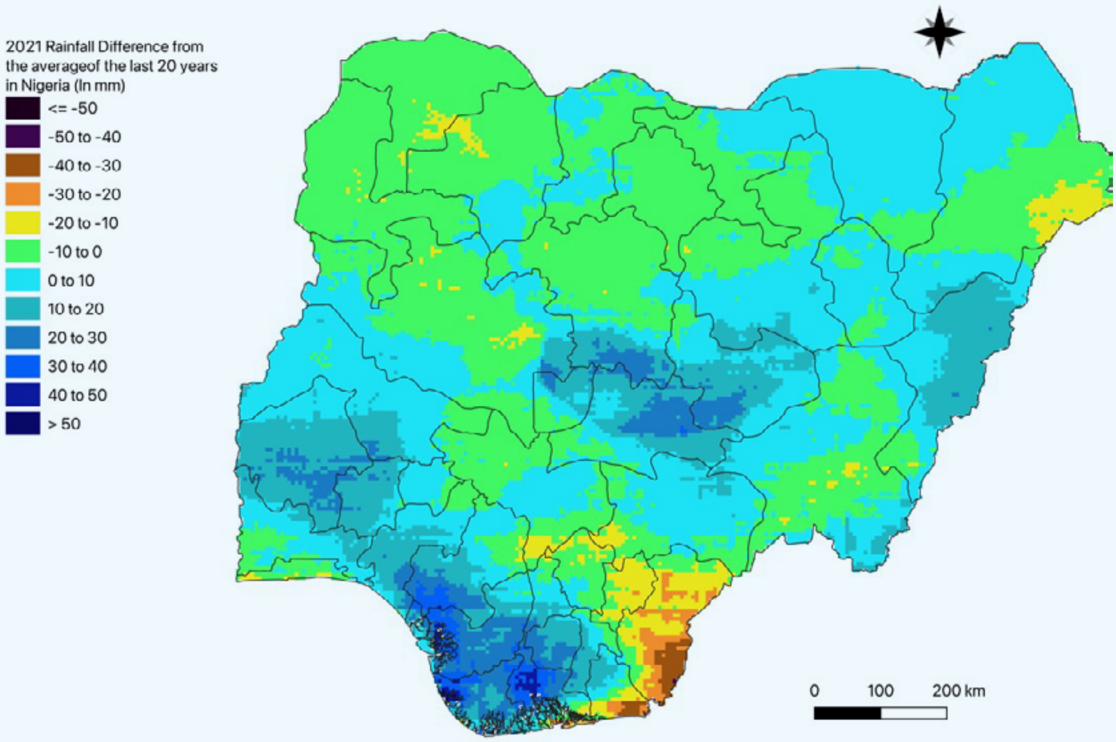


Figure 6. Transitions of water seasonality in Nigeria/Lake Chad. **Data source:** Surface Water Body dataset; Data processing and mapping: Authors.

Figure 4 shows the area of the Niger River that is identified as a permanent water surface, as no change in seasonality occurred between the first and last observation years (1984 and 2021). However, new seasonal water surfaces can be seen along the river, meaning that the area has changed into seasonal water bodies. This may explain the increase in water occurrence noted in the previous section at these same locations as well as the lack of change observed in the river's central part. Figure 5 shows new seasonal and permanent water (in green) in Nigeria/Niger river, as well as a few losses which are shown in pink. On the other hand, areas around Lake Chad (Figure 6.) are dominated by the presence of new seasonal and ephemeral seasonal water surfaces as well as the presence of new permanent water bodies. However, a loss in seasonality can also be observed at the same locations, especially in the southern areas. This may also explain the increase in water occurrence observed in these areas in 2021.

3. Rainfall Anomalies

Figure 7: Rainfall anomalies in Nigeria



Data source: *CHIRPS dataset; Data processing and mapping: Authors.*

A precipitation anomaly is a deviation from the average or expected precipitation patterns for a given area over a period of time. Anomalies are characterized by above-average (excess) or below-average (deficiency) precipitation compared to the long-term average. The rainfall anomaly between 2021 and the average of the last twenty years is computed and shown in Figure 7 using the CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) datasets.

