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Research Application Summary

Savannah phenological characteristics in Karamoja sub-region, Uganda

Magaya, J.P., [1] Barasa, B.,[2] Egeru, A.[2, 3] & Namaalwa, J.J.[2]

[1]College of Engineering, Design, Art and Technology, P.O. Box 7062, Kampala, Uganda
[2]Department of Environmental Management, Makerere University, P.O. Box 7062, Kampala, Uganda
[3]Regional Universities Forum for Capacity Building in Agriculture, P.O. Box 16811, Wandegeya, Kampala, Uganda
*Corresponding author: magayait@gmail.com

Abstract

Phenological properties such as the timing and rate of green up, aptitude and duration of vegetation growth, and timing and rate of vegetation senescence are important indicators of global environmental changes. It is vital to study these properties since savannahs play an important role in the global carbon cycle due to their global dominance on landscape level. With long term and continuous satellite observations, it is possible to monitor changes in abiotic and biotic attributes of savannahs such as phenological chracteristics and relate them to global, regional and local scale environmental changes including climatic variability and change. This study was done to determine savannah phenological characteristics in Karamoja sub-region using the Moderate-resolution Imaging Spectroradiometer (MODIS) Normalised Difference Vegetation Index (NDVI) derived data. Data processing and analysis was undertaken using TIMESAT program and ArCGIS. Results showed that representative vegetation types (varying grassland, woodland, bushland, thickets and shrubs) often had unique seasonal and interannual phenological and spatial patterns. Further, growing periods were chose as key phenophases to disuss the regional phenology patterns in Karamoja region during 2000, 2008 and 2017. Three indeces i.e., Start of the growing season (SGS), end of the growing season (EGS) and length of the growing season (LGS) were identified. The start of the growing season is variable in the sub-region but generally occurs between March – April with a clear short-term session for woodlands and grasslands in June. These two land cover types have a variable second peak period in August (Woodlands) and between September and October (grasslands). A long term time series analysis of the phenological characteristics over the sub-region is required to better indentify the internal dynamics within the land cover types.

Keywords: Drylands, growing seasons, Karamoja, landscape, NDVI, vegetation, Uganda

Résumé

Les propriétés phénologiques telles que le moment et le taux de verdissement, l'aptitude et la durée de la croissance de la végétation, ainsi que le moment et le taux de sénescence de la végétation sont des indicateurs importants des changements environnementaux mondiaux. Il est essentiel d'étudier ces propriétés car les savanes jouent un rôle important dans le cycle mondial du carbone en raison de leur domination mondiale au niveau du paysage. Avec des observations satellitaires continues et à long terme, il est possible de surveiller les changements dans les attributs abiotiques et biotiques des savanes telles que les caractéristiques phénologiques et de les relier aux changements environnementaux à l'échelle mondiale, régionale et locale, y compris la variabilité et les changements climatiques. Cette étude a été réalisée pour déterminer les caractéristiques phénologiques de la savane dans la sous-région de Karamoja à l'aide des données dérivées de l'indice de végétation par différence de végétation normalisée -NDVI du spectroradiomètre imageur à résolution moyenne -MODIS. Le traitement et l'analyse des données ont été effectués à l'aide du programme TIMESAT et ArCGIS. Les résultats ont montré que les types de végétation représentatifs (prairies, bois, buissons, fourrés et arbustes variés) avaient souvent des modèles phénologiques spatiaux, saisonniers et interannuels uniques. De plus, les périodes de croissance ont été choisies comme phénophases clés pour discuter des modèles phénologiques régionaux dans la région de Karamoja en 2000, 2008 et 2017. Trois indices, à savoir le début de la saison de croissance (DSC), la fin de la saison de croissance (FSC) et la durée de la saison de croissance (LGS) ont été identifiés. Le début de la saison de croissance est variable dans la sous-région mais se produit généralement entre mars et avril avec une session claire à court terme pour les zones boisées et les prairies en juin. Ces deux types de couverture terrestre ont une deuxième période de pointe variable en août (régions boisées) et entre septembre et octobre (prairies). Une analyse chronologique à long terme des caractéristiques phénologiques sur la sous-région est nécessaire pour mieux identifier la dynamique interne au sein des types de couverture terrestre.

