https://doi.org/10.17221/73/2020-JFS

Effect of the standard levels of forest road segments on soil loss

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Citation: Yolmeh G., Parsakhoo A., Sheikh V., Mohamadi J. (2021): Effect of the standard levels of forest road segments on soil loss. J. Fort. Sci., 67: 80–86.

Abstract: Roads with the low standard level are often more susceptible to soil loss and production of sediment during rainfall events. The main aims of this research were to investigate the relationships between the standard level of the road and soil loss and determine the most effective road attributes in soil loss. Therefore, 30 road segments were selected in Bahramnia forest district, Golestan Province. These segments were classified into low standard, medium standard and high standard levels based on longitudinal slope, coverage on cut slopes, distance from runoff origin to culvert, traffic volume, and surfacing quality. A rubber bar was installed at the end of each segment to divert runoff into a sediment trap. In each trap, a series of wooden pins marked the locations for repeated elevation measurements of trapped sediment. Sediment volume was measured after each rainfall event. Results of the study showed that the most effective road attributes in soil loss were distance from runoff origin to trap and depth of ditch. Soil loss from road segments increased with the decreasing standard level of segments but this relationship was moderately strong (correlation coefficient: –0.45). An average amount of soil loss from low level standard road segments was 6.56 $t\cdot ha^{-1}\cdot year^{-1}$ while an amount of soil loss for high level standard roads was 2.66 $t\cdot ha^{-1}\cdot year^{-1}$. Indeed, by improving the road attributes and standard level, less sediment is produced from road segments.

Keywords: sediment trap; rainfall duration-intensity; road standards; runoff; Bahramnia forest

Forest roads are constructed to access the forest interior, for wood extraction, conservation, afforestation and recreation, but the road construction is a great land-use change in a forest ecosystem which plays an important role in soil erosion particularly in the sensitive steep terrain of a mountainous area (Afzalimehr, Dey 2009; Aust et al. 2015). The road construction in a forest ecosystem not only removes the plant cover, leaving soil surfaces unprotected against raindrop impact, but also has critical consequences for soil hydrology and soil erosion. The road construction can be a reason for soil instability, when the soil is exposed to rainfall energy. Forest road attributes should be designed and constructed according to a standard guide. It was reported that standard sections of the road have higher resistance against the erosive power of rainfall and runoff (Luce, Black 1999; Sheridan, Noske 2007; Madjnounian et al. 2010; Surfleet et al. 2011). Lang (2016) in a study in Virginia indicated that the mean sediment delivery for low standard roads was approximately 48 times greater than for high standard roads and 3.5 times greater than for medium standard roads. Sixty-eight percent of standard roads produced sediment delivery rates less than 2 $t\cdot ha^{-1}\cdot year^{-1}$ and 92% produced less than about 10 $t\cdot ha^{-1}\cdot year^{-1}$. Mostafa et al. (2016) in a research in Iran found that the runoff production on low standard roads was about 39% higher than on standard roads.

Soil loss and runoff rates on forest road depend on climate factors, soil moisture and texture, hy-

https://doi.org/10.17221/73/2020-JFS

draulic parameters, topography, road network planning, road slope, road width, land-use types, road-use types, vegetation cover, number of horizontal and vertical curves, drainage structures, traffic volume, surfacing and subgrade materials, soil-bearing capacity, construction and maintenance (Croke et al. 2005; Madjnounian et al. 2005; Cao et al. 2009; Dymond et al. 2014). The investigation of the relationship between standard levels of road and soil loss and determining the most effective road attributes in soil loss can be useful for allocating the road maintenance budget to critical segments of roads (Nearing et al. 1991; Robichaud, Brown 2002; Brown et al. 2013; Broda et al. 2016). In Hyrcanian forests, much more attention should be paid to the impacts of road standard levels specifically in relation to soil loss and sediment yield. The main aims of this research were to investigate the relationships between standard levels of road and soil loss as well as determine the most effective variables of road in soil loss.

MATERIAL AND METHODS

Description of the study area. District one in Bahramnia forest district with an area of 1 713 ha is located in the Golestan Province and in watershed number 85 (36°43'27'' to 36°48'6''N and 54°21'26'' to 54°24'57''E) (Figure 1). The bedrock of this forest is limestone and sandstone with altitude ranging from 100 to 1 000 m a.s.l. The forest is mixed deciduous which is dominated by *Parrotia persica*, *Carpinus betulus*, *Fagus orientalis*, *Quercus castaneifolia* and *Zelkova carpinifolia*. This forest has been established on brown forest soil with mostly clay-loam-silty texture and worn stones. The mean forest stock growth in the study area was 247 $m^3 \cdot ha^{-1}$. The climate of the region is Mediterranean warm and moist with mean annual precipitation of 562 mm which is lowest in July and August. In Bahramnia forest, 30.3 km of forest roads were constructed in 1989. Some segments of roads in this forest are susceptible to erosion and in rainy seasons water erosion occurs (Mohammadi et al. 2014).

