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Applicability of Satellite Remote Sensing in Accounting Above-Ground Carbon in Miombo Woodlands

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Abstract The crisis of climate change has drawn attention of ecologists all over the world to explore ways that could effectively enhance the sequestration of carbon in forests and woodlands. This necessitates forest inventory, along with knowledge of techniques that are quick and manageable. The present study was carried out in Miombo woodlands of western Tanzania namely, Kitwe and Mgaraganza. The aim of the present study was to investigate the effectiveness of remote sensing in estimating the stock of carbon in Miombo woodlands. Two types of data namely, ground-truthing and satellite imagery were used. Ground-truthing data were obtained by measuring the diameter at breast height (DBH) of all trees in 30 and 20 concentric plots in Kitwe and Mgaraganza forests, respectively. The average DBH of trees in each forest was fitted in biomass allometric models to estimate the ground-truthing vegetation biomass. On the other hand, Landsat images of the two forests were used to compute the Normalised Vegetation Index (NDVI). The computed NDVI were regressed with the ground-truthing vegetation biomass to get the remotely sensed vegetation biomass which was assumed to be 50% carbon. The coefficients of determination between the ground-truthing above-ground biomass and the NDVI values were statistically significant at $P<0.05$. The above-ground carbon stock obtained by ground-truthing in Mgaraganza and Kitwe forests was 3 and 2 times higher than that of satellite remotely sensed data respectively. The above-ground carbon stock obtained from satellite remote sensing gives some impression thus a basis for remote sensing in Miombo woodlands.
Keywords *Biomass; Ground-Truthing; Landsat*

1. Introduction

Local to global estimations of biomass and its dynamics are essential inputs to climate change forecasting models, mitigation and adaptation strategies. Thus, the growing levels of carbon dioxide (CO_2) in the atmosphere call for reliable estimation of biomass which is directly related to carbon. Food and Agriculture Organisation (FAO) (2004) defines biomass as organic material above and below-ground both living and dead. The approaches of biomass estimations can be destructive or non-destructive, depending on the purpose of the study. Among the non-destructive methods of estimating biomass are satellite photography and imagery. The later uses the technology of remote sensing.

According to Gibbs et al. (2007), remote sensing refers to the acquisition and recording of information about objects on earth without any physical contact between the sensor and the subject of analysis. Remote sensing has been increasingly used to acquire information about ecological processes. This is because the technology provides spatial coverage by measurement of reflected and emitted electromagnetic radiation across a wide range of wavebands.

According to Hall et al. (2006), biomass remote sensing measures the amount of microwave, optical or infrared radiation reflected or scattered by the imaged area in the direction of the sensor. This amount is related to biomass levels of vegetation in the imaged resolution at a certain electromagnetic wavelength. Thus the strong correlation between spectral data and vegetation parameters, the repetitiveness of data collection and the global coverage are in favour of the use of remote sensing for biomass estimation over large areas, especially in remote places (Lu, 2006).

Earlier studies have investigated the relationship of spectral vegetation indices derived from satellite data to ground-truthing parameters using correlation or regression analysis (Tucker and Sellers, 1986). Remote sensing of green vegetation is based on the absorption and reflection of different wavelengths of light and the properties of chlorophyll cause a reflection of infra-red and absorption of red light (Ray, 1994).

Rouse et al. (1974) developed the Normalised Vegetation Index abbreviated as NDVI. This is a satellite metric used to detect changes in pixel-scale vegetation chlorophyll content, green biomass and APAR (Absorbed Photosynthetically Active Radiation) (Jensen, 1996; Huete et al., 2002; Asner, 2004).

$$\text{NDVI} = \frac{(\rho\text{NIR} - \rho\,\text{Re d})}{(\rho\text{NIR} + \rho\,\text{Re d})} \qquad \text{OR} \qquad \text{NDVI} = \frac{\text{band 4} - \text{band 3}}{\text{band 4} + \text{band 3}}$$

In Miombo woodlands, the relationships between field measurements and vegetation indices have been explored to some extent. NDVI value depends on the optical properties of plant tissues (twigs and/or leaves, wood, litter, etc.) that determine the landscape-scale reflectance of ecosystems. Also, each pixel in the NDVI image is therefore representative of the chlorophyll-containing biomass in the spatial area represented by that pixel. Thus NDVI uses the distinctive spectral reflectivity properties of plants (Jensen, 1996; Asner, 2004).

