Assessing the relationship of slope and runoff volume on skid trails (Case study: Nav 3 district)

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ABSTRACT: The effect of slope on runoff volume was evaluated on skid trails in the natural forest in the north of Iran. The objective of this study was to determine the relationship between runoff volume and slope in order to control runoff and skid trail maintenance by using water diversions. Two levels of slope > 20% and < 20% were studied in adjacent parcels in district 3 of Nav in Asalem. Treatment plots with three replications were established on skid trails after skidding and the runoff volume was recorded after duration of 3 rainfalls. The results showed that there was a positive and significant correlation between slope steepness and runoff volume, and between runoff volume and slope length ($P < 0.05$). Also, regression analysis results showed that there was a linear relation between runoff volume, slope length and slope steepness. Effective recommendations to control and decrease runoff volume are precise scheduling of skid trail designing, construction, maintenance and limiting skid trails to a longitudinal slope of less than 20% and rehabilitation of skid trails by using water diversions.

Keywords: bulk density; Nav district; runoff; skid trail; water diversion

In steep terrain, roads and skid trails contribute to the highest sediment loss per unit area within the catchment (Hartano et al. 2003; Croke, Nethery 2006; Sidle et al. 2006). The modification of hydrological pathways by roads and skid trails affects surface erosion. Roads and trails modify site hydrology by decreasing the hydraulic conductivity and infiltration capacity of the surface (Erpul, Canga 1998; Sidle et al. 2006; Holko et al. 2011). The design and location of roads and trails determine whether surface water generated by these various mechanisms will exacerbate surface erosion (Sidle et al. 2006). Soil compaction has been considered as the principal form of damage associated with harvesting traffic. Compaction increases soil bulk density, decreases water and air movement into soil and increases surface runoff and erosion (Williamson, Neilson 2000; Croke et al. 2001; Adekalu et al. 2006; Ampoorter et al. 2007; Makineci et al. 2007; Agherkakli et al. 2010; Ampoorter et al. 2010). So, water must be delivered off skid trails before it causes erosion and sedimentation impacts on water quality (Grace, Clinton 2007; Uhířová et al. 2009). Drainage and rehabilitation of skid trails after harvesting, restrictions to logging activities in relation to catchment slopes, soil type and rainfall must be used in forestry operations to mitigate the impact of logging (Wallbrink, Croke 2002). The aim of these practices is runoff and soil loss controlling on skid trails for reducing environmental effects. Creation of water diversions makes it possible to control runoff and is a very effective strategy for reducing soil detachment and movement (Croke et al. 2001).

Solgi (2007) considered the amount of soil disturbance by skidder on skid trails and found that runoff was affected by the number of traffic and slope length. Also, vegetation cover is an effective factor in relation to runoff volume (Gomi et al. 2008; Jordan, Martinez–Zavala 2008; Jordan Lopez et al. 2009). However, slope is the main explaining variable of runoff (Arnàez et al. 2004).

The objective of this study was to estimate runoff volume on skid trails and determine the relationship of slope length and slope steepness with runoff in order to propose some recommendations for the skid trail maintenance.

