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Relationships between Soil Moisture and RADARSAT derived Backscattering Coefficient Values: a case studies in Artvin-Merkez and Gümüşhane-Karanlıkdere Forest Planning Units

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Abstract: The purpose of this study was to determine the relationships between soil moisture and backscattering coefficient values calculated for each sampling plot and compare with soil moisture in different forest sites and crown closure classes using Radarsat satellite images in Artvin-Merkez and Gümüşhane-Karanlıkdere forest planning units. Results indicate that in low coverage and degraded forest areas in dry and fresh-moderate fresh forest sites in Artvin forest planning unit, the relations between soil moisture and backscatter coefficient values were negatively correlated with r=-0.85 and r=-0.73, respectively. However, there was no relationship between backscatter coefficient values and soil moisture in medium crown coverage and full coverage stands. Similarly, at low coverage and degraded forest areas in very dry-dry and fresh-moderate fresh forest sites in Gümüşhane-Karanlıkdere forest planning unit were positively correlated high and significant r=0.78 and r=0.83, respectively.
Keywords: Crown closure, Soil moisture, Radarsat image.

Toprak Nemi İle Radarsat Geri Yansıtım Değerleri Arasındaki İlişkiler; Artvin-Merkez ve Gümüşhane-Karanlıkdere Orman Planlama Birimi Örnekleri

Özet: Bu çalışmanın amacı, Artvin-Merkez ve Gümüşhane-Karanlıkdere planlama birimlerinde farklı yetişme özellikleri ve farklı meşcere kapalılığına sahip örnek alanlardan elde edilen toprak nemi ile Radarsat uydu görüntüsü kullanılarak her bir örnek alandan elde edilen geri yansıtım değerleri arasındaki ilişkilerin belirlenmesidir. Artvin-Merkez planlama biriminde kuru ve taze-tazece yetişme ortamları ile düşük ve bozuk orman alanlarında toprak nemi ile geri yansıtım değerleri arasında sırasıyla negatif ilişkiler bulunmuştur (r=-0.85 ve r=-0.73). Buna karşın, orta ve tam kapalı meşcerelerde herhangi bir ilişki bulunamamıştır. Gümüşhane-Karanlıkdere planlama biriminde ise çok kuru-kuru ve taze-tazece yetişme ortamları ile düşük ve bozuk orman alanlarında toprak nemi ile geri yansıtım değerleri arasında sırasıyla pozitif ilişkiler bulunmuştur (r=0.78 ve r=0.83)
Anahtar Kelimeler: Meşcere kapalılığı, Toprak nemi, Radarsat uydu görüntüsü

Introduction

Forest management decisions and land-use planning including afforestation activities and silvicultural prescriptions are based on sound site information to formulate suitable management actions on the ground in Turkey (Altun, 2008). Generally, indirect method, expressed in terms of site index, which is defined as the dominant height of a population of trees at a specific reference age (Dieguez-Aranda, et al, 2006), is used in determining forest sites in Turkish forestry. Determining forest sites according to direct method, soil moisture and available water holding capacity of the soils are mainly taken into account as they are very important parameters in forest sites classification. The available water holding capacity is very important to tree species, density and production of the forest (Pan et al., 2006). The availability of 'soil moisture' is taken as a potential factor for forest development. Therefore, land with sufficient soil moisture is regarded to be a potential area for forest development (Bhagat, 2009). Though accurate forest site productivity may not be fully represented by indirect method, it is the most practical method extensively used in most part of the world. Even though indirect method is the most widely accepted method for estimating site productivity, it does not reflect the forest sites appropriately when a forest is expressed particularly with low crown closure, treeless and degraded areas in Turkish forests (Altun, 2008; Günlü et al., 2009). In this respect, forest site classification has long been a problem for managers of Turkish forests.

