ISSN 2354-9114 (online), ISSN 0024-9521 (print)
Indonesian Journal of Geography Vol 55, No 1 (2023): 51-58
DOI: 10.22146/ijg.61697 website: https://jurnal.ugm.ac.id/ijg

INDONESIAN JOURNAL OF GEOGRAPHY

RESEARCH ARTICLE

Monitoring the the Impacts of Climate Change and Variability on the Phenology of Natural Vegetation Using 250m MODIS-NDVI Satellite Data: Cace Study of the Dryland Ecosystem of Sokoto, North-Westrn Nigeria.

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Received : 2020-11-27
Revised: 2020-07-26
Accepted: 2023-01-02

Keywords: Phenology; Vegetation; Climate Change; Dryland; Ecosystem

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Abstract. Recent climate change and variability together with other anthropogenic drivers have exerted tremendous pressure on the fragile dryland ecosystem of Sokoto, North-western Nigeria. Vegetation phenology is one of the active indicators of the impacts of climate change on the ecosystem. This study aimed to monitor how the ecosystem of the area responds to the challenges associated with climate change in order to provide baseline information for policies and programmes geared towards addressing these challenges. It explored the applications of remote sensing data (MODIS-NDVI), GIS and statistical analyses in achieving this aim. Image processing operations such as data extraction, raster calculations, geometric transformations and creation of the region of interest were conducted using ArcGIS 10.5 model builder while TIMESAT software was used determined the vegetation phenological events such as the start, end and length of the growing seasons. The results indicated a persistent decline in the length of the growing seasons of the major vegetation classes in the area due to late onset and early cessation of the growing season which is positively correlated with rainfall distribution. From the year 2001 to 2016, 36% and 33% declined in the length of the growing season were recorded for shrubs and grasses respectively. These are positively correlated with the annual rainfall distributions in the area, with the correlation coefficient of r = 0.40 and r = 0.36 for the shrubs and grasses respectively. Implications of these on the ecosystem and livelihoods of the people in the area were discussed and ways forward suggested.

1. Introduction

The term phenology refers to the timing of repeated biological events in plants such as the emergence of leaf, leaf coloration, flowering and leaf fall (Ibrahim et al., 2021; Ma et al., 2013; Tian et al., 2021). It deals with the variations in the timing of vegetation growth stages such as the start, the peak, the end and the length of the growing season and how these are related to the prevailing climatic conditions (Adole et al., 2016; Jiao et al., 2015; Vintrou et al., 2014). Vegetation Phenology therefore is an expression of the response of vegetation to the intra and inter-annual variations in climatic parameters such as rainfall and temperatures and also a key indicator of terrestrial ecosystem functioning (Adole, Dash, & Atkinson, 2018; Filipponi, Smiraglia, Mandrone, & Tornato, 2021; Tian et al., 2021; Vrieling et al., 2019).

Vegetation phenology can be studied either using ground-based techniques or by application of remote sensing satellite data. However, while the ground-based phenological studies offer a more detailed and fine temporal resolution information on different vegetation types, the technique is time consuming, limited in spatial coverage and only applicable in areas accessible to man (Adole et al., 2018; Rodriguez-Galiano, Dash, & Atkinson, 2015). On the other hand, remote sensing satellite-based techniques offer a wider spatial coverage, longer temporal dimension including the ability to monitor the phenology of the past years and is applicable even in areas with limited accessibility or inaccessible to man (Adole et al., 2018; Richardson et al., 2018; Tian et al., 2021; Ugoyibo, Joy, & Chinwe, 2021). In the more developed countries of Europe, North America and Australia, the study of vegetation phenology has received much attention with scholars exploring detailed characteristics and trends in the phenology of different vegetation type, at different spatio-temporal resolutions and employing both ground-based and remote sensing-based techniques (Adole et al., 2016; Ibrahim et al., 2021; Igboabuchi, Echereme, & Ekwealor, 2018; Osunmadewa, Gebrehiwot, & Csaplovics, 2018).

