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Effect of Forest Roads-stream Crossings on Physical-Chemical Properties of Water

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ABSTRACT

Aims: Forest roads are one of the sources of stream water pollution, and the intersection of the road and the stream contributes the most to this issue. In Iran, due to the high costs of water quality analysis and the difficulty of field operations, there needs to be more literature in this regard. So, in this research, the effects of age and cut slope characteristics of forest roads were studied on the water quality properties of streams in a Hyrcanian forest.

Materials & Methods: Twelve road-stream crossings were randomly selected on road segments constructed 15 and 30 years ago. The cut slope gradients on these road segments were 120, 130, 140, and 150%, which could affect water quality as an independent variable. Three stream sections farther from the road network (700 m at upstream) were randomly selected as control. At control points and road-stream crossing (5 m upstream and downstream), water samples were collected from the center and near the stream bed using a 4-liter gauge. Acidity (pH), Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Nitrate, Phosphate, and Ammonium were measured for each water sample.

Findings: Results showed that the road age and cut slope gradient significantly affected the physical-chemical properties of stream water. Higher values of EC (0.05 $s.m^{-1}$), TDS (3000000 $t.h^{-1}.y^{-1}$), TSS (12000 $t.h^{-1}.yr^{-1}$), Nitrate (3000 $t.h^{-1}.y^{-1}$), Phosphate (350 $t.h^{-1}.y^{-1}$) and Ammonium (400 $t.h^{-1}.y^{-1}$) were found at the road-stream crossing as compared to controls. A comparison of pH values shows no significant differences among the road-stream crossing and control samples. In addition, steeper cut slopes and 15-year-old roads showed higher concentrations of physical-chemical materials than gentle slopes and 30-year-old roads.

Conclusion: In conclusion, water quality can be improved by designing and building gentle slopes at road-stream intersections and soil protection and erosion control in steep slopes. Also, the present research results showed that the water quality improves with the distance from the time of road construction and the natural stabilization of intersections. So, this study is a good starting point for further research on the details and objectives of forest management in order to preserve this ecosystem.

Keywords: Road Age; Cut Slope; Water Quality; Suspended Solid; Darabkola Forest.

CITATION LINKS

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Introduction

The forest road is one of the first risk levels for non-point source pollution from forest management activities. The high concentration of sediment in runoff on excavations and cut slopes was identified as the primary source of sediment [1]. Vegetation, rock fragments, and soil texture are important factors in the rate of runoff and soil loss in different parts of the road [2]. The main factors that increase the potential for erosion and impacts on water quality include disruption of natural surface and subsurface drainage patterns in the watersheds, bare soil and steep slopes against rainfall, and reduced permeability [3, 4, 5]. It was detected that 20% of the outlet of water-carrying pipes was directly related to the streams. Gully erosion at the drainage outlet creates a direct connection between the roads to the stream and will have adverse effects [6, 7]. Hosseini et al. [8] estimated sediments from forest roads using the Sediment Model (SEDMODL). The study was conducted on Parcels 26, 27, and 33 of Series 1 of the Darabkola Forest. The results of this model in predicting the sediment production of regional roads showed that the sediment production rate in these roads is 77.51 $t.y^{-1}$. Moreover, they found that slope gradient, the distance between road and stream, and cut slope height are the most influential factors in sediment yield to stream. Safari et al. [9] investigated the rate of sediment carryover and transport to the streams by the roads in Darabkola Forest using the Washington Road Surface Erosion Model (WARSEM). In order to evaluate the results of the model used, the sedimentation rate was directly measured in different sections of the road using a rainfall simulator. The results showed that the model had sufficient accuracy and efficiency for estimating erosion and sedimentation resulting from Darabkola forest roads and similar forest watersheds. Investigation of the observed sediment rate in the watershed outlet showed that according to the model results and direct measurements, 16% and 9% of the produced and transported sediments in the watershed resulted from the studied forest road surface. Wang et al. [10] examined the changes in pollution and accumulation of suspended sediments caused by road construction in the streams of West Virginia. The results showed that the pollution increased tenfold after road construction. The results indicated that two years after the road construction, the amount of transported sediments was at a better status concerning the water quality. Brown et al. [11] reported that the application of the sand reduced the sediment concentration in road surface runoff so that in sand-free treatment, it was 3.5 times and 2.6 times higher compared to roads with low and high sand, respectively. The road length and slope of the area contribute to the amount of sediment [12]. Chuman et al. [13] stated that the concentrations of major Anions (Nitrate, Sulfate, and Chlorine) are mainly related to anthropogenic activities and road compactness. Some studies showed that forest roads and timber utilization affect the water quality of forest streams [14, 15].

