Technical Efficiency Evaluation of Forest Roads with Respect to Topographical Factors and Soil Characteristics

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Abstract

Forest roads are usually single-lane roads built to unique technical standards with the purposes of accessing to forests and performing forestry in addition to other activities. With this study, in Karacaoren Forest Sub-District Directorate, evaluation of technical efficiency which consists of different variables of forest roads by scoring system was aimed to allow the function of the forest roads to be optimally performed over long time periods. Eleven different variables were evaluated to determine the technical efficiency of the forest roads in the study; these variables are the following: the road platform width, ditch width (condition), road expansion in curves and hairpin turns, superstructure, culvert condition, road-shadow condition, cut-fill slope stability, platform degradation, road inclination, and growth of plants on the road platform (the presence of bushy plants).

The technical efficiency for each 100 m section of the forest roads was firstly evaluated in case area using the variables. Forest roads that the efficiency status was determined according to technical standards were recorded in the ArcGIS database. Finally, effects of topography (the slope, aspect) and soil characteristics on the technical efficiency variables were analyzed and mapped using SPSS and ArcGIS software.

Our results showed that the “ditch width (condition)” and “platform width” variables were mostly not suitable according to the standards and the “plant growth” and “fill side slope stabilization” variables on the road platform were in good condition. The slope of the study area had a significant ($p < 0.05$) influence on the platform width, while the aspect of the study area had a significant ($p< 0.05$) influence on the ditch condition, the platform degradation condition, and the plant growth on the road platform. In general, the soil depth had some impact ($p < 0.05$) on the platform width, the cut side slope stability, and the plant growth on the road platform. The soil stoniness also affected ($p < 0.05$) the platform width, the cut side slope stability, and the plant growth on the road platform. However, the platform width, the cut side slope stability, and the platform degradation condition were all affected ($p< 0.05$) by erosion in the study area.

Based on these results it concluded that the forest roads should be planned in sunny areas with slopes less than 51%, on “shallow soils” with “little stony” stoniness, and with “none to very little” erosion levels.

Keywords: Forest road, technical efficiency variables, GIS, SPSS, topography, soil characteristics.

Introduction

Forest roads, are infrastructural facilities that serve for utilization and conservation of forest resources and implementation of forestry activities; forest road also provide transportation of various forest products; allow people to work and live in the forest and enable recreational activities. They have unique geometry, construction techniques and costs as well as various properties in terms of economic, ecological, technical, social and institutional aspects (Eker and Ada 2011, Keller and Sherar 2004, Tolosana et al. 2000, Bruce et al. 2011, Deegen et al. 2011, Laschi et al. 2016, Whittaker et al. 2011, Jaafari et al. 2015).

A well-developed road network is essential structure, in order to facilitate and assitst forestry activities including production wood and non-wood-based products, wood utilization, hydrological regulation, soil protection, biodiversity conservation, ecotourism and firefighting (Abdi et al. 2012, Hayati et al. 2012).

Forest road planning is conducted in accordance with the Communiqué no. 292 by Directorate General of Forests in Turkey (GDF 2008). Place, route, slope, width, curves and lases are examined for evaluation of roads already built in the forest (GDF 2008). The amount of forest roads that have been planned constructed for implementing forestry activities (i.e. protection, afforestation, recreation, and erosion control) in Turkey determined to be 282,000 km, 177,000 km of which has already been constructed by General Directorate of Forestry (GDF). The total road length that can be used for forestry services has reached up to 243 000 km including 66 000 km of forest village roads and motorways that pass through forests (GDF 2015). In Turkey forest roads are divided into three main groups with respect to the amount of load to be transported over them, the objective of construction, the traffic density, and the tonnages: primary forest roads, secondary forest roads (Types A and B secondary forest roads), and tractor roads. The forest roads in Turkey are mostly built according to B-Type Secondary Forest Road geometrical standard and the geometrical standards for these roads are shown in Table 1 (GDF 2008).

Table 1. Geometrical standards of forest roads

Road features	Unit	Main forest roads	Secondary forest roads				Tractor roads
			A-Type	B-Type			
				HBT	NBT	EBT	
Platform width	m	7	6	5	4	3	3.5
Number of road line	Number	2	1	1	1	1	1
Roadway width	m	3	3	3	3	3	3
Maximum longitudinal slope	%	8	10	9	12	12	20
Minimum curve diameter	m	50	35	20	12	8	8
Shoulder width	m	0.50	0.50	0.50	0.50	0.50	
Ditch width	m	1.00	1.00	1.00	1.00	0.50	
Superstructure width	m	6	5	4		3	
Bridge width	m	7+(2×0.6)	6+(2×0.6)	5+(2×0.6)		4+(2×0.6)	

Notes: HBT: High standard B type forest road, NBT: Normal B type forest road, EBT: Extreme B type road

requirements of the existed standard so that they can fully perform their predicted functions (Hasdemir and Demir 2000, Péterfalvi et al. 2015). To ensure that forest roads are constructed with minimum environmental impact and that they serve their functions in the best way for long time periods, they need to be planned and constructed according to the technical standards set out in Communique No: 292 (GDF 2008).

