International Journal of Agriculture, Forestry and Fisheries
2015; 3(6): 222-226
Published online October 23, 2015 (http://www.openscienceonline.com/journal/ijaff)

Estimation of *Acacia senegal* Tree Biomass Using Allometric Equation and Remote Sensing, North Kordofan State, Sudan

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To cite this article

Hatim Mohamed Ahmed Elamin, Hassan Elnour Adam, Mohamed El Nour Taha, Elmar Csaplovics. Estimation of *Acacia senegal* Tree Biomass Using Allometric Equation and Remote Sensing, North Kordofan State, Sudan. *International Journal of Agriculture, Forestry and Fisheries*. Vol. 3, No. 6, 2015, pp. 222-226.

Abstract

The current study was conducted in *Um Habila* Reserved Forest (2.7 square Kilometres) which is located in El Rahad Locality in North Kordofan State, Sudan.It dealt principally with the estimation of woody biomass of *Acacia senegal* trees by applying allometric equations for ground data combined with satellite data sets.Primary data were obtained by the application of random sampling techniques, counting a total of 27 trees. The tree coordinates and diameters were recorded. Remote sensing data were acquired from SPOT-5 (08.11.2009) earth observation satellite and integrated with the in-situ data. The study findings revealed that the mean diameter of *Acacia senegal* tree was 7.31 cm ± 1.68 cm. The tree above ground biomass (TAGB), tree below ground biomass (TBGB) and total tree biomass (TTB) of *Acacia senegal* were found to be 15.15± 9.01 kg, 3.03 ±1.80 kg, and 18.18±10.81 kg, respectively. Remotely sensed data were integrated with the terrestrial method for creating and correlating the relationship between them, resulting in development of the power model based on spectral reflectance (IR) with adjusted R^2 of 0.504. The application of allometric equations is useful as non-destructive method for local biomass estimations and the application of remote sensing is recommended for biomass estimation in wide coverage areas.

Keywords

Tree Biomass, *Acacia senegal*, Tree Coordinates, Remote Sensing, Satellite Data Sets, North Kordofan

1. Introduction

The natural *Acacia senegal* stands constitute one of the most important types of natural forests in Sudan, which occur in the gum arabic belt that lies within the low-rainfall savannah zone between latitudes 10°–14°N (Sahni, 1968; Vogt, 1995). The belt is considered as an important area because it accommodates around one fifth of the inhabitants of the Sudan and two thirds of its livestock population. Moreover, the belt acts as a natural barrier to protect more than 50% of the total area of Sudan from desert encroachment (Ballal, 2002). The growing number of climate change agreements and action plans at scales ranging from local to international have led to a greater need for information on forest carbon stocks now and in the future. Developing carbon estimates from inventory data for multiple forest stands or entire forests is generally an unwieldy process. As forest carbon markets and greenhouse gas policies continue to develop, the question of how do forest management practices affect positively or negatively carbon storage becomes increasingly important and needs an answer. Accounting for carbon in harvested wood presents an additional challenge when addressing questions related to management options and carbon storage. Because of the urgent and ever-increasing demand for forest carbon information, a tool is needed to calculate forest carbon stocks at smaller scales and to estimate forest management impacts on carbon (Hoover *et al.*, 2011). As stated by Parresol (1999) and Zheng *et al.* (2004), the biomass assessment has many purposes. Besides it serves for resource use and environmental management, the biomass assessment is also important to determine how much fuel wood or timber is available for use. Thus, the need arises to know how much biomass is available at specific point in a given time. In environmental management, biomass quantification is of paramount importance to assess both the productivity and sustainability of the forest. As well, the biomass is a key indicator in carbon sequestration. For this purpose, there is an urgent need to know how much biomass is lost or accumulated over time. Consequently, the amount of carbon sequestered can be inferred from the biomass change since 50% of the forest dry biomass is carbon (Losi *et al.*, 2003). The Kyoto Protocol requires transparent reporting of forest removal and accumulation (biomass change). This implies the use of precise procedures to quantify forest biomass and its uncertainty.

