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Assessment of Unpaved Forest Road Surface Condition based on Slope Steepness and Bearing Capacity

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ABSTRACT

Aims: The technical health of forest road surfaces is essential to access the forest and vehicle traffic safety. This research investigated the effect of longitudinal slope and bearing capacity in different climate conditions on unpaved roads, especially road surface elements.

Materials & Methods: First, 500-meter road segments were randomly determined in Mediterranean, sub-humid, and semi-arid climates in Shastkalateh, Rezaeian, and Arabdagh forests, respectively. In each climate zone, unit samples on roads were divided into slope classes of <5% and >5%. The unpaved road surface condition index (UPCI) was calculated by considering corrugations, potholes, erosion, oversized aggregate, crown condition, and rutting in the field survey. Three soil samples were collected for California bearing ratio (CBR) analysis in each road segment. Proctor and CBR tests were conducted according to ASTM standards for each slope class.

Findings: Results indicated that in slope class<5%, the UPCI value in sub-humid climates was significantly lower than in other climate zones ($P<0.05$). Maximum UPCI (8.68) was observed for roads located in a semi-arid climate. In addition, an increase in slope classes from <5% to >5% can decrease UPCI by about 6.6%, 11.8%, and 11.1% in Mediterranean, semi-arid and sub-humid climates, respectively. There was a positive and significant correlation between soil CBR and UPCI variables in all climates.

Conclusion: In conclusion, road surface in sub-humid climates needs more attention for a maintenance operation, especially in steep slopes of mountainous forests. Besides, more knowledge about slope gradient and climate effects on road surface quality is necessary to decrease road deterioration by traffic on steep slopes.

Keywords: Potholes; Longitudinal Slope; Sub-humid Climate; Field Survey; ASTM.

CITATION LINKS

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Introduction

Gravel forest roads consist of materials constructed based on 60% gravel, 35% sand, and 5% fine particles [1]. On average, 433 USD is spent annually for the repair and maintenance travel way in Hyrcanian forests. The cessation of forest harvesting and lack of maintenance funds is one of the most critical problems in road maintenance operations [2]. Different types of deterioration, such as potholes, rutting, dustiness, exposed oversized aggregates, and crown defects be seen on unpaved surfaces of gravel roads [3, 4]. The amount of this deterioration is different in various longitudinal slopes and baring capacities, and this issue affects the spatial dispersal of road defects and, consequently, maintenance practices [5, 6]. Deterioration of unpaved forest roads can be evaluated using Unpaved Condition Index (UPCI), which is based on potholes, corrugations, overexposed aggregates, erosion, roadside drainage, and rutting [7, 8]. Forest roads usually consist of two layers. The first layer is the natural bed of the earth, and the second layer is the road pavement, which is between 10 and 20 cm thick. The capacity of surfacing layers to support the traffic loads applied to the ground is defined as bearing capacity [3]. A proper parameter for determining the strength of road layers is the California Bearing Ratio (CBR). CBR measurements in forest conditions are often done using the Dynamic Cone Penetrometer (DCP) and the conventional Falling Weight Deflectometer (FWD) [6, 7]. According to CBR value, engineers improve forest roads [9, 10].

Surface drainage of water from a forest road is accomplished through the longitudinal slope and cross slope, a crown in the central lane sloping downward toward the shoulders [9, 10]. Because of the weak surfaces of forest roads such as earth and gravel, road slopes on tangents must be steep to drain water [11, 12]. Girardin et al. [13] indicated that the deterioration of roads and loss of surface materials increased exponentially by increasing longitudinal slope, especially in road networks without maintenance operations in a five-year cycle. According to Kiss et al. [14] research, variation in the roughness of surfacing, sub-base density, and road traffic are influential factors for detecting road degradation. The steepness of road surfaces is effective in road hydrology, especially in infiltration, saturated moisture content, and surface flows [15, 16].

However, among the influencing factors not only road slope, but also the climate of forest region was reported in the literature to affect unpaved road surface condition [9, 10, 12, 13, 16, 17]. Different climates result in rainfall, flows, temperature, evaporation, precipitation, ice, and dry duration that these factors will have a significant impact on the road quality by soil fraction, inflation, and erosion. Qiao et al. [4] reported that road surface condition is affected by climate factors, especially rainfall events. According to several studies [5, 6, 18], the impact of slope gradient and climate influence on road surface conditions are issues that require more study in field experiments.

