J. Appl. Environ. Biol. Sci., 2(11)567-580, 2012

ISSN 2090-4274
Journal of Applied Environmental and Biological Sciences
www.textroad.com

Evaluation of Sediment Erosion Prediction Models to Forest Road in Mountain Area

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ABSTRACT

Erosion from forest roads is a known problem in mountainous area. Erosion from unpaved forest roads and trails can be a significant contributor of sediment within a forest watershed. Unpaved roads are a large and chronic source of sediment in forested watersheds, and accurate predictions of road sediment production are needed to guide road treatments and assess cumulative watershed effects. A variety of erosion and sediment prediction models which emphasize specific landscape and hydrological parameters have been applied to unpaved roads across a wide range of locations. However, little work has been devoted to the comparison of these models or to their application in mountain area. Three road erosion prediction models were compared for applicability in the mountain area based on their spatial scales, data requirements, assumptions, applicability to forest watershed and ease of use. This study was performed for prediction of annual sediment mean in a forest road network in the Anbardağ Forest District (Giresun Forest Enterprise) in the Eastern Black Sea Region of Turkey, and it is used as a case study area for comparison of the WEPP:Road, SEDMODL, and STJ-EROS models. Field observations in the forest watershed provided data for the input parameters of the models for individual road segments, and predictions of sediment generated from each segment were compared among models. The results presented here can improve current models for predicting road sediment production and guide future research.
KEYWORDS: Forest Road; Erosion; Prediction Modeling; Sediment; Mountain area.

1. INTRODUCTION

Forest roads are at the core of modern forestry, providing quick, economical access to the mountain areas. To facilitate forest operations in areas managed for timber production, a well developed network of roads must exist.

A road network in forest lands provides easy access to forest resources for extraction, regeneration, protection, and recreation activities [1]. Traditionally, the planning of low-volume road networks highly depends on economical and social considerations [2].

It is recognized that there is a general lack of understanding of erosive processes from unpaved roads and trails and the corresponding impact within a watershed [3,4,5,6,7,8]. The design of a road surface has important implications for its potential for erosion. Roads can be constructed as insloping, or outsloping, crowned, [9]. Insloped roads deliver runoff to the ditch while outsloped roads deliver runoff to the fillslope, usually via a diffuse pathway. Ditches are usually absent on low traffic, outsloped roads. Crowned roads deliver part of their runoff to a ditch and part to a fillslope. Cutslopes are the slope of a cutting, while a fillslope is the slope of a fill.

Sediment can be eroded from all road features. On unpaved roads, road surface erosion is generally the dominant source of sediment [7,10]. The factors affecting surface erosion from roads include rainfall intensity and duration, snowfall, the characteristics of surface materials, road slope, traffic, construction and maintenance, and the contributing road area [11,12].

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Sediment from forest roads can be generated by: surface erosion on the road surface, fill slopes, ditches, and cut slopes; mass movements induced by roads; and gullies created by road runoff [13,14]. Sediment from forest roads is a concern due to its potential delivery to stream systems which can result in degraded water quality [15,16]. Forest roads have been shown to be a primary sediment source and cause of increased sediment yields in a wide range of forested areas [17,18]. The disruption of geomorphologic and hydrologic processes by roads increases both surface erosion and the frequency of mass wasting [19,20,21,22]. These increases are of particular concern in forested areas because natural erosion rates tend to be very low. Surface erosion from unpaved road surfaces has been shown to be an important sediment source in Australia [23], New Zealand [24,25], Malaysia [26], the United States [27,28)], Poland [29,30], Ghana [31] and Kenya [32].

A relatively small proportion of the road length in forested watersheds is typically responsible for the road-related increase in sediment loads [14,27,33]. This indicates that the adverse effects of forest roads on water quality and aquatic resources can be most efficiently reduced by identifying which road segments are generating large amounts of sediment. Since most forest managers are unable to measure road sediment production, models must be used to prioritize rehabilitation treatments.

Research is needed to improve forest road management practices in mountain area. Once erosive road segments are prioritized, appropriate management practices must be identified and applied.

The models for predicting road sediment production can be grouped into three classes: (1) physically-based models, such as the Water Erosion Prediction Project (WEPP:Road) model [34]; (2) conceptual-empirical models, such as Sediment Model Version (SEDMODL) [35]; and (3) empirical models developed from local road erosion data [36,37,33,38,14].

The objectives of this study were:1) To predict the amount of sediment produced from forest road segments, 2) To compare predicted sediment quantities using three models (WEPP:Road, SEDMODL and STJ-EROS models).

The overall goal of this research is to identify three models, for use in mountain area, which can provide an estimate of sediment contributions from forest roads in a forest watershed in the Anbardağ forest district city of Giresun, in the Black Sea region of Turkey.

