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# ESTIMATING ABOVE-GROUND CARBON BIOMASS USING SATELLITE IMAGE REFLECTION VALUES: A CASE STUDY IN CAMYAZI FOREST DIRECTORATE, TURKEY

## PROCJENA NADZEMNE BIOMASE UGLJIKA KORIŠTENJEM VRIJEDNOSTI REFLEKSIJE SATELITSKIH SNIMAKA: STUDIJA SLUČAJA U DIREKCIJI ŠUMA, CAMYAZI, TURSKA

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### Summary

Forest ecosystems which contain half of the terrestrial carbon deposits; play a significant role in shaping the global climate. Two different methods are used to determine the above-ground carbon stock capacity of forestlands. Direct measurement method takes a long time and requires both extensive as well as expensive field and laboratory work. One of the more indirect methods, satellite imaging on the other hand, costs less, is easier and practical compared to direct methods. It is also easier to integrate into geographic information systems (GIS). This paper provides a regression equation between the reflection values from RapidEye high resolution satellite image and sample areas where terrestrial aboveground biomass (AGB) carbon stock capacity was calculated by direct measurement method. As a result of the calculations made, using the RapidEye imagery and a "Band 4" devised equation producing $R^2$=0.71 depending upon the data from Erzurum Camyazi Forest Directorate encompassing 9,917 ha study area, the amount of carbon stored within stands was found 285 208 tons. From this value, we can conclude that average carbon stock of the study area is 28.8 tons/ha.


**KEY WORDS:** aboveground biomass, carbon sequestration, remote sensing, RapidEye

## INTRODUCTION
## UVOD

Today, almost all of the climate scientists accept that Earth's climate is deteriorating. The destruction of forests and wetlands is a primary contributor to global climate change. The increase in greenhouse gas concentrations and particles in the atmosphere will result in the destruction of the natural environment, depletion of the ozone layer and lead to an increase in global temperature (Ozturk 2002). Temperature rise on a global scale and climate change have caused increasing concern, urging the international parties to start negotiations to devise a solution. At the UN World Summit in Rio de Janeiro in 1992, Framework Convention on Climate Change was opened for signature to reduce greenhouse gas emissions. It entered into effect in 1994 and was signed by 192 states. Also, the Kyoto Protocol signed in 1997 as a part of the "United Nations Framework Convention on Climate Change" is the only international protocol on global warming and climate

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change, designed to reduce the gases emissions that cause the greenhouse effect.

The amount of biomass held and carbon stored in forest ecosystems plays important roles in global carbon cycle. They are considered as one of the most significant carbon sinks to reduce global warming. Carbon sequestration by terrestrial ecosystems is important in the global carbon balance for limiting the concentration of $CO_2$ in the atmosphere (Muukkonen, 2006). There are three main deposits of carbon in the world. These deposits are the atmosphere, terrestrial and oceanic ecosystems. Each year, forest ecosystems take 100 gigatons of $CO_2$ from the atmosphere and give half of it back to the atmosphere. On the contrary, earth's oceans receive 104 gigatons of $CO_2$ from the atmosphere and give 100 gigatons back. These facts reveal the importance of forests and forest ecosystems in terms of carbon stock (OGM 2014). Forest trees have the maximum amount of leaves compared to other plant species; they produce more $CO_2$ than pastures and agricultural plant communities (Asan, 1999). Total biomass includes both aboveground biomass (AGB; e.g. trees, shrubs, and vines) and belowground biomass (e.g. living roots, dead fine and coarse litter associated with the soil) (Lu et al. 2014). Forest ecosystem stores about 80% of all above-ground and 40% of all below-ground terrestrial organic carbon (IPCC, 2001).

