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The Effect of Soil Properties on Landslides along Forest Road

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Abstract

Forest roads provide access to forest resources in order to conduct forest operations and to extract all types of forest products economically. Forest roads should be well planned in such a way that damages on the forest ecosystem are minimized. The landslides, caused by the natural or man-induced complex environmental factors, are considered as one of the major environmental impacts along the forest roads. Some soil properties may weaken the cohesion of the soil and accelerate the road disruptions. In this study, causes of the landslides that happen on the forest roads in Maçka Region in northeast of Turkey have been investigated in terms of the soil properties. For this purpose, soil samples were collected separately from the sample fields (SF) subject to landslides and from the areas of control points (CP) with no landslide occurrences. Dispersion rates (DR) indicating the sensitivity of the soil samples to erosion, and their physical and chemical properties have been investigated. The results indicated that most of the landslides along the roadway occurred on the cut slopes. As a result of soil analysis, the soils of entire study area were found to be sensitive to erosion (DR > 15) and the soil type was generally in the sandy clay form. It was found that there was negative and meaningful correlation between DR and Fe along with Silt, while there was a meaningful and positive correlation between DR and Sand. In order to find out whether SF and CP are different in terms of soil properties, Independent Sample T-test was conducted. The results revealed that there was a significant difference only in P (Phosphorus) content while the differences between other soil properties were found to be insignificant.

Keywords: Forest roads, Landslides, Soil properties, Turkey

1. Introduction

Forest roads are important structures that ensure services and products provided by forest resources. Forest roads should be well planned by considering both road costs and potential damages on stands, forest soil, and natural landscape. The fact of having regular and extensive forest routes with any scientific and technical intervention including forest management and forest protection requirements is effective on forest road planning. In addition, intra-forest afforestation, fast access service to forest fires again is related to the dispersal of the road network within the forest. In this regard, forest road construction is of great importance in terms of forestry applications (Erdaş, 1997).

On the other hand, the forest roads constructions may cause some environmental problems, if they are not planned by considering required protective measures or not implemented in the field by using suitable techniques. One of the major environmental problems due to improper forest road construction is the acceleration of soil erosion. Usually the main reasons for an increased erosion after the construction of forest roads can be listed as; the elimination of protective flora along the way in part or in whole, the degradation of the natural structure of soil and the yield strength of the soil or the damage and the change of pressure and tensile stress in cut and fill slopes (Megahan, 1977; Görcelioglu, 2004a).

As it is well known, soil erosion should not be only thought as a simple earth moving incident because it has potential to initiate a chain of events such as sediment delivery to streams along with harmful additives, floods, and landslides (Uzunsoy and Görcelioglu, 1985). The road construction related landslides result in serious long term impacts on forest ecosystem along the forest roads.

The cause of a landslide that has occurred on the forest roads can be defined as the natural or man-induced complex environmental factors. Some soil properties, which are one of the environmental factors, weaken the cohesion of the soil and accelerate the road

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disruptions. The thin soil (clay and organic matter) and stabilizer elements (Ca and Mg) in the soil both strengthen the cohesion and the soil whose cohesion is weak can easily face erosion (Balcı, 1996; Görecelioglu, 2004b). Also the aggregate stability decreases rapidly with the increasing soil Na content in the soil (Balcı, 1996). The high content of clay content and organic matter increases the percentage of water-resistant aggregate by 95% (Göl and Dengiz, 2007).

The main objective of this study is to investigate the landslides occurrence along the forest roads regarding with soil properties. It is also aimed to specify the soil properties associated with the DR and to provide some suggestions to prevent landslides caused by forest road construction.

2. Materials and Methods

2.1. Study Area

Research area covers Macka Forestry Department which is located in the limits of Trabzon province borders. Maçka Region is in between 40° 60' with 40° 39' North latitude and 80° 50' and 39° 90' East longitude and is located 968 km^2 wide in the Eastern Black Sea region (Figure 1). The region has a quite sloping and steep topography. Maçka Forestry Department is located on totally 101110 ha area consisting of forested area of 41555 ha (36.6 %) and deforested area of 59555 ha (OGM, 2017). Maçka Forestry Department has approximately 472 km of forest road. These forest roads have been built mostly in the form of valley paths that follow the stream base coupled with a hillside which was bounded with a curve. In the forest area which has a quite slanted and rugged topography, the crest is seen scarcely any (Acar, 1993).