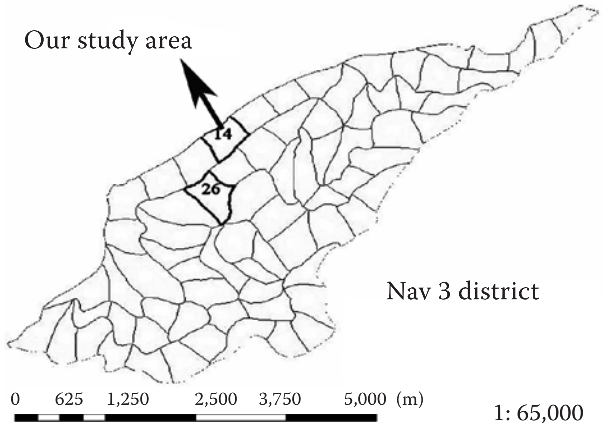

Fig. 1. Study area

MATERIAL AND METHODS

Study area is located in northern Iran, Guilan province, Nav 3 district, Parcel 14, 26 with 49.7 and 60.78 ha, respectively (Fig.1). Nav 3 district is situated between 39'30'' to 44'30'' north latitude and 37'20'' to 61'12'' east longitude. The height of the study area above sea level starts from 500 m and continues till about 2,100 m. The mean annual precipitation is 1,038.7 mm at Hashtpar city metrological station, which is the closest metrological station to our study area. The natural vegetation is a deciduous forest with dominant species of *Fagus orientalis* Lipsky, *Carpinus betulus* L. and *Quercus castanifolia* C. A. May. This research was performed in the autumn of 2009. Two skid trails were delineated as the research area, passing through the stand in north-south direction. Logs were extracted by wheeled skidder and direction of skidding was downward. Characteristics of rainfall and other factors were the same on 2 skid trails. Total precipitation was 17.5, 28 and 34.5 mm and mean intensity was 1.5, 1.27 and 2.6 $mm\cdot h^{-1}$ in rainfall 1, 2 and 3, respectively. Table 1 lists the variables that were treated in the study area.

Two skid trails with two slope classes were selected for this study: more than 20% (Parcel 26) and less than 20% (Parcel 14) (Naghdi et al. 2009). Skid trail width was 3 m. Runoff was measured using the runoff plots (Hartano et al. 2003). The plot borders were made of earth levees. The edges of the runoff plots were above the soil surface to prevent input from splashes entering the plot from the surrounding areas. A ditch was positioned at the down slope end of the plot and a tank was installed at the end of the plot to collect the runoff. Experimental plots were 25, 50 and 75 m in length and 3 m in width (Fig. 2) on each skid trail that were replicated 3 times for each slope class. The statistical method was a complete block design (3 blocks). Runoff volume was calculated by measuring the height of water in the tanks after duration of 3 rainfalls.

Soil samples were taken from the skid trail of Parcel 26 to determine soil texture. Soil texture was determined by the Bouyoucos method (Jordan, Martinez-Zavala 2008). Soil samples were also taken to measure bulk density (Hartano et al. 2003). Samples were taken using a steel ring of 94.95 cm^3 in volume.

Data were analysed using Statistical Package for the Social Sciences (SPSS) for Windows version 13. Linear regression analysis was used to determine the relationship of slope length, slope steepness and runoff volume. The Pearson' correlation analysis was used to determine whether there is a correlation between runoff volume and slope steepness, and between runoff volume and plot length (slope length). The independent samples *t*-test compared differences in mean soil bulk density between skid trail and undisturbed area (control area) at $\alpha = 0.05$ significance level.

RESULTS

Soil characteristics

Table 2 shows the results of the soil analysis. The soil texture for skid trails was clay loam.

The soil bulk density of skid trail was measured as minimum 1.28 $g\cdot cm^{-3}$ to maximum 1.73 $g\cdot cm^{-3}$ while the mean soil bulk density of 1.13 $g\cdot cm^{-3}$ was record-

Table1. Factors considered in experimental plots

Variable	Treatment
Soil type	clay loam
Plot length	3 levels used: 25, 50, 75 m
Skid trail slope	> 20%, < 20%
Skid trail width	3 m
Skid trail use	more than 15 passages on skidding duration
Time since construction	0 year
Skid trail vegetation cover	no vegetation cover

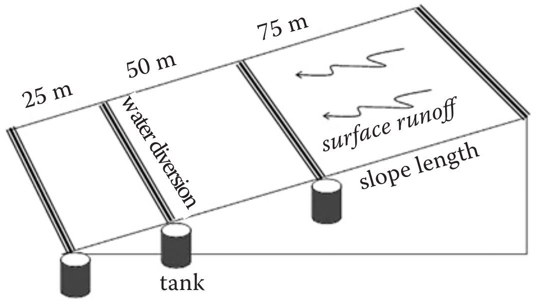

Fig. 2. Plan view of experimental plots

Table 2. Soil characteristics

	Sand (%)	Clay (%)	Silt (%)
Mean	3.59	31.88	37.52
SD	0.11	5.77	5.87

ed on the control area. Also, considerable differences were found between the area and skid trail with regard to the bulk density *t*-test ($P = 0.005$, $\alpha = 0.05$).

Runoff

The results of runoff volume on the skid trail of Parcel 26 are shown in Fig. 3. The highest and lowest amount of runoff volume mean occurred at 75 m and 50 m plot length, being 123 and 96.33 l, respectively. The results of runoff volume on the skid trail of Parcel 14 are shown in Fig. 4. The highest amount of runoff volume mean was 9.33 ± 0.41 at 75 m plot length and the lowest amount of runoff volume mean was 3.88 ± 0.66 at 25 m plot length.