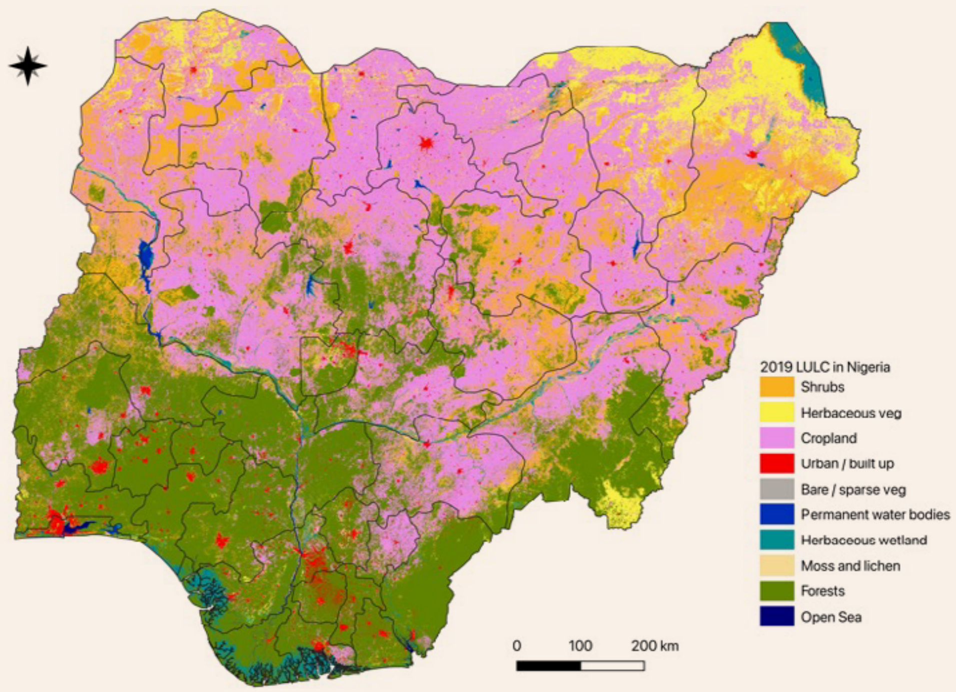
In Figure 7, significant increases in rainfall of more than 40 mm occurred in 2021 compared to the 20 years average in the southern part of the country. Increases ranging from 10 mm to 30 mm can be observed in the central and western regions. However, significant rainfall decreases ranging from -10 mm to -40 mm are seen in the country's northern regions while less significant rainfall decreases are seen in the southern regions.

4. Land Cover in Nigeria

The Copernicus Global Land Use Land Cover datasets publish the Annual Dynamics of Global Land Cover at 100 meters spatial resolution. This has been updated every year from 2015 to 2019, covering the entire planet. Land cover plays a significant role in the Earth's climate system. The term refers to spatial information on different types of features found on the Earth's surface such as forests, grasslands, croplands, water surfaces, etc. In this section, we used data from the Copernicus Global Land Cover platform to generate Nigeria's land use map. The map contains spatial information on the arrangements, activities and inputs people use and undertake to produce, change, or maintain a certain type of land cover. The land uses are classified into ten classes representing distinct types of physical features covering the Earth's surface, e.g., forests, grasslands, croplands, lakes, and wetlands.

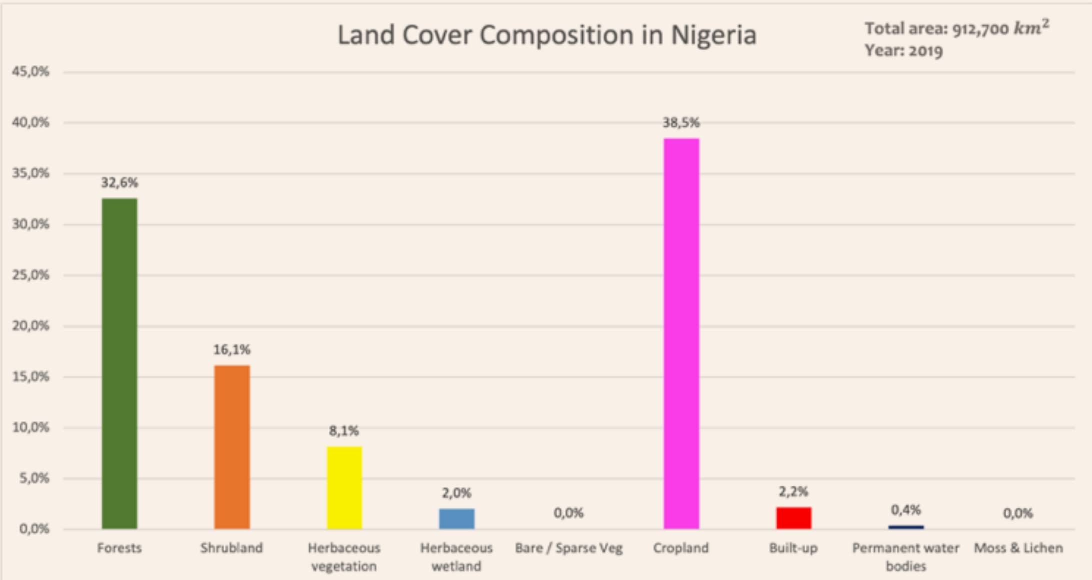
Figures 8 and 9 show that Nigeria's land surface is dominated by croplands which cover 38.5 percent of the country's total area which is estimated at 912,700 square kilometers (. This is followed by forests which cover 32.6 percent of the total land area, shrublands (16.1 percent), and herbaceous vegetation (8.1 percent). Other types of land uses are urban/built-up areas (2.2 percent), herbaceous wetlands (2 percent), and permanent water bodies (0.4 percent).

