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Assesment of Start and End of Growing Seasons in different Ecological Zones of Nigeria Using Satellite Data

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Abstract

The work analyzes phonological parameters: start of season (SOS), end of season (EOS), peak of season (POS), and length of season (LOS) using the Advanced Very High-Resolution Radiometer (AVHRR) Global Inventory Modeling and Mapping Studies (GIMMS) Normalized Difference Vegetation Index Version 3g (NDVI-3g) data from 1982 to 2015. The inflexion point method was used in determining the phenological metrics. Results show that the Humid zone (H) has the highest mean NDVI, indicating healthier vegetation cover, while the Warm Arid zone (WA) has the lowest mean NDVI, suggesting less vegetation. Seasonal variations in NDVI values are observed, with highest values during the wet season and lower values during the dry season. The Cold Sub-Humid zone (CSH) has the lowest mean temperature, while the Warm Arid zone (WA) has the highest mean temperature. Precipitation analysis shows that the Humid zone (H) has the highest mean precipitation, indicating better agricultural circumstances, while the Warm Arid zone (WA) has the lowest mean precipitation, indicating limited water supply. The phenology shifts in the zones occur at various rates from 1982 to 2015. The growth season is long and has an early start and late end in the H zone. The WSH zone also has an early start but a relatively short growing season. The growing season is shorter and starts earlier in the SA zone. The growing season in the WA zone begins rather early and lasts reasonably long. In the CSH zone, the growing season starts late and also has a relatively short length. In each zone, these changes in phenology shift rates may have a big impact on agriculture, ecosystems, and weather patterns.

Keywords: Phenology, NDVI, climate, Inflexion points, start of season, end of season, length of season

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Introduction

Over 65% of Nigeria's population depends on rainfed agriculture, which is vulnerable to rainfall inconsistency due to its controls on soil moisture and, consequently, crop yield. As a result, the agriculture sector plays a critical role in the country's economy by providing employment and food for a sizeable portion of its population. (Amissah-Arthur and Jagtap, 1999; Oguntunde et al., 2011). In order to improve agricultural operations, increase food security, and lessen the effects of climate variability and change, it is crucial to understand the beginning, end, and length of the growing seasons (Oguntunde, et al., 2014). But the accuracy and spatial coverage of conventional methods used by farmers to track growth seasons are constrained. However, improvements in remote sensing technology, especially the utilization of satellite data, present a chance to enhance the evaluation of agricultural trends across wide geographic areas.

Ati et al., 2002 defined the onset of rains or the start of the growing season as the reception of an adequate amount of rainfall for the survival of seedlings after sowing. The start of the growing season is a vital characteristic to which other seasonal rainfall features are linked (Odekunle, 2004). The end of the growing season is defined as the last useful rain that contributes to the availability of water for any crop that was sown after the onset date (Omotosho et al., 2000). The growing season, according to Odekunle et al. (2005), is the time of year when the pattern of rainfall is suitable for seed germination and plant growth. It's known as the rainy or wet season in the tropics. Nigeria, a typical tropical nation, has varying amounts of precipitation depending on the location and the time of year. Following the path of the sun throughout the year, the rain belt seems to oscillate between the northern and southern regions of the nation. A delay of one or two weeks in the start of the season might affect the harvest output, so it is important to measure and estimate this variation in the start of the season, end of the season, and length of the rainy season. According to Omotosho et al. (2000), there can be inter-annual variations of up to 70 days in the beginning of the growing season at a station in Nigeria. This seasonal variability makes it difficult to choose the right crop type and species as well as to schedule the planting date (Mugalavai et al., 2008).

The use of satellite data for tracking agricultural trends and vegetation dynamics has been extensively studied in the literature. Studies carried out in various parts of the world have shown how well remote sensing can identify the beginning and conclusion of growth seasons. To better understand agroecological zones and agricultural potential, Dubovyk et al. (2015) used satellite-derived vegetation indices to identify the beginning of greenness in various regions of Africa. Yousif et al. (2018) studied the association between crop yield and satellite-derived vegetation indices in various Sudanese states and shed important light on trends in agricultural productivity. Similar to this, Cui & Shi (2021) created a technique to gauge the length of the growing seasons in China by examining remote sensing data, enabling enhanced crop management tactics. Additionally, using solely surface synoptic data, Omotosho et al. (2000) created new empirical long-range techniques for forecasting the dates of beginning and cessation as well as the monthly and annual amounts of rainfall for Kano in the West African Sahel.

In Nigeria context, the impact of climate change on the length of main crops' growth seasons was recently investigated by Ugbah et al. (2018), who also highlighted the significance of precise phenological data for adaptation and resilience. Additionally, Odekunle (2004) investigated the length of the growing season in Nigeria using cumulative percentage mean rainfall and daily rainfall probability methods applied to the daily rainfall data for Ikeja, Ondo, Ilorin, Kaduna, and Kano collected from the archives of the Nigerian Meteorological Services between 1961 and 2000 (40 years) and found that the active lengths of the growing season were roughly 5 months, 5 months, 4 months, 4 months, and 2 months, respectively. In their analysis of temperature and precipitation data from 41 synoptic stations obtained from the Nigerian Meteorological Agency (NiMet) dispersed throughout Nigeria between 1981 and 2017, Ugbah et al. (2018) found an increase in the trend of annual mean maximum and minimum temperature anomalies, while the rainfall analysis showed positive standardized anomalies above 0.5.

Jagtap, S. (1995) examined the dynamics of spatial and temporal change in annual, seasonal, and monthly rainfall for 30 years (1961-1990) using daily rainfall data in an effort to provide baseline data for agricultural development activities in Nigeria. He discovered that annual rainfall declined in Nigeria over both time and space. The findings also indicated that there had been significant changes in the timing of the rainy season and the amount of early precipitation, which had led to a nearly one-month reduction in the growth season and probably increased the danger of planting early.

Oladipo and Kyari (1993) estimated the length of the growing season and dates of its onset and termination from long-term rainfall series in northern Nigeria. They came to the conclusion that the time series of these variables are homogeneous, random, and can be regarded as normally distributed, with a progressive shortening of the growing season from a mean of about 200 days in the south to less than 100 days in the north.

Oguntunde et al. (2011) investigated if Nigeria's rainfall pattern had a trend or periodicity throughout the previous century and found that rainfall changes were between 3.46 and +0.76 mm/yr^2. In addition, they found that 22% of the overall landscape had substantial changes at 5% levels and that there was a noticeable difference in rainfall changes between the time periods of 1931–1960 and 1961–1990. About 90% of the entire terrain had negative trends. Their findings also discovered four distinctly different rainfall cycles, with periods of 2-3, 5-7, 10-15, and 30 years.

