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Estimation of Basal Area in West Oak Forests of Iran Using Remote Sensing Imagery

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ABSTRACT

The objective of this study is to evaluate the capability of satellite imagery for the estimation of basal area in Northern Zagros Forests. The data of the high resolution geometric (HRG) sensor of SPOT-5 satellite dated in July 2005 were used. Investigation of the quality of Satellite images shows that these images have no radiometric distortion. Overlaying of geocoded images with the digital topographic maps indicated that the images have high geometric precision. A number of 319 circular plots (0.1 ha) were established using systematic random method in the study area. All trees having diameter at breast height (DBH) (*i.e.* 1.3 m above ground) greater than 5 cm were callipered in each plot. Basal area in each plot was determined using field data. Main bands, artificial bands such as vegetation indices and principle component analysis (PCA) were studied. Digital numbers related to each plot were extracted from original and artificial bands. All plots were ordinated by major geographic aspects and the best fitted regression models were determined for both the study area without consideration of aspects and with consideration of major geographic aspects by multiple regression analysis (step wise regression). The results from regression analysis indicated that the square root of basal area without consideration of aspects has a high correlation with band B1 ($r = -0.60$). The consideration of aspects resulted in correlation of different indices with square root of basal area such that in northern forests, band B1 had higher correlation coefficient ($r = -0.67$) among other indices. In Eastern forests, the same band showed correlation of basal area with different correlation coefficient ($r = -0.65$). In southern and western forests, the square root of basal area had higher correlation ($r = -0.68$) with RVI. The use of the square root of basal area as a dependent variable in multivariate linear regression improved the results. The assessment of model validity indicated that the proposed models are properly valid.

Keywords: Northern Zagros Forests; Basal Area; SPOT-5 Data

1. Introduction

Northern Zagros oak forests represent the most important forest communities in natural forested landscapes in west of Iran [1]. These forests have a great economical value and are a source of revenue for local residents. Even though these forests have been known as conservative forests, the local communities have to traditionally utilize them as a source. In this traditional forest management, the owner of forest applies mixture styles of evenaged coppice on tree (on trunk & crown) and unevenaged coppice (on ground) for preparing food for domestic animals and for wood [1]. These forests produce little amount of woods for industry and have low standing volume; however, tree crowns are utilized in every 3-year period. Thus, the basal area can be an appropriate index to determine the changes in these forests and can provide valuable information about the effect of management activities on the forests. The estimation of this index using field study is difficult, taking plenty of time and needing a great deal of money. In last decades, the science of forest biometry has markedly progressed, resulting in using more sophisticated instruments in forest inventory. This provides an opportunity for collecting data and computing indices with less field working and time. One of the most important instruments used in forest inventory is remote sensing. The integration of the data and information collected from satellite images and field data is the base of modern forest biometry [2].

Many studies have used satellite data to estimate forest quantitative parameters such as density, standing volume, basal area, and etc. in last two decades [3]. Ripple *et al.* compared Digital Landsat Thematic Mapper (TM) and Satellite SPOT High Resolution Visible (HRV) images of coniferous forests to estimate standing volume using correlation and regression analyses. Significant inverse relationships were found between softwood volume and the spectral bands from both sensors ($P < 0.01$). The highest correlations were found between the logarithm of softwood volume and the near-infrared band (HRV band 3, r = –0.89; TM band 4, r = –0.83) [4]. Brockhhause & Khorram compared Spot and Landsat-TM data to inventory forest resources. Their results showed that there is a significant correlation between band XS3 (Infra-Red) and TM bands (2, 3, 4, 5 and 7). They found no significant correlation between age classes and Spot bands, while a significant correlation was found between age classes and TM bands. The correlation coefficients between basal area and TM band7 and between age classes and TM band5 were –0.48 and –0.62, respectively [5]. Xian *et al*. were investigated the capability of TM data for the estimation of canopy density and standing volume. Their results indicated that applying TM data can reduce the number of samples and the inventory costs by 60% - 70% and can provide more reasonable volume and canopy density estimates [6]. Xu *et al*. evaluated the ability of TM data for the estimation of oak forest canopy in dry season. Their results illustrated that the band TM3 had the highest correlation coefficient (–0.83) and the coefficient of determination (0.69) with canopy. The NDVI index showed higher coefficients of correlation (0.84) and determination (0.70) with canopy than SR index. The cubic NDVI index had higher coefficients of correlation (0.85) and determination (0.73) with canopy [7]. Suarez *et al*. indicated that the SPOT4 and ETM+ have both a high capability to estimate stand height, diameter and basal area in afforested stands [8]. Jao *et al*. studied the estimation of canopy density on an ever-green oak forest using aerial photographs and TM satellite images and resulted that this estimation is reasonably possible [9]. Arzani *et al*. used Landsat satellite data to study the production and some vegetation characteristics in two different climates. They found that the VNIR1 and VNIR2 indices show higher correlations with production, canopy percentage and foliage percentage in semi-arid areas, while in arid areas, the NDVI index had higher correlation with the vegetation characteristics [10]. Darvishsefat *et al*. applied the ETM+ data imagery for *Haloxylon* spp. canopy estimation and figured out the NDVI index has a reasonable correlation (r = 0.65) with density [11]. The objective of this study is to evaluate the capability of satellite imagery for the estimation of basal area in Northern Zagros Forests.