Figure 8: Land use and land cover in Nigeria, 2019



Source: Data processing: Authors.

Figure 9: Land cover distribution in Nigeria



Source: Data processing: Authors.

Notably, croplands which represent the most significant land cover class, are concentrated in the northern parts of the country. The southern regions are dominated by forests while herbaceous vegetation and shrublands are mostly found in the northern parts of the country.

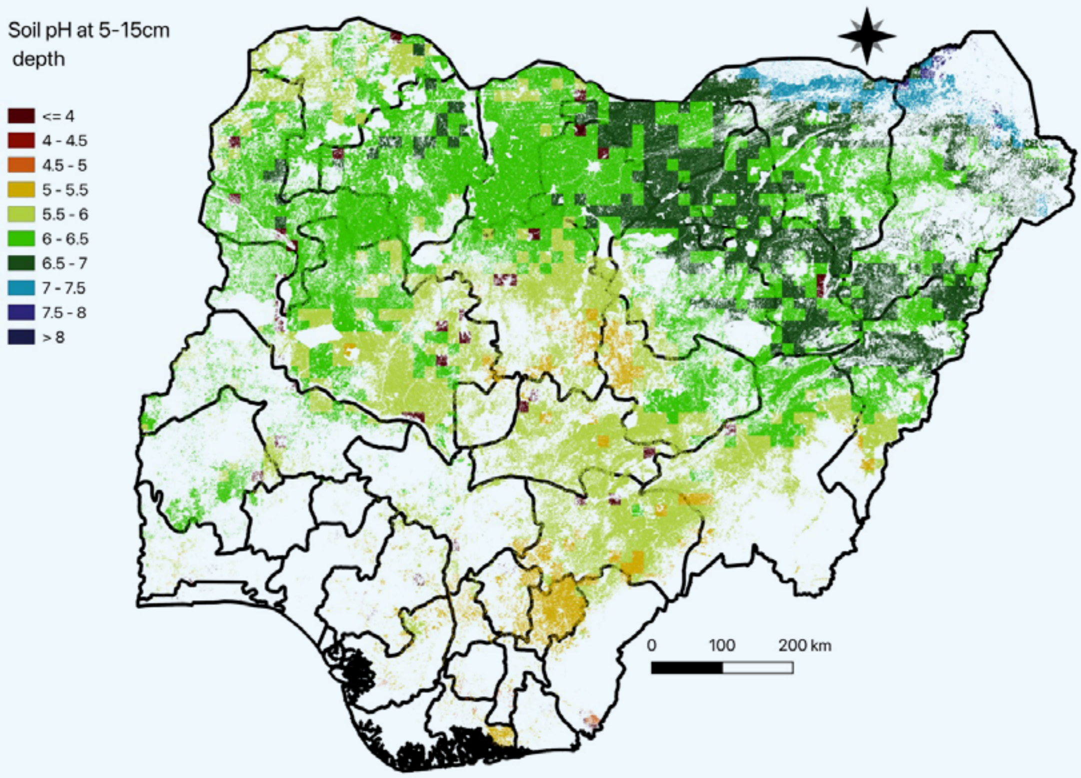
5. Soil Properties

5.1. Soil pH

This section presents the results of the analysis conducted at 5-15 cm on Nigeria's cropland soils. The purpose of this analysis was to determine the acidity or alkalinity of the cropland soils, which is a key factor in plant growth and nutrient uptake. Data were sourced from the SoilGrids dataset and the Copernicus Global Land Cover platform.

The analysis showed that cropland soils in Nigeria ranged from strongly acidic (pH<4) to slightly akaline (pH=7.9), with a mean pH of 6.16. The pH values of cropland soils varied significantly among Nigeria's different regions (Figure 10). The highest pH values are found in the northern regions. These values decrease in the southern regions where strongly acidic soils (pH<4) are found.