Although the overall effects of forest roads on water quality have been determined, further studies are needed in this regard. In Iran, there needs to be more literature due to the high costs of water quality analysis and the time-consuming and challenging field operations. In addition, determining water quality characteristics is one of the essential components in water resources management planning that makes field studies necessary so that obtained data could provide the basis for decision-making and planning. The main objective of this study was to investigate the effects of forest road age and cut slope characteristics on the physical-chemical properties of streams in a broad-leaved deciduous Forest. This research hypothesized that stream water quality significantly increased with increasing road age and decreasing cut slope gradient.

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Materials & Methods

Geography of the Study Area

Darabkola forest, with an area of 2612 hectares, is located in watershed 74 and the southeastern Sari City, Mazandaran Province, Iran (36° 33′ 20″ to 36″30′ 33° N, 52′14° 40″ to 52′ 31° 55″ E. This area is in the altitude range of 180 to 880m above sea level. The average annual precipitation is 938.8 mm, and the mean annual temperature is 16.7°C. According to the Darabkola forestry plan booklet, the area has a cold and humid climate according to the Emberger method. The average slope of the forest is about 40%. The forest site has four kinds of soil, including (I) nondevelopment randzin to washed randzin soil, (II) brown with alkaline soil pH, (III) washed brown with classic, and (IV) washed brown with pseudogap (Figure 1; Forestry Plan Booklet of Darabkola). A summary of the characteristics of the stations under study is given in Table 1.

Data Collection

Twelve road-stream crossings were randomly selected on road segments constructed 15 and 30 years ago (independent variable). Cut slope gradients on these road segments were 120, 130, 140, and 150%, which could affect water quality as another independent variable. Three stream sections farther from the road network (700 m at upstream) were randomly selected as control. At control points and road-stream crossing (5 m upstream and downstream), water samples were collected from the center and near the stream bed using a 4-liter gauge. [14, 15]. Acidity (pH), Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Nitrate, Phosphate, and Ammonium were measured for each water sample.

Total Suspended Solids (TSS): Total suspended solids (non-filterable residue) refer to the portion of sediments suspended in a water column. Suspended sediment was measured by drying or filtering a water sam-

