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Assessment of effect of road or road construction on soil physical and chemical properties in northern forests of Iran

Atta Safari [*1], Ataollah Kavian [2], Aidin Parsakhoo [3]

[1]M.Sc. of Watershed management, Faculty of Natural Resources, Sari Agricultural Sciences and Natural Resources University, Sari, P. O. Box: 737, Sari, I.R.Iran.

[2]Assisstant professor, Department of Watershed management, Faculty of Natural Resources, Sari Agricultural Sciences and Natural Resources University, Sari, I.R.Iran.

[3]Assisstant professor, Department of Forestry, Faculty of Natural Resources, Gorgan Agricultural Sciences and Natural Resources University, Gorgan, I.R.Iran.

ABSTRACT

Forests are an important economic source for human and have key role in nutrient cycle, hydrology and ecosystem performance, any interference in this vital ecosystem causes to damage to forests. Mechanical logging and road construction in forest areas have led to much soil compaction. Soil physical and chemical properties were studied in parts of road and non-road in the Darabkola forest of Iran. To investigate the soil properties, sixty samples of the top soil (0–20 cm deep) in two parts of forest ground and forest road surface were collected by cylinder for physical and chemical analysis: forest ground (30 samples) and forest road surface (30 samples). Also, soil compaction and runoff production investigated in mentioned parts. Therefore, produced runoff volume due rainfall in two studied parts was measured in equal area after the natural rainfall. The results showed that there was significant difference among soil different properties rate and too produced runoff rate in two studied parts. Correlation matrix results in part of forest road indicated that there was significant negative and positive correlation between runoff and silt, clay, bulk density, lime and gravel, organic matter, PH, EC respectively and too in part of forest ground there was significant negative and positive correlation between runoff and moisture, clay, silt and gravel, organic matter, PH, EC respectively.

Keywords: Soil properties, road construction, forest road, forest ground, Darabkola forest.

INTRODUCTION

Forests are an important economic source for human and have key role in nutrient cycle, hydrology and ecosystem performance. Any interference in this vital ecosystem causes to damage to forests (Hosseini *et al*., 2012). In recent decades, the narrow belt of Hyrcanian forests in north of Iran has been changed