In the African continent however, there are limited studies in vegetation penology. This is in spite of the fact that, Africa accounts for 17% world forest, and forest covers 23% of the Africa's total land surface area. The continent is also endowed with diverse range of vegetation types with complex dynamics ranging from tropical rainforest, mangrove forest, to deciduous forest, savannah woodland, mountain vegetation, savannah grassland, semi-desert and desert vegetation (Adole et al., 2016, 2018; FAO, 2010). Again, Africa

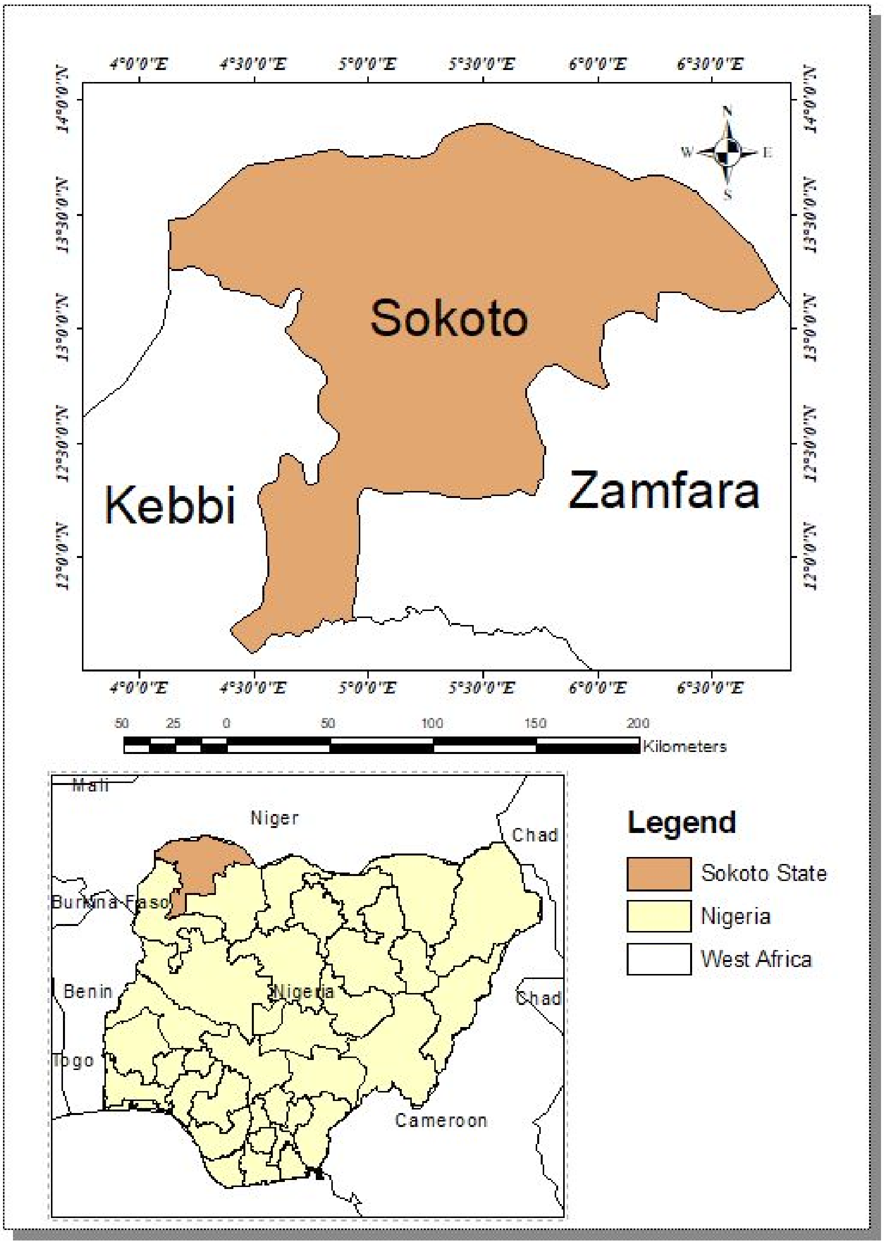

Figure 1 The Study Area.