2. MATERİALS AND METHODS

2.1.Study area

The study area was located at approximately 40^0 42' 47” N and 38^0 01' 49" E on the Anbardağ forest management city of Giresun, in the Black Sea region of Turkey. The research forest is about 458 ha in which 374.5 ha is forest land and 83.5 ha is open area (non forest area). The dominant tree species in the forest are *Picea orientalis*, *Fagus orientalis*, and *Carpinus betulus*. The average ground elevation and side-slope were 1750 m and 69%, respectively. Mean annual precipitation were from 1300mm at the Giresun city metrological station, which is 25 km far from the study area.

In the Anbardağ forest, there are village roads and forest roads, with the lengths of approximately 89km. and 136km., respectively. A total of 32 road segments were identified and total of 3763m forest road segment length. The stream network in the research forest consists of two types of streams including medium width and small width types.

2.2.Model descriptions

The road network in the forest watershed was divided into segments having uniform characteristics defined by a unique set of properties pertinent to erosion and sediment delivery to stream (road design, flow length, surface condition, etc.) These properties define the inputs of the erosion prediction models used to estimate sediment yield.

2.2.1.WEPP:Road model

WEPP:Road consists of three overland flow elements :the road surface, the fillslope, and the forested buffer. The WEPP:Road interface was designed to calculate sediment production from the entire road prism as well as the mass of sediment transported through a forested buffer.

Users only need to parameterize 13 variables, including the identification of a climate station, soil texture class and soil rock content, basic road characteristics, and buffer length and gradient. The erosion potential of a given soil depends more on the vegetation cover than on the soil texture. Therefore, only four soil textures (sand, silt, clay, and loam) are listed for WEPP:Road [9]. There are four road designs options on the WEPP:Road model, (1) Insloped, bare ditch, (2) Insloped, vegetated or rocked ditch, (3) Outsloped, unrutted, (4) Outsloped, rutted.

The road surface can be native, graveled, or paved. A graveled surface increases the soil rock content and the hydraulic conductivity of the soil [9]. The reduction in rain splash and overland flow erosion associated with graveling can reduce sediment production by up to an order of magnitude [33]. A paved surface reduces the sediment production from the road surface, but increases the amount of runoff [9].

The three traffic classes are high, low, or none. The low traffic class applies to roads with light administrative or recreational traffic, while roads with restricted access and vegetation covering more than 50% of the surface are classified as having no traffic [9].

2.2.2.SEDMODL model

SEDMODL calculates sediment yield from the road surface and cut-slope. Total sediment is the sum of these yields multiplied by a road age factor. To calculate total sediment produced from each landscape element, three linear equations are used. The following equation is used to predict total sediment production in t/yr:

$$TotalSediment=(TS+CS)A_F \quad (1)$$

where TS is tread sediment (t/yr), CS is cut-slope sediment (t/yr), and Af is road age factor. Age factor is assigned a score of 10 if the road was created or graded within the year and assigned a score of 2 for two years or more. The tread sediment is calculated based on the equation:

$$TS=L_r W_r GE_r S_f T_f G_f P_f D_f, \quad (2)$$

Where L_r is road length (m), W_r is road width (m), GE_r is geologic erosion rate (t/ha/yr), S_f is road tread surfacing factor, T_f is traffic factor, G_f is road grade factor, P_f is precipitation factor, and D_f is sediment delivery ratio. The cut-slope sediment is calculated with the equation:

$$CS=GE_r CS_f CS_h L_r D_f, \quad (3)$$

where CS_f is cut-slope factor and CS_h is cut-slope height.

According to SEDMODL, tread sediment is based upon road dimensions, geologic erosion rate, road surface, traffic intensity, slope, precipitation, and sediment delivery. The only inputs associated with units are length (m), width (m), and the geologic erosion rate (t/ha/yr) as provided in a table in the work of [3]. Erosion rate depends on the lithology and geologic age of the sediment. The remaining inputs are assigned factors based on tables provided by the SEDMODL methodology [3,35]. Road gradient is assigned a factor based on three categories: less than 5%, 5-10%, and greater than 10%. Road surface options include asphalt, gravel, grassed native, native surface, and native with ruts. Traffic intensity is divided into seven categories: highway, main haul, county road, primary road, secondary road, spur road, and abandoned [35].

