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Research Article

Modeling Forest Stand Volume and Live Aboveground Woody Biomass Using Landsat 5 Tm Satellite Imagery Spectral and Textural Features

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ABSTRACT

Even though, field-based forest surveying provides highly accurate measurements, it has limitations with regard to incurring high cost, being time consuming and having low spatial coverage and frequency. Taking this challenge into account, this study presents the utility of Landsat 5 TM satellite imagery spectral and textural features for the estimation of forest stand level stem volume and live Aboveground Woody Biomass (AGB) for Eucalyptus globulus plantation forest. The research was conducted to improve accuracy and decrease uncertainties in the modern approach in general, and replace the classical approach in the study site in particular by developing a function that estimate both attributes (dependent variables) as a function of spectral and textural features. The modeling of the stem volume and AGB equations as a function of spectral and textural independent variables were developed using ordinary least square regression method. Based on Pearson correlation statistics test result among dependents and independents variables, Tasseled Cap brightness, GLCM Dissimilarity and GLC Variance were found as best explanatory variables for stem volume estimation. It was also found that Landsat 5 TM Band 5, GLCM Dissimilarity and GLCM Variance were found as best explanatory variables for AGB estimation. The modern approach estimated almost similar mean stem volume and aboveground biomass abundance with field measurement data. The overall findings presented in this study are encouraging and show that Landsat 5 TM imagery was successful in predicting both attributes with reasonable accuracy (Adjusted R2 is 0.50 and 0.51 for stem volume and AGB, respectively). Mean residual is 0 for both stem volume and AGB. Further research is recommended to document the performance of the Landsat 5 TM satellite data under different environmental conditions and topographical changes, as well as for other species.

Keywords: Aboveground biomass; GIS; OLS; Remote Sensing; Stem volume

INTRODUCTION

In the current dynamic environmental change, reliable, up to date, and synoptic spatial information regarding the status, trends, and structural characteristics of natural resources, like forests are required to ensure the implementation of sustainable natural resource management practices. To underatand the impacts of the changes, remote sensing and Geographic Information Systems (GIS) play a great role.

Remote sensing technology recently becomes more popular as huge areas can be covered with less efforts and time. Since its introduction in the 1960s, GIS also has been providing tools to enable natural resources managers to make informed decisions. For instance, in the case of forest data like forest stand volume and biomass, its database and spatial analysis capability is employed to facilitate the forest management planning processes to update, manipulate, and analyze data. According to Philip (1983), forest stand volume refers to the aggregate sum of the volume of all of the trees per unit area (cubic meters per a given

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area) in a given forest including bark but excluding branches and stumps of each tree.

Biomass density for forest or mass per unit area, in this study, is expressed for analysis purpose in a more specific manner, which is the total amount of aboveground living organic matter in trees, expressed as oven-dry weight per unit area.

Both stem volume and AGB can be estimated using different approaches, such as using field, remote sensing and GIS. Using field observation, it can be done using destructive or non-destructive (indirect) approach. Using destructive methods, the parameters can be estimated by felling and measuring the volume and AGB of each standing tree in a given small sampling unit. In the case of indirect methods, the the parameters can be computed using either site specific or region-based allometric volume and AGB equations.

Allometric equation is a statistically derived expression of the relationship between volume and AGB, and other woody plant or stand variables. These equations are used to estimate volume and AGB from easily measured variables such as DBH stand height and crown closure.

Even though, field-based forest surveying provides highly accurate measurements, it has limitations with regard to incurring high cost, being time consuming and having low spatial coverage and frequency. In addition to this, in some cases, destructive sampling is laborious and negatively affect environment. This makes sustaining the socio-economic and ecological benefits of forests under challenge.

On the other hand, remote sensing and GIS studies have been recommended as cost-effective sources of gathering information and valuable tools for determining forest biophysical attributes. It was also confirmed that using these technologies are more preferable by forest policy makers, managers, silviculturists, and ecologists in order to make sound decisions for a variety of applications. The objective of this research is to presents the utility of Landsat 5 TM satellite imagery spectral and textural features for the estimation of forest stand level stem volume and live Aboveground Woody Biomass (AGB) for Eucalyptus globulus plantation forest.