Mots-clés: zones arides, saisons de croissance, Karamoja, paysage, NDVI, végétation, Ouganda

Introduction

The global energy system is closely interlinked with global change processes providing positive and negative feedback loops to the system from time to time. As such, changes in vegetation phenology due to global climate change have been found to directly impact the dynamic balance of terrestrial carbon and nutrients and the biodiversity pattern, and at the same time provide feedbacks to climate system (Wang *et al.,* 2017a). Vegetation phenology is the study of recurring patterns of vegetation growth and development , as well as their connection to climate and other seasonal environmental drivers(White *et al.,* 1997). Monitoring these global feedback processes is critical for deciphering the global biogeochemical changes that are taking place and that have effects at landscape to local scale levels. Vegetation penology has emerged as an important indicator of global change and the carbon cycle owing to its direct effects on vegetation photosynthesis, carbon sequestration and land–atmosphere water and energy exchange (PeNuelas and Filella, 2009). The responses of plants to seasonal and inter-annual variations of climate, hydrology, soil and anthropogenic factors can be deciphered from vegetation phenological dynamics (White *et al.,* 1997).

Through the various feedback mechanisms such as influencing the seasonality of albedo, surface roughness length, canopy conductance; and fluxes of water, energy, CO_2 and biogenic volatile organic compounds, vegetation phenology affects the climate system (Richardson *et al.,* 2013). As such, the vegetation phenology analysis is a critical component in understanding the global terrestrial ecosystems as well as the global climate variability and change dynamics (Wang *et al.,* 2017b). This is particularly made possible by the phenological properties such as the timing and rate of green up, aptitude and duration of the vegetation growth, and timing and rate of vegetation senescence. Several studies have documented the biogeographic phenological patterns and shifts temperate ecosystems (Wang *et al.,* 2017a, there have been very limited studies on the phenology of savannas irrespective of their sensitivity to climate change as well as their vast coverage of approximately one eighth of the global land surface. Savannas are complex assemblages of multiple tree, shrub, and grass vegetation strata, each with variable phenological responses to seasonal climate and environmental factors. Owing to this fact, changes in the savannah phenology has significant implications to carbon, water and energy cycles between the atmosphere and land surface.

Vegetation phenology has a long history of observation probably used for the first time thousands of years ago to note changes in vegetation and harvests. With advances in remote sensing, it is possible to quantify phenological changes through time and space thereby facilitating phenological monitoring at various scales; local, regional and global scales (Myneni *et al.,* 2007). The quantification can for example, be analyzed and estimated using earth observation, site level measurements, or ecosystem modeling (Boke-Olén, 2007). One of such earth observation systems that has increasingly been applied and relied upon is the Moderate Resolution Imaging Spectroradiometer (MODIS). The MODIS provides valuable data for monitoring ecosystem dynamics with appropriate spatial and temporal resolutions and substantially improved geometric and radiometric properties (Zhang *et al.,* 2006). This study used the MODIS derived Normalised Difference Vegetation Index (NDVI) to determine savannah phenological characteristics in Karamoja sub-region.

Materials and methods

Description of study area. The Karamoja region, covers an area of 27,319 km^2 approximately 10% of Uganda and lies approximately between 1 31′ to 4 N and 33 30′ to 35 E, in North eastern Uganda (Figure 1). It is administratively made up of Kotido, Abim, Moroto, Amudat, Napak, Kaboong, and Nakapiripirit districts. The region borders Kenya to the east, South Sudan to the north and the districts of Kitgum , Pader, Lira, Agago, Amuria and Katakwi to the west: and Kumi, Soronko and Kapchorwa to the south (Uganda Investiment Authority, 2016). Karamoja is set on a large plateau at an average elevation of approximately 1000 m above sea level. The land plain rises to northeast toward the hilly terrain bordering the escarpment above the neighboring Turkana District in Kenya. To the extreme North lies Kidepo National park with a mountainous terrain leading into South Sudan. In the South also lie rugged peaks of Mt. Elgon national park. The region has 4 preeminent mountains interspersing the plains, Mount Morungole in the north, Mount Kadam in the south, Mount Napak in the southwest and the largest, Mount Moroto, in the east (Uganda Investiment Authority, 2016). The region receives an annual average rainfall ranging between 300 mm in the pastoral regions to 1200 mm in western areas of Abim and Nakapiripirit. Average annual temperatures range from 16°C in the highlands to 24°C in the rest of the region. The region's vegetation is typically semi-arid with dry tree savannah species dominating grass species. The vegetation of Karamoja ranges from thorn-bush in the dry eastern and central parts to open or wooded grasslands in the western parts. Vegetation is characterized by communities that include: Acacia–Commiphora thickets, Chrysopogon grass steppe, Lannea–Acacia–Balanites–Albizia (Egeru *et al.,* 2014).