The amount of sediment yield potential from a road segment can vary with annual regional precipitation. According to WFPB [39] exceeding the average annual precipitation of 1200mm can increase the effects of erosion factors on sediment yield estimation about two times. In the methodology of SEDMODL, the precipitation factor was computed based on the average annual precipitation (Pavr in mm) in the basin [40]:

$$P_f=(P_{avr} /1524)^{0.8} \quad (4)$$

The average annual precipitation can be estimated by using an interpolation method based on a meteorology station with known elevation and average precipitation. In this study, following formula was used to estimate the average annual precipitation in the research forest [41]:

$$P_h=P_0 +(54h/100) \quad (5)$$

where Ph is the estimated average annual precipitation at a study site (mm), P_0 the annual precipitation at the nearest meteorology station (mm), h the elevation difference between meteorology station and study site (m), 54 the increase in annual precipitation for every 100m increment in elevation.

Cut-slope sediment depends on road length, cut-slope cover and height, erosion rate, and sediment delivery. The cut-slope cover is defined by the percentage of vegetation covering the

slope area; percentages range from 0-100% with a factor for each [3,35]. Cut-slope height is grouped into four categories based on slope: 0-15%, 15-30%, 30-60%, and greater than 60%.

A factor for sediment delivery was multiplied to both the tread and cut-slope sediment predictions. The model suggests assigning a factor of 1 if the road is less than 30 m from a stream, a range of 0.35-0.1 if the road is 30-60 m away from the stream, and 0 if the road is greater than 60 m from the [3,35].The distances of the road to the stream were used from the input of fill-slope and forest buffer length in WEPP: Road.

As noted during field observations, water channelizes during rain events; this results in higher velocities and farther traveling distances. In order to compare road segments in terms of sediment production, a factor of 0.05 was assigned to the roads greater than 60 m from a stream.

2.2.3. STJ-EROS model

The St John sediment budget model (STJ-EROS) is a GIS-based, catchment-scale model based on empirical data and application of a sediment delivery ratio [7]. The empirical models for estimating road surface erosion developed by Ramos-Scharron and MacDonald [37] assumed that rainfall, road length, width and slope, and grading frequency can explain most of the variation of sediment yield from the road surface. Sediment yield from cutslopes are assumed uniform, and a uniform silt-size particle correction is applied.

The road algorithm for the STJ-EROS model includes equations for both graded and ungraded roads. The equations for graded (S_G) and ungraded (SU_G) roads are the following:

$$S_G=[-0.432+4.73*S^{1.25}*r]*L*W*(1.204) \quad (6)$$

$$SU_G=[0.432+1.88*S^{1.25}*r]*L*W*(1.136) \quad (7)$$

where S represents slope (deg), r represents annual rainfall (cm), L represents road length (m), and W represents road width (m). The rest of the coefficients are developed empirical parameters. The equations are applicable for slopes ranging from 1% to 21%.

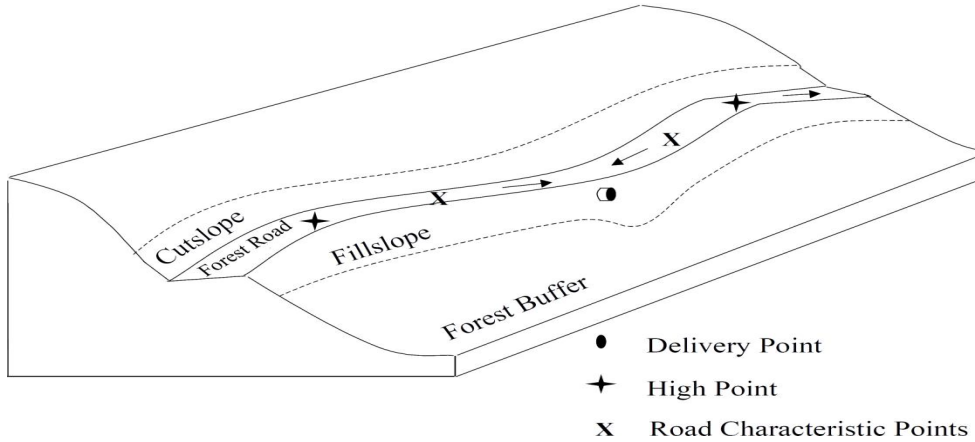
STJ-EROS assumes that 91% of the sediment yield from the road comes from these equations and the other 9% come from cut-slope [7].

2.3. Field data collection

2.3.1. Road characteristics

A site visit to the Anbardağ forest road in December 2010 provided the input data for the road erosion prediction models and identified the potential erodibility from each road segment. The following factors were defined for each segment: road length and width, road slope, surface cover condition, presence of rills or gullies, soil type and texture, percent cover and condition of cut- and fill-slopes, traffic intensity, and the distance from the road to the stream. A handheld GPS was used to track location, to mark key points such as changes in grade and drainage points, and to map elevation change along the road network (Figure.1).