Corresponding Author E-mail: Attasafari@yahoo.com

(Parsakhoo *et al*., 2011). Erosion and soil loss are the most important impacts of roads, so determining of the erosion rate is essential for comprehensive management of watersheds (Fu *et al*., 2010). In initial investigations it was proved that the ground based skidding system was used in Drarabkola forests. There was deep ruts on surface of skid trails in Darabkola forest which cause to runoff canalizing and water erosion occurrence on steep slopes (Lotfalian *et al*., 2012). Forest roads and skid trails play an important role in rural development, providing wood transportation system and tourism recreation (Parsakhoo *et al*., 2009). Roads can also have negative environmental effects on ecosystem (Dong *et al*., 2012). The construction and use of roads can lead to loss of soil from road corridor and consequently delivery of sediment to forest basins (Aruga *et al*., 2005). A better understanding of road-sediment production rates is needed to guide future development and erosion control efforts (Jordán-López *et al*., 2009). The skid trails are the narrow routes which are derived from forest road network. In ground based skidding system, these routes are necessary to transport timbers from trunk's adjacent to depot. The passage of skidders machines on skid trails increases the soil compaction through wheels and log pressure. These disturbed areas in forests are the important parts of runoff and sediment production. Increase in runoff and soil loss after road construction have been measured in different Mediterranean and Hyrcanian forest and shrublands (Arnaez et al., 2004; Cerdà, 2007; Cao *et al*., 2009; Jordán-López *et al*., 2009), but generally, there are few studies assessing the soil compaction, erosional and runoff response immediately after skidding operations (Parsakhoo *et al*., 2009). The recent development of forest road networks brings out the role of roads as runoff and sediment sources, which has not been sufficiently considered. It is well known that forest roads may cause many local changes to soil properties increasing soil erosion and mass movements after very strong rainstorms (Gresswell *et al*., 1979; Sidle et al., 1985; Larsen and Parks, 1997; Gucinski et al., 2001) or as a consequence of the of raindrops splash and surface runoff (Froehlich, 1995; Ziegler et al., 2000a). Construction of forest roads constitutes the most damaging facet of forestry activities: the forest has to be cleared for them and they are thus a cause of deforestation. Soil erosion is particularly important in forested areas, because natural erosion rates tend to be very low (Ramos-Scharrón and MacDonald, 2005).Overland flow from forest road can carry sediments eroded from the road surface, extend channel systems (Montgomery, 1994; Wemple, 1994). Watersheds with dense road networks commonly experience increased sedimentation and peak flows (Jordán-López *et al*., 2009). Forest roads can be a significant source of runoff and sediment production (La Marche and Lettenmaier, 2001; Wemple *et al*., 1996; Ziegler and Giambelluca, 1997). Erosion on a disturbed soil, such as a forest road, is determined by infiltration, raindrop splash, concentrated flow, and vegetative cover (Foltz et al., 2009). It is known that unpaved roads may cause important local changes to soil properties, intercept surface and subsurface water flows, generate surface flow in areas far from established channels, and are a major sediment source in forested watersheds (e.g. Megahan *et al*., 1983; Luce and Wemple, 2001), but these processes are rarely quantified (Martínez-Zavala *et al*., 2008). Roads are therefore potentially susceptible to rainfall-induced erosion processes, even during low magnitude rainfall events (Ziegler *et al*., 2001). Human-induced changes to vegetation cover, soils, and topography may provoke important changes on the hydrologic response of disturbed surfaces, which may in turn alter a diverse array of biogeochemical processes (Ramos-Scharrón, 2010). Land modifications alter surface and subsurface water flow vectors, which typically lead to increased soil erosion and sediment yield (Dunne, 1979; Walling, 1997) and induce a number of adverse on-site and off-site effects including diminished soil productivity (Lal, 1998; Eswaran *et al*., 2001), degraded water quality (Lal and Stewart, 1994), and increased sedimentation levels on both man-made impoundments and natural habitats (Walling and Fang, 2003; Syvitski et al., 2005). Forest soil is an important component of the natural environment, and is a primary medium for many biological activities for flora and fauna (Croke *et al*., 2001; James *et al*., 2004). Soil loss and displacement is a serious problem in forest road sub grading project by heavy equipment (Parsakhoo *et al*., 2009). In addition, sub grading forest roads may cause considerable local changes to soil properties and to the geomorphologic and hydrologic behavior of hill slopes, increasing soil erosion and mass movements after extreme rainstorms (James and McNeil, 2006; Demir *et al*., 2007; Mahmoudzadeh, 2007; Sui *et al*., 2008). Road construction removes the forest vegetation, disturbs forest floor, and damages soil structure, which dramatically increases the soil loss (Parsakhoo *et al*., 2009). The highly compacted surface of the roadbed largely explains the variety and intensity of erosion processes (Arna´ez et al., 2004). High rates of sediment production occur after the construction of forest roads (Megaham *et al*., 2001), when they are used for frequent transport of logs (Reid and Dunne, 1984), or when no upkeep is carried out (Arna´ez *et al*., 2004). The main sediment sources created by selective harvesting of Hyrcanian broad leaved forests come from building skid trails or forest roads and log haulage ruts that often extend the drainage network and deliver large quantities of sediment to forest area. The main objective of this study is to determine the effects of road or road construction on soil physical and chemical properties in Darabkola forests.

MATERIALS AND METHODS

Study site

Darabkola forest with an area of 2612 ha is located in watershed number 74 and in southeast of the city of Sari in Mazandaran Province, Iran. The latitude, longitude and elevation ranges of this forest are 36° 33' 20″ to 36° 33' 30″ N, 52° 14' 40″ to 52° 31' 55″E and 180 to 800 m at sea level, respectively (Figure 1). The soil depth is 110 to 120 cm. The bed rock is marl, calcareous sandstone and limestone. The general aspect of the hillside is north and its average slope is 40%. The climate is very moist with average temperature ranging from 26.1°C in August to 7.5°C in February. Mean annual air temperature is 16.7°C. The region receives 983.8 mm of precipitation annually. Minimum and maximum rainfall is 36.1 to 119.8 mm which occurred in July and November respectively (Forest management plan handbook of Darabkola, 2003).