2. Materials and Methods

2.1. Study Area

The study area (15,700 ha) is located in a mountainous managed mixed forest (Northern Zagros forests) in Kurdistan province in the west of Iran (**Figure 1** and **Table 1**). The study area is positioned in 45˚30′N to 46˚15′N longitude and 35˚45′E to 36˚15′E latitude. The elevation of the study area ranges from 1200 m to 2200 m above sea level. Average annual precipitation is about 760 mm/year and average annual temperature is between 12˚C to 18˚C [1]. The dominant tree layer mainly consists of Quercus Libani Oliv. (more than 50%), *Quercus brantii* Lindl. (30%) and *Quercus infectoria* Oliv. (20%) with *Crataegus* spp, *Pyrus* spp, *Acer cineracens* and *Pistacia mutica* as the most common admixed tree species.

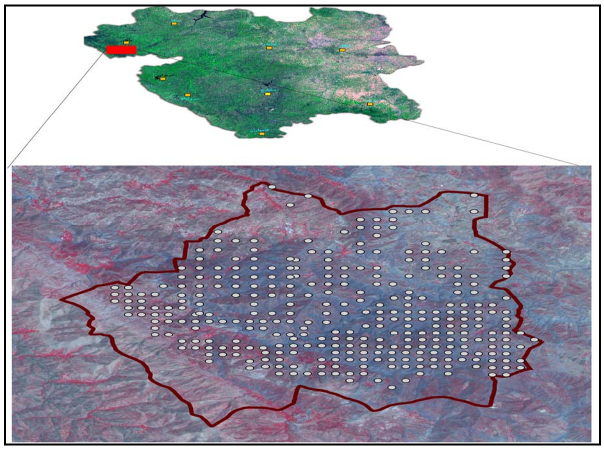

Figure 1. Study area location and sample plots distribution.

Table 1. Descriptive statistics of basal area in studied stands.

Stands	Mean ± std. error (m^2/ha)	Std. deviation (m^2/ha)	Maximum (m^2/ha)	Minimum (m^2/ha)
Exclusive geographical direction	13.96 ± 0.43	±7.78	42.30	1.96
Northern-faced forests (n = 96)	15.57 ± 0.88	±8.70	35.84	1.96
Southern-faced forests (n = 78)	11.96 ± 0.66	±5.94	30.79	2.51
Eastern-faced forests (n = 76)	13.64 ± 0.88	±7.86	42.30	2.19
Western-faced forests (n = 62)	14.18 ± 0.97	±7.76	35.30	2.39

2.2. Satellite Data

The data of the high resolution geometric (HRG) sensor of SPOT5 satellite dated in July 2005 were used for purposes of this study. Radiometric correction and orthorectification process was done by SPOT Imaging Corporation. However, investigation of the quality of satellite images shows that these images have no radiometric distortion. Overlaying of geocoded images with the digital topographic maps indicated that the images have high geometric precision.