Figure 1. Conceptual model of a road network



Each model predicts sediment production based on a single road segment. Therefore the road network must be divided into segments, with each segment uniform in terms of slope, road width, surface cover material and condition, traffic intensity, and road design. The network was first divided based on slope. A hand-held Garmin 60 CSx PS unit was used to collect road attribute data. After road segments were identified through breaks in the road profile of each track, they were input manually into GIS. By creating a polyline feature, each road segment was manually drawn into a shapefile based on the points chosen from the original track. To check the uniformity of road segment, pictures assigned to each GIS track were examined to determine visual changes in slope, surface cover condition, cut-slope condition, and distance to the stream. A total of 32 road segments were identified and total of 3763m forest road segment length.

Using the field notes and photos taken from December, attributes were assigned to each segment. The following attributes were characterized: surface description, traffic intensity, road design, distance to stream, cut-slope and fill-slope condition, ditch condition, drainage condition, road gradient and fillslope gradient, road length-width, coarse rock content and soil texture. Road surface description was based on the degree of compaction of the roadbed, the soil type amount of loose sediment, and the presence of rills or ruts.

Traffic intensity was determined based on personal observation over the course of the seven day field visit and conversations with the local inhabitants. Intensities ranged from high to very low; high representing the main travel way and very low representing trails used by one household. Distance to the stream was estimated by fill-slope and forest buffer lengths. The road design was determined to be crowned, outsloping, or insloping based on field observations and photos. The cut-slope and fill-slopes were noted for their corresponding slopes and percentage of vegetative cover. Road gradient and fillslope gradient were both manually measured with a clinometers. Widths and lengths were all taken using measurement 20m tape measure. Coarse rock content and soil texture were both performed on soil adjacent to the road grade itself. Coarse rock content was established using a 2 mm sieve by taking a ratio between total soil volume and rock volume greater than 2 mm diameter. Soil texture was evaluated using the hand-texturing procedure developed by Thein [42].

2.3.2. Climate

Average annual precipitation during the study was noted for the Giresun weather station, located 25 km north of the study site. The long-term average precipitation based on 30 years of record, for the Giresun, Turkey area is 1300 mm.

3. Statistical analyses

Model parameters were defined based on field observations. Each model was then run to prediction sediment yield for each road segment within the forest watershed. A paired Wilcox test was used to statistically test for significant segment differences among mean sediment yield predictions. Spearman's rank test is a nonparametric test for evaluating the relationship between two variables by calculating a correlation coefficient.

3. RESULTS AND DISCUSSION

3.1.Model selection

The models chosen for application were WEPP: Road, SEDMODL and STJ-EROS.

WEPP: Road was chosen because it was developed specifically to predict sediment from individual roads and is free and easy to access online. It requires little training or preparation and the input data is easy to acquire. WEPP: Road is a relatively well known model, having been applied to a variety of locations and even to road networks within the United States [43,44].

SEDMODL is a versatile model which can be adapted to most regions because it allows the user to input most site specific information. It only requires two equations and the data for the input parameters are relatively easy to obtain.

STJ-EROS was selected because it is one of the few models developed and applied in mountain conditions. The entire model requires many inputs; however, this allows it to present a comprehensive prediction of sediment production from various sources within a watershed.

Each model chosen for application to the Giresun (anbardağ forest road) can be incorporated with GIS and can output sediment loading on a forest watershed scale for the entire road network. Particularly valuable is the ability to evaluate the erosion potential of each road segment (Figure.2).

Figure 2. Examples of road segments classified in terms of sediment availability

3.2. Model analysis

3.2.1. WEPP:Road

Before running the WEPP:Road model, the climate parameters were adjusted using The Rocky Mountain Climate Generator (Rock: Clime) provided by the developers of the WEPP models, to fit the characteristics of Giresun, Turkey [9,45].To generate climate file with daily values of precipitation, temperature, solar radiation, and wind speed obtained from the weather stations, the WEPP model uses CLIGEN, which is a stochastic weather generation model [45]. For a specific location and length of time, the Rock: Clime application in FS WEPP is used to determine spatial climate variability in mountain regions [46]. To generate climate data, Rock: Clime can access database of PRISM (Parameter- elevation Regressions on Independent Slopes Model), which estimates precipitation and temperature based on orographic effects [47]. In Rock: Clime, the inputs of monthly average precipitation and temperature values can be adjusted [48]. Because meteorological database in Turkey is not generated in the data format of CLIGEN model, climate parameters for the study area were obtained from the weather station in the city of Giresun and transformed into the format used in CLIGEN. The climate parameters include maximum and minimum air temperature, relative humidity, precipitation, solar radiation, and wind speed. These amounts were compared to the average annual precipitation generated stochastically for the WEPP:Road runs.

