# Modelling of forest road sediment in the northern forest of Iran (Lomir Watershed)

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**ABSTRACT**: Forest roads are the most important ways of access; nevertheless, they are the main source of sediment production. The delivered sediment by forest roads causes environmental problems and pollution of water resources. This study has been done to present a model for estimating the sediment yield of forest road using a multiple regression analysis on the Caspian southern coasts (north of Iran, Lomir watershed). For this purpose, 45 wood dams were created and their sediment volume (dependent variable) was measured. The following independent variables were estimated: road length, road width, road slope, vegetation cover, height of cut slope and road age. Then, a regression analysis was done using SPSS software to present a linear model. In the next step, the accuracy and capability of the presented model were considered and validated using the model for estimating the wood dam sediment. The results showed that road length and road width have significant effects in sediment generation. Also, the presented model can estimate the forest road sediment in northern Iran.

**Keywords**: wood dams; SPSS; multiple regression; culvert

Developing and maintaining the economic activities that are vital for the quality of modern life would be difficult without roads. Roads provide access for people to study, enjoy or contemplate natural ecosystems. In fact, the development of human civilization has benefited from transportation systems that evolved from foot trails to complex highway systems (Grubler 1994). Forest roads are a vital part of forest management, a forest road network provides easy access to all regions of forest for transportation of products, personnel, regeneration and recreation activities (Demir, Hasdemir 2005). Due to the degrading impacts on water quality, soil erosion and sediment delivery to waterways are primarily major concerns in forest management. Sedimentation can negatively impact fish spawning and aquatic macroinvertebrate habitats in addition to transporting attached nutrient constituents directly to streams (Davies-Colley, Smith 2001). Transformation of forests into farmlands and roads resulted in an increase of runoff and sediment generation (Gholzom, Gholami 2012).

Construction and maintaining of roads have become controversial, however, because of public concerns about their short- and long-term effects on the environment and the value that society now places on roadless wilderness (Cole, Landres 1996). Previous studies indicated that forest roads produce the highest amount of sediment yield to streams (Reid, Dune 1984; Binkley, Brown 1993). Forest road construction removes the vegetation cover and damages the soil structure, which dramatically increases the sediment yield (Megahan 1974; Grace 2002; Gholami et al. 2010). The sediment delivered to streams from road sections leads to many influences on water quality (i.e. increased water temperature and reduced oxygen) and aquatic life (i.e. siltation of spawning beds and aquatic insect habitats).

Therefore, forest road managers should consider not only the total road cost but also environmental impacts (Akay et al. 2008).

Identification of specific areas that actively contribute sediment to the stream channel network is a necessary prerequisite for understanding the sediment delivery process and developing successful sediment management programs (Roehl 1962; Dietrich, Dunne 1978; Khanbilvardi, Rogowski 1984).

Several sediment prediction models have been developed for estimating average sediment from a forest road network to the streams. The Forest Road Sediment Assessment Methodology (FROSAM) model was developed as a practical approach for measuring the sediment yield from forest roads as well as measuring the capabilities of road improvement methods (Washington Forest Practices Board Manual 1997). In this model, the source areas for sediment yield include ditches, road surface, cut and fill slope. In the model, the erosion factors were traffic, vegetation cover, gravel and percent of sediment delivery. Road Sediment Delivery Model (SEDMODL) was used to estimate the average annual sediment yield from a road network to streams in a forest watershed. The formulas used in the model are based on empirical relationships between road erosion factors such as road use, parent material, road surfacing, surface slope, vegetation cover on cut slope or fill slope and distance from streams (Megahan et al. 1986; Bilby et al. 1989; WDNR 1995).