Gumus (2009), aimed to determine measures considering the technical (geometric properties, construction technique), economic and social (exploitation of forests, transportation of personnel, equipment and materials into the forest, the preservation and development of forests and transporting various forest products out of the forest and help them meet their healthcare, education and other social needs for rural population), ecological (having potential impacts on the forest ecosystem) characteristics of existing roads that could be used to represent them. In a survey conducted on a specialist group firstly roads were graded by multiple-choice indicators, then "Analytic Hierarchy Process" was used to assess the forest roads by weighting indicators.

Forest roads in Turkey are generally built in normal B Type Secondary Forest Road standard. The standards are 4 m Platform width, 1 m the trench width, usually 9% the maximum incline but rarely 12%, 12 m curves and lase with a minimum radius and these roads provide accessing to everywhere of forests and these roads are applied in normal topographic and terrain conditions.

It is believed that conservation of nature began with human history (Sen and Bugday 2015). Improper road construction may cause environmental impacts such as the destruction of forest areas, biodiversity loss and habitat fragmentation, pollution of streams, risk of erosion, diminishment of forest communities, and changes in wildlife habitats (Karlson et al. 2014, Kimmins 2011). The possibility of insect infestation related tree damages during forest road construction is higher in the sands that are close to the road (Eroglu et al. 2005). It is known that trees injured for any reason are especially vulnerable to insect attacks (Ozcan et al. 2006). In addition, when forest roads have not been carefully designed and managed, excessive economical costs may arise and forest ecosystems may be damaged to high levels (Jadczyk 2009, Hui et al. 2003, Smulders et al. 2009, Da Silva et al. 2010, Keller and Sherar 2004, Naghdi 2004, Gucinski et al. 2001, Demir 2007).

To be able to intensively operate forests, forest road networks need to be equipped in accordance with the

Previous studies showed that assessed existing forest roads regarding with economic, ecologic, and visual aspects, and developed a grading system to enable road classification using technical characteristic of the road, the visual degradations on the road surface, and the economy and characteristics of the land where the road passes and their associated sub characteristics. It has been considered other functions of the forest road such as economic parameters, road construction and maintenance costs, production volume, forest fire fighting, non-wood forest products, and ecotourism to achieve an optimal forest road network with high quality and low price (Hayati 2012, Grigolato et al. 2013, Cetin and Sevik 2016).

The quality of roads is associated with building and maintenance quality, in point of both techniques and materials, and it can vary during road lifespan (Kiss et al. 2015). Increasing the road standards was an important factor in terms of the efficiency of raw wood material transportation. Road platform had to be expanded that the entirety of the road had to be coated substantially with a surface material, and that the road would last longer with the installation of proper drainage systems (Ryan et al. 2004, Pellegrini et al. 2013). Forest road ecosystems had very complex structures and stated that the slope and aspect had an effect on road analysis (Lugo 2007). The factors associated with the erosion of forest roads such as road width, cut and fill side slope, construction methods, and drainage facilities (Gorcelioglu 1996).

Landslide risks were greater on ground with lower stability, shady and semi-shady aspects such as north or west facing slopes, and areas that have greater rainfall with limited drainage capacities. Therefore, a very good drainage system was essential to prevent water damage on the roads and the environment. Also, with increasing slope incline, the side slope stability decreased requiring a large number of cuts and fills, which eventually increased road cost. Briefly, when making forest road network plans, engineering geology studies should be conducted before the road planning and it is important that preliminary determination of ground with low carrying capacity and taking necessary measures (Buyuk et.al. 2001).

All the environmental information and core values using Geographical Information Systems (GIS) to create an information system and database to assist in establishing balances between sensitive ecosystems (Ozturk 2015). Because GIS is used in many areas, it can be applied during the forest road planning stage. GIS has been used in the planning of the primary and secondary forest road network and when choosing the optimal routes out of a number of possible pre-existing networks (Nevečerel et al. 2007, Najafi and Richards 2013, Mohtashami 2012, Pentek et al. 2005).

The aim of this study was to evaluate technical efficiency variables for each 100 meters section of 46.122 km forest road in the Karacaoren Forest Sub-District Directorate. Roads sections that provided or did not provide the efficiency status of the technical standard variables were mapped in the ArcGIS. In the study, the impact of topography (slope, aspect) and soil characteristics (soil depth – soil stoniness – erosion) on the quality of the technical standards quality of forest roads was revealed using GIS and SPSS software.

Materials and Methods

Description of study site

This study was carried out on existing forest roads in the Karacaoren Forest Sub-District Directorate, Daday, Kastamonu (Figure 1). The size of area of sub-directorate was 12706.7 hectares. There was a total of 96.689 km of roads (46.122 km of forest roads and 50.567 km of motorway, forest village roads) (Figure 2).