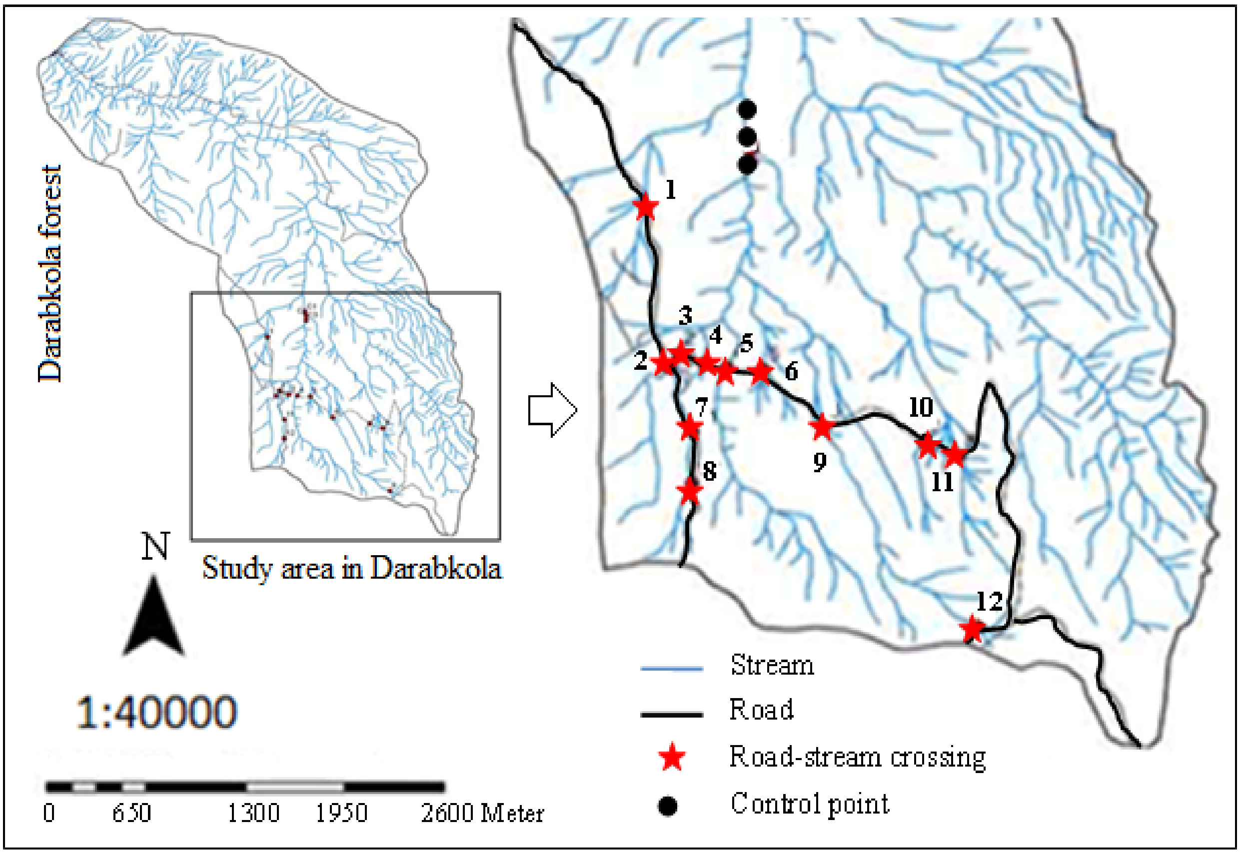

Figure 1) Location of road-stream crossing and control points as research stations.

Table 1) Characteristics of each of the studied road-stream crossings.

Crossing	Cut slope height (m)	Cut slope gradient (%)	Traffic ($n.h^{-1}$)	Organic matter (%)	Silt (%)	Sand (%)	Clay (%)
1	2.5	150	2	11	35	33	32
2	2.7	120	2	4	33	40	27
3	3.1	120	2	15	32	37	31
4	3.3	130	2	8	29	37	34
5	1.9	140	2	14	30	36	34
6	2.4	120	2	10	32	33	35
7	3.1	130	2	10	29	30	41
8	3.0	150	2	6	33	31	36
9	2.8	130	2	4	32	37	31
10	2.9	140	2	5	28	34	38
11	2.3	130	2	11	29	31	40
12	2.5	140	2	12	32	33	35

Table 2) T-test comparing water quality variables between 15-year and 30-year-old roads.

Variable	Intersect. (15 Y. Road)			Intersect.(30 Y. Road)		
	Freedom Deg.	t	Sig.	Freedom Deg.	t	Sig.
pH	16	1.482	0.158	16	2.450	0.026
EC	16	1.501	0.153	16	-4.021	0.001
TSS	16	3.029	0.016	16	-1.720	0.105
TDS	16	2.677	0.028	16	-2.474	0.025
PO_4^{-3}	16	3.265	0.010	16	0.144	0.888
NO_3^-	16	3.115	0.014	16	0.769	0.453
NH^+_4	16	1.850	0.088	16	-0.540	0.597

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ple (usually a depth-integrated sample) and weighing the residual portion, which is expressed as a concentration in mg.l^{-1} or parts per million (ppm) [16].

Acidity (pH): Regarding water quality, pH is important as it determines the solubility of heavy metals. The pH of a substance is a measure of hydrogen ion (H+) activity. Litmus strips color indicators were used to measure pH [12, 17].