Figure 10: Soil pH of croplands at 5-15cm depth in Nigeria

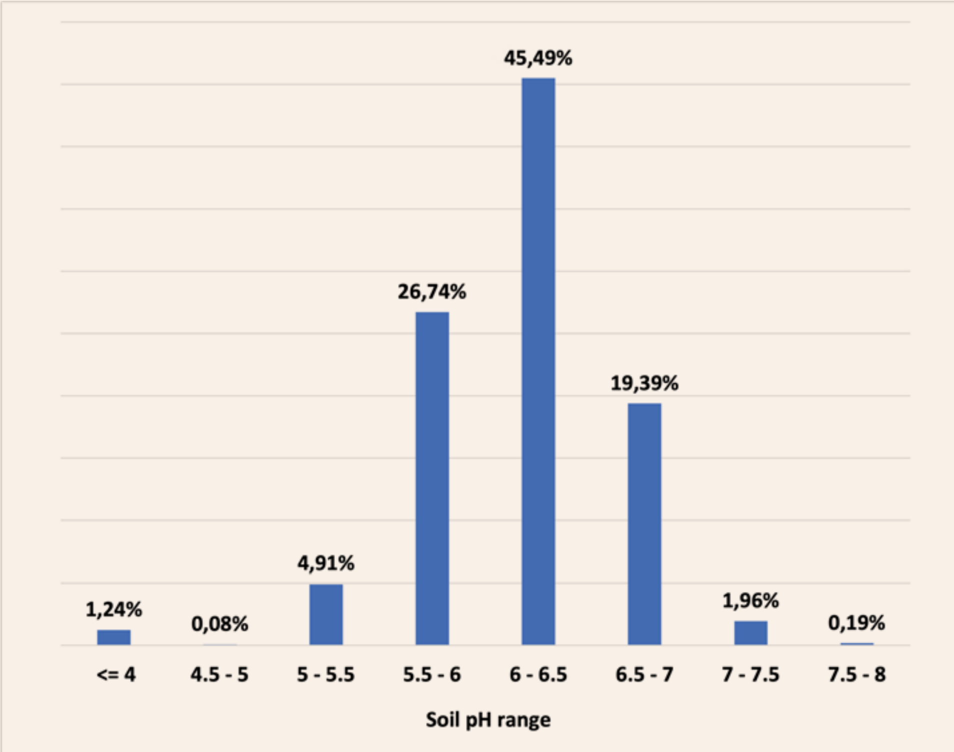


Source: Data processing and map: Authors.

Figure 11 represents the percentage of each soil pH range found in Nigeria's total cropland area. Most cropland soils in Nigeria are acidic as 91.62 percent have a pH value between 5.5 and 7. These conditions are favorable for some major crops encountered in Nigeria such as cassava, maize (MS, et al. 2022) and rice (Shamshuddin et al. 2017) (Halim et al. 2018). Soils with these pH values enhance the solubility of minerals and nutrients (such as boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn)) therefore making them available to plants (Queenland Government 2022) (SUNY college of Environmental Science and Forestry n.d.). Only 21.54 percent of croplands in Nigeria have a pH value between 6.5 and 8, which is a favorable range for the growth of millet (Staggenborg and Prasad 2010), another important crop in Nigeria.

Notably, 8.38 percent of Nigeria's croplands have a soil pH that is less than 5.5 or greater than 7. These soil pH values cause aluminum toxicity (Fageria and Nascente 2014) (Queenland Government 2022) or result in nutrient unavailability (Shamshuddin et al. 2017) for cassava, maize and rice. This has negative effects on the growth and yields of these crops. Further, 78.46 percent of Nigeria's croplands are not favorable for growth of millet due to these same reasons.

Figure 11: Cropland distribution by soil pH classes at 5-15cm depth in Nigeria

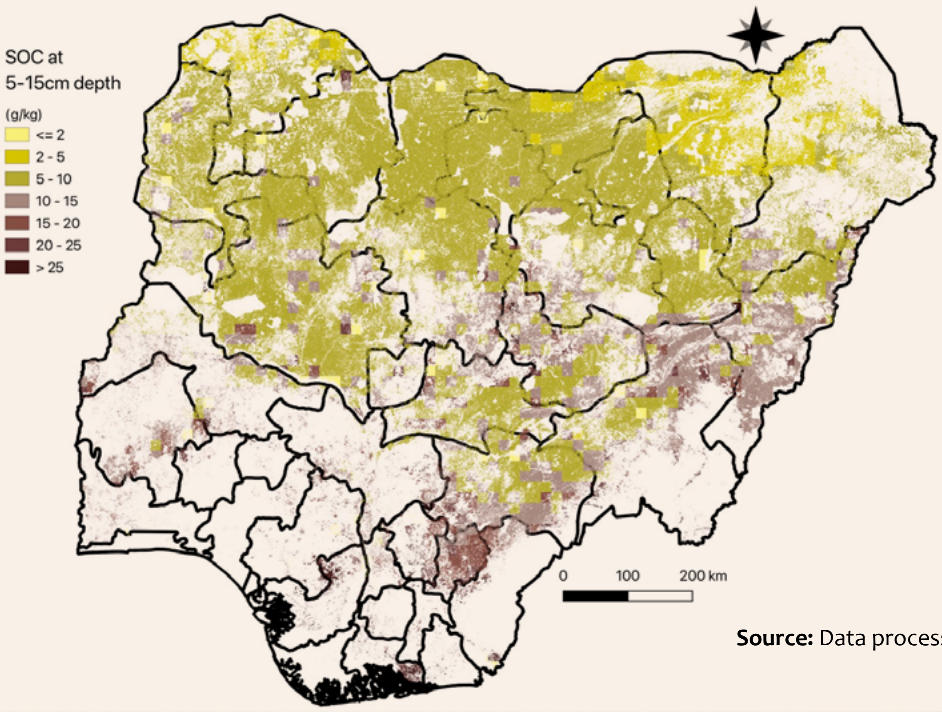


Source: Data processing: Authors

5.2. Soil Organic Carbon

This study also involved a soil carbon analysis using cropland soils from different Nigerian regions. The objective was to assess the amount of soil organic carbon (SOC) found at 5-15 cm depth in the country's cropland soils using the SoilGrids dataset. The results showed significant variations in SOC levels across the country, with the southern regions generally having higher levels than the central and northern regions (Figure 12). The SOC in Nigeria's cropland soils varies between 0 and 60.4 g/kg (0 – 6.04 percent) with an average value of 8.6 g/kg (0.86 percent).