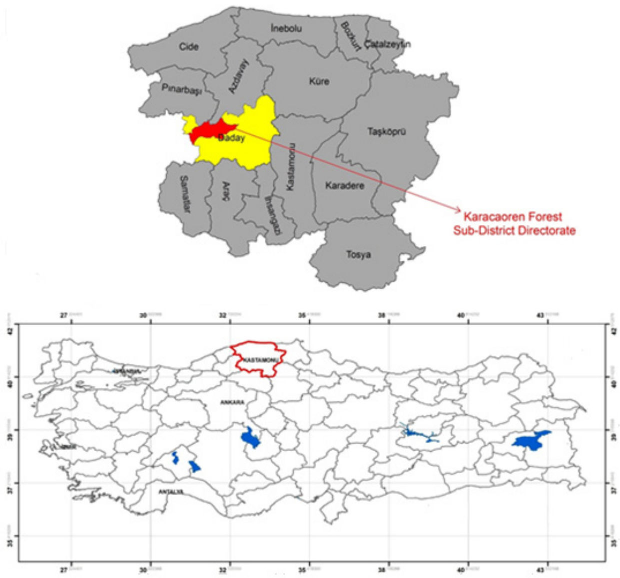

Figure 1. Location of the Karacaoren Forest Sub-District Directorate

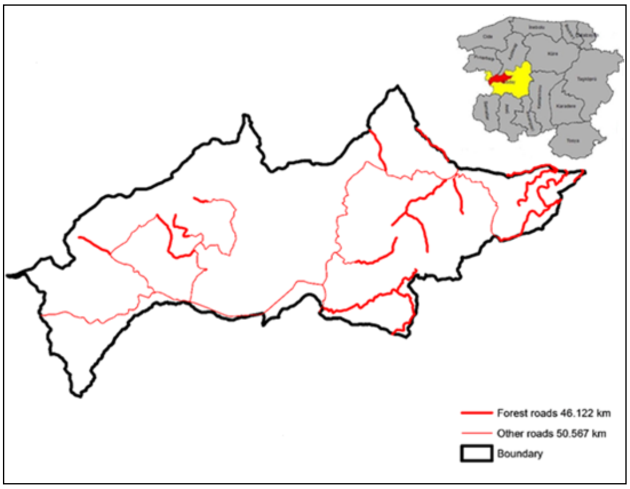

Figure 2. Forest Road Network Plan of the Karacaoren Forest Sub-District Directorate (GDF 2008)

Data Collection and Processing

The road Network Plan (GDF 2008) of the Karacaoren Forest Sub-District Directorate was used to obtain general information and to establish a database concerning of the forest roads. To create a digital terrain model of the study area, 1/25000 scale standard topographic maps were used. ArcGIS and SPSS software packages were also used in creating the database, identifying and mapping the technical efficiency level of the existing forest roads, and executing the performance analysis. A field chart was used to record the measurements and observations carried out on the existing forest roads in the Karacaoren Forest Sub-District Directorate.

Measurements and observations in the field

Total of 46.122 km were divided into 100 m sections, and then the technical efficiency level of each section was determined as data and positional level. Eleven technical variables, the road platform width, ditch width (condition), road expansion in curves and hairpin turns, superstructure, culvert., road-shadow condition, cut-fill side slope, platform degradation, road inclination, and growth of plants on the road platform were measured and observed directly in the field for each 100 m section of the existing forest roads (Figure 3);

- For each 100 m section of each forest road, the road platform width was measured with the help of a spring tape measure on the middle of each section and recorded on a field chart.
- The widths of the ditches were also measured with a spring tape measure for each 100 m in the middle of each section. The usability of the ditches was examined.
- The presence of road expansion in the curves and hairpin turns were evaluated and measured with a spring tape measure along the roads for each horizontal curve and hairpin turn.
- The dimensions of the culverts, the plugged-broken status, and locations were examined in the study area.
- The 50% exposure to tree shadow of each 100 m road section of the road platform was observed.
- The presence of surface erosion and the stabilization provided with plants on the side slope were recorded.
- The road deformation was assessed by examining the intensity and the size of deterioration on the road.
- The road inclination of the road section is measured with a clinometer of Suunto type.
- The presence of bushy plants on the road platform and the places planted with bushes were observed and their locations were saved on the field chart.

Each technical variable listed in Table 2 was scored as two different values "1" or "0". If the measured or observed technical variable on the forest roads was up to the standard, it was assigned the score "1", otherwise it was assigned the score"0".