Forests are the largest terrestrial carbon deposits. This fact alone reveals the necessity of learning how much carbon forests store. Many biomass estimation studies conducted are focused on above-ground forest biomass (De Gier et al., 2012; Riegel et al., 2013; Langner et al., 2012; Gulsunar, 2011) because it accounts for the majority of the total accumulated biomass in the forest ecosystem. Usually, as in the other tree components, regional and national biomass and carbon stock values related to above-ground biomass are calculated with the help of allometric biomass expansion factor (BEF) that are developed with the help of forest inventory data that is based on sample fields (Brown, 2002; Goodale et al., 2002). In conventional techniques on basis of statistical assessment (i.e., tree species, vertical structure, stand height and stand density), the forest AGB information comes from expensive and time consuming field surveys due to the high sampling intensity. As alternative, multi-parameter remote sensing techniques have been applied, in which remotely sensed data are used as proxy for quantitative forest AGB at various scales. (Tian et al. 2012). The study conducted by Yang et al. (2008), deal with the carbon stock capacity and the changes in carbon stock capacity of Pearl River Delta in China, between 1989 and 2003. It was concluded that there was a 16.76% increase in regional carbon stock and that 80% of this increment was stored in the stands. Gough, et al. (2008) conducted a study about how multiyear observations of forest carbon fluxes provide critical insight into the constraints on annual carbon stock rates. They examined how climate, disturbance, and forest succession simultaneously influence annual forest carbon stock. They also described how foresters and land managers can use knowledge gained from long-term ecosystem-scale studies to better manage forests for carbon sequestration. In addition to biomass factors, allometric biomass equations have been developed for a large number of tree species in different regions both geographically and ecologically (Peichl and Arain 2007). Also, carbon stock equations developed for some types of trees can be used without biomass equalities and are preferred because this increases the accuracy of the stock capacity estimations and are quick to implement.

Land Use, Land-Use Change and Forestry (LULUCF) guide is frequently used for determining the amount of carbon in forest ecosystems (Penman et al. 2003). In the LULUCF guide, the annual carbon stock changes in the carbon pools that belong to the biomass of forest ecosystems are determined by using various equations and factors. Carbon flux measurements, remote sensing and modeling methods are used to determine the aboveground plant biomass. Remote sensing provides a practical and economical instrument to study vegetation cover and has been applied to map vegetation cover from local to global scales over the last three decades (Malatesta et al. 2013). Remote sensing methods are based on the relationship between forest stand parameters and their spectral properties. In this method, ground measurements are also needed to verify the remote sensed data (Ravindranath and Ostwald 2008). Remote sensing and geostatistical approaches have been used to map above-ground biomass by calibrating statistical models with field information (Goetz et al. 2009). A common approach has been the use of regression analyses of reflectance channels, and spectral and textural indices based on information from sampling sites. (Galeana-Pizaña et al. 2014). In one of the study (Sulistyawati et al. 2006), the statistical relationship between the amount of carbon determined with field measurements and spectral characteristics is used to develop a model that predicts the amount of carbon stored in workspace. In the study conducted by Chung et al. (2009), two different forest biomass estimation methods were used; (1) k-Nearest Neighbor (k-NN) method and (2) Biomass from Cluster Labeling Using Structure and Type (BioCLUST) method. Both of the biomass estimation methods using NFI data and satellite data are useful to provide total forest biomass information at large-scale as well as at small-scale. Even though the BioCLUST gives a more precise estimate, the method requires additional forest attributes and a more complex process than k-NN method.

The study conducted by Myeong et al. (2006), a change in carbon stock capacity of urban green spaces in 1985, 1992 and 1999 was recorded using the Landsat 7 satellite images. The study conducted by Tan et al. (2007), changes in carbon stock capacity in the forested area of North-eastern China between 1982 and 1999 were identified by satellite. To do this, forest inventory and NOAA / AVHRR normalized difference vegetation index for three different periods 1984–1988, 1989–1993 and 1994–1998 was used. Different types of optical sensor data, such as Landsat, SPOT, ASTER, CBERS, QuickBird, MODIS, and AVHRR can be used for biomass estimation (Lu et al. 2014). Landsat TM7, TM4, SR, RVI, and SAVI were significantly and positively correlated with AGB in Savannakhet Province (Vicharnakorn et al. 2014; Dube and Mutanga 2015). The study conducted by Comez (2012) determined that there are significant differences in carbon stocks stored in among different stand types, tree mass, dead and live trees. Carbon stocks in trees, ground vegetation, and forest layers were significantly different between stand types due to forest growth and past silvicultural treatments. Annual carbon sequestration of standing trees was estimated between 0.520–3.076 tC/ha/year in relation to stand types. Bulut (2012) obtained a biomass equation by biomass measurements of Beech wood species. The resulting equation and the other equations in the literature are used to calculate the total biomass amount of the field and the related stored carbon content. This calculated value is used to estimate the carbon stock capacity of the whole area with controlled classification of three different satellite images (SPOT-5, Quickbird-2, Landsat). The highest accuracy was achieved by the Landsat image.