In estimating above-ground biomass and hence carbon stock by remote sensing, it is necessary to gather additional field data in order to validate the satellite biomass estimates for that area and in other areas as well (Australian Greenhouse Office, 1999). Once the remotely sensed data are validated, they can be used to estimate forest biomass for wider areas where there are very little or no field measurements. Land cover assessments in Miombo woodlands have been successfully done using a variety of remote sensing data including LANDSAT imagery (Prins and Kikula, 1996).

Therefore, the specific objective of this study was to explore the feasibility of determining the stock of carbon using remotely sensed data in selected Miombo woodlands of Tanzania.

2. Materials and Methods

2.1. The Study Area

The present study was confined to forested ecosystems that are under different forest tenures namely, Private owned forest (Kitwe) and Village forest (Mgaraganza) in Western Tanzania. These forests are secondary re-growths following serious anthropogenic disturbance initially, since Kitwe forest has been protected from wildfires for over 15 years.

Kitwe forest is located between latitudes 4º 54' and 4º 55' S, and longitudes 29º 36' and 29º 37' E, while, Mgaraganza is found between latitudes 4º 45' and 4º 46' S, and longitudes 29º 38' and 29º 39' E (Figures 1 and 2).

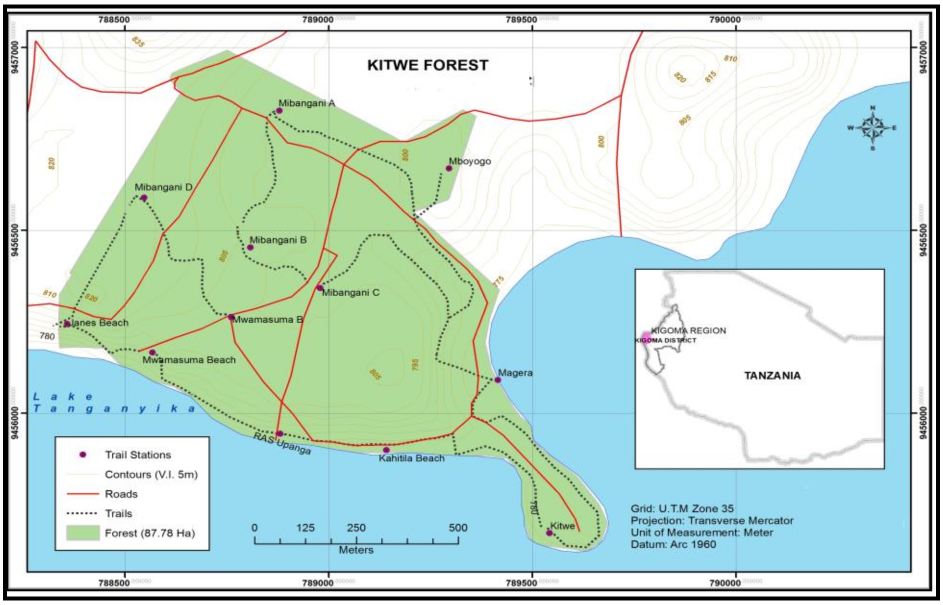

Figure 1: *Location of Kitwe Forest*

2.2. Ground-Truthing Data

In this study, 30 and 20 circular concentric plots were established in Kitwe and Mgaraganza forests respectively. The inventory design which was used in this study was systematic random sampling. The distance between the concentric plots was 100 m and 50 m in Kitwe and Mgaraganza forests respectively on the basis of their area coverage. Radius with 15 m was used to sample trees with DBH ≥ 20cm, radius with 10 m was used to sample trees with DBH ≥ 10 cm but less than 20 cm and radius with 5 m was used to sample trees with DBH ≥ 5 cm but less than 10 cm (Vesa et al., 2010). In the present study, a tree is defined as a woody species with diameter at breast height (DBH) of ≥ 5 cm as adopted from studies carried out in Miombo woodlands of the Eastern Arc Mountains by Chamshama et al. (2004); Zahabu (2008), and in Mozambique by Ryan and Williams (2011). DBH of trees were measured using diameter calipers. Then the average DBH was found in each forest, which was then used in estimating the ground-truthing biomass from the following allometric models (Chidumayo, 1997):

$$B = 2.23DBH - 6.44 \quad (DBH < 11cm)$$
$$B = 17.43DBH - 188.84 \quad (DBH > 11 cm)$$

Where B = biomass

Woody biomass was assumed to be 50% carbon (Munishi and Shear, 2004), which was estimated as carbon sequestered in tonnes/hectare.

