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Determination of the Most Effective Factor on Sediment Production Due to Road in Forest Mountainous Roads

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Abstract: Road existence and its important in forest are essential and unavoidable. Establishment of road is including calculable and incalculable expenses in forest ecosystem. Sediment production is due to road establishment that avoid usable soils for forest vegetation special in north forests of Iran. For this research a road situated in Estakhr Posht forests of Neka (North of Iran) was studied. In this survey, the mentioned road divided to 123 smaller lengths. The most effective factor recognized road length slope by variables combination test and finally the most appropriate model was calculated to estimate sediment production. After estimation of sediment volume, the significant factors were recognized with deletion the effective repeated factors using independent test on effective factors. The produced sediments volume was estimated using an estimation model of the most produced sediment of road for whole of lengths. The portable sediment volume estimated 3264919.3 ton yr^{-1}.

Key words: Road · Sediment prediction model · Independent variable test · Combination test · Mazandaran province · Neka

INTRODUCTION

Forest roads are recognized as the greatest potential source of accelerated erosion associated with forest management [1]. Roads, Erosion and Sediment Delivery Roads create a contiguous linear physical alteration to hill slopes. To create the running surface, or tread, it is necessary to excavate into the natural hill slope. Normally this excavated material is used as fill, to make a portion of the running surface. Both cut and fill slopes steeper than the natural slopes and, at least for some period of time after construction, are unvegetated. Cut and fill slopes have a higher erosion potential than the native hill slopes, both because of the steeper slope and because of the exposed, relatively loose soil. On steeper hill slopes the risk of mass erosion (landslides) from roads is also elevated [2].

Roads also alter the flow of water. Road cuts may intercept ground water and the road surface normally collects surface water. This water is routed down the road to a location where it is discharged away from the road. Roads must also cross streams. Most stream crossing structures are culverts. During high flows, stream flows can exceed culvert capacity. When culvert capacity is exceeded, fill washout or channel diversion may occur. Drainage waters remove eroded sediments from the roadway and some times in to streams. Traffic on gravel surface roads also increases the potential for sediment delivery to streams. Reid and Dunne [3] found that sediment yield from road surfaces in western Washington on actively used logging roads was 1000 times that of the yield from abandoned roads and up to 500 tons/kilometer. However, a separate study found that sediment yield from secondary roads was 10 tons per kilometer of road, while for active roads it was 26 tons per kilometer [4]. This is an order of magnitude difference from Reid and Dunne [3], even though the studies were conducted on areas of similar geology and climate. Sediment delivery to streams is extremely variable, depending on traffic levels, quality of road surfacing, climate, drainage design, maintenance practices and other factors.

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Roads have been identified as the major source of sediment from forest lands that reach streams [5-7]. Components such as location and construction of forest roads are elemental in controlling sediment and runoff water emanating from roads. Careful and considerate road construction and design is an important aspect in reducing the environmental impact of road management practices.

Removal of water from the road system with minimal soil movement is a major concern in road research. Swift [8] cites two methods for improving road designs to protect water quality: keeping sediment from flowing into intermediate stream channels and removing runoff from the roadway with minimal soil erosion. One of the most important design principles involved in accomplishing these two goals is flow dispersion to slow runoff to non-erosive velocities. Two primary areas of concern and problems due to erosion and sedimentation are the turn-out ditch and the roadside ditch. These areas serve as zones of flow concentration in which runoff from the traveled way, cut slope and upland forest converge. Ditches have increased potential for erosion due to large volumes of water at high velocity. The kinetic energy of runoff water is greatly increased with increasing runoff volume and velocity, since kinetic energy is defined as half the product of mass and the square of velocity. Specifically, four commonly used erosion control techniques (vegetation, rip-rap, sediment fences and settling basins) will be compared.

Road system elements that either produce or control sediment delivery were measured or categorized. The objective of this study was to determine the relative potential for forest roads to deliver sediment to the watershed. The availability of such information will help timber sale administrators make better decisions to protect their investments in road and trail construction, while also protecting water quality. This study describes the forest road system in the Neka watershed. For this study, a forest road is any road that has been used for forest management activities. There are many miles of abandoned road grades in the Neka watershed. This study is purposed assessment of sediment production yield from a forest road using sediment prediction model and results of it can be used to expansion of road construction in future.

