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EFFECT OF LAND USE AND TOPOGRAPHIC FACTORS ON SOIL ORGANIC CARBON CONTENT AND MAPPING OF ORGANIC CARBON DISTRIBUTION USING REGRESSION KRIGING METHOD

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Abstract: The study investigates the effects of land use type and topographic properties on soil organic carbon (SOC) in a catchment with a high annual soil loss due to erosion. In addition, the SOC content was determined by modeling the SOC distribution map using the regression-kriging (RK) method. Within this context, the effects of forest land (FL), degraded forest (DF), barren area (BA) and agricultural areas (AA) and different topographic factors (elevation, slope, aspect) on SOC were examined. The catchment had an area of 10675 ha and 429 soil samples were collected to determine the SOC contents of the soils. The results revealed that land use type had a significant effect on SOC and FL had the highest SOC content. However, there was no relationship between elevation and SOC. On the other hand, the SOC content decreased inversely proportional to the slope of the lands. The soil loss due to erosion is considered an important factor causing the decrease. The aspect of the land was also determined to have an important effect on the SOC content. The increase was mostly attributed to relatively less sunlight received by the northern slopes in Turkey. The lands on the northern slopes had the highest SOC content, while the lowest SOC content was determined in the southwest areas. The SOC contents depending on the land use type were close to each other according to the RK and normal regression methods.

Key words: soil organic carbon, land use, soil management, soil ecology, regression kriging

1. INTRODUCTION

Soil organic carbon (SOC) content is among the main indices of soil productivity. Soil is a part of a much larger global carbon cycle involving the conversion of carbon in the plant covers, oceans and atmosphere (Kane, 2015). Soil organic carbon is an important soil property that is affected by land use, topography and agricultural applications (Hijbeek et al., 2017; Singh et al., 2020).

Land use type is an ever-changing and important ecological subject that can affect the properties of soil. Agricultural, forest, pasture and residential areas are constantly changing with increasing population. The use of chemical fertilizers and pesticides to enhance the productivity of soils degrade the physical and chemical properties of soils, thus negatively affecting soil ecology (McKenzie & Ryan, 1999; Ollinger et al., 2002). Topography is an important factor affecting soil properties. Affecting many physiochemical and biochemical events in soil, soil moisture is affected by the slope and aspect of lands (Daniels et al., 1987). In a similar vein, soil temperature is closely related to aspect (Carletti et al., 2009). Various studies have shown that areas that are more exposed to sunlight have higher soil temperature and organic carbon fragmentation and richer underground biomass compared with those of other areas. Qi et al., (2016) in their study, reported that the biological activity is higher in the warmed soils, which causes fragmentation to organic C. On the other hand, areas that receive less sunlight have been reported to have higher soil moisture and richer surface vegetation (Huang et al., 2015; Nahidan et al., 2015; Xue et al., 2018). Land use type also affects soil properties (Paltineanu et al., 2020). SOC, pH, structure and nutrients vary depending on land use type. These properties are negatively affected in agricultural areas with soil cultivation and areas subjected to erosion, while they are positively affected in rich forest lands, pasture lands and meadows (Karlen et al., 2006; Nanganoa et al., 2019).

Spatial estimation and mapping of soil properties play important roles in agricultural production, sustainable land management and land status (Ma et al., 2017; Miller, 2017). In recent years, various soil mapping methods from simple linear models to complex machine learning methods have been used for SOC mapping (Minasny et al., 2008). Kriging interpolation method is a geostatistical method and has recently become popular (Huang & Chen, 2007, Mishra et al., 2009). Kriging and derivation methods are thought to be more accurate and robust for SOC estimation (Hengl et al., 2007, Kerry & Oliver, 2007). Various researchers have previously examined the relationships between SOC and land properties (topography, land use type, etc.) (Li & Lindstrom, 2001; Compos et al., 2007; Achalu et al., 2012; Wubie & Assen, 2019; Paltineanu et al., 2019). However, majority of the studies were carried out using limited areas and low numbers of soil samples. The objective of this study is to investigate the effects of different land use types (forest land-FL, degraded forest-DF, barren area-BA and agricultural area-AA) and topographic factors (elevation, slope, aspect) on soil organic carbon (SOC).