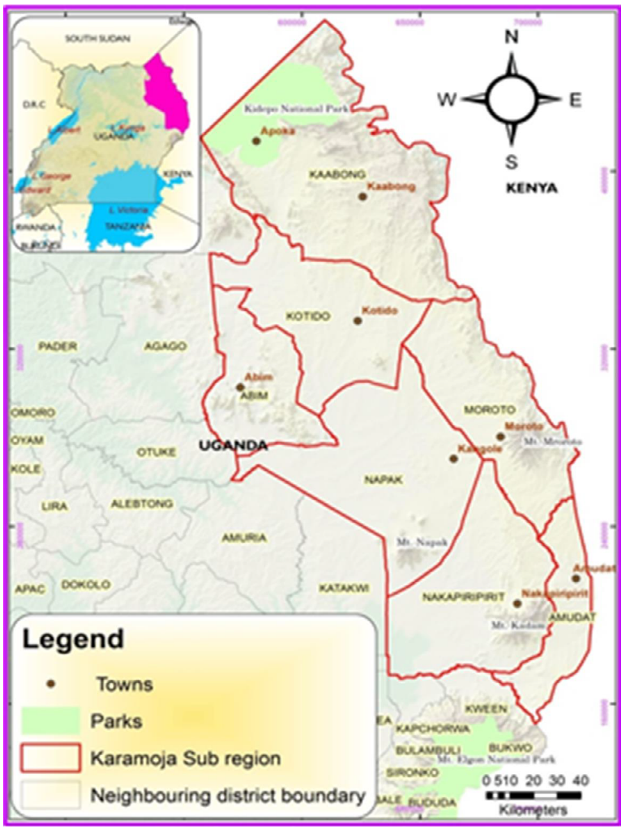

Figure 1. Location of Karamoja sub-region

Data and data sources. Using R Modistsp tool, Moderate-resolution Imaging Spectroradiometer (MODIS) files were obtained from https://earthexplorer.usgs.gov/ and used to extract NDVI values within a time series between 2000-2017), MODIS NDVI 16-day composite time series at 250m spatial resolution (MOD13Q1) were downloaded and used in this study to derive savannah phenological characteristics in Karamoja sub-region. Field based phenology data were also collected to compare and validate satellite derived phenology. Landsat images (2000-2017) downloaded from https://earthexplorer.usgs.gov/ and used for fine scale phenological interpretation and comparisons of different land cover management. Since NDVI MODIS contained some atmospheric effects and cloud contamination, there was need for pre-processing of the satellite data. Therefore, using Timesat program, a smooth filtering function known as the Savitzky-Golay was applied on NDVI MODIS (Moderate-resolution Imaging Spectroradiometer) data so as to remove the outliers and any missing values (Jönsson and Eklundh, 2004). The NDVI data at 250 m resolution and16-day composite intervals, acquired by MODIS on the Terra platform (MOD13Q1) were used for the NDVI time series and phenological analysis. This resulted in 23 composite NDVI per year, providing a total time series of about 191 NDVI images. The MODIS NDVI images were reprojected into a WGS84 area projection suitable for analysis. For each of the selected homogeneous sites MODIS NDVI time series data were extracted through a time series of 2000-2017. The mean NDVI time series data were extracted for all areas of interest excluding pixels that were affected by clouds or snow. These data provided the basis for examining the NDVI trends, and the associated phenology metrics for the different land cover types.