Although these are a number of recently published papers focusing on biomass estimation, carbon stock and the use of satellite imagery the abundant array of possibilities forced us to device this study, in which the above ground carbon stock capacity of sample plots were calculated, using RapidEye satellite imagery. To do this, above ground carbon stock capacity from 344 sample plots taken within Camyazi Forest Directorate were calculated using "BEF and Carbon coefficient" from Turkey's National Greenhouse Gas Inventory Report (NIR) for UNFCCC. In this report, BEF coefficient generated by "Asan 2006" for Turkish forests. The stand parameters such as diameter, height, etc. obtained from field survey were using in the equations for calculating the aboveground carbon stock capacity at sample areas. The purpose of this particular study is to formalize a regression equation between the above ground carbon stock capacity calculated through extensive field surveying of 344 sample point areas taken in Camyazi Forest Directorate, Turkey and the reflectance values corresponding to each sample point from RapidEye imagery.

## MATERIALS AND METHODS
## MATERIJALI I METODE

In this study area, located in Kars province, Turkey where there are dense stands of Scotch pine (*Pinus sylvestris* L.), 9 917 ha of Camyazi Forest Directorate within the total acreage of 61 646 ha of Erzurum Regional Forest Directorate was selected as the study area (Figure 1).

1/25 000 scaled standard topographic maps of the study area, data acquired from field surveying done by a licensed forestry subcontractor, Buse Inc., to make a Forest Management Plan 2009 and a coinciding RapidEye satellite imagery dated 2009 were used. Figure 2 shows the land use in the study area map where the dominant tree species is Scotch pine.

Biomass estimation using remote sensing technology is a comprehensive procedure with many steps: field survey data collection, biomass calculation at plot level, remote sensing data selection, variable extraction, proper algorithm selection, and error evaluation.