It was detected that forest road bases had soaked CBR values below 15%. On these roads, different types of deterioration can be observed [19, 20, 21]. Roads with high material strength present soaked CBR values above 15% at 95% Proctor compaction, providing a trafficable surface under all weather conditions [22, 23, 24]. The climatic diversity of the Hyrcanian forests (Mediterranean, sub-humid, and semi-arid) and the presence of various longitudinal gradients in the forest roads of these areas have caused various anomalies in the top layer of the forest roads. Therefore, it is necessary to evaluate the role of climate and the slope on the amount of damage to plan the location and time of forest road protection and maintenance operations. This re-

search aimed to investigate the effect of the longitudinal slope of forest roads and climate conditions on the unpaved road surface condition. This study hypothesized that the road UPCI was low in the weak bearing capacity surface and humid climate.

Materials & Methods

Study Area Description

The research was done in the Mediterranean, sub-humid, and semi-arid climate zones within the Hyrcanian forests of Iran (Figure 1). Based on the forestry plan booklet, study areas, including Shastkalateh, Rezaeian, and Arabdagh forests, are located on the southern coast of the Caspian Sea in the uneven-aged broadleaf natural forests. Ambrothermic diagrams of the study areas have been shown in Figure 2. In these regions, the road network is used by wood transportation trucks and public vehicles for recreation and forest monitoring. This traffic can increase the damage to unpaved roads, especially on steep slopes, due to braking frequency. A general description of study areas has been illustrated in Table 1.

Table 1) General characteristics of study areas (Forestry plan booklet).

Study area	Mediterranean zone (Shastkalateh)	Sub-humid zone (Rezaeian)	Semi-Arid zone (Arabdagh)
Coordinate	54°21′26′′ to 54°24′57′′ N 36°43′27′′ to 36°48′06′′ E	55°01′00′′ to 55°06′30′′ N 36°52′30′′ to 36°48′01′′ E	55°37′04′′ to 55°47′07′′ N 37°32′01′′ to 37°36′05′′ E
Forest extent (ha)	1713.3	12465	2240
Elevation range (m)	230-700	790-1270	200-955
Lithology	Lime and sandstone (conglomerate)	Lime - Marl and dolomite lime	Lime–loess deposits
Soil type	Silt clay loam- Silt clay	Silt clay loam- Silt clay	Silt loam- Silt clay loam
Mean annual rainfall (mm)	526	583.1	536.7
Mean annual temperature (°C)	15.4	12.9	16.9
Aridity index	20.71	25.46	19.95
Dominant forest species	*Carpinus betulus L., Parrotia persica C.A. Mey*	*Carpinus betulus L.,Tilia begonifolia*	*Carpinus betulus L., Zelkova carpinifolia*
Road length (km)	30.3	108.8	25
Road density (m ha^{-1})	18.1	8.4	11.1