Electrical Conductivity (EC): Electrical conductivity measures the ease with which electrical current passes through water and is expressed in micro Siemens per centimeter. Electrical conductivity was measured using an EC meter [18].

Total Dissolved Solids (TDS): Total dissolved solids measure inorganic salts dissolved in water. It was measured by collect-

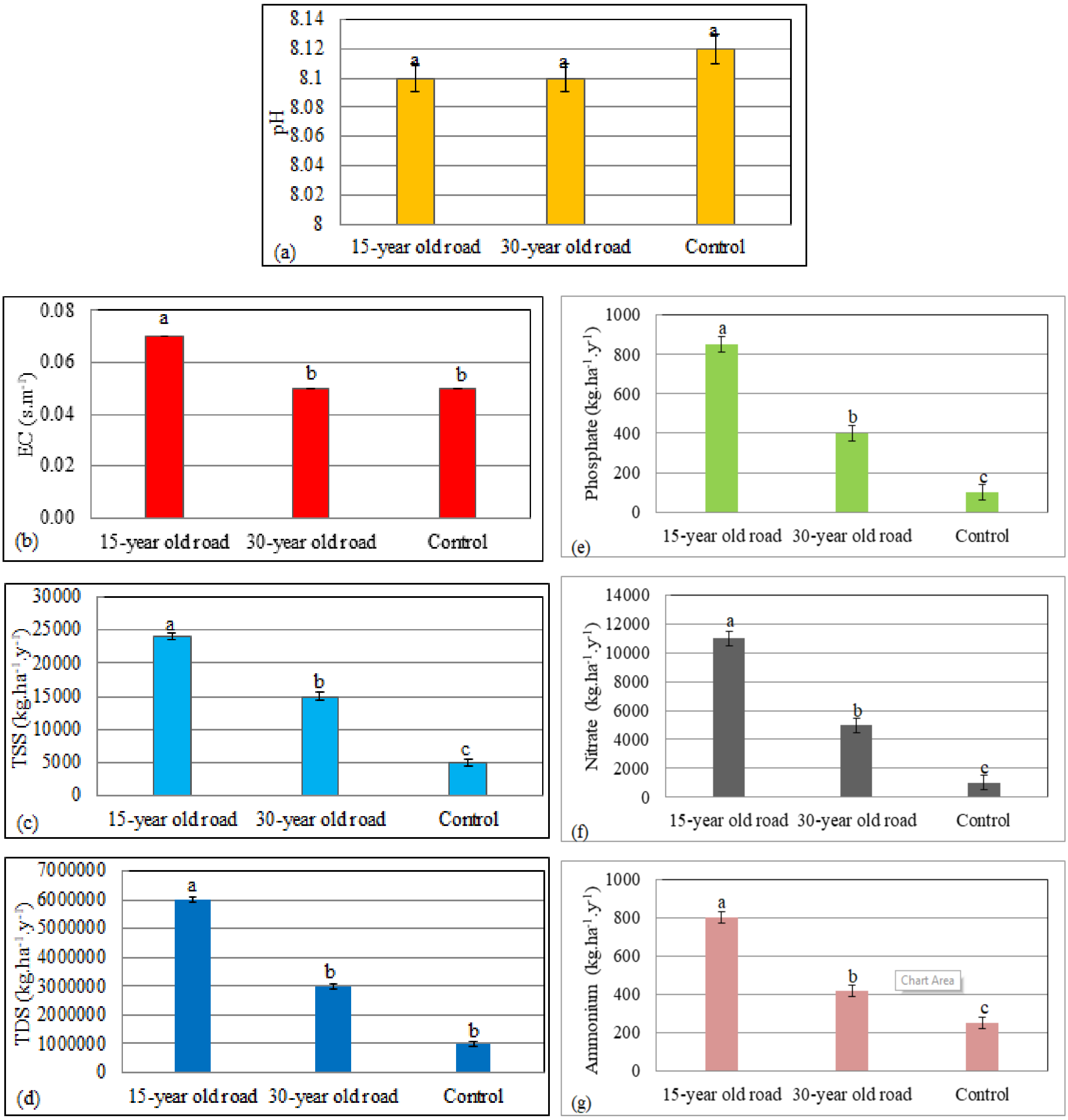

Figure 2) Effect of road age and control on the pH (a), EC (b), TSS (c), TDS (d), Phosphate (e), Nitrate (f), and Ammonium (g) of stream water. Different letters on columns show a significant difference at a probability level of 5%.