Figure 1. Case study locat

Soil analysis

Sixty samples of the top soil (0–20 cm deep) were collected by cylinder (484 cm^3) for physical (soil texture, bulk density and moisture) and chemical analysis (T.N.V or $CaCO^3$, organic matter, pH and electrical conductivity). Soil samples were oven-dried at 105°C for 24 hours and weighted using digital balance. Soil texture was determined by the Bouyoucos hydrometer method. Lime percentage (T.N.V or $CaCO^3$) was measured using the NaOH titration method. Soil organic carbon was determined using the Walkley–Black technique. The organic matter content was calculated multiplying the organic carbon content by 1.724. Soil bulk density (BD) was calculated using Equation 1:

$$BD = \frac{Dry\ weight\ of\ soil(g)}{Cylinder\ volume\ (cm^3)} \qquad \text{Equation (1)}$$

The soil erodibility equation provides an estimate of K, which can be calculated using the Equation 2 (Wischmeier and Smith, 1978):

$$K = \frac{0.00021M^{1.14}(12 - OM) + 3.25(C_{soilstr} - 2) + 2.25(Cperm - 3)}{100} \qquad \text{Equation (2)}$$

Where K is the soil erodibility factor; OM is the organic matter content (%); C_{perm} is the soil permeability class which can have one of the 6-class values: 1 refers to fast, 2 from moderate to fast, 3 to moderate, 4 from slow to moderate, 5 to slow and 6 to very slow; $C_{soilstr}$ is the soil structure class ranging from 1 to 4 (friable is 1, fine polyhedral is 2, medium to coarse polyhedral is 3 and solid is 4); M is particle size parameter and can be written as Equation 3:

$$M = (m_{silt} + m_{vfsand})(100 - m_c) \qquad \text{Equation (3)}$$

The Mean Weight Diameter (MWD) of soil aggregate was calculated using the wet sieving method and according to Equation 4:

$$MWD = \sum_{i=1}^{n} x_i w_i \qquad \text{Equation (4)}$$

Where x_i is the mean diameter of remained aggregate on sieve; w_i is the ratio of the weight of remained aggregates on each sieve to total weight of sample and n is the number of sieve.

RESULTS

Statistical characters of the soil physical and chemical properties

Statistical characters and ANOVA p-value of soil different properties in two parts of forest road and forest ground showed in table 1 and figures 2 and 3. Also, soil compaction and runoff production investigated in mentioned parts as figure 2. In this study, produced runoff volume due natural rainfall in two parts of forest road and non-road surface was measured in equal area after the natural rainfall. ANOVA test showed there was significant differences among soil different properties rate in studied parts ($P<0.001$; Table 1).

Table 1. Statistical characters and ANOVA p-value of soil properties in different parts

Measured variables	Forest road		Forest ground		ANOVA, p
	Mean	Std. Deviation	Mean	Std. Deviation	
Clay (%)	36.54[a]	0.97	9.54[b]	0.12	0.000
Silt (%)	31.48[a]	1.49	23.42[b]	1.95	0.009
Sand (%)	31.98[b]	1.09	65.27[a]	1.90	0.002
Very fine sand (%)	6.91[a]	0.9	0.82[b]	0.08	0.000
Bulk density (g cm^{-3})	1.72[a]	0.02	1.56[b]	0.03	0.000
Soil moisture (%)	35.24[b]	1.29	48.16[a]	1.74	0.000
Organic matter (%)	1.88[b]	0.05	6.72[a]	0.07	0.000
Organic carbon (%)	1.11[b]	0.03	3.87[a]	0.05	0.000
$CaCO^3$ (%)	3.39[a]	0.12	0.58[b]	0.02	0.005
PH	6.53[b]	0.09	6.75[a]	0.03	0.015
Electrical conductivity (ds m^{-1})	0.18[b]	0.00	0.32[a]	0.01	0.001

In a same row, values with same superscript are not significantly different at 5% level based on Duncan's test.