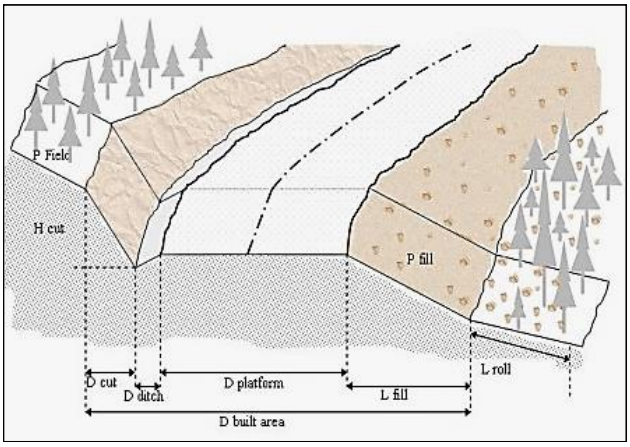

Figure 3. Image of some of the technical measurements made at a cross section of an area (Aricak 2008)

Table 2. Technical variables, parameters and scores

Variable	Parameter	Score
Platform width	Road platform width 4 m or 5 m	1
	Road platform width < 4 m or > 5 m	0
Ditch width (condition)	Ditch width 1-1,2 m	1
	No ditch, or ditch width 0-1 m or >1,2 m	0
Road expansion in curves and hairpin turns	There is road expansion in curves / hairpins turns or it is not necessary	1
	There is no road expansion in the curves and hairpin turns	0
Superstructure	Hard stable ground	1
	Unsurfaced road	0
Culvert condition	Existent and usable or not necessary	1
	Needs to be done or is a plugged-broken case	0
Road-shadow condition	There are no shadows on 50% of the road platform due to tree shade	1
	There are shadows on 50% of the road platform due to tree shade	0
Cut side slope stability	No surface erosion / no flow on cut side slope	1
	There is surface erosion/flow on cut side slope	0
Fill side slope stability	No surface erosion / no flow on fill side slope	1
	There is surface erosion / flow on fill side slope	0
Platform degradation	No deterioration on the road platform	1
	There is a deterioration on the road platform	0
Road inclination	2-10 %	1
	0-2 % or 10 % <	0
Growth of plants on the road platform (presence of bushy plants)	No bushy vegetation on the road platform	1
	There is bushy vegetation on the road platform	0

The effect of the topography (slope and aspect) and soil characteristics on the technical variables of the forest roads was also studied. According to IUFRO, a slope of 0-51% is considered to be a low slope area, and a slope equal to or greater than 51% is considered to be a high slope area (URL-1, 2017). The forest roads on the south, southeast, southwest, and west facing slopes are called sunny sites, while the north, northeast, east, and northwest facing slopes are called shady sites. The soil characteristics of the forest roads were assessed in terms of soil depth (0-20 cm: very shallow, 20-50 cm: shallow, 50-90 cm: moderate deep, and over 90 cm: deep), stoniness (0-5 %: less stony, 6-15 %: moderate stony, 16-50%: stony, and over 50%: very stony) and erosion levels (non- or slight, moderate, and severe) (Anonymous 2015).

Topography, soil characteristics and the forest roads were intersected and mapped in ArcGIS software. The effect of the topography and soil characteristics on the technical variables was tested using "Chi-Square Test for Independence" in SPSS software package.

Results

The total of 46.122 km in the Karacaoren Forest Sub-District Directorate was evaluated for their technical efficiency using the scoring system.

The platform width did not match the standard for 36.773 km of the forest roads (80%). A total of 38.754 km of forest roads (84%) did not have ditches or the ditches were not of usable quality. A total of 17.270 km of the forest roads (37%) were unsurfaced. A total of 2.638 of the km forest roads (6%) had culvert structures that were inadequate or plugged due to the material coming from river and were broken due to pressure. A total of the 4.870 km of the forest roads (11%) did not have adequate road expansion in the curves and hairpin turns. A total of the 15.296 km of the forest roads (33%) were within the 0-2% or more than 10% slope groups which are not preferred. A total of 26.723 km of the forest roads (58%) had shade on 50% of the platform of each 100 m road section due to tree shadows. A total of 10.955 km of the forest roads had unstable cut side slopes because plant and soil stabilization were not provided. A total of 1.535 km of the forest roads had unstable fill side slope because it was observed that plant and soil stabilization was not provided. A total of 16.991 km of the forest roads had deterioration on the road platform. A total of 2.342 km of the forest roads had plant growth on the road platform.

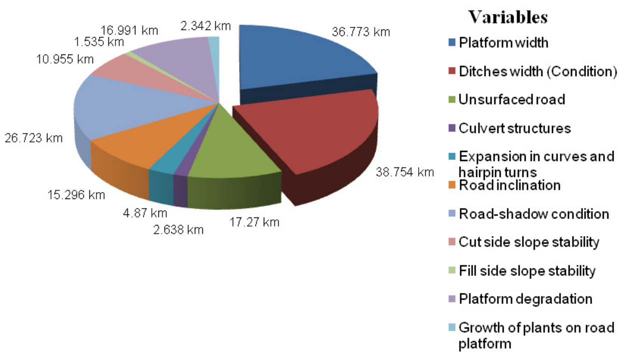

Figure 4. Showing the amount of forest roads that are not in good condition depending on the variables

The effect of topography (slope, aspect), and soil characteristics on technical variables was shown in Table 3. There was seen that:

- Land slope was effective on platform width;
- Shady/sunny aspect was effective on ditch width, platform degradation and growth of plants on the road platform;
- Soil depth was effective on platform width, ditch width, cut side slope stability and platform degradation;
- Stoniness was effective on platform width, cut side slope stability and growth of plants on road platform;
- Erosion was effective on platform width, cut side slope stability and platform degradation

A total of 3.540 km of the existing roads (8%) exceeded a 51% land slope in the area; therefore, these roads were considered to be in the high slope group according to IUFRO, whereas 42.582 km (92%) of the roads fit in the lower slope group. Slope map data of the study area and the technical standards data were analyzed together using the chi-square test for independence. It was found that the "*p*" value (Asymp. Sig.=0.001) was smaller than 0.05; therefore, it was concluded that there was a significant correlation between the platform width and the land slope. However, the land slope had no effect on the other variables (Table 3).