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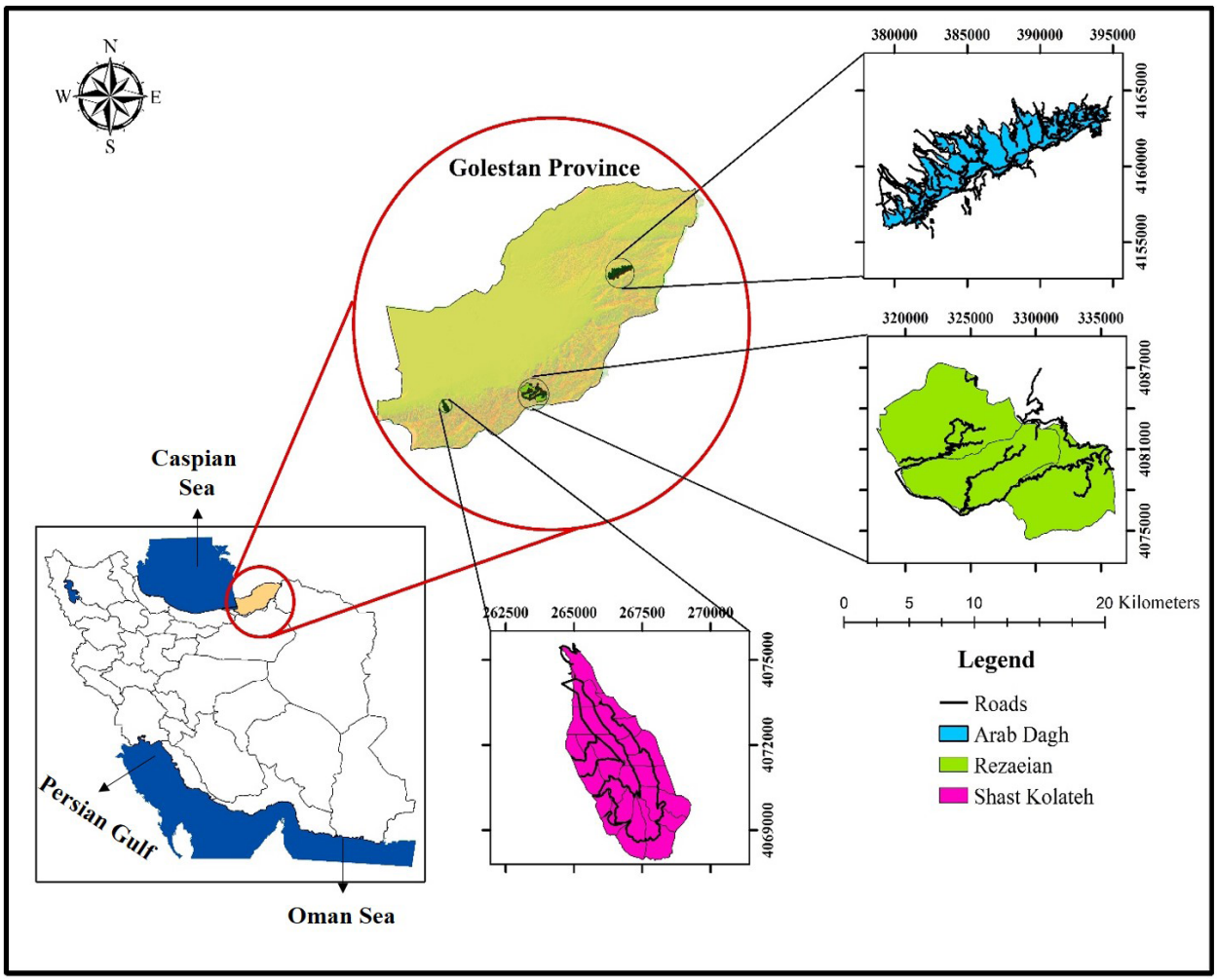

Figure 1) The geographical of the study areas.

Case Studies Inventory and Field Data

This study used a field survey to monitor unpaved road conditions based on UPCI [7]. 500-meter road segments (18 segments) were randomly determined in Mediterranean, sub-humid, and semi-arid climates and the UPCI values were calculated in the field survey. Totally 54 sample units and 27 km of road were monitored in this study. Twenty-seven samples were located on roads with a slope of >5% and 27 on a slope of <5%. UPCI was estimated using Eq. (1).

$$UPCI=10 - 1.16CR-2.25PT - 1.47ER - 0.33RT - 1.56OA - 1.58CW \quad \text{Eq. (1)}$$

Where CR is corrugations in cm, PT is potholes in cm. ER is a nominal erosion variable (considered as one of the erosion areas more significant than 50 cm^2). RT is rutting in cm. OA is the exposed oversized aggregate nominal variable (considered as one of the oversized aggregates is greater than 5 cm), and CW is the crown condition nominal variable that is considered as 0 if the crow has good condition, 0.5 in fair condition, and 1 in poor condition [8]. UPCI values for gravel roads in different climates have been shown in Table 2.

Three soil samples were collected for California bearing ratio analysis in each road segment. The proctored test was done following ASTM D1557 to find maximum dry density and optimum water content. Mean CBR values were measured using ASTM D1883 for each slope class (Figure 3).

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Table 2) UPCI values for gravel roads in different climates [7, 8].

Condition	Semi-Arid	Mediterranean	Sub-Humid
Very good	8.2 to 10	8.2 to 10	8.2 to 10
Good	5.2 to 8.1	5.7 to 8.1	7.2 to 8.1
Regular	4.2 to 5.1	4.7 to 5.6	5.2 to 7.1
Poor	2.2 to 4.1	2.7 to 4.6	3.7 to 5.1
Very poor	1 to 2.1	1 to 2.6	1 to 3.6