MATERIALS AND METHODS

Study Area: Study area is located on northern slope of Alborz Mountain Chains between Neka and Behshahr cities (North of Iran) with 815 hectare areas. Estakhr Posht region is situated between 36° 25' to 36° 29' North latitude and 53° 17' to 53° 31' East longitude with 3141meter length of roads. The general road aspects are northern and north western. The average slope of field is about 40% (Min. 31% and Max. 45%), the height of study area at sea level starts from 300 meter and continues till about 1000 meter. Zalem-Rood River is flowing in this region. Lithology of presence structure are Kertaseh (Marne, Silt stone, Lime stone) and Myosin (Marne and Sand stone). These regions are belonging to third period of geology. Mean annual precipitation was from 1300 mm at the Sari city meteorological station, which is 10 kilometer far from the study area [9].

Sediment Prediction Model (SEDMODL): The sediment yield is typically produced from four overland flow components including road surface, excavation and earth filling cut slope and hydrologic network of region. Since the road sections in the research forest are in sloped with a ditch, surface water stay away from the fill-slope area. Based on the field observations and calculations, sediment yield from a regenerated fill-slope produces very small amount of sediment which can be ignored in the sediment prediction. In the formulation, the sediment yield from road surface and ditch were combined into one unit and called tread sediment. The road tread width includes both running surface width and ditch width. Therefore, total sediment delivered from each road section was predicted based on two components of road tread and cut-slope in 2007 (Eq. 1) [10, 11].

$$\text{Total Sediment (ton yr}^{-1}) = (Ts + Cs) \times A_f \tag{1}$$

Where:

TS; tread sediment, CS; cut - slope sediment and A_f, road age factor. Tread sediment varies based on road dimensions including length (Lr), width (W) and various erosion factors including geologic erosion rate (GEr), road tread surfacing (Sf), traffic (T_f), road grade (G_f), precipitation (P_f) and sediment delivery factors (D_f) (Eq. 2).

$$TS = Lr \times Wr \times GEr \times S_f \times T_f \times G_f \times P_f \times D_f \tag{2}$$

Cut - slope sediment is a function of geologic erosion rate, cut - slope factor (CS_f), cut-slope height (CSh), road length and sediment delivery factor (Eq. 3).

$$CS = GEr \times CS_f \times CSh \times Lr \times D_f \tag{3}$$

The majority of sediment yield from a new road is produced during the first two years until cut-slope, fill slope and ditch areas are properly covered by

Table 1: Geologic erosion rates based on lithology and geologic age (ton ha^{-1} yr^{-1})

	Geologic age of formations				
Lithology	Quaternary	Tertiary	Mesozoic	Paleozoic	Precambrian
Metamorphic	-	37	37	37	37
Schist	-	248	148	148	148
Basalt	37	37	74	74	74
Andesite	37	37	74	74	74
Ash	124	124	124	124	124
Tuff	124	124	74	74	74
Gabbro	-	25	25	25	25
Granite	-	49	74	74	74
Intrusive	-	37	37	37	37
Hard Sediment	-	37	37	74	74
Gravelly Sediment	37	37	-	-	-
Soft Sediment	74	74	-	-	-
Fine-Grained Soft Sediment	148	148	-	-	-

- Geologic erosion rates weren't recorded at different geologic ages

Table 2: Road treads surfacing factors

Surface type	Surfacing factor
Asphalt	0.03
Gravel	0.20
Pit run	0.50
Grassed native	0.50
Native surface	1.00
Native with ruts	2.00

Table 3: Road traffic factors

Road classes	Traffic factor
Highway	120.0
Main haul	120.0
County road	50.0
Primary road	10.0
Secondary road	2.0
Spur road	1.0
Abandoned/blocked	0.1

vegetations. According to the empirical observation, sediment yield is affected by time following construction [12]. The model considered the effects of the road age by multiplying the total sediment by the road age factor. It was assumed that the road age factor within the first year is 10, while it was 2 after two years or more [10].

Repeated Factors: Pay attention to this research was performed in a region, alone; therefore some of effective independent factors in roading and cut - slope components are unchangeable in whole of road lengths. These factors are deleted in statistics analysis by reason of ineffective.

Road Age: The road age is 30 years that number 2 should be incorporate in the model.