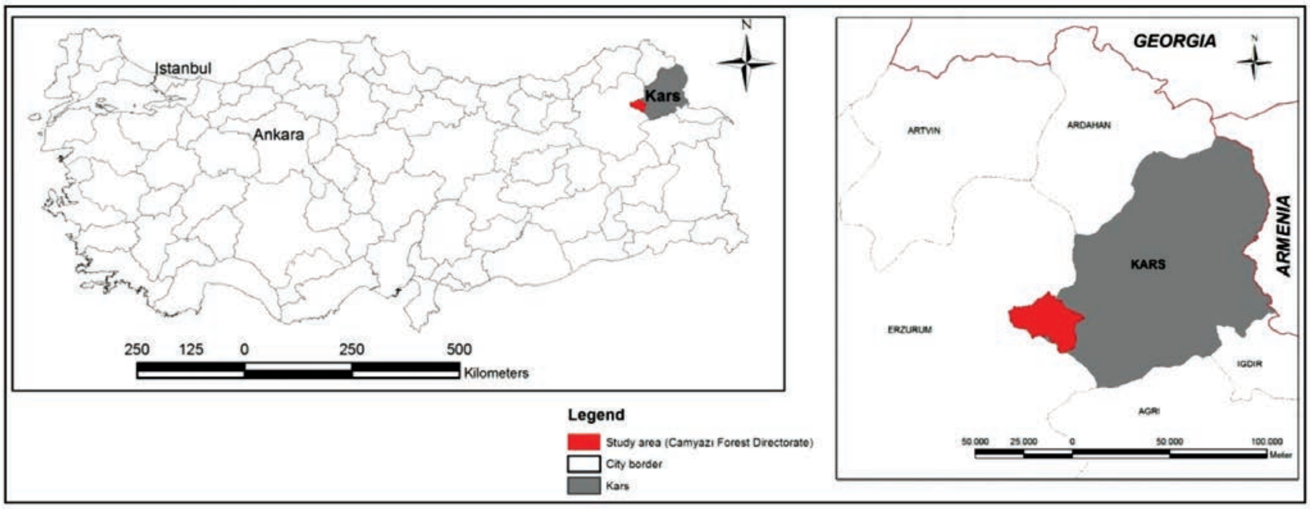


**Figure 1.** The location of the research area
Slika 1. Lokacija istraživačkog područja

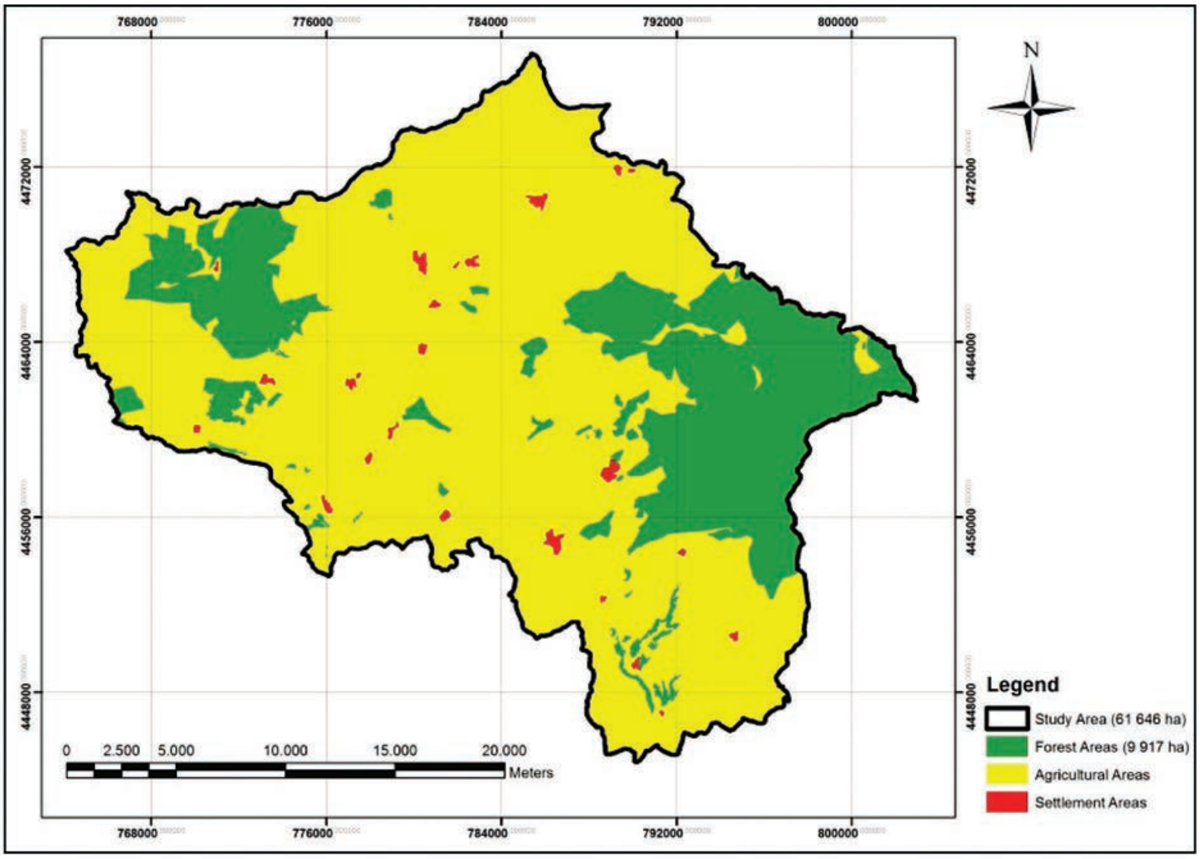


**Figure 2.** Study area land use map
Slika 2. Mapa korištenja zemljišta istraživanog područja

In the study area, 344 samples with different stand closures between 400 $m^2$, 600 $m^2$ and 800 $m^2$ were chosen. Figure 3 shows the 344 sample plots chosen within the Camyazi Forest Directorate shown on the RapidEye satellite image.

Topographical maps, the stand maps and the RapidEye satellite image are located on the ArcGIS database. Carbon stock amounts of the 344 sample plots shown on Figure 3 were calculated using the field data. For all tree species in the sample plots, BEF1 coefficient from NIR Turkey for Turkey's forests generated by Asan (2006) was used. Volume measurements of the trees acquired with the measurements in the sample plot are multiplied by calculated coefficients for each tree species groups in Turkey's forests (0.640 for deciduous, 0.473 for coniferous) and then converted to oven dry weight. After that, it is multiplied with coefficients (1.22 in coniferous and 1.24 in deciduous) that is the conversion factor to convert biomass that corresponds to 1 $m^3$ of standing volume and converted to above ground biomass (AGB) weight. Carbon amount of the above-ground biomass (AGB) was calculated by multiplying the AGB value with the coefficient of 0.50.