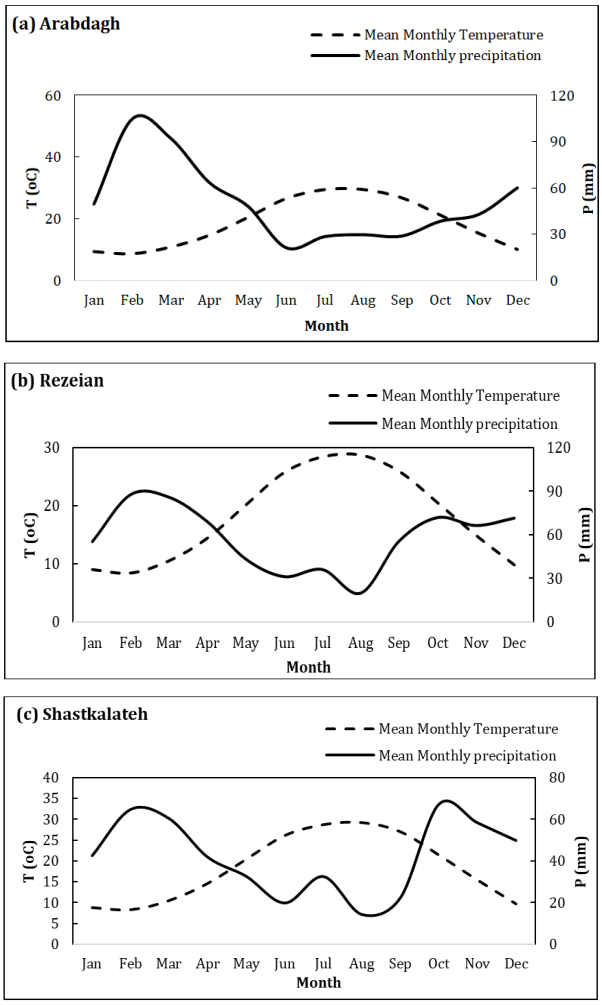

Figure 2) Ambrothermic diagrams of the study areas.

Figure 3) CBR meter instrument.

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Statistical Analysis

The factorial experimental design was used to investigate the effects of independent variables, including slope steepness, bearing capacity, and climate, on UPCI as a dependent variable. The normality of the data was tested using the Kolmogorov-Smirnov. Data were analyzed in SPSS Statistics version 23 software. Means comparisons and correlation analysis were made using Tukey and Pearson tests, respectively [7, 8].

Findings

ANOVA for the Effects of Climate and Slope Gradient on Unpaved Road Surface Condition

Results of the analysis of variance showed that the climate condition and longitudinal slope classes significantly affected unpaved road surface conditions or UPCI (P<0.001). Moreover, it was detected that the interaction effects of climate and slope classes were not significant (P>0.05; Table 3).

Effects of Climate on UPCI

In slope class<5%, the UPCI value in the sub-humid region was significantly lower than in other climates (P<0.05). Unpaved road conditions in mentioned slope and climates were from good to very good. Maximum UPCI with a value of 8.68 was observed for roads in a semi-arid climate. UPCI for roads with a slope <5% located in Mediterranean, semi-arid, and sub-humid climates were 8.06, 8.68, and 7.58, respectively. Similarly, in slope class>5%, the UPCI value in the sub-humid region was significantly lower than in other climates (P<0.05). The road surface condition in this climate was regular. UPCI for roads with a slope >5% located in Mediterranean, semi-arid and sub-humid climates were 7.55, 7.77, and 6.82, respectively (Table 4).

Effects of Longitudinal Slope Classes on UPCI

An increase in slope from <5% to >5% can decrease UPCI by about 6.6%, 11.8%, and 11.1% in Mediterranean, semi-arid and sub-humid climates. Indeed, in all climate zones, UPCI on roads with a slope of <5% was significantly lower than that of slope class of >5%. A minimum UPCI with a value of 6.82 was observed on roads with a slope class of >5% located in sub-humid climates (Table 5).

Effect of road CBR on UPCI

Results showed that the maximum dry density in the slope class of >5% was more than that of the slope class of <5%. Moreover, the unconfined compressive strength curve showed the higher required force for influencing samples in a slope class of <5% (Figure 4). Correlation analysis showed that in Mediterranean, semi-arid and sub-humid climates, there was a positive and signifi-

Table 3) ANOVA for climate and slope gradient effects on UPCI.

Source	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	74.212[a]	5	14.842	9.984	.000
Intercept	14137.810	1	14137.810	9.510E3	.000
Climate	41.756	2	20.878	14.043	.000
Slope	31.039	1	31.039	20.878	.000
Climate * slope	1.669	2	.834	.561	.571
Error	341.936	230	1.487		
Total	14532.369	236			
Corrected Total	416.148	235			

Table 4) Effect of climate on UPCI in different longitudinal slope and CBR classes.