Ishaku et al. (2021) used monthly rainfall data for Plateau, Nasarawa, and Benue obtained from the head office of the Nigerian Meteorological Office (NIMETS) to analyze the start, end, and length of the rainy season. They used the Walter (1967) formula and discovered that, despite the variability in the start, end, and length dates for the period and location, the regression technique established 7th, 20th, and 10th April as onset dates for the growing season in Plateau, Nasarawa, and Benue states respectively. It is also interesting to note that October 16th was the average cessation date across all locations (Ishaku et al., 2021).

Despite these advancements, more research is still needed to understand the various ecological zones of Nigeria, each of which has its own unique climatic and agricultural characteristics. As an understanding of the phenological metrics typically influenced by climate, temperature, and precipitation patterns, which impact vegetation growth and productivity, offers valuable insights into the timing and duration of growing seasons in different AEZs and is essential for effective agricultural planning, resource management, and policy making, this research aims to improve our understanding of the temporal dynamics of agricultural activities in Nigeria's different ecological zones. This study attempts to fill this knowledge gap by establishing when the growing season starts, its length, peak and when it finishes in various ecological zones of Nigeria using cutting-edge satellite data and sophisticated research tools. Policymakers and agricultural stakeholders may find the study's findings to be a useful resource for formulating plans to improve the region's food security and farming methods.

MATERIALS AND METHODS

Study area

Nigeria is located in Africa and comprise of 36 states and the Federal Capital Territory (Abuja). It is the most densely populated country in West Africa. It is located in between the dry Sahel and desert to the north and the Atlantic Ocean to the south. The geographical location of Nigeria is at latitudes 4° – 14°N and longitude 2°W – 14° East and covers an area of about 923,769 km^2 (Igbawua et al., 2016). It is bordered to the west by Benin republic, to the northwest and north by Niger republic, to the northeast by Chad and to the east by Cameroon, while the south is bordered with the Atlantic Ocean. The land cover ranges from thick mangrove forests and dense rain forest in the southern region to a near-desert condition in the northern region of the country. The vegetation zones include; forest, guinea, Sudan and Sahel savannah. There are two basic rivers in Nigeria; the Benue and Niger rivers. There are a lot of river networks in Nigeria, most settlements are located at the banks of some rivers or streams. The rainfall distribution in the forest and guinea savannah regions is higher than the dry Sahel. Figure 1 is the geographical map of Nigeria, showing its location on the African map.

Data

Global Inventory Modelling and Mapping Studies (GIMMS), Advanced Very High Resolution Radiometer (AVHRR), Normalized Difference Vegetation Index (NDVI) was used as a proxy for vegetation. Vegetation greenness (NDVI) is a measure of vegetation health calculated from satellite data which ranged from -1 to +1. Climate parameters (temperature and precipitaion) were obtained from Climate Research Unit (CRU). The Agro-ecological Zones (AEZ) were extracted from International Food Policy Research Institute (IFPRI) data base (Kate, 2009). The are some of the data sources used in this study. The AEZ distribution is separated into humid, sub-humid, semi-arid, arid, and tropical mountains.

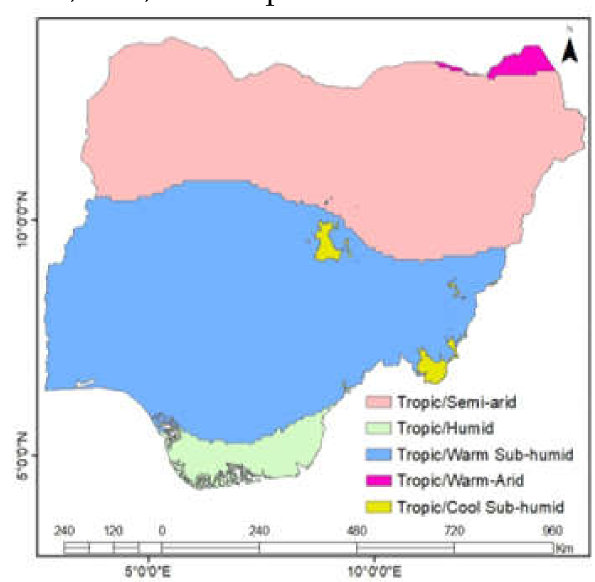


Fig. 1 Study Area with Agro-ecological zones

Methods

The inflexion point method was used in detrmining the phenological metrics. The first inflexion point (L1) represents the SOS (Zeng et al., 2020). Hou et al. (2019), extracted SOS as the point where the NDVI rise is about 30% of the minimum (base) value. The EOS is extracted when the falls below the SOS point. The length of the growing season (LOS) was estimated at the difference between SOS and EOS, and the Peak of Season (POS) is the highest NDVI of the season. The methodology used in extracting the phenological metrics is given in figure 2.

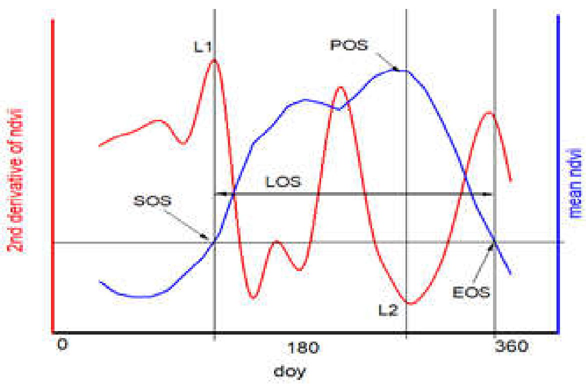


Fig. 2 Methodology used in extracting phenological metrics using inflexion point. L1 is the inflexion point that signifies the rise in NDVI (SOS). L2 shows the peak of the season (POS) and LOS represents the difference between SOS and EOS. The blue and red lines depict the original and differentiated NDVI series.

The rate of phonological shift (R_{PS}) is given by (Wang et al., 2016)

$$R_{PS} = \frac{n\ x\ (\sum_{i=1}^{n} i \times Day_i) - (\sum_{i=1}^{n} i \times \sum_{i=1}^{n} Day)}{n\ x\ \sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} i)^2} \quad (1)$$

Where n the total is number of years; and Day_i is the seasonal phenology (SOS, POS, EOS and LOS) of year i, where is from 1 to .

