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Spatial variability of soil organic carbon density under different land covers and soil types in a sub-humid terrestrial ecosystem

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Abstract

The main objectives of the current study are i) to estimate SOC in different soil depths and to generate their spatial distribution maps, ii) to assess relationship between variation of different soil types and SOC density, iii) to determine effects of land cover types on SOC in Inebolu Watershed located in sub-humid terrestrial ecosystem. In order to determine land cover types of the study area, aster satellite image was used and five main land cover types that are bare land, sparsely vegetated area, broadleaved forest area, mixed forest area and needleleaved forest area were classified. Results indicated that soil types and land cover were two crucial influencing factors for spatial variation of SOC density. It was determined that SOC density of soil types, Vertic Haplustept (12.93 kg.m^{-2}) was significantly higher than other soil subgroups. In this case, it can be said that main reasons of this result are indicated as soil profile depth and pedological development. In addition, when comparing the two main factors, land cover explained more of the SOC density variability and was the main controlling factor in the surface; in the subsurface, not only land cover types but also some properties of soil types such as texture, genetic horizons, soil depth have an important role on SOC density. On the other hand, it can be conclude that the combination of the soil type and land cover was a dramatically better predictor of SOC density.

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Introduction

Soil organic carbon (SOC) stock has a great importance component in any terrestrial ecosystem, and is any variation in its abundance and composition has important effects on many of the processes that occur within this system (Vasconcelos et al., 2014; İmamoğlu and Dengiz, 2016). The magnitude of organic matter and soil organic carbon (SOC) stock result from an equilibrium between the inputs (mostly from biomass detritus) and outputs to the system (mostly decomposition and transport), which are driven by various parameters of natural or human origins (Schlesinger and Palmer Winkler, 2000; Amundson, 2001; Khan and Kar, 2017). The decrease of organic matter in top soils can have dramatic negative effects on water holding capacity of the soil, on structure stability and compactness, nutrient storage and supply and on soil biological life (Sombroek et al., 1993). These cause mainly a combination of unfavorable natural biophysical conditions and negative human impacts. The negative human impacts are mainly the result of inappropriate land use, including deforestation, overgrazing and inappropriate agricultural practices that lead to soil erosion, salinization and vegetation degradation, which are strongly linked to harmful changes in hydrological processes that affect the soil water and carbon balance.

The SOC stock in terrestrial ecosystems is almost thrice as large as the carbon storage in the plant biomass of such environments and approximately twice as large as carbon storage in the atmosphere (Batjes and

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Sombroek, 1997; Grimm et al., 2008; Sevgi et al., 2011). The carbon balance of terrestrial ecosystems can be changed markedly by the direct impact of human activities. Land use change is responsible for 20% of the global anthropogenic CO_2 emissions during the 1990s (Anonymous, 2007). The type of land use system is an important factor that controls SOC levels particularly in the top soils. Changes of land use and management practices influence the amount and rate of SOC losses (Guggenberger et al., 1995). The clearing of forests or woodlands and their conversion into farmland in the terrestrial ecosystem reduces the soil organic carbon content, mainly through reduced production of detritus, increased erosion rates and decomposition of soil organic matter by oxidation. Many researchers agree and their results have confirmed that soil organic carbon associated with different land uses varies dramatically at the regional or catchment scale (David White II et al., 2009; Zhang et al., 2011; Jaiarree et al., 2011). Based on 1407 soil profiles in Laos, Chaplot et al. (2009) found that median SOC density under forestland (112.0 $Mg.ha^{-1}$) is significantly higher than continuous cultivation (108.8 $Mg.ha^{-1}$) management at 0-30 cm depth. Chiti et al. (2011) found that mean SOC density under rice field soils (63.3 $Mg.ha^{-1}$) is significantly greater than arable land soils (53.1 $Mg.ha^{-1}$) at 0-30 cm depth in Italy, using a database created from the national project and regional map reports. Land use can reflect differences in regional scale SOC spatial distribution, expressing its dominant influence at the hillside and catchment level (Fang et al., 2012). In addition, conversion of forests to pasture did not change soil carbon (Guo and Gifford, 2002) or may actually increase the soil organic matter content (Sombroek et al., 1993). Changes in soil carbon under shifting cultivation were half as large (Detwiler, 1986). Commercial logging and tree harvesting did not result in long-term decreases in soil organic matter (Knoepp and Swank, 1997; Houghton et al., 2001; Yanai et al., 2003). Changes in the amount of soil organic matter following conversion of natural forests to other land uses depend on several factors such as the type of forest ecosystem undergoing change (Rhoades et al., 2000), the post conversion land management, the climate (Pastor and Post, 1986) and the soil type and texture (Schjønning et al., 1999).