Geological Erosion Rate: The sediment yield potential from a specific road segment highly depends on sub-soil properties and geology [12, 13]. For example the silt-dominated soils are the most erodible soils, followed by clay-dominated and gravel dominated soils [14, 15]. After determining the geologic information of lithology and geologic age, the geological erosion rates for common parent materials obtained from Table 1 [2, 3, 11, 16].

Tread Surfacing Factor: The quality of the road surfacing material directly affects the sediment yield from the road tread surface. Tread surfacing factors for common road surface types are shown in Table 2 [17].

Traffic Factor: The sediment yield from a road tread surface is also affected by road use, as well as road surface material [16]. The effect of road use on sediment yield is represented by traffic factor [11]. Reid and Dunne [3] reported that traffic factor was to be the single most essential factor influencing sediment generation. There is an opposite relationship between traffic factor and surfacing factor. The most heavily used roads with high traffic factor have high quality surfacing with low surfacing factor, while rarely used roads with low traffic factor have low quality surfacing with high surfacing factor [10]. Traffic factors for various road classes are indicated in Table 3 [3, 17].

Precipitation Factor: The amount of sediment yield potential from a road segment can vary with annual regional precipitation. According exceeding the average

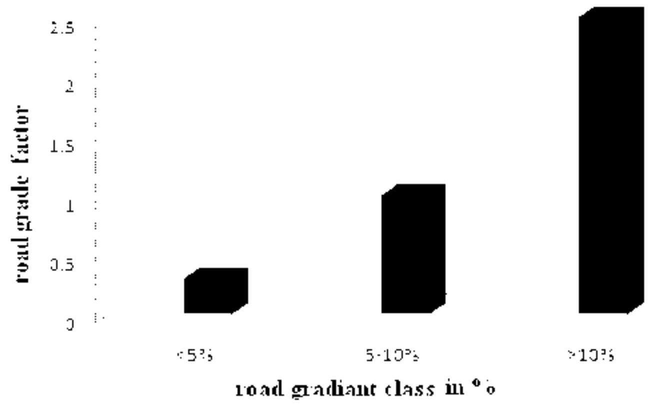

Fig. 1: Numeric value for road grade factor

Fig. 2: Numeric value for delivery factor

annual precipitation of 1200mm can increase the effects of erosion factors on sediment yield estimation about two times [6]. In the methodology of SEDMODL, the precipitation factor was computed based on the average annual precipitation (P_{avr} in mm) in the basin (Eq. 4) [3].

$$p_f = \left(\frac{p_{avr}}{1524}\right)^{0.8} \quad (4)$$

Unrepeated Factors: The factors that are changeable in different lengths of road are considered in statistic analysis. These factors will analyzed in independent variables test as separately and theirs share will determine in produced sediment volume.

Road Grade Factor: A road grade factor was assigned to each road segment based on the road gradient classes. Luce and Black [10] and Reinig *et al.* [18] suggested road grade factor for various road classes fallowing in Figure 1 [7].

Delivery Factor: Delivery factor is distance between nearest stream until a part of road [6]. The road sections with a long distance to the streams tend to have a low percentage of sediment yields since most of the sediment from the road section traps in the forest land and cannot reach the streams [19]. In the methodology of SEDMODL model, the erosion delivery factor for each road stage was estimated based on the distance from the middle point of the nearest stream to the middle point of the road stage [6].

The road segments that were located further than 60m did not deliver sediment to streams since sediment was infiltrated into the forest floor. A delivery factor for road segments with no sediment delivery to streams was zero. The sediment delivery factors for each segment were determined based on the sediment delivery zones generated by using ‘‘buffer’’ tool in Arc View GIS 3.2. Delivery factor for various distances between roads with streams fallowing in Figure 2.

Cut - Slope Cover Factor: The cut - slope cover factor can be defined as the percent of non-erodible

Table 4: The cut - slope cover factors as a function of vegetation or rock cover rates

Vegetation or rock cover (%)	Cover factor
100	0.1023
90	0.1500
80	0.2003
70	0.2540
60	0.3116
50	0.3742
40	0.4435
30	0.5222
20	0.6155
10	0.7700
0	1.000

cover on road tread, cut-slope and fill slope areas [10] Cut - slope cover factor for various road classes fallowing in Table 4.

Cut-Slope Height: Increasing the cut-slope height increases the amount of sediment yield from cut - slope area to ditch area through soil creep, sheet wash and slumping [12]. In the SEDMODL model, cut - slope height was determined based on hillside gradient class over the length of a road segment that drains to the stream [6]. Four gradient classes were specified during the field measurements and cut-slope height was assigned, that fallowing in Figure 3 [10].