The direct method takes into consideration of edaphic, climate and topographic factors as they are time-demanding, expensive and hard to conduct for larger areas. Thus, it necessitates the use of powerful information technologies such as Geographic Information Systems (GIS) and Remote Sensing to help develop forest site maps. Recent developments in remote sensing technology have showed that soil moisture can be measured by a variety of remote sensing techniques. Radar satellite images have been used to ensure such information for various regions of the world (Brucker et al., 1988, Bertuzzi et al., 1992; Mattikalli et al., 1998). In determining soil moisture using active microwave radar has been used an active area of study for the past twenty years. Microwave remote sensing is delicate to soil moisture since its dielectric constant (Wang et al., 2004). Surface soil moisture content (0-5 cm) is very important for many applications involving monitoring differential drying patterns and assessing water availability for plant development (Hymer et al., 2000). Previous researches indicated that soil moisture can most accurately be to bring out in the upper 5 cm of the soil profile using SAR (Engman and Chauhan, 1995).

Radar satellite images present benefits for monitoring near-surface soil moisture (0-5 cm), involving synoptic, timely coverage with repeat passes and day or night operational capability. For these reasons, the radar satellite image techniques are used to monitor surface soil moisture (Bindlish and Barros, 2000; Ahmad et al., 2010; He et al., 2014; Zwieback et al., 2015). The important difficulties in retrieving the soil moisture with SAR images are due to soil texture, surface roughness and vegetation cover. The quantity of moisture stored in the upper soil layer changes the electric constant of the material and then affects the SAR return. Since the dielectric constant for water is at least 10 times bigger than that of dry soil, the presence of water in top few centimeters of bare soil can be detected in SAR imagery (Lillesand and Kiefer, 2000).

When the radar signal strikes the Earth’s surface, part of the signal is reflected back to receiver. The reflected portion of the signal is called backscatter. Radar backscatter intensity is very important factor in radar satellite images. However, radar backscatter is not directly related to soil moisture. It is also influenced by soil roughness, amount of vegetation, structure and system parameters such as incidence angle and frequency (Wang et al., 2004). Surface roughness and vegetation influence backscatter more than soil moisture (Zribi and Dechamber, 2002; van Oevelen and Hoekman, 1999). Because most areas where the water availability is of great importance are covered by vegetation, the use of the satellite data in soil moisture estimation is thus limited. Due to the backscatter from vegetation over the soil, the best results are produced when detecting soil moisture from bare soil or low vegetation. Dense forest canopies prevent the estimation of soil moisture underneath.

The present paper focuses on comparing and understanding the relationships between two images from the Radarsat satellite that were processed and correlated to ground measured soil moisture values to both crown closure classes and forest sites in Artvin-Merkez forest planning unit located in eastern part of Turkey and Gümüşhane-Karanlıkdere forest planning unit located in northeastern part of Turkey.

Material and Methods

Study Area

The study area comprises both Artvin-Central and Gümüşhane-Karanlıkdere forest planning units. The research area of Artvin-Central forest planning unit covers Genya Mountain within the management district of Artvin Central State Forest Enterprise, between 41°32′00″–41°07′30″ north latitudes and 41°32′00″–41°53′00″ east longitudes, an area within the Eastern Black Sea region of Turkey (Fig1a). Elevation ranges from 750 to 2,047 m with an average of 1,430 m. The study area situates on a step topographic surface with a slope ranging from 32% to 90%, with an average of 65%. Mean annual temperature is 6.6°C and the precipitation is 1,157 mm (Anonymous, 2001b). The study area covers mixed stands of spruce (*Picea orientalis*) and beech (*Fagus orientalis*) and pure stands of spruce (*Picea orientalis*).

The Karanlıkdere forest planning unit is between 40°17′39″–40°20′28″north latitudes and 39°11′14″–39°14′ 06″east longitudes, an area within the Eastern Black Sea Region, Turkey (Fig1b). Elevation of the research area ranges from 1,545 m to 2,270 m with an average of 1,908 m. The study area is situated on a steep topographic surface with a slope ranging from 33% to 70%, with an average of 50%. The area is located in the upper land of Harsit River which carries the effects of the sea to the inland. But the climate of this area is generally moist and has low temperature with high level water shortages during vegetation period, almost nearing to the continental climate. Mean annual temperature is about 5.5°C and the precipitation is 792.7 mm (Anonymous, 2001a). The study area covers mixed stands of pine ‘‘(*Pinus sylvestris L.*) and fir (*Abies nordmanniona subsp. nordmannianna* (Stev) Spach.’’ The forest structure is even-aged.