2.3. Field Data and Regression Analysis

A number of 319 circular plots (0.1 ha) were established using systematic random method in the study area. All trees having diameter at breast height (DBH) (*i.e.* 1.3 m above ground) greater than 5 cm were callipered in each plot. Basal area in each plot was determined using field data. Main bands, artificial bands such as vegetation indices and principle component analysis (PCA) were studied. Digital numbers related to each plot were extracted from original and artificial bands. Correlation and regression analysis were performed to study the statistical relationships between standing basal area and digital numbers of satellite data. All plots were ordinated by major geographic aspects and the best fitted regression models were determined for both study areas without consideration of aspects and consideration of major geographic aspects by multiple regression analysis (step wise regression). The use of square root of basal area as a dependent variable in multivariate linear regression improved the results. A number of 32 sample plots from the 319 measured plots were randomly selected and served as control plots for verification of derived models. These control plots were not used for correlation and regression analysis.

3. Results

3.1. Suggested Model for Northern-Faced Forests

In the northern-faced forests, the root of basal area [SQRT(BA)] had highest coefficient of correlation with band B1 (r = 0.67) among the other indices (**Table 7**). In the model for the northern-faced forests, the band B1 is a predictive variable. According to the ANOVA of regression, the hypothesis of "no linear relationship" was rejected with significant level of 99% (F = 69.88, P < 0.01). The hypotheses of "The slope of the regression model = 0" and "The intercept of the regression model = 0" were rejected at the significant level of 99% (**Table 2**). The Kolmogrov-Smirnov test showed that the distribution of residuals was normal (P = 0.66, K-S Z = 0.732). Nine out of 10 control samples were accepted in validity test of the model.

Table 2. Regression coefficients and summery model for suggested model for northern forests.

Model	Coefficients	SE	t	P	Beta
b_0	3.467	0.270	12.825	<0.01	-
b_1	0.018	0.002	–8.359	<0.01	–0.670
$SQRT(BA) = b_0 + b_1B_1$					
N = 88 R^2Adj.= 0.44 MSE = 0.073 F = 69.88 P < 0.01 Bias = –0.017 m^2/ha Bias = –4.62%					

3.2. Suggested Model for Southern-Faced Forests

The root of basal area [SQRT(BA)] showed the highest coefficient of correlation with RVI index (r = 0.68) among the other indices (**Table 7**) in the southern-faced forests. The RVI and B3 are predictive variables for the model of these forests. Multiple correlation coefficient between SQRT(BA) and predictive variables is 72%. The ANOVA of regression model revealed that hypothesis of "no linear relationship" is rejected with significant level of 99% (F = 37.71, P < 0.01). The hypotheses of "The slope of the regression model = 0" and "The intercept of the regression model = 0" are laso rejected at the significant level of 99% (**Table 3**). The distribution of residuals was normal (P = 0.67, K-S Z = 0.76) based on the Kolmogrov-Smirnov test. The whole control samples were accepted in validity test of the model.

Table 3. Regression coefficients and summery model for suggested model for southern Forest.

Model	Coefficients	SE	t	P	Beta
b_0	3.955	0.513	7.705	<0.01	-
b_3	–0.007	0.002	–2.930	<0.01	–0.381
RVI	–1.980	0.265	–7.481	<0.01	–0.973
$SQRT(BA) = b_0 + b_1B_3 + b_2RVI$					
n= 72 R^2Adj =0.51 MSE = 0.037 F = 37.71 P < 0.01 Bias = –0.035 m^2/ha Bias = –2.94%					

3.3. Suggested Model for Eastern-Faced Forests

Band B1 showed the highest coefficient of correlation (r = –0.66) with the root of basal area [SQRT(BA)] in the eastern-faced forests (**Table 7**) as the northern-faced forests; however, the PCA1 and B1 are predictive variables in their model. Multiple correlation coefficient between SQRT(BA) and predictive variables are 66%. Based on the ANOVA of regression, all hypotheses are rejected at the significant level of 99% (**Table 4**). The Colmogrov-Smirnov test showed that the residuals are normally distributed (P = 0.73, K-S Z = 0.76). The whole control samples were accepted in validity test of the model.