2. MATERIALS AND METHOD

2.1. Study Area

The study sites (Fig. 1) are in the Çapakçur catchment (38°53′58″—38°48′15″ N, 40°16′49″—40°28′35″ E) in Bingöl, Turkey. The catchment has an area of 10675 ha. The region is dominated by the continental climate: Winters are cold and rainy and summers are hot. Long-term climate data recorded for the region reveals that mean annual precipitation is 936.9 mm, mean annual temperature is 12°C (max. 18.4°C, min. 6.4°C) and annual evaporation 1202.5 mm (Demir et al., 2015). The catchment has a rough physiographic structure. It is under a high risk of erosion due to its climate, topography and geological structure (Fig.2). (Yüksel & Avcı, 2015; Demir et al., 2019). The catchment contains forests, pasture areas and agricultural lands. The forest vegetation usually comprise oak (*Quercus* sp.), juniper, quaking aspen, wild pear and birch trees, etc. Fruit trees such as walnut, apple, pear and quince trees and wheat, barley and clover are usually grown in the agricultural areas (Anonymous, 2015).

There are four main land use types in the Çapakçur catchment classified as barren areas (BA), degraded forest lands (DF), fertile forest lands (FL) and agricultural areas (AA) (Fig 3). Barren areas (BA) are areas in which a specific vegetation does not grow and annual herbaceous plants grow sparsely due to erosion and climatic conditions. Degraded forest lands (DF) are barren forest lands created by the disruption of natural oak vegetation due to cutting and grazing. Fertile forest lands (FL) are dominated by forest vegetation and their soils are mostly covered by trees growing in the region (usually oak trees). Agricultural areas (AA) are usually cultivated by people living in the area to meet their own needs.

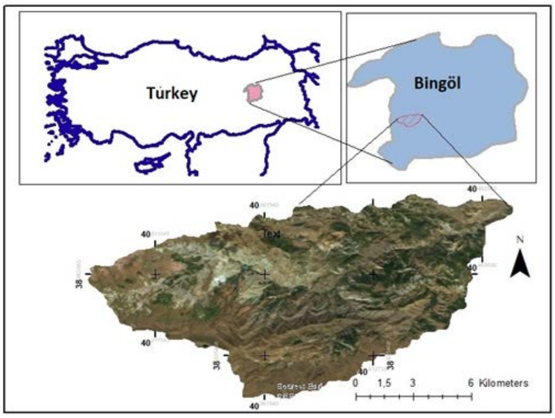

Figure 1. Locations of the study sites

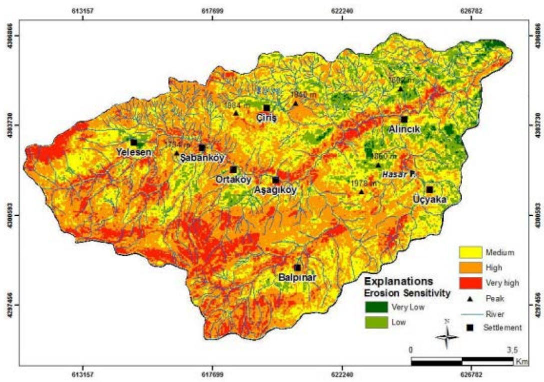

Figure.2 Erosion sensitivity map of Çapakçur catchment (Yüksel & Avcı, 2015)

2.2. Collection and Analysis of the Soil Samples

In the study area, 429 soil samples were collected in 2019 from depths of 0-30 cm using the grid (500 m x 500 m) sampling method (Fig. 4). The soil samples brought to the laboratory were prepared for analysis by grinding, drying and sieving. The organic carbon contents of the soils were determined using the titration method proposed by Walkley & Black (1934). The attributes (elevation, aspect, slope and land use type) and SOC content of each sample were recorded in a computer.