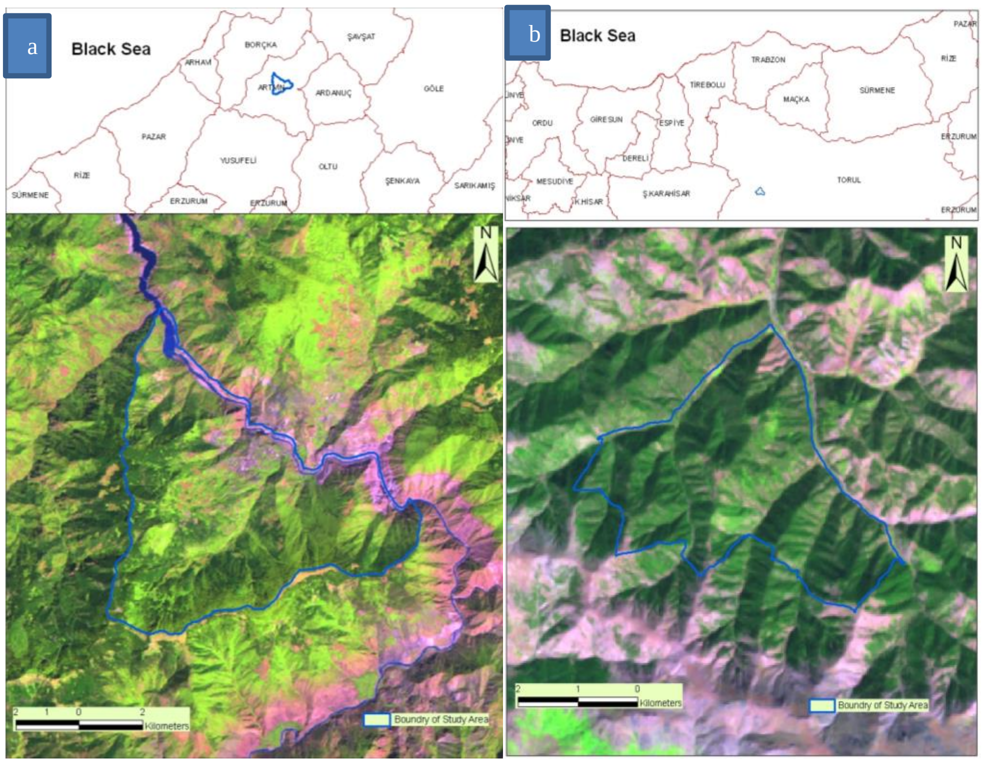

Figure 1. The research area and boundary a) Artvin- Central b) Gümüşhane-Karanlıkdere forest planning unit.

Data Sources

The data used in this study involve Radarsat satellite images (acquired in August 25, 2006 for Artvin Central forest planning unit and September 17, 2004 for Gümüşhane-Karanlıkdere forest planning unit) images and field soil moisture sampling (112 sampling points for Artvin planning unit and 122 for Gümüşhane-Karanlıkdere Planning unit). Additionally, forest cover type map is used to determine the relationships between soil moisture and backscatter values. Crown closure classes are also used in this study.

Classification of Forest Sites and Crown Closures

The forest sites already identified by the direct method such as very dry, moderate fresh, fresh and moist in Artvin- Central Planning unit (Altun et al., 2008) and very dry, dry, moderate fresh and fresh in Gümüşhane-Karanlıkdere planning unit (Altun et al., 2008; Bakkaloğlu, 2003) are used in this study. Crown closure classes were used to determine the relationships between soil moisture and forest sites. Crown closure, also known as crown cover, is the percentage of ground covered by a vertical projection of the outermost perimeter of the crowns in a stand. Crown closure classes were obtained from forest cover type maps (2006 for Artvin Central planning unit and 1987 for Gümüşhane-Karanlıkdere planning unit) related to these research areas. Crown closures were classified into four classes, 1 (low coverage of 11-40%), 2 (medium coverage of 41-70%), 3 (full coverage of 71-100%), degraded forest (sparsely distributed, 0-10% closure) in Artvin-Central planning unit and three classes, 1 (low coverage of 11-40%), 2 (medium coverage of 41-70%) and degraded forest (sparsely distributed, 0-10% closure) in Gümüşhane-Karanlıkdere planning unit.