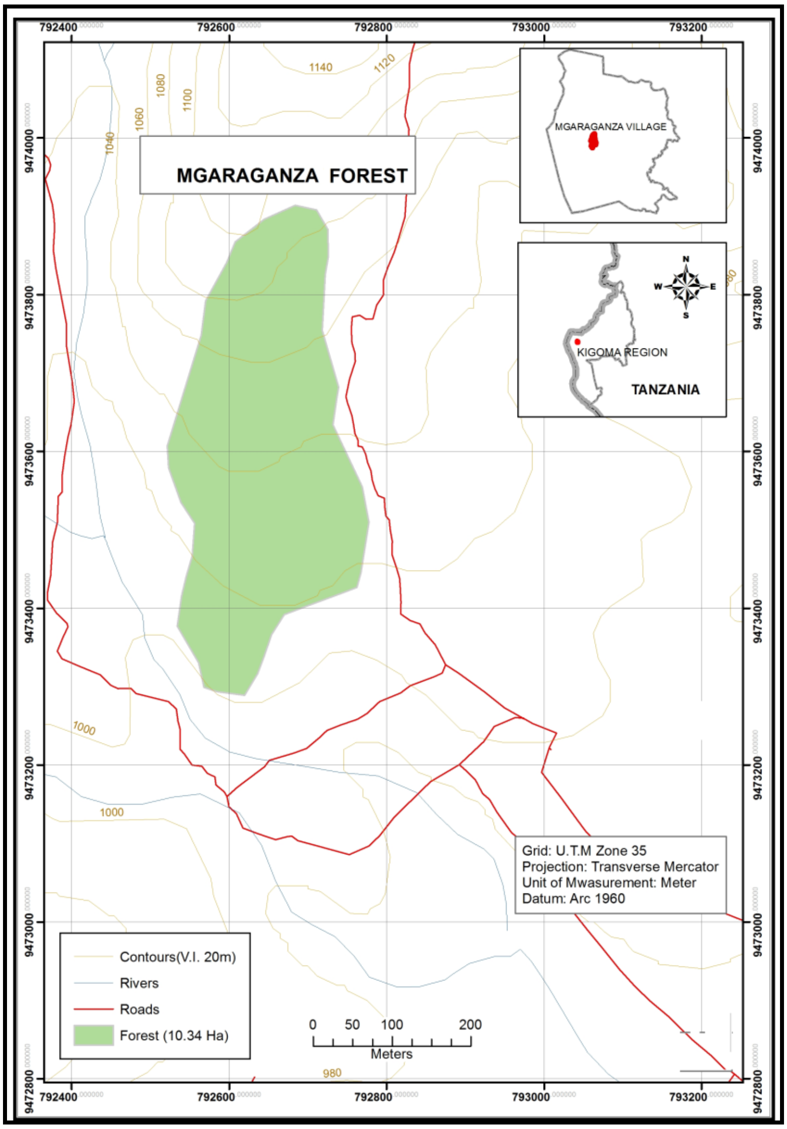

Figure 2: *Location of Mgaraganza Forest*

2.3. Capturing of Remote Information by Satellite

In the present study, Landsat was used in estimating above-ground biomass hence carbon stock. Landsat data is available at a finer scale of 25 m but does not have high temporal resolution. The decision to use Landsat TM image in the present study follows the recommendations put forward by Lu (2005) as the best method of studying succession forests like Miombo woodlands.

A 30 m resolution Landsat TM image acquired on May 31, 2012 was geometrically rectified using control points taken from topographic maps at UTM South 36 zone. Image processing and classification were carried out using Erdas Imagine 8.3.1 (GIS software) (www.intergraph.com) and Arc View GIS 3.2.