has been recognized as one of the highly vulnerable continent to climate change with high rate of vegetation loss (FAO, 2010; IPCC, 2001; Niang et al., 2014). This is not withstanding, the phenology of the continent's diverse vegetation types and its role in the global biogeochemical cycles is yet to be fully assessed and documented particularly at the local and regional scales. A recent survey by Adole et al. (2016), revealed that studies on African vegetation phenology accounts for less than 2% of the global total, most of which are at continental scales using coarse spatial resolution data. Such type of studies could easily conceal regional and local variations in the vegetation phenology, leading to gross misrepresentation and under reporting of the true phenological characteristics of the varied vegetation types in different ecological zones of the continent. This underscores the need for a more detailed study of the continent's vegetation phenology at both regional and local scales using relatively a higher spatial and temporal resolution data, which is the focus of this study.

Vegetation phenology is an important factor to consider in planning and developing climate change adaptation and mitigation strategies (Adole et al., 2016, 2018; Osunmadewa et al., 2018; Vrieling et al., 2019). As such, understanding the past and present vegetation phenology and its dynamics is therefore very essential for a developing country like Nigeria. This is particularly in realization of the fact that, during the recent decades, climate change and variability had significantly impacted and will continue to impact on its fragile ecosystem (Barker, 2007; FAO, 2013; IPCC, 2014; Parmesan & Yohe, 2003; Walther et al., 2002). Thus, careful analysis of vegetation phenological events such as the beginning, peak, end and the length of the growing seasons will provide a baseline information on how climate change and variability affects the ecosystems of the area. This will also serve as an evidence-based information to aid the policy makers in the formulation of appropriate policy and programmes in order to address these challenges.

2. Methods

Study Area

Sokoto State is located to the North-western part of Nigeria, between latitudes 11° 30' to 13° 50' N and longitudes 4° 00' to 6° 00' E (Figure 1). The state shares common boundaries with the republic of Niger to the North and West, Zamfara State to the East and Kebbi State to the South. Sokoto consist of 23 local government areas covering approximately 23,000 kilometres square. The state is characterized by tropical continental climate with a very fragile ecosystem. Temperatures are high throughout the year while rainfall, low and erratic which barely lasts for more than five months in a year. Average annual rainfall barely exceeds 630 mm while temperatures could be as high as 45°C or even higher, particularly during the month of April which usually records the highest temperature. The area is also characterized by Sudan Savannah type of vegetation dominated by short grasses and shrubs, interspaced by short woody trees (Davis, 1982). Together, these provide a vast grazing land for the large population of livestock and wild herbivores in the area. The grasses look green and luxuriant during the rainy season, but eventually wither and die during the dry season, leaving the more drought resistant thorny shrubs that usually shed their leaves as an adaptation mechanism to reduce water loss through transpiration.

Farming is the major occupation in the area, with animal rearing by the Fulani people, accounts for over 80% of the means of livelihoods in the area. A number of people engage in fishing particularly along Rivers Sokoto, Rima, and in some smaller steams and pools that are seasonal and holds water only during the rainy season. However, almost everybody in the area engage in one form of non-farming activity or the other both during the wet and dry season to basically supplement the dwindling income from both lowland and upland farming (Iliya, 1999). On the upland, grains such as millet, guinea corn, maize, and legumes such as cowpeas and groundnut are cultivated. On the Fadama/lowlands and along the floodplains of the major rivers, crops such as tomato, onions, garlic, wheat and rice are cultivated under irrigation (Iliya, 1999).

