Monitoring vegetation dynamics and ecosystem service provision in semi-arid Bobirwa sub-district of Botswana using MODIS-NDVI time series data from 2000-2015

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Abstract

Our study uses freely available, remotely-sensed Normalized Difference Vegetation Index (NDVI) data and participatory processes to examine the links between vegetation dynamics and recent changes in the delivery of key ecosystem services in the semi-arid Bobirwa sub-district in the Limpopo Basin, Botswana. The results show that degradation in the study area is provoked by both human activity and adverse climate with pronounced consequences on the delivery of key local ecosystem services.

Keywords: *NDVI, Remote Sensing, Time Series, Semi-arid Regions,* ***Provisioning Ecosystem Services, Botswana***

Introduction

Vegetation dynamics provide critical information for both explaining and understanding land degradation and recent changes in the delivery of local ecosystem services. More so, changes in remotely-sensed vegetation conditions provide a novel way to further understand both climatic and anthropogenic drivers of change in the flow of benefits from ecosystems and the changes in human dependence on the natural environment. Despite this importance, there exists a knowledge gap in southern Africa, particularly in Botswana, regarding the use of freely available remotely-sensed time series data to study vegetation dynamics over space and time, and how this can be linked to changes in human well-being. Coarse scale analyses using GIMMS NDVI3g data fail to fully account for local level trends. This paper presents a step-by-step methodology to authenticate recent trends (Brandt et al., 2014), and explain the

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implications on the delivery of provisioning ecosystem services in semi-arid Bobirwa sub-district, Botswana.

Methodology

This research examines the temporal and spatial dynamics of surface vegetation in semi-arid Bobirwa sub-district (Botswana) in the Limpopo Basin, using time series remotely-sensed NDVI data. It was undertaken in order to understand the effect of local climate and human activity on vegetation conditions, as well as draw implications of the observed changes on the delivery of provisioning ecosystem services which constitute an important part of human well-being and a potential adaptation strategy to changing climate.

The study complements non-participatory techniques with participatory methods through use of remote-sensing and focus group discussion techniques in data poor regions. Global Inventory Monitoring and Modeling Studies (GIMMS) and Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) time-series data is used to examine vegetation dynamics over Bobirwa sub-district, as well as to identify the underlying drivers. The Maximum Value Composite (MVC) is used to examine the spatial and temporal trends in vegetation conditions using GIMMS and MODIS NDVI data.

Results

Long-term time series data

Initially, long-term, coarse-scale vegetation trends were derived and analyzed. Composites of the Global Inventory Modeling and Monitoring Studies (GIMMS) dataset, covering the period 1982-2015 with a temporal resolution of 15 days and a spatial resolution of 8km was used. GIMMS is currently thought to be sensor-corrected, being consistent with NDVI from SPOT Vegetation and MODIS Terra satellites (Tucker et al., 2005).

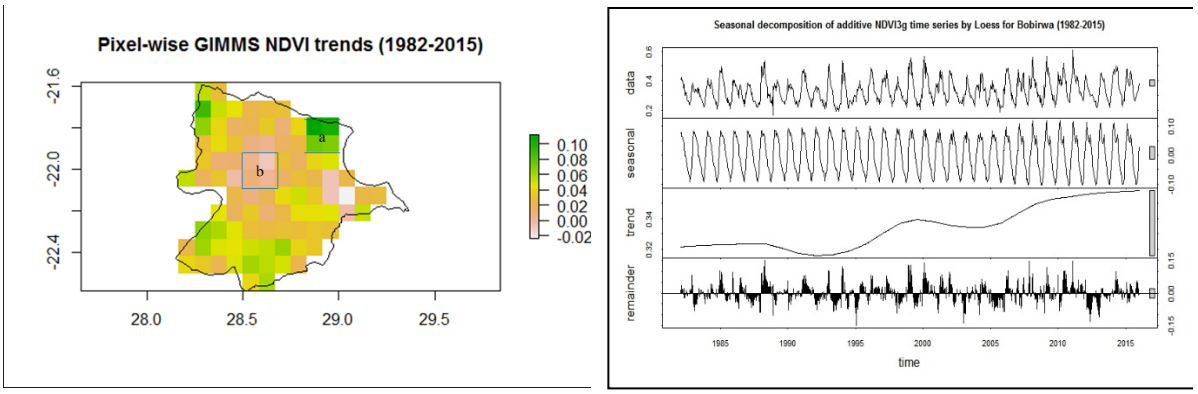

Figure 1. (a) Spatial trends in annual maximum GIMMS NDVI for Bobirwa sub-district for the period 1982-2015. Spatial variations can be observed at a scale of approximately 9km (Source: Authors own)

Figure 1. (b) Decomposed trends in annual maximum NDVI for Bobirwa sub-district using GIIMS data (1982-2015)(Source: Authors own)

Figure 1 (a) shows that greening and browning is spatially distributed, while **Figure 1 (b)** shows gives an idea of a generally increasing trend in vegetation conditions for the 34-year period. While **Figure 1(a)** shows areas undergoing degradation (browning), as well as those where vegetation conditions are improving (greening), the increasing NDVI trend shown in **Figure 1(b),** a spatial average of **Figure 1(a)** masks these dynamics. This masking of actual trends also exists in the pixels due to the coarse resolution; hence the need to refine the analyses on those portions undergoing significant greening and browning.

Medium resolution time series data

Areas showing both positive (greening) and negative (browning or degradation) trends (portions marked *a* and b in Figures 1 (a) and 2(a), respectively) were further analyzed using Moderate Resolution Imaging Spectroradiometer (MODIS) time-series dataset. The MODIS dataset has a spatial resolution of 250m, hence trends can be observed at the village/community level. We used a smoothed Maximum Value Composite (MVC) for the period 2000-2015.