The model was set to run the data for a one year period. The soil texture determined was clay loam. The rest of the input parameters include: road design, road surface type, traffic level, road gradient, road length, road width, fill gradient, fill length, buffer gradient, buffer length, and percent rock fragment. Table 1 summarizes the simulation input values of road attributes to the WEPP:Road model.

Table 1. Summary of the road attributes

Attribute	Forest Roads
Total Surveyed Road Length (m)	3763
Total Number of Road Segments	32
Avg. Road Length (m)	121.4
Avg. Road Slope (%)	5
Avg. Road Width (m)	4.5
Avg. Buffer Length (m)	0.3
Avg. Buffer Slope (%)	0.1
Avg. Fill Length (m)	34.5
Avg. Fill Slope (%)	3.1

The road attributes that had the greatest variation on the 32 road segment in the experiment were road slope and road segment length. These two factors can greatly influence soil erosion

from forest roads [49,50]. Grace [49] reported that road section length is a primary factor determining the distance sediment moves downslope in a survey of 235 forest road sections throughout the National Forests of Alabama and Georgia.

As a result, the insloping segments were reclassified as "outsloped rutted." A total of 20 road segments were classified as "outsloped rutted" and 12 segments classified as "outsloped unrutted."

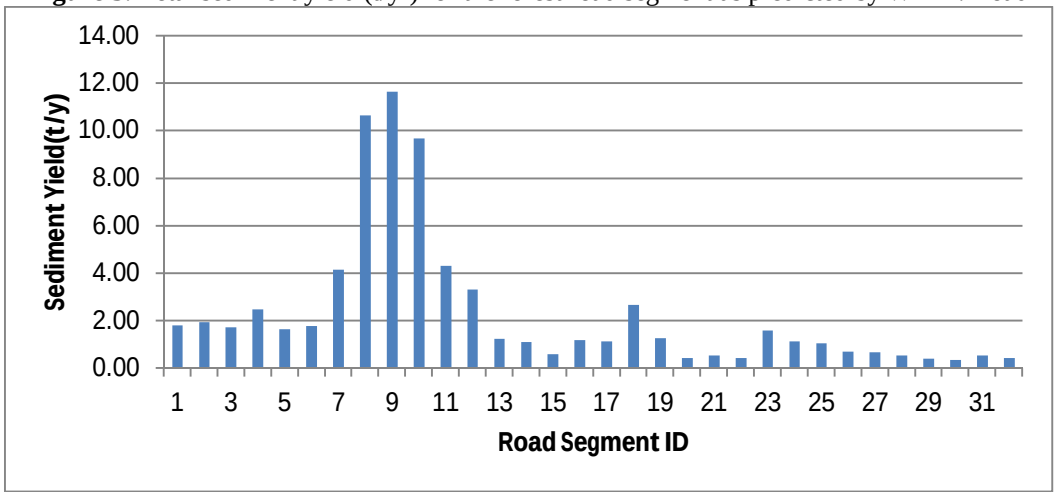
All road segments were considered to have a native road surface; other options included gravel or paved. All roads are assumed to have no surface vegetation [9]. WEPP: Road characterizes traffic intensity based on data from forested logging roads. A total of 12 segments were considered high traffic roads, 20 roads were considered to carry low traffic levels. Traffic is a categorical variable in WEPP:Road because traffic increases the supply of easily erodible sediment[27,52,53,33], reduces vegetative cover [54] and promotes the formation of ruts that concentrate flow [55].

WEPP:Road makes assumptions regarding the condition of the fill-slope and buffer between the road and the stream. Fill and buffer slopes were not directly measured in the field. Values were estimated based on field notes and photographs. WEPP: Road accepts fill slopes ranging from 0.1 to 150% and buffer slopes ranging from 0.1 to 100% [9]. For relatively flat areas near the stream or at stream crossings, values of 0.5% were used for the fill or buffer slope. The model accepts fill lengths from 0.3 to 100 m and buffer lengths from 0.3 to 300 m. Fill length was determined based on visual and photographic observations of the distance from the road to the stream. A value of 0.5 m for the fill length was entered at stream crossings. Buffer conditions were generally not present on the majority of roads; however in the forested areas of the watershed, appropriate buffer lengths and slopes were included as inputs. In cases where a buffer was not present, a length of 0.3 and a slope of 0.1 were used (the model does not accept values of 0 for these inputs). The majority of road segments had a negligible percentage of rock fragments.

WEPP:Road allows the user to input more than one road segment. Microsoft Excel was used to organize the input parameters for use by WEPP: Road. Outputs include, average annual sediment leaving the road (kg), for each segment. The model provided output for one year and was converted to tons/year.

A summary of sediment yield prediction from each road segment is shown Figure 3. WEPP:Road predicted segment 9 to have the highest sediment yield at 11.67 t/yr. The segment with the lowest estimated sediment yield was segment 30 at 0.36 t/yr.