Figure 12: Cropland soil organic carbon at 5-15cm depth in Nigeria

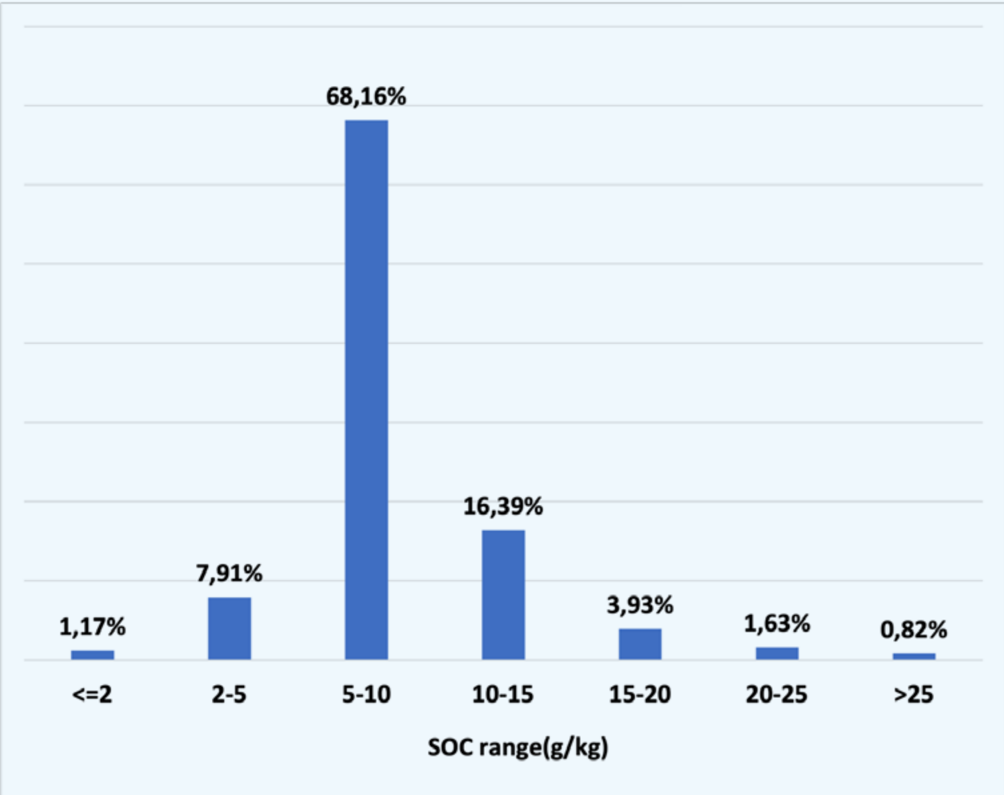


Source: Data processing and map: Authors.

Figure 13 represents the percentage of each SOC range (in g/Kg) encountered over Nigeria's total cropland area. The analysis shows that 97.55 percent of cropland soils in Nigeria have an SOC value that is less than 20 g/kg (2 percent). These low SOC values decrease the soil's physical resistance and resilience (Rumpel et al. 2020) which may affect soil fertility and decrease potential crop production. This also means that only small amounts of atmospheric carbon are sequestered by the soil.

The 2.45 percent of cropland soils with an SOC value of more than 20 g/kg (2 percent) are more favorable to soil's physical, chemical, and biological processes (Blanco-Canqui et al. 2013). In this case, soil fertility (Rumpel et al. 2020) and porosity (Johannes et al. 2017) will tend to increase, consequently, better crop yields are expected. This also means that more atmospheric carbon is sequestered in these soils and so they contribute more to climate change mitigation (Rumpel et al. 2020) (Blanco-Canqui et al. 2013).

Figure 13: Cropland distribution by soil organic carbon at 5-15cm depth in Nigeria



Source: Data processing: Authors.

