Prediction of Some Stand Parameters using Pan-Sharpened IKONOS Satellite Image

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Abstract
The objective of this study is to evaluate the relationships between stand parameters (stand volume, basal area and dominant height), and band reflectance values and six vegetation indices (VIs) obtained from pan-sharpened, IKONOS satellite image in Artvin-Genya Mountain located in northeastern part of Turkey. Multiple stepwise regression analysis is used to estimate the stand parameters. The results indicated that a linear combination of EVI and DVI for stand volume and basal area (adjusted $R^2=0.55$; a root mean square error (RMSE)=153.53 m$^3$ ha$^{-1}$ and adjusted $R^2=0.59$; RMSE=12.37 m$^2$ ha$^{-1}$), respectively, and a linear combination of SAVI, EVI and DVI for dominant height (adjusted $R^2=0.57$; RMSE=3.80 m) were better predictors than a linear combination of IKONOS Band 1 and Band 4 for stand volume and basal area, and the IKONOS Band 1 and Band 2 for dominant height ($R^2=0.41$; RMSE=181.01 m$^3$ ha$^{-1}$, $R^2=0.43$; RMSE=14.84 m$^2$ ha$^{-1}$ and $R^2=0.45$; RMSE=4.62 m), respectively. This study concludes that the regression models developed with IKONOS VIs were able to predict stand parameters better than do the IKONOS band reflectance values in Artvin-Genya Mountain forest areas.

Keywords: Artvin, stand parameters, pan-sharpened IKONOS satellite image.

Introduction
The forest management planning process in Turkey is carried out with 10 or 20-year cycles. The planning phase starts with a field inventory that is essential for all levels of forest management planning [Baskent et al., 2005]. Stand parameters such as stand volume, basal area, tree density and quadratic mean diameter are required for effective and successive resource management [Zimble et al., 2003; Chubey et al., 2006]. Traditionally, these structural parameters of stands are commonly obtained through national forest inventories from sample plots specifically distributed over a forest based on a certain sampling design. Although this technique offers highly accuracy measurements of stand attributes, it is very expensive and consuming [Trotter et al., 1997].
Over the last decades, remote sensing has played a significant role in forestry management, especially as a tool for obtaining information about the structure of forest resources in inventories of large forested areas [Leckie and Gillis, 1995; Chiavetta et al., 2008]. Recent developments in remote sensing tools such as the availability of higher resolution satellite data, provides an opportunity to obtain the required information at lower costs and in a reasonably short time [Peuhkurinen et al., 2008]. Such new developments in information technologies have open new areas of opportunities in gathering large volume of forest data with a reasonable cost and time.

Several studies have demonstrated that empirical relationship between the ground and satellite data such as wavelength bands and VIs are needed for the estimation of stand parameters using satellite data. Landsat TM/ETM+ and SPOT satellite data have been used to predict stand parameters. For example, Trotter et al. [1997] modelled timber volume using Landsat imagery in conifer plantation. The model for timber volume was performed with $R^2=0.3$ and $\text{RMSE} > 100 \text{ m}^3 \text{ ha}^{-1}$. The relationship between Landsat satellite data band reflectance values and, tree density and stand age in *Pinus teada* L. in Texas was demonstrated by Sivanpillai et al. [2006]. They developed the models to estimate the stand age and number of trees with $R^2=0.604$, $\text{RMSE}=312.5 \text{ n ha}^{-1}$ and $R^2=0.78$, $\text{RMSE}=2.89$, respectively. Stand volume by Landsat ETM satellite image was determined with $R^2=0.71$ and $\text{RMSE}=74.7 \text{ m}^3 \text{ ha}^{-1}$ in the study of Hall et al. [2006]. Mohammadi et al. [2010] examined that tree density and stand volume by Landsat ETM+ imagery were obtained with $R^2=0.734$, $\text{RMSE}=170.13 \text{ n ha}^{-1}$ and $R^2=0.43$, $\text{RMSE}=97.4$, respectively. Gebreslasie et al. [2010] predicted some stand attributes using Aster satellite data in the plantation areas with $R^2$ and $\text{RMSE}$ values for stand volume, basal area and tree height of $0.81$ and $0.14 \text{ m}^3 \text{ ha}^{-1}$; $0.67$ and $9.2 \text{ m}^2 \text{ ha}^{-1}$; $0.52$ and $2.85 \text{ m}$, respectively. Poulain et al. [2010] examined the relationships between the basal area and Aster satellite image in Nothofagus pumilio forest regions and reported the predicted $R^2$ and $\text{RMSE}$ values of $0.72$ and $8.13 \text{ m}^2 \text{ ha}^{-1}$. In recent years, high resolution satellite images such as IKONOS, Quickbird and WorldView have been used in the estimation of stand attributes. Kayitakire et al. [2006] postulated that estimation of the basal area may be obtained from image texture analysis with IKONOS-2 satellite image. However, he concluded that the basal area was poorly correlated with texture variables ($R^2=0.35$, $\text{RMSE}=6.853 \text{ m}^2 \text{ ha}^{-1}$).