Road segment classifications based on technical standards. In this study 30 road segments with total length of 4 420 m were selected according to stream crossing. Road segments were classified into low standard, medium standard and high standard levels based on longitudinal slope, coverage on cut slopes, and distance from runoff origin to culvert, traffic volume and surfacing quality (Table 1). Details of road segments are provided in Table 2.

Sediment measurements for each segment. In this study, narrow trenches were hand-excavated at the end of segments between 30° and 45° angle across the road surface and a rubber bar was buried leaving approximately 15 cm of the belt exposed above the road surface. The rubber bar diverts runoff into a sediment trap. Within the sediment traps, a series of five wooden rulers marked the locations for repeated elevation measurements of sediment (Figure 2). Elevation gains (m) of deposited sediment and depositional area (m^2) were recorded after each rainfall event and multiplied to calculate sediment volumes (m^3). Three bulk density samples were collected using the soil core method for each sediment catchment area and analyzed after one year of sediment accumulation. Sediment volume increases were multiplied by mean bulk density to calculate sediment mass (Wischmeier, Smith 1958). Sediment volume was measured after each rainfall event during one year from 19 March 2019 to 19 March 2020. Rainfall duration-intensity was recorded using local rainfall gages.

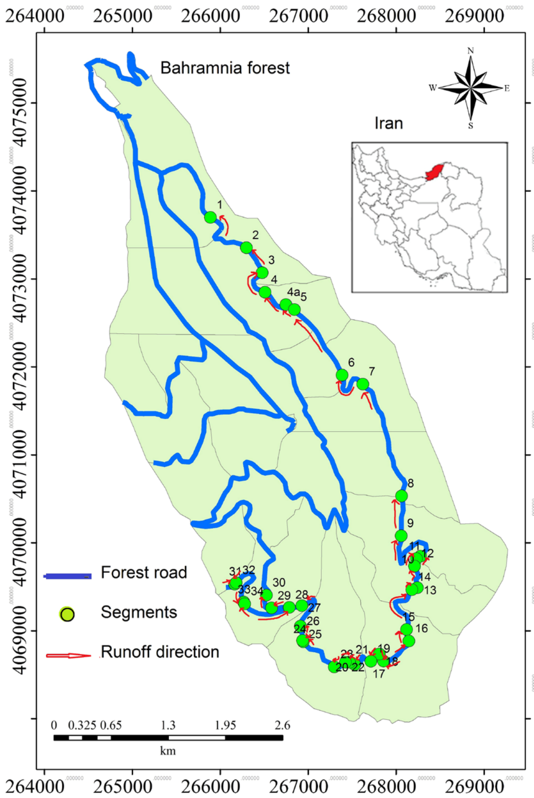

Figure 1. Location of the study area

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Table 1. Standard levels of secondary forest roads based on Lang (2016)

Technical parameters of road	High standard	Medium standard	Low standard
Longitudinal slope (%)	< 5	6–9	> 10
Bare soil on road (%)	< 25	26–50	51–100
Bare soil on ditch (%)	< 25	26–50	51–100
Bare soil on cutslope (%)	< 25	26–50	51–100
Distance from runoff origin to trap (m)	< 150	151–200	> 201
Traffic volume	seldom	often	logged
Surfacing quality	graveled	sparsely graveled	bare
Cutslope height (m)	< 1.5	1.6–2	> 2.1
Cutslope gradient (%)	> 150	100–149	< 99
Width of road without ditch (m)	4.5–5	> 5.1	< 4.4
Depth of ditch (cm)	31–35	25–30	36 < depth < 24
Width of ditch (m)	1–1.2	0.8–0.9	1.2 < width < 0.7
Type of ditch	grassy	stony	bare
Forest canopy cover on road (%)	51–100	26–50	< 25

Statistical analysis. The dataset consisted of independent variables including road attributes as standard levels and dependent variable including the mass of delivered sediment. The dependent data had unequal variances (determined by Levene's test) and non-normal distributions (Shapiro-Wilk test). Median differences in dependent variables by overall road standards were tested using nonparametric Kruskal-Wallis and Wilcoxon tests. Data were statistically analyzed using ANOVA procedure and Pearson correlation in SAS program. Tukey-Kramer HSD test was used to compare means among treatments and diagram designed by Excel software.