6. Drought Index

Drought is a natural phenomenon marked by prolonged, dry weather conditions which cause intense water shortages (World Bank 2019) and can have negative impacts on lives, properties, and activities (World Bank 2019). In parts of West Africa, drought hazards have contributed to the scarcity of natural resources and low yields resulting in crop failures, food price inflation, hunger, and malnutrition (United Nations Office for Disaster Risk Reduction (UNDRR) 2021). (World Bank 2019) identified four types of droughts: meteorological drought, hydrological drought, agricultural drought, and socioeconomic drought. We oriented our analysis to agricultural drought in general, which is determined by soil moisture measurements. We used the modified vegetation water supply index (MVWSI) developed by (WU and LU 2016) to design an index for agricultural drought risk assessment. (WU and LU 2016) showed that the use of MVWSI can eliminate regional and seasonal features at a large scale by introducing the relative normalized difference vegetation index (RNDVI) and the relative land surface temperature (RLST). The RNDVI is defined as the relative difference of the normalized difference vegetation index (NDVI) observed in the current year over the average normalized difference vegetation index over the last 20 years, termed $\overline{NDVI}$.

$$RNDVI = \frac{NDVI}{\overline{NDVI}}$$

As RNDVI is unstable for exceedingly small values of $\overline{NDVI}$, only values of $\overline{NDVI}$ ≥ 0.1 are considered, otherwise RNDVI equals one. The RLST is defined in the same way.

$$RLST = \frac{LST}{\overline{LST}}$$

Both Land Surface Temperature (LST) and $\overline{LST}$ are considered in degrees Celsius (C). As RLST is unstable for exceedingly small values of $\overline{LST}$, only values $\overline{LST} \geq 10\,°$ are considered, otherwise RLST equals one.

Finally, MVWSI is defined as the ratio of the relative normalized difference vegetation index (RNDVI) and the square of relative land surface temperature (RLST).

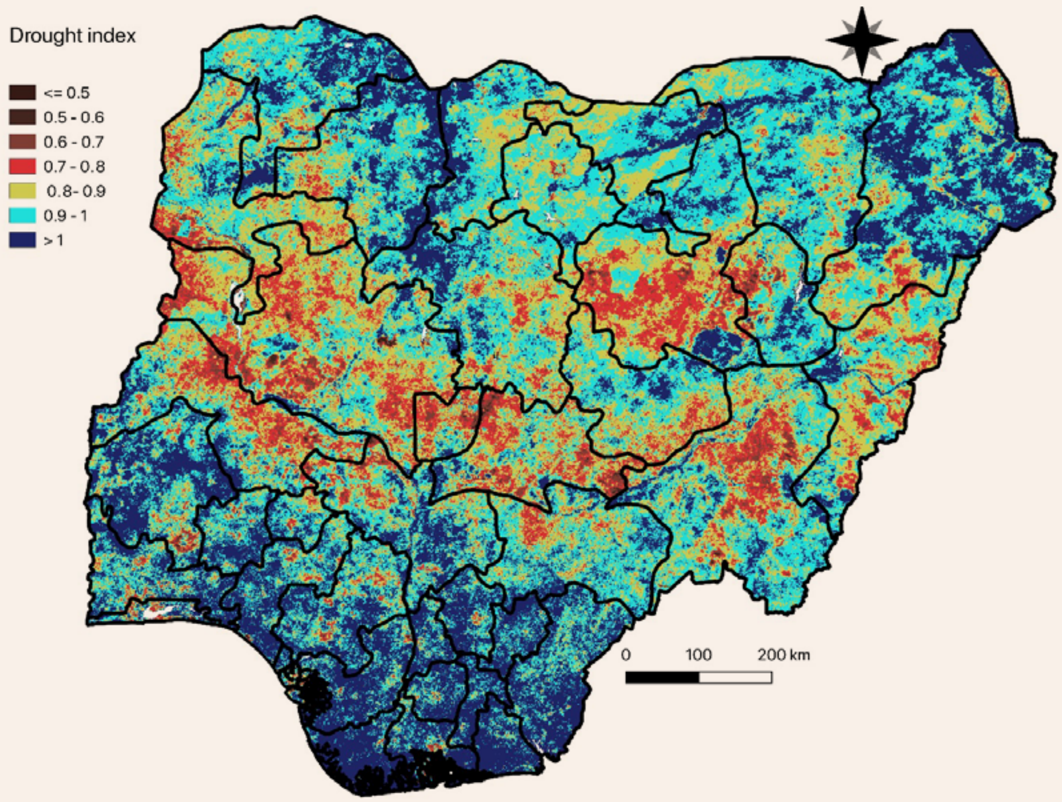
$$MVWSI = \frac{RNDVI}{RLST^2}$$

(WU and LU 2016) justified the choice of $RLST^2$ instead of RLST because of the low values of RLST. In addition, tests have proven that the square is always greater than the other power ($RLST^3$, $RLST^4$, $RLST^5$ ...).

According to (WU and LU 2016), values of MVWSI between 0 and 1 represent drought-prone areas. The smaller the MVWSI value, the lower the vegetation water supply and the more pronounced the drought is. Regions with an MVWSI greater than one do not suffer from drought.

In this study, we focus on determining Nigeria's MVWSI index in 2021. We collected 2001-2021 data on NDVI and LST. The means of 2021 data are considered to be the current year means, while the 2001-2020 means are considered to be the long-term averages for the last 20 years. Figure 14 presents the MVWSI map produced.

Figure 14: Nigeria's drought index, 2021



Source: Data processing and map: Authors.