Figure 3. Different types of land in the Çapakçur catchment (a: Forest Land, b: Degraded forest land, c: Barren area, d: Agricultural area)

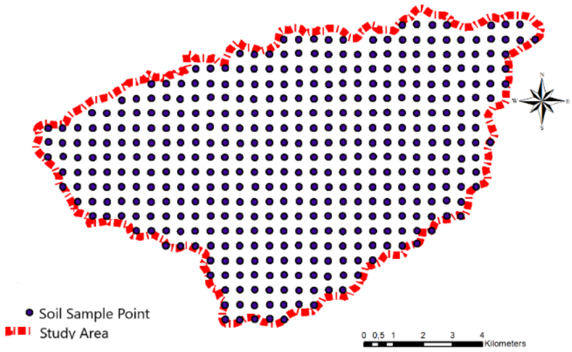

Figure 4. Soil sampling map

2.3. Mapping of the SOC Distribution, Evaluation of the Data and Statistical Analyses

The ArcMAP 10.6 mapping program was used to map the topographic properties of the Çapakçur catchment. The JMP 15 statistics program was used for the statistical evaluation of the data. Variance analysis (ANOVA) was employed to determine the changes in the SOC content depending on the topographic properties.

The topographic properties noted during the collection of the soil samples from the study area and information obtained from the Ministry of Agriculture and Forestry were merged and recorded in the ArcMAP mapping program to obtain a new map. Moreover, the SOC value of each sample was loaded into the ArcMAP program. The slope, aspect, elevation and land use maps of the study area were created using the data.

Furthermore, the map of the percentile distribution of soil organic carbon, which functions as a continental carbon reservoir greatly affecting the productivity of the ecosystem and global climate change, was modeled. The regression kriging (RK) method is a hybrid geostatistical method that has recently become more popular and was used in the study to model the soil organic carbon map of the Çapakçur catchment. Geostatistical methods assume that all values, along with a dependent variable, are results of a coincidental process. The measurements obtained from close locations are more similar to each other than those obtained from locations that are farther from each other. (Matheron, 1962). In this study, the SOC distribution map of the Çapakçur catchment was modeled using the RK method and the

SOC content was determined based on the land use types. RK is a hybrid approach combining deterministic and stochastic processes.

RK was first used by Ahmed & Marsily (1987) in 1987 under the name of "Combination of Linear Regression and Kriging". Odeh et al., (1995) revealed the advantage of the RK method over other kriging methods and their method was published as the regression-kriging method. The RK method was more commonly used and applied after the study carried out by Tomislav et al., (2007). The roots of the RK method can be traced back to the Universal Kriging (UK) method, which is a spatial estimation method using an auxiliary variable introduced by Matheron (1962) (Hengl, 2007).

RK is a hybrid approach combining deterministic and stochastic processes (Fig 5). The realization of the observation of the target variable is denoted by z: $z(s_1)$, $z(s_2)$, … $z(s_n)$, where $s_i = (x_i, y_i)$ are geographical coordinates. The function used in the estimation of the spatial model is (Hengl, 2007):

$$Z(s_0) = E\ \{\ Z \mid Z(s_i), q_k(s_0), \gamma\ (h), s\ \in \mathbb{A}\}$$

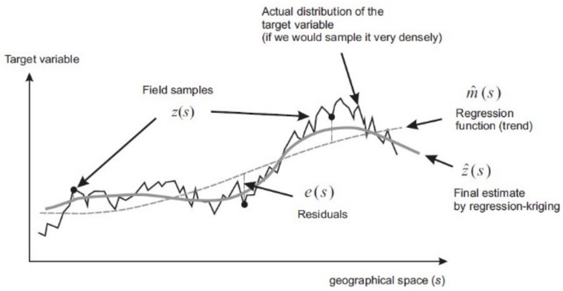

Figure 5. Regression kriging (Hengl, 2007; Tomislav et al., 2007)

Where Z (s_i) represents input point dataset, $q_k(s_0)$ represents deterministic predictors, γ(h) represents covariance model defining the spatial autocorrelation structure and $\mathbb{A}$ represents geographical domain of interest. Matheron (1962) proposed that the value of the locations that cannot be found using observation data for the soil properties can be modeled as the summation of deterministic and stochastic components.

$$z(s_0) = \mathrm{m}(s_0) + \mathrm{e}(s_0)$$
$$= \sum_{k=0}^{p} \beta_k . q_k(s_0) + \sum_{i=1}^{n} \lambda_i e(s_i)$$

Where $m(s_0)$ is the adaptation of the deterministic part to the model, $e(s_0)$ is the interpolation of the residual value, β_k is the coefficients of the deterministic model, λ_i is the kriging weights determined by the spatial correlation of the residual values and $e(s_i)$ residual value at point i. In this study, the spatial distribution of the organic carbon of the Çapakçur catchment was modeled using the kriging method and the R studio program, which uses a coding system (Fig 6).