MATERIALS AND METHODS

Study Area

The study area for this research is Chancho plantation forest, which is found 60 km northwest of Addis Ababa-Ethiopia. Geographically, it is located in latitudes 9°15'43" – 9°16'17" N and longitudes 38°46'57"– 38°47'44" E (Figure 1) with a total area coverage of 3586.

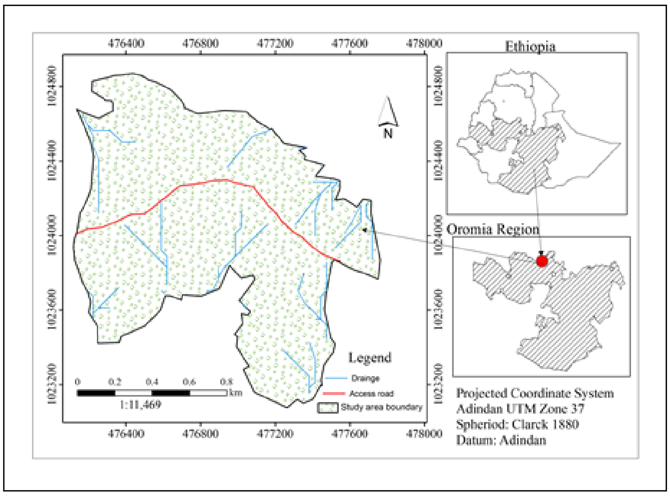

Figure 1: Location map of the study area (Please prepare best inset map)

Data Source

For this research, 37 temporarily different remote sensing products and randomly distributed ground based sample plots data over 168 ha forest stand were used. Landsat 5 TM sensor on board image scene with path 168 and row 054 were used. In order to bring both data to a temporal coincidence and cloud free imagery (image acquisition date of January 10, 2011) of the site,; ground based data (which was collected in January, 2011) were used.. A single topo sheet with number 0938D4, at the scale of 1:50,000 and published in 1973 by the Ethiopian Mapping Agency was also used. The field inventory data and study area boundary were obtained from Oromia Forest and Wildlife Enterprise (a district administration in Ethiopia). The remote sensing data was freely downloaded from the Landsat data archive at the EROSDC.

Field inventory data and sampling design summary

In order to select an appropriate forest stand, discussions were made with district forest and wildlife enterprise officials and experts. The spatial location and extent of each stand, planting dates (age), coppice status, management regimes, and cloud free months attributes were used in the selection procedure of an appropriate forest stand. To check that the 37 plots were laid representing the population of the sapling. The sampling intensity of the inventory was also calculated using equation (1) (Reference here) and was decided to be 0.22% compared to the, acceptable minimum standard 0.1% (Parent, 2000).

$$I(\%) = \frac{Number\ \ of\ \ plots \times Unitary\ \ plot\ area\,(ha) \times 100}{Total\ \ area\,(ha)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$= \frac{37 \times 0.01ha \times 100}{168ha} = 0.22\%$$

The ground based data were collected using tape meter in a circular sample plots which were laid out with a radius of 5.64 m (area = 100 m2). This plot size is recommendable for homogeneous and even aged plantation forest resources assessment. Each plot has a spatial location and data that represents the specific area of the forest.

The coordinates of each sample plot are recorded in the center of each plot using Global Positioning System (GPS) (with accuracy ≤ 10 m). All trees in the plot were measured for DBH.

The DBH values of individual trees in the 37 sampled plots were employed to calculate individual tree stem volume and AGB using equation (2) and equation (3) allometric functions, respectively.