According to the Meteorological Station of Maçka, annual average rainfall is 638 mm and the average temperature is 12.4°C. In the region, starting from Lias to the end of the Eocene, developing by the periods, magmatism containing products such as volcanic sedimentary, volcanic and intrusive rocks are common. During the periods when magmatic activities have pauses, clay sequences have accumulated (Güven, 1993). Research area falls in the area of the Basin of Değirmendere where large part of the area is filled with rock that is classified as vulnerable to erosion (Figure 2). Due to the Maçka Region climate type and geological structure, landslides are frequently observed.

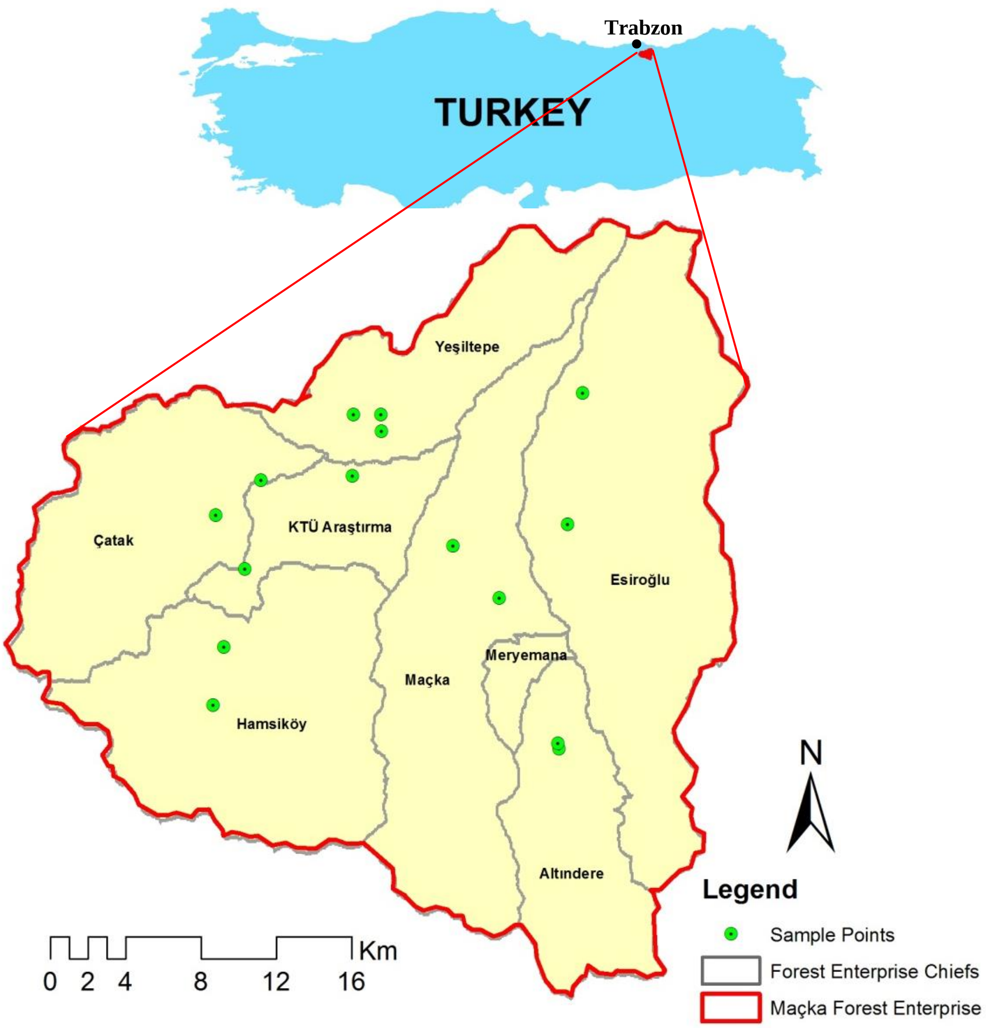

Figure 1. Location map of Maçka Forest Enterprise and sample points

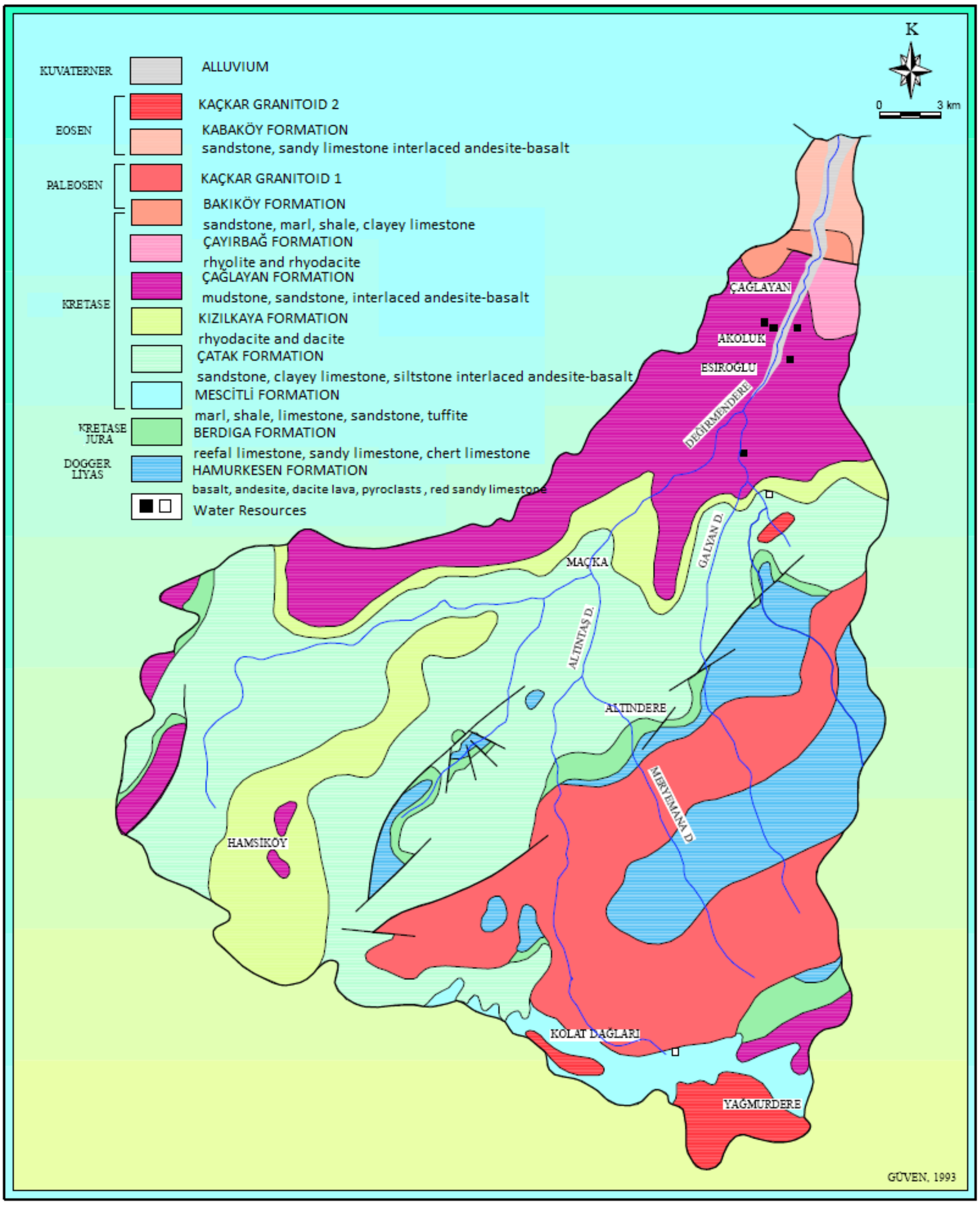

Figure 2. Geography map of Değirmendere Basin (Güven, 1993)