The correlation coefficient and regression analysis between NDVI and climate variables was determined using equation (2) and (3) given by

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \times \sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (2)$$

$$y = a_m . x + b \quad (3)$$

Where, y and x are the independent and dependent variables respectively. a_m and b are the regression slope and intercept respectively.

$$a_m = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}} \quad (4)$$

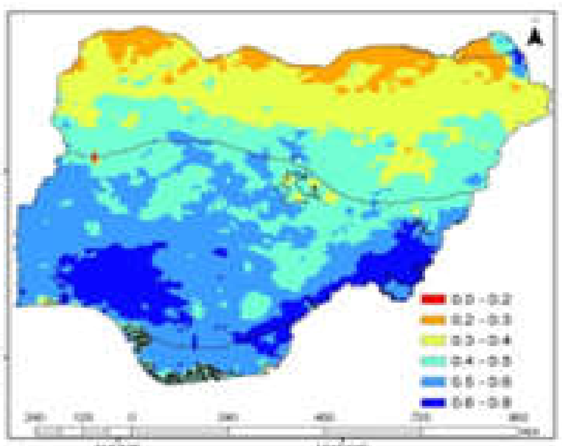
Results

Mean NDVI and climate variables over the study area

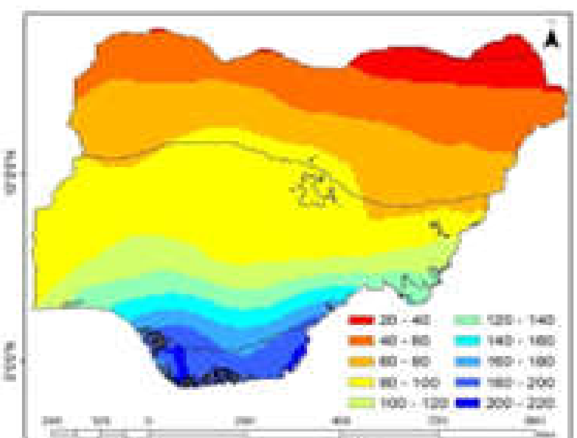
Figure 3, shows the mean (a) NDVI, (b) Precipitation and (c) Temperature from 1982 to 2015. Analysis from results show that the minimum NDVI in the Semi-Arid zone (SA) is 0.3295, while in the Humid zone (H), it is 0.639, 0.743, and 0.538. In the Warm Sub-Humid zone (WSH), it is 0.152, 0.743, and 0.538. In the Warm Arid zone (WA), it is 0.241, 0.603, and 0.363. In the Cold Sub-Humid zone (CSH), the minimum NDVI is 0.381, 0.723, and 0.53. These values indicate that the Humid zone (H) has the highest mean NDVI, indicating healthier vegetation, while the Warm Arid zone (WA) has the lowest mean NDVI, suggesting less vegetation cover.

The Semi-Arid zone experiences lowest precipitation of 27.16 mm, maximum precipitation of 92.053 mm, and mean precipitation of 59.107 mm. The Humid zone experiences minimum precipitation of 153.035 mm, maximum precipitation of 172.965 mm, and mean precipitation of 166.6635 mm. The Warm Sub-Humid zone experiences minimum precipitation of 69.66 mm, maximum precipitation of 198.33 mm, and mean precipitation of 107.22 mm. Warm Arid (WA): The Warm Arid zone experiences lowest precipitation of 21.93 mm, maximum precipitation of 29.98 mm, and mean precipitation of 26.27 mm. The Cold Sub-Humid zone experiences minimum precipitation of 86.72 mm, maximum precipitation of 167.55 mm, and mean precipitation of 112.76 mm. These statistics clearly show that the Humid zone (H) has the highest mean precipitation, which indicates better agricultural circumstances, while the Warm Arid zone (WA) has the lowest mean precipitation, which indicates a restricted supply of water.

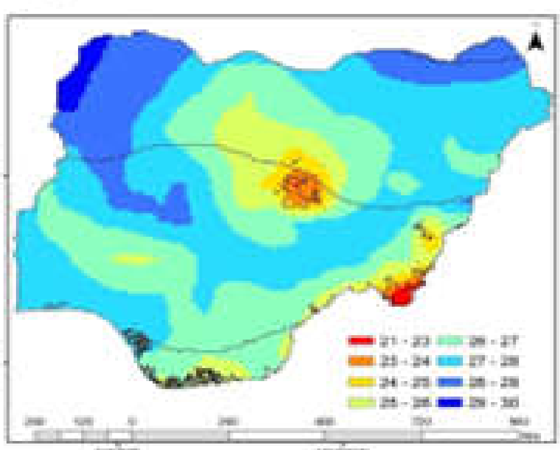
The Semi-Arid zone's mean temperature is 32°C, with a low temperature of 23.44°C and a maximum of 29.38°C. The Humid Zone's mean temperature is 24.144°C, with a minimum temperature of 23.675°C and a maximum of 24.6205°C. The Warm Sub-Humid zone has a mean temperature of 26.87°C, a low of 22.102°C, a maximum of 28.31°C, and a range in between. The Warm Arid zone has an average temperature of 28.311°C, a minimum temperature of 28.107°C, and a high temperature of 28.437°C. The Cold Sub-Humid zone has a mean temperature of 23.48°C, a minimum of 21.114°C, a maximum of 26.149°C, and a range in between. As can be observed, the Cold Sub-Humid zone (CSH) has the lowest mean temperature, indicating chilly conditions, and the Warm Arid zone (WA) has the highest mean temperature, indicating hot conditions.



(a) NDVI



(b) Precipitation (mm/month)



(c) Temperature (°C)

Fig. 3 Mean (a) NDVI, (b) Precipitation and (c) Temperature from 1982 to 2015

Monthly mean NDVI and climate variables

Figure 4 shows monthly NDVI distribution of minimum, maximum and mean NDVI values. Results reveal that in the CSH zone, NDVI values range from 0.365 in December to 0.751 in September. With greater NDVI values during the rainier months and lower values during the drier months, vegetation exhibits a seasonal pattern. The peak NDVI values, which signify the height of vegetation growth during the wet season, are seen from June to September. NDVI values in the WSH zone range from a minimum of 0.387 in January to a maximum of 0.712 in October. The Warm Sub-Humid zone experiences a gradual increase in NDVI values from January to October, suggesting vegetation growth and health improve during the rainy season. The WA zone's NDVI values fluctuate just slightly from month to month, averaging 0.195 in December and 0.599 in September. Due to the arid climate and scarce water supply, the WA zone has generally consistent NDVI values, which indicates minimal vegetation cover. The SA zone's NDVI values range from 0.681 in September to a minimum of 0.247 in March. From March through September, the NDVI of the SA region gradually rises, indicating greater vegetation health during the wet season. The H zone's NDVI values fluctuate seasonally, with a minimum of 0.278 in March and a maximum of 0.591 in November. High NDVI values are typically maintained in the humid zone, indicating consistently robust and abundant vegetation.