Data

The main data used in this research is the Normalised Difference Vegetation Index (NDVI) acquired by the Moderate-resolution Imaging Spectroradiometer (MODIS) on-board NASA's Terra (EOS AM). MODIS-NDVI (MOD13Q1.V6) is designed to provide consistent spatial and temporal comparisons of vegetation condition using blue, red and near-infrared reflectance centred at 469 nanometres, 645 nanometres and 858 nanometres respectively (Cao, Chen, Matsushita, & Imura, 2010; Hmimina et al., 2013; Stefanov & Netzband, 2005; Xiong et al., 2004). The data is computed from the atmospherically corrected bi-directional surface reflectance that have been masked for water, clouds, heavy aerosols and cloud shadows. MOD13Q1 data are provided as 16 days composites at 250 meters spatial resolution and is widely used for global monitoring of vegetation conditions and land cover changes. The data can also be used for modelling global biogeochemical and hydrologic processes, global and regional climate as well as characterizing land surface biophysical properties and processes such as primary production and land cover conversion (Cao et al., 2010; Wu, Xiong and Cao, 2008). A total of 368 MOD13Q1.V6 composite images for the years from 2001 to 2016, 23 images per year, were downloaded, processed and used in this study. Annual rainfall distribution of the area obtained from the Nigerian Meteorological Agency (NIMET) was also used to determine the degree of relationship between rainfall distribution and the length of the growing season.

Image Processing

All the image pre-processing operations were carried out in an ArcGIS 10.3 model builder environment. First is the extraction of NDVI sub-dataset from the series of datasets contained in MOD13Q1.V6 vegetation indices data. MOD 13Q1.V6 is composed of 12 different sub-datasets, carrying different sets of information. This was followed by raster calculation to rescale the data range to the original NDVI range of "From -1 to +1". Geometric transformations were then performed to re-project the original dataset from sinusoidal projection to WGS 84 for appropriate representation of the study area. Next, is the clipping of the study area or region of interest from the larger dataset and then raster conversion from HDF to BSQ format for input into the TIMESAT software, for the computation of vegetation phenological events such as the Start of Growing Season (SGS), End of Growing Season (EGS) and the Length of Growing Season (LGS.) Figure 2 shows the data pre-processing sequence performed in ArcGIS 10.4 model builder environment while Figure 3 shows the clipped study area from the larger MOD13Q1.V6 dataset.

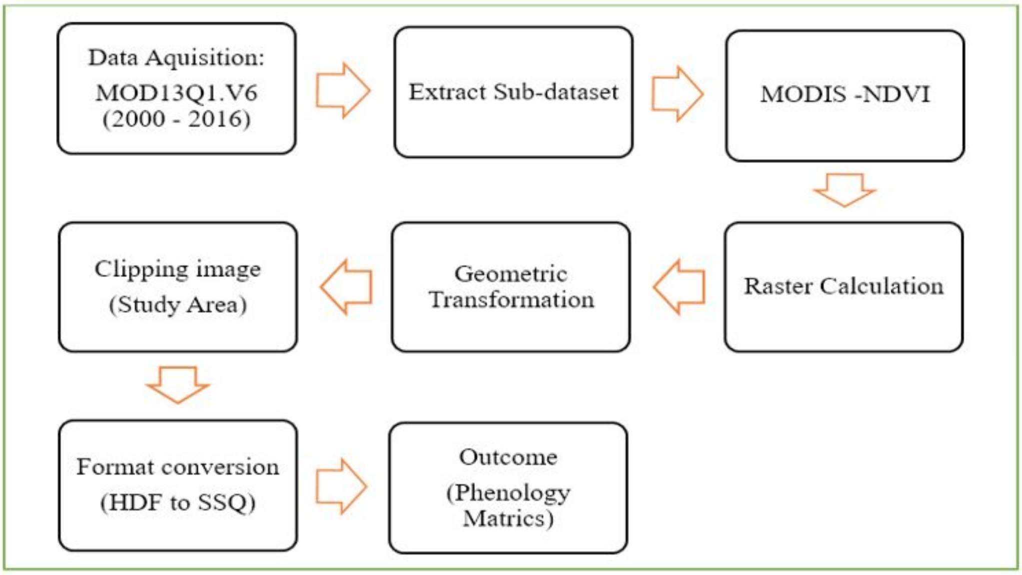

Figure 2 Data Pre-processing Sequence.