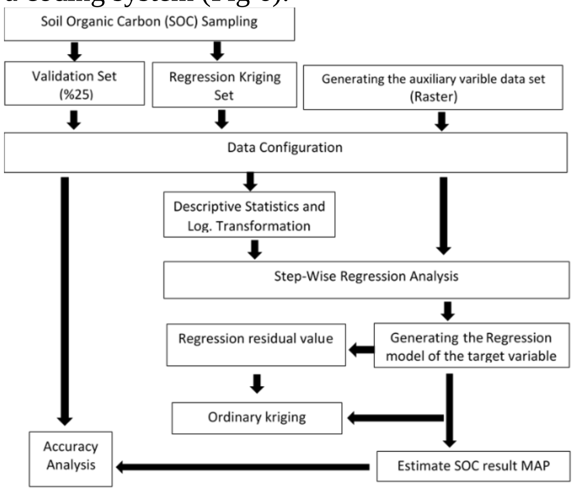

Figure 6. Flowchart of Regression Kriging in the study

The methodology of the study: (i) obtaining the chemical analysis of the soil samples (429 samples) that were collected during the field study, (ii) dividing the soil samples as the training and data sets (iii) producing auxiliary variables for the regression model using satellite images and vector data, (iv) running the multilinear regression model using the soil samples and auxiliary variables, (v) selecting the best predictor variables using stepwise regression, (vi) applying the stepwise regression model, (vii) mapping the spatial distribution of the residual value interpolation using ordinary kriging, (viii) applying RK after achieving configuration with the regression model and interpolation. The RK model requires estimation at each point level according to a predetermined resolution (30 m). The attributes of all points, which are numerous in the area, are highly important. All attributes of auxiliary variables are assigned to all points and soil samples. During this process, all data are converted to the ASCII format and scripts that can be used by the R Studio program.

3. RESULTS AND DISCUSSION

3.1. Topographic Properties of the Catchment

The Çapakçur catchment is located at the southwest border of Bingöl. Aspect is an important topographic property that affects soil formation and ecosystems inside and outside soils. The distributions of the aspects in the catchment are generally similar to each other (Fig 7a). The northern aspect was the most common aspect in the study area (24.63%), while the southwestern aspect was the least common aspect (5.97%). The catchment has a heterogenous slope distribution (Fig 7b). Although highly steep areas are more common, plain areas can also be found. About half of the catchment has a slope higher than 40%. Plain or near-plain areas (with a slope of 0%-20%) constitute about 14% of the area. Fig 7c shows the elevation map for the Çapakçur catchment. The lowest elevation level is 1150 m, while the highest point is measured to be 2560 m. The elevation of 35.31% of the catchment is in the range of 1500 m – 1750 m. Fig 7d shows the current land use map of the Çapakçur catchment. The area is mostly covered by barren areas (68.71%). The area covered by the fertile forest lands is considerably low (5.43%). On the other hand, degraded forest lands cover 24.01% of the total area. The agricultural areas in the Çapakçur catchment cover an area of 1.75%.

3.2. Modeling of the SOC Distribution

Regression analysis was one of the determining stages of the study. The model helps establish a regression model, which is one of the deterministic methods. The results are included in the modeling of spatial autocorrelation, which is provided by the stochastic methods. This section constitutes the deterministic part of the hybrid method and various studies have employed regression types that uses multilinear regression (MLR), logistic regression or Cubist model. The MLR analysis and, then, stepwise regression analysis was used in the study due to the presence of multiple predictor variables.