Because water will not accumulate on forest roads built in sunny areas, the road deformation will be much lower in sunny areas than in shady areas. The road maintenance will be also much lower in sunny areas than in shady areas. Therefore, the cost of maintenance service of the forest road will be lower in sunny areas.

A total of 31.677 km of the existing forest roads (69%) are located in sunny areas of the study area, while 14.445 km of the forest roads (31%) located in shady areas of the study area.

When the sunny/shady area map of the study area and the technical standards data were analyzed, the "*p*" values of the ditch width (condition) (Asymp. Sig.=0.038), platform degradation condition (Asymp. Sig.=0.008) and road platform plant growth (Asymp. Sig.=0.023) were found to be smaller than 0.05, indicating that they had significant correlations with the shady/sunny areas (Table 3).

The "*p*" values of the platform width (Asymp. Sig.=0.000), ditch width (condition) (Asymp. Sig.=0.000), cut side slope stability (Asymp. Sig.=0.000) and road platform degradation condition (Asymp. Sig. =0.000) were smaller than 0.05, indicating that they had a significant influence with the soil depth (Table 3).

The "*p*" values of the platform width (Asymp. Sig.=0.002), cut side slope stability (Asymp. Sig.=0.020)

Table 3. Chi-square test for independence

Topography \ Technical variables		Platform width	Ditch width (condition)	Cut side slope stability	Fill side slope stability	Platform degradation	Growth of plants on road platform
Land slope		0.001*	0.348	0.408	0.993	0.245	0.190
Shady/sunny aspect		0.680	0.038*	0.480	0.831	0.008*	0.023*
Soil characteristics	Depth	0.000*	0.000*	0.000*	0.642	0.000*	0.110
	Stoniness	0.002*	0.119	0.020*	0.600	0.556	0.042*
	Erosion	0.000*	0.085	0.002*	0.480	0.008*	0.086

*Significant at $p<0.05$

and road platform plant growth (Asymp. Sig.=0.042) were significantly correlated with the soil stoniness groups (Table 3).

Erosion levels represent the soil level of proneness to water erosion and ranged as follows: none to very little, medium, severe, and very severe (Anonymous 2015). The *"p"* values of the platform width (Asymp. Sig.=0.000), cut side slope stability (Asymp. Sig.=0.002), and platform surface degradation condition (Asymp. Sig.=0.008) showed significant correlation with the erosion categories. Sariyildiz et al. (2013) have stated that shrubby plantings are significantly effective in preventing runoff and soil erosion in sloping areas. We also note that roads covered with dense vegetation had no problem in terms of side slope stabilization (Table 3).

Discussion

On the existing roads, the "ditch width (condition)" and "platform width" variables were mostly found to be not suitable according to the standards. Our results are similar to those of a previous study by Unver (2013). Unver (2013) conducted a study to determine the quality of the forest roads with a scoring system and noted that the ditches did not have a sufficient width, were not built properly and demonstrated that these conditions favourably influenced the quality of a road and its lifetime.

As a result, flowing with the slope effect, the material moving to the cut side slope completely or partially closed the ditches. The narrowing of the platform width may also be due to the flow of material from the cut side slope or ecological and economic reasons.

The "plant growth" and "fill side slope stabilization" variables on the road platform were found to be in good condition. Unver (2013) also determined that plants provided stability on the roadsides. The forest roads were constantly in use; therefore, there were few plants on the road platform. The fill side slope stabilization was in good condition. This may be because the movement of the cut material to the fill reduced the slope increasing the water-holding capacity and decreasing the runoff erosion. Simultaneously, due to the rich organic material accumulated on the fill side slope, planting was seen to be denser on the fill side slopes.

It was seen that the constructed platform width of the study area was smaller than it needed to be. A few reasons for this may have been that road construction is difficult with increasing land slope or that the roads have become smaller due to improper maintenance. Therefore, as long as forest roads are planned in areas that do not have high slopes (slope less than 51%), the platform width should be constructed to the required standards.

Forest roads should be planned in sunny areas as much as possible, so that the ditch structure can serve its function better due to the drying effect of the sunlight. This would minimize water pooling on the road and reduce platform deformation and plant growth on the road platform. Due to various reasons, such as wood transportation by trucks, tire pressure, drainage problems, frost, negative weather conditions, and unsuitable construction techniques, deterioration is seen on forest roads (Eroglu et al. 2006).