Figure 3. Total sediment yield (t/yr) for the forest road segment as predicted by WEPP: Road



3.2.2. SEDMODL

SEDMODL utilizes one linear equation which multiplies a series of factors. As a result, it is relatively clear that an increase or decrease in a specific factor will increase or decrease sediment yield. This road segment was defined as a 121 m x 4.5 m forest road having a native surface with ruts, a median slope of 5 %, and a sediment delivery median factor of 0.35. This road was created

more than one year ago, has a cut-slope height average of 4 m and cut-slope vegetative cover average of 70%. For all the roads, the erosion rate and precipitation factor were constant at 0.0037t/m^2 and 0.88 respectively [35].

Geology data coverage for the research forest was generated based on a 1:100,000 scale geologic map of Giresun. Then, this coverage was used to determine geologic erosion rates for the road segment in t/ha/ year. The results indicated that available geologic age and lithology combinations in the research forest were Mesozoic/ Hard Sediment, Tertiary/Hard Sediment, and Tertiary/ Metamorphic. The estimated annual geologic erosion rate for all of these classes was 37t/ha [35. Therefore, the geologic erosion rate in tons per square meter (0.0037 t) was the least effective erosion factor on sediment yield from each road segments.

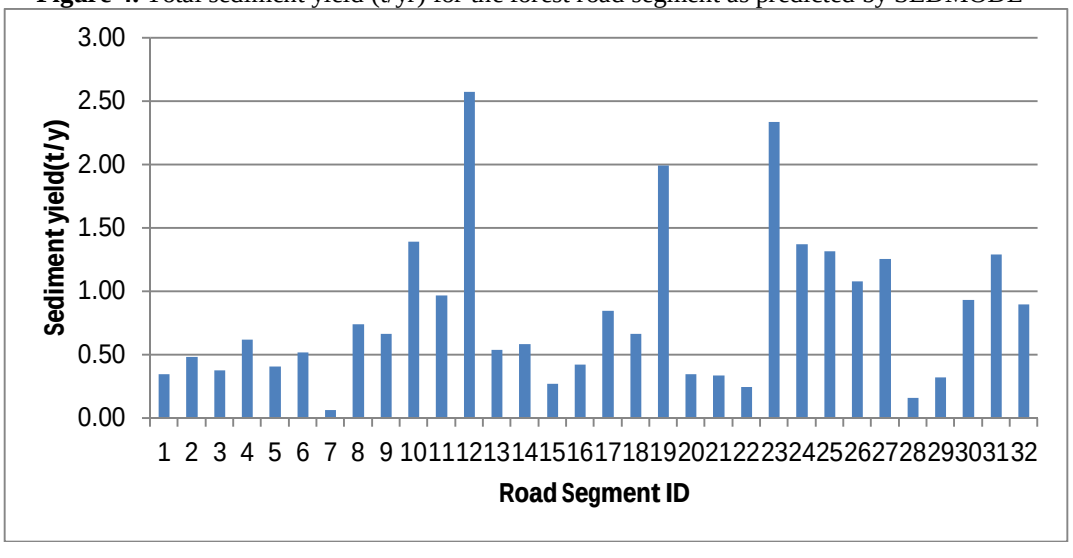
Based on the field measurements, the percentages of vegetation and rock cover on cut-slopes for unpaved roads were estimated as 70% and 60%, respectively. The associated average cutslope cover factors were 0.2540, and 0.3116 respectively. Luce and Black [36] also indicated that reduction in the amount of cut-slope vegetation and rock cover material caused a significant increase in sediment yield.

The cut-slope, heights were not directly measured in the field. Values were estimated based on field notes and photographs. 25 segments had 60% slope and 3m. cut slope height while, 7 segments had 65% slope and 7m. cut slope height. Luce and Black [36] also suggested that high cut-slopes were the most important source of sediment yield from the road segment after two years or more.

These results correlate with the findings presented in the literature review. In general, studies have shown that road characteristics such as slope, length, traffic intensity, and soil type affect sediment output more so than other factors [36,9].

The sediment yields predictions for each road segment by SEDMODL are summarized in figure 4. SEDMODL estimated segment 12 to have the highest sediment yield at approximately 2.58 t/y. The segment estimated to yield the least amount of sediment was road segment 7 at 0.07t/yr.

