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The Assessment of Sediment Production Yield from Forest Road Using Sediment Prediction Model

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Abstract: Forest road construction is including high costs as if in operations of road construction the saving be inappropriate thus, it is following more damages. Therefore, this study was performed for estimate of annual sediment mean in a forest road network of forest watershed in southeast of Sari city (North of Iran) using a sediment prediction model with considering to the effective factors. In order to, different data includes: topography, roads and also, precipitation mean were recorded. Result of this research showed that the SEDMODEL model with GIS is appropriate compound for using by road construction managers for prediction of sediment total. This result of it can be used for expansion of road construction in future.

Key words: Forest roads, sediment, prediction model, GIS

INTRODUCTION

A forest road network, produce the conditions for easy available to forest, performing of cultural operations and also for recreation and outdoor recreation purposes (Demir and Hasdemir, 2005). Ordinary, designing of forest road network is depending to economy problems (Sarikhani and Majnonian, 2006; Demir, 2007). Road construction in forest is with high costs. Occasionally, saving in these costs is following the more problems as environmental degradation and endanger of regions ecology. Appropriate costs for road construction will prevent of production of these unwilling problems (Demir and Hasdemir, 2005).

Gardner (1997) mentioned the nature degradation and sediment production as the most important of environmental negative effects for forest roads. These effects are in depended to the characteristics of road cross section, excavation and earth filling slope, road superstructure and road clean cutting cross. Wemple and Jones (2003) introduced topography conditions, slope length, depth and soil properties as the effective factors in run off production of road surface in under domains.

Akay (2007) in his research mentioned designing of introductory routs is need to region DEM with high resolution for preparation of appropriate aspect and slope maps. Soil type, floodways distance, standards and technical principals of road construction, economic data and volume per hectare are the other of entrance data. Also, forest routs are effective on ecological, society, economic factors with considering to theirs structure type.

Swift (2003) investigated conditions of road and its erosion in northwest of Karolina. He surveyed the sediment conditions in road bed, open and covered drain pipes and traffic on these roads. He mentioned that appropriate design of road is need to low maintain and repair and also the produced erosion by water flow on road bed be decreased. Therefore, the costs of construction, repair and maintain will decrease if produced erosion by water flow on road bed be decreased. The most of landslide density occurs in Marne of Kertaseh period and Marne lime stone and the most movement occurs in Jurassic clays, Marne and lime stone. Thus, correlations between landslide and topography conditions are representative hydrology regime of unstable slopes (Akay, 2007).

In during these years, the construction and management of forest roads are with considering to forest conservation problems because of without attention to these natural ecosystems the valuable collections will endanger (Egan *et al*., 1985; Gardner, 1997; Ochterski, 2004). This study is with purpose assessment of sediment production yield from a forest road using sediment prediction model and results of it can be used for 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 ha areas. Estakhr Posht region is situated between 36°25' to 36°29' North latitude and 53°17' to 53°31' East longitude with 3141 m length of

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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 m and continues till about 1000 m. 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 were from 1300 mm at the Sari city metrological station, which is 10 km far from the study area (Anonymous, 2003). This research was performed in the summer of 2007.

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 (Eq. 1) (Luce and Black, 1999; Zezere, 1999).

$$\text{Total sediment (ton/year)} = (Ts+Cs) \times A_f \quad (1)$$

Where:
TS = Tread sediment
CS = Cut-slope sediment
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):

$$TS = Lr \times Wr \times GEr \times S_f \times T_f \times G_f \times P_f \times D_f \quad (2)$$

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):

$$CS = GEr \times CS_f \times CSh \times Lr \times D_f \quad (3)$$

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 vegetations. According to the empirical observation, sediment yield is affected by time following construction (Boise Cascade Corporation, 1999). 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 (Luce and Black, 1999).

Geological erosion rate: The sediment yield potential from a specific road segment highly depends on sub-soil properties and geology (Ketcheson and Megahan, 1996; Boise Cascade Corporation, 1999). For example the silt- dominated soils are the most erodible soils, followed by clay-dominated and gravel dominated soils (Ebne Jalal and Shafayee Bejestan, 2000; Steinmuller, 2003). After determining the geologic information of lithology and geologic age, the geological erosion rates for common parent materials obtained from Table 1 (Reid and Dunne, 1984; Burroughs *et al.*, 1992; Zezere, 1999; Akay, 2007).