Figure 5, shows monthly NDVI distribution of minimum, maximum and mean NDVI values. Results indicate that, the Cool Sub-Humid zone has temperatures that range from 21.03612141°C in January to 28.81144727°C in March. From January to March, the temperature rises steadily before peaking in March. The temperature starts to drop after March and reaches its lowest point in July. The Warm Sub-Humid zone experiences seasonal temperature variations, with a low temperature of 25.27 °C in January and a maximum temperature of 30.09 °C in March. From January until March, the temperature gradually rises; from then until October, it is comparatively constant before beginning to fall once more. The WA zone's temperature varies considerably, with minimums of 18.40 °C in January and maximums of 34.67 °C in April. From January to April, the temperature progressively rises, mirroring the sweltering conditions typical of dry regions. From May through December, it steadily declines. A minimum temperature of 19.99 °C in January and a high temperature of 33.43 °C in April are typical for the SA zone. From January to April, the temperature tends to rise, suggesting the hot conditions typical of semi-arid regions. From May to December, it then starts to decline. With a minimum of 22.47 °C in February and a maximum of 27.48 °C in September, the temperature in the H zone changes only modestly. From February to September, when NDVI values are substantially higher and the temperature steadily rises, the conditions are ideal for vegetation development.

Also from Figure 5, it can be seen that the CSH zone experiences significant seasonal variation in precipitation, with a minimum of 0.10 mm in December and a maximum of 312.42 mm in July. The Cool Sub-Humid zone sees a lot of rain during the wettest months of May to September, which encourages the growth of plants. December is the year's driest month, and the dry season begins in November and lasts until April. A noticeable seasonal pattern can be seen in the WSH zone's precipitation, which varies from a minimum of 13.61 mm in January to a maximum of 320.89 mm in September. From March through October, the Warm Sub-Humid zone undergoes a rainy season during which heavy rainfall encourages the growth of vegetation. Between November and February is the dry season, which is characterized by much less precipitation. The rainfall in WA is typically infrequent throughout the year, with some months seeing little to no precipitation. There is occasional precipitation between March and August, however, the amounts are small in comparison to other places. October through February frequently had no recorded precipitation. The SA region experiences considerable seasonal variations in precipitation, with very low levels during the dry season and higher values during the rainy season. The most precipitation falls between June and September, promoting vegetation development throughout the rainy season. Contrarily, the months of December through April experience decreased levels of precipitation, which compromises the health of the plants. Significant changes may be seen in the H Zone's precipitation, which ranges from a minimum of 0.12 mm in May to a maximum of 492.62 mm in May. The wettest month in the humid zone is May, where significant levels of precipitation are experienced throughout the year and promote ongoing vegetation development.