Correlations of the soil physical and chemical properties

In this research, soil different samples in two parts of forest road and forest ground culled and measured, therefore Correlation coefficients (Pearson correlations) between soil different properties inclusive physical and chemical properties determined and proved in tables 2, 3 and 4.

Table 2. Correlation coefficients (Pearson correlations) between soil different properties

variables	Clay	Silt	Sand	V.f.Sand	BD	Soil moisture	OM	OC	$CaCO^3$	PH	EC
Clay	1										
Silt	0.870**	1									
Sand	-0.995**	-0.917**	1								
V.f.Sand	0.609	0.560	-0.612	1							
BD	0.982**	0.900**	-0.986**	0.688*	1						
Soil moisture	-0.978**	-0.790*	0.960**	-0.656	-0.949**	1					
OM	-0.998**	-0.887**	0.996**	-0.628	-0.985**	0.972**	1				
OC	-0.997**	-0.883**	0.995**	-0.640	-0.983**	0.979**	0.999**	1			
CaCO3	0.997**	0.881**	-0.994**	0.638	0.982**	-0.980**	-0.997**	-0.998**	1		
PH	-0.816**	-0.811**	0.833**	-0.733*	-0.867**	0.789*	0.840**	0.843**	-0.835**	1	
EC	-0.997**	-0.887**	0.996**	-0.624	-0.982**	0.975**	0.999**	0.999**	-0.996**	0.842**	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 3. Correlation coefficients (Pearson correlations) between soil physical properties

Variables	Clay	Silt	Sand	Very fine sand	Bulk density	Soil moisture
Clay	1					
Silt	0.870**	1				
Sand	-0.995**	-0.917**	1			
Very fine sand	0.609	0.560	-0.612	1		
Bulk density	0.982**	0.900**	-0.986**	0.688*	1	
Soil moisture	-0.978**	-0.790*	0.960**	-0.656	-0.949**	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 4. Correlation coefficients (Pearson correlations) between soil chemical properties

Variables	Organic matter	Organic carbon	$CaCO^3$	PH	Electrical conductivity
Organic matter	1				
Organic carbon	0.999**	1			
$CaCO^3$	-0.997**	-0.998**	1		
PH	0.840**	0.843**	-0.835**	1	
Electrical conductivity	0.999**	0.999**	-0.996**	0.842**	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Correlations between soil properties and runoff in forest road and forest ground

In current study, Pearson correlation between soil different properties and runoff due natural rainfall in two mentioned parts determined and proved in tables 5.

Table 5. Correlations between soil properties and runoff in two studied parts

Variables	Forest road		Forest ground	
	Pearson correlation	Sig. (2-tailed)	Pearson correlation	Sig. (2-tailed)
Clay	0.671*	0.041	0.735*	0.032
Silt	0.842**	0.005	0.706*	0.036
Sand	-0.735*	0.027	-0.772*	0.049
Very fine sand	0.493	0.148	0.461	0.211
Bulk density	0.732*	0.014	0.526	0.129
Soil moisture	0.585	0.069	0.874**	0.004
Organic matter	-0.743*	0.045	-0.672*	0.047
Organic carbon	-0.689*	0.031	-0.686*	0.034
$CaCO^3$	0.695*	0.042	0.632	0.068
PH	-0.788*	0.019	-0.759*	0.022
Electrical conductivity	-0.739*	0.024	-0.745*	0.025

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Roads construction influencing runoff responses

There was significant differences among runoff volume in studied parts ($P<0.001$; Table 6). The maximum and minimum runoff volume was observed in forest road and forest ground, respectively (Figure 2).