2.2. Soil Sample Collection and Data Analysis

In the first stage, field observations have been performed in the forest roads within the study area as preliminary research. Then, total of 15 SFs were determined at the cut and fill slopes with landslides occurrence. For control, CPs were located at the cut and fill slopes which are 20 m away from each of SF with no landslide occurrence. SF and CP points were selected from the areas exposing similar terrain characteristics (i.e. slope, aspect), road geometry (i.e. the depth and gradient of the cut slopes), and flora (Figure 3). In addition, UTM coordinates of SF and CP points were recorded by a GPS. In order to determine some physical and chemical properties of soil in SF and CP, soil samples were collected from the cut and fill slopes where active landslide was observed. Soil samples were obtained from both disturbed and undisturbed land surfaces at 0-20 cm depth. Soil samples were labelled and placed into polythene bags. While collecting these sampled, it was paid attention to make sure they would represent the sample fields.

2.3. Statistical Analysis

To indicate the erosion sensitivity of soil samples and some physical and chemical properties of the soil, their relationship with DR was investigated by the correlation coefficient calculations. Also, Independent Sample T-test was performed to show the difference between SF and CP. For all the statistical analysis, SPSS (Version 19.0 for Windows) program was used and significance of the results were evaluated in levels of imposed $P<0.05$.

Figure 3. Sample SF (left) and CP (right) points in the study area

3. Results and Discussion

The results indicated that most of the 15 landslides occurred at the cut slopes in the form of the slope landslide, while others occurred at the cut and fill slopes in the form of slipping (Figure 4). Table 1 indicates site information about SF points. It was found that the study area consists of bedrocks such as sandstone, ragstone, argillaceous limestone, silt stone, marn, basalt, quartzite, andesite, and dacite.

The previous studies conducted about the effects of bedrock textures on erosion indicated that basalt, quartzite, and granite were classified as erosion resistant bedrocks (Balcı and Öztan, 1987; Erdas, 1997). However, sandstone, limestone, marl, claystone-marl, and claystone bedrocks were vulnerable to erosion (Görcelioğlu, 2003).

According to the results of physical and chemical properties of sample soils taken from SF and CP points; it was determined that the entire territory was sensitive to erosion (DR > 15) and in general, it was established that the soil type was sandy loam. An average DR value

Table 1. Landslide, cut/fill slope, and soil type at the SFs

SF	Location (Cut/Fill Slope)	Landslide Type	Soil Type
1	Cut	Slope	Sandy Loam
2	Cut and Fill	Slipping	Sandy Clay Loam
3	Cut and Fill	Slipping	Sandy Loam
4	Cut	Slope	Sandy Clay Loam
5	Cut and Fill	Slipping	Sandy Loam
6	Cut and Fill	Slipping	Sandy Loam
7	Cut	Slope	Sandy Loam
8	Cut and Fill	Slipping	Sandy Loam
9	Cut	Slope	Sandy Loam
10	Cut and Fill	Slipping	Loamy Clay
11	Cut	Slope	Sandy Loam
12	Cut	Slope	Sandy Loam
13	Cut and Fill	Slipping	Sandy Loam
14	Cut	Slope	Loamy Sand
15	Cut	Slope	Sandy Loam

Figure 4. Slope landslide (left) and slipping (right)

was found to be 53 in SF and 45 in CP. Consequently, it was revealed that, DR was 1.18 times greater in the areas with landslide occurrence. In addition, in the soil samples taken from SF; Na, Mg, Ca, Cu, Zn, P, pH, and other Sand values found to be more than that of taken from CP, while other values (K, Mn, Fe, Dust, and Clay) were found to be less (Table 2).

Independent Sample T-test results showed that P (Phosphorus) was found to be significantly different between soil samples taken from SF and CP, while other values were found to be similar. In addition, considering an average value of P in soil samples of SF and CP in Table 2; P was found to be greater in SF. Different results have been found related to other soil properties. Rhoton et al. (1990) reported that Na increased from undisturbed soil to severely eroded soil. Bhatia and Narain (1985) stated that there is a significant negative relationship between wearability and variable Na. In addition, Balcı (1996) suggested that aggregate stability rapidly decreases with increasing of Na in the soil.