Remote sensing offers suitable methods that can be applied for land use inventory (Köhl *et al.*, 2006). Meanwhile, the application of GIS technology in forest management and other fields of natural resource management has increased over time. This technology has allowed management and integration of an important quantity of spatial and temporal information (Franklin, 2001; Longley *et al.*, 2007).

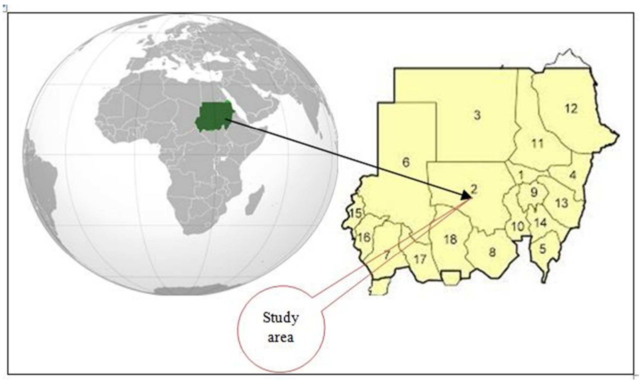
The conventional method of biomass assessment relies heavily on field measurements, therefore it is time consuming, labour intensive, and difficult to implement in remote areas (De Gier, 2003; Lu, 2006). In case of small scale studies, the conventional approach seems sufficient; nevertheless, the more challenging issue of carbon sequestration requires area of wider spatial scale. The use of remote sensing technique is the most practical and cost effective alternative to acquiring data over larger areas. Furthermore, it provides spatial information crucial to characterize the spatial distribution of biomass density. As well, remote sensing technology offers synoptic view and periodic measurement of the area of interest. Also remote sensing technique has been used extensively for vegetation mapping and monitoring, in addition to investigating land cover change and landscape patterns (Kasischke *et al.*, 1997).

Therefore, the importance of forest species biomass for different purposes and the availability of suitable earth observation data support the implementation of this study. The current paper concerned primarily with the application of allometric equation combined with remote sensing data for assessing above-ground biomass of *Acacia senegal* trees and also to determine the accumulation of the biomass, in addition to development of regression models for tree biomass estimation based on remote sensing indicators for wide area coverage.

2. Materials and Methods

2.1. The Study Area Description

The study was conducted in *Um Habila* Natural Reserved Forest in El Rahad Locality, North Kordofan State, Sudan (Figure 1). The forest is located within the following coordinates: north east corner (12°47.40'N and 30°37.49'E), south east corner (12°46.02'N and 30°37.94' E), south west corner (12°45.89'N and 30°37.19'E) and north west corner (12°47.27'N and 30°37.13' E). It covers an area of 2.7 square kilometres. The environment of the *Acacia senegal* tree stands is characterised by mean rainfall amount ranging from 200 mm to 500 mm per annum in Summer, the maximum mean temperature between 30°-40°C, the minimum mean temperature between 16°–28°C and the annual mean temperature between 22°-32°C (Webb *et al.*, 1984).



Source: https://en.wikipedia.org/wiki/North_Kurdufan (accessed on 12.09.2015)

Fig. (1). *Location of study area.*

2.2. Field Data Collection

An explorative survey in the targeted forest was conducted for the purpose of collecting basic information concerning the forest. Then after a detailed survey (inventory) was carried out in July 2012. Primary data were obtained by application of random sampling. The tree coordinates and tree diameters were recorded. For multi-stem trees, the quadratic mean diameter (QMD) was calculated for the tree using the following equation:

$$QMD = \sqrt{(\pi * BA)/(4 * N)} \quad (1)$$

Where:

QMD = Quadratic Mean Diameter

BA = Total basal area = $ba_1 + ba_2 + \ldots\ldots ba_N$

N = Number of stems.