The main objectives of the current study are i) to estimate SOC in different soil depths and to generate their spatial distribution maps, ii) to assess relationship between variation of different soil types and SOC density, iii) to determine effects of land cover types on SOC in İnebolu Basin.

Material and Methods

Field Description of the Study Area

The study area, Inebolu Basin, found in border of Kastamonu province geographically located in west part of the Black Sea region of Turkey is coordinated at 4636000-4648000 N and 557000-569000 E (UTM-m) and the total area is approximately 114 km^2 (Figure 1).

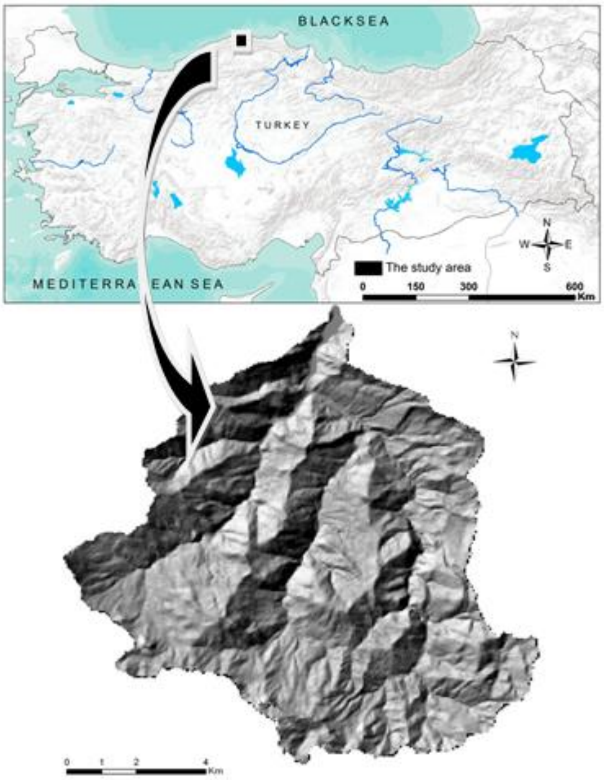

Figure 1. Location map of the study area

Mean sea level altitude of the Basin is 621 m. The study area is representativeness of semiarid catchments and the mean annual temperature, rainfall, average relative moisture and evaporation are 1033 mm, 13 °C, 75% and 680.58 respectively. According to Soil Survey Staff (Anonymous, 1999), soil temperature and moisture regime are mesic and ustic. The study area consists of various topographic features (flat, hilly, rolling etc.) particularly includes mountainous highland areas and slope varies between 2% and 45%. The underlying bedrocks within the study area consist of quartzit-quartz schist, andesine, sand stone-mud stone, and lime stone. Land use and vegetation of the study area are generally, covered by forest, arable land and pasture.

Methods

Soil sampling

Two kinds of soil sampling methods which are surface and profile were used to determine soil organic carbon density in the Basin. Soil samples were obtained from surface in random system (Figure 2).

