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Evaluating the influence of the Red Edge band from RapidEye sensor in quantifying leaf area index for hydrological applications specifically focussing on plant canopy interception

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ABSTRACT

Reliable and accurate quantification of plant Leaf Area Index (LAI) is critical in understanding its role in reducing runoff. The main aim of the present study was to evaluate the ability of the Red Edge (RE) band derived from RapidEye in estimating LAI for applications in quantifying canopy interception at landscape scale. To achieve this objective, the study also compares the predictive power of two machine learning algorithms (Random Forest-RF and Stochastic Gradient Boosting-SGB) in estimating LAI. Comparatively, the results of the study have demonstrated that the inclusion of spectral information derived from the Red Edge band yields high accurate LAI estimates, when compared to the use of traditional traditional Red, Green, Blue and Near Infra-Red (traditional RGBNIR) spectral information. The results indicate that the use of the four traditional RGBNIR bands yielded comparatively lower R^2 values and high Root Mean Squares, Mean Absolute Error (*Pinus taeda*: R^2 of 0.60; the lowest RMSE (0.35 m^2/m^2) and MAE of 28); whereas the use of integration of traditional RGBNIR + RE in more accurate LAI estimates (*Pinus taeda:* $R^2 = 0.65$; RMSE = 0.30 m^2/m^2) and the lowest MAE of 0.23). These findings therefore underscores the importance of new generation multispectral sensors with strategically-position bands and machine learning algorithms in estimating LAI for quantifying canopy interception, especially in resource-poor areas.

1. Introduction

The assessment of hydrological components using remote sensing has increased remarkably in the recent years, due to the advances in earth observation technologies. Canopy interception is an important water balance component in hydrological modeling (Savenije, 2004), by which vegetation canopy acts as a barrier for rainwater to reach the surface and possibly make its way to water sources, such as rivers and dams (Bulcock and Jewitt, 2010). Thus, canopy interception represents a major distraction of rainwater, especially in forest ecosystems, thereby disturbing the ultimate surface run-off and the availability of water at large. It has also been noted that interception alters the amount, spatial distribution and timing of the rainwater input to the surface (Carlyle-Moses and Gash, 2011). In addition, the loss of intercepted water (through evaporation) represents a large portion of the annual water budget that is lost during and between rainfall events. For instance, Carlyle-Moses and Gash (2011) highlighted that in most forested regions, the annual interception loss may vary from ten to fifty percent of annual rainfall, depending on vegetation characteristics. In this regard, the partitioning of rainwater through interception has possible implications on surface run-off and the availability of water. Moreover, with predictions on rainfall variability across most regions, due to climate change. There is need to account for rainwater partitioning, as well as understand the contribution of vegetation in obstructing rainwater for better conservation of water. Failure to account for canopy interception can impact on the

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long-term predictions of waterloss and its availability for well-informed management and conservation.

For decades, field-based methods have been used to determine canopy interception, using theLAI. However, these methods are very expensive and time consuming (Jonckheere et al., 2004). This poses a major challenge for their operational application at large spatial scales, especially in resource-constrained areas, like southern Africa. Remote sensing therefore offers timely and up-to-date information which is critical for vegetation monitoring (Adam et al., 2010). Currently, a wide range of remote sensing images, ranging from multi-spectral to hyperspectral sensors, with varying spatial, spectral and temporal characteristics are available for exploring various vegetation characteristics (Adam et al., 2010).

Specifically, hyperspectral data is still the most accurate earth observation data that has been noted to be of high accuracy in estimating vegetation structural attributes such as the canopy storage capacity and LAI is the hyperspectral data. Hypersectral data is characterised by narrow spectral channels which can optimally detect minute vegetation traits that could otherways be blended into mixed pixels when using broadband sensors (Mariotto et al., 2013). Due to high costs, unavailability, limited spatial coverage, and complexities in analysing due to lack of skills, especially in sub-Saharan Africa, such datasets are not favorable (Adam et al., 2010; Dube et al., 2017). Meanwhile, Landsat data series remains the most optimal spatial data source for regions with limited resources. Furthermore, it has the longest historic data, its free and readily available, with less complications in preprocessing and analyising it. Despite the recently launched, improved Landsat 8 operational land imager, Landsat moderate spatial resolution as well as the lack of spectral channels such as the Red edge, critical in vegetation mapping limits its utility (Sibanda et al., 2016). In that regard there is need for identifying other sensors with comprehensive spectral and spatial information that could be utilised in mapping and understanding critical water related issues such the canopy water storage capacity and interception.