Soil moisture is liquid water occupying the empty spaces among soil particles. The soil moisture value for a particular soil is the ratio of water to soil. In this study, soil moisture samples were taken in 0-10 cm portion from 234 sample plots. Then, soil samples were air-dried, grounded and sieved through a 2 mm-mesh-sized sieve before further analysis and gravimetric soil moisture values were calculated. Different GPS readings were taken at each sample plot to permit accurate link to soil moisture data to Radarsat pixels. Gravimetric soil moisture was calculated based on the ‘double weight’ method as delineated in Rowell (1994) and then transform to volumetric soil moisture (%) based on the known bulk density of soil at both sites.

Image Analysis

Radarsat images, received from active remote sensors, were used due to its availability, timely repeat coverages (temporal resolution) for the specified field area, and its relatively recent availability. Radarsat operates at C-band, 5.6 cm wavelength and 5.3 GHz frequency with HH polarization. Radarsat images have bean mode, descending at an incidence angle of 23°. Both Radarsat images have pixel resolution of 12.5 x 12.5 m.

In order to relate radar information with physical characteristics of the earth in Radarsat satellite images, radar calibration should be needed. Because further phases like image registration and speckle suppression have to be processed, we took the linear scale and not dB scale as the calibration result. Through calibration, the digital number of each pixel in the raw image was converted to calibrated linear backscattering coefficient (σ^0). If the radar brightness over point and distributed targets is the objective, the output of calibrated result should be given in decibels (dB). Since the study areas are characterized by hilly terrain, backscatter was adjusted according to the local angle of incidence using a Digital Elevation Model (DEM). Calculation of the local angle of incidence for each Radarsat pixel required accurate co-registration of each image to the DEM and the resultant root mean error of the registration was less than one pixel. In general, surface soil moisture content has been predicted with an empirical relationship to transform the measured backscattering coefficient (σ^0) into soil moisture (Dobson and Ulaby, 1986; Ulaby et al., 1996; Sahebi et al., 2003). The data can then be converted from linear (σ^0) to decibels σ (dB) by the following formula (Shimada et al., 2007).

$$\sigma^o = 10x \log10[DN^2] + CF$$

σ^o= backscattering coefficient
DN: the digital number is in Radarsat images.
CF: conversion factor (=-83)

Radarsat images were carried out using Erdas Imagine 9.0™ (Erdas, 2002) using image processing. Subsets of satellite images were rectified using 1/25,000 scale Topographical Maps with UTM projection (ED 50 datum) and first order nearest neighbor rules. A total of 30 ground points were used to register the images. Ground points were used to ensure accurate georeferencing. After the georeferencing was complete, subsets of satellite images were selected from the original satellite images to match the research areas where field sampling took place.

Radar images include some degree or speckle. Microwave signals returning from a given location on the earth’s surface can be in stage or out of stage by varying degrees when received by the sensors. This produces a seemingly random pattern of brighter and darker pixels in radar images (Lillesand and Kiefer, 2000), called speckle. Speckle is a principle characteristic of Radarsat images (Glenn and Carr, 2003) and can be reduced the application of image processing techniques by special filtering. In this study, Radarsat satellite images were filtered with a 3x3 median filter to reduce the influence of speckle and to develop the satellite images for interpretation. This filter smoothes data and reduce speckle. The logic behind the image processing techniques was indicated in Figure 2