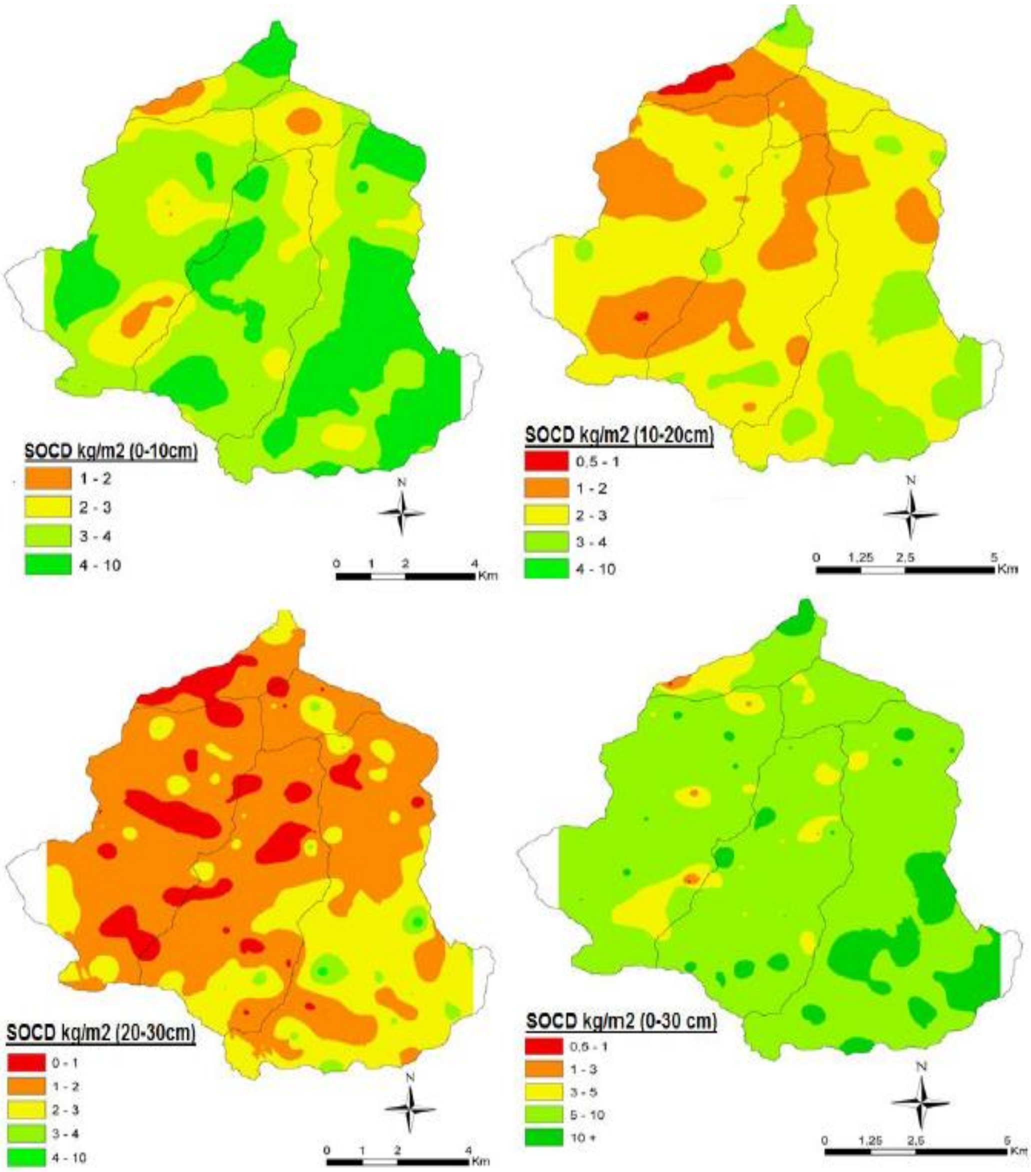

Figure 2. Spatial distribution maps of the SOCD for each depth

Total 230 soil samples were collected from surface (0-20 cm) for each land use and land cover. In addition, 32 soil profiles were investigated and described. 61 soil samples were taken from each horizon of profiles. The samples were transported to the laboratory. The soil samples were crumbled gently by hand without root material. These samples were used to determine some physico-chemical properties such as bulk density and organic matter. Selected soil properties were determined by the following methods: Bulk density (Blacke and Hartge, 1986) and organic matter was determined in air-dry samples using the Walkley-Black wet digestion method (Nelson and Sommers, 1982).

Soil organic carbon density estimation

For each profile, SOC density (SOCD) was estimated in the soil layer of profile (0-100 cm) with the following equation:

$$\mathrm{SOCD_D} = \sum_{i=1}^{n} \frac{(1-\delta i\%)\,\mathrm{x}\ \rho i\ x\ \mathrm{C}i\ x\ \mathrm{T}i}{100}$$

For each soil depths, SOC density was estimated with the following equation:

$$\mathrm{SOCD_D} = \frac{(1-\delta i\%)\,x\ \rho i\ x\ \mathrm{C}i\ x\ \mathrm{T}i}{100}$$

Where; $\mathrm{SOCD_D}$ represents the SOC density of a soil profile with a depth D (cm); n is the number of pedogenic horizons in the soil survey, δ*i* % represents the volumetric percentage of the fraction > 2 mm (rock fragments), ρ*i* is the bulk density ($g.cm^{-3}$), C*i* is the SOC content ($g.kg^{-1}$), and T*i* represents the thickness (cm) of the layer *i.* The SOC was estimated to a maximum depth of 100 cm.