The procedure of image processing was done in the Geographical Information System (GIS) laboratory of the Institute of Resource Assessment of the University of Dar es Salaam.

2.4. Satellite Image Processing for Evaluation of Biomass and Carbon

Interpretation of the satellite image was done using the procedures outlined by Lillesand (2000). The procedures start by sub-setting the images (selecting and extracting the study area from the full scene images), georeferencing the images to the UTM map coordinate system, colour compositing and supervised classification which facilitated in computation of NDVI values for the pixels in the two forests.

The procedures outlined by Gamon et al. (1995) were then used to estimate the above-ground biomass hence carbon stock which was remotely sensed by Landsat TM. First, the relationship between the NDVI values and the above-ground biomass collected in the field was established. This relationship was expressed as a linear equation using NDVI values as independent variable (Figure 3). Then, the satellite remotely sensed above-ground biomass was computed for the NDVI values using the established equations.

The values of above-ground carbon stock which was estimated by ground-truthing and the remotely sensed values were then visually compared.

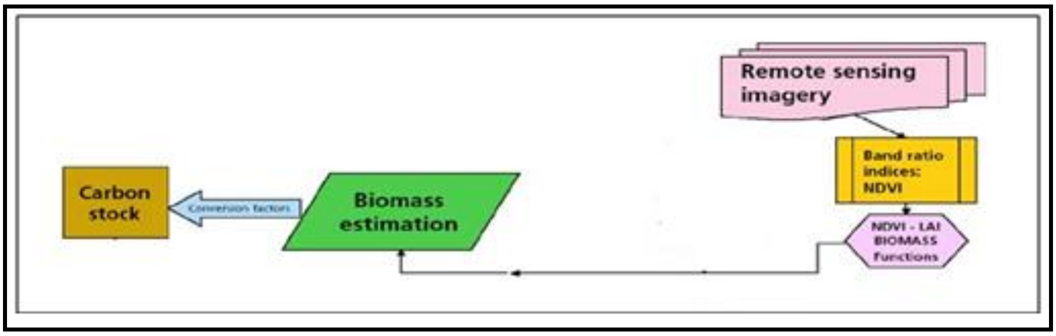

Figure 3: *A Scheme for Estimation of Above-Groud Biomass*
Source: Modified from Ponce-Hernandez et al. (2004)

3. Results

NDVI values for the pixels were computed from the Landsat imagery, and then mapped as shown in Figures 4 and 5.

The high NDVI appeared dark-green in colour signifying high chlorophyll-containing biomass, while medium NDVI values appeared as light green and yellowish depicting low and the lowest chlorophyll-containing biomass respectively. The negative NDVI values were observed in areas that appeared purple and light purple to indicate bare soils, rocks, clouds and valleys that had no plant biomass.

The relationship between NDVI values and the ground-truthing above-ground biomass data of the two Miombo woodlands studied is presented in Table 1. The coefficients of determination between the ground-truthing above-ground biomass and the NDVI values were statistically significant at $P < 0.05$.