Factors and reservoirs affecting soil carbon were taken into consideration to determine auxiliary variables. With this respect, in the study, Landsat 8 satellite data bands, Digital Elevation Model (DEM), slope, aspect, Normalized Difference Vegetation Index (NDVI), Ratio Vegetation Index (RATIO), Soil Adjusted Vegetation (SAVI), Transformed Index (TVI), Tasseled Cap, distance to water, distance to road, Big Soil Group (BSG), erosion classes and stand map were used as the auxiliary variables for the RK method. The vegetation indices used in the RK method were produced using satellite images. Vegetation indices were preferred among auxiliary variables and they are frequently used in soil and plant studies. The Landsat 8 OLI/TIRS satellite data dated 20 August 2018 was used. When determining the date of the satellite image, the time frame in which the field studies were carried out and soil samples were collected was taken into consideration.

NDVI is a frequently used numerical data that give information about green vegetation using soil brightness. RATIO is the vegetation index distinguishing green vegetation from soil (Rouse et al., 1974). SAVI minimizes the effect of soil on soil vegetation by adding the soil correction factor (L) to

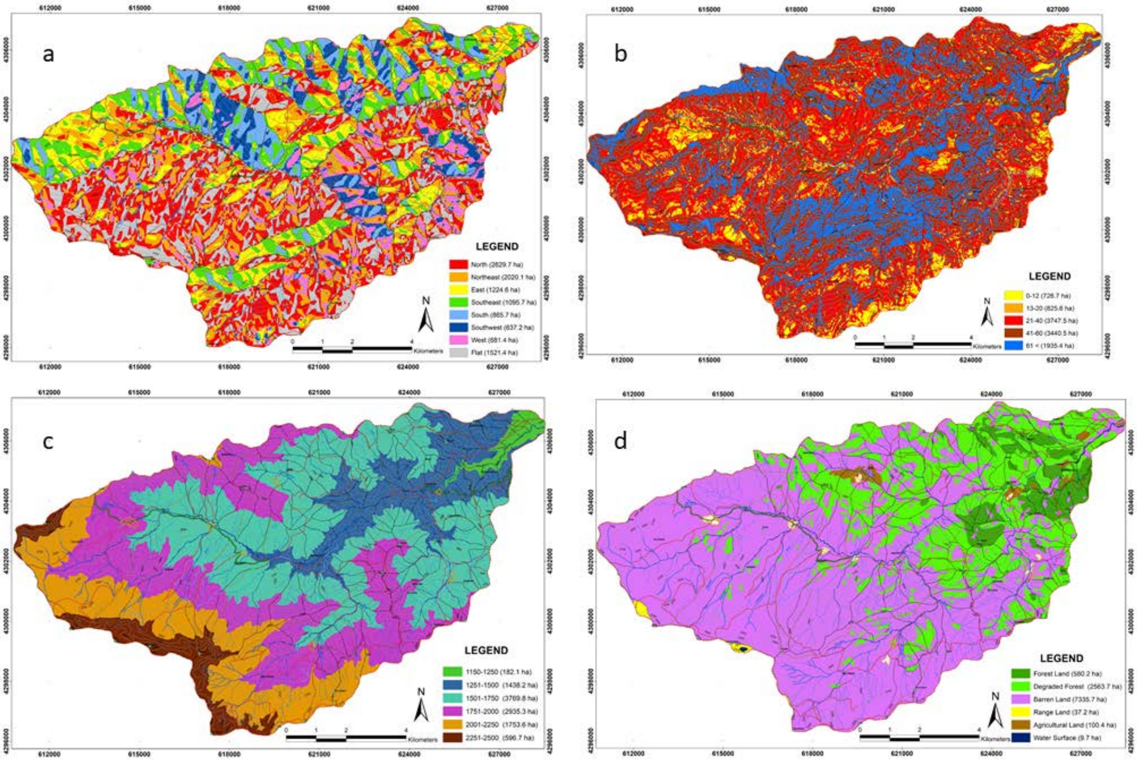

Figure 7. Topographic properties of Çapakçur basin. (a. Aspect map b. Slope map c. Elevation map d. Land use map)

the NDVI equation (Huete et al., 1988). TVI is the modified vegetation index obtained from the NDVI data (Deering, 1975). Tasseled Cap transformation is the enrichment of the vegetation indices using six visible bands of the Landsat data. Tasseled Cap transformation allows the transformation of the brightness, greenness and wetness indices and determination of the coefficients of Landsat bands (Ersoy Mirici et al., 2016). The data on distance to water and distance to road were produced using the Euclidean distance analysis in ArcGIS 10.3.