Slope	CBR	Climate	Mean UPCI	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
<5%	7.64	Mediterranean	8.057[b]	0.193	7.677	8.437
	8.72	Semi-arid	8.680[a]	0.198	8.291	9.070
	6.11	Sub-humid	7.578[c]	0.193	7.198	7.958
>5%	7.13	Mediterranean	7.553[a]	0.193	7.173	7.933
	6.90	Semi-arid	7.769[a]	0.198	7.379	8.158
	5.49	Sub-humid	6.816[b]	0.193	6.436	7.196

Different superscript in a column indicates significant difference at a probability level of 5%.

Table 5) Effect of longitudinal slope classes of forest roads on UPCI in different climate zones.

Climate	Slope	Mean UPCI	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Mediterranean	<5%	8.057[a]	0.193	7.677	8.437
	>5%	7.553[b]	0.193	7.173	7.933
Semi-arid	<5%	8.680[a]	0.198	8.291	9.070
	>5%	7.769[b]	0.198	7.379	8.158
Sub-humid	<5%	7.578[a]	0.193	7.198	7.958
	>5%	6.816[b]	0.193	6.436	7.196

Different superscript in a column indicates significant difference at a probability level of 5%.

Table 6) Pearson correlation coefficient for the relationship of CBR and UPCI.

Correlation	Mediterranean	Semi-arid	Sub-humid
	UPCI	UPCI	UPCI
CBR	0.48*	0.65**	0.59**

* and ** show significant correlation at 5% and 1% probability.

cant correlation between soil CBR and UPCI variables at probability levels of 5, 1, and 1%, respectively. This means that in the bed with high bearing capacity, the condition of the top layer of the roads was more suitable (Table 6).

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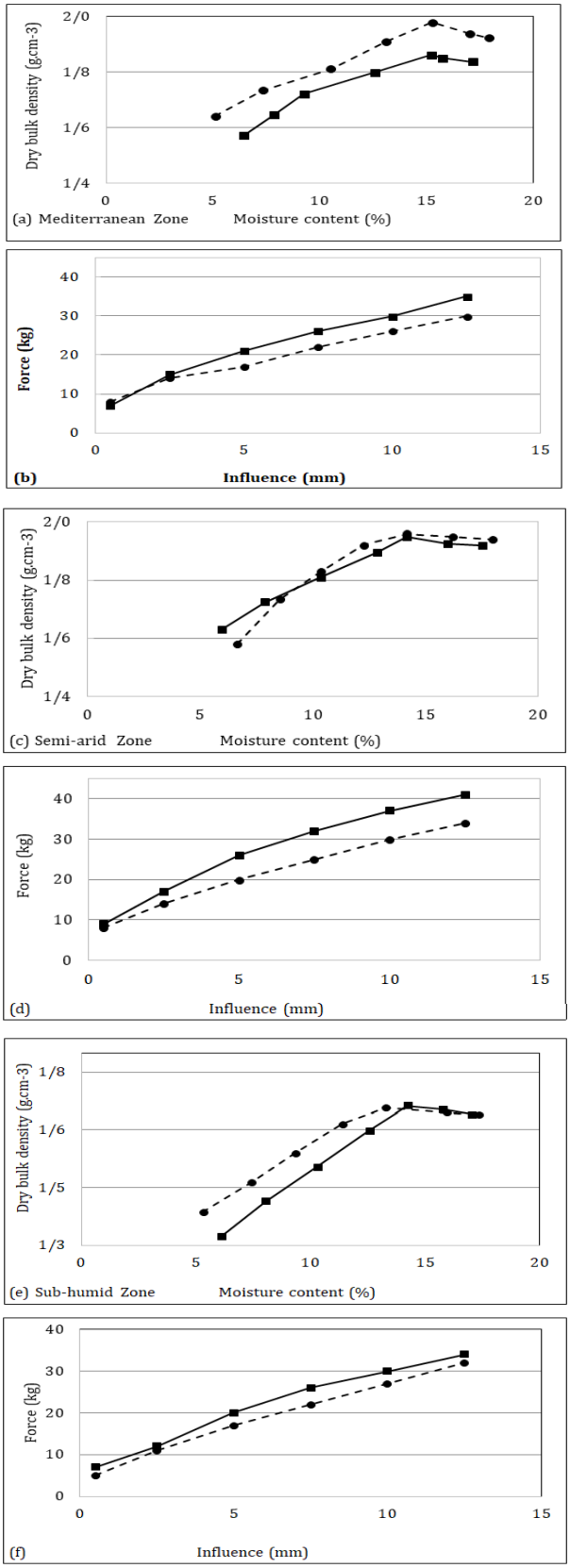

Figure 4) The dry bulk density and unconfined compressive strength of roadbed in different longitudinal slope classes (Continues line: <5%; Dashed line: >5%).