Research Method: In this research, roads were divided in short distances. Number 123 lengths were obtained and

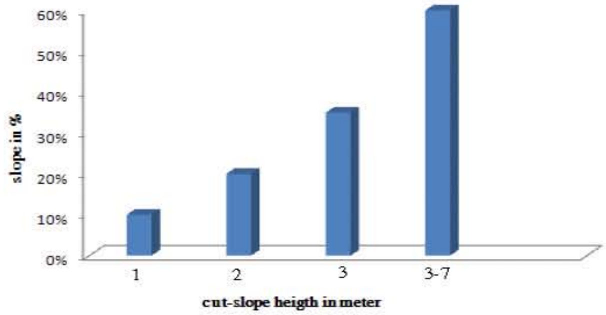

Fig. 3: Numeric value for cut - slope height

digital model layers of height, slope and aspect maps were designed using Arc View software. Hydrology grid map prepared with transition of height digital map of Arc View space to DiGeM software. Length and cross slopes of road, cut and fill slopes were inventoried in these distances. The distance every component with the nearest natural stream calculated using Arc View software and buffer performing.

Numerical values for every model variables obtained by explained graphs and tables in above and were replaced in final model. For assessment sharing every factor, the data analysis performed for independent variables model. In order to, the repeated factors such as geology, precipitation, road age, traffic and road tread surfacing factors were deleted of model. Then, the effects of the other factors on independent variable (produced sediments volume) were analyzed. Finally, the most effective factor was determined using combination test of significant factors.

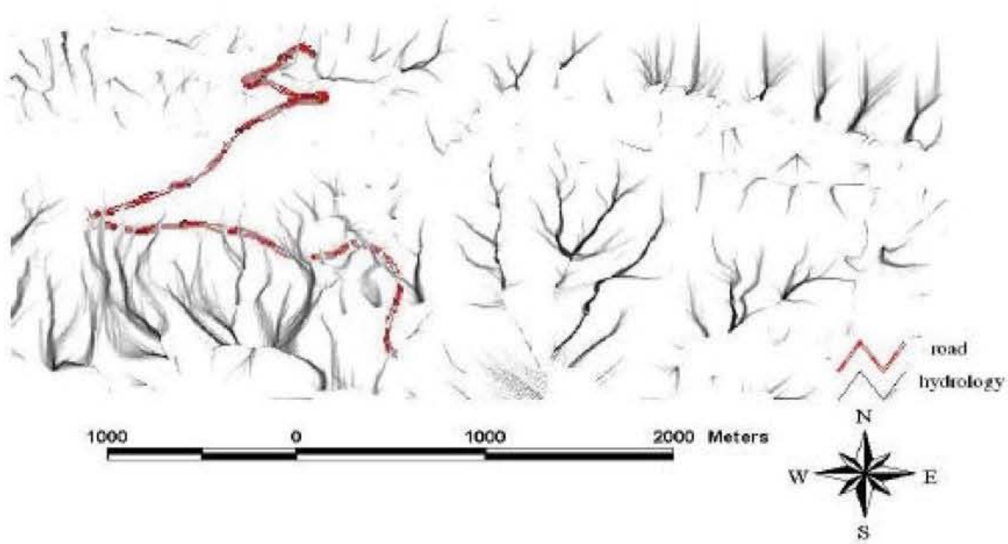

Fig. 4: The road and hydrology grid of study area

Table 5: The characteristics of parcel 34

GE_r	$CS_{f\%}$	CS_h	$D_{f\%}$	L_{rm}	CS	W_{rm}	GE_r	S_f	T_f	$P_{f\,mm}$	G_f	$D_{f\%}$	L_{rm}	TS	A_f	Total Sediment (ton/year)
74	60	3	100	20	2664	6.5	74	0.03	120	0.88	1	100	20	30676	2	66680

Fig. 5: The parcel of 34

Figure 4 is showing the studied road on hydrology grid map of study area that is recorded by GPS. Table 5 and Figure 5 are showing the characteristics and position of parcel 34, respectively. Pay attention to parcel 34 cut the hydrology grid, therefore numerical value of delivery factor considered 100%. The slope was 60% and numerical value for cut height was 3. By reason of road length slope was less than 7% for this parcel, therefore numerical value of this factor (that is road grade) will consider number 1.