The Water Erosion Prediction Project (WEPP) model was developed to estimate sediment yield, considering the specific conditions for soil, climate, vegetation cover, road surface, ditch, and topography (Elliot et al. 1999). The WEPP, a road interface model, assumes expressing the sediment production from three overland flow factors including road surface, fill slope, and a forested buffer area. Sediment yield is estimated based on road gradient, road width, road type, road design, and traffic density. The X-DRAIN (Cross Drain Spacing and Sediment yield Program) model was developed as a stand-alone and network interface to access the sediment yield data generated by the WEPP model for more than 130,000 combinations of topography, soil types, and climates (Elliot et al. 1999). The user controls erosion factors such as slope, climate, soil and stream distance. The present research has been conducted to investigate the effective factors on forest road sediment and to present a model for estimating forest road sediment in the northern forest of Iran (Lomir watershed).

## MATERIAL AND METHODS

The study area is located in northern Iran, southern Caspian coasts and Alborz highlands in Guilan province, Lomir watershed (Fig. 1). The Lomir watershed

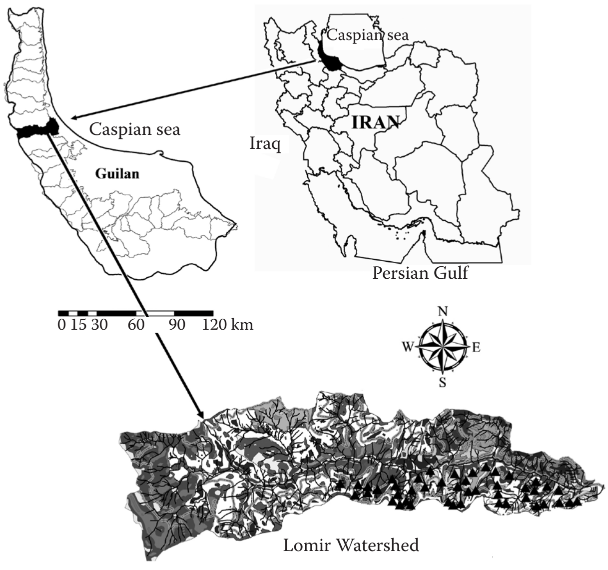


Fig. 1. Location of the study area in Iran

is located between 48°54' to 49°21' north latitude and 37°35' to 37°33' east longitude. The mean annual precipitation is 1,440 mm. This research was conducted on the roads of approximately 28,000 m in length in the Lomir watershed. At first, in order to create a homogeneous unit map (based on traffic, geology, road pavement and rainfall value), some digital maps were applied such as: topographic and geology maps and isohyet counter. In this study the effective factors on volume road sediment generation (such as road length, road width, road slope, road age, height of cut slope and vegetation cover) were measured with field studies and GIS capabilities (Table 1).

A wood dam was used for estimating the sediment volume from forest roads. Figure 2 shows a sample of wood dams. 45 sediment wood dams were created to gather sediment and to present a model. The location of the wood dams was selected based on field studies and GIS analysis. We selected such a wood dam location in order to investigate the effects of slope, aspect, vegetation cover and so on. We established 45 wood dams at suitable places and estimated the volume of the wood dam reservoir (difference in volume before and after annual sedimentation). Finally, the volume of forest road sediment was estimated by field measuring the wood dam sediment volume. The sediment at forest road is estimated by overall road sediment and entrapped sediment in the wood dam sediment. The volume of the wood dam reservoir and their sediment were estimated by surveying before and after sedimentation.

A multiple regression method was applied to present a linear model, using SPSS software. The volume of sediment was selected as a dependent variable.