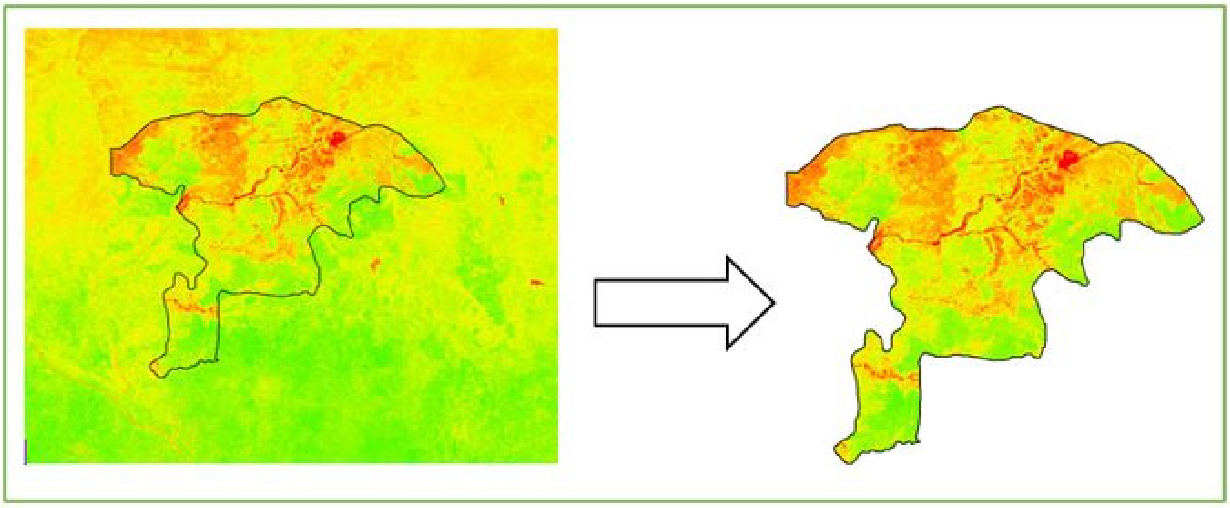

Figure 3 Clipped Study Area.

Identification and Extraction of Vegetation Phenology

The term natural vegetation as used in this research refers to all categories of plant communities in the study area that grow naturally on the field without any conscious human management. It comprises mainly of annual non-woody herbaceous grasses and short to medium-sized shrubs, with multiple permanent woody stems above the ground, but without a single trunk. Inter-spaced within these two broad classes of natural vegetation in the study area are found some occurrences of short woody deciduous trees. This type of natural vegetation provides an extensive grazing land for large population of domestic livestock and wild herbivores. The shrubs and trees also provide the major source of domestic fuel woods for the rural majority.

To extract the phenological events of the natural vegetation of the area, a number of grass-dominated (Grassland) and shrub-dominated (Shrubland) fields were visually identified on the field and GPS coordinates were then randomly taken from them. The coordinates were overlaid on the MODIS-NDVI satellite image in order to identify their exact locations on the image. Their corresponding pixel values (NDVI values) were determined and then used as input locations on the TIMESAT time series vegetation processing software for the computation of phenological events. Savitzky-Golay function of the TIMESAT software was used to filter and smooth the noise in the original NDVI data of the selected sample locations (Eklundh & Jönsson, 2015; Tan et al., 2011). Three major phenological events defined below are particularly of interest to this study namely:

i. Start of the Growing Season (SGS): The onset of the photosynthetic activities which correspond to the period when plants germinate and start growing. At this time, NDVI values begin to increase steadily.
ii. End of the Growing Season (EGS): The period at which the photosynthetic activities of the plants begin to decline rapidly. NDVI values also begin to decrease steadily signifying a decline in the physiological activities of the plants. Thereafter, the physiological activities of the plants become near zero.
iii. Length of the Growing Season (LGS): The time difference between the start and end of the growing season. This represent the time of the year (season) in which suitable conditions for the growth of plants prevail (Bohovic, Dobrovolny, & Klein, 2016; Tang et al., 2015; Zhang et al., 2003).