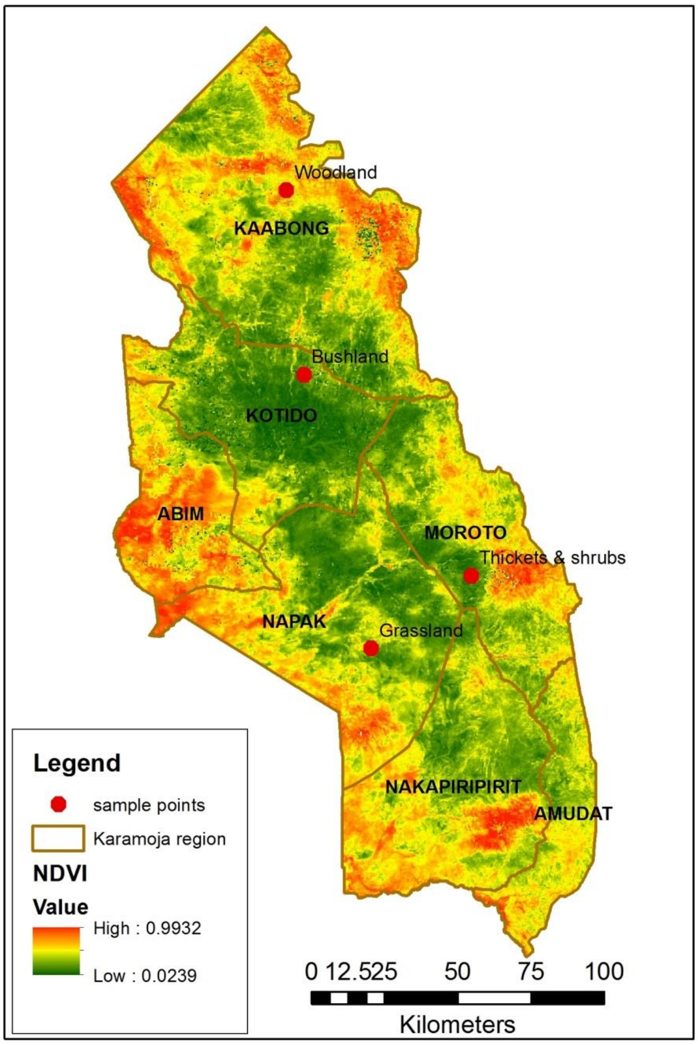

Figure 2. Locations of homogeneous sample points

Phenology extraction and validation. Both image-based and point-based NDVI time series were examined with respect to their growth and phenology patterns. However, only areas with relatively homogeneous landcover types (Figure 2) were selected to examine the variation in phenology and their response to climate variables. To sample the study area, several criteria were taken into account to ascertain representation of the major landcover types and avoid mixed or heterogeneous landcover patterns. The NDVI time series data were used to derive land surface phenometrics. The ArcMap zonal statistics was used to extract mean NDVI values that were used extract savannah phonological characteristics within a time series of 2000-2017. The savannah phenological characteristics were extracted using the TIMESTAT program (Jonsson and Eklundh, 2010). TIMESAT first implements a simple median filter to remove noise and then Savitzky-Golay to remove noise, spikes and irregular values that may have been caused as a result of cloud cover and atmospheric conditions. This allowed producing smoothened NDVI profiles and phenological parameters. The parameter thresholds were determined in TIMESAT program by analyzing time series data in order to obtain accurate NDVI profiles and phenological parameters. To determine the start and end of growing seasons, the ratio of NDVI aptitude to annual lowest values in the early and late growing season was calculated. In oder to validate satellite phenological parameters, four field sites of different vegetation types (grassland, bushland, woodland, thickets and shrubs) in Karamoja region were mapped and visited to collect information on SGS and EGS in 2017.

Results

Four phenological characteristics in the sub-region were identified: start of the growing season (SGS)-Onset, Maximum greeness (peak), End of the growing season (EGS) -senescence-Off set and the length of the growing season (LGS) for woodland, bushland, grassland, thickets and shrubs. Different phenological metrics were extracted for each savannah vegetation type; woodland, bushland, savannah, thickets and shrubs (Figure 4); results revealed variation in phenological patterns. In 2007, woodlands show a pronounced two peaks of a smaller between March-May with a withdrawal period in around June and an accelerated peaking in August-September period; this was comparatively different from 2000 and 2008. Meanwhile, grasslands, bushlands and thickets and shrubs in 2017 had a gradual phenological activity (Figure 3).