Remotely sensed data were acquired from SPOT-5 (08.11.2009) satellite and integrated with the in-situ data. Moreover, the satellite image was geometrically and radiometrically corrected. Then the coordinates of the ground sample points were projected onto the image and the spectral reflectance values (DN) of the related pixels were recorded.

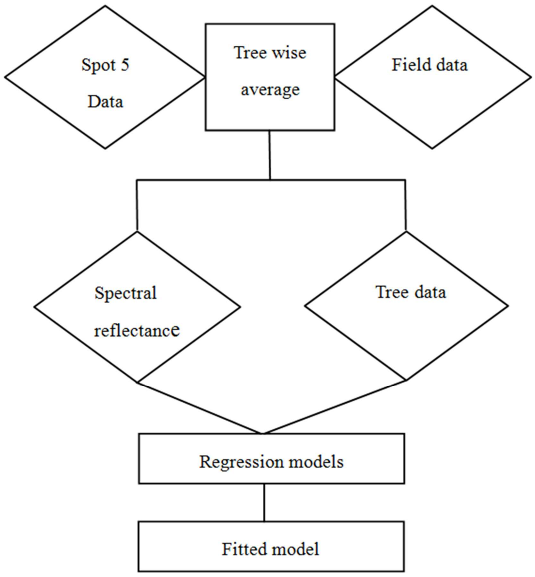


Fig. (2). *Chart illustrating the research methodology.*

2.3. Biomass Calculations

Many allometric equations (Brown *et al.*, 1989; Brown, 1997; FAO, 1997; Nelson *et al*., 1999; Murali and Bhat, 2005) for biomass calculations were reviewed and those developed by Brown (1997) were applied (equation (2).

$$Y = 0.139 * DBH^{2.32} \tag{2}$$

Where:
Y= Biomass (Kg)
DBH= Diameter at Breast Height (cm)

Equation (2) fits to calculating the biomass of *Acacia senegal* trees based on field inventory data obtained from the forest, because it relies on the conditions that the species group is general, rainfall is ranging from dry to less than 1500 mm and the diameter ranges between 5 cm up to 40 cm. The independent variable of the equation is the diameter at breast height (DBH).

With regard to the below ground biomass (BGB), 0.2 of the above ground biomass (AGB) was taken to estimate the below ground biomass (MacDicken, 1997). The carbon pool is estimated as 50% of dry biomass (Losi*et al.,* 2003).

Besides the application of allometric equation, ERDAS software (version 9.1) was used for satellite image processing and interpretation based on the spectral reflectance of the trees. The digital numbers (DN) were extracted and integrated with the calculated biomass of *Acacia senegal* trees using allometric equation. Data were analyzed using both SPSS and excel programs. Figure (2) is a graphical illustration of developing fitting equations using regression models (Inverse, Cubic, Quadratic, Power, Logarithmic, Linear, Exponential, Compound and Logistic), based on both ground and remotely sensed data.

3. Results and Discussion

The study findings presented in Table (1) revealed that the average diameter of *Acacia senegal* tree is 7.31 cm ± 1.678614, minimum and maximum diameters were 5.20 and 11.51 cm, respectively. The average AGB, BGB and TB in kg were estimated in respective order as 15.15 ± 9.01, 3.03 ± 1.80 and 18.18 ± 10.81. The minimum AGB, BGB and TB were found to be 6.38 kg, 1.28 kg and 7.66 kg, respectively. As well, the maximum AGB (40.26 kg), BGB (8.05 kg) and TB (48.32 kg) were determined.

Table (1). *Average above, below and total Acacia senegal biomass from field survey calculations.*

Item	QMD (cm)	AGB (Kg)	BGB (Kg)	TB (Kg)
Average	7.31	15.15	3.03	18.18
STDEV	1.68	9.01	1.80	10.81
Min.	5.20	6.38	1.28	7.66
Max.	11.51	40.26	8.05	48.32

The integration of both remotely sensed data (spectral reflectance represented by n-IR values) and the biomass data based on the allometric equation (terrestrial method) resulted in the development of a variety of biomass models presented in the appendix attached.