RESULTS AND DISCUSSION

Results of the study showed that the bare soil of ditch (P = 0.000) was the most important parameter that influenced the standard level of the road. Ditch maintenance is necessary to maintain drainage, but it may result in increased soil loss due to

Figure 2. Rubber bar for diverting runoff into a sediment trap

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Table 2. Details of road segment

Segment	Slope (%)	Segment length (m)	Bare soil on road (%)	Ditch bare soil (%)	Cutslope bare soil (%)	Traffic volume	Surfacing quality	Cutslope height (m)	Cutslope gradient (%)	Width of road (m)	Depth of ditch (cm)	Width of ditch (m)	Type of ditch	Canopy (%)
1	9.0	280.0	0.0	75.0	65.0	2.0	2.0	2.5	95.0	6.2	0.6	1.6	2.0	35.0
2	4.0	280.0	0.0	50.0	50.0	2.0	2.0	2.0	70.0	5.4	0.6	1.7	2.0	60.0
3	6.0	300.0	10.0	60.0	30.0	2.0	2.0	1.5	75.0	6.0	0.5	1.7	2.0	45.0
4	7.0	300.0	0.0	80.0	40.0	2.0	2.0	1.5	60.0	6.2	0.7	1.9	2.0	40.0
5	8.0	120.0	0.0	50.0	30.0	2.0	2.0	3.0	70.0	4.5	0.4	1.6	2.0	55.0
6	4.0	350.0	10.0	80.0	30.0	2.0	2.0	1.7	75.0	5.5	0.5	1.5	2.0	50.0
7	4.0	195.0	10.0	10.0	40.0	2.0	2.0	3.0	65.0	6.0	0.5	2.0	2.0	50.0
8	3.0	50.0	0.0	20.0	10.0	2.0	2.0	2.5	60.0	6.0	0.3	1.2	2.0	30.0
9	4.0	70.0	0.0	60.0	20.0	2.0	2.0	1.7	30.0	5.5	0.5	1.6	2.0	30.0
10	6.0	250.0	10.0	30.0	0.0	2.0	2.0	1.8	30.0	6.0	0.6	1.9	2.0	30.0
11	7.0	40.0	0.0	0.0	10.0	2.0	2.0	1.5	60.0	6.5	0.3	1.1	2.0	70.0
12	7.0	180.0	0.0	80.0	50.0	2.0	2.0	6.0	70.0	5.0	0.4	1.6	2.0	40.0
13	6.0	120.0	0.0	70.0	0.0	2.0	2.0	1.5	40.0	5.5	0.6	1.8	2.0	40.0
14	12.0	80.0	10.0	80.0	20.0	2.0	2.0	2.5	50.0	6.0	0.4	1.4	2.0	40.0
15	14.0	100.0	10.0	100.0	0.0	2.0	2.0	4.0	60.0	4.2	0.3	1.4	1.0	40.0
16	10.0	180.0	15.0	60.0	20.0	2.0	2.0	3.0	70.0	4.5	0.5	1.7	2.0	40.0
17	2.0	40.0	0.0	80.0	0.0	2.0	2.0	1.5	90.0	5.7	0.2	1.2	2.0	40.0
18	5.0	80.0	5.0	50.0	20.0	2.0	2.0	4.0	80.0	6.5	0.3	1.2	2.0	60.0
19	4.0	80.0	0.0	90.0	0.0	2.0	2.0	2.5	60.0	6.0	0.6	1.9	2.0	60.0
20	5.0	150.0	0.0	70.0	0.0	2.0	2.0	2.0	30.0	6.5	0.7	1.3	2.0	60.0
21	8.0	170.0	0.0	60.0	40.0	2.0	2.0	4.0	80.0	5.0	0.5	1.6	2.0	60.0
22	3.0	90.0	0.0	90.0	20.0	2.0	2.0	3.0	40.0	5.5	0.4	2.3	2.0	50.0
23	7.0	100.0	0.0	100.0	20.0	2.0	2.0	2.0	50.0	6.0	0.5	1.3	1.0	50.0
24	5.0	110.0	0.0	90.0	0.0	2.0	2.0	1.5	90.0	6.5	0.4	1.7	2.0	40.0
25	6.0	110.0	15.0	40.0	20.0	2.0	2.0	2.0	40.0	6.0	0.6	1.9	2.0	35.0
26	7.0	85.0	0.0	60.0	0.0	2.0	2.0	0.0	0.0	6.0	0.6	1.2	2.0	40.0
27	6.0	90.0	0.0	100.0	10.0	1.0	1.0	1.5	70.0	6.0	0.5	2.1	1.0	50.0
28	4.0	90.0	0.0	100.0	20.0	1.0	1.0	2.0	90.0	5.0	0.5	1.5	1.0	30.0
29	7.0	250.0	0.0	100.0	0.0	1.0	1.0	1.0	60.0	5.0	0.5	1.5	1.0	40.0
30	6.0	80.0	0.0	100.0	0.0	1.0	1.0	1.5	50.0	4.0	0.6	1.6	1.0	30.0