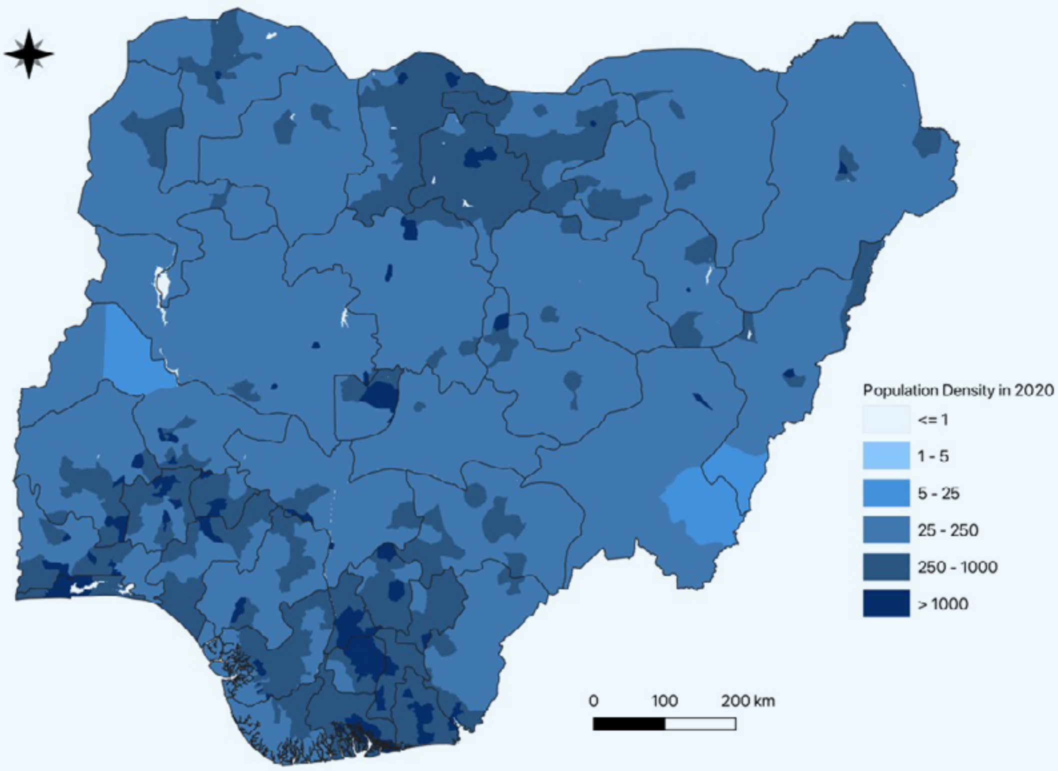
States like Niger, Kwara, Nasarawa, Bauchi, Gombe, Taraba and Abuja in Nigeria's middle belt are more exposed to agricultural drought hazards. Moreover, the fact that agriculture is predominantly rainfed and contributes significantly to the country's Gross Domestic Product (GDP) makes these regions, and the country as a whole, particularly vulnerable. Some of the dominant crops in these regions such as sorghum and millet are drought tolerant (Abreha, Enyew, and Carlsson 2022) (Tadele, Shanker, and Shanker 2016) and can be used to improve adaptation strategies under certain conditions that do not exceed these crops' limits. Other important crops in these regions such as rice, yams and maize (McMillen et al. 2022) are drought sensitive and therefore susceptible to stress and failure (McMillen et al. 2022). This might cause food price inflation and lead to severe hunger, and malnutrition (United Nations Office for Disaster Risk Reduction (UNDRR) 2021). Northern Nigeria is less exposed to agricultural drought hazards, and the region's dominant crops such as millet and sorghum are drought tolerant. Nigeria's southern regions are mostly moderately affected or drought-free.

7. Population Density

The population density adjusted from the Gridded Population of the World, Version 4 (GPWv4), consists of estimates of human population density (number of people per square kilometer) based on counts consistent with national censuses and population registers concerned with relative spatial distribution. These data are adjusted to match the 2015 Revision of the United Nation's World Population Prospects (UN WPP) country totals, for the years 2000, 2005, 2011, 2015, and 2020. A proportional allocation gridding algorithm, using approximately 13.5 million national and sub-national administrative units, was used to assign UN WPP-adjusted population counts to 30 arc-second grid cells. The density raster was created by dividing the UN WPP-adjusted population count raster for a given target year by the land area raster. The data files were produced as global rasters at 30 arc-second (~1 km at the equator) resolution.

In this section, we focus on Nigeria's 2020 population density using data extracted from the GPWv4 platform. Figure 15 illustrates how the population is distributed across the country. The map shows that the highest population density of more than 250 people per square kilometer (km^2) is concentrated in the northern and southern parts of the country. Overall, most regions are characterized by a population density ranging from 25 to 1,000 people per km^2. However, areas between Adamawa and Taraba regions as well as the eastern part of Kwara have the lowest population density of less than 25 people per km^2.