AGB (coniferous) = Standing volume x 0.473 × 1.22

AGB (deciduous) = Standing volume x 0.640 ×1.24

Carbon Amount of Above-ground Biomass = AGB × 0.50

The carbon value for each sample plot is converted to tones/pixel size (25 $m^2$) depending on the reflectance value coming from "5 × 5$m^2$" RapidEye pixels.

Geometrical corrected RapidEye satellite image was first divided into bands so that the operations can be performed. Reflection values of the separate areas allocated for each band were calculated. To calculate the reflection values of the satellite image, pixel digital numbers had to be converted to radiance values. To this $L_\lambda=(DN_\lambda.gain_\lambda)+bias_\lambda$ equation is used. Then each pixel's value to be converted to digital numbers radiance values were converted to reflection values using the below formula:

$$p_\lambda = \frac{\pi \cdot L_\lambda \cdot d^2}{E_{sun\lambda} \cdot \cos(\Theta)}$$

where "p" is reflection value of each pixel; "λ" represents image bands; "L" is radiance of each pixel; "d" is the distance between the Sun and Earth; "Esun" represents solar atmospheric radiance; "θ" is solar angle; "DN" is digital number of each pixel; gain represents the gain value of each band, and bias is the bias value of each band.

At this stage, necessary values have been derived from the metadata from the image. Three different image processing methods were used on the Satellite image.

1. Using the reflection values of each band separately (Band 1, Band 2 etc.)
2. Simple ratio (Band 4/3, Band 5/3, Band 5/3 and Band 5/1, etc.),
3. Normalized ratios are (NDVI) values.

Besides, RapidEye is one of the first commercial earth observation programme utilizing a specific band on board, targeting the changes in chlorophyll contend of plants, Red-Edge (Band4). Thus, other variables derived from Band 4 and its derivatives were produced and used in equations.

After the reflection values of all the pixels of the image were calculated with three different methods, the image was converted to vector data format. As a result of the conversion operation, a point layer, with 3 964 929 pixels and each pixel representing a field of 5m × 5m had been created. 344 sample fields, with their terrestrial measurements complete, carbon stock capacity calculated and numerically stored in the GIS environment had been added as a separate data layer. Ranging from 400 to 800 $m^2$ in size, each sample area held at least 16 and up to 32 pixels. For each field, a single image was needed. So, the averages of reflection values of the pixels that fall within the boundaries of the sample area were used. Reflection value of each sample field was identified by overlaying these layers in the ArcGIS.

## RESULTS AND DISCUSSION
## REZULTATI I RASPRAVA

Reflection values of the sample areas in the investigated area were calculated with the specified formula and many variables $(Band4)^2$, $(Band4)^3$, $(1/ Band4)^2$, (Band1/Band2), (Band 3/Band4), NDVI, etc.) were obtained as a result of the image enhancement process.

The relationship between these independent variables and the amount of carbon stock of the 258 sample fields was determined using regression analysis (SPSS 13.5 software). For establishing the regression models, curve estimation approach including Linear, Logarithmic, Inverse, Quadratic, Compound, Power, S, Growth, Exponential were all tested. 86 control points were used for controlling the regression model result. Table 1 shows the most successful parameter estimates models.

The Carbon stock of sample pixels (tones/pixels) and scaled reflectance value of $(Band\ 4)^2$ for the 258 plots is shown in Figure 4.

After the equation producing the highest $R^2$ was selected, this particular equation was first tested with the number of sample points reserved for control, 86 control points. Calculated values were compared to the ground measurements by employing pairwise sample t-test. Under P>0.05 confidence level, no difference was noticeable between them so it was decided the equation was viable. Above ground forest biomass (AGB) from SPOT-5 data, using a non-parametric