These functions were developed after destructive sampling of 40 sampling of *E. globulus* trees for Addis Ababa-Ethiopia *E. globulus* coppice forest, which is nearby the study area. According to this author, for the stem volume and AGB inventory of the plantation of E.globulus coppice trees, these functions were recommendable (since it is more cost efficient than the function involving other forest attributes).

$$V = b_{0_v} DBH^{b1v} \quad (2)$$

$$AGB = b_0 DBH^{b1} \quad (3)$$

where, V is Single tree stem volume, AGB is Single tree aboveground biomass, b0v is Coefficient (0.0001) for V, b1v is Coefficient (2.603) for V, b0 is Coefficient (0.3478) for AGB, b1 is Coefficient (2.2024) for AGB, and DBH is Diameter at Breast Height of individual trees.

Then plot level stem volume and AGB were calculated as the sum of individual tree stem volume and AGB in each plot. These plot levels were converted to hectare level by using equation (4 and 5) for stem volume and AGB, respectively.

$$V = \frac{\sum^{n}\left(\sum V_{ij}\right)}{na} \quad (4)$$

where:

V = Average stem volume per hectare (m^3/ha) estimated from 37 samples

a = Size of sample plot (100 m^2)

V_{ij} = Volume of an individual standing tree (m^3/tree) measured on the ith plot

n = Number of plots (37)

$$AGB = \frac{\sum^{n}\left(\sum AGB_{ij}\right)}{na} \quad (5)$$

where:

AGB = Average aboveground biomass per hectare in (kg/ha) estimated from 37 samples

AGB_{ij} = Aboveground biomass of an individual standing tree (kg/tree) measured on the ith plot

Finally, both stem volume and AGB were converted from hectare base to stand base by multiplying the average value of each of them by the total area of the forest.

The ground based filed data was collected using projected coordinate system (PCS) in UTM Zone 37, Clark 1880 Spheroid and Adindan Datum (the local datum for Africa/Ethiopia). Therefore, in order to fit the rest of input datasets, all of them were projected to this convenient PCS. Then, image pre-processing like visual examination of the imagery was conducted to assess contamination by in-scene components such as clouds, smoke, haze, line dropouts and striping.

The raw satellite data in each Landsat 5 TM band (except thermal) were converted to reflectance using ENVI software in two-step process. First DN's were converted to radiance values. Then these radiance values were converted to reflectance values. During this process the parameters required as an input for the software were referred form the image metadata file as well as from Landsat 7 handbooks.

Image Post-processing, data extraction and model construction

Table 1 presents univariate descriptive images statistics, which was computed from Landsat 5 TM images of the study area. By integrating the 6 individual bands, a total of 17 images were generated and used as independent variables during model development processes. These images were: Simple Ratio Index (TM4/TM3), Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Three bands of principal component analysis (PCA) (i.e. Principal Component1 (PC1), Principal Component2 (PC2) and Principal Component3 (PC3)), Three Tasseled Caps (TC) bands, i.e. brightness (TC1), greenness (TC2) and wetness (TC3), and Eight texture features based on the Grey Level Co-Occurrence Matrix (GLCM) from TM4: GLCM Mean, GLCM Variance, GLCM Homogeneity, GLCM Contrast, GLCM Dissimilarity, GLCM Entropy, GLCM Second moment, and GLCM Correlation.

In this analysis, prior to the computation of the texture features, a variance from each Landsat 5 TM were calculated and it was found TM4 representing the highest variance of the forest stand (Table 1). This band was ultimately selected for the texture features generation using a 5 × 5 moving window. The 5 5 window sizes were chosen to cover a range of sizes corresponding roughly to the space between the homogenous patches of trees in the plantation forest. The texture layers were calculated in each direction with single shifting pixel and were quantified into a 64 gray levels.

After these data sets were processed, the outputs were exported to ArcGIS software. Then, the 37 sampled plots were overlaid on each dataset and their corresponding values were extracted using Extracted value by point's tools. Once extraction process from these 22 independent variables completed, they were exported to SPSS software in order to identify how they are related to each other as well as with dependent variables (Table 2).

