Estimating aboveground net primary productivity of reforested trees in urban landscape using integrated biophysical variables and remotely sensed data

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Abstract

Urban reforestation initiatives have been identified as reliable approaches for carbon sequestration and climate change mitigation. Thus, knowledge on net primary productivity (NPP) as a surrogate of net carbon uptake by reforested trees is important for understanding the contribution of reforestation program in the global carbon cycle and climate change regulation. Hence, this study sought to predict NPP of reforested trees in urban landscape using remotely sensed dataset and biophysical variables. Using Sentinel 2 image data and 10 x10 m plot sizes to determine landscape biophysical and biochemical variables, the MOD17 model established an NPPD17 of 6.24 Mg C. ha^{-1} with a coefficient of determination (R^2) of 0.91 and RMSE of 0.83 Mg. ha^{-1}. The findings also demonstrated a significant variation in NPP among reforested trees. For instance, deciduous *Acacia* and *Dalbergia* species obtained higher NPP (7.62 and 7.58 Mg C ha^{-1}), whereas, evergreen *Syzygium* and shrub *Artimisia* produced lower (4.54 and 5.26 Mg C ha^{-1}) NPP. These results demonstrate the strength of remote sensing and biophysical parameters in estimating NPP of reforested urban landscape.

Keywords: carbon flux, species, MOD17, photosynthetically active radiation

Introduction

Spatially explicit information on net primary productivity (NPP) is critical for understanding ecosystem dynamics and their role in the global carbon cycle (Pachavo and Murwira 2014). Globally, the transformation of natural landscapes into urban environments account for the largest proportion of carbon emissions and climate change. Continuous deforestation and forest degradation due to urbanization contributes to increasing greenhouse gas emissions and climate change risks within urban landscapes (Sithole et al. 2018). This has necessitated long-term initiatives and policy frameworks for combating carbon emissions and climate change mitigation approaches. Consequently, reforestation has emerged as a low-cost and long-term strategy for reducing greenhouse gas effects and to regulate climate systems within urban landscapes, especially in developing regions such as Africa. However, the spatio-temporal information on carbon dynamics of reforested trees in Africa's urban landscapes remain uncertain. Meanwhile, there is need for concise and timely knowledge on carbon uptake by reforested trees in order to establish well-informed decision-making and policy-framework for the management and monitoring of forest ecosystems and their services in urban landscapes. In this regard, accurate estimation of NPP as a function of carbon uptake is key to understanding the contribution of reforestation initiative on carbon cycle and climate change regulation in urban landscape. The utility of remote sensing and biophysical parameters have shown promising potential in modelling ecosystem services such carbon stock, NPP and biomass. Hence, this study sought to estimate NPP of reforested trees within urban landscape using Sentinel-2 image and biophysical parameters.

Materials and methods

This study was conducted north of Durban city in KwaZulu-Natal province, South Africa. The reforestation project covers approximately 800ha with highly mixed species. Field data collected was done between 21st and 25th of February 2020. The study established 10 x 10 m plot size-windows where numerous biophysical (i.e. photosynthetic active radiation and leaf area index) and biochemical (i.e. chlorophyll concentration) variables were measured and recorded using quantum sensor (ACC-PAR-LP80), Chlorophyll Meter and Light Sensor Logger. In addition, the tree height and diameter of individual trees were measured and used in allometric model to compute biomass, which was converted to carbon stock using the factor of 0.5 following literature. Furthermore, Sentinel-2 MSI acquired from ESA was used to generate predictive indices, while MOD17 model was adopted to estimate NPP.

Results and Discussion

The estimated overall mean NPP was 6.23 Mg C ha^{-1} with an R^2 of 0.91 and RMSE of 0.83 Mg ha^{-1}. Such unprecedented estimation performance can be explained by MOD17 model's ability to integrate photosynthetic properties that are essential for plant productivity through energy conversion by green-biomass into carbon stock. This finding is also affirmed by Ardö (2015) who reported that MOD17 model obtained higher NPP estimates due to its sensitivity to incident radiation absorbed by green-plants biomass. Furthermore, the results show that NPP varies between reforested tree species with deciduous *Acacia* and *Dalbergia* obtaining higher NPP (7.62 and 7.58 Mg C ha^{-1}), compared to evergreen *Syzygium* and shrub *Artimisia* with the lower (4.54 and 5.26 Mg C ha^{-1}) NPP. This finding can be attributed to the distinct differences in biochemical (i.e. chlorophyll content, carotenoids etc.) and biophysical (leaf area, leaf stomata etc.) properties between taxons which significantly influences photosynthetic process and carbon uptake. Waring et al (1997) note that the unequal radiation absorption index by green-plants due to differences in pigments, leaf optical properties and leaf distribution can lead to unequal primary productivity between the species of different genera. Overall, this study demonstrate that urban reforestation initiatives play a significant role in carbon sequestration and climate systems regulation within urban landscape, hence necessitating effective management and conservation of reforestation ecosystem and its services.

Conclusion

The integration of Sentinel-2's derived spectral dataset and measured biophysical variables successfully estimated aboveground net primary productivity with reforested urban landscape. This provides information that benefits policy-makers, decision-makers and forest managers to plan for monitoring and larger scale projects.

References

Ardö, J. (2015) Comparison between remote sensing and a dynamic vegetation model for estimating terrestrial primary production of Africa. *Carbon balance and management,* 10**,** 8.

Pachavo, G. & A. Murwira (2014) Remote sensing net primary productivity (NPP) estimation with the aid of GIS modelled shortwave radiation (SWR) in a Southern African Savanna. *International Journal of Applied Earth Observation and Geoinformation,* 30**,** 217-226.

Sithole, K., J. Odindi & O. Mutanga (2018) Assessing the utility of topographic variables in predicting structural complexity of tree stands in a reforested urban landscape. *Urban forestry & urban greening*, 31**,** 120-129.

Waring, R., J. Landsberg & M. Williams (1998) Net primary production of forests: a constant fraction of gross primary production? *Tree physiology*, 18**,** 129-134.