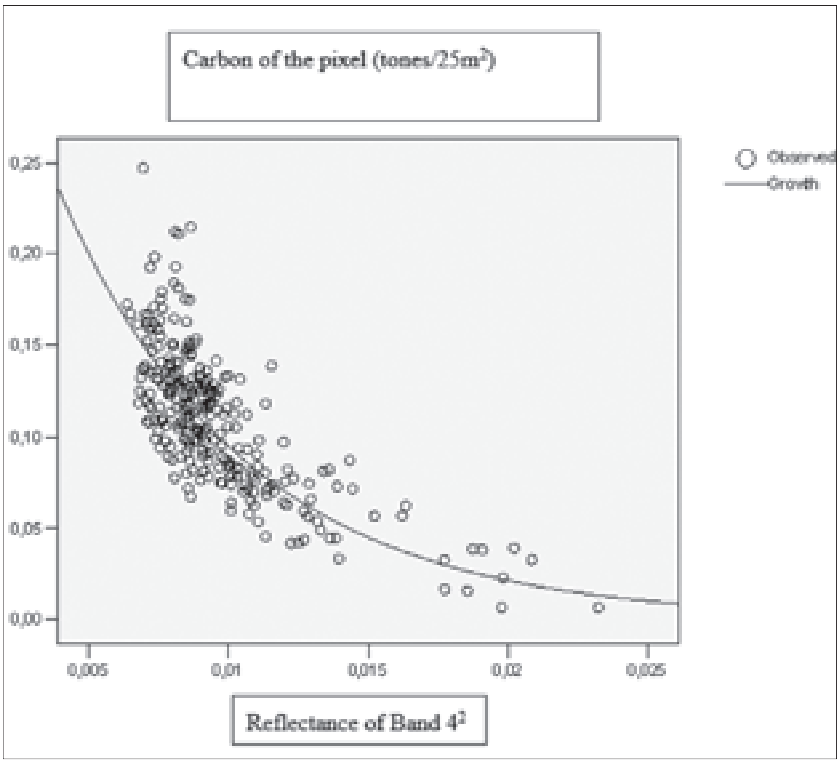


**Figure 4.Carbon** stock of sample pixels (tones/pixels) and scaled reflectance value of $(Band\ 4)^2$ for 258 plots. The $R^2$ is 0.71.The growth line represents the final model for carbon stock and reflectance value of $(Band\ 4)^2$

Slika 4. Pohrana ugljika uzoraka piksela (tona/piksela) te skalirana vrijednost refleksije $(Pojas\ 4)^2$ za 258 zemljišnih čestica. $R^2$ je 0.71.Linija porasta predstavlja konačni model za pohranu ugljika i vrijednost refleksije $(Pojas\ 4)^2$