The results of correlation analysis (Pearson' test) between runoff volume and two slope classes (less than 20% and more than 20%) on skid trails are shown in Table 3. Results showed that there was a significant and positive correlation between runoff and slope classes ($n = 18$).

Correlations between runoff volume and slope length were also analysed by Pearson' test. The results showed that there was a significant and positive correlation between runoff volume and plot length except rainfall 3 in more than 20% slope class ($n = 9$) (Table 4).

Table 3. *R*-Pearson and *P*-value between runoff volume and slope steepness

	Rainfall 1	Rainfall 2	Rainfall 3
R	0.969**	0.972**	0.969**
P	0	0	0

**correlation is significant at $\alpha = 0.01$

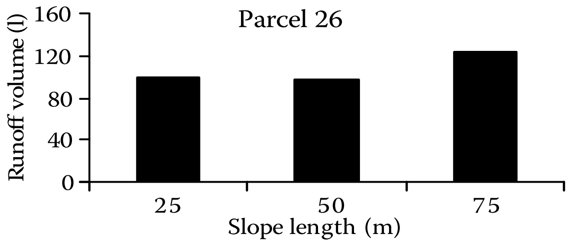

Fig. 3. Runoff volume on skid trail

The relationship of slope length and runoff volume in two slope classes is presented in Fig. 5. The figure shows that increases in slope length can lead to increased runoff in two slope classes. The results of linear regression analysis are shown in Table 5. In the linear regression $r = 0.922$, $r^2 = 0.894$, adjusted $r^2 = 0.843$ and *P* value was significant (Sig = 0, $\alpha = 0.05$). On the basis of this result, the regression equation is as follows:

$$Y = 0.065x_1 + 4.178x_2 - 34.424$$

where:
Y – runoff volume (l),
x_1 – slope length (m),
x_2 – slope steepness (%).

DISCUSSION

Road construction, timber harvesting and wood extraction disturb sites and soil in forests. So, runoff control practices such as rehabilitation of skid trails and forest roads after harvesting and construction of water diversions are essential to reduce the quantity of runoff and to minimize the sediment movement (Croke et al. 2001; Grace, Clinton 2007). The results showed that the length of slope had a significant effect on runoff volume. However, further analysis showed that increases in slope length can lead to increased runoff ($P < 0.05$); slope steepness can affect runoff volume, too (P = 0). Also, there was a linear relationship between runoff volume, slope length and slope steepness. So, the regression equation is useful to relate runoff volume to slope length and slope steepness. The steep slopes

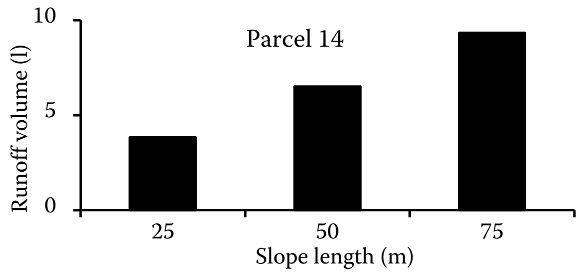

Fig. 4. Runoff volume on skid trail

Table 4. *R*-Pearson and *P*-value between runoff volume and plot length

	Rainfall 1		Rainfall 2		Rainfall 3	
	R	*P*	*R*	*P*	*R*	*P*
More than 20%	0.733*	0.014	0.811**	0.008	0.122	0.754
Less than 20%	0.982**	0	0.982**	0	0.998**	0

*correlation is significant at α= 0.05, **correlation is significant at α = 0.01

of the skid trails can enhance runoff volume (Jordan, Martinez-Zavala 2004; Jordan-Lopez et al. 2009). This indicates that slope steepness affected both runoff and slope length (Fig. 3). This may be so because runoff was strongly determined by slope steepness and there was no difference between two skid trails in rainfall characteristics, soil texture, canopy and vegetation cover (Hartano et al. 2003; Gomi et al. 2008; Jordan-Lopez et al. 2009).

Also, the significant increase in soil bulk density on the skid trail can be interpreted that the movement of a vehicle on the skid trail causes soil compaction, decreases the hydraulic conductivity, water content and infiltration capacity and increases runoff (Makineci et al. 2007; Nghdi et al. 2009; Agherkakli et al. 2010). Plant cover is the most sensitive variable in the control of runoff (Mohammed, Gumbs 1982; Jordan, Martinez-Zavala 2008). Plant covers enhance the infiltration rates and reduce runoff volume but there was no vegetation cover on skid trails. So, when the slope increases, the runoff needs more time for infiltration so that the amount and velocity of runoff per slope length increase. Slope gradient is one of the main explaining variables of runoff (Fox, Bryan 1999; Arnàez et al. 2003).