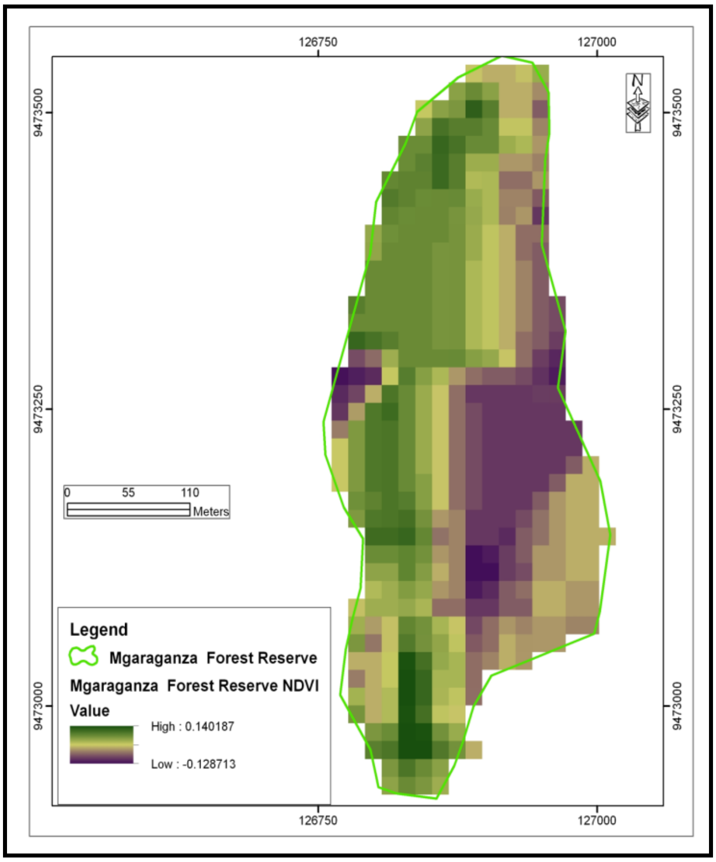

Figure 4: *Computed NDVI for Above-Ground Biomass in Mgaraganza Forest*

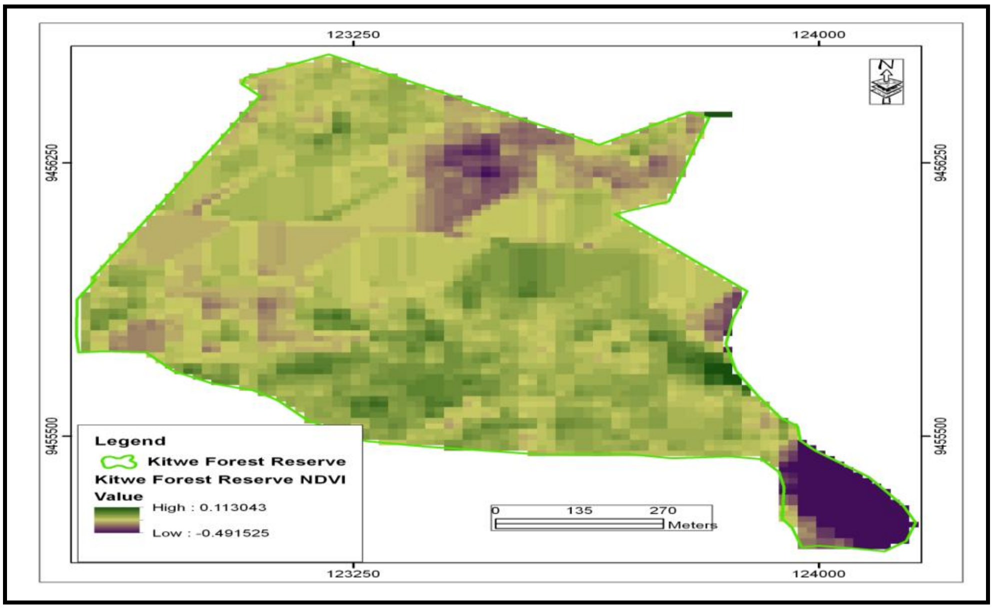

Figure 5: *Computed NDVI for Above-Ground Biomass in Kitwe Forest*

Table 1: *Ground-Truthing and Satellite Remotely Sensed Above-Ground Biomass and Carbon in the Study Area*

Forest	G/truthing Average DBH (cm)	High NDVI	G/truthing Biomass values – NDVI values regression relations			Equation	Remotely sensed above-ground biomass (t ha⁻)	Remotely sensed above-ground carbon (t ha⁻)	G/truthing above-ground biomass (t ha⁻)	G/truthing above-ground carbon (t ha⁻)
			R^2	P	F					
Mgaraganza	10	0.140187	0.22	0.01	7.32	Y = 37 – 183.57 NDVI	5.30	2.65	16.63	8.32
Kitwe	12	0.113043	0.23	0.02	5.97	Y = 36.4 – 213.3 NDVI	12.30	6.15	23.39	11.69

Also, Table 1 shows that in Kitwe forest the remotely sensed and ground-truthing biomass and hence carbon stock was high compared to that of Mgaraganza forest. By visual comparison, the above-ground carbon stock obtained by ground-truthing in Mgaraganza and Kitwe forests was 3 and 2 times higher than that of satellite remotely sensed data respectively.