3.4. Suggested Model for Western-Faced Forests

The western-faced forests behaved similar to southern-faced forests as they showed the highest coefficient of correlation between the root of basal area [SQRT(BA)] and the RVI index (r = –0.68), shown in **Table 7**; while three predictive variables including RVI, PCA2 and PCA3 are selected for their model. Multiple correlation coefficient between SQRT(BA) and predictive variables are 80%. All hypotheses were rejected as the other forests at the significant level of 99% (**Table 5**). The test of normality by the Kolmogrov-Smirnov showed the normal distribution of the residuals (P = 0.72, K-S Z = 0.69). The whole control samples were accepted in validity test of the model.

Table 4. Regression coefficients and summery model for suggested model for eastern-faced forest.

Model	Coefficients	SE	t	P	Beta
b_0	3.252	0.317	10.256	<0.05	-
b_1	–0.027	0.006	–4.850	<0.05	–1.138
PCA_1	0.008	0.004	2.206	<0.05	0.518
$\mathrm{SQRT(BA)} = b_0 + b_1B_1 + b_2 \times PCA_1$					
n = 62 R^2Adj. = 0.46 MSE = 0.058 F = 27.83 P < 0.01 Bias = –0.056 m^2/ha Bias = –4.3%					

Table 5. Regression coefficients and summery model for suggested model for western forests.

Model	Coefficients	SE	t	P	Beta
b_0	7.551	0.925	8.165	<0.05	-
RVI	–4.662	0.684	–6.817	<0.05	–1.772
PCA_2	–0.038	0.008	–4.767	<0.05	–1.253
PCA_3	–0.034	0.014	–2.405	<0.05	–0.222
$\mathrm{SQRT(BA)} = b_0 + b_1\,RVI + b_2PCA_2 + b_3PCA_3$					
n = 58 R^2Adj. = 0.62 MSE = 0.041 F = 31.60 P < 0.01 Bias = –0.038 m^2/ha Bias = –2.7%					

3.5. Suggested Model for Forests (Exclusive Geographical Directions)

In the studied forests (exclusive geographical directions), the root of basal area [SQRT(BA)] had the highest coefficient of correlation with with band B1 (r = 0.60) among the other indices (**Table 7**). In the model for the western -faced forests, the RVI, PCA2 and PCA3 are predictive variables. Multiple correlation coefficient between SQRT-(BA) and predictive variables are 80%. According to the ANOVA of regression, the hypothesis of "no linear relationship" was rejected with significant level of 99% (F = 111.19, P < 0.01). The hypotheses of "The slope of the regression model = 0" and "The intercept of the regression model = 0" were rejected at the significant level of 99% (**Table 6**). The Colmogrov-Smirnov test showed that the distribution of residuals was normal (P = 0.54, K-S Z = 0.81). The whole control samples were accepted in validity test of the model.

4. Conclusion

The analysis of the table of correlation matrix between dependent variables (Digital numbers related to each plot extracted from original and artificial bands) and the root of basal area [SQRT(BA)] showed that in the studied forests (exclusive geographical directions), the root of basal area had the highest coefficient of correlation with band B1 (r = –0.60) among the other indices (**Table 7**). In the northern, eastern, southern and western-faced forests the root of basal area [SQRT(BA)] had the highest coefficient of correlation with band B1 (r = –0.67), band B1 (r = –0.65), RVI index (r = –0.68) and RVI index (r = –0.68), respectively. It is generally expected to have a high relationship between band B3 (near-Infrared band) and vegetation cover [4,5,7,9,12]; however, it was, in this study, observed that the high relationship was established between the basal area and band B1 (in the northern forests, eastern forests and exclusive geographical directions). Similar observations have been made by Suarez *et al*. [8]. The reason for this could be related to this fact that northern and eastern forests generally have a higher density and lower soil reflections; thus, the main bands can provide better results. Naseri suggested using band B1 for such studies [13]. The use of these indices has been, on the one hand, confirmed by the higher relationship of vegetation characteristics on western and southern forests [10,11,13,14] and on the other hand, showed that the vegetation characteristics have lower sensitivity relative to sparser cover (due to the existence of lower soil moisture and sparser vegetal cover on western and southern forests). Hosseini and Moradi have obtained different results [15,16]. The negative coefficient of correlation indicates that the rate of reflectance in samples decreases with an increase in basal area. The same results were found by Khorrami *et al*. [3], Azizi *et al*. [17] and Ripple *et al*. [4] in the study of volume estimation. However, Mohammadi *et al*. [18] have found positive relationship in the estimation of number per ha. The regression analyses showed that the classification of samples based on geographical aspects and determination of a separate model for each class has increased the correlation coefficient and the modified coefficient of determination up to 18% and 7% on western and southern aspects, respectively. This increase is about 2% on eastern aspects and stayed without any change on northern aspects while the coefficient of correlation increased about 1%. Khorrami *et al*. carried out their research in a pure beech stand stand only on northern aspects in order to