Table 6. Results of ANOVA test for runoff volume in different parts

Variations Resource	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	68.745	1	35.682	10.341	0.000
Within Groups	95.613	9	3.217		
Total	152.466	11			

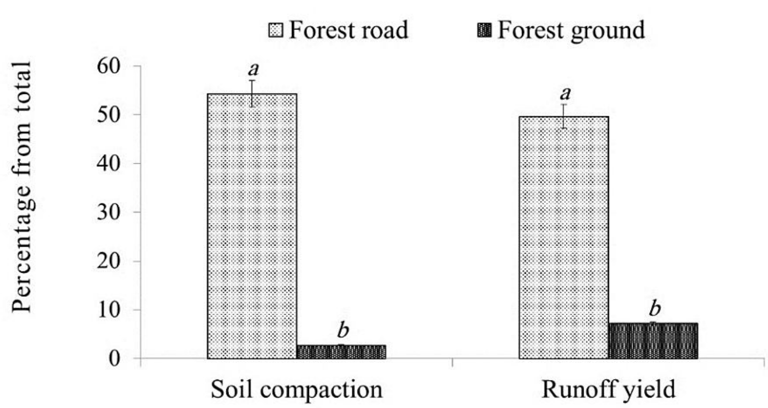

Figure 2. Comparison of soil compaction and runoff yield in two parts study

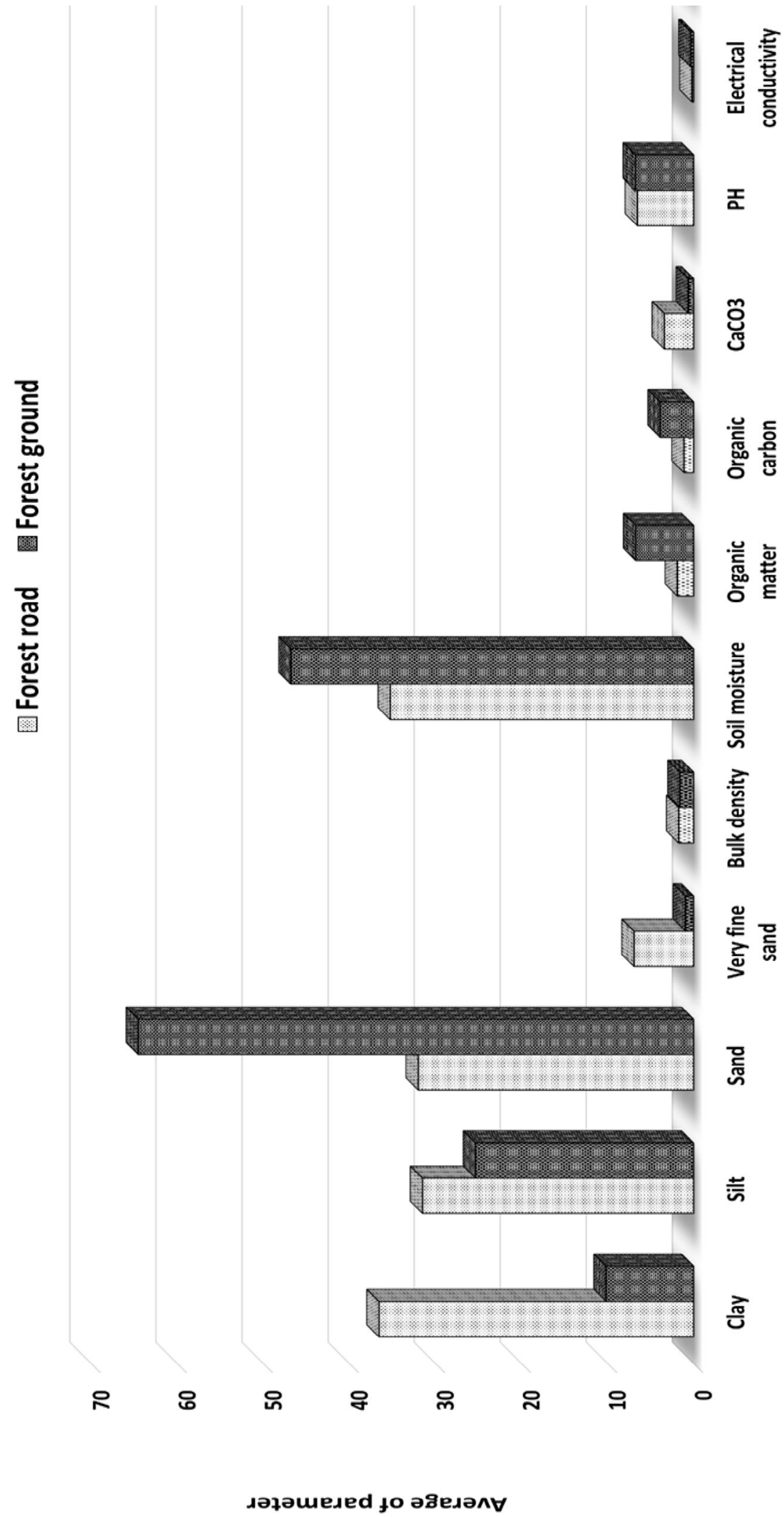

Figure 3. Soil different properties values in two parts study

DISCUSSION

This study was conducted to investigate the relationships among forest soil compaction and destruction rate with road construction. According to the investigations it can be concluded that many factors effect on runoff volume increase and soil compaction occurrence especially in forest roads. Results of the researches about the effects of forest road on forest soil destruction and runoff yield shows that the constructed roads in forest area after a little time can be reformed due to natural and human reasons and the erosion and disturbances is appeared on road surface. The effective factors are different base on area conditions. Therefore, with considering the objectives of study the role of forest roads on soil properties is confirmed. This is due to human activities such as timber skidding and traffic of heavy machines as well as the reduction of vegetation cover. Thus, the understanding of the results of previous studies is useful to prepare management politics for true managing of water and soil resources in forest watersheds. In current study the soil physical and chemical properties was measured in two different parts of forest road and forest ground in the Darabkola watershed and then the effects of forest roads construction on soil compaction and runoff rate was analyzed. A soil sample from 0-20 cm was taken using metal cylinder from forest roads surface and forest grounds. These soil samples and produced runoff volume due natural rainfall in studied parts collected were transmitted to the laboratory.

Assessment of soil different properties in two studied parts