4. Discussion

The ground-truthing data from this study and the remotely sensed above-ground carbon stock were different, in that the ground-truthing above-ground carbon was higher than that of remotely sensed data. This could be explained by the low NDVI values that were computed from the satellite images. Although Kitwe forest is protected from fire, previously both forests were severely disturbed by deforestation and wildfires. Furthermore, since wildfires are common in Miombo woodlands it is likely that the vegetated land in Mgaraganza forest is intermittently burnt but takes the advantage of resprouting after fire incidences. The magnitude of NDVI is related to the level of photosynthetic activity of the vegetation understudy, thus the associated spectral reflectance depends on forest structure, type, age, condition, biomass, leaf area and even photosynthetic rate (Shugart et al., 2010). According to Okin and Roberts (2004), Vegetation Indices sometimes tend to underestimate live biomass due to their sensitivity to non-photosynthetic vegetation (NPV) and to low organic matter content in soils. The effect of NPV is particularly important in Miombo woodlands where tree density is low and disturbance may create several open patches in which NPV such as litter, dry woody material and soils are components of the surface.

In Kitwe and Mgaraganza forests, the ground-truthing carbon stock exceeded the remotely sensed data by 2 and 3 times respectively. This could be explained by the heterogeneity of forest and non-forest classes within 30 m of Landsat data. According to Huete and Liu (1994), potential problems with analysing remotely sensed data in Miombo woodlands is these woodlands are disreputably difficult to classify correctly. This is due high heterogeneity in Miombo vegetation. Besides, Miombo is seasonally deciduous and has a thick grass layer under the canopy. It is very difficult to distinguish tree, twigs and/or leaves from grasses in the wet season when looking at reflectance information.

The similarity between ground-truthing and satellite remotely sensed data in estimating above-ground carbon stock was that Kitwe forest ranked - high in both methods though with different values. This could be caused by active photosynthetic activity and resultant productivity hence increased carbon stock. Sitch et al. (2007) insisted that although remote sensing satellites do not directly measure carbon, they are able to detect certain physical properties such as species composition which can be linked to carbon storage. Lu (2001) suggested that plant species composition, stand structure, associated canopy shadow and vegetation vigour of leaves, branches and bark are important factors affecting vegetation reflectance hence biomass. This aerial approach of estimating biomass showed that the low above-ground carbon stock was obtained in Mgaraganza forest. This could be attributed to the forested valley in the eastern part of the forest (Figure 4), which was sensed as a non-vegetated area, thus assigned negative NDVI value. Foody et al. (2003) insisted that satellite remote sensing procedures optimized to predict biomass at one site may have very poor performance in other sites. This could also be caused by cloud levels and lighting conditions (Schroeder et al., 2006).

Furthermore, the coefficients of determination between the ground-truthing biomass and NDVI values reported in this study were generally low compared to coefficients that have been reported in other studies. Ribeiro et al. (2008) reported low though significant relationship between woody biomass measured in the field and NDVI derived from Landsat ETM+ of 0.3 ($P<0.0001$) in Mozambican Miombo woodlands. Thus, the coefficients of determination between ground-truthing above-ground biomass and the NDVI values that were recorded in the present study are in agreement to those reported by Ribeiro et al. (2008).

5. Conclusion

Extensive ground-based data supplemented by remote sensing method is endlessly vital for developing countries like Tanzania in order to benefit from carbon trading initiative. Accurate estimations of carbon stocks for carbon credit allocation based on deforestation (Mollicone et al., 2007) or carbon stock baselines (Gurney and Raymond, 2008) are very important. On the basis of the results of the present study, the above-ground carbon stock obtained from satellite remote sensing gives some impression thus a basis for remote sensing in Miombo woodlands. This is concluded based on the discrepancy between ground-truthing and satellite remotely sensed data. Also, differences in the estimated Landsat TM above-ground carbon between the studied forests could be caused by errors during ground-truthing, image processing and the spatial variability.

Conversely, the remotely sensed data could not be a suitable method to assess the biomass and hence carbon stock in Miombo woodlands as it underestimates the true biomass on above-ground hence carbon stock. In these areas, the effect of depiction of the soil may be expressed while the low organic matter content in soils renders the soil bright and mineralogically assorted.

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