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ing electrical conductivity data and converting it to TDS values using a multiplication factor (0.55–0.8) [13].

Nitrate (No_3^-): Nitrate concentrations greater than 10 $mg.l^{-1}$ can also adversely affect human health. Stream Nitrate loads were measured using the Cadmium reduction method [19].

Ammonium (NH_4^+): Ammonia concentrations as low as 0.03 mg can be potentially toxic to aquatic organisms in the short term; concentrations greater than 0.002 mg may be toxic over the long term. The Nessler method is the most common spectrophotometric method to measure $NH4^+$ in water [20].

Phosphates ($PO4\ _3^-$): Phosphorus is often the nutrient that limits biological production in aquatic ecosystems. The Phosphate was measured by the ascorbic acid method [21].

Data Analysis

The normality of the data was evaluated using Kolmogorov-Smirnov test. Independent t-tests were performed to compare water quality variables between 15-year and 30-year-old roads. For multiple comparisons, one-way ANOVA (Overall Comparison) and Tukey's test (grouping) at the probability level of 95% were used after analysis of variance homogeneity by Levene's test in SPSS software. The correlation between road parameters and water quality was analyzed using the Pearson test.

Findings

The results of the present study showed that the road age significantly affected all physical-chemical properties of stream water (Table 2). Higher values of EC (0.05 $s.m^{-1}$), TDS (3000000 $t.h^{-1}.y^{-1}$), TSS (12000 $t.h^{-1}.y^{-1}$), Nitrate (3000 $t.h^{-1}.y^{-1}$), Phosphate (350 $t.h^{-1}.y^{-1}$) and Ammonium (400 $t.h^{-1}.y^{-1}$) were found at the road-stream crossing as compared to controls. In addition, 15-year-old roads showed higher concentrations of physical-chemical materials than 30-year-old roads. A comparison of pH values (8.2) shows no significant differences among the road-stream crossing and control samples (Figure 2).

Moreover, the amount of EC (0.06 $s.m^{-1}$), TDS (6000000 $t.h^{-1}.y^{-1}$), TSS (27000 $t.h^{-1}.y^{-1}$), Nitrate (11000 $t.h^{-1}.y^{-1}$), Phosphate (850 $t.h^{-1}.y^{-1}$) and Ammonium (800 $t.h^{-1}.y^{-1}$) was higher in road-stream crossing with steeper cut slopes (Table 3). Findings of the effect of cut slope gradient on water quality showed that water quality variables at the slope classes of 140 and 150% significantly differ from other slope classes. The results of this study also showed an increasing trend of TSS, TDS, and PO_4^{-3} variables with increasing the slope of cut slope (Figure 3).