There are some other related studies trying to establish any relations between different satellite images and stand parameters. Leboeuf et al. [2007] examined the relationships between biomass and tree shadow fraction generated from Quickbird imagery in boreal black spruce forest regions in Canada using regressions techniques. Results obtained from this study indicate reasonable accuracy ($R^2=0.84$ and $\text{RMSE}=14.2 \text{ t/ha}$). Özdemir [2008] modeled the association between ground measured stem volume and tree properties with pan-sharpened Quickbird satellite imagery in Crimean juniperus forest areas. The model estimated the stem volume by shadow area with $R^2=0.67$ and $\text{RMSE}=3.5312 \text{ m}^3 \text{ ha}^{-1}$. Mora et al. [2010] analyzed the mean stand height and Quickbird panchromatic satellite data in boreal forest areas in Yukon, Canada using tree regression method. The model for mean stand height explained with $R^2=0.53$ and $\text{RMSE}=2.84 \text{ m}$. Song et al. [2010] demonstrated the relationships between the mean crown size and Quickbird and IKONOS satellite data using linear regression analysis in hardwood forest areas, with a moderate correlation of mean crown size ($R^2=0.60$, $\text{RMSE}=0.82$). Özdemir and Karnieli [2011] investigated the possibility of predicting stand parameters using the image texture obtained from WorldView-2 satellite data in a dry land.
forest and found that the R² and RMSE values were 0.38 and 109.56 n ha⁻¹ for the tree density, 0.54 and 1.79 m² ha⁻¹ for basal area, and 0.42 and 27.18 m³ ha⁻¹ for the stand volume. Gomez et al. [2012] tested the relationship between the quadratic mean diameter, basal area and number of trees, and Quickbird-2 satellite imagery using classification and regression tree analysis. The model accuracies obtained from this study were founded with R²=0.8 and RMSE=0.13 m; R²=0.7 and RMSE=5.79 m² ha⁻¹; R²=0.46 and RMSE=98.86, respectively.

The objective of this study is to evaluate the use of IKONOS satellite data to predict some stand parameters such as stand volume, basal area and dominant height in the northeastern part of the Black Sea Region, Turkey.

Materials and methods

Study area
The study area is located in the northeastern part of Black Sea Region, Turkey. It is bounded by 41°32′00″-41°53′00″ on the east longitudes and 41°32′00″-41°07′30″ on the north latitudes (Fig. 1). The study area covers 5232 ha of area. Elevation ranges from 750 to 2047 m above the sea level. The winters are mild and wet, the summers are relatively cool and dry. Mean annual temperature is about 6.6 °C and the precipitation is nearly 1157 mm. Main soil types are sandy clay loam, clay loam, and sandy loam. Main species are Abies nordmanniana (Stev.) Spach subsp. nordmanniana, Picea orientalis (L.) Link, Fagus orientalis Lipsky, Pinus sylvestris L., Carpinus betulus L., Quercus petraea (Maattuschka) Liebl. subsp. iberica (Steven ex Bieb.) Krassiln., Ostrya carpinifolia Scop. and Pinus pinea L.