**Table 1** Most successful models of estimated parameters
Tablica 1. Najuspiješniji model procijenjenih parametara

| | **Model** *Model* | **Equation** *Jednadžba* | $R^2$ | $b_0$ | $b_1$ | $b_2$ |
|---|---|---|---|---|---|---|
| Band1 *Pojas 1* | Growth / *Rast* | $y = e^{(b_0 + b_1 \cdot x)}$ | 0.434 | 5.249 | –83.758 | |
| Band2 *Pojas 2* | Growth / *Rast* | $y = e^{(b_0 + b_1 \cdot x)}$ | 0.620 | 2.274 | –56.744 | |
| Band3 *Pojas 3* | Growth / *Rast* | $y = e^{(b_0 + b_1 \cdot x)}$ | 0.491 | –0.036 | –37.421 | |
| Band4 *Pojas 4* | Growth / *Rast* | $y = e^{(b_0 + b_1 \cdot x)}$ | 0.704 | 0.836 | –32.222 | |
| **Band4²** ***Pojas 4²*** | **Growth** / ***Rast*** | $y = e^{(b_0 + b_1 \cdot x)}$ | *0.714 | –0.864 | –148.967 | |
| Band4³ *Pojas 4³* | Growth / *Rast* | $y = e^{(b_0 + b_1 \cdot x)}$ | 0.713 | –1.438 | –886.361 | |
| 1/ Band4² 1/*Pojas 4²* | S | $y = e^{(b_0 + \frac{b_1}{x})}$ | *0.714 | –0.865 | –148.967 | |
| 1/ Band4³ 1/ *Pojas 4³* | S | $y = e^{(b_0 + \frac{b_1}{x})}$ | 0.713 | –1.438 | –886.361 | |
| Band5 *Pojas 5* | Growth / *Rast* | $y = e^{(b_0 + \frac{b_1}{x})}$ | 0.565 | 0.593 | –14.863 | |
| NDVI *NDVI* | Quadratic / *Kvadratni* | $y = b_0 + b_1x + b_2x^2$ | 0.104 | –0.484 | 2.314 | –2.240 |
| Band1/Band2 *Pojas 1/Pojas 2* | S | $y = e^{(b_0 + \frac{b_1}{x})}$ | 0.630 | 6.254 | –9.594 | |
| Band1/Band3 *Pojas 1/Pojas 3* | S | $y = e^{(b_0 + \frac{b_1}{x})}$ | 0.484 | 0.970 | –4.902 | |
| Band1/Band4 *Pojas 1/Pojas 4* | S | $y = e^{(b_0 + \frac{b_1}{x})}$ | 0.676 | 1.968 | –3.967 | |
| Band1/Band5 *Pojas 1/Pojas 5* | S | $y = e^{(b_0 + \frac{b_1}{x})}$ | 0.359 | 0.379 | –1.245 | |
| Band2/Band1 *Pojas 2/Pojas 1* | Growth / *Rast* | $y = e^{(b_0 + b_1 \cdot x)}$ | 0.629 | 6.240 | –9.566 | |
| Band2/Band3 *Pojas 2/Pojas 3* | S | $y = e^{(b_0 + \frac{b_1}{x})}$ | 0.243 | –1.192 | –4.679 | |
| Band2/Band4 *Pojas 2/Pojas 4* | S | $y = e^{(b_0 + \frac{b_1}{x})}$ | 0.553 | 4.692 | –5.806 | |
| Band2/Band5 *Pojas 2/Pojas 5* | Quadratic / *Kvadratni* | $y = b_0 + b_1x + b_2x^2$ | 0.149 | –0.696 | 3.552 | –3.864 |
| Band3/Band1 *Pojas 3/Pojas 1* | Growth / *Rast* | $y = e^{(b_0 + b_1 \cdot x)}$ | 0.482 | 0.955 | –4.866 | |
| Band3/Band2 *Pojas 3/Pojas 2* | Growth / *Rast* | $y = e^{(b_0 + b_1 \cdot x)}$ | 0.243 | 1.191 | –4.666 | |
| Band3/Band4 *Pojas 3/Pojas 4* | Quadratic / *Kvadratni* | $y = b_0 + b_1x + b_2x^2$ | 0.154 | –1.732 | 5.856 | –4.639 |
| Band3/Band5 *Pojas 3/Pojas 5* | Quadratic / *Kvadratni* | $y = b_0 + b_1x + b_2x^2$ | 0.076 | –0.080 | 1.202 | –1.875 |
| Band4/Band1 *Pojas 4/Pojas 1* | Growth / *Rast* | $y = e^{(b_0 + b_1 \cdot x)}$ | 0.672 | 1.942 | –3.935 | |
| Band4/Band2 *Pojas 4/Pojas 2* | Growth / *Rast* | $y = e^{(b_0 + b_1 \cdot x)}$ | 0.550 | 4.678 | –5.787 | |
| Band4/Band3 *Pojas 4/Pojas 3* | Quadratic / *Kvadratni* | $y = b_0 + b_1x + b_2x^2$ | 0.169 | –1.851 | 2.423 | –0.746 |
| Band4/Band5 *Pojas 4/Pojas 5* | Quadratic / *Kvadratni* | $y = b_0 + b_1x + b_2x^2$ | 0.075 | –0.292 | 1.729 | –1.846 |
| Band5/Band1 *Pojas 5/Pojas 1* | Growth / *Rast* | $y = e^{(b_0 + b_1 \cdot x)}$ | 0.354 | 0.334 | –1.221 | |
| Band5/Band2 *Pojas 5/Pojas 2* | Quadratic / *Kvadratni* | $y = b_0 + b_1x + b_2x^2$ | 0.148 | –0.484 | 0.528 | –0.116 |
| Band5/Band3 *Pojas 5/Pojas 3* | Quadratic / *Kvadratni* | $y = b_0 + b_1x + b_2x^2$ | 0.162 | –0.421 | 0.323 | –0.049 |
| Band5/Band4 *Pojas 5/Pojas 4* | Quadratic / *Kvadratni* | $y = b_0 + b_1x + b_2x^2$ | 0.116 | –1.220 | 1.308 | –0.320 |

y: carbon stock capacity of pixel (*kapacitet piksela pohrane ugljika)*
x: reflectance value *(vrijednost reflektiranja*)

method trained with field data for a remote forest in China area produced satisfactory results (R = 0.69, RMSE = 20.7 tons $ha^{-1}$) (Tian et al., 2012).