Based on the "soil depth" characteristic in the present study, it would be better to plan forest roads in shallow soil areas. Sariyildiz et al. (2016) indicated that the soil carbon stock is greater in shallow soil (0-20 cm depths) because shallow soils are rich in organic matter and high soil stabilization depends on the amount of organic matter. Because the soil stability depending on the amount of organic matter is greater in shallow soil, achieving cut side slope and platform stability would be easier in such regions. Areas that are little stony based on "soil stoniness" are preferred for the planning of forest roads. If the area to be used for road construction has little stoniness, the soil stabilization is greater, which means that it will be easier to achieve cut side slope and platform stability. Based on the "erosion levels" of the soil characteristics, achieving cut stability becomes more difficult and deformation on the platform increases as water erosion severity increases. Therefore, whenever possible, areas with lower erosion levels are preferred for planning forest roads.

The forests in the world are generally spreading in mountainous regions. Forest roads are one of the most important transport facilities in conducting forestry operations and are planned in these mountainously terrain. In this regard, while the roads are planned, the technical standards used for this study can be applied to all mountainous regions.

Conclusion

Planned areas for forest road construction should be selected correctly so that forest roads, which are open to environmental factors, can maintain their technical standards.

We suggest that forest road routes should be planned in sunny areas with slopes less than 51%, on "shallow soils" with "little stony" stoniness, and with "none to very little" erosion levels. In this way, the technical standards of the platform width, ditch width (condition), and cut side slope stabilization will be achieved both at the construction stage and during the use of the roads and platform surface deterioration and plant growth on the platform will be prevented. In addition, the results show that land slope, aspect, and soil characteristics do not have any impact on the technical standard quality of fill side slope stabilization.

In line with the results of the study, the following suggestions can be found in general:

- Maintenance and repair work can be first started on the roads with more problems. For this study maintenance and repair works should be started from platform width (80% of forest roads were out of the standard) and ditches (84% forest roads did not have ditches and the ditches were not of usable quality). So, the status of the variables obtained as a result of the study can be considered when creating maintenance and repair programmes for the existing forest roads.
- Unit transportation costs can be determined according to the technical efficiency of the forest roads in forest product transport.
- Based on the efficiency level of the roads, access to forests for different purposes may be restricted.

References

Abdi, E., Rahbari-SiSakht, S. and Moghdami-Rad, M. 2012. Improving cross drain systems to minimize sediment delivery using GIS. *Forestry Studies in China Journal* 14 (4): 209-306. doi: 10.1007/s11632-012-0411-z

Acar, H.H. and Unver, S. 2007. Evaluation and grading of existing forest roads. *Turkish Journal of Forest Engineering* 44: 37-38.

Anonymous. 2015. National Soil Database. Available online at: http://aris.cob.gov.tr/sites/default/files/lejant.pdf. Last accessed on: 23 June 2016.

Arıcak, B. 2008. Orman Yolu İnşaatında Dolgu ve İnşaat Etki Alanlarının Uzaktan Algılama Verileri ile Belirlenmesi Üzerine Bir Araştırma. [A research on determination of filling areas and construction impact zones in building forest roads by using remote sensing data]. Doktora Tezi. Karadeniz Teknik Üniversitesi Fen Bilimleri Enstitüsü, Trabzon, 116 pp. (in Turkish with English summary). Available online at: http://www.irfanakar.com/turkish/pdf2/ua/tezler/orman/1%20(3).pdf

Bruce, J.C., Han, H.S., Akay, A.E. and Chung, **W.** 2011. ACCEL: Spreadsheet-Based Cost Estimation for Forest Road Construction. *Western Journal of Applied Forestry* 26(4): 189–197.

Büyük, E., Acar, H.H., Şentürk, N., Altun, L. and Kulaç, S. 2001. Samsun'da Orman Yollarında Ortaya Çıkan Heyelanların Zemin Mekaniği Açısından İncelenmesi. [The Investigation of Landslide Emerging on Forest Roads Around Samsun from the Point of Soil Mechanics]. *Ekoloji Çevre Dergisi – Ecology Environment Journal* 41: 3-7 (in Turkish).

Cetin, M. and Sevik, H. 2016. Evaluating the recreation potential of Ilgaz Mountain National Park in Turkey. *Environmental Monitoring and Assessment* 188(1): 1-10.

Da Silva, A.M., Braga Alves, C. and Alves, S.H. 2010. Roadside vegetation: estimation and potential for carbon sequestration. *iForest* 3: 124-129. doi: 10.3832/ifor0550-003.

Deegen, P., Hostettler, M. and Navarro, G.A. 2011. The Faustmann model as a model for a forestry of prices. *European Journal of Forest Research* 130(3): 353–368.

Demir, M. 2007. Impacts, management and functional planning criterion of forest road network system in Turkey. *Transportation Research* Part A 41(1): 56–68.

Eker, M. and Ada, N. 2011. Orman yolu kalite analizine yönelik ölçüt ve gösterge setinin oluşturulması [The constitution of criteria and indicator set for quality analysis of a forest road]. *Türkiye Ormancılık Dergisi – Turkish Journal of Forestry* 12(2): 89-97. Available online at: http://dergipark.gov.tr/tjf/issue/20897/224415 (in Turkish).