In the study, the DEM, slope, NDVI, TVI, SAVI, Tasseled Cap, stand types and Landsat bands (2,4,5,6,7) were distinguished as the data that were used in spatial modeling and had a strong relationship with the dependent variable and auxiliary (independent) variables in the stepwise regression model. Stepwise regression model revealed a R^2 value of 0.61. Fig. 8 shows the spatial distribution of the soil organic carbon in the Çapakçur catchment according to the RK method.

According to the model, the northeast region of the Çapakçur catchment was estimated to have the highest SOC (%) values. The mean FL (4.32%), AA (3.40%), DF (3.32%) and BA (2.92%) values were found by examining the relationship between the SOC (%) map and land use. The results indicated that the SOC contents of the FL and AA were high and land use had a high potential in terms of ecosystem productivity.

The distribution of SOC in any given area is highly heterogenous. Its distribution generally depends on soil type, land use and climatic conditions. Pastures cover about 40% of world's lands (Orgiazzi et al., 2016) and contain 20% of the world's SOC stock (FAO & ITP, 2015). Similarly, peatlands contain about 30% of the world's SOC (Parish et al., 2008). On the other hand, dry lands have a limited SOC storage due to various bioclimatic factors. The soil samples collected from the catchment were analyzed and the SOC content of each sample was determined. The SOC content ranged from 0% and 7% in the catchment, which is affected by different land use types and topographic factors. Considering the SOC distribution map, the FL in the north of the area contained greater amounts of SOC.

Land use types can change depending on various factors and cause serious changes in soil properties. SOC is undoubtedly the most important among these properties. Table 1 shows the mean SOC contents of the different land use areas in the Çapakçur catchment according to the ANOVA test results. The analysis revealed that the changes in the land use types had a statistically significant effect on mean SOC values. The SOC content of the FL was higher than that of other land types ($p<0.05$), while the BA had the lowest SOC content. Therefore, the areas with a high plant vegetation and fully-covered soil surface have higher SOC content compared with that of other areas. Soils in balance with the natural forest ecosystem have high carbon (C) intensity. On the other hand, intensely processed agricultural areas have lower C contents. A mean of 0.4 Mg ha^{-1} carbon is annually accumulated in forest soils (Lal, 2005). Forest soils play important roles in the C cycles due to the large areas they cover around the world (Detwiler & Hall, 1988; Jabággy & Jackson, 2000).