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 Fig. 1 (Foltz, 1999).

Traffic factor: The sediment yield from a road tread surface is also affected by road use, as well as road

Table 1: Geologic erosion rates based on lithology and geologic age (in ton/ha/year)

	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

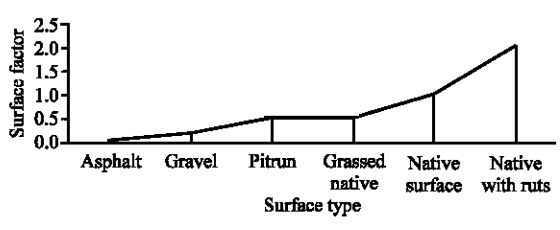

Fig. 1: Numeric value for tread surfacing factor

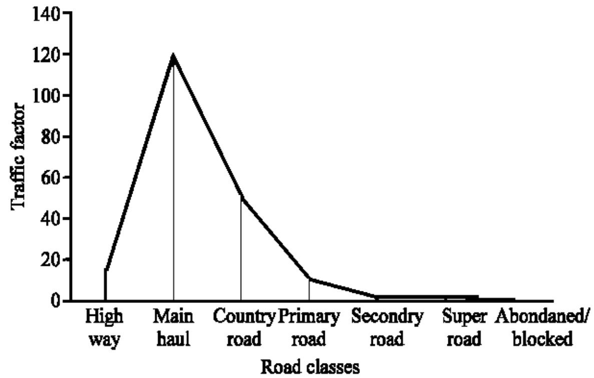

Fig. 2: Numeric value for traffic factor

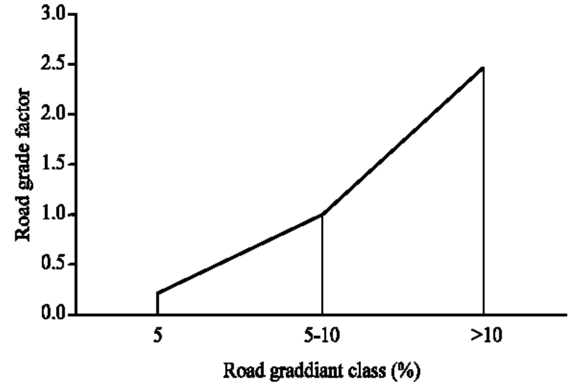

Fig. 3: Numeric value for road grade factor

surface material (Burroughs *et al*., 1992). The effect of road use on sediment yield is represented by traffic factor (Zezere, 1999). Reid and Dunne (1984) 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 (Luce and Block, 1999). Traffic factors for various road classes are indicated in Fig. 2 (Reid and Dunne, 1984; Foltz, 1999).

Road grade factor: A road grade factor was assigned to each road segment based on the road gradient classes. Luce and Black (1999) and Reinig *et al*. (2002) suggested road grade factor for various road classes fallowing in Fig. 3 (Ochterski, 2004).

Precipitation factor: The amount of sediment yield potential from a road segment can vary with annual regional precipitation. According exceeding the average annual precipitation of 1200 mm can increase the effects of erosion factors on sediment yield estimation about two times (Gardner, 1997). 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) (Reid and Dunne, 1984).

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

Delivery factor: Delivery factor is distance between nearest stream until a part of road (Gardner, 1997). 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

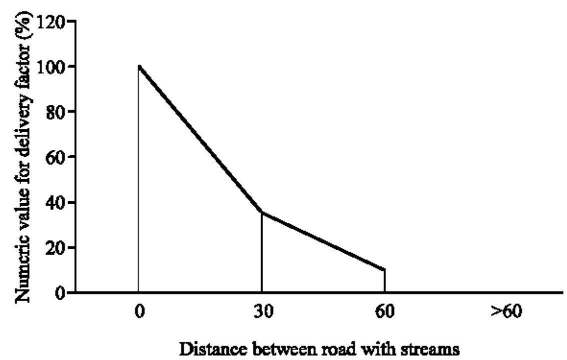

Fig. 4: Numeric value for delivery factor

and cannot reach the streams (Grace, 2002). 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 (Gardner, 1997).

The road segments that were located further than 60 m 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 road classes fallowing in Fig. 4.