Eroglu, H., Acar, H.H., Ucuncu, O. and Imamoglu, S. 2006. Soil stabilization of forest roads sub-base using lime mud waste from the chemical recovery process in alkaline pulp mill. *Journal of Applied Sciences* 6: 1199-1203.

Eroglu, M., Alkan-Akıncı, H. and Ozcan, G.E. 2005. Kabuk Böceği Salgınlarının Nedenleri ve Boyutları [Sizes and Causes of the Bark Beetle Outbreak, Forest and Hunting]. *Orman ve Av* 82 (5): 27–34 (in Turkish).

GDF. 2008. Forest Roads Planning, Construction and Maintenance. Turkish Republic, Environment and Forestry Ministry, General Directorate of Forestry, Construction and Supply Head Department, Edict No.: 292, Ankara.

GDF. 2008. Karacaören Orman İşletme Şefliği Yol Ağı Planı, Çevre ve Orman Bakanlığı OGM, Ankara [The Road Network Plan of the Karacaoren Forest Sub-District Directorate, Ministry of Environment and Forestry GDF, Ankara] (in Turkish).

Grigolato, S., Pellegrini, M. and Cavalli, R., 2013. Temporal analysis of the traffic loads on forest road networks. *Forest – Biogeosciences and Forestry* 6(5): 255–261.

Gucinski, H., Furniss, M.J., Ziemer, R.R. and Brookes, M.H. 2001. Forest roads: A synthesis of scientific information. General Technical Report PNW-GTR-509. Portland, Oregon: U.S. Dept. of Agriculture, Forest Service. 103 p. Available online at: https://www.fs.fed.us/pnw/pubs/gtr509.pdf

Görcelioglu, E. 1996. Ağaçlandırma alanlarında su ve toprak koruma amacıyla kullanılan teraslar ve orman yollarında erozyon kontrolü. [Erosion Control in Terraces and Forest Roads Used For The Purpose of Water And Soil Conservation in Forest Plantations]. *İstanbul Üniversitesi Orman Fakültesi Dergisi – Journal of the Faculty of Forestry Istanbul University (JFFIU)* 46(2): 23-36 (in Turkish).

Gumus, S. 2009. Constitution of the forest road evaluation form for Turkish forestry. *African Journal of Biotechnology* 8(20): 5389-5394.

Hasdemir, M. and Demir, M. 2000. Türkiye'de Orman Yollarını Karayolundan Ayıran Özellikler ve Bu Yolların Sınıflandırılması [Distinctive Features Forest Road from Highway in Turkey and Classification of These Roads]. *İstanbul Üniversitesi Orman Fakültesi Dergisi – Journal of the Faculty of Forestry Istanbul University*, Seri B, 50 (2): 85-96 (in Turkish).

Hayati, E., Majnounian, B. and Abdi, E. 2012: Qualitative evaluation and optimization of forest road network to minimize total costs and environmental impacts. *iForest* 5: 121-125. doi: 10.3832/ifor0610-009.

Hui C., Shuang-cheng, L. and Yi-li, Z. 2003. Impact of road construction on vegetation alongside Qinghal-Xizang highway and railway. *Chinese Geographical Science* 13 (4): 340-346. doi: 10.1007/s11769-003-0040-5.

Jadczyk, P. 2009. Natural effects of large-area forest decline in the western Sudeten. *Environment Protection Engineering* 35 (1): 49-56. Available online at: http://epe.pwr.wroc.pl/2009/Jadczyk_1-2009.pdf.

Jaafari, A., Najafi, A., Rezaeian, J. and Sattarian, A. 2015. Modeling erosion and sediment delivery from unpaved roads in the north mountainous forest of Iran. *GEM – International Journal on Geomathematics* 6(2): 346-356.

Keller, G. and Sherar, J. 2004. Ingeniería de caminos rurales; Guía de campo para las mejores prácticas de administración de caminos rurales. Producido por US Agency for International Development (USAID) en Cooperación con USDA, Forest Service, International Programs & Conservation Management Institute, Virginia Polytechnic Institute and State University. Versión en español producida por Instituto Mexicano del Transporte, Secretaría de Comunicaciones y Transportes, México. 2005. Revisado enero 2008. 181 pp. (in Spanish).

Karlson, M., Mörtberg U. and Balfors, B. 2014. Road ecology in environmental impact assessment. *Environmental Impact Assessment Review* 48: 10-19.

Kimmins, J.P.H. 2011. Balancing act: Environmental issues in forestry. UBC Press, Vancouver, BC, Canada, 310 pp.

Kiss, K., Malinen, J. and Tokola, T. 2015. Forest road quality control using ALS data. *Canadian Journal of Forest Research* 45(11): 1636–1642.

Laschi, A., Neri, F., Montorselli, N.B. and Marchi, E. 2016. A Methodological Approach Exploiting Modern Techniques for Forest Road Network Planning. *Croatian Journal of Forest Engineering* 37(2): 319-331.