Several studies have so far evaluated the utility of standard spectral information in estimating and mapping vegetation structures such as LAI. Results of these studies suggests that the utility of standard spectral data in characterising spatial vegetation information, such as LAI, are limited by saturation issues. Consequently, vegetation indices such as the normalized difference vegetation index (NDVI) have been used, to a certain extent, as a pancea for these saturation issues especially in the arid subtropical regions where soil reflectance has been the major noise suppressing the vegetation spectral signature. Vegetation indices have the ability to minimise the soil back round effect while augmenting the signal of vegetation (Dube et al., 2014).

Concisely, the Normalized Difference Vegetation Index (NDVI), as derived from the remotely sensed Near Infrared (NIR) and the red (R) bands have been widely used to determine canopy LAI and their role in rain water partitioning (Canisius et al., 2010; Wang et al., 2005). However, it has been discovered that the NDVI saturates in high biomass (high LAI) and densely-vegetated areas (Huete et al., 2002; Mutanga and Skidmore, 2004). Furthermore, NDVIis very sensitive to canopy background. This results in significant errors in the estimation of vegetation characteristics. In addition, the use of NDVI derived from multi-spectral coarse spatial resolution sensors (e.g MODIS), is limited due to their mixed pixels problem despite their wide utilisation at regional scales (Basuki et al., 2012; Carreiras et al., 2012a). In this regard, these sensors have since became unsuitable for estimating vegetation characteristics at a localized scale.

The more recent development and increase in the available earth observation facilities has availed quality spatial information required forth mapping of various vegetation characteristics. The remote sensing community has recently seen the launching of Sentinel-2 multispectral imager, WorldView −2 and 3 as well as RapidEye to mention a few. The Red edge portion of the electromagnetic spectrum covered by these broadband sensors have been noted to be influential in optimal mapping and estimation accuracies of vegetation biochemical properties. The Red edge portion of the electromagnetic spectral is sensitive to various leaf optical properties such LAI, leaf angle distribution and chlorophyll which interact with incoming radiation facilitating the mapping of vegetation (Sibanda et al., 2015). It has also been noted that the use of the Red Edge computing NDVI has high potential to improve the estimation accuracy of canopy cover. For instance, the study by Mutanga and Skidmore (2004) demonstrated a the robustness of the vegetation indices derived from wavelengths within the Red Edge, compared to the standard NDVI in estimating biomass for high canopy density. Similarly, Lee et al. (2004) determined whether the narrow-wavebands from the new-generation hyperspectral remote sensing data could better estimate LAI, when compared to the use of the traditional broad-band multispectral data. They found that the Red Edge channel regions are more important, when compared to those in the use of the Near Infra-Red portion of the electromagnetic spectrum.

It is therefore anticipated that the improved estimation accuracy, reported by previous studies using LAI, derived from the Red Edge bands may also enhance the estimation of canopy interception for hydrological purposes. With advances in remote sensing technology in water related studies, the performance of different sensors, especially in understanding various water balance components is increasing. However, the ability of the Red Edge from the RapidEye imagery has not been tested in estimating canopy interception. Thus, the aim of this study is to evaluate the performance of the Red Edge band of the RapidEye imagery in determining canopy interception for hydrological purposes. To achieve this objective, the study also compares the predictive power of two machine learning algorithms (Random Forest-RF and Stochastic Gradient Boosting-SGB) in estimating LAI.

2. Materials and methods

2.1. Description of the study area

The study was conducted at Clan Sappi Forests (a paper and pulp company) area (between Latitudes 29°24′46.74″S, 29°17′45.94″S and Longitude 30°18′32.89″E, 30°28′28.21″E), part of the uMgeni catchment, situated between Greytown and Pietermaritzburg in the province of KwaZulu-Natal, South Africa (Fig. 1). The Clan area is characterised by gentle undulating terrain with apedal and plinthic soil classes of the Ecca group. Sub-tropical climatic conditions prevail, with the rainy season occurring from October to February with mean annual rainfall variability ranging from 700 mm to 1500 mm. The mean annual temperature is approximately 21.7 °C which, together with high summer rainfall, provides favorable conditions for the production of various commercial forests (Scott and Lesch, 1997). For example, the area is currently home to various Eucalyptus and Pine trees occupying approximately 6700 ha, mainly grown for pulpwood.

2.2. Field data collection

Field LAI data was conducted on the 30th of July and the 22nd of August 2013, in conjunction with Sappi annual routine-field surveys. In measuring LAI from the three plantation forest species, the portable, handheld LI-COR LAI-2000 plant canopy analyzer, a ground-based optical instrument was used. It is important to note that since the LI-COR LAI-2000 plant canopy analyzer is portable

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