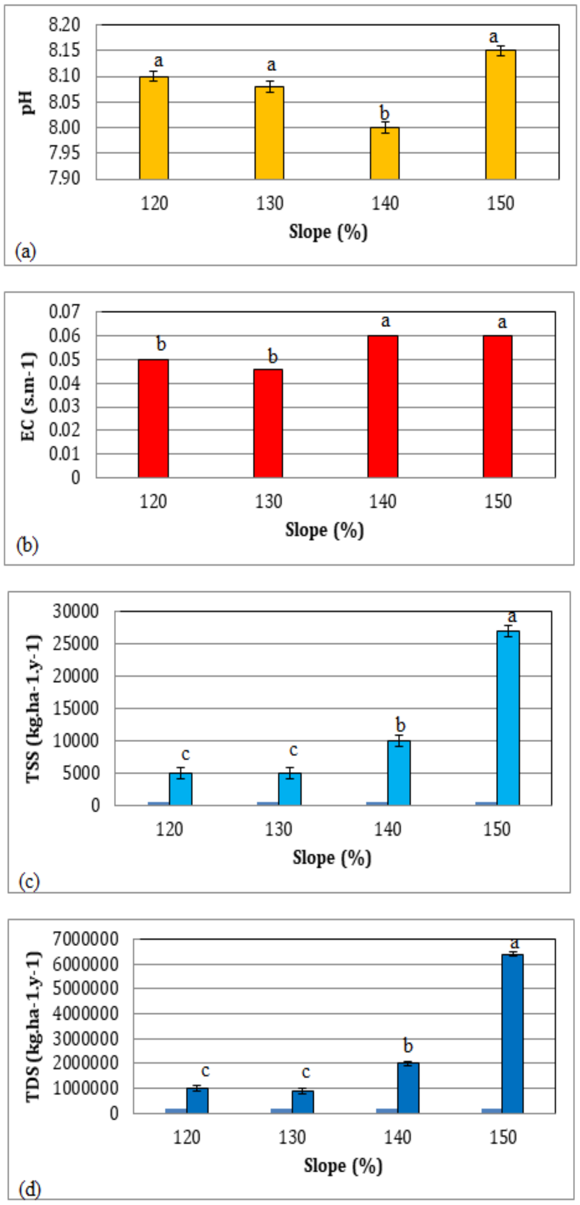

Figure 3) Changes in pH (a), EC (b), TSS (c), and TDS (d) in different slopes of cut slope. Different letters on columns show a significant difference at a probability level of 5%.

Table 3) Analysis of variance of cut slope characteristics' effect on stream water's physical chemicals as cross sections.

Variable	Source	Total Sq.	Freedom Deg.	Middle Sq.	F	Sig.
pH	Among	0.222	3	0.074	6.015	0.002
	Inside	0.393	32	0.012		
EC	Among	0.001	3	0.000	6.410	0.002
	Inside	0.001	32	0.000		
TSS	Among	6.260	3	2.087	2.967	0.047
	Inside	21.81	32	0.703		
TDS	Among	8.785	3	2.928	3.883	0.018
	Inside	24.131	32	0.754		
PO_4^{-3}	Among	2544969.96	3	848323.321	6.510	0.001
	Inside	4169685.02	32	130302.657		
NO_3^-	Among	8.736	3	2.912	3.540	0.025
	Inside	26.321	32	0.823		
NH^+_4	Among	2003866.418	3	667955.473	3.535	0.026
	Inside	6046894.956	32	188965.467		

Table 4) Pearson correlation among road parameters and water quality at crossing sections.

Code	Variables	1	2	3	4	5	6	7	8	9
1	Road Age	1								
2	Cut slope Gradient	0.04	1							
3	Sand	-0.02	0.03	1						
4	Silt	0.08	0.11	-0.42*	1					
5	Clay	-0.17	0.18	-0.41*	0.18	1				
6	Organic Matter	0.07	-0.22	-0.17	-0.22	0.12	1			
7	PO_4^{-3}	-0.63**	0.47*	-0.35	0.67*	0.48*	-0.33	1		
8	NO_3^-	-0.42*	0.51*	-0.50*	0.55*	0.39*	-0.52*	0.12	1	
9	NH^+_4	-0.41*	0.61**	-0.32	0.43*	0.40*	-0.49*	0.19	-0.22	1

*and ** show a significant correlation at a probability level of 95 and 99%, respectively.

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The results of the present study showed that the amount of PO_4^{-3}, NO_3^{-} and NH^+_4 increased with increasing silt and clay content in stream water. There was a negative correlation between the quality variables of the water with organic matter (Table 4).

Discussion

In this study, it was detected that road age and cut slope gradient significantly affected the forest's physical-chemical properties of stream water. This result agreed with the findings of Makineci et al. [21], which pointed out the significant effect of roads on pH and EC variables of forest runoff. The reason was that amount of soil loss and consequently suspended load at the crossings of road streams during operation and after the road's closure was high [5]. It was reported that the water quality was improved two years after road construction, but sediments were still present at road-stream crossings [10]. According to the results of the present study, the age of the road (number of years after road construction) is one of the factors that can affect the water quality of streams, especially at the crossings.