Field measurements
In this study, 176 circular ground sample plots (GSPs) (during August 2002) were established with 300 x 300 m intervals and the necessary measurements were taken in each GSP. The sizes of a GSP ranged from 400 m² to 800 m², depending on stand crown closure. The boundaries of each GSP were located using ground control points as well as
a Global Positioning System (GPS) device. The positional RMSE of the GSP data was less than 4 m (determined by Garmin Etrex GPS device). At each GSP, diameter at breast height (DBH) were measured in all trees with a diameter greater than 8 cm at breast height. Stand volume in sample plots was predicted by using local single entry stand tables (Akalp, 1978). In each sample plot, dominant height and age measurements were taken from dominant and co-dominant trees (100 dominant and co-dominant highest trees per hectare; the four highest trees for GSPs of 400 m$^2$, the six highest trees for GSPs of 600 m$^2$ and the eight trees for GSPs of 800 m$^2$) for free-growing oriental spruce trees without any obvious evidence of growth abnormalities or damage. The dominant height of a tree was calculated as average height of these dominant or co-dominant trees, and the ages of the trees were bored with an increment borer at breast height. The basal area (m$^2$ ha$^{-1}$) was calculated with dendrometric formula:

$$G = \frac{10000}{A} x 100 \sum_{i=1}^{n} (d_{1.3})^2 x \frac{\pi}{4}$$  \[1\]

Where $d_{1.3}$ is the tree diameter measured at 1.30 m from the ground, $A$ is the sampling plot area (m$^2$) and $n$ is the number of trees in the sampling plot.

The 176 sample plots were randomly split into two data sets such as model fitting and the validation data using Select Cases Procedure in SPSS (SPSS, 2007). About 80% of total data (141 sample plots) was used to develop the models based on IKONOS satellite data. The remaining 35 sample plots, about 20% of total data as independent data set, were randomly reserved for calibration process of these models and were not used in fitting and developing the models.

**Remote sensing data and processing**

The IKONOS satellite data was acquired on the 10th of September, 2004. The satellite data consisted of four spectral bands with 4m spatial resolution and one panchromatic band with 1m spatial resolution. The pan-sharpened IKONOS satellite image with 1 m resolution was used in this study. The study area was extracted from the satellite image by using subset tools. The IKONOS satellite image was rectified using 32 ground control points, orbital properties of the satellite image sensor and digital elevation model (DEM) depend on the 1/25.000 topographic maps. The root mean square error (RMSE) of the rectified satellite image was 1.44 and 2.05 m for the X and Y coordinates, respectively. Also, the total of the RMSE was found to 2.50 m [Çakır, 2006]. Image processing, rectifying and the other analysis were carried out using ERDAS Imagine 9.1™ [Erdas, 2002].

**Plot-level spectral data extraction from IKONOS image**

The coordinates of sample plots were taken by GPS tool. The GPS tool has average positional error of ±4m. Therefore, it is nearly impossible to locate accuracy each sample plot and test point on the center of 1 m grid of IKONOS pixels. To solve this problem associated with locational and analyze spectral values in field plot, we used a moving window means the spectral reflectance values in surrounding pixels (25 x 25 pixel for 400 m$^2$, 30x30 pixels for 600 m$^2$ and 35x35 pixels for 800 m$^2$) centered on the GPS location of each field plot were extracted from the IKONOS spectral bands. Some VIs were calculated to estimate their potential for the prediction of stand parameters (Tab. 1).
Table 1 - The vegetation indices used in this study.