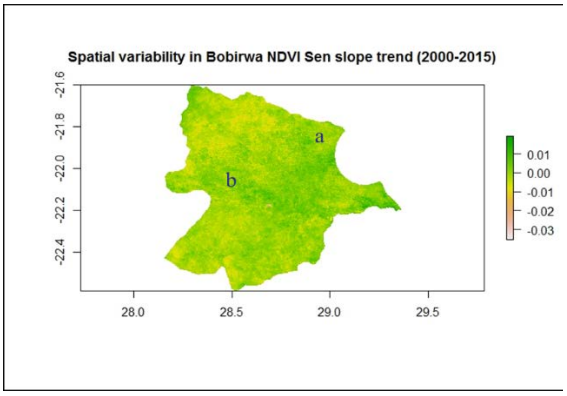

Figure 2. (a) Spatial variability spatially (Source: Authors own)

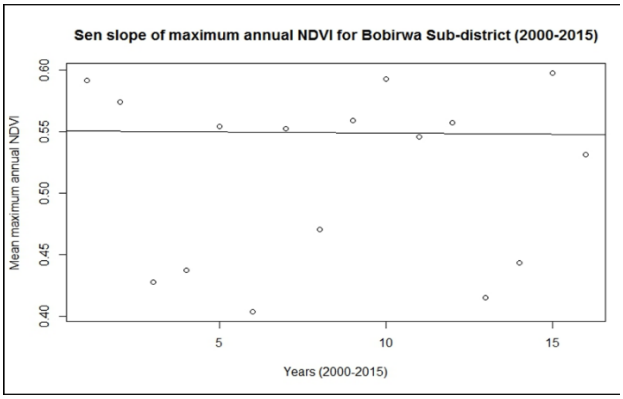

Figure 2. (b) MODIS NDVI Sen slope trends for Bobirwa for the period 2000-2015. Spatial variations can be observed at a scale of 250 m for smaller areas (Source: Authors own)

For the 16-year period, **Figure 2 (a)** also shows that greening and browning are spatially distributed and non-uniform. However, the Thiel Sen Slope in **Figure 2 (b)** reveals an overall decline in the maximum NDVI value for the same period, indicating declining vegetation conditions.

Field observations

Field observations around 8 villages revealed various land-use and/or land-cover types, vegetation types and prevailing ecosystem conditions. Signs of the impacts of climate extremes, drought and human pressure were also visible. Vast areas of bare land, gullies and spreading Acacia trees were observed around the villages. It was common practice to leave important trees (e.g. *Colophospermum mopane* and wild fruits) around the village settlement, homesteads and on crop fields. Trees and shrubs around crop fields were also left uncleared. Dry land farming was also being illegally practiced at the 'cattle posts' (communal grazing area). Irrigated farming on private farms and protected areas were also other land-uses observed. Nonetheless, actual cause of the trends was not obvious.

Key provisioning ecosystem services

A total of 15 key provisioning services were identified. These were cultivated crop production, livestock production, fresh water fish, wild fruits, wild foods (Mopane caterpillars and game), timber and poles, thatch, palm plants, natural pastures, natural medicines, fresh water, biomass fuel, dyes, sand mining and precious stones. The land-use and/land-cover types providing these ecosystem services were woodlands, crop lands, grasslands, water bodies, barren land, built-up areas (settled areas) and privately owned-farms.

Community insights

A combination of participatory mapping exercises, focus group discussions and one-on-one interviews with the local communities concurred that the surrounding environment was deteriorating. The local communities explained vegetation loss and degradation as mainly due to:

- Recurring droughts almost every 3-4 years
- Erratic and poorly distributed rainfall (both spatially and temporally)
- Legal and illegal clearing of woodland for crop production and firewood
- Overgrazing especially from increasing livestock population
- Erosion and gullies from sudden heavy downpours
- Damming of major rivers upstream

However, the local community also explained the greening in some parts as due to:

- Proliferation and spreading of more drought tolerant vegetation species (especially Acacias and *Hyphaene petersiana*)
- Conservation of woodlands and important tree species
- Several river channels in the sub-district, some of which drain into Limpopo River

The community expressed concern that recurring droughts, damming of rivers upstream, FMD-induced overstocking and population pressure could further deteriorate vegetation conditions. This also meant a decline in water availability, cultivated crop yields, natural pastures, natural medicines, livestock production, Mopane caterpillars, palm leaves for basketry, wood fuel, timber, wild fruits and thatch. With Botswana being among the top African countries expected to surpass the 1.5°C threshold set by the Paris Agreement (Nkemelang et al., 2018), the decline in vegetation and key ecosystem services reported in our study may perhaps become magnified not only locally but also globally in other semi-arid regions.

Conclusion

Our study highlights the importance of integrating participatory and non-participatory techniques to validate research findings. Local knowledge is critical for explaining observed trends in remotely-sensed vegetation conditions, especially in data poor regions. As a proxy for environmental condition, vegetation trends were linked to reported trends in the delivery of key ecosystem services in semi-arid Bobirwa sub-district. Although climate is shown to be an important driver of vegetation condition, human pressure is also contributing to these spatial variations. However, we showed that the actual drivers of change can be revealed through field

observations and community insights. As such, vegetation greening patterns alone give inconclusive evidence as discussions with local communities revealed contrasting patterns concerning the delivery of certain key provisioning ecosystem services. Further studies should therefore investigate changes in species composition and distribution to explain the greening and browning of vegetation.

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