Using Pearson's product moment correlation coefficients results, those statically significant independent variables were exported to ArcGIS software to develop a model using Ordinary Least Square regression (OLS) method. Through iterative process, the stem volume and AGB equations as a function of spectral and textural variables were developed. Using these equations and Raster Calculator (Spatial Analyst tool) in ArcGIS software, the stem volume and AGB biomass at stand level were calculated. The model performance assessment and validation were carried out based Ordinary Least Square regression null hypothesis assumptions.

Table 1: Spectral reflectance of the study area (%).

Band name		Minimum	Maximum	Mean	Standard deviation
Visible	Band 1	0	7.7	3	2.7
	Band 2	0	16.4	4.9	4.5
	Band 3	0	13.7	3.2	3.1
Reflective infrared	Band 4	0	23	8.8	8.1
	Band 5	0	1.2	3	3
	Band 7	0	0	0	0

RESULTS AND DISCUSSIONS

In this research, the mean stem volume and AGB were found to be 49.13 m^3/ha and 48.81 ton/ha, respectively. The total stem volume and AGB over the study area were estimated at 8,253.36 m^3/ha and 8,200 ton/ha, respectively. For stem volume, the minimum and maximum values were estimated at 0.01 m^3/ha and 61.29 m^3/ha while for AGB the minimum and maximum values were estimated to be 47.11 ton/ha and 147.86 ton/ha, respectively.

From the allometric equations the mean stem volume and AGB were found to be 48.73 m^3/ha and 48.25 ton/ha, respectively. The total stem volume and AGB over the study area were found to be 8,186.9 m^3/ha and 8,106.7 ton/ha, respectively. For stem volume, the minimum and maximum values were found to be 7.10 m^3/ha and 128.6 m^3/ha, respectively, while for AGB, the minimum and maximum values were 6.41 ton/ha and 132.43 ton/ha, respectively. These results showed that the results from the newly developed model in both stem volume and AGB based on mean values are not considerably different. There were some difference in the minimum, maximum, and range values.

Since there are no researches on the modern approach in the above mentioned areas, it was difficult to substantiate the outcomes of the modern approach. There were also no past researches in using Landsat 5 TM spectral and textural features, OLS method and for *E.globulus*, it was also difficult to substantiate the outcomes of the present study with similar finding in different place. Past researches also concluded that promising results can be obtained in plantation forests consisting of pure stands dominated by one tree species.

Analysis of Pearson correlation test result showed that some of the values were found negatively correlated and others were found positively correlated with stem volume and AGB (Table 2). Although, some have significant relationships, they were not considered in the model since they showed multicollinearity effect with Variance Inflation Factor value more than 7.5 value.

Relatively low correlation coefficients were observed for both stem volume and AGB with their corresponding independent variables with the correlation (R2) values less than 0.355 and 0.348 in absolute value term, respectively. Despite the poor correlation, general evidence was observed on TM5 from Landsat 5 TM bands, TC1 from Tasseled Caps Transformation and GLCM Dissimilarity from texture features which performed better than other independent variables in terms of absolute value correlations when related to stem volume. Whereas TM5 from Landsat 5 TM bands, TC2 from Tasseled Caps Transformation and GLCM Dissimilarity from texture features which performed better than other independent variables in terms of absolute value correlations when related to stem volume plantation attributes.

Table 2: Correlations between Remote Sensing data stem volume and AGB.

Parameters	Stem volume	Parameters	AGB
stem volume	1	AGB	1
TM1	-0.575**	TM1	-0.577**
TM2	-0.626**	TM2	-0.629**
TM3	-0.631**	TM3	-0.633**
TM4	-0.633**	TM4	-0.645**
TM5	-0.636**	TM5	-0.646**