Discussion

The slope of the road and its loading capacity play an essential role in road failures in different climatic conditions. Therefore, it is imperative to evaluate the severity of these failures to plan protection and maintenance operations properly. Results of the analysis of variance showed that the climate condition and longitudinal slope classes had a significant effect on UPCI. This was in agreement with the findings of some researchers. For example, Girardin et al. [13] indicated that the deterioration of roads and loss of surface materials increased exponentially by increasing the longitudinal slope.

Moreover, Darboux et al. [19], found that the runoff volume increase with increasing slope gradient. In this study, maximum UPCI was observed for roads located in a semi-arid climate. A steeper longitudinal slope may be needed in sub-humid areas with intensive rainfall to provide better water drainage [7, 8]. In such cases, the longitudinal slope for secondary forest road types may be increased to 9%.

Similarly, in slope class>5%, the UPCI value in the sub-humid region was significantly lower than in other climates. This result was in agreement with the findings of Akgul et al. [20], which indicated that rainfall is the essential meteorological factor in the degradation of forest roads [4, 21]. In addition, in this climate zone, rainfall properties changes can rapidly alter road foundations' moisture content and consequently lead to the deterioration [3, 18].

Forest roads with a weak CBR (less than 15%) have access problems during the rainy season when not maintained [22, 23]. An increase in slope classes can decrease UPCI by about 6.6%, 11.8%, and 11.1% in Mediterranean, semi-arid and sub-humid climates. This was in agreement with the findings of Girardin et al. [13]. They indicated that roads with a slope gradient >4% generally exhib-

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ited higher proportions of all forms of degradation except for potholes. It was shown that by increasing the slope, water would drain from the travel lanes approximately 23% faster [17]. UPCI degradation in steep slopes is often found due to material loss by runoff [23] and vehicle speed [12]. This was in agreement with the present study's findings, which shows that runoff-induced material loss in road section with slope >5%. Ciobanu et al. [12] reported that road surfaces could be damaged when vehicles travel up or down steep sections of roads. Other factors, such as transport flow and lack of road compaction in the two slope categories, may influence the presence of Corrugations, potholes, and ruts on the road surface. Moreover, our results showed high potholes on roads with slopes of less than 5%. These observations are consistent with the guidelines of Ryan et al. [24, 25], which state that a slope <3% would also be at risk of degradation, given that it leads to preferential pothole formation. Such recurrences on the road surface would indicate, in this case, an accumulation of runoff [11]. In a humid climate, the roadbed's atmospheric precipitation and high humidity accelerate the process of deterioration. Flows in the form of runoff cause erosion, rutting of the road, and washing of adhesive agents of pavement materials. This issue is aggravated on steep surfaces, so the frequency of breakdowns was higher on steep roads than on low-slope roads.

Conclusion

This study used field observation to detect forest graveled road degradation at two slope gradients under three climates in Hyrcanian forests. All hypothesis of the research was accepted during the study. The field approach proved that road degradation is a function of the slope and climate. It was concluded that forest roads with higher slope gradients showed lower mean UPCI by 10% in all climates. UPCI value in the sub-humid region was lower than in Mediterranean and semi-arid climates. Maximum UPCI was observed for roads located in a semi-arid climate. In sub-humid climates, it is necessary to improve unpaved road surface conditions through graveling and rolling operations. In addition, the slope gradient is one crucial factor that influences UPCI. Open-top culverts can drain runoff from the road surface on long and steep slopes, and this structure should be designed for the study area. Finally, road surface in sub-humid climate needs more attention for maintenance operation, especially on steep slopes.

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Authors A. Parsakhoo and A. Rezaee performed the analysis and took the lead in writing the manuscript. A. Najafi and J. Mohammadi helped with the interpretation. All authors contributed to the manuscript and read and approved its final version.

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