3. Results and Discussions

As mentioned above, the natural vegetation of the study consists mainly of annual non-woody herbaceous grasses and short to medium sized shrubs. Figure 4, show the 2001 phenology of these classes of vegetation in the study area. Based on the figure, the growing season for both the grasses and shrubs starts roughly about 145 Julian days which corresponds to the 25th of May in the year 2001. However, the growing season for the grasses terminates around 289 Julian days which correspond to the 16th of October resulting in a growing season with the total length of 144 days. On the other hand, the growing season of the shrubs extends up to 321 Julian days which corresponds to the 17th of November, resulting in a growing season with a total length of 176 days.

The longer growing season of shrubs over that of grasses could be attributed to the fact that shrubs are more tolerant to dry conditions than grasses. This is because shrubs possess relatively more developed and longer root systems that can absorb water from certain depth below the soil to keep them growing during the dry season. Their thick bark and numerous branches also help in conserving water, while their small-sized leaves that normally shed during dry season prevent excessive loss of moisture via transpiration.

However, the length of the growing season appears to be declining with time, due to either delay in the start or early termination of the growing season or both. Figure 5 shows the 2006 vegetation phenology in the study area. Based on the figure, there is a delay in the start of the growing season for both the grasses and shrubs from 145 Julian days in 2001 to 161 Julian days which correspond to 10th June in that year 2006. On the other hand, the growing season for the grasses terminates the same 289 Julian days, corresponding to 16th October as in 2001, resulting in a growing season with 128 days as against 144 days in 2001. For the shrubs the growing season terminates roughly around 305 Julian days corresponding to 1st November, resulting in a growing season with a total length of 144 days as against 176 days in 2001.

Figure 4 2001 Vegetation Phenology

Figure 5 2006 Vegetation Phenology

This shows a clear decline in the length of growing season for the two vegetation classes which could negatively affect the provision of ecosystem goods and services including food and pasture supply, which could also impact negatively on the livelihoods of the inhabitants of the area that are mostly farmers and animal herders. The declining trend in the length of growing season however seems to continue, occasioned by inter-annual variability.

Figure 6 depict the vegetation phenology in 2011. The figure reveals a further delay in the commencement of the growing season for both grasses and shrubs in 2011. For the grasses, the growing season commences around 193 Julian day as against 161 Julian days in 2006. This corresponds to 12th of July recording over a month delay compared to 2006 and almost one and half month delay compared to 2001. For the shrubs, the growing season commences around 177 Julian days as against 161 in 2006, representing about half of a month delay in comparison with 2006 and over a month of delay in relation to the situation in 2001. However, the growing season terminates around 305 Julian days corresponding to 1st November for both the grasses and shrubs. This results in a growing season with a total length of 112 and 128 for the grasses and shrubs respectively.

By the year 2016, a further declining trend in the length of growing season was also the case for the two classes of vegetation in the study area. Figure 7 shows the 2016 vegetation phenology in the area. Based on the figure, the growing season commences almost the same time as in 2011, which is 177 and 193 Julian days corresponding to 26th June and 12th July for the shrubs and grasses respectively. However, for both the shrubs and grasses, the growing season terminates around 289 Julian days corresponding to 16th October, resulting in a growing season with a total length of 112 days and 96 days for the shrubs and grasses respectively.