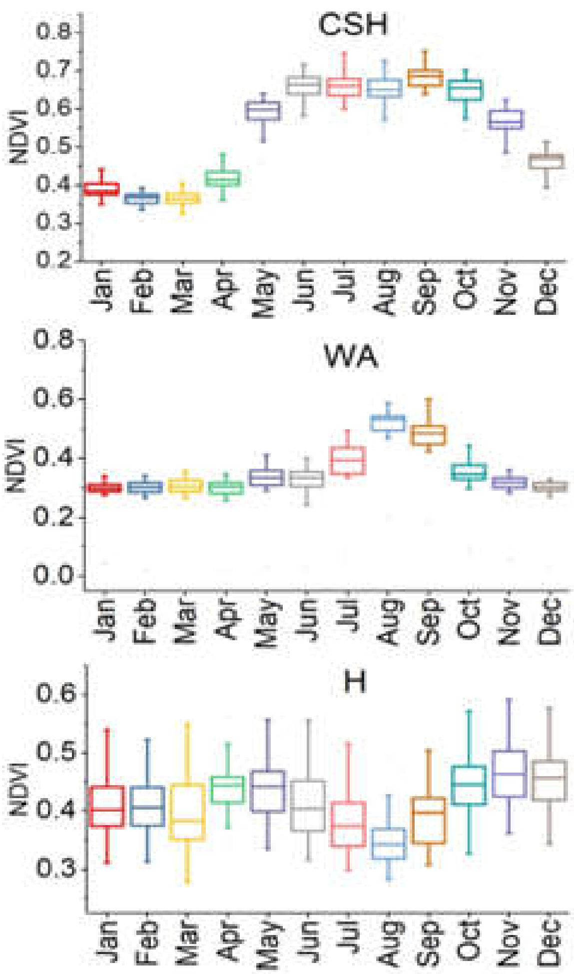


Fig. 4 Mean monthly NDVI values across the AEZ

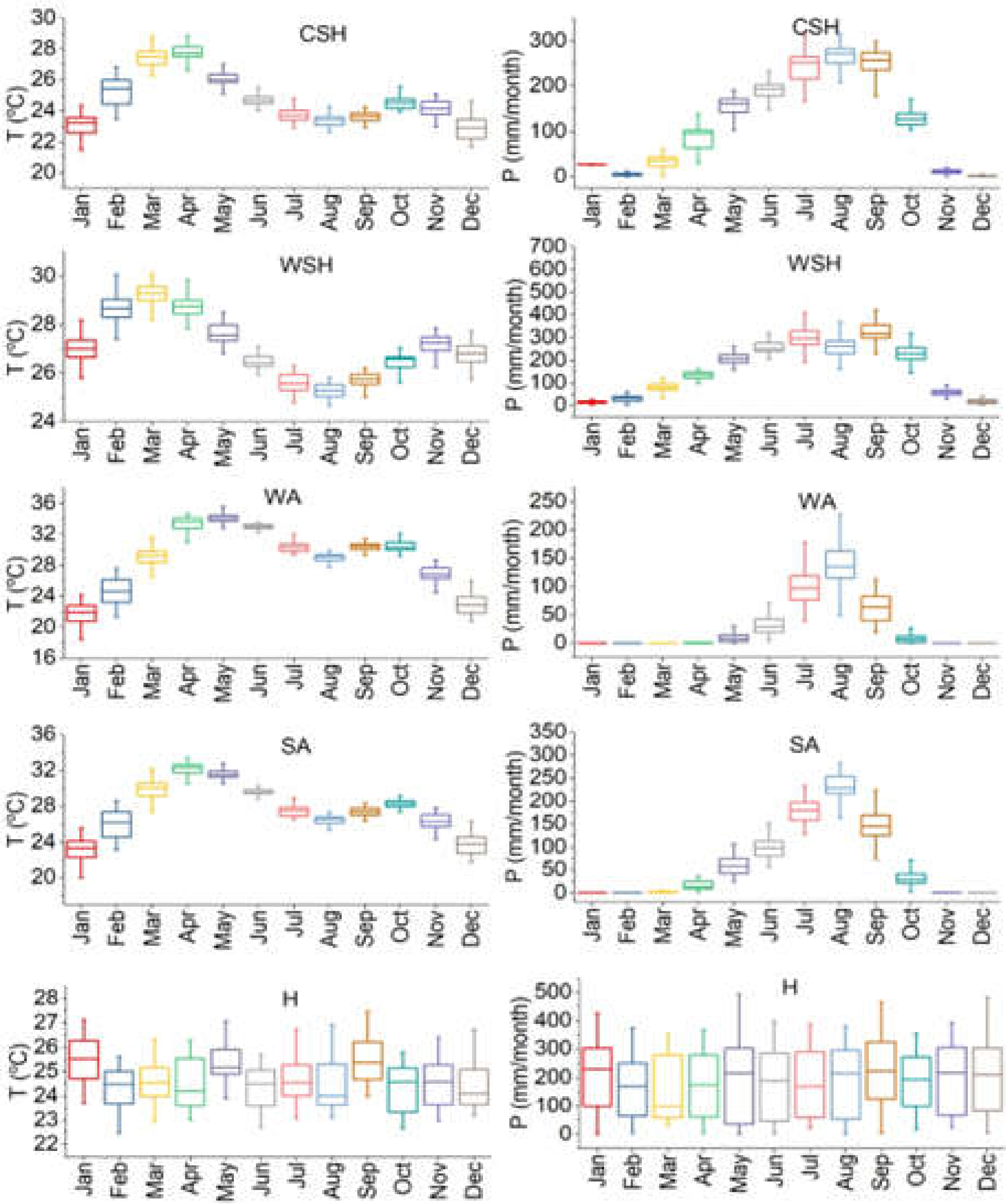


Fig. 5 Monthly temperature and precipitation values across the AEZ

Regression Trend in NDVI and climate variables

A regression analysis was applied to NDVI and climate variables to assess their temporal changes from 182 to 2015. The NDVI regression coefficient for the year (0.000737yr^{-1}) for the CSH zone shows a very little positive change in NDVI per year. The temperature and precipitation is changing over time with trends 0.0183 °C/yr and -0.092 mm/yr respectively. In the WSH, a slight improvement in annual NDVI is indicated by the regression coefficient for the year (0.002 yr^{-1}) for NDVI. The regression coefficient for temperature and precipitation indicates 0.018 °C/yr and 0.137 mm/yr respectively. For the SA zone, the NDVI regression coefficient indicated 0.00106 yr^{-1} showing a slight improvement in from 1982 to 2015. Meanwhile, the annual temperature and precipitation indicated trend values of 0.024 °C/yr and 0.386 mm/yr respectively. In contrast, the NDVI regression shows a negative coefficient of -0.00150 yr^{-1} WA zone but temperature and precipitation are increasing positively at 0.0248 °C/yr and 0.395 yr^{-1} respectively. A very slight increase in annual NDVI in the H zone is indicated by the regression coefficient with a value 0.000694 yr^{-1}.Accordingly, temperature and precipitation increased together with NDVI in H zone at 0.0138 °C/yr and 0.526 mm/yr respectively

Extraction of Start and End of Seasons in Agro-ecological zones (AEZ) of Nigeria

Figure 6 displays the mean NDVI and the 2nd derivative of NDVI, which were utilized to extract phenological metrics for different Agro-Ecological Zones (AEZs). The inflection points in the 2nd derivative are critical in detecting the onset of the growing season when the NDVI signal starts to rise from its minimum value. The first local maximum in the NDVI curve signifies the time at which the season commences. For the Humid (H) zone, the Start of Season (SOS), Peak of Season (POS), and End of Season (EOS) were observed at Julian days 80, 150, and 360, respectively. The Length of Season (LOS) was found to be 280 days. At SOS, POS, and EOS, the mean NDVI values were calculated as 0.480, 0.600, and 0.530, respectively. In the Humid (H) zone, the correlation between NDVI and temperature at SOS, EOS, and POS was found to be 0.017 ($p > 0.05$), 0.171 ($p > 0.05$), and -0.088 ($p > 0.05$), respectively. These results indicate weak and non-significant correlations between NDVI and temperature during the start, end, and peak of the season in the Humid zone. Furthermore, the correlation between NDVI and precipitation at SOS, EOS, and POS showed values of 0.005 ($p > 0.05$), 0.045 ($p > 0.05$), and 0.087 ($p > 0.05$), respectively. This suggests weak and non-significant associations between NDVI and precipitation during the start, end, and peak of the season in the Humid zone.

Moving on to the Warm Semi-Humid (WSH) zone, the SOS, POS, and EOS were all identified on Julian days 112, 225, and 350, respectively, while the LOS was 238 days. The average NDVI values at SOS, POS, and EOS were found to be 0.430, 0.650, and 0.450, respectively. In the WSH zone, the correlation between NDVI and temperature at SOS, EOS, and POS was observed to be -0.186 ($p > 0.05$), 0.385 ($p < 0.05$), and 0.254 ($p > 0.05$), respectively. These findings suggest a weak and non-significant negative correlation between NDVI and temperature during the start of the season, a moderate and significant positive correlation at the end of the season, and a weak and non-significant positive correlation at the peak of the season in the Warm sub-humid zone. On the other hand, the correlation between NDVI and precipitation at SOS, EOS, and POS in the Warm sub-humid zone showed values of 0.308 ($p > 0.05$), 0.110 ($p > 0.05$), and 0.189 ($p > 0.05$), respectively. These results indicate weak and non-significant positive correlations between NDVI and precipitation during the start, end, and peak of the season in the Warm sub-humid zone.