NDVI	0.56**	NDVI	0.57**
TM4/TM3	0.250	TM4/TM3	0.241
PC1	0.672**	PC1	0.679**
PC2	0.355*	PC2	0.348*
PC3	-0.305	PC3	-0.319
TC1	-0.674**	TC1	-0.544**
TC2	-0.530**	TC2	-0.681**
TC3	-0.672**	TC3	-0.678**
EVI	0.308	EVI	0.323
GLCM Variance	-0.590**	GLCM Variance	-0.603**
GLCM Mean	-0.152	GLCM Mean	-0.144
GLCM Homogeneity	0.034	GLCM Homogeneity	0.042
GLCM Contrast	-0.123	GLCM Contrast	-0.117
GLCM Dissimilarity	0.720**	GLCM Dissimilarity	0.728**
GLCM Entropy	-0.077	GLCM Entropy	-0.067
GCLM Second moment	0.039	GCLM Second moment	0.027
GCLM Correlation	0.282	GCLM Correlation	0.271

**Correlation is significant at $p<0.01$ level (2-tailed).

*Correlation is significant at $p<0.05$ level (2-tailed).

Model Performance Assessment and Validation

The model performance assessment and validation were carried out through testing (accepting or rejecting) the Ordinary Least Square regression null hypothesis assumptions under different test statistics. This is based on a 95% confidence level and critical Probability (p) value = 0.05 set for this study.

The Student's "t" test was used to assess whether or not an independent variable is statistically significant (Table 3,4). In both models, each independent variable was assessed based on its Coefficient sign, Probability or Robust Probability, and Variance Inflation Factor (VIF). The Ordinary Least Square regression result showed that, for both models, all independent coefficients are different from zero, hence statistically significant at a Robust p-values smaller than 0.05. The null hypothesis for this test is that the coefficients for all intents and purposes, equal to zero (and consequently is not helping the model). Therefore, the null hypothesis is rejected and the results of both models are accepted.

Table 3: Coefficient table for stem volume model.

Variable	Coefficient	SE	t-value	p-value	Robust SE	Robust t-value	Robust p-value	VIF
Intercept	14.294	1.770	8.076	0.000	1.560	9.163	0.000*	
GLCM Dissimilarity	0.826	0.418	1.974	0.057	0.347	2.378	0.023*	3.43
GLCM Variance	-0.093	0.037	-2.524	0.017*	0.030	-3.092	0.004*	3.45
TC1	-73.852	12.086	-6.111	0.000*	10.745	-6.873	0.000*	1.06

Table 4: Coefficient table for AGB model.

Variable	Coefficient	SE	t-value	p-value	Robust SE	Robust t- value	Robust p- value	VIF
Intercept	14962	1869	8.0	0.00*	1616	9.3	0.00*	
TM5	-78988	12759	-6.2	0.00*	11280	-7.0	0.00*	3.43
GLCM Variance	-97	39	-2.5	0.02*	33	-2.9	0.01*	3.45
GLCM Dissimilarity	860	442	1.9	0.06	378	2.3	0.03*	1.06

*Coefficient is significant at $p< 0.05$ level (2-tailed).

With regard to the signs associated with the coefficients of independent variables for both models, all of them were found the same sign as their correlation coefficient values with dependent variables. Therefore, all independent variables associated with a statistically significant coefficient were found important to both regression models.

In order check model biasness due to redundancy (multicollinearity) effect among independent variables, the results were tested based on their Variance Inflation Factors value, with values less than 7.5 accepted. For TC1, GLCM Dissimilarity and GLCM Variance the VIFs were found 1.06, 3.43 and 3.45, respectively for stem volume model. Similarly, the VIFs for TM5, GLCM Dissimilarity and GLCM Variance were also found 3.43, 1.06 and 3.45, respectively for AGB model. Since these values area less than 7.5, they are not redundant independent variables in the models and do not bring biasness on the model.

The Koenker (BP) Statistic (Koenker's studentized Bruesch-Pagan statistic) is a test to determine if the independent variables in the model have a consistent relationship to the dependent variable both in geographic space and in data space. The null hypothesis for this test is that the model is stationary. For a 95% confidence level, a p-value smaller than 0.05 indicates statistically significant heteroscedasticity and/or non-stationarity. Based on this test, stationarity was assessed and found both models are free from heteroscedasticity effect. The results obtained is not statically significant, p = 0.44 and 0.43 for stem volume and AGB, respectively.