In the woodlands, the monthly NDVI indicated that the onset occurs around Mid-March throughout the years (2000, 2008 and 2017). In August (2000 and 2017), vegetation starts to be senescent throughout the region (Table 1). From June to Mid-August the peak is reached. In 2008 and 2017 a longer greening up occurred with a peak value of 0.759 and 0.712, respectively. The lowest rate of greening up was registered in 2000 (0.634). Results from the bushland vegetation type (Table 2) showed that 2017 had the shortest greening up period with a peak value of 0.683 experienced in Mid-July. Bushland vegetation experiences the start of greening up in April and senescence in August with a peak greening up in July (Table 2).

Results emerging from the the grasslands indicate that between 2000, 2008 and 2017 flowering started in April with the longest length of growing season experienced in 2017 with a period of 8 months but with the lowest greening up peak (0.532) that occured towards the end of

September (Table 3). Meanwhile, the thickets and shrubs phenological changes for 2000, 2008, and 2017 are reflected in Table 4. For all the years, the onset is registered in April with the highest greening up experienced in July while the longest growing season of six months was experienced in 2000.

Table 1. Phenological Parameters from TIMESAT Program (SGS- Start of the growing season, EGS-End of growing season, LGS-Length of the growing season) for Woodlands

Year	SGS	EGS	LGS	Peak	Peak NDVI	SGS Value	EOS Value
2000	Mid- Mar	Sept	6.5	Aug	0.634	0.469	0.567
2008	Mid -Mar	Mid-Oct	7	Jun	0.759	0.555	0.554
2017	Mid-Mar	Nov	8.5	Mid-Aug	0.712	0.455	0.627

Table 2. Phenological parameters from TIMESAT Program Program (SGS- Start of the growing season, EGS-end of growing season, LGS-Length of the growing season) for Bushland

Year	SGS	EGS	LGS	Peak	Peak NDVI	SGS Value	EOS Value
2000	Apr	Aug	5	Jul	0.572	0.394	0.552
2008	Mid-Mar	Mid-Aug	6	Mid-Jun	0.544	0.456	0.584
2017	Apr	Mid-Aug	4.5	Mid-Jul	0.683	0.318	0.654

Table 3. Phenological parameters from TIMESAT Program Program (SGS- Start of the growing season, EGS-End of growing season, LGS-Length of the growing season) for grassland

Year	SGS	EGS	LGS	Peak	Peak NDVI	SGS Value	EOS Value
2000	Apr	Aug	5	Jul	0.653	0.521	0.6
2008	Apr	Jul	4	Jun	0.678	0.46	0.544
2017	Apr	Nov	8	Sept	0.532	0.318	0.409

Table 4. Phenological parameters from TIMESAT Program Program (SGS- Start of the growing season, EGS-End of growing season, LGS-Length of the growing Sseason) for Thicket and shrubs

Year	SGS	EGS	LGS	Peak	Peak NDVI	SGS Value	EOS Valuee
2000	Apr	Sept	6	Jul	0.394	0.242	0.266
2008	Apr	Aug	5	Jul	0.499	0.269	0.445
2017	Apr	Aug	5	Jul	0.456	0.269	0.389