Findings of the effect of cut slope characteristics on water quality showed that water quality variables at the gentle slope were significantly different from steep slopes. In forest roads, steep side slopes increase flow velocity and discharge and consequently soluble elements [15], and it is less affected by the processes of soil and bedrock [22]. Moreover, our findings were in agreement with the results of Van Der Perk et al. [23] and Meynendonckx et al. [24] researches who noted that the PO_4^{-3}transport is a function of the slope and that on higher slopes, higher amounts of PO_4^{-3} enter the stream along with sediments. Indeed, steep cut slopes concentrate the flow movement downward and affect the erosion and sediment rates as also nutrients and the water quality of the stream. The results of this study also showed an increasing trend of TSS, TDS, and PO_4^{-3} variables with increasing the slope of the cut slope. However, other water quality variables observed no significant increase in cut slope. Our control points were located 700 meters from the road, and the sampling points were located around the road, i.e., 5 meters upstream and downstream. For this reason, the statistical differences between the control points and roads with shorter lifespans became significant.

This study showed that only the relationship between the lime percentage of the soil and the mean annual PO_4^{-3} and the soil loam percentage and mean annual pH was significant. Meanwhile, the results of many previous studies indicated a significant relationship between soil properties and water quality variables [25]. Although, in most cases, there was no significant relationship between soil and water variables, the results of this study showed a positive correlation between water quality variables with percentages of clay (except pH) and silt. These results were inconsistent with the findings of Wudneh et al. [26]. They found a positive correlation between Phosphorus and sand, Phosphorus and clay, and a negative correlation between Phosphorus and silt. Other researchers, like Liu et al. [20], detected a negative correlation between total Nitrogen and sand and a positive correlation between total Nitrogen and clay, which was proved by the current study's findings. Also, the pH had a positive correlation with the sand and a negative correlation with the silt and the clay. Silt can increase the Phosphorus concentration in the drained water [27]. The present study showed a negative correlation between the quality variables of the water with organic matter (except pH) and the percentage of lime. Similarly, McDaniel and David [28] found a strong correlation between organic matter and PO_4^{-3}. According to the results of previous studies and the present study, it can be said on the percentage of soil components and water quality that as a result of precipitation and runoff, the soil particles are leached. Because the finer particles (clay and often silt) are more eroded than the larger, heavier particles, and they carry more nutrients and ions compared to the larger particles [24], as the finer particles of the soil increase, the load of the water variables increases as well, explaining the positive correlation between clay and silt percentages and the water variables. In addition, lime and organic matter [25] also act as a source of ions and nutrients to help accumulate particles and prevent their perturbation in water [29, 30]. In general, soil properties will also affect the water quality. Considering the importance of water quality and that in preparation of the forestry plans, soil studies should be one of the essential parts, water quality data can be obtained with less time and cost by obtaining the values and relationships between soil and water variables. Water qualities of streams can change under the influence of utilization, road characteristics (age, cut slope characteristics), soil properties (percentage of components, lime, and organic matter), discharge, precipitation, and physical properties of the sub-basins. In contrast to what it seems, in some cases, the sub-watersheds physical properties and natural factors play a more critical role in water quality than anthropogenic interference. Although the main factor affecting water quality over the long term has not been precisely determined due to the complexity and extent of influencing factors, the most important factor explaining changes in the water quality of the streams is the combination of natural (such as precipitation) and anthropogenic (utilization) factors.

Conclusion

The research findings showed that steep slopes on less old roads could cause significant changes in water quality parameters such as EC, TDS, TSS, PO_4^{-3}, NO_3^-, and NH^+_4. So, our research hypothesis (stream water quality significantly increased with increasing road age and decreasing cut slope gradient) was proved. In conclusion, water quality can be improved by designing and building gentle slopes at road-stream intersections and soil protection and erosion control on steep slopes. Also, the present research results showed that the water quality improves with the distance from the time of road construction and the natural stabilization of intersections. So, this study is a good starting point for further research on the details and objectives of forest management in order to preserve this ecosystem.

Ethical Permissions: The case was not found by the authors.
Conflict of Interests: The authors have declared no conflict of interest.

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