| Vegetation indices | Equations | Reference |
|--------------------|-----------|-----------|
| NDVI               | (NIR-Red)/(NIR + Red) | Rouse et al. [1973] |
| SR                 | (NIR)/(Red) | Jordan [1969] |
| SAVI               | (NIR-Red)*(1+L)/(NIR+Red+L) | Huete [1988] |
| EVI                | (NIR-Red)/((NIR+(C1*Red)-(C2*Blue))*(1+L)) | Huete et al. [1999] |
| IPVI               | (NIR)/(NIR+Red) | Crippen [1990] |
| DVI                | (NIR)-(Red) | Clevers [1988] |

NDVI, Normalize Difference Vegetation Index; SR, Simple ratio; SAVI, Soil Adjusted Vegetation Index; EVI, Enhanced Vegetation Index; IPVI, Infrared Percentage Vegetation Index; DVI, Difference Vegetation Index; red and green (visible wavelengths); NIR (near infrared wavelengths). Coefficients (C1 = 6.0 and C2 = 7.5) and soil adjustment factor L = 1.0.

Statistical analysis

In this study, multiple stepwise regression analysis was used to model the relationship between three stand parameters (stand volume, basal area and dominant height as dependent variables) and the four rough band values and six VIs on transformed IKONOS satellite bands (as independent variables). The stepwise variable selection technique was used to choose the best predictive variables based on p values equal to or less than 0.05 and the highest adjusted R² values. The multiple stepwise regression analysis was performed using SPSS version 15.0 [SPSS, 2007]. In this study, the models were defined as follow:

\[
SP = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_n X_n + \varepsilon \quad [2]
\]

where \( SP \) is the stand parameters, e.g. stand volume, basal area and dominant height, response variables, \( X_1, X_2, ..., X_n \), are independent variable vectors corresponding to IKONOS satellite data, (i.e. the spectral reflectance values and VIs, and the combination variables, \( \beta_1, ..., \beta_n \) represent model coefficients, and \( \varepsilon \) is the additive bias [Corona et al., 1998; Fontes et al., 2003].

The regression models were evaluated based on some accuracy statistics. The accuracy statistics included the absolute and relative biases and the root mean square error (RMSE and RMSE %). These statistics were calculated for the models as followings: (Eq. 3-6).

\[
bias = \frac{\sum (y_i - \hat{y}_i)}{n} \quad [3]
\]

\[
bias\% = 100 \frac{\sum (y_i - \hat{y}_i) / n}{\sum \hat{y}_i / n} \quad [4]
\]
\[ RMSE = \sqrt{\frac{\sum(y_i - \hat{y}_i)^2}{n-1}} \] [5]

\[ RMSE\% = 100 \frac{\sqrt{\sum(y_i - \hat{y}_i)^2 / (n-1)}}{\sum y_i / n} \] [6]

Where \( n \) is the number of observations, and \( y_i \) and \( \hat{y}_i \) are observed and predicted values of stand parameters by regression models developed for stand volume, basal area and dominant height.

**Validation**

In this study, model validation was performed based on the difference (residual values) between observed and predicted values for validation data set including 35 sample plots as independent data. The student’s t-test, also called paired sample t test, was used to evaluate the null hypothesis at the 95% significance level for mean value of residual equal to zero. If the students’ t tests revealed that the null hypothesis cannot be rejected and mean residuals statistically are not significantly differ from zero the developed models is statistically suitable for estimates of the stand parameters with IKONOS satellite data variables in studied forest stands.

**Results**

**Descriptive statistics of stand volume, basal area and dominant height**

Stand volume, basal area and dominant height ranged from 47.24 m\(^3\) ha\(^{-1}\) to 873.66 m\(^3\) ha\(^{-1}\), 5.34 m\(^2\) ha\(^{-1}\) to 76.46 m\(^2\) ha\(^{-1}\) and 7.26 m to 32.65 m in (Tab. 2), respectively. The mean stand volume was 445.03 m\(^3\) ha\(^{-1}\) (standard deviation=173.29), the mean basal area was 41.98 m\(^2\) ha\(^{-1}\) (standard deviation=14.95) and the mean dominant height was 21.01 m (standard deviation=5.00).