Cut-slope cover factor: The cut-slope cover factor can be defined as the percent of non-erodible cover on road tread, cut-slope and fill slope areas (Luce and Black, 1999). Cut-slope cover factor for various road classes fallowing in Table 2.

Cut-slope height: Increasing the cut-slope height increases the amount of sediment yield from cut-slope

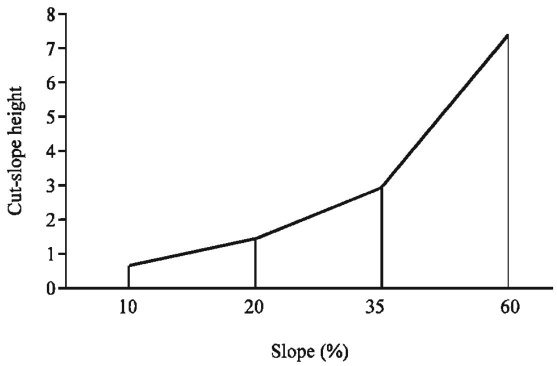

Fig. 5: Numeric value for cut-slope height

Table 2: 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	0.77
0	1.00

area to ditch area through soil creep, sheet wash and slumping (Boise Cascade Corporation, 1999). 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 (Gardner, 1997). Four gradient classes were specified during the field measurements and cut-slope height was assigned, that fallowing in Fig. 5 (Luce and Black, 1999).

Research method: In this research, roads were divided in short distances. Length and cross slopes of roads and also, excavation and cut slopes and fill slopes were measured in every distance. Distances of these segments were calculated with nearest of natural stream using Arc View GIS software's. This process was performed in 154 segments of aforementioned road.

RESULTS

Map layers designed for roads and hydrology network with 1:25000 scale using Arc View software. Digital elevation model, slope, aspect and road maps showed in Fig. 6-9.

Geology: Results of this research showed that geology and lithology periods in study areas are Mesozoic

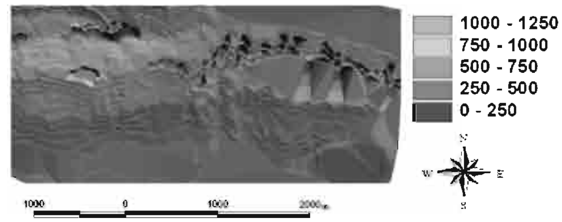

Fig. 6: Digital elevation model map

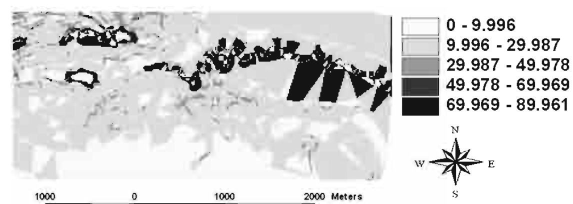

Fig. 7: Slope map

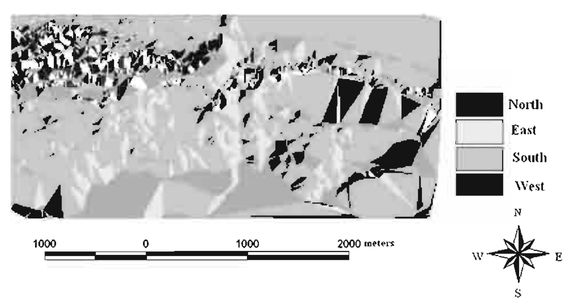

Fig. 8: Aspect map

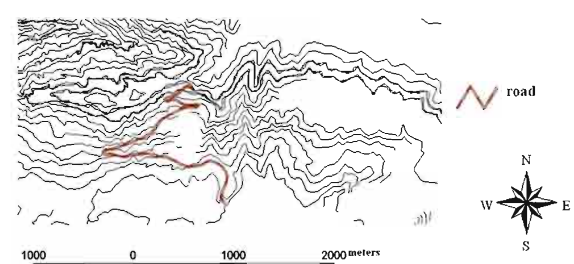

Fig. 9: Map of existence road

Andesite and Basalt, respectively. Numeric value from this factor is 74 for aforementioned roads that are resulted of Table 1.

Road surfacing: Upper surface factor was asphalt cover that is equal to 0.03; therefore, this factor isn't important for production of sediment.

Traffic: This factor estimated 120 traffic.