Among these models, the power model proved as the best fitting regression model for estimation of *Acacia senegal* tree biomass (adjusted R^2=0.504) and it showed the minimal standard error of the estimates (0.177); both the formula and graphic illustration are shown in equation (3) and Figure (3).

$$Y = a * x^{a1} \tag{3}$$

Where:
Y= biomass
X= spectral reflectance
a and a_1= constants (34.01 and 0.373, respectively)

The model variables are the biomass, which stands for the dependent variable and the spectral reflectance represented by infrared (IR); it stands for the independent variable. According to this model, and whenever the biomass of *Acacia senegal* tree is needed to determine, there is no need to go to the field and measure directly the tree. Just getting the spectral reflectance of the area is quite sufficient, and then it will be applied to the model to estimate the tree biomass. For that reason, it is possible to conclude that such a model could be used to map the biomass of *Acacia senegal* trees, particularly in case of large and inaccessible areas.

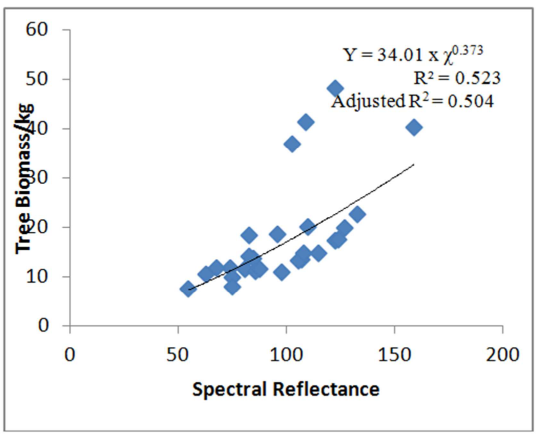


Fig. (3). *Power regression curve for estimation of Acacia senegal biomass.*

4. Conclusions

The power model with adjusted R^2 of 0.504 was verified to be best fitting regression model that could be applied for estimation of *Acacia senegal* tree biomass, as it showed the minimal standard error of the estimates.

Such a model has to be considered by the Forests National Corporation (FNC) and relevant institutions for assessment of the environmental characteristics of the tree. Subsequently, the FNC can formulate and design carbon market projects based on active participation of local communities, for whom the tree is very important due to its inevitable function of gum production (non-timber forest product) and many other recognizable indirect benefits. Moreover, as there are many factories in the area, particularly the petroleum refinery factory nearby Elobeid town; the capital of North Kordofan State, trees are very important for carbon sequestration in the area and thus contribute to preservation of sound global climate conditions.

Acknowledgements

We would like to acknowledge with great appreciation the American Association of Geographers (AAG) for providing training in GIS and remote sensing as well as ERDAS and ArcGIS software. Our special thanks go to the Institute of Photogrammetry and Remote Sensing, Technical University of Dresden, Germany, for supervision and training in remote sensing.

Appendix

Models developed for Acacia senegal biomass estimation using ground and satellite data.

Equation name	Equation structure	R^2	Adjusted R^2	Standard error of the estimate
Inverse	$Y= a + a_1/x$	0.593	0.577	15.774
Cubic	$Y=a + a_1x + a_2x^2 + a_3x^3$	0.612	0.562	15.059
Quadratic	$Y=a + a_1x + a_2x^2$	0.589	0.555	16.185
Power model	$Y=a * x^{a1}$	0.523	0.504	0.177
Logarithmic model	$Y=a + a_1\log(x)$	0.529	0.510	16.976
Linear model	$Y=a + a_1x$	0.407	0.383	19.056
Exponential model	$Y=a * e^{a1x}$	0.384	0.360	0.201
Compound	$Y=a * a_1^x$	0.384	0.360	0.201
Logistic	$Y= 1/(a * a_1^x)$	0.384	0.360	0.201

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