Interpolation and statistical analysis

Geostatistical method was used to generate SOC distribution map of the study area for surface and subsurface soils for both depth, values of SOC were described with classical statistics (mean, standard deviation, maximum and minimum mean, and coefficient of variation, Skewness, Kurtosis). In addition, range, nugget and sill variance values were determined using semi-variograms. The degree of spatial dependence of a random variable Z(xi) over a certain distance can be described by the following semivariogram function:

$$\gamma(h)=\frac{1}{2N(h)}\sum_{i=1}^{n}(Z_{(x_i)}-Z_{(x_i+h)})^2$$

Where γ(h) is the semivariance for the interval distance class h, N(h) is the number of pairs of the lag interval, $Z(x_i)$ is the measured sample value at point i, and $Z(x_i+h)$ is the measured sample value at position (i+h). To determine spatial variability of SFI variables, the isotropic semivariogram models as Exponential and Gaussian were used.

The isotropic exponential model:

$$\gamma(h)=C_0+C\left[1-\exp\left(\frac{-h}{a}\right)\right]$$

The isotropic spherical model:

$$\gamma(h)=\begin{cases} C_0+C\left[\dfrac{3h}{2a}-\dfrac{1}{2}\left(\dfrac{h}{a}\right)^3\right] & 0\le h\le a \\ C_0+C & h>a \end{cases}$$

Where; Co is the nugget variance ≥0, C is the structural variance ≥ Co, (Co+C) is the sill variance, and is the range of spatial correlation.

Geostatistical software (GS+ 7.0, 2007) was used to construct semivariograms and spatial structure analysis for variables. In addition, maps of SOC variables for each depth (surface and subsurface soils) were produced by kriging technique (Isaaks and Srivastava, 1989) using ArcGIS 9.3v geography information system program.

Results and Discussion

Estimation of SOCD in different soil depths and interpolation maps

Accumulation or reduction soil organic carbon content can be markedly noticed in surface soil due to shifting land use types and land cover in short term. Various reviews agree this case that the loss amounts to 20 to 50% of the original carbon in the topsoil, but deeper layers would be little affected, if at all (Murty et al., 2002; Guo and Gifford, 2002). On the other hand, conversion of forests to pasture did not change soil carbon (Guo and Gifford, 2002) or may actually increase the soil organic matter content (Sombroek et al., 1993). The descriptive statistics properties of SOCD for different depths are presented in Table 1.

Table 1. Descriptive statistics of the SOCD for each depth

	Depths of SOCD			
Properties	0-10 cm	10-20 cm	20-30 cm	0-30 cm/total
Mean	3.56	2.35	1.69	7.59
Standard Deviation	1.31	0.99	0.88	2.71
Sample Variance	1.72	0.997	0.77	7.37
Minimum	0.21	0.18	0.06	0.44
Maximum	7.27	4.91	4.85	15.39
Skewness	-0.01	0.26	0.65	0.25
Kurtosis	-0.2	-0.39	0.37	0.13
Samples (n)	230	230	230	230

According to Table 1, it can be seen that mean value of SOCD decreases with increasing soil depth and varies between about 3.6 kg.m^{-2} and 1.7 kg.m^{-2}. In addition to that, it was determined SOCD level between 0.44 and 15.39 kg.m^{-2} in 0-30 cm for each soil samples.

Geostatistics provides a set of statistical tools for incorporating spatial coordinates of observations in data processing (Loganathan et al., 2007). It also provides a tool to optimise sampling design and interpolate to unsampled locations, taking into account the spatial correlation of adjacent pixels based on the semi-variance. This procedure is optimal in that estimates are unbiased and the estimation variance is minimal (Di et al., 1989). This technique has been widely applied by soil scientists (Leenaers et al., 1990; Kravchenko and Bullock, 1999; Başkan and Dengiz, 2008). The isotropic exponential and model provided the best fit value for the computed semi-variance points for SOCD in this study. The experiment semivariogram depicts the variance of the sample values at various separation distances (Hani et al., 2010). The ratio of nugget to sill (nugget/sill) can be used to express the extent of spatial autocorrelations of environmental factors. If the ratio is low (<25%), the variable has strong spatial autocorrelations at a regional scale. A high ratio of the nugget effect (>75%) indicates spatial heterogeneity of soil properties. In this study, low ratio of nugget to sill (less than 25%) was found for each depth of SOCD indicated the existence of a strong spatial auto-correlation (Table 2).