In the Semi-Arid (SA) zone, the SOS, POS, and EOS occurred on Julian days 170, 258, and 330, respectively, with the LOS being 160 days. The mean NDVI values at SOS, POS, and EOS were 0.270, 0.580, and 0.350, respectively. At SOS, EOS, and POS, it was shown that the correlation between NDVI and temperature was -0.327 ($p > 0.05$), 0.086 ($p > 0.05$), and 0.019 (p 0.05), respectively. Based on these results, the season began with a weak negative connection, ended with a weak positive correlation, and peaked with a substantial positive correlation. Furthermore, at SOS, EOS, and POS, the correlation between NDVI and precipitation showed values of 0.338 ($p > 0.05$), 0.086 ($p > 0.05$), and 0.019 (p 0.05), respectively (Table 1), In the SA zone, this implies a weak and non-significant correlation between NDVI and precipitation at the beginning and end of the season, but a strong positive correlation during the peak of the season.

For the Warm Arid (WA) zone, the SOS, POS, and EOS appeared on Julian Days 184, 240, and 296, respectively, with a LOS of 112 days. The mean NDVI values at SOS, POS, and EOS were obtained as 0.30, 0.53, and 0.30, respectively. The correlation between the temperature at SOS, EOS, and POS in the Warm Arid (WA) zone was discovered to be -0.354 (p 0.05), -0.038 ($p > 0.05$), and 0.040 ($p > 0.05$), respectively. These findings show a weak and non-significant association with temperature at the beginning of the season, a strong negative correlation at the end of the season, and a weak and non-significant correlation at the top of the season. Additionally, at SOS, EOS, and POS, the association between NDVI and precipitation yielded values of 0.121 ($p > 0.05$), -0.311 ($p > 0.05$), and -0.259 ($p > 0.05$), respectively. This suggests that there are only weak and insignificant correlations between NDVI and precipitation in the Warm Arid zone at the beginning, end, and peak of the season.

Finally, in the Cold Semi-Humid (CSH) zone, the SOS, POS, and EOS were observed at Julian days 112, 265, and 340, respectively, with a LOS of 228 days. The mean NDVI values at SOS, POS, and EOS were 0.45, 0.68, and 0.43, respectively. The correlation between NDVI and temperature at SOS, EOS, and POS was found to be -0.390 ($p > 0.05$), 0.406 ($p < 0.05$), and 0.358 ($p < 0.05$), respectively. This indicates a weak negative correlation at the start of the season, a significant positive correlation at the peak of the season, and a significant positive correlation at the end of the season. On the other hand, the correlation between NDVI and precipitation at SOS, EOS, and POS showed values of 0.095 ($p > 0.05$), 0.063 ($p > 0.05$), and -0.055 ($p > 0.05$), respectively (Table 1), suggesting weak and non-significant correlations between NDVI and precipitation across these phenological stages in the CSH zone.