Figure 4. Total sediment yield (t/yr) for the forest road segment as predicted by SEDMODL

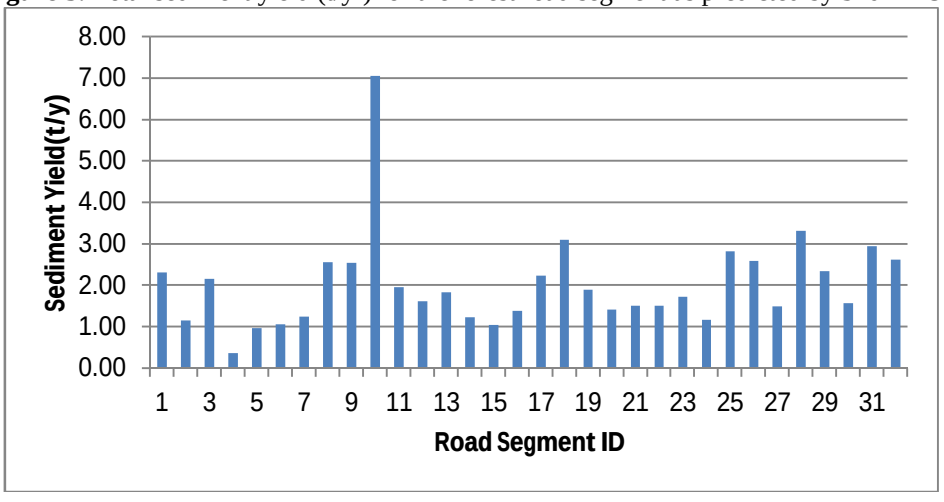


3.2.3. STJ-EROS

The input values for STJ-EROS were taken directly from field measurements could be evaluated by varying each input by a specified percentage. STJ-EROS was determined based on the median values of each input. This road segment was an road segment with dimensions 121 m x 4.5 m, a slope average of 5 %, and a sediment delivery ratio average of 35%.

Figure 5 summarizes the sediment yields prediction from the forest road by STJ-EROS. The highest producing road segment is 10 estimated to yield approximately 7.7t/yr. The segment estimated to yield the least amount of sediment was road segment 4 at 0.36t/yr.

Figure 5. Total sediment yield (t/yr) for the forest road segment as predicted by STJ-EROS



3.3.Model Comparison

The outputs of each model were compared to determine if there was a significant difference in the mean estimated amount of sediment produced from each road segment. The null and alternative hypotheses were as follows:

H_0 : $\mu_A = \mu_B = \mu_C$: There is no significant difference between the mean estimated sediment yields from the road segments as calculated by SEDMODL (μ_A), WEPP: Road (μ_B), and STJ-EROS (μ_C).

H_1 : $\mu_A \neq \mu_B \neq \mu_C$: There is a significant difference between the mean estimated sediment yields from the road segments as calculated by SEDMODL (μ_A), WEPP: Road (μ_B), and STJ-EROS (μ_C).

Model outputs were given in kg/yr, converted to tons/year, and first tested for normality. Because each data set had 32 observations, a Shapiro Wilks normality test was performed on each data set with an alpha of 0.05. All p-values were less than the stated alpha of 0.05, leading to the rejection of the null hypothesis that the data follows a normal distribution.

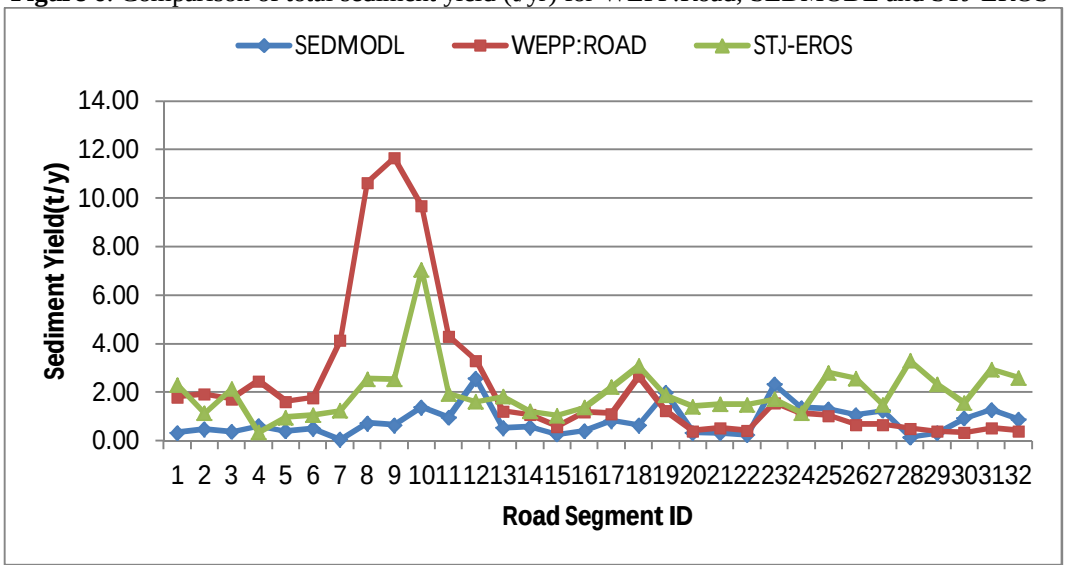
To compare the means of the sediment outputs to determine if they were significantly different, a nonparametric, paired Wilcox test with a (alpha of 0.05/3=0.017) was applied. The statistical comparison between model outputs (Table 2) indicated no significant difference between SEDMODL and WEPP:Road; but differences between other model pairings were significant.