Table 2. Parameters of isotropic models for best fitted semi-variogram models of SOCD for each depth.

Depth (cm)	Model	Nugget	Sill	Range	RSS	R^2	Nugget/Sill ratio (%)
SOCD (0-10)	Spherical	0.247	1.340	2916	0.0148	0.975	18.43
SOCD (10-20)	Spherical	0.141	0.638	2954	7.024×10^{-3}	0.943	22.10
SOCD (20-30)	Exponential	0.001	0.407	2028	1.801×10^{-3}	0.942	0.25
SOCD (0-30)	Exponential	0.100	4.309	2202	0.223	0.969	2.32

Assessment of relationship between variation of different soil types and SOCD

The parameters of the spherical and exponential models were used for kriging to produce the spatial distribution maps of SOCD for each depth in soils in the study area. These maps are shown in Figure 2 and SOCD were classified at four and five levels in Table 3.

Table 3. Distribution of SOCD for each depth

Class	Description (kg.m^{-2})	Area (ha)	Ratio (%)	Class	Description (kg.m^{-2})	Area (ha)	Ratio (%)
SOCD (0-10 cm)					SOCD (20-30 cm)		
1	1-2	244.0	2.19	1	0-1	11056.0	9.9
2	2-3	2007.3	18.00	2	1-2	6785.5	60.8
3	3-4	5517.6	49.47	3	2-3	3048.4	27.3
4	4+	3384.4	30.34	4	3-4	200.6	1.8
SOCD (10-20 cm)				5	4+	12.7	0.11
1	0.5-1	110.4	0.99		SOCD (0-30 cm)		
2	1-2	2830.0	25.37	1	0.5-1	1.08	0.01
3	2-3	656.1	58.83	2	1-3	38.8	0.3
4	3-4	1646.1	14.76	3	3-5	704.4	6.3
5	4+	5.4	0.05	4	5-10	9257.8	83.0
				5	10 +	1151.1	10.3

As it can be seen from the Table 3, the highest SOC density coded as forth class for 10 cm soil depth located at south east parts of the study area generally covered by natural forest and pasture whereas, SOC density was determined the lowest level found on north parts of the Basin where generally used for rainfed agriculture. Besides, SOC density is dramatically decreasing with increasing soil depth which trend can be also observe in this study. As for SOCD 10-20 cm and 20-30 cm, more than 4 kg.m^{-2} SOCD value of lands was found in south east part of the study area and they cover about 0.05 and 0.11% of the total area, respectively.

Soil organic carbon is the largest terrestrial carbon pool (Janzen, 2004), and plays an important role in the global carbon cycle. Assessments of SOC density within and among soil types are important in understanding causes and effects of climate or land use changes on the ecosystem CO_2 balance. According to Soil Survey Staff (Anonymous, 1999), major soil groups of the study area were classified as in subgroup level and determined to assess relationship between variation of different soil types and SOC stock (Table 4).

Table 4. Amount of SOCD for each soil types classified by taking into consideration of soil survey staff (Anonymous, 1999)

Order	Suborder	Great Group	Subgroup	SOCD (kg.m^{-2})
ENTISOL	Fluvent	Ustifluvent	Vertic Ustifluvent	2.46
	Orthent	Ustorthent	Lithic Ustorthent	0.87
		Ustorthent	Typic Ustorthent	6.50
INCEPTISOL	Ustept	Haplustept	Lithic Haplustept	6.05
		Haplustept	Typic Haplustept	7.31
		Haplustept	Vertic Haplustept	12.93

The horizon succession of Entisol was defined as A/C or A/R. This means that this soil order had no diagnostic subsurface horizons and low pedogenetic development. Therefore, Entisol can be defined as a young soil formed on sediment alluvial deposit or rock. There are three subgroups which are Lithic Ustorthent, Vertic Ustifluvent and Typic Ustorthent were defined (Figure 3) and it was found their SOC density significantly different mainly stemmed from land cover, soil depth and texture. The highest SOCD value (6.5 kg.m^{-2}) was determined in Typic Ustorthent covered by natural forest and pasture whereas, Lithic Ustorthent located on hillslope position includes the lowest SOCD value due to soil erosion process. In addition, Vertic Ustifluvent which includes high clay content in surface layer has 2.46 kg.m^{-2} SOC. The horizon succession of Inceptisol was defined as A/B/C.