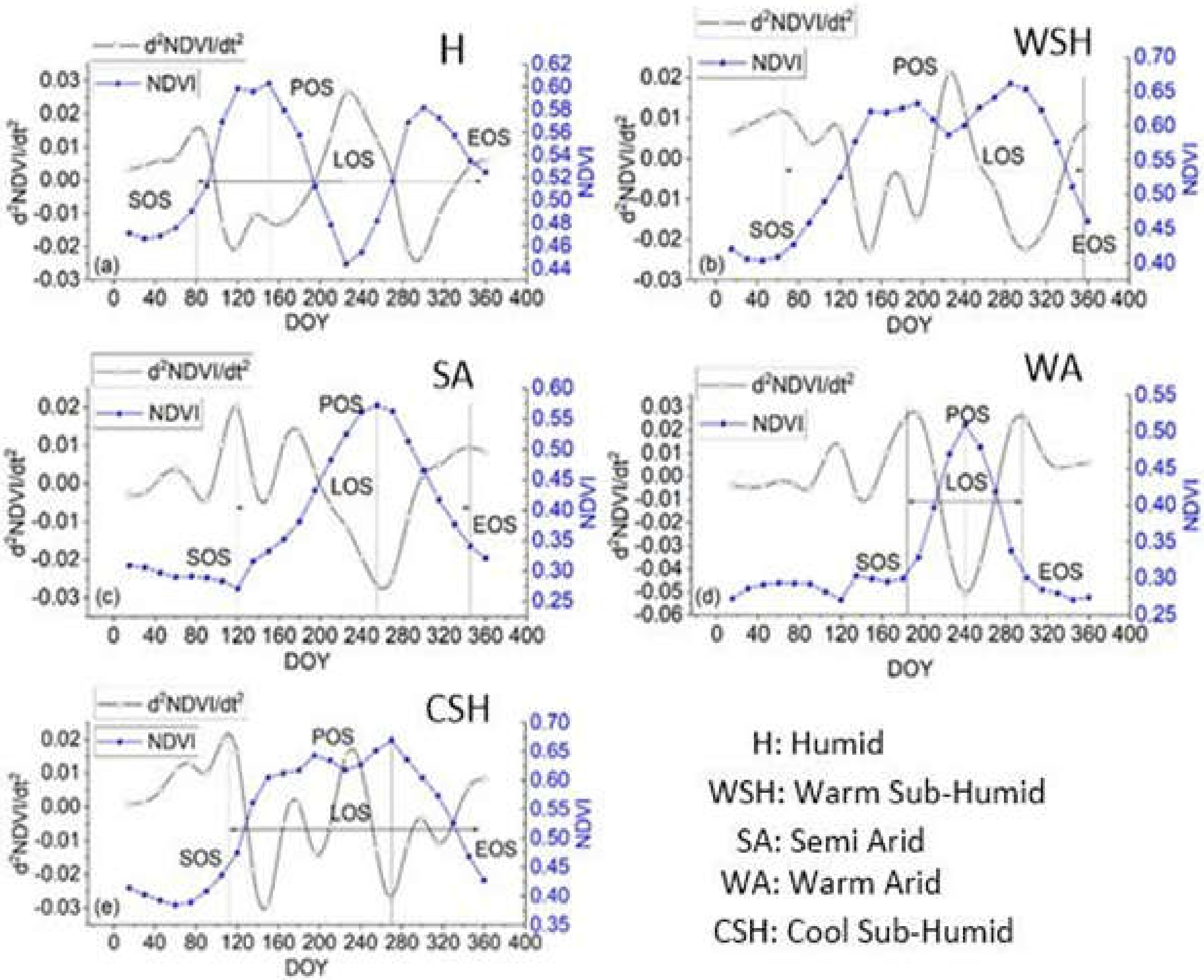


Fig. 6 Phenological Metrics for the various agro-ecological zones

Table1 Correlation between NDVI and climate variables

Month	CSH		WSH		SA		WA		H	
	temp	pre	temp	pre	temp	pre	temp	pre	temp	pre
Jan	0.320	-0.183	0.271	-0.007	0.453**	-0.121	-0.102	--	0.339*	-0.054
Feb	-0.079	-0.200	0.323	0.444	0.042	0.035	-0.063	--	0.164	-0.030
Mar	0.0207	0.033	0.049	0.184	0.054	-0.004	-0.141	-0.006	0.017	0.005
Apr	-0.390	0.095	-0.186	0.308	-0.238	0.096	-0.039	0.081	-0.120	0.225
May	-0.341*	0.383*	-0.276	0.160	-0.163	0.165	-0.162	-0.124	-0.088	0.087
Jun	0.212	0.120	0.374*	-0.096	-0.327	0.338	-0.435*	0.055	-0.005	-0.015
Jul	0.369*	-0.018	0.395*	-0.182	0.021	0.302	-0.354*	0.121	-0.150	0.197
Aug	0.514**	0.152	0.254	0.189	0.231	-0.006	0.040	-0.259	0.088	0.010
Sep	0.358*	-0.055	0.190	-0.115	0.019	0.348*	-0.149	0.071	-0.161	0.183
Oct	0.435*	0.225	0.370*	0.345	0.286	0.438**	-0.038	-0.311	-0.084	0.201
Nov	0.193	0.132	0.310	0.235	0.086	0.098	-0.304	--	-0.054	0.026
Dec	0.406*	0.063	0.385*	0.110	0.317	0.073	0.041	--	0.171	0.045

Rate of Phenology Shift

Table 2 shows the rate of phenology shift in the various AEZs computed using equation 1. Based on the values of SOS (Start of Season), POS (Peak of Season), EOS (End of Season), and LOS (Length of Season), the rate of phenology shift in the various zones may be examined. An early start to the growing season is indicated by a negative SOS value, whereas a late start is indicated by a positive SOS number. An early end to the growing season is indicated by a negative value for EOS, whereas a late finish is indicated by a positive value. The apex of the growing season is represented by the POS.

In the Humid zone, the growing season commences early, as evidenced by a negative value of -0.708 for the Start of Season (SOS). Moreover, the peak of the growing season occurs later, exhibiting a positive value of 1.522 for the Peak of Season (POS). Additionally, the End of Season (EOS) is delayed, with a positive value of 0.626. The length of the growing season in this zone is relatively long, as denoted by a positive value of 1.334 for the Length of Season (LOS) (Table 2). These findings indicate the distinctive phenological dynamics of the humid zone, with an early start, a later peak, a delayed end, and an extended duration of the growing season.

In the WSH zone, the growing season initiates early, as reflected by a negative value of -0.803 for the Start of Season (SOS). Furthermore, the Peak of Season (POS) in this zone occurs later, evident from a positive value of 1.587. Conversely, the End of Season (EOS) in the Warm Seasonal Humid zone arrives early, as indicated by a positive value of 0.390. The Length of Season (LOS) in this zone is relatively short, denoted by a positive value of 1.194 (Table 2). These results highlight the distinctive phenological characteristics of the Warm Seasonal Humid zone, featuring an early start, a delayed peak, an early end, and a relatively short duration of the growing season.

The growing season commences relatively early in SA, as evidenced by a positive value of 0.338 for the Start of Season (SOS). Moreover, the Peak of Season (POS) in this zone occurs early, as indicated by a positive value of 0.454. Similarly, the End of Season (EOS) in the Semi-Arid zone also arrives early, with a positive value of 0.090. Notably, the Length of Season (LOS) in this zone is relatively short, denoted by a negative value of -0.247. These findings suggest that the Semi-Arid zone experiences an early start, early peak, early end, and a comparatively shorter duration of the growing season, making it distinct in its phenological patterns.

In the WA zone, the growing season initiates relatively early, as indicated by a negative value of -0.143 for the Start of Season (SOS). Moreover, the Peak of Season (POS) in this zone occurs early, with a positive value of 0.249. Conversely, the End of Season (EOS) in the Warm Arid zone arrives relatively late, as denoted by a positive value of 0.607. Despite the late end, the Length of Season (LOS) in this zone is relatively short, as evidenced by a positive value of 0.750. These observations highlight the unique phenological patterns of the Warm Arid zone, characterized by an early start, early peak, and relatively late end, with a relatively short overall duration of the growing season.

In the WA zone, the growing season initiates relatively early, as indicated by a negative value of -0.143 for the Start of Season (SOS). Moreover, the Peak of Season (POS) in this zone occurs early, with a positive value of 0.249. Conversely, the End of Season (EOS) in the Warm Arid

zone arrives relatively late, as denoted by a positive value of 0.607. Despite the late end, the Length of Season (LOS) in this zone is relatively short, as evidenced by a positive value of 0.750. These observations highlight the unique phenological patterns of the Warm Arid zone, characterized by an early start and peak of the growing season, but with a relatively late end, resulting in a relatively short overall duration of the growing season.

Table 2 Rate of phonological shift

	SOS	POS	EOS	LOS
H	-0.708	1.522	0.626	1.334
WSH	-0.803	1.587	0.390	1.194
SA	0.338	0.454	0.090	-0.247
WA	-0.143	0.249	0.607	0.750
CSH	0.876	1.247	0.905	0.028

Discussion

The greenness and health of vegetation are measured by the NDVI. The Warm Arid zone (WA) has the lowest mean NDVI (0.363) and the Humid zone (H) has the highest mean NDVI (0.5775) in the data provided. In general, the NDVI values fall into the following hierarchy: H > WSH > SA > CSH > WA. Given the abundance of water supplies, higher levels of precipitation and milder temperatures in the humid zone, favorable conditions for vegetation development can be linked to the higher NDVI values there. On the other side, the Warm Arid zone has higher temperatures and less precipitation, which results in less vegetation cover and a lower NDVI. Higher NDVI values indicate healthier vegetation, while higher precipitation values indicate more rainfall. Humid zones have the highest mean NDVI and precipitation, indicating a positive correlation between vegetation health and higher rainfall. Water resources contribute to lush vegetation in the H zone. Warm Arid zones have the lowest mean NDVI and precipitation, limiting vegetation in arid regions due to insufficient rainfall.