The results also showed that there was no significant correlation ($P = 0.754$) between runoff volumes and plot lengths in rainfall 3 (more than 20%). It may be related to other factors such as plot location, soil characteristics, rainfall characteristics (Mohammed, Gumbs 1982; Beuselinck et al. 2002; Wemple, Jones 2003) that were not considered in this experiment and should be investigated in future.

Regarding these results, it is necessary to control and reduce runoff on steep skid trails (more than 20%) after forest harvesting by creation of water diversions (Wallbrink, Croke 2002). Also, the results showed that in skid trails with more than 20% slope class, water diversions should be constructed in short intervals (regarding the runoff volume on different slope lengths) while in less than 20% slope class, water diversions could be constructed in long intervals (more than 75 m). From this it can be concluded that the treatment of slope is probably a more important factor in the decreased runoff volume than the treatment of the water diversion although this may be true only of the situation of this experiment.

In a mechanized logging system in the northern forest of Iran, logs are extracted by skidders on skid trails and these cause damage to forest soil. So it

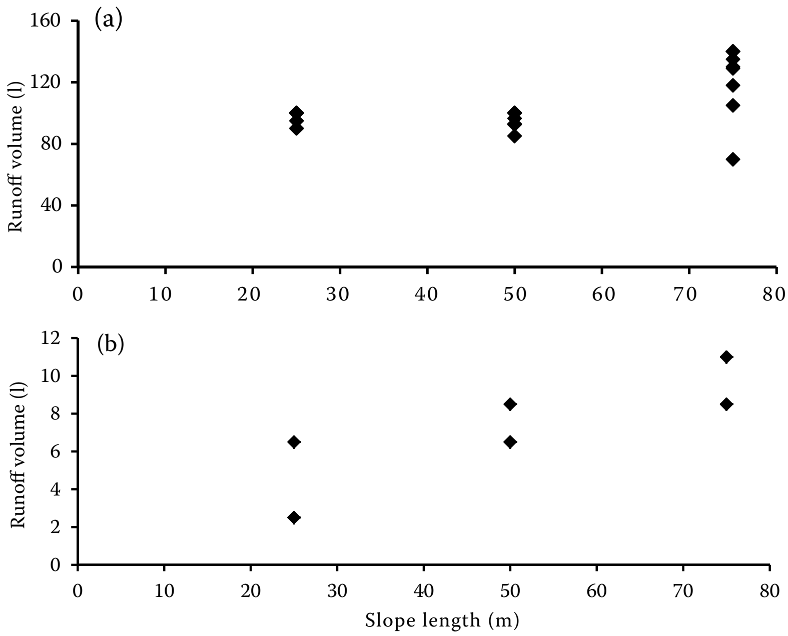

Fig. 5. Runoff volume as a function of the slope length: (a) Parcel 26, (b) Parcel 14

Table 5. The results of linear regression analysis

Model	Sum of squares	df	Mean Square	*F*	Sig
Regression	120,040.086	2	60,020.043	143.660	0.000
Residual	21,307.414	51	417.792		
Total	141,347.500	53			

is necessary to control runoff and erosion from forest roads and skid trials especially in mountain forests, thus avoiding damage. Results from this study showed that slope is an effective factor on the amount of runoff volume along skid trails. The highest runoff volume occurs at more than 20% slope class. So precise planning of skid trails is one of the effective recommendations to decrease runoff amount and other damage from runoff. In this regard, limiting skid trails to a longitudinal slope of less than 20% should be considered.

A possible complementary action to decrease runoff is the construction of water diversions on skid trails. Also, skid trails should be abandoned between successive harvests and should be drained by water diversions that should be placed at regular intervals according to soil type and slope. Underlying factors that increase runoff and erosion risk, such as steep topography, vulnerable soil types, a high rainfall pattern, should also be taken into consideration with more care. The results suggest an appropriate and precise scheduling of skid trail maintenance in order to minimize damage to soil and using of skid trails in other skidding periods.

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Received for publication April 11, 2012
Accepted after corrections July 9, 2012

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