**Table 2 - Descriptive statistics of the model and validation samples for stand volume, basal area and dominant height.**

|                | Stand volume (m\(^3\) ha\(^{-1}\)) | Basal area (m\(^2\) ha\(^{-1}\)) | Dominant height (m) |
|----------------|-----------------------------------|----------------------------------|---------------------|
|                | Model      Validation             | Model      Validation             | Model      Validation |
| N              | 141        35                      | 141        35                      | 141        35                      |
| Mean           | 445.03     446.04                  | 41.98      44.61                   | 21.01      19.83                   |
| SD             | 173.29     167.06                  | 14.95      15.40                   | 5.00       4.23                    |
| Range          | 826.42     668.43                  | 71.12      67.26                   | 25.39      16.82                   |
| Minimum        | 47.24      90.72                   | 5.34       9.71                     | 7.26       12.45                   |
| Maximum        | 873.66     759.15                  | 76.46      76.97                   | 32.65      29.27                   |
**Estimating stand parameters using IKONOS satellite data**

The selected best regression subgroup models, accuracy statistics such as coefficients of determination \(R^2\), the standard error of model (Sy.x), bias, bias\%, RMSE, RMSE\%, Durbin-Watson values, and the error estimate of stand volume, basal area and dominant height are presented in relation to the spectral reflectance values in Table 3 and for VIs in Table 4. In these selected subgroup regression models for stand volume, basal area and dominant height, the F statistics and coefficients were significant at a probability level of 95 percent \((p<0.05)\). The stand volume model with the spectral reflectance values was developed with bands 1, 2, 3 and 4 as independent variables, and this model performance was calculated with adjusted \(R^2=0.41\) and RMSE=181.01 m\(^3\) ha\(^{-1}\). The stand volume model with VIs was developed by DVI and EVI as independent variables, and the model performance was calculated with adjusted \(R^2=0.55\) and RMSE=153.5 m\(^3\) ha\(^{-1}\). The basal area model had an adjusted \(R^2\) of 0.43 and RMSE=14.87 m\(^2\) ha\(^{-1}\) from IKONOS bands 1, 2, 3 and 4. Likewise, the basal area model had an adjusted \(R^2\) of 0.59 and RMSE=12.37 m\(^2\) ha\(^{-1}\) using VIs as DVI and EVI. The model for dominant height resulted in an adjusted \(R^2=0.45\) with a RMSE=4.62 m using IKONOS band 1 and 2. However, using IKONOS VIs, SAVI, EVI and DVI as predictor variables of dominant height, the adjusted \(R^2\) was 0.57 with a RMSE of 3.8 m. Compared to two different models, the stand volume, basal area and dominant height models with IKONOS VIs showed the better accuracy statistics than did the model with IKONOS band spectral reflectance values.