The Warm Arid zone (WA) has the lowest mean precipitation (26.27 mm), while the Humid zone (H) has the highest average precipitation (166.6635 mm). The numbers for precipitation often follow the sequence H > CSH > WSH > SA > WA. Due to its location and proximity to water bodies, the H zone has increased precipitation, which creates a climate that is more suited for rain-fed agriculture and natural vegetation. On the other side, the Warm Arid zone receives little rainfall, which restricts the development of crops and vegetation there. The positive correlation between temperature and NDVI in some zones may vary across regions. In the Warm Arid zone (WA), water stress can cause lower NDVI values due to warm and dry conditions. In the H zone, despite a moderate mean temperature (24.144°C), NDVI is high (0.5775), suggesting abundant water availability plays a more significant role in supporting vegetation.

The mean temperature in the Warm Arid zone (WA) is 28.311°C, whereas the mean temperature in the Cold Sub-Humid zone (CSH) is 23.48°C. The trend of the temperature values is usually WA > WSH > SA > H > CSH. The Warm Arid zone's higher temperatures are typical of arid and semi-arid locations where evaporation rates frequently outpace precipitation, creating hot and dry conditions. On the other side, the Cold Sub-Humid zone has colder climate conditions because of its higher latitude and altitude, which enjoy milder temperatures. There is no direct correlation between precipitation and temperature across zones, as each experiences a unique climate due to geography and local factors. The Warm Arid zone (WA) has the highest mean temperature (28.311°C) and lowest precipitation (26.27 mm), indicating a typical arid climate with hot and dry conditions. The CSH has a moderate mean temperature (23.48°C) and high precipitation (112.76 mm), suggesting a cooler climate with sufficient rainfall for vegetation growth

The CSH zone has a seasonal pattern in NDVI, temperature, and precipitation. The highest NDVI values occur during the rainy season, from June to September, which aligns with the highest precipitation values. Temperature and precipitation patterns complement each other, with higher temperatures in March and April promoting evapotranspiration and vegetation growth. However, during the dry season, precipitation decreases, leading to a decline in NDVI due to water scarcity. The growing season begins in early April (SOS), peaks in late September (POS), and ends in early December (EOS) in the (CSH zone. This zone has a roughly nine-month growing season.

Vegetation health in Nigeria's WSH zone is positively correlated with precipitation, with the wet season supporting plant growth. Temperature does not significantly impact vegetation health, but the peak of NDVI in October aligns with the highest precipitation period. The zone experiences a well-defined wet season from April to December, with higher NDVI values and abundant rainfall. The dry season from December to March has lower NDVI values and reduced precipitation, affecting vegetation health. The growing season begins in early April (SOS), peaks in early August (POS), and lasts until late December (EOS). In this zone, the growing season lasts roughly nine months.

The WA zone has a dry and hot climate, with limited vegetation and high temperatures. Water availability is the most influential factor, affecting NDVI growth. Months with little to no rainfall experience lower vegetation health, while those with some precipitation may see slight improvements. The arid climate and limited water resources result in minimal vegetation growth, with typical desert climate fluctuations. The growing season begins in early July (SOS), peaks in late August (POS), and concludes in late October (EOS) in the zone. This zone has a roughly three-month growing season.

The SA zone exhibits distinct seasonal patterns in NDVI, temperature, and precipitation, with significant differences between dry and wet seasons. NDVI and precipitation have a positive correlation, with higher values during the wet season, supporting vegetation growth. Temperature does not show a significant correlation with NDVI, suggesting that water availability from precipitation is more critical for vegetation health. The peak of vegetation health (NDVI) in September aligns with the highest precipitation period, indicating the SA zone's heavy reliance on rainy seasons for growth. The growing season starts in June (SOS), peaks in mid-September (POS), and ends in early September (EOS). This zone has a roughly four-month growing season.

The H zone offers a stable and favorable environment for vegetation growth, with consistently high NDVI values throughout the year. Abundant rainfall supports continuous vegetation health and growth, while temperature does not significantly impact vegetation health. The wet and warm climate in the H zone ensures high NDVI values, with favorable precipitation levels supporting lush vegetation. The growing season begins in early March (SOS), peaks in late May (POS), and lasts until the end of December (EOS). This zone has a roughly nine-month growing season. These results suggest that the phenological patterns seen in various AEZs are considerably influenced by climate and environmental factors. Recognizing these variations is difficult.

Arguably, the zones exhibit different rates of phenology shift. The H zone has an early start, late end, and a long growing season. The WSH zone also has an early start but a relatively short growing season. The SA zone starts early but has a shorter growing season. The WA zone starts relatively early and has a relatively long growing season. The CSH zone starts late and also has a relatively short growing season. These variations in phenology shift rates can have significant implications for agriculture, ecosystems, and climate patterns in each zone.

Conclusion

The study analyzes season start and end dates using vegetation satellite data (NDVI) and climate data from 1982 to 2015 in various agro-ecological zones of Nigeria. Results show that the Humid zone (H) has the highest mean NDVI, indicating healthier vegetation cover, while the Warm Arid zone (WA) has the lowest mean NDVI, suggesting less vegetation. Seasonal variations in NDVI values are observed, with highest values during the wet season and lower values during the dry season. The Cold Sub-Humid zone (CSH) has the lowest mean temperature, while the Warm Arid zone (WA) has the highest mean temperature. Precipitation analysis shows that the Humid zone (H) has the highest mean precipitation, indicating better agricultural circumstances, while the Warm Arid zone (WA) has the lowest mean precipitation, indicating limited water supply. Seasonal variations in precipitation are evident in most zones, with wetter months supporting vegetation growth and drier months impacting vegetation health.

The study highlights unique climatic and vegetation patterns in different agro-ecological zones of Nigeria, with implications for agricultural planning, water resource management, and understanding climate change's impacts on vegetation health. Further research and monitoring are necessary to track long-term trends and devise appropriate strategies for sustainable land use and resource management.

The phenology shifts in the zones occur at various rates from 1982 to 2015. The growth season is long and has an early start and late end in the H zone. The WSH zone also has an early start but a relatively short growing season. The growing season is shorter and starts earlier in the SA zone. The growing season in the WA zone begins rather early and lasts reasonably long. In the CSH zone, the growing season starts late and also has a relatively short length. In each zone, these changes in phenology shift rates may have a big impact on agriculture, ecosystems, and weather patterns.

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