Figure 15: Population density (number of people per km^2) in Nigeria, 2020

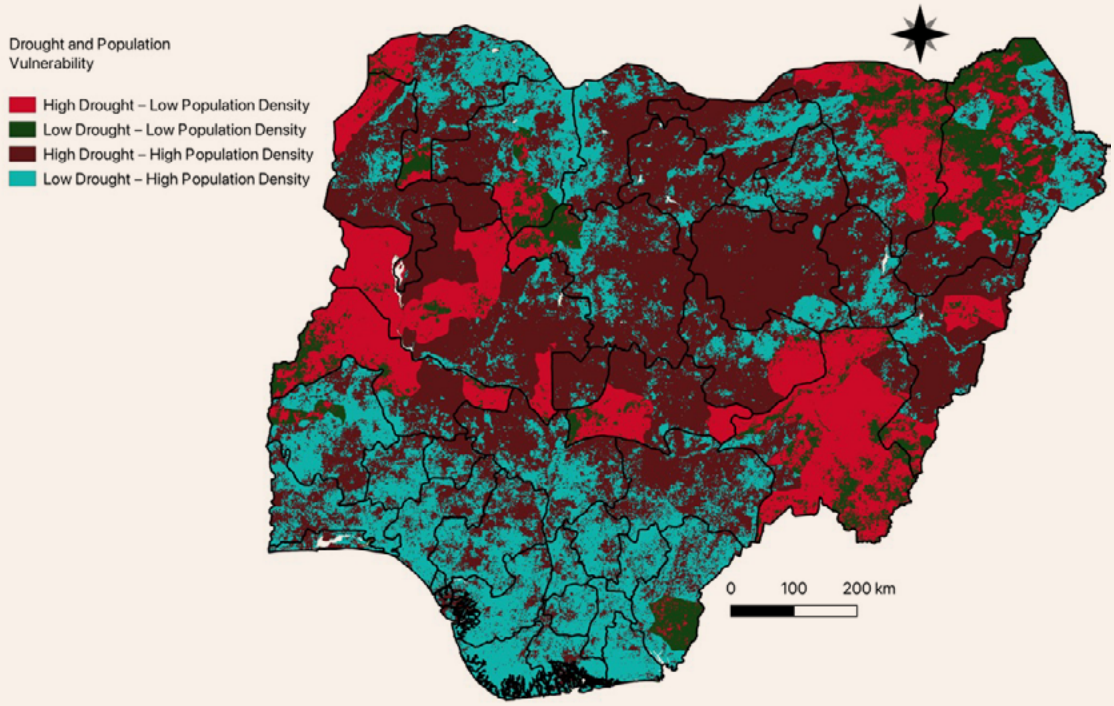


Source: Data processing and map: Authors.

8. A Climate Risk Typology based on Drought Index and Population Density

Figure 16 shows a typology of climate risks based on the interaction of climate exposure (drought index) and vulnerability (population density). Parts of Nigeria like Taraba, some parts of Kebbi, Niger and Kwara are exposed to drought, but their population density is low. While drought may be severe in these regions, fewer numbers of people affected. Higher numbers of people affected by drought are found in in some parts of northern Nigeria including Kaduna, Niger, Kebbi, Bauchi, Kano, Jigawa, Abuja, Nassawara, Plateau and Adamawa. Vulnerability is high in these parts as they have high population densities and greater drought intensities. In Nigeria, only small parts of Borno, Yobe, Kaduna, Cross River and Kwara are resilient to drought with low drought intensity and small population densities.

Figure 16: Typology of micro-regions based on drought and population density



Source: Data processing and map: Authors.

9. Conclusion

Nigeria is a land of immense diversity which boasts a variety of micro-climates ranging from hot and humid to parched and desert-like. The country's climate is influenced by multiple factors, including water bodies, rainfall, soil properties, and population density. Water bodies, such as the Niger and Benue Rivers, have a significant impact on Nigeria's climate, with rainfall levels differing considerably from region to region. Soil composition within the country also varies widely. Some areas have soils that are rich in nutrients while others are poorly vegetated with low soil fertility. Consequently, the country's climate plays a crucial role in determining the prevalence of drought and the viability of agricultural land. Dry regions are more susceptible to drought, while areas with higher rainfall are more suitable for agricultural production.

In conclusion, the physical characteristics and climate of Nigeria significantly influence the availability of agricultural resources and crop suitability. Crop yields and water availability are impacted by climate variables such as rainfall, soil carbon, and soil pH. Water bodies also play a vital role in making irrigation possible and realizing the related benefits. The sustainability of Nigeria's agricultural production may be jeopardized by drought and environmental factors. To ensure the proper management of resources and sustainable agriculture, it is essential for policy makers and researchers to consider the impact of drought, cropland, soil pH, soil carbon, water bodies, rainfall, and climate variables. This way, Nigeria will continue to enjoy the benefits of its agricultural output while safeguarding its natural resources for future generations.

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