**Table 3 - Parameters of the ‘best fit’ regression models of some stand parameters based on the band values.**

| Model Group | Model description | Coefficients of Independent Variables | t statistics | p-value |
|-------------|-------------------|--------------------------------------|--------------|---------|
| Stand volume | V                 | Constant -7.868                      | -0.024       | 0.000   |
|              |                   | Band 1 17.571                        | 4.452        | 0.000   |
|              |                   | Band 2 -24.010                       | -6.083       | 0.000   |
|              |                   | Band 3 7.819                         | 4.943        | 0.000   |
|              |                   | Band 4 2.030                         | 8.379        | 0.000   |
|              | V                 | Bias=2.077                           | Bias%=0.461  | RMSE=181.01 \(\text{RMSE}%=40.21\) |
| Basal area   | G                 | Constant -8.666                      | -0.296       | 0.000   |
|              |                   | Band 1 1.629                         | 4.673        | 0.000   |
|              |                   | Band 2 0.175                         | 8.636        | 0.000   |
|              |                   | Band 3 -2.107                        | -6.201       | 0.000   |
|              |                   | Band 4 0.632                         | 4.710        | 0.000   |
|              | G                 | Bias=0.837                           | Bias%=-1.937 | RMSE=14.87 \(\text{RMSE}%=34.38\) |
| Dominant height | h               | Constant 42.579                      | 16.87        | 0.000   |
|              |                   | Band 2 0.043                         | 9.29         | 0.000   |
|              |                   | Band 4 -0.158                        | -9.74        | 0.000   |
|              | h                 | Bias=0.453                           | Bias%=2.201  | RMSE=4.62 \(\text{RMSE}%=22.46\) |

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Table 4 - Parameters of the ‘best fit’ regression models of the stand parameters based on some vegetation indices.

| Model Group     | Model description | Dependent Variables | Independent Variables | Coefficients of Independent Variables | t statistics | p-value | $R^2$ | Sy. $x$ | $\text{Bias} = 0.367$ | $\text{Bias}\% = 0.076$ | RMSE = 153.53 | RMSE\% = 31.73 |
|-----------------|-------------------|---------------------|-----------------------|----------------------------------------|--------------|---------|-------|--------|----------------|----------------|----------------|----------------|
| Stand volume    | V                 | Constant            |                       | 281.018                                | 12.779       | 0.000   |       | 60.524 |                       |                |                  |                  |
|                 |                   | DVI                 |                       | -2.506                                 | -6.350       | 0.000   |       |        |                       |                |                  |                  |
|                 |                   | EVI                 |                       | -7750.164                              | -7.816       | 0.000   |       |        |                       |                |                  |                  |
|                 |                   |                      |                       | $R^2_a = 0.55$                          |              |         |       |        | $\text{Bias} = 0.297$ | $\text{Bias}\% = 0.705$ | RMSE = 12.37 | RMSE\% = 29.37 |
| Basal area      | G                 | Constant            |                       | 31.362                                 | 19.395       | 0.000   |       | 4.727  |                       |                |                  |                  |
|                 |                   | EVI                 |                       | -0.255                                 | -9.262       | 0.000   |       |        |                       |                |                  |                  |
|                 |                   | DVI                 |                       | -707.984                               | -10.423      | 0.000   |       |        |                       |                |                  |                  |
|                 |                   |                      |                       | $R^2_a = 0.59$                          |              |         |       |        | $\text{Bias} = 0.079$ | $\text{Bias}\% = 0.377$ | RMSE = 3.80  | RMSE\% = 18.14 |
| Dominant height | h                 | Constant            |                       | 4.183                                  | 1.388        | 0.000   |       | 1.829  |                       |                |                  |                  |
|                 |                   | SAVI                |                       | 36.471                                 | 4.364        | 0.000   |       |        |                       |                |                  |                  |
|                 |                   | EVI                 |                       | -0.078                                 | -6.939       | 0.000   |       |        |                       |                |                  |                  |
|                 |                   | DVI                 |                       | -138.364                               | -3.517       | 0.000   |       |        |                       |                |                  |                  |