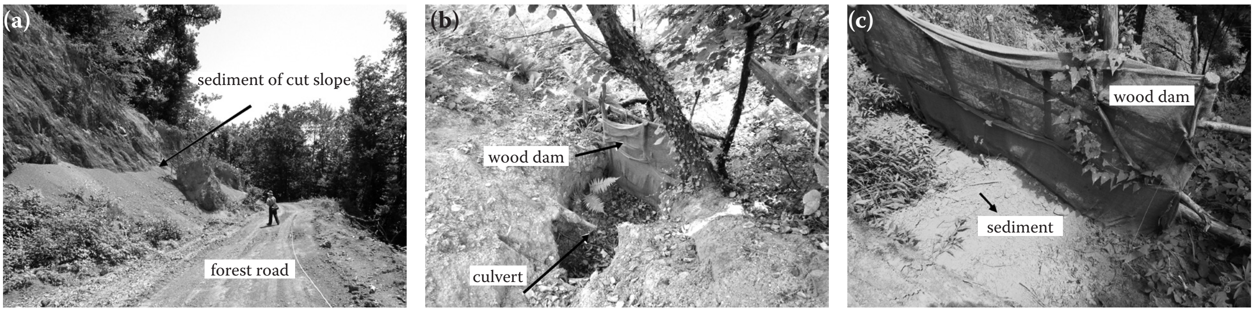


Fig. 2. A view of wood dam catchment, forest road, cut slope and its sediment (a), and a sample of wood dam (b and c). The sediment of cut slope and the sediment of wood dam were estimated. Then both of them will add up to the total sediment of a forest road

Table 1. The samples of data for statistical modelling in SPSS

| Mean sediment volume ($m^3$) | Road | | | Height of cut slope (m) | Vegetation cover (%) | Road age (yr) |
|---|---|---|---|---|---|---|
| | length (m) | width (m) | slope (%) | | | |
| 1.198 | 55 | 4.5 | 3 | 3.5 | 65 | 3 |
| 2.41 | 62 | 5 | 1 | 4.5 | 60 | 3 |
| 1.34 | 71 | 5 | 3 | 3 | 60 | 3 |
| 2.85 | 52 | 5.5 | 10 | 5 | 60 | 3 |
| 1.75 | 73 | 5 | 7 | 4.5 | 63 | 4 |
| 2.9 | 69 | 5 | 10 | 5 | 68 | 4 |
| 0.995 | 43 | 5.5 | 3 | 3 | 72 | 4 |
| 0.9 | 52 | 5.4 | 3 | 3 | 90 | 4 |
| 1.01 | 70 | 5 | 4 | 3 | 80 | 6 |
| 1.24 | 40 | 5 | 5 | 3 | 81 | 6 |
| 1.21 | 35 | 5 | 5 | 3.5 | 70 | 6 |
| 1.95 | 42 | 5 | 6 | 4 | 70 | 6 |
| 3.91 | 73 | 6 | 12 | 5 | 80 | 8 |
| 1.4 | 71 | 5 | 6 | 4 | 82 | 8 |
| 2.1 | 60 | 5.5 | 9 | 4 | 85 | 8 |
| 2 | 55 | 5.5 | 8 | 5 | 85 | 8 |
| 0.662 | 45 | 4.5 | 2 | 2 | 85 | 9 |
| 0.989 | 57 | 5 | 3 | 3.5 | 86 | 9 |
| 1.1 | 58 | 5 | 4 | 3.5 | 88 | 9 |
| 1.45 | 47 | 5 | 5 | 4 | 90 | 9 |
| 1.02 | 65 | 5 | 4 | 3 | 92 | 9 |
| 0.72 | 63 | 4.5 | 0 | 2.5 | 95 | 9 |
| 1.156 | 56 | 5 | 4 | 4 | 70 | 4 |
| 2.98 | 65 | 6 | 10 | 4.5 | 78 | 4 |
| 2.02 | 60 | 5.5 | 9 | 4 | 60 | 4 |
| 2.99 | 61 | 6 | 10 | 4.5 | 60 | 4 |
| 1.03 | 59.5 | 6 | 5 | 3.5 | 80 | 8 |
| 0.98 | 55 | 6 | 4 | 3 | 93 | 8 |
| 2.172 | 65 | 5 | 9 | 4 | 85 | 8 |
| 1.78 | 35.5 | 4.3 | 8 | 4 | 91 | 8 |

Road length, road width, road slope, vegetation cover, height of cut slope and road age were studied as independent variables. 30 wood dam data or samples were used to present the model and 15 samples were used to validate the model efficiency. Regression analysis was done to create a linear model to estimate the volume of forest road sediment. In the next step, the efficiency of the presented linear model for estimation of sediment volume was investigated. In this stage, the presented model was applied for estimating the sediment volume of the wood dams (15 wood dams) that were not used for presenting the model. Model efficiency was validated and statistical analysis defined the most important factors for sediment generating.