The resulting equation and reflection of pixels on the entire satellite image are used to calculate the values of the amount of carbon stock of each pixel and these values were collected and carbon stock capacity of the total working area of was found. Thus, RapidEye satellite image calculated that the amount of carbon stored in the 9 917 ha study area that is mostly covered in Scotch pine and located in the 61 646 ha Camyazi Forest Directorate is 285 208 tons.

## CONCLUSION
## RASPRAVA

Forests are the largest carbon deposits and very important in this sense to the world. There is a linear relationship between the amount of woodland areas and the amount of carbon stored. Also in the context of the Kyoto Protocol, woodlands and the amount of carbon stored here is very important for the carbon exchanges in the coming years.

In the study, forestry plan inventory data and remote sensing techniques were utilized to determine the amount of carbon deposited in the stand within the boundaries of the Camyazi Forest Directorate. As a result of the calculations made, using the RapidEye imagery and a $(Band\ 4)^2$ devised equation producing $R^2$=0.71 depending upon the data from Erzurum Camyazi Forest Directorate, the amount of carbon stored within stand was found 285 208 tons. From this value, we can conclude that average carbon stock of the study area is 28.8 tons/ha.

Remote sensing techniques used in this study showed that these techniques can save time, budget and labor when calculating carbon stock capacity data (which is rather time and resource consuming to calculate) and accurate results may be achieved. Besides, the study showed that the Red-Edge band (Band 4) of RapidEye satellite image that is sensitive to biomass and chlorophyll can be used in studies related to carbon stock. When the study conducted by Myeong et al. (2006) and our study are compared, it became clear that both manifest accuracy rates close to one another.

Equations of biomass and carbon stock for each type of tree have not yet been completed. They have to complete as soon as possible and the carbon stock capacity needs to be identified more accurately. When calculating the capacity for this type of study, the financial side of the study has to be considered and combined methods with low costs have to be preferred.

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## Sažetak

Postoje tri glavna nalazišta ugljika na svijetu. To su atmosfera, zemaljski i oceanski ekosustavi. Šume su najveće zemaljsko nalazište ugljika. Postoji linearni odnos između količine šumskih područja i pohranjenog ugljika. Također, u kontekstu Kyoto protokola, šumska zemljišta i količina pohranjenog ugljika jako su važni za razmjenu ugljika u nadolazećim godinama.

Svrha ovog istraživanja je formalizirati jednadžbu regresije između kapaciteta pohrane nadzemnog ugljika izračunatog kroz ekstenzivni terenski pregled 344 područja uzoraka u Direkciji šuma Camyazi, Turska, te vrijednosti refleksije koje odgovaraju svakom uzorku od slika RapidEye.

U istraživanju su se koristili inventarni podaci plana gospodarenja te tehnike daljinskog istraživanja za utvrđivanje količine ugljika pohranjene u sastojini unutar granica Direkcije šuma Camyazi, Turska. Kao rezultat izvršenih kalkulacija, korištenjem slika RapidEye te $(\text{Pojas } 4)^2$ izvedene jednadžbe koja daje $R^2$=0.71, ovisno o podacima Direkcije šuma Erzurum Camyazi, utvrđeno je da je količina ugljika pohranjena u sastojini iznosila 285 208 tona. Iz te vrijednosti možemo zaključiti da je prosječna pohrana ugljika u ispitivanom području 28.8 tona/ha.

Tehnike daljinskog istraživanja korištene u ovome istraživanju pokazale su da te tehnike mogu uštedjeti vrijeme, financijska sredstva i posao kod izračuna podataka kapaciteta pohrane ugljika (koje zahtijeva prilično vremena i sredstava za izračun), a mogu se dobiti precizni rezultati. Uz to, istraživanje je pokazalo da je Red-Edge pojas (Pojas 4) satelitske slike RapidEye-a osjetljiv na biomasu i klorofil se može koristiti u istraživanjima povezanim s pohranom ugljika.

Jednadžbe za biomasu i pohranu ugljika za svaku vrstu šumskog drveća još nisu dovršene. Trebaju se dovršiti što je prije moguće i kapacitet pohrane ugljika treba se točnije utvrditi. Kod izračuna kapaciteta za ovaj tip istraživanja treba uzeti u obzir financijsku stranu istraživanja uz preferiranje kombinirane metode s niskim troškovima.

**KLJUČNE RIJEČI**: nadzemna biomasa, pohrana ugljika, daljinska istraživanja, RapidEye