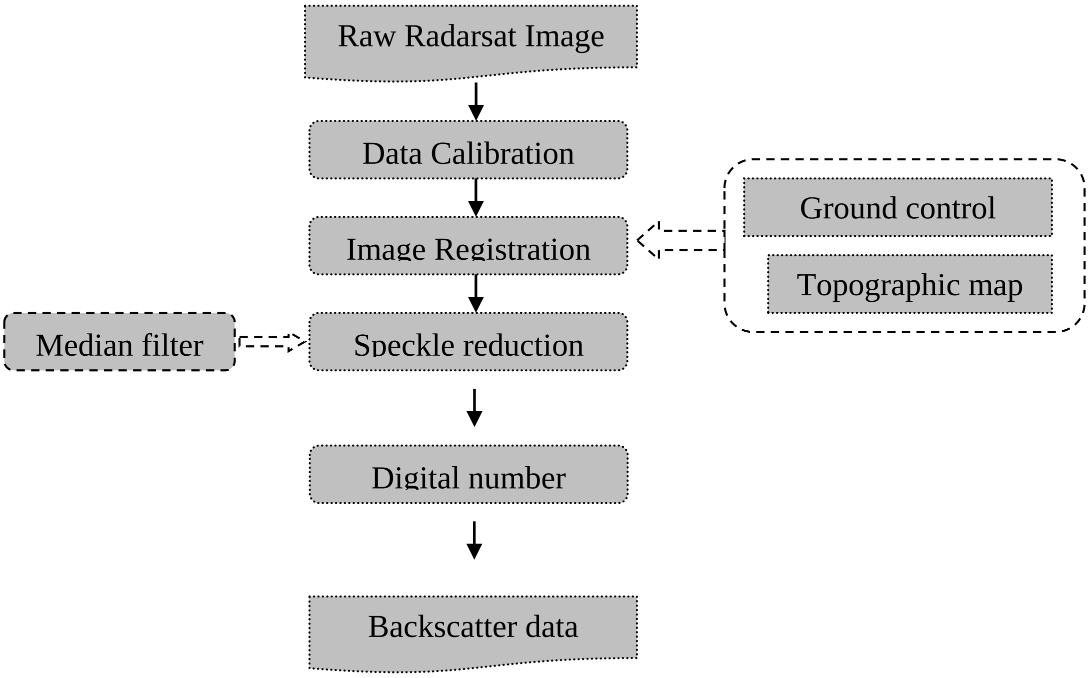

Figure 2. The flowchart showing image processing stages

Statistical Analysis

In each planning unit, soil moisture measured in the upper horizon (0-10 cm) in the field experiment was correlated with backscatter values of these experimental points taken in the Radarsat satellite images. SPSS Cross-Tabulation procedure was used to test statistical analysis in this study (SPSS, 2007).

Results and Discussions

The results obtained from the analyses were evaluated for Artvin and Gümüşhane-Karanlıkdere forest planning units. Results show that there is a direct relationship between backscatter values and soil moisture. The observed correlations were high in crown closure classes of low coverage and degraded forest stands at different forest sites of Artvin and Gümüşhane-Karanlıkdere planning units. However, in medium and full covered stands no relationship could be established between the soil moisture and backscatter values. In dry and fresh-moderate fresh forest sites in Artvin planning unit, we confirmed that the relationships between soil moisture and backscatter values were high and significant, r=-0.85 and r=-0.73, respectively. Similarly, at very dry-dry and fresh-moderate fresh forest sites in Gümüşhane-Karanlıkdere planning unit the relationships were high and significant, r=0.78 and r=0.83, respectively (Figure 3-6). Also, descriptive statistics values related to the figures were given in Table 1-4. Musaoglu (1999) found the similar correlation between soil moisture and backscattering values of JERS. SAR image at three different soil depths (0-0.5, 0.5-6 and 6-20 cm) were found 0.22, 0.60 and -0.90 respectively, in dry forest sites; 0.70, 0.29 and 0.50 respectively, and in moderate fresh forest sites 0.90, 0.51 and 0.78 respectively.

Since the low coverage and degraded forest stands have sparsely distributed vegetation, the estimation of soil moisture was possible in Radarsat images. Therefore, C and X band radar signals can be used on bare soil or little vegetation cover (Baghdadi et al., 2008; Zribi and Dechambre, 2002; Zribi et al., 2008). Other researches have also studied the relationships between about soil moisture and backscatter in SAR images. Moeremans and Dautrebande (2000) confirmed that it was useful to identify bare or sparsely vegetated fields with a value of 0.70 and for agricultural bare soil fields with a value of 0.75. Hutchinson (2003) found that the correlations between soil moisture and backscatter values were r=0.62 and r=0.67 for burned and unburned areas, respectively. Eric et al. (2009) found a positive (r = 0.74) correlation between backscatter and soil moisture in sites dominated by herbaceous vegetation cover and a negative (r = − 0.82) correlation in all open (non-forested) areas using ERS SAR image. Notarnicola et al. (2006) confirmed a correlation coefficient between 0.52 (horizontal polarization) and 0.56 (vertical polarization) between C-band AirSAR measurements and soil moisture. Balik Sanli et al. (2008) found that the correlation between soil moisture and backscattering value of Radarsat, Asar and Palsar images were 0.81, 0.76 and 0.86, respectively.