According to Table 5 There was significant positive correlation between clay, silt, bulk density, lime, moisture of soil and runoff which shows the dramatically effect of this mentioned properties in increase of runoff. In addition, according to Table 5 there is significant negative correlation between gravel content, organic matter, organic carbon, soil pH, electrical conductivity and runoff which indicates the runoff decreases with increasing this mentioned properties. Also, according to the ANOVA results that there was significant difference between soil different properties rate in two parts of forest road and forest ground. The soft soils have low infiltration and high runoff because of their low porosity and high cohesion. Vared and Bulton (1991) and Ramous et al., (2000) reported that the silt is the most sensitive particles to erosion because of their size and it can causes to increase soil compaction and decrease infiltration which consequently the runoff increases. Investigations in forest ground showed that high content of gravel causes to decrease runoff due to more speed of water infiltration (Santous et al., 2003). Also, the soil properties were investigated in forest roads that results showed the low content of gravel causes to high content of clay and silt which was effective on runoff and erosion (Ramous et al., 2000; Santous et al., 2003). The gravel particles is very massive for transmission, so the gravel causes to increase soil infiltration and decrease runoff and erosion rate (Refahi, 2006). The relationship between clay and silt with runoff and erosion was confirmed by Mayer and Harmoon (1984) and Doiker et al., (2001). The increasing of clay content causes to decrease infiltration and increase runoff and consequently increase soil loss (Vahabi and Mahdian, 2008; Vahabi and Nikami, 2008), which this result wasn't in agreement with the finding of Auto et al., (1998) and Jang et al., (2004). High level of soil bulk density in forest roads indicates the increasing of soil compaction and reduction of porosity and infiltration which cause to runoff and erosion (Adcaloo et al., 2006) which was in agreement with the finding of Kolka and Smith (2004). The soil properties in study sites is another factors of decreasing runoff which its main properties is more gravel content, organic matter, lower moisture and lower silt content. Therefore according to the findings of this research it is necessary to manage forest harvesting to control and prevent soil destruction.