## RESULTS

A homogeneous unit map of the study area was generated using GIS and overlay analysis capability, and the locations of sediment wood dams were marked in this map. The generated homogeneous unit map and location of wood dams are shown in Fig. 3.

A multiple regression method was used to present a model for simulating the sediment volume. Correlations between the sediment generation factors and sediment volume are documented in Table 2. The presented linear model (Table 3) was equivalent to $R^2 = 0.8$ and was significant. Regression analysis presenting a linear model to simulate the forest road sediment volume and the model is given below (Equation 1):

$$V_S = 0.535H_c + 0.115S - 1.001 \qquad (1)$$

where:

$V_S$ – road sediment volume ($m^3$),

$H_c$ – height of cut slope (m),

$S$ – slope of the road (%).

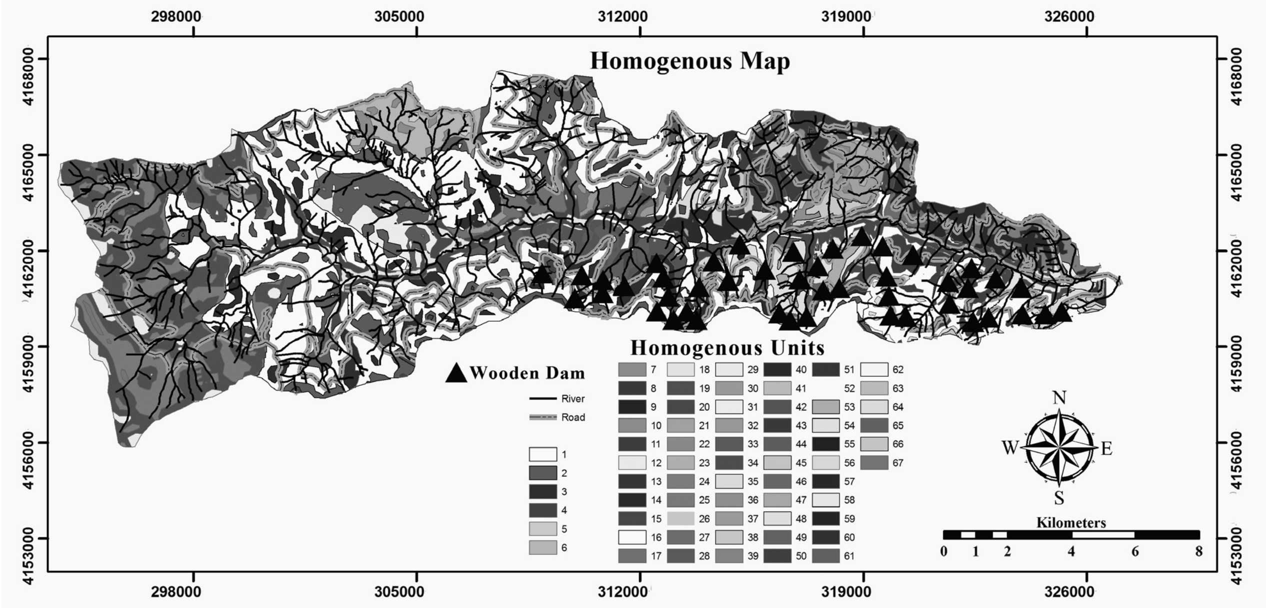


Fig. 3. The location of sediment wood dams in the study area and the homogeneous unit map of the study area. The map is generated to overlaying geology map, aspect map, slope map and the location of wood dams in Geographic Information System (GIS)

The model was used to estimate the sediment volume for model validation (in 15 wood dams). The evaluated results of the model efficiency are shown in Fig. 4. A comparison of the values estimated by the model and the values recorded in field studies confirmed the linear model efficiency for simulating the sediment volume in the forest road of Lomir watershed.

