Modelling grass biomass dynamics in Kenyan rangelands based on Sentinel satellite data

Janne Heiskanen [1,2], Ilja Vuorinne [1], Linda Pesonen [1], Ian Ocholla [1], Mwadime Mjomba [3], Taiga Korpelainen [1], Petri Pellikka [1]

[1] Department of Geosciences and Geography, University of Helsinki, Finland – janne.heiskanen@helsinki.fi
[2] Finnish Meteorological Institute, Helsinki, Finland
[3] Taita Environmental Research and Resource Arc (TERRA), Wundanyi, Kenya

Keywords: Savannah, biomass, vegetation index, satellite, shortwave infrared.

1. Introduction

Savannah rangelands have a vital role in supporting biodiversity and providing livelihoods for pastoral and agro-pastoral communities in sub-Saharan Africa. However, these ecosystems face numerous threats, including climate change, land degradation, and unsustainable land use practices. Sustainable and adaptive management of rangelands requires understanding of grass biomass dynamics, as it is an elementary resource for cattle and wildlife, and a key indicator of rangeland health and productivity.

Remote sensing technologies, such as those provided by the Sentinel satellites, offer valuable tools for assessing and monitoring biomass resources and conditions over large spatial extents and at regular intervals. Sentinel-1 provides synthetic aperture radar (SAR) data that is less sensitive to weather conditions than optical Sentinel-2 data. Together these data sets might provide better biomass prediction models than either of the data sets alone. Furthermore, performance of optical prediction models show regional and temporal variability. These warrant further studies on Sentinel-1 and Sentinel-2 data fusion and performance of spectral indices.

In this study, we investigated performance of Sentinel satellite data for grass biomass modelling in the dry savannahs in southern Kenya using field data collected across dry and rainy seasons.

2. Material and Methods

Our study area is located in the lowlands of Taita-Taveta County, southeastern Kenya. It includes LUMO Community Wildlife Conservancy and Taita Hills Wildlife Sanctuary (THWS). Land cover consist of dry savannah grassland and bushland (Fig. 1). The area has two rainy season, long rains from March to May and short rains from November to December. Based on the closest weather station in Maktau, the mean annual precipitation varies between 400 and 600 mm. The land use in LUMO includes both cattle grazing and wildlife conservation, while THWS is more strictly conservation.

We collected samples of grass and low shrub biomass from 36 plots (20 m × 20 m), each consisting of four 1 m^2 subplots. The plots were selected subjectively to cover variation grass biomass levels with the study area. We sampled once all the plots and repeated sampling in 12 plots multiple times during 2022 and 2023. Grass biomass was measured by clipping and weighting the samples, which were dried in the oven for dry weight. Mean biomass was used for each plot based on the four subplots to match the measurements with satellite resolution.

Figure 1. Typical dry savannah grassland with grazing cattle in in LUMO Community Wildlife Conservancy.

Sentinel-1 SAR data and Sentinel-2 multispectral imagery were acquired for the study plots using Google Earth Engine. The closest observation in time to biomass sampling was selected modelling. We allowed a maximum time difference of 10 days between field sampling and satellite observation. For Sentinel-1, features extracted for the plots included backscatter (HH, HV) and HH/HV ratio while spectral reflectance and a broad range of spectral indices were used for Sentinel-2.

We employed Generalized Additive Models (GAMs) to analyze the relationship between grass biomass and all the features. GAMs were fitted to the entire dataset and separately for each sampling time and plot to account for temporal and spatial variability. Random forest was used for developing a combined Sentinel-1 and Sentinel-2 model.

3. Results

Our analysis revealed significant relationships between grass biomass and several predictor variables derived from Sentinel-2 data, particularly those incorporating shortwave infrared (SWIR) bands. Among these, the Normalized Burn Ratio 2 (NBR2), calculated using the two SWIR bands, emerged as the most effective predictor of grass biomass when combining data over all sampling times (D^2 = 0.64). It demonstrated strong relationships with both dry and fresh weight measurements, and models including both grass and low shrubs. The combination of Sentinel-1 SAR data did not improve model performance, suggesting that optical data alone may be sufficient for grass biomass estimation in the study area. Plot-level analysis confirmed the consistent performance of NBR2 across plots with multiple measurements. However, seasonal variation in model performance was greater suggesting that single index might not be optimal throughout the seasons (Fig. 2).

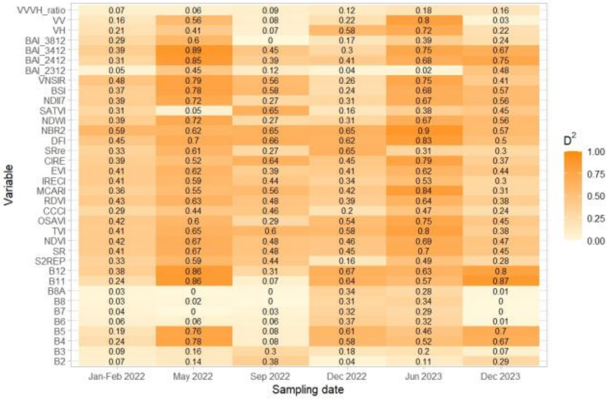

Figure 2. Modelling results for grass biomass (dry weight) separately for each sampling date. Deviance explained (D^2) show model fit for each Sentinel-1 and Sentinel-2 predictor variable.

4. Conclusion

Our study highlights the utility of Sentinel-2 optical data, particularly SWIR bands, for modelling grass biomass in semi-arid rangeland ecosystems. By leveraging Sentinel satellite data, we have gained valuable insights into the spatiotemporal dynamics of grass biomass in southern Kenya. These findings have important implications for developing monitoring methods to support rangeland management and wildlife conservation by informing adaptive management strategies aimed at sustainable utilization of grazing resources.