In the validation process, a value for the t-test showed that all developed models are unbiased; that is, the mean errors from the models are not statistically significantly different from zero, t value=0.428, p=0.672 for band values and t value=-0.168, p=0.868 for VIs values; t value=1.337, p=0.190 for band values and t value=1.349, p=0.186 for VIs values, and t value=-0.422, p=0.676 for band values and t value=-0.682, p=0.500 for VIs values for all sub-group models to stand volume, basal area and dominant height, respectively. Thus, these models including IKONOS satellite data as predictor variables were statistically acceptable and suitable for predicting the aforementioned parameters. In validation process, the bias, bias\%, RMSE and RMSE\% values were calculated for stand volume (bias=-4.515, bias\%=1.002, RMSE=141.149 and RMSE\%=32.383 for VIs values; bias=10.179, bias\%=2.335, RMSE=159.214 and RMSE\%=35.337 for band values), basal area (bias=2.857, bias\%=6.842, RMSE=12.969 and RMSE\%=31.061 for VIs values; bias=3.229, bias\%=7.803, RMSE=14.539 and RMSE\%=35.136 for band values) and dominant height (bias=-0.311, bias\%=-1.544, RMSE=4.378 and RMSE\%=21.732 for VIs values; bias=-0.551, bias\%=-2.703, RMSE=4.812 and RMSE\%=23.606 for band values), respectively.

Discussion
Forest stand parameters such as stand volume, basal area and dominant height in the research area in Artvin-Genya Mountain located in northeastern part of Turkey were investigated by multiple regression analysis with band reflectance values and VIs obtained from IKONOS satellite image. The VIs models indicated better predictors of stand volume, basal area and dominant height ($R^2=0.55$; RMSE; 153.53 m$^3$ ha$^{-1}$; $R^2=0.59$; RMSE=12.37 m$^2$ ha$^{-1}$ and $R^2=0.57$; RMSE=3.80 m) than the band reflectance values models ($R^2=0.41$; RMSE=181.01
Our results demonstrated that changes of stand parameters between 41% to 59% could be clarified by IKONOS imagery. Regarding this, Kayitakire et al. [2006] carried out panchromatic IKONOS satellite data in the prediction of stand parameters for homogenous Norway spruce stands using texture attributes and linear regression and found a poor association for basal area ($R^2=35\%$; RMSE=16%), but strong correlation for dominant height ($R^2$ changes from 0.76 to 0.82). Leboeuf et al. [2007] examined the relationships between biomass and tree shadow fraction generated from Quickbird imagery in boreal Black spruce forest regions in Canada using regression techniques ($R^2=0.84$ and RMSE=14.2 t/ha). Özdemir [2008] modeled the association between ground measurement stem volume and tree properties obtained from pan-sharpened Quickbird satellite imagery in Crimean-Juniperus mixed forest areas ($R^2=0.67$ and RMSE=3.5312 m$^3$ ha$^{-1}$). Peuhkurinen et al. [2008] applied the IKONOS satellite data for use in estimating stand parameters by the the non-parametric nearest neighbor method called k-MSN dependent on spectral features obtained from standwise spectral histograms and they found that the lowest RMSE for the mean basal area, stand volume and height were 5.6%, 31.3%, and 3.1%, respectively. Pasher and King [2010] modeled multivariate forest structure using high spatial resolution image. The model for forest structural parameters using the Redundancy analysis (RDA) method was obtained with $R^2=0.35$. Song et al. [2010] indicated certain relationships between mean crown size, Quickbird and IKONOS satellite data using linear regression analysis in hardwood forests with a moderate correlation of mean crown size ($R^2=0.60$, RMSE=0.82). Özdemir and Karniel [2011] investigated the possibility of estimating stand attributes using the image texture obtained from WorldView-2 satellite data in a dryland forest with $R^2$ and RMSE values of 0.38 and 109.56 m ha$^{-1}$ for the tree density, 0.54 and 1.79 m$^2$ ha$^{-1}$ for basal area, and 0.42 and 27.18 m$^3$ ha$^{-1}$ for the stand volume, respectively. Gomez et al. [2012] tested the relationship between the quadratic mean diameter, basal area and number of trees, and Quickbird-2 satellite imagery using classification and regression tree analysis. The model accuracies obtained from this study were found $R^2=0.8$ and RMSE=0.13 m; $R^2=0.7$ and RMSE=5.79 m$^2$ ha$^{-1}$; $R^2=0.46$ and RMSE=98.86 m ha$^{-1}$, respectively. The $R^2$ values for stand volume (VIs models) obtained from the current research were higher than that of the study of Özdemir and Karniel [2011]. Similarly, the $R^2$ values for basal area (VIs model) generated from the current study were higher than other studies Kayitakire et al. [2006]; $R^2=0.54$, Özdemir and Karniel [2011].The $R^2$ values for dominant height (VIs model) generated from this current study were higher than that of Mora et al. [2010]. The research results indicated that both the stand volume and basal area could be better estimated using pan-sharpened IKONOS satellite image than that in using high resolution satellite images. However, the RMSE for stand volume, basal area and dominant height determined here were higher than that described by aforementioned studies that utilized similar resolution satellite images in different method of prediction. Our results indicate that the VIs generated by IKONOS imagery are moderate related to forest stand parameters in the study area. The developed models can be used by forest administrators to establish better understanding in developing management alternatives in managed forest stands. Also, this information can be applied to update current forest cover type maps, develop better silvicultural prescriptions and forest management planning alternatives. However, the models developed in this research area are restricted to this geographic area and the specific stand structure focusing mainly for coniferous stands. Therefore, our study offers regression models for the extensive majority of
cases quite similar to the coniferous forest in northeastern Turkey. When compatibility of the regression models developed in this study is evaluated for deciduous forest or mixed forest, however, the regression models may not be suitable for estimating the forest stand attributes. Thus, future studies including different forest ecosystems are required to evaluate wider application of these models particularly for northeastern forest areas. The other limitation is associated with the application of the regression models dependent on the acquired time or location of other satellite images. Besides the above restrictions, the results obtained from this study can be applied to coniferous forests particularly in northeastern of Turkey.