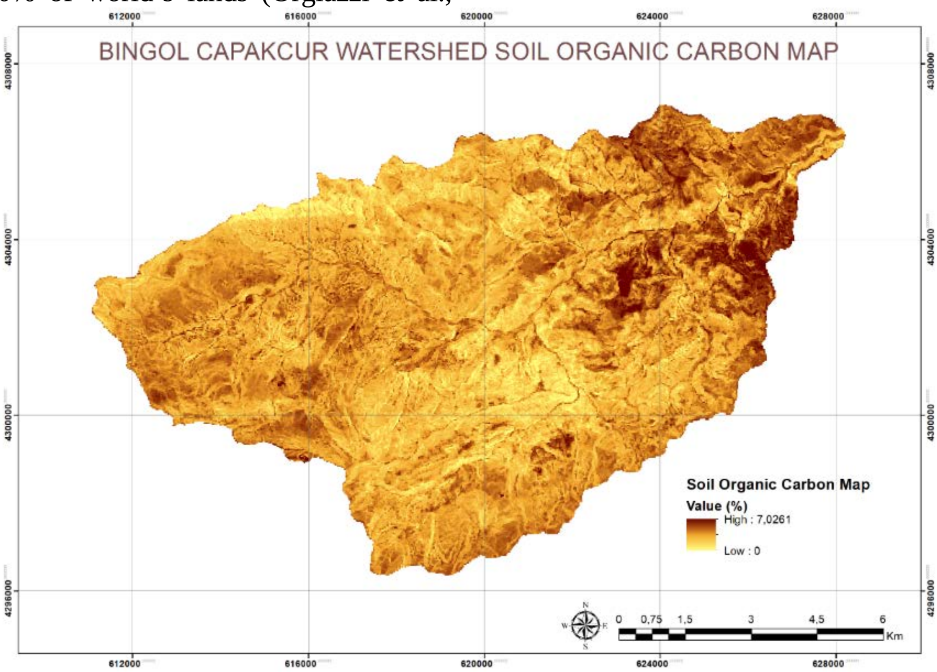

Figure 8. Soil organic carbon distribution (SOC) map of Çapakçur catchment

Table 1. The effect of land use type on soil organic carbon

Land Type	Number of Sample	Mean (%)	Std Error
BA	296	2.87C	0.07
DF	104	2.87**C**	0.12
FL	19	6.26**A**	0.28
AA	10	4.10**B**	0.39

BD: Barren Degraded Area, DF: Degraded Forest, FL: Forest Land, AA: Agricultural Area ,% : $g.g^{-1}$

Table 2. Relationship of soil organic carbon level with topographic characteristics in Çapakçur catchment

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Land Type	3	220.43	73.47	46.09	**<.0001***
Aspect	7	69.30	9.90	5.03	**<.0001***
Slope	4	138.52	34.63	19.33	**<.0001***
Elevation	5	19.31	3.86	1.86	0.1002

*Signifaicant 0.05 level

A parallelism emerges between the land use types and SOC content when the RK method and ANOVA test results are compared with each other. According to RK and ANOVA, SOC contents of the land types in descending order were the FL, AA, DF and BA. The SOC contents in the RK method was higher than those determined using the ANOVA test results. A similar result was also obtained by Gia Pham et al., (2019). This can be attributed to the effect of the auxiliary variables in the RK method.

The Çapakçur catchment has high erosion risk and annual soil loss (Yüksel & Avcı, 2015). Especially the soils in forestless lands that are affected by erosion are poor in terms of their physical and chemical properties. Its rich part on the surface is removed from the soil with surface runoff. Erosion is an important factor causing the lower SOC contents of DF and BA compared with that of FL. Çapakçur has a limited AA due to its topographic structure. The agricultural activities in the catchment are usually carried out by small, family-owned businesses. Thus, soil cultivation, fertilization and agricultural activities are not intensive in the area. The SOC content of these areas was lower than that of FL but higher than those of BA and DF. In other words, the agricultural activities in the catchment are limited enough to maintain the SOC amount at a certain level. Various studies have reported the severe decrease in SOC due to intensive agricultural activities (Söderström et al., 2014). Guo & Gifford (2002) reported that carbon stocks decreased by 10% and 13% with the conversion of pastures and natural forest lands into agricultural areas, respectively.

3.3. Changes in the SOC Content Depending on Topographic Properties

Table 2 shows how SOC content is affected by the topographic properties of the Çapakçur catchment. Land use type, aspect and slope had statistically significant effects on SOC ($p<0.05$). However, there was no relationship between land elevation and SOC.

Table 3. Impact of land aspect class on soil organic carbon

Aspect	Number of Sample	Mean (%)	Std Error
N	111	3.69**A**	0.13
W	17	3.21**AB**	0.34
S	39	2.91**AB**	0.22
E	60	2.80**B**	0.18
NE	73	2.95**B**	0.16
F	67	2.66**B**	0.17
SE	36	2.76**B**	0.23
SW	26	2.65**B**	0.27

%: $g.g^{-1}$

Table 3 shows the effect of aspect on SOC. The N aspect had the highest mean SOC level (3.698%), while the lowest mean SOC level was determined in the SW aspect (2.653%). In terms of the SOC content, the E, NE, F, SE and SW land aspects were statistically in the same group. In other words, there were no significant differences among these aspects. Land aspect is an important topographic factor affecting soil temperature and soil-moisture balance. Thus, it has an important effect on temperature and moisture regimes (Griffiths et al., 2009). This affects both the distribution of soil plant cover and biological and chemical processes of soils (Bale et al., 1998). Lozano-Garcia et al. (2016) suggested using land aspect as a factor in studies on the modeling of SOC estimation due to its importance. Turkey is in the northern hemisphere (Gokcol et al., 2009) and, thus, southern land surfaces receive more sunlight. Therefore, determining higher SOC contents in the northern aspect is expectable.