Table 6. Regression coefficients and summery model for suggested model for studied forests (exclusive geographical directions).

Model	Coefficients	SE	t	P	Beta
b_0	3.153	0.141	22.406	<0.01	-
B_1	−0.009	0.001	−7.285	<0.01	−0.426
RVI	−0.794	0.124	−6.389	<0.01	−1.920
$SQRT(BA) = b_0 + b_1B_1 + b_2RVI$					
n = 287 R^2Adj. = 0.44 MSE = 0.062 F = 111.19 P < 0.01 Bias = −0.061 m^2/ha Bias = −4.6%					

Table 7. Pearson's correlation coefficient between standing volume of sample plots and corresponded spectral values (DNs) in original bands.

Main bands, artificial bands / Dependent Variable	B_1	B_2	B_3	AVI	DVI	IPVI	NDVI	RVI	NRVI	SAVI	TVI	PCA1	PCA2	PCA3
Northern-faced forests (n = 88)														
SQRT(BA)	**0.67-	**0.61-	0.05-	**0.46	**0.46	**0.49	**0.49	**0.53-	**0.49-	**0.49	**0.51	**0.57-	**0.6	**0.39-
Southern-faced forests (n = 72)														
SQRT(BA)	**0.56-	**0.40-	**0.37	**0.67	**0.67	**0.67	**0.67	**0.68-	**0.67-	**0.67	**0.68	*0.24-	**0.61	*0.27-
Eastern-faced forests (n = 69)														
SQRT(BA)	**0.66-	**0.59-	0.05-	**0.53-	**0.53-	**0.54	**0.54-	**0.55-	**0.54-	**0.54	**0.54	**0.53-	**0.40	**0.36-
Western-faced forests (n = 58)														
SQRT(BA)	**0.65-	**0.55-	0.05	**0.66	**0.66	**0.67	**0.67	**0.68-	**0.67-	**0.67	**0.38	**0.46-	**0.53	**0.43-
Studied Forests (exclusive geographical directions) (n = 287)														
SQRT(BA)	**0.60-	**0.52-	0.06	**0.53	**0.53	*0.55	**0.55	**0.58-	**0.55-	**0.55	**0.57	**0.44-	**0.44	**0.38-

**Significant at 99% confidence level; *Significant at 95% confidence level; ns: No significant.

eliminate the effect of geographical aspects [3]. In this research, applying of regression analysis led to better results and Naseri [13], Hosseini [15], and Xu *et al*. [7] confirmed these findings. The use of mathematical transformations such as logarithmic function, power function, root function, and reciprocal function on de pendent variable (basal area) and their relationships with independent variable resulted in an increase in correlation coefficient such that the maximum coefficient was obtained between the root of basal area and the independent variable. Many previous studies have obtained better results when using logarithmic functions [3,4,7,17]. In Iran, many studies on quantitative characteristics of forest stands have conducted in northern forests with a high density of deciduous trees. In this research, the coefficient of correlation was determined 66% (exclusive geographical directions) and it was reached 80% when considering the geographical aspects. The low canopy density of Zagros forests and the similarity of the results with other studies can be a good indication of relatively reasonable capability of SPOT data for the study area [3,17].

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