Almost half of forest areas are degraded in Turkey creating a serious problem in determining sites with appropriate indirect method. As the target trees (dominant and co-dominant) in the degraded areas have been cut down either with management plan or irregular disturbances, it is almost impossible to find suitable (or target) trees to determine sites with indirect method. Therefore, it is possible that active satellite images should be used to determine forest site classification in degraded, open and treeless area.

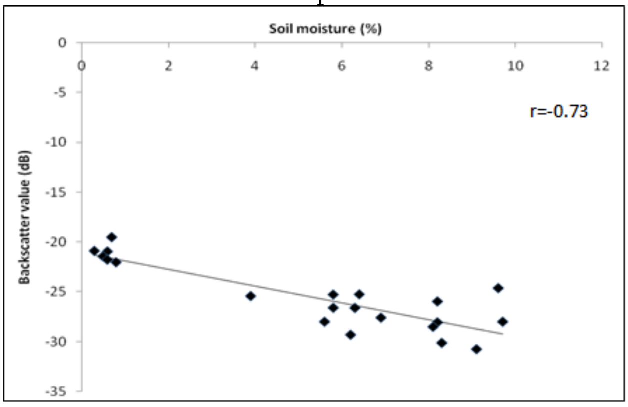

Figure 3. Relationship between soil moisture and backscatter values at low crown closure and degraded forest in fresh and moderate fresh forest sites in Artvin-Merkez forest planning unit

Table 1. Descriptive Statistics for fresh and moderate fresh forest sites

	N	Minimum	Maximum	Mean	Std. Deviation
Backscatter value	21	,30	9,70	5,3143	3,37421
Soil moiture	21	-31,00	-20,00	-25,5714	3,27981
Valid N (listwise)	21				

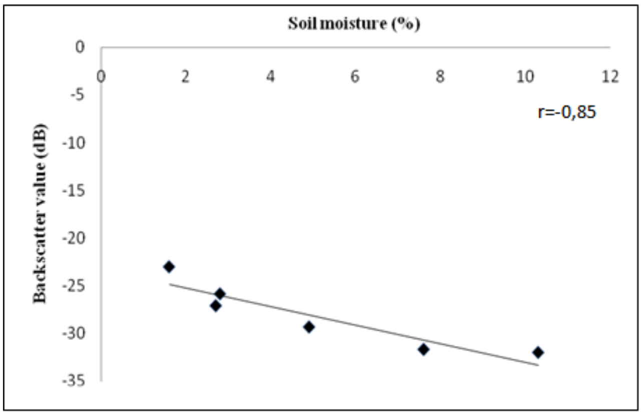

Figure 4. Relationship between soil moisture and backscatter values at low crown closure and degraded forest in dry forest sites in Artvin-Merkez forest planning unit

Table 2. Descriptive Statistics for dry forest sites

	N	Minimum	Maximum	Mean	Std. Deviation
Backscatter value	6	-30,00	-23,00	-27,3333	2,87518
Soil moiture	6	1,60	10,50	5,1333	3,40451
Valid N (listwise)	6				