## DISCUSSION AND CONCLUSIONS

The effective factors in forest road sediment production are vegetation cover, slope, geology, traffic, annual rainfall, road length, road width, height of cut slope and road age (Meghan 1974; Casermeiro et al. 2004; Sheridan, Noske 2007; Akay et al. 2008). In this study, the results showed that the road length and width had significant effects

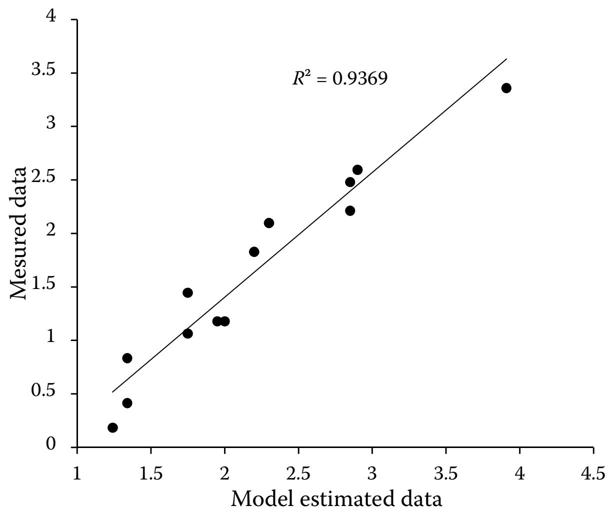


Fig. 4. Comparison of the estimated sediment using the presented linear model with actual sediment (the data for wood dams was not used for presenting the linear model)

Table 2. Correlation between sediment volume and its effective factors ($n$ = 35)

| | Road length (m) | Road width (m) | Road slope (%) | Cover (%) | Age (yr) | Height of cut slope (m) |
|---|---|---|---|---|---|---|
| Sediment volume | 0.318 | 0.458 | 0.832 | –0.409 | –0.299 | 0.850 |

Table 3. The results of multiple regression analysis (linear model, $R^2$ = 0.8)

| | | Sum of squares | df | Mean square | $F$ | $P$ |
|---|---|---|---|---|---|---|
| Model | regression | 15.487 | 2 | 7.743 | 54.726 | $0.000^b$ |
| | residual | 3.820 | 27 | 0.141 | | |
| | total | 19.307 | 29 | | | |

on the sediment volume. The amount of produced sediment from forest roads highly depends on road dimensions (Reid, Dunne 1984; Akay et al. 2008; Fu et al. 2009).

The results of correlation analysis (Pearson's test) of sediment volume and sediment production factors showed that there was a significant and positive correlation between sediment volume and road slope. The increasing slope causes an increase in runoff velocity and erosion. The results also showed that there was a negative correlation between sediment volume and road age (Table 2). This may be related to the revegetation of different parts of forest road at the time of construction (Baharuddin et al. 1995; Cerda 2007). Vegetation cover is an important factor, playing a key role in sediment absorption, decrease of runoff velocity and volume, and protection of soil against erosion and sedimentation (Casermeiro et al. 2004; Foltz et al. 2009; Gholami, Khaleghi 2013). Our results showed the negative relationship between sediment and vegetation cover. We presented a regional model by statistical analysis (Eq. 1). The liner model validation proved the efficiency of the presented model in estimating the forest road sediment. So, we can apply the model to other roads in the northern forest areas of Iran. Runoff control practices such as rehabilitation and reduction of trails and forest roads after the 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; Gholami et al. 2009).

The statistical analysis showed that an increase in the road area can lead to an increase in runoff and sediment. Thus, for reducing the sediment volume in forest roads, it is suggested to minimize the road surface by selecting an optimum track. However, in seasons with intense rainfall events, a considerable amount of sediment yield might occur, especially in the road sections with low quality surfacing. In order to prevent an excessive sediment yield due to intense rainfall, the surfacing quality of the roads should be improved.

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