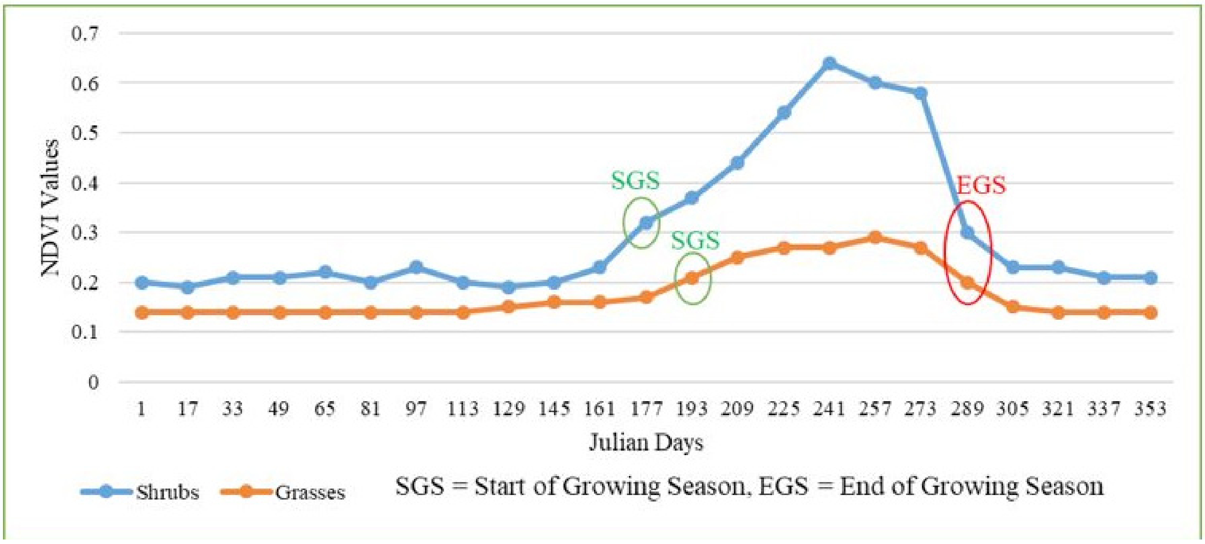

Figure 7 2016 Vegetation Phenology

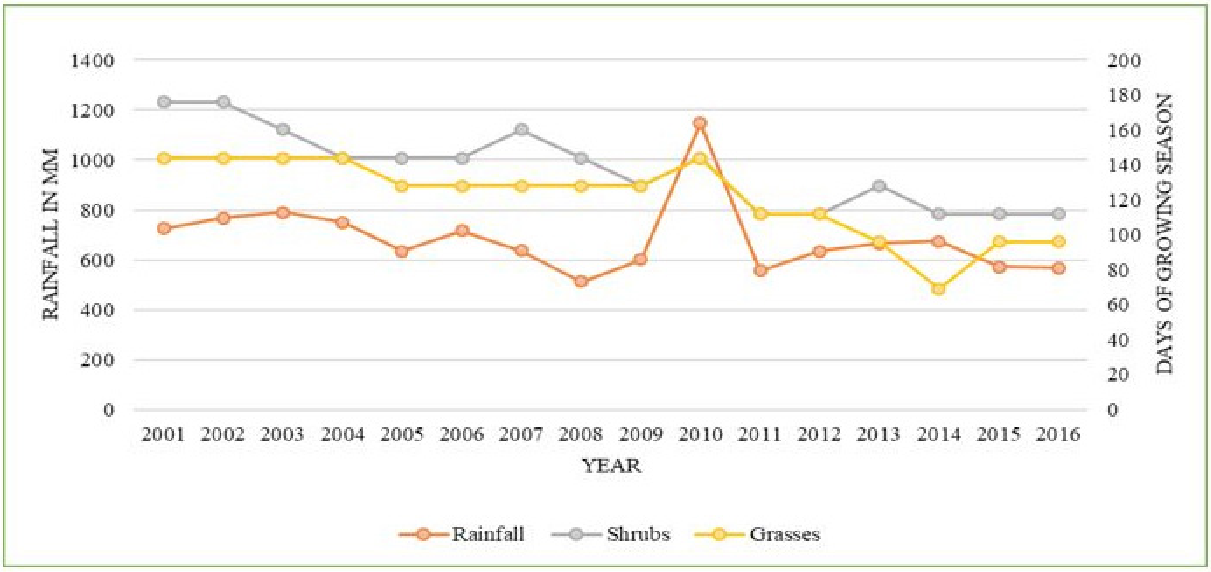

Figure 8 Relationship between rainfall distribution and Vegetation Phenology.