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soil disturbance or removal of vegetative or other soil covers (Jia et al. 2019). Other effective parameters on the standard level of the road were longitudinal slope (P = 0.006), width of road without ditch (P = 0.005), distance from runoff origin to trap (P = 0.035), type of ditch cover (0.030) and forest canopy cover on the road (P = 0.022). Moreover, the most important attributes of the road that influenced soil loss were distance from runoff origin to trap (P = 0.001) and depth of ditch (P = 0.001). It is important to maintain forest roads by considering not only cost efficiency but also the appropriate management of water and soil (Jordán-López et al. 2009; Jones et al. 2011). Without improving road attributes, heavy rains remove large amounts of soil from all portions of the roadway (Foltz et al. 2009; Vymazal, Březinová 2018). Other effective parameters on soil loss from road segments were longitudinal slope (P = 0.043) and width of ditch (P = 0.019; Table 3). Moqadamirad et al. (2013) investigated the effect of the forest road longitudinal slope on runoff and sediment production in Kouhmian forest. Results showed that the soil loss and runoff production increased with increasing longitudinal slope beyond the standards. Ditches can be a significant cause of soil loss due to carrying concentrated overland flow that can have substantial erosive energy (Streeter et al. 2019).

Amounts of soil loss from different standard levels of road segments are shown in Figure 3. Soil loss from a road segment depends on segment largeness. Proper water control spacing and application of soil stabilization methods can stabilize soil in large segments. The rainfall characteristics especially drop size and duration were the reasons for negative correlation between canopy cover and soil loss and positive correlation between canopy cover and road standard level. Most of the rainfall events in our study area were light rains of short duration. The drops of these rainfall events are caught by canopy and therefore the road surface is protected from drop impact. Soil loss from road segments with the low standard level was significantly higher than in the other standard levels. Findings of current research showed that soil loss from road segments was negatively correlated with standard levels of forest roads. Soil loss from road segments increased with the decreasing standard level of segments (Figure 4). All sediment traps collected a total of 7.98 t of sediment over the one-year period. The highest sediment mass (6.56 t·ha^{-1}·year^{-1}) was deposited in the road segments with low standard levels, where longitudinal slope and distance from runoff origin to trap were more than 10% and 200 m, respectively, and

Table 3. Correlation between technical parameters of the road and standard levels and soil loss

Technical parameters of road	Standard level		Soil loss	
	correlation coefficient	P-value	correlation coefficient	P-value
Longitudinal slope (%)	–0.490	0.006	–0.373	0.043
Bare soil on road (%)	–0.209	0.269	–0.288	0.123
Bare soil on ditch (%)	–0.635	0.000	–0.181	0.338
Bare soil on cutslope (%)	–0.273	0.145	–0.343	0.063
Distance from runoff origin to trap (m)	–0.387	0.035	–0.556	0.001
Traffic volume	0.312	0.093	0.211	0.263
Surfacing quality	0.312	0.093	0.211	0.263
Cutslope height (m)	–0.181	0.339	–0.115	0.546
Cutslope gradient (%)	–0.355	0.054	0.079	0.677
Width of road without ditch (m)	0.503	0.005	0.299	0.109
Depth of ditch (cm)	–0.181	0.339	–0.566	0.001
Width of ditch (m)	–0.281	0.133	–0.425	0.019
Type of ditch cover	0.397	0.030	0.222	0.239
Forest canopy cover on road (%)	0.416	0.022	0.011	0.952
Silt content (%)	–0.164	0.385	–0.316	0.089
Sand content (%)	0.063	0.742	0.077	0.686
Clay content (%)	0.096	0.615	0.219	0.244