A negative relationship between slope gradient and SOC content was determined in the study (Table 4). The highest SOC content was found in the 0%-20% slope range, while the lands with a slope higher than 80% had the lowest SOC contents. SOC content proportionally decreased as the gradient increased. Slope is an important topographic factor affecting erosion (Zing, 1940; Smith & Wischmeier, 1958). Various field and laboratory studies have found a positive relationship between slope and erosion intensity (Watson & Laflen, 1986; Assouline & Ben-Hur, 2006; Ziadat & Taimeh, 2013; Zhang et al., 2015). Erosion is the most important ecological problem that reduces SOC (Olson, 2010; Olson et al., 2016). The high correlation between slope gradient and SOC content is a noteworthy finding of this study (Fig.9). The negative relationship between slope and SOC content is confirmed by many researchers (Olson et al., 2012; Li et al., 2019; Wubie & Assen, 2019).

Table 4. The impact of land slope on SOC in the Çapakçur catchment

Slpoe Class (%)	**Number of Sample**	**Mean (%)**	**Std Error**
0-20	53	3.74**A**	0.18
20-40	165	3.33**AB**	0.10
40-60	134	3.01**B**	0.11
60-80	58	2.31**C**	0.17
80<	19	1.16**D**	0.30

%: $g.g^{-1}$

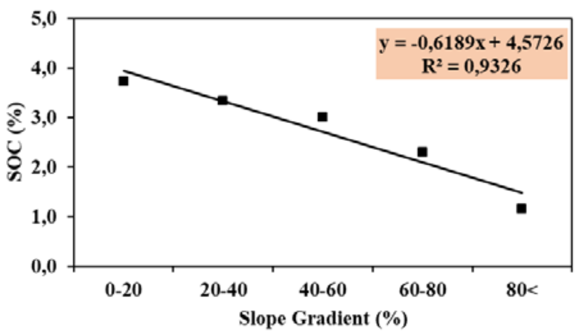

Figure 9. Relationship between the SOC and slope (Slope %: $m.m^{-1}$; SOC % : $g.g^{-1}$ of dry soil mass)

Table 5 shows the information on the relationship between elevation and SOC. The results showed that land elevation did not have an effect on SOC. Some of the previous studies have found a positive relationship between elevation and SOC, while other studies have reported that there was no relationship between elevation and SOC (Schrumpf, 2001; Kitayama & Aiba, 2002; Soethe et al., 2007; Girardin et al., 2010). Considering the soil formation factors, decreasing temperature with increasing elevation is expected to contribute to SOC accumulation because of its effects on the decomposition and degradation processes. However, SOC is affected by many factors including climate, topography, plant cover and soil type and thus, it did not affect SOC, as it was expected.

Table 5. The effect of land elevation class on SOC

Elevation Class (m)	**Number of Sample**	**Mean (%)**	**Std Error**
1000-1250	8	2.95	0.50
1250-1500	59	3.28	0.18
1500-1750	145	3.21	0.11
1750-2000	125	2.75	0.12
2000-2250	64	3.14	0.18
2250<	28	2.86	0.27

%: $g.g^{-1}$

4. CONCLUSION

The effects of land use and topographic properties on SOC in a catchment with a high erosion risk were investigated in the study. The results were as follows:

i. Land use had a significant effect on SOC. The SOC content of the fertile forest lands were higher than that of the degraded forest lands, barren areas and agricultural areas. The results showed that plant vegetation was effective on SOC accumulation. On the other hand, it is predicted that the SOC contents of the areas that become barren due to various factors (cutting, grazing, fire, erosion) can decrease.
ii. The SOC contents were higher in the northern aspect which does not receive direct sunlight. The SOC content decreased with increasing slope and was not correlated with elevation. There was a negative correlation especially between slope gradient and SOC content, which was attributed to erosion. Within this context, it can be asserted that topographic factors significantly affect soil biomass in addition to other factors.
iii. Forest lands had a large effect on SOC and these lands should be monitored, protected and improved, which will greatly contribute to the carbon cycle.

iv. SOC values obtained with the regression-kriging method were found to be compatible with the analysis values.

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