Lugo, A.E. and Gucinski, H., 2000. Function, Effects and Management of Forest Roads. *Forest Ecology and Management*, 133(3): 249-262. Available online at: http://dx.doi.org/10.1016/S0378-1127(99)00237-6

Mohtashami, S., Bergkvist, I., Löfgren, B. and Berg, S. 2012. A GIS approach to analyzing off-road transportation: a cases study in Sweden. *Croatian Journal of Forest Engineering* 33(2): 275-284.

Najafi, A. and Richards, E.W. 2013. Designing a Forest Road Network Using Mixed Integer Programming. *Croatian Journal of Forest Engineering* 34(1): 17–30.

Naghdi, R. 2004. Comparative study of tree length hand cut to length logging method. PhD Thesis. College of Natural Resources, University of Tehran, Iran, 320 pp.

Nevečerel, H., Pentek, T., Pičman, D. and Stankić, I. 2007. Traffic load of forest roads as a criterion for their categorization – GIS analysis. *Croatian Journal of Forest Engineering* 28(1): 27-38.

OGM. 2015. Orman ve Su İşleri Bakanlığı, Orman Genel Müdürlüğü 2014 Yılı İdare Faaliyet Raporu, Strateji Geliştirme Dairesi Başkanlığı Ankara (Ministry of Forestry and Water Management, General Directorate of Forestry, 2014 Annual Report, Strategy Development Department) (in Turkish).

Ozturk, S. 2015. Determining management strategies for the Sarikum Nature Protection Area. *Environmental Monitoring and Assessment* 187(3): 1-9.

Pellegrini, M., Grigolato, S. and Cavalli, R. 2013. Spatial Multi-Criteria Decision Process to Define Maintenance Priorities of Forest Road Network: an Application in the Italian Alpine Region. *Croatian Journal of Forest Engineering* 34(1): 31–42.

Pentek, T., Pičman, D., Potočnik, I., Dvorščak, P. and Nevečerel, H. 2005. Analysis of an existing forest road network. *Croatian Journal of Forest Engineering* 26(1): 39-50.

Péterfalvi, J., Primusz, P., Markó,G., Kisfaludi, B. and Kosztka, M. 2015. Evaluation of the Effect of Lime-Stabilized Subgrade on the Performance of an Experimental Road Pavement. *Croatian Journal of Forest Engineering* 36(2): 269-282.

Ryan, T., Phillips, H., Ramsay, J. and Dempsey, J. 2004. Forest Road Manual: Guidelines for the design, construction and management of forest roads. COFORD, National Council for Forest Research and Development, Dublin. 170 pp. Available online at: https://www.unirc.it/documentazione/materiale_didattico/598_2007_39_832.pdf

Sariyildiz, T., Savaci, G. and Kravkaz, I.S. 2016. Effects of tree species, stand age and land-use change on soil carbon and nitrogen stock rates in northwestern Turkey. *iForest* 9: 165-170. doi:10.3832/ifor1567-008.

Sariyildiz, T., Kravkaz, I. S. and Savacı, **G.** 2013. Influence of Sainfoin Cover (*Onobrychis viciifolia* Scop) and Dog rose (*Rose canina*) on Soil Loss, Runoff and Some Soil Properties at Erosion Control Terraces. In: ICFS, International Caucasian Forestry Symposium, 24-26 October, 2013, Artvin, Turkey. Poster presentation, p. 1035.

Sen, G. and Bugday, S.E. 2015. Kastamonu İli Korunan Alanları. [Assigned Areas in Various Status for Use and Protection of Property in Kastamonu Province. *Kastamonu Üniversitesi Orman Fakültesi Dergisi – Journal of Forestry Faculty, Kastamonu University* 15 (2) :214-230 (in Turkish with English abstract).

Smulders, M.J.M., Cobben, M.M.P., Arens, P. and Verboom, J. 2009. Land scape genetics of fragmented forests: anticipating climate change by facilitating migration. *iForest* 2: 128-132. doi: 10.3832/ifor0505-002.

Tolosana Esteban, E., González de Linares, V.M. and Vignote Peña, S. 2000. El Aprovechamiento Maderero. 1ª ed. S.A. Mundi-Prensa Libros, Madrid, p. 419–438 (in Castellano).

Ünver, S. 2013. Orman Yollarında Puanlandırma Yöntemiyle Yol Kalite Sınıflarının Belirlenmesi: Karanlıkdere Örneği. [Determination of Quality Classes of Forest Roads by the Point Method: Karanlıkdere Sample]. *Kastamonu Üniversitesi Orman Fakültesi Dergisi – Journal of Forestry Faculty, Kastamonu University* 13 (2): 211-219 (in Turkish with English abstract). Available online at: http://dergipark.gov.tr/download/article-file/159510

Whittaker, C., Mortimer, N., Murphy, R. and Matthews, R. 2011: Energy and greenhouse gas balance of the use of forest residues for bioenergy production in the UK. *Biomass and Bioenergy* 35: 4581–4594.