Assessment of runoff rate in two studied parts

The sampling was conducted in two sites of forest road and forest ground to investigating and evaluating the effects of forest road construction on runoff. Then the soil compaction rate and runoff production in road surface was compared to forest ground and the variations were investigated. The results indicated that there was obvious variation in runoff and soil compaction in mentioned parts. According to the Table 6 and Figure 2 there was significant difference in runoff (at probability level of 99%) among forest road and forest surface which was in agreement with the findings of many researchers which investigated the effects of forest road, traffic of heavy skidding machines and forest road construction on runoff. The researchers were Montgomery (1994), Metengren and Kobayashi (1999), Jones et al., (2000), Kolka and smith (2004), Arnaez et al., (2004), Soa and Kalak (2008), Sakay et al., (2008), Folthz et al., (2009), Naghdi et al., (2009), Jordán-López et al., (2009), Lotfalian et al., (2012). The comparison of the produced runoff in forest road with forest ground showed that the runoff rate in forest road was more than that of forest ground and also according to Duncan test there was significant difference in runoff rates of mentioned parts. There was significant difference between the produced runoff from forest road with forest ground which was in agreement with the findings of Kolka and smith (2004), Jordán-López et al., (2009), Folthz et al., (2009), Ramous-Scharoun and Mcdonald (2005). In other words, it can be possible to show the negative effects of forest roads and human activities (forest road construction and machines traffic) on runoff increasing. According to the ANOVA results that there was significant difference between produced runoff rate in two parts of forest road and forest ground. Metengren and Kobayashi (1999), Kolka and smith (2004), Soa and Kalak (2008), Sakay et al., (2008) in their studies reported that the skidding machines traffic on forest roads causes to decrease soil infiltration and increase soil bulk density and compaction and also increase runoff. Because the traffic causes to soil disturbance. There were large differences between the forest road and forest ground for runoff rate which this indicated the unsuitable effects of road construction and consequently traffic and harvesting on forest soil in shape of runoff and soil compaction (Soa and Kalak, 2008), which this can causes to decrease stability and destroy forest ecosystem. Soa and Kalak (2008) and Naghdi *et al*., (2009) reported that the soil disturbance during skidding and wheel ruts is affected by intensity of timber harvesting from forest. They also found that the compaction rate of soil and consequently increasing runoff and erosion is depend on harvesting method and harvesting intensity. Shee *et al*., (2008) showed that the soil erosion decreased with increasing distances from roads. The results of the investigation of soil properties in part of forest road showed that there was significant positive and negative correlation between runoff and parameters of silt (at probability level of 99%), soil bulk density, clay, lime (at probability level of 95%) and gravel content, organic matter, organic carbon, soil pH and electrical conductivity (at probability level of 95%) respectively (Table 5). Also, the results of the investigation of soil properties in part of forest ground showed that there was significant positive and negative correlation between runoff and parameters of soil moisture (at probability level of 99%), clay, silt (at probability level of 95%) and gravel content, organic matter, organic carbon, soil pH and electrical conductivity (at probability level of 95%) respectively (Table 5).

Conclusions

Results of the current research showed the significant difference in runoff volume among different parts of forest road and forest ground. The investigation on forest roads and forest surface showed that the maximum and minimum runoff rate was recorded in forest road and forest ground, respectively. Results of correlation matrix showed that in forest road treatment the runoff had significant negative correlation with gravel, organic matter, pH, electrical conductivity and significant positive correlation with clay, silt, soil bulk density and lime. Also, in forest ground treatment the runoff had significant negative correlation with gravel, organic matter, pH, electrical conductivity and significant positive correlation with clay, silt and soil moisture. In recent research, the runoff rate of forest roads was more than that of forest ground part, that this difference was significant. This issue shows the effects of human activities such as forest road construction and forest harvesting (traffic of skidding machines) on soil compaction and destruction which have dramatically consequences. The heavy machines traffic on forest road had significant effect on soil displacement and the soil destruction from forest surface. Human activities such as road construction and traffic of machines is very important factors in soil destruction. Rutting of roads due to traffic of skidding machines, such as skidder and Timberjack, for forest harvesting causes to forest soil destruction and consequently increasing runoff and erosion, which our finding confirms this issue. Therefore, road construction is necessary to harvest forest and it cannot be rejected and politic and management programs must be considered to control and decrease destruction. So, according to the findings of this research it is necessary to consider effective methods to control and prevent forest soil destruction.

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