RESULTS AND DISCUSSION

Sediment volume every 123 lengths were inventoried using sediment prediction model. The sum of portable sediment volume obtained 3264919.3 ton/year for this road. Geology, road tread surfacing, road traffic, precipitation, road cross and age factors were deleted of model by reason of theirs unify and unchangeable in whole of roads lengths. Road grade, delivery factor, cut and fill slopes cover, slope, cut - slope height and road length were considered in analysis and theirs effects on sediment volume were tested, separately. Different tests performed for introduction of significant factors that 1 and 2 models were resulted, finally. Delivery factor and road grade had significant correlation with sediment volume of road at confidence level of 99% (Table 6).

$$\text{Ln (total)} = 8.805550 + 1.285285\ (G) \quad (1)$$

$$\text{Ln (total)} = 6.002091 + 1.160085\ \ln\ (D) \quad (2)$$

Foltz and Burroughs [20] used of annual precipitation mean in their study and pointed to significant of this factor in theirs research. Akay [2] incorporated the most precipitation factor instead of precipitation mean that estimated as significant. Therefore, in this research the most precipitation was used, although it hadn't significant relation to the most of sediment volume. Luce and Black [10] introduced vegetation factor as significant. But, significant correlation wasn't visible between this factor and produced sediment volume in this research.

Akay and Sessions [21] mentioned road tread surfacing and cut - slope cover factors as significant. The road tread surfacing factor introduced as the most effective factor for sediment volume due to road. But, in this research above mentioned factors were deleted by reason of repeat in analysis. Also, Akay and Sessions [21] estimated the mean of sediment volume due to road with good view viewpoint economic for two surfacing of different treads. Results of theirs research showed that sediment volume for road with high quality of tread surfacing and length slope more than 10% is higher of sediment volume due to road with less quality and length slope less than 10%, that is according to results of our research.

Table 6: Analysis of calculated equations

Model	Coefficient Variance (%)	R^2
$\text{Ln(total)} = 8.805550^* + 1.285285^*\ (G)$	6.49	0.51
$\text{Ln(total)} = 6.002091^* + 1.160085\ \text{Ln}\ (D)$	3.69	0.74

*Significant at level of 1%

Table 7: Analysis of variance the appropriate model for sediment volume factor

Depended variable	Degree of Freedom	Sum of Square	Mean of Square	Coefficient Variance	R^2	F - value	Pr>F
Sediment volume	4	13343.58	3335.90	1.54	0.99	130816.25	0.0001
Error	119	3.03457	0.02550	-	-	-	-

Foltz [17] resulted as similar and introduced the road grade more effective of road tread surfacing factor. For obtaining to the most effective factor the variables combination test performed and road grade factor were introduced as the most effective factor, finally that is showed in table 7.

Then, the most appropriate model for sediment volume factor calculated as below (Equation 3). Where Ln(y) is sediment volume; D, delivery factor; G, road grade or length slope of road.

$$Ln(y) = -0.171508 (D) + 0.000902 (D^2) + 4.042995 \ln (D) + 0.614011 (G) \quad (3)$$

Totally, with considering primary model of sediment prediction, it is mentionable that the produced sediment volume by roading component (Ts) is more effective than to slope factor of cut - slope (Cs) in produced sediment volume by a road. Also, Khalilpour, *et al.* [22] assessed roading factor more effective than to cut - slope with considering higher numerical value for this factor, without performing of analysis and with intervention whole of repeated factors. Results of this research showed that produced sediment by a road is affected by different erosion factors and theirs influence intensity are depended to considering existence standards in road establishment and its utilizing conditions. In this road, length slope and or road grade with delivery factor were the effective factors in sediment production due to road.

Pay attention to, estimated sediment production of this road (with small length) is very high. Therefore, pay attention to the standards of forest roads production (that is mentioned in publication of Iran programming and management organization with number 131, Sarikhani and Majnonian, [23]), the operators of forest road construction should be considered to the conditions of geology structure and pedology of regions. Also, planning of efficient and appropriate drainage grid can be effective in reduction of sediment volume. Furthermore, division of road to smaller lengths wasn't appropriate method and this factor doesn't show its predictable effects on total volume of sediment. Therefore, it is proposed that in future researches, the length of roads should be longer for achievement to real influence of this factor.

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