Each model's significance was assessed based on Joint F-Statistic and Joint Wald Statistic which, are measures of the overall model significance. The null hypothesis for this test is that the independent variables in the model are not effective. For a 95% confidence level, a p-value smaller than 0.05 indicates statistical significance. Thus, for both models, the p-values were found smaller than 0.05. Therefore, the models are statistically significant and hence accepted.

In order to check whether or not a key variable is missing from the model a **Spatial Autocorrelation (Moran's I)** test was run on the regression residuals (Table 5,6). The result indicated that for both models the residuals are randomly distributed and not statistically significant since p = 0.95 and 0.91 for stem volume and AGB, respectively. Statistically significant clustering of high and/or low residuals (model under and over predictions) indicates a key variable is missing from the model. Therefore, the developed models in this study did not miss key variables.

Table 5: Global Moran's I summary for stem volume Model.

Global Moran's I Summary	
Moran's Index:	-0.022049
Expected Index:	-0.027778
Variance:	0.007403
Z Score:	0.066588
p-value:	0.946910

Table 6: Global Moran's I summary for AGB Model.

Global Moran's I Summary	
Moran's Index:	-0.017964
Expected Index:	-0.027778

Variance:	0.007397
Z Score:	0.114100
p-value:	0.909159

The overall model performance was assessed based on Adjusted R-Squared values. Possible values range from 0 to 1 (0 to 100 percent), with 0 denoting that model does not explain any variation and 1 denoting that it perfectly explains the observed variation. The models' adjusted R-Squared values were found to be 0.50 for stem volume model and 0.51 for AGB model. These would indicate the independent variables modeled for stem volume model explains 50% of the variation in the dependent variable, whereas, the independent variables modeled for AGB model explains 51% of the variation in the dependent variable. Both values are found to be in an acceptable range of performance level.

The reason why these values were not found perfect or near to perfect could be explained as the field plots have small plot area size as compared to the Landsat 5 TM pixel size (1/9 of Landsat 5 TM pixel size). Although results could be constructed using 100 m2 sample plots, it is still encouraging that up to 50% and 51% of stem volume and AGB variation, respectively, could be explained by spectral and textural data.

Finally, the models prediction accuracy was tested based on their residuals mean values, which are the observed values (yi) minus the estimated (ji) values. It is also statistically tested based on the Jarque-Bera statistic, which indicates whether or not the residual are normally distributed with mean zero value and constant variance. The null hypothesis for this test is that the residuals are normally distributed. When the p-value for this test is smaller than 0.05 for a 95% confidence level, the residuals are not normally distributed, indicating that results from Ordinary Least Square regression model are not trustworthy. The Jarque-Bera statistic result of this study) indicates that there is no statistically significant, p=0.12 and 0.10, for stem volume and AGB, respectively. Therefore, the result in this study is accepted.

CONCLUSION AND RECOMMENDATIONS

Landsat 5 TM has significant potential to estimate the stem volume and aboveground biomass with acceptable accuracy (Adjusted R2 is 0.50 and 0.51 for stem volume and AGB, respectively; mean residual is 0 for both stem volume and AGB). The results from the new developed model in both stem volume and AGB based on mean values are not considerably different from the species specific allometric equation.

The application of the developed stem volume and aboveground biomass function area wide for the enterprise and other concerned bodies. The classical approach can be replaced by the developed model and applied for sustainable forest management planning in the study area for the same species, as well as for other research purposes. The inclusion of GLCM features improved to estimate forest structural attributes from optical Landsat 5 TM data.

For further studies in estimating stem volume and aboveground biomass using this similar approach, it is recommended to use larger field data sample plot size (up to 900 m2), in order to increase the overall performance of the models, across other coppice rotations and seedling trees of the same species. To increase the credibility and gain sufficient confidence about the models, and to ensure that model predictions represent the most likely outcome of the reality, in addition to the statistical test, the model validation should be supported with extra field data collected from the study site other than the data used for model construction. Further research is recommended to document the performance of the Landsat 5 TM satellite data under different environmental conditions and topographical changes, as well as for other species.

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