Table 3: Obtained results of delivery factor

No. of segments	Roads No. that are cutting the stream	The distance maximum is 30 m	The distance maximum is 60 m	Without delivery factor
154	90	74	30	-

Road grade: Road length slope (%) was recorded in every 154 distances. Results showed that number 25 segments of 154 segments had 5% length slope with numeric value 0.25. Number of 107 segments had 7.5% length slope with numeric value of 1. Also, number of 22 segments of all had length slope of 13 to 14% with numeric value 2.5.

Precipitation factor: This factor calculated 0.88 using Eq. 4 (with replace of 1300 mm for annual precipitation mean in this equation).

Delivery factor: This factor is calculated using GPS and Arc view software by helping two buffers with 30 and 60 m crosses, the distances between road segments with stream network of area was calculated that showed in Table 3.

Cutting slope cover: Plant covering (%) of slope surfaces in excavation and cut slopes and fill slopes was estimated for road segments as plant covering in 78, 32, 16, 10 and 18 segments were 60, 70, 40, 30% and coverless, respectively.

Cut-slope height: Slope map and slope classes were designed using DEM map with 1: 25000 scale. It was basis of cutting slope height. Cut slope was measured in every segments using Arc view software and afterwards 35% slope that numeric value of its cut slope height was 3 m. Number of 24 segments had 65% slope that its cut slope height was 7.5. Number of 12 segments had 25% slopes with cut slope height of 1.5 m and 4 slopes had slopes less than 10% with cut slope height 0.75.

Road age: Road age of aforementioned road is 30 years that 2 should be incorporated in model correlation.

DISCUSSION

In this research 154 segments of an asphalt road were investigated. Map layers were designed for roads and hydrology network with 1: 25000 scale using Arc view software. With using of sediment prediction model, the portable sediment loading were calculated about 3264919.3 ton/year for this road. Using of 1: 25000 geology maps, the topography of study area was determined at first, afterwards, it used for estimation rate of geology erosion (ton/ha/year). Result of this research showed that the geology and lithology periods in all of road segments were similar including Mesozoic Andesite and bedrock of silt Marne, respectively.

They are very important for road segments as one of the most effective factors in sediment production according to the results of Table 1. Road surface factor was asphalt for all road segments thus; they haven't any effective role for production of sediment (Luce and Black, 1999). Totally, terrific factor is more effective than road surface. This result is according to Foltz and Burroughs (1990) research results. They mentioned that sediment yield in weak road surface is 4 to 7 equal more than road with appropriate road surface.

Also, theirs researches showed that in roads with high traffic of skidding, the volume of sediment yield is 2 to 25 equal more than roads with low traffic and or lower loading weight. Luce and Black (1999) resulted that the increase of road length slope is due to increase of sediment yield volume. Therefore, this is according to obtained results in this research. Akay and Sessions (2005) investigated the mean of sediment yield volume due to road with optimistic economical opinion for two different road surfaces. Theirs research showed that sediment yield volume of a road with high quality of road surface and length slope more than 10% is more than produced sediment due to a road with low quality of road surface and length slope less than 10%. Therefore, this subject confirmed that the effect of road slope is more than road tread surfacing factor. Thus, the result of Fultz research (1999) is according to results of this research. Every 154 segments of road, situated in distance less than 60 m relation to the nearest stream network.

Also, Luce and Black (1999) mentioned that the plant covers factor in surfaces with slope in excavation and cut slopes and fill slopes, have attention able negative effect is produced sediments by road. Slope map and slope class were determined using DEM map with scale of 1: 25000 and it was base of cutting slope height. Luce and Black (1999) mentioned that the increase of cutting slope height in the first two years of road establishment can be one important source for production of sediment.

Therefore, in this research the factor of cutting slope height (that 24 segments of all recorded segments have height more than 7.5 m) has important role in increase of sediment volume due to one road. Thus, try to reduction of cut slope height in excavation and cut slopes and fill slopes and or avoidance of routs with inappropriate slope is impossible. Results of this research showed that transferred sediments volume by road (TS) is more effective than cutting slope factor (CS) in produced sediment yield volume by road. Theirs effective on road is relation to road type and grade and use type and traffic in this road.

The most important ratio for sediment yield volume is including use type of road, road length slope and cutting slope height. 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, 2006), the operators of forest road construction should be considered to the conditions of geology structure and pedology of regions.

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