To further assess the acceptability of these model fits, we used the magnitude and distribution of residual values versus predicted values for the stand parameter model using remote sensing data based on band reflectance values and VIs. The presence of heteroscedasticity associated with the error term of the models was checked by plotting the residuals against the predicted values. The presence of heteroscedasticity showed increasing error variation with increasing predicted values. However, the residuals crossing the center of the data show equal residual variance, homoscedasticity [White, 1980]. We examined any obvious dependencies or patterns representing systematic divergences and a breakdown of assumptions of multiple least-square regressions (Fig. 2).

![Figure 2](image_url)

**Figure 2** - The residual values versus (a) the predicted stand volume by band values, (b) the predicted stand volume by VIs, (c) the predicted basal area by band values, (d) the predicted basal area by VIs, (e) the predicted dominant height by band values, (f) the dominant height by VIs.
Figure 2 shows the residuals versus the predicted stand parameters such as stand volume, basal area and dominant height by band reflectance values and VIs. It displays the homogeneous variance over the full range of the predicted stand parameters. Thus any weighting factor with alternative transformations was not necessary to remove heteroscedastic variance error. Also, these residuals of the model indicate that there are no observable patterns in Figure 2 and thus, there are no serious violations of the assumption of constant variance, such as homoscedasticity.

**Conclusions**

The relationships between band reflectance values and VIs obtained from IKONOS satellite image, and the stand volume, basal area and dominant height were determined by multiple regression analyses. The model containing EVI and DVI as independent variables was the best predictor of stand volume and basal area (R²=0.55; RMSE=153.53 m³ ha⁻¹ and R²=0.59; RMSE=12.37 m² ha⁻¹), respectively. The model including SAVI, EVI and DVI as independent variables was the best predictor of dominant height (R²=0.45; RMSE=4.62 m). In conclusion, our results demonstrated that IKONOS VIs are better predictors of stand parameters as compared to IKONOS band spectral reflectance values and the regression model (used VIs) obtained from IKONOS satellite data is beneficial for modeling stand volume, basal area and dominant height in other areas that have similar forest ecosystems circumstances to our study area.

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