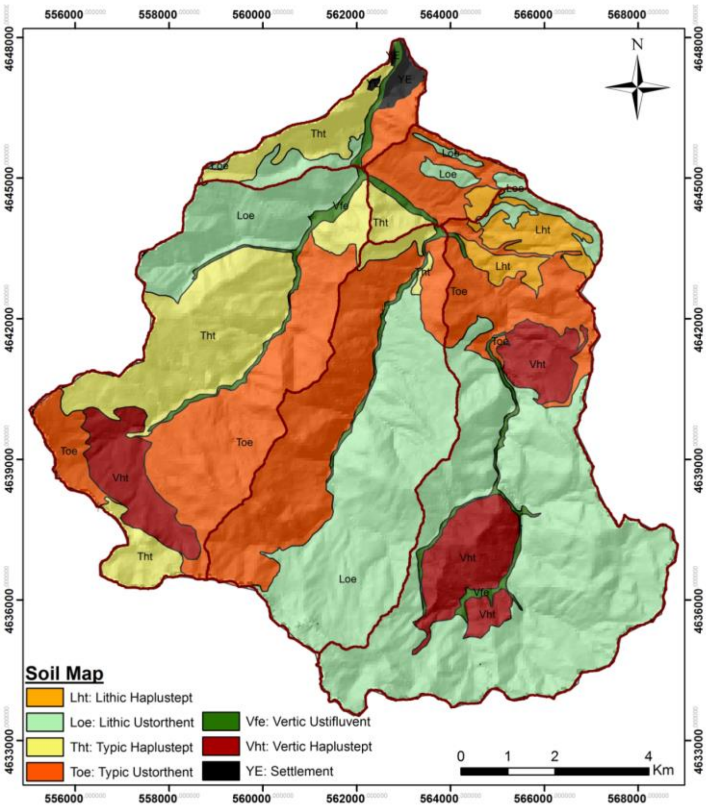

Figure 3. Soil map of the study area

Main subsurface diagnostic horizon for this order is cambic horizon developed as a result of structural formation in soil profile. This order has also three subgroups which are Lithic Haplustept, Typic Haplustept and Vertic Haplustept. Vertic Haplustept has the highest SOC content in the Inceptisol, followed by Typic Haplustept (7.31 $kg.m^{-2}$), Lithic Haplustept (6.05 $kg.m^{-2}$). Moreover, when compared at these two order soil, it can be seen there is a significantly difference between two soil orders. Inceptisol has more SOC content than that of Entisol because of more pedogenic process, soil depth, and fine texture.

Dengiz at el. (2015) also estimated the same results in their study carried out in Madendere Basin. According to their result, Haplustept (37.58 $kg.m^2$) was significantly higher than other soil great groups, flowed by Dystrustept (10.20 $kg.m^2$), Calciustept (5.69 $kg.m^2$), and Ustorthent (3.78 $kg.m^2$). They reported for this result that there were two important cases affected on SOC density in soil types. One of them is mainly pedological development and soil layers' depth and secondly is land use and land covers.

Effect of land cover types on SOCD

Land cover can have a huge impact on soil carbon stocks. Kızılkaya and Dengiz (2010) in a study according to land cover changes in natural forest of Cankiri-Uludere Basin indicated that deforestation and subsequent tillage practices resulted in significant decrease in organic matter and total nitrogen. To determine land cover of the study area, aster satellite image that has 15m x 15m spatial resolution and dated 2013 was used. According to remote sensing analysis, primary land covers are bare land, sparsely vegetated area, broadleaved forest area, mixed forest area and needleleaved forest area (Figure 4). Sparsely vegetated area is the highest land cover in the study area and has about 33.01 % of the total area, followed by broadleaved forest area (27.37%), bare land (14.94%), mixed forest area (14.01%) and needleleaved forest area (10.66%).