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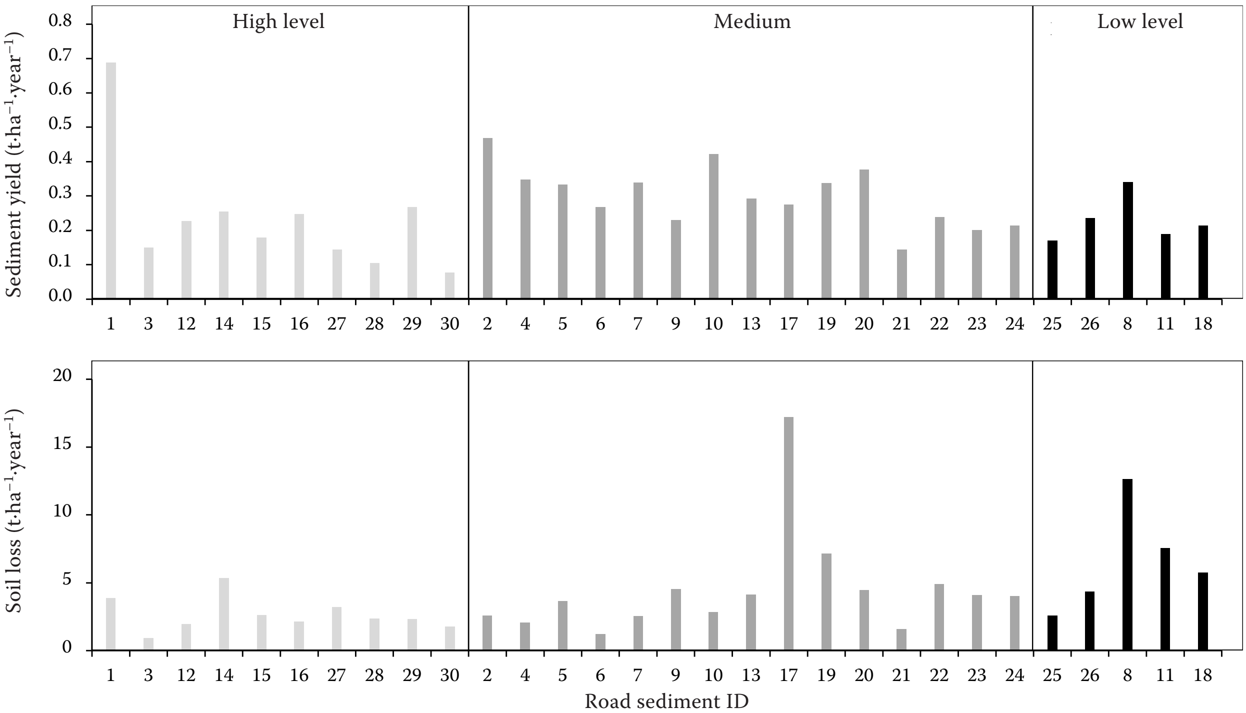

Figure 3. Sediment yield and soil loss from different road segments

the bare soil on the cut slope and ditch dimensions were large. The second greatest amount of delivered sediment mass (4.46 t·ha^{-1}·year^{-1}) originated from medium standard roads located in the segments with a longitudinal slope of 6–9%, distance from runoff origin to trap 150–200 m and the bare soil on the cut slope of 25–50% (Figure 4). In this research the relationship between standard level and soil loss is moderately strong at best, the relationship was not stronger because of the influences of unpredicted behaviour of runoff and other unpredicted environmental parameters.

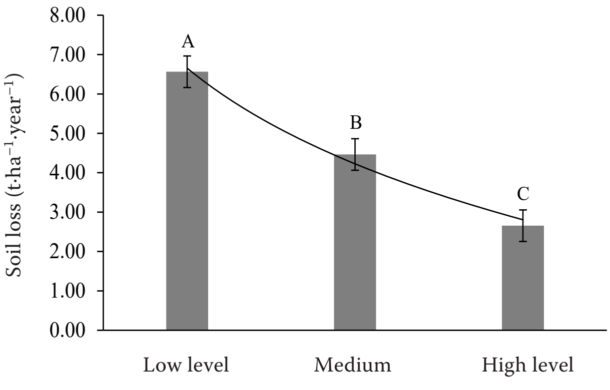

Figure 4. Soil loss from different standard levels of road segments with the correlation coefficient of –0.451 (P = 0.012)

CONCLUSIONS

Road characteristics including bare soil of ditch, longitudinal slope, road width, distance from runoff origin to trap, type of ditch cover and forest canopy cover on the road control variation in the standard level of the road. Standard level of the road remained relatively high due to the low longitudinal slope, greater canopy cover and greater soil cover on ditch surfaces. Low standard roads have a greater erosion potential. Low standard road segments tended to have greater sediment delivery because of the distance from runoff origin to trap, deep ditch, steep longitudinal slope and wide ditch. Indeed, by improving the road attributes and standard level, less sediment is produced from road segments and may not require additional conservation practices and may have more time between scheduled road maintenance periods.

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Received: May 20, 2020
Accepted: November 1, 2020