Based on the correlation analysis indicating relationship between DR and some physical and chemical properties of soil; there was negative and meaningful correlation between DR and Fe along with Silt while there was a meaningful and positive correlation between DR and Sand. It was found a trivial relationship between other soil properties (Table 3). In the previous studies, it was found that the thin (Clay and organic matter) and clustering elements (Ca and Mg) in the soil both strengthen the cohesion, while the soil whose cohesion is weak can easily face erosion (Balcı, 1996; Görecelioglu, 2004b).

Table3. Correlation between soil properties and DR

Soil Properties	r	P*
Na	0.185	0.326
Mg	0.097	0.611
K	-0.150	0.428
Ca	0.194	0.305
Mn	-0.142	0.453
Fe	-0.433	0.017
Cu	-0.156	0.412
Zn	-0.013	0.947
P	0.178	0.346
pH	0.123	0.517
Sand	0.458	0.011
Silt	-0.463	0.010
Clay	-0.330	0.075
Soil Type	-0.029	0.880

* P< 0.05

Table2. Summary table of Independent Sample T-test between soil properties of SF and CP

Soil Properties	Soil Samples		F	T	P*
	SF	CP			
	Mean±SE	Mean±SE			
Na	2043.2±169.09	2450.07±216.27	0.289	0.064	0.950
Mg	31074.13±6211.81	33847.87±4933.84	0.735	-0.350	0.729
K	5482.20±782.82	6330.20±1413.87	1.703	-0.525	0.604
Ca	30248.87±12419.67	20722.87±6397.96	2.246	0.682	0.501
Mn	1924.33±255.22	2354.00±241.27	0.097	-1.223	0.231
Fe	76023.33±7177.40	80345.33±7493.28	0.078	-0.417	0.680
Cu	93.60±15.54	91.20±13.05	0.307	0.118	0.907
Zn	295.80±67.98	263.60±33.18	1.714	0.426	0.674
P	32.73±2.14	14.00±2.10	0.624	6.246	0.000
DR	53.13±3.69	45.27±4.15	0.010	1.418	0.167
pH	6.57±0.18	6.68±0.13	2.199	-0.525	0.604
Sand	75.00±2.30	70.13±2.71	0.659	1.370	0.182
Silt	12.73±1.16	13.73±1.21	0.263	-0.599	0.554
Clay	12.27±1.49	16.13±2.18	2.447	-1.465	0.154
Soil Type	1.47±0.24	2.27±0.41	2.936	-1.697	0.101

* P< 0.05

4. Conclusions

In order to investigate the effects of soil properties on the landslides along the forest roads; analysis hve been performed on soil samples collected separately from landslide areas of SF and from CP where there was no landslide. It was determined that most of the landslides in the study area were in the form of slope landslide in cut slopes. Based on the soil analysis, it was found that entire territory of the study area was sensitive to erosion (DR> 15) and in general it was revealed that the soil species was the sandy clay. An average DR value was found to be as 53 in SF and 45 in CP. Accordingly, it was determined that in the areas with landslide occurrence, DR was greater (1.18 times). There was statistically negative and meaningful correlation between DR and Fe along with Silt, and there was a meaningful and positive correlation between DR and Sand.

In order to find out whether SF and CP were different in terms of soil properties, Independent Sample T-test was utilized which indicated that P (Phosphorus) has been found to be significantly different. In addition, an average value of P at SF was greater than that of CP points.

The results suggested that soil properties should be examined using ground surveys before forest road constructions. Particularly, Fe, Silt, Sand and P values associated with DR should be carefully evaluated. Based on this pre-evaluation, alternative routes should be generated and the most appropriate route should be selected and applied in the field. Besides, it is important to take soil protection measures in the areas that are generally susceptible to soil loss. Decision makers should be also aware of additional investment necessary in constructing roads at the areas with high landslide risk.

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