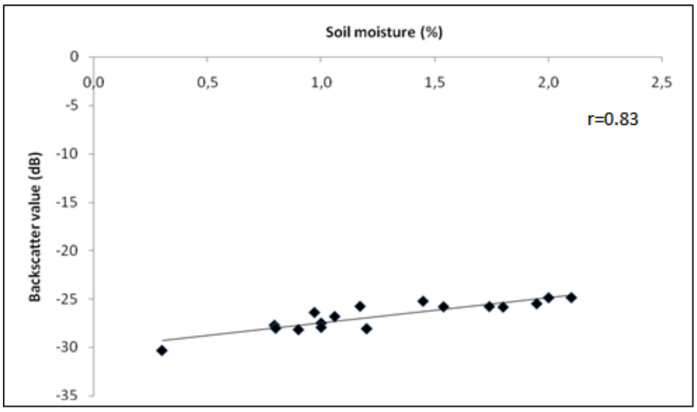

Figure 5. Relationship between soil moisture and backscatter values at low coverage and degraded forest in fresh and moderate fresh forest sites in Gümüşhane-Karanlıkdere forest planning unit.

Table 3. Descriptive Statistics for fresh and moderate fresh forest sites

	N	Minimum	Maximum	Mean	Std. Deviation
Backscatter value	17	-31,00	-26,00	-27,2353	1,30045
Soil moiture	17	,30	2,10	1,3059	,49431
Valid N (listwise)	17				

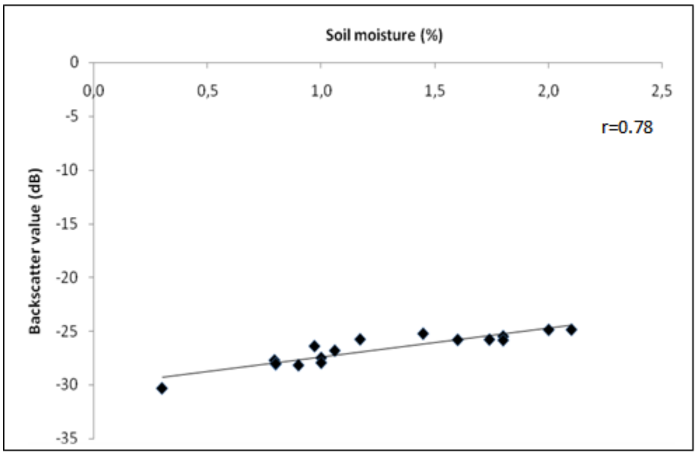

Figure 6. Relationship between soil moisture and backscatter values at low coverage and degraded forest in very dry and dry forest sites in Gümüşhane-Karanlıkdere forest planning unit

Table 4. Descriptive Statistics for very dry and dry forest sites

	N	Minimum	Maximum	Mean	Std. Deviation
Backscatter value	15	-31,00	-25,00	-26,6667	1,91485
Soil moiture	15	,50	2,00	1,3067	,41998
Valid N (listwise)	15				

As expected, results showed that measurements of C-band Radarsat backscatters were not correlated with surface soil moisture in the medium and full covered stands in both Artvin and Gümüşhane-Karanlıkdere forest planning units. The inadequate or unsatisfied correlation was due to the fact that the soil moisture estimation was used to reduce the effect of vegetation at top soil surface. Even though radar signals may penetrate vegetation, the interpretation of surface backscatter is usually difficult because of interactions between vegetation and underlying soils (Wang et al., 2004). In addition, the current dense and high vegetation cover decreases X and C band radar signals from attaining the ground values (Ulaby et al., 1986; Bagndadi et al., 2008). Eric et al. (2009) found that there was no relationship between backscatter and soil moisture in the forested (black spruce dominated areas) wetland site. Therefore, when the vegetation density is higher in medium and full covered stands, the Radarsat backscatter is primarily from vegetation grade and the soil moisture estimation is not possible in Radarsat images. However, since the area is not under heavy management over few decades in full covered stands in Artvin-Merkez planning unit and thus the target trees have not been cut down either with management plan or irregular disturbances, it is possible to find appropriate trees to determine sites with indirect method.

Conclusions

The results obtained from the present work indicate that it is possible to estimate the soil moisture from Radarsat images particularly in low coverage and degraded forest stands as the trees or vegetation are sparsely distributed and have low vegetation., However, where vegetation density is higher in medium and full covered stands, the Radarsat backscatter is primarily from vegetation grade and the soil moisture estimation is not possible in Radarsat images. Thus, L-band data of the Radarsat or other SAR image that is designed to achieve high performance and flexibility can be used successfully for monitoring in areas where high vegetation density occurs.

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