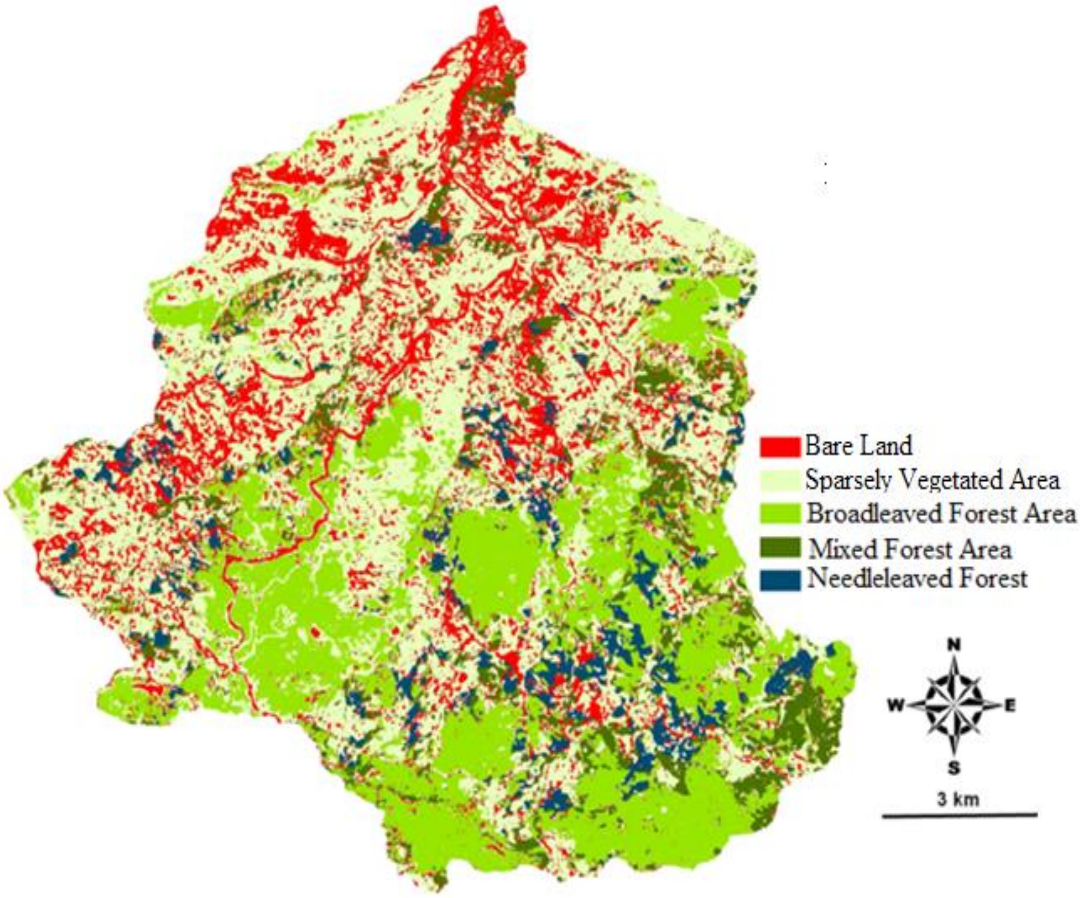

Figure 4. Land Cover maps of the study area

Distribution of SOCD classes under different land cover types for each soil depth was given in Table 5. Result of SOCD distribution for 10 cm soil depth in the Table 5 showed that the highest soil organic carbon density coded as 4. class was found under mixed forest area covering about 1029.5 ha whereas, it was determined that the area of SOC density between 1 and 2 $kg.m^{-2}$ under all land cover types has the lowest distribution in the Basin. As for depth of between 10-20 cm, third class of SOCD has common distribution in the study area.

The highest distribution area for this class was determined under sparsely vegetate cover whereas, 687.6 ha of the total area that includes between 2 and 3 kg.m^{-2} SOC content was detected under needleleaved forest cover. It was also observed that general trend of organic carbon concentration decreases with increasing soil depth under all land cover types. This case can be said for soil depth of between 20-30 cm. The highest SOC density class coded as five was found as the lowest distribution area for each land cover type in the study area. On the other hand, very low and low SOC density classes have common distribution area in the Basin.

Conclusion

In this study it was investigated the relationship between soil type and land cover, with SOC density spatial distribution in the İnebolu Basin. Relative to the subsurface layer, soil type and land cover have a greater impact on SOC density in the surface layer. Comparing the two main factors, land cover explained more of the SOC density variability and was the main controlling factor in the surface; in the subsurface, not only land cover types but also some properties of soil types such as texture, genetic horizons, and soil depth have an important role on SOC density. On the other hand, it can be said that the combination of the soil type and land cover was a dramatically better predictor of SOC density. In addition, the results showed that at the catchment scale, soil type and land cover should be combined SOC spatial distribution and estimate SOC density with the land use and land management priorities

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