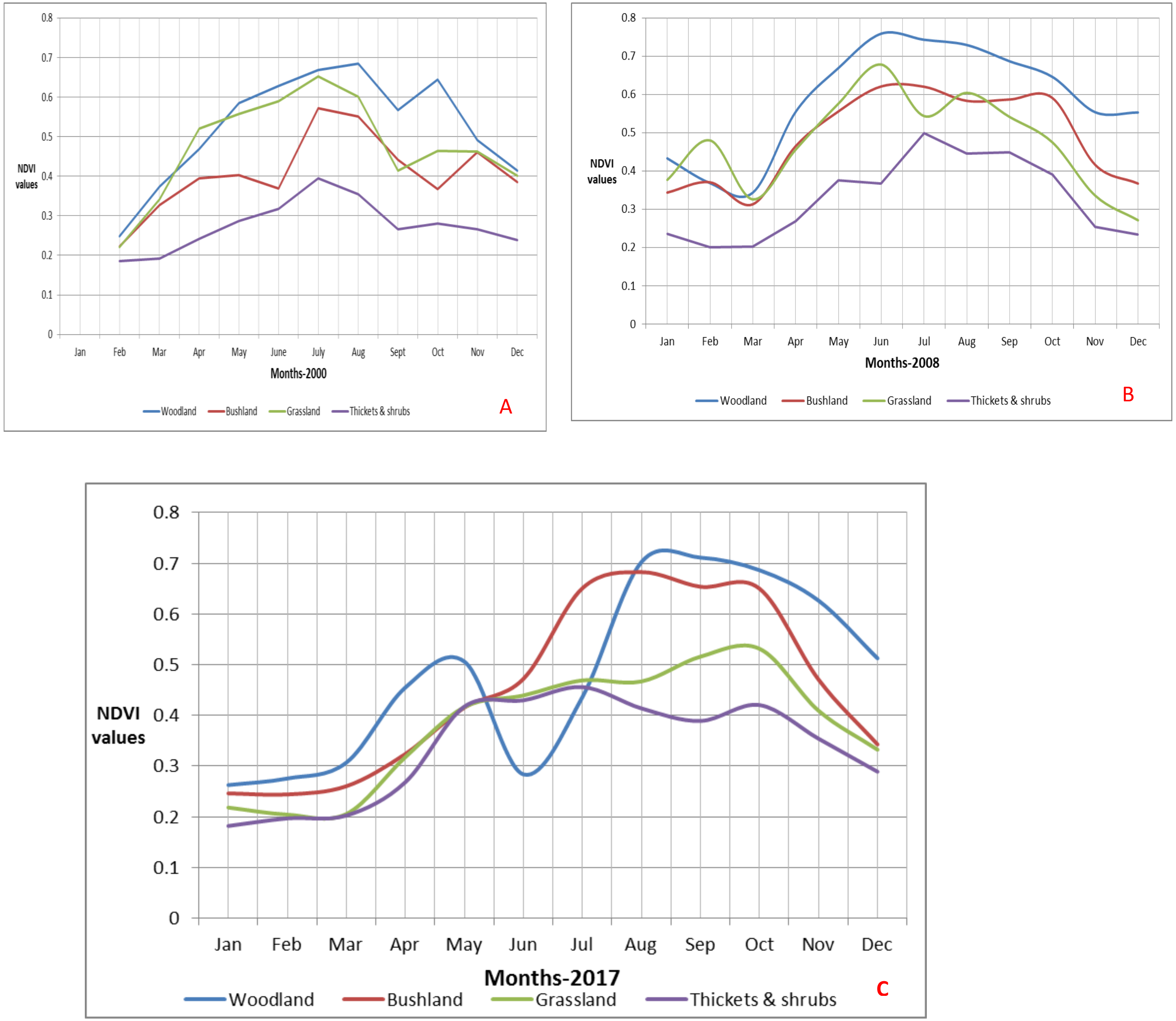

Figure 3. Average NDVI trajectories for each Savannah vegetation after being smoothened for a given time series a) 2000, b) 2008 , c) 2017. Trends in magnitude, timing, and shape of NDVI are different for each vegetation type and each year

Discussion

This study has shown variation in phenological characteristics between grasslands, woodlands, and thicket and thrublands. This variation in the length of the growing season as well as onset and peak vegetation performance reveals the underlying heterogeneity in the dryland areas of Karamoja. This reveals the functional heterogeneity that influences the dryland environments productivity in terms of rangeland resources of importance such as forage. According to Fynn (2012), rangelands worldwide are subject to considerable spatial and temporal variation in resources especially forage quantity and quality. These often affect stability and profitability of livestock production and foraging patterns that are adapted to these variabilities help to ameliorate the effects of variations. Menawhile, Segoli *et al*. (2012) argued that the heterogeneity between and within the dryland landscapes especially where the shrublands are located are a result of 'islands of fertility' in effect further reinforcing the argument of heterogeneity that exists in the dryland environments. The prolonged length of growing season for woodlands and thickets and shrublands could be a result of longer moisture retention ability of tree cover compared to grassy herbaceous plants as seen in the grasslands with a shorter length of growing season.

Conclusion

This study has demonstrated the feasibility of utilizing remote sensing times series derived data to provide phenological information of relevance for the management of variable landscape. In particular, it has been able to reveal the unique phenological attributes associated with different vegetation cover types thus revealing the inherent heterogeneity that exists within the dryland landscapes that has supported the viability of pastoral production system for centuries in Africa. It is recommended that further studies on time-space vegetation unique responses to rainfall regimes and rainfall gradient be undertaken to better reveal the biogeochemical interactions that are underlying in Karamoja landscapes.

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