It can be observed from the above results that, on the whole, for the period of 16 years (2001 - 2016), there is a shift/ delay in the commencement of growing season from 145 Julian days (25th May) to 177 Julian days (26th June) and 193 Julian days (12th July) respectively for shrubs and grasses in the study area. The length of the growing season has also declined from 176 days in 2001 to 112 in 2016 for the shrubs representing 36% decrease in the length of growing season over 16 years period. The corresponding decrease for the grasses is from 144 days in 2001 to 96 days in 2016 representing 33% decrease in the length of the growing season over the same period. This result is however, supported by the finding of Adole et al., (2018). Although the work was on continental scale using 500m MODIS-EVI, it was found that in the areas covering the Sahel, Sudan and Guinea region of West Africa (Lat. 0° - 20°N) within which lies the study area, the growing season for the natural vegetation including shrubs and greases is from the month of June to November, with 36% of the start of growing season in the month of June (Adole et al., 2018). They also observed that the length of the growing season varies in the region according to latitudes and rainfall patterns, but generally ranges between 150 – 310 days.

However, in order to determine the degree of influence of climate change in the above trends in vegetation phenology, annual distribution of rainfall which is most critical climatic element influencing vegetation growth and ecosystem productivity in the study area was correlated with annual length of the growing seasons from 2001 to 2016. The result (Figure 8) revealed a positive correlation between the two, with a correlation coefficient of r = 0.40 and r = 0.35 for the shrubs and grasses respectively.

Figure 8 reveals declining trends in both rainfall distribution and the length of growing seasons except for the year 2010, which experienced abnormal heavy rainfall in the study area, leading to widespread flooding that destroyed many farmland and residential areas (NIMET, 2010). This clearly established the degree of impact of climate change on the ecosystem of the area. In the same way, Ugoyibo, Joy and Chinwe (2021) reported a positive correlation between vegetation phenology and rainfall distributions in the wetland regions of Southern Nigeria.

Conclusion

This study monitored how the phenology of natural vegetation of Sokoto state in the North-western Nigeria is responding to the recent climate change and variability in the area. The findings of the study revealed both inter- annual variability and a persistent decline in both the rainfall and the length of growing season of grasses and shrubs which are the two dominant natural vegetation classes in the area. The decline in the length of the growing seasons is caused either by the delay in the commencement or early termination of the growing season or both, usually due to the similar delay in the onset or early cessation of rainfalls or both. Over the 16 years period (2001 - 2016), the length of the growing season declined by 36% for shrubs and 33% for grasses. This is a very negative trend capable of affecting the ability of ecosystem to provide the essential goods and services including food supply and pasture for domestic livestock that supports human livelihoods and economic development of the area. The situation becomes even more critical considering the multiple roles of vegetation in supporting and stabilising ecosystem and people's overdependence on ecosystem in the area, through such economic activities as crop cultivation and animal husbandry that are both environment and climate dependants. This underscores the ardent needs for necessary and timely adaptation and mitigation measure in order to protect the fragile ecosystem of the area and ensure improved livelihoods and sustainable development of the area.

Advocating and supporting people to embark on Ecosystem-based Adaptation measures involving sustainable land management practices will in no small measure help to improve the situation. Harnessing, developing and efficient use of alternative sources of energy such as solar and wind energy available in the area will also help greatly in reducing pressure on the vegetation as presently, vast number of rural populations solely depends on the vegetation as a source of fuel woods. Also, building the capacity of the people in the area to pursue alternative means of livelihoods that are less dependent on the physical environment such as aquaculture and skills acquisition will also help in both conserving the ecosystem and improving the livelihoods of the inhabitant of the area. There is also the need for the formulation and implementation of appropriate environmental laws and policies aimed at protecting the fragile ecosystem of the area. Finally, inculcating environmental consciousness in people through environmental education, workshop and conferences will help in bringing attitudinal changes that would ensure positive attitude in dealing with the physical environment.

Finally, we stressed that climate change is a reality and is posing serious challenges to both ecosystem and livelihoods including food security in the study area a situation that can be effectively monitored using geoinformatics. However, we recommend the use of a higher spatial resolution datasets such as Landsat and Sentinel for a more detailed characterization of the vegetation phenology in the study area that may reveal subtle variations at local scales.

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