Table 2. Summary of p-values for pairwise comparison of sediment data

Pairwise comparison of model	(alpha = 0.017)
SEDMODL - WEPP:Road	0.127
SEDMODL - STJ-EROS	0.001
WEPP:Road - STJ-EROS	0.008

Figure 6 compares the outputs of all three models, illustrating the differences between each model output. WEPP: Road predicts road segment 9 to have the greatest sediment yield within the forest road. Alternatively, SEDMODL predicts road segment 12 to have the greatest sediment yield within the forest road. STJ-EROS predicts road segment 10 to have the greatest sediment yield within the forest road.

Figure 6. Comparison of total sediment yield (t/yr) for WEPP:Road, SEDMODL and STJ-EROS



The relationship between sediment yields from each model pair is determined. The trend lines and corresponding R^2 correlation coefficients were calculated for each paired comparison to evaluate whether a correlation exists between model outputs. There does not appear to be any relationship between the yields of SEDMODL and WEPP: Road or between SEDMODL and STJ-EROS; the R^2 values for both relationships are close to zero indicating no correlation between sediment estimations. An R^2 value of 0.58 for the relationship between WEPP: Road and STJ-EROS indicate that there is a slight correlation between outputs.

To verify the results of the models, the road segments identified by the models to have high erosion potential were compared to those chosen through field classification. Through this comparison, the erosion prediction models were evaluated as to whether they can be effectively applied to the Anbardağ forest road.

4. Conclusions

The outputs of each model were compared only quantitatively to determine differences in sediment yield prediction, in the process of road segment. Because no background data involving sediment yield is available, it is difficult to determine the accuracy of these models. This study does not seek to identify the 'best' or 'worst' model, but rather to assess them results of each model by comparing them to first-hand field observations.

The WEPP: Road model is one of the few erosion prediction models available free online with a user-friendly interface. Because the WEPP: Road model and its counterparts have been used extensively, there are many resources online to help the user in the measurement and description of inputs.The climate generator allows the user to adjust temperature, rainfall, the number of wet days, elevation, and geographic coordinates based on an existing climate file provided by the program; however, the adjusted climate still carries some attributes of original climate file. Although a useful guide is provided for the user, many inputs may change according to assumptions based on their specific site conditions.

SEDMODL was a very easy model to use and understand. The simple equations allow the user to understand exactly how changes in inputs will affect the output. The inputs are general and easy to obtain. The ease of use of SEDMODL recommends it for use in forest watersheds where background data is not available and where land managers may not have the experience or resources to use more comprehensive models.

Like SEDMODL, STJ-EROS utilizes a simple equation to estimate sediment yield. While one or two equations may not be as comprehensive as the algorithms involved in WEPP: Road, they may easier to use for land managers.

STJ-EROS only requires four inputs: road length, width, slope, and precipitation. While these factors are some of the most important, this model does not consider traffic, specific road surface characteristics, or the condition of the cut- and fill-slopes.

This study field data were collected on 32 forest road segment on the Anbardağ Forest District and Giresun Forest Enterprise in the Eastern Black Sea Region. Road characteristic data were measured and used as input variables for predictions of sediment yield with the WEPP: Road, SEDMODL and STJ-EROS. The mean road segment length was 121.4 meters and the mean road slope was 5 percent for the 32 road segment in the investigation. The results indicated that the total predictions of sediment yield from forest road WEPP: Road, SEDMODL and STJ-EROS were 73.25 t/yr, 26.42 t/yr and 64.77 t/yr respectively.

The slight correlation between WEPP:Road and STJ-EROS, supported by the R^2 coefficient, does not necessarily mean these models are better at predicting sediment yield in the mountain area.

As with any model, it is important to understand that it is a tool that is only as good as the data going into it. Field observations are essential to determining management practices, but a useful model can aid in the process by decreasing time and cost. While the models evaluated in this study might be useful, it is clear that more work is needed to develop a forest road erosion prediction model specific to the Turkey. The results presented here can improve current models for predicting road sediment production and guide future research.

Acknowledgments

I would like to thank Dr. William J. Elliot for building WEPP Climate files for countries, during and valuable helps during this research. Also thanks to Assoc.Prof. Dr.Ömer Kara help on model input files soil studies.

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