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Estimating sediment yield from a forest road network using SEDMODEL and GIS technique (case study Arasbaran forests)

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ABSTRACT

Aims: This study has been done to investigate the effects of the access road network of Arasbaran forest areas on erosion in order to achieve appropriate criteria for sustainable development in forest areas while protecting forest soil.
Materials & Methods: This research was carried out to introduce the SEDMODEL and its capabilities in estimating the production of sediment from road construction Sutanchay watershed in Arasbaran forest, located in the northwest of Iran. From road networks, 10km were selected for research. Initially, the maps of geology, slope, rainfall, and drainage density, were prepared in the GIS system. Then, excavation trenches, road surface coverage, and traffic volume were examined in 34 stations through field surveys. The statistical method of Fisher distribution was used to compare the model estimation and observation values.
Findings: Statistical analysis of the data showed no significant difference between sediment delivery and the Metric method in the erosion assessment resulting from access roads. The standard error of the metric method and the SEDMODEL was calculated to be 1.34×10^{-3} and 1.37×10^{-3}, respectively. The results showed that sedimentation caused by road surface was more than 19,000 tons, of which 240 ton are related to 3km of asphalt road and the rest are related to 7km of dirt road. Total sedimentation of the watershed was estimated to be 46,000 tons.
Conclusion: The application of the sediment delivery model provides a realistic estimate of forest soil erosion caused by the road network. This model can be considered as a planning criterion in the sustainable development of forest areas.

Keywords: Arasbaran; Cut-slope; erosion; Excavation trench; Roadside.

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Introduction

The opening-up of forests in terms of a forest road network is a precondition for state-of-the-art forest management and advanced silviculture[1]. Forest roads are constructed to improve access to forest ecosystems to promote forest management, support resource extraction, and facilitate travel, firefighting, and the transport of materials, tourism and national defense, and, more recently, the construction of renewable energy projects in remote areas [2]. Although forest roads cover a relatively low percentage of most forested areas, they can significantly affect water flow paths and, consequently, alter the runoff generation processes, and eventually could have a significant effect on hydrological response during storm episodes [3].

In some cases, problems and failures in the forest roads result from improper and inadequate construction design, particularly at the points of road-streams crossings [4]. A widespread failure during flash flood events is that culverts do not have the appropriate dimensions to discharge sediments and wood debris, which results in over road flow, downslope erosion, road loss, and debris flow downstream [5]. The enhanced understanding of runoff and erosion processes in forest roads can provide the necessary knowledge to reduce sediment production and delivery to streams [6].

Various models as Water Erosion Prediction Project (WEPP), Road Sediment Delivery Model (SEDMODEL), and Washington Road Surface Erosion Model (WARSEM) have been developed to evaluate the impact of forest roads construction on hydrological processes and erosion and sediment yield in forest areas [7]. Nowadays, Sediment Delivery Model (SEDMODEL; Boise Cascade Corporation, 1999) is frequently used to estimate forest road sediment yield [8]. SEDMODEL is a GIS-based road erosion and delivery model which identifies road segments with a high potential for delivering sediment to streams[9].

A three-dimensional forest road alignment model, TRACER, was developed to assist a forest road designer with a rapid evaluation of alternative road paths. Development of a design procedure incorporating modern graphics capability, hardware, software languages, modern optimization techniques, and environmental considerations will improve the design process for forest roads [10].

Akay et al. (2008) has introduced a sediment model (SEDMODEL) combination with GIS to estimate the average annual sedimentation due to road networks and to identify sediment-producing parts. This method is based on experimental relationships between erosion factors, including the type of road use, the parent material of the area used in the construction of the road, road surface condition, the longitudinal slope of the road, vegetation, excavation trench, and the distance from the water body [8].

Parsakhoo et al. (2014) was used SEDMODEL to estimate sediment yield from forest roads with gravel and asphalted surfacing of Lolet and Lat talar forests in the Hyrcanian zone of Iran. The estimated annual sediment yield for all road sections by SEDMODEL and rainfall simulator were 10,935.45 and 10,509.29 g.m-2, respectively. The calibration and validation process results showed that the variation accounted for in the predicted values by SEDMODEL with the observed values under rainfall simulation was 3.90% [11].

Sedimentation rate due to the existing forest roads was estimated in a part of the experimental forest station of Tarbiat Modares University using SEDMODEL and GIS-based on influential factors which consist of geology, road, slope, precipitation, vegetation covers, and drainage network was reported by Asadollahi et al. (2016). They concluded that erosion resulting from this road network was estimated at 1576.4

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$t.y^{-1}$. without considering SEDMODEL. This amount was estimated at 140.7 $t.y^{-1}$ considering SEDMODEL on the basis distance of the waterway. The results showed that the share of sediment produced by roads was about 1.33% of the observed sediment at the outlet of the basin, while roads accounted for only 0.017% of the basin area[12]. Dalir et al. proposed multiple regression analysis to estimate sediment yield of forest road in the southern shores of the Caspian Sea (northern 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, the height of cut slope, and road age. The results showed that road length and road width have significant effects on sediment generation [13]. Estimation of erosion and sediment of forest asphalt roads in Shabankareh area of Kermanshah Iran showed that the height of trenches and wall coverings were the leading indicators affecting the road erosion rate, respectively [14]. Based on this literature review, it is widely accepted that forest roads may alter the hydrologic response of the watersheds because of the alteration of the landscape and its hydrologic functioning, morphology, land uses, and hydrologic characteristics. One of the biggest problems caused by road construction in forests and natural areas is the creation and increase of various forms of erosion, such as gully and massive erosion around roads [15].

Therefore, recognizing the impact of the road on the quantity and quality of sediment production can be an excellent help for optimal management and utilization. Qualitative studies can identify sensitive and critical areas and provide appropriate methods to control erosion, and quantitative methods can be used to estimate the amount of sediment from these areas.

Arasbaran forests are a genetic reservoir and the only place for the growth of rare plant species in Iran. Due to the importance of having rich flora and fauna, scarce species in 1971 were conserved, and UNESCO has listed it as a wildlife refuge since 1976. Nevertheless, in recent years, unprincipled road construction in some parts of this region, due to the large volume of excavation, leads to the destruction of animal and plant habitats, the reduction of aesthetic values, and the damage of sensitive areas.

Therefore, this study has been done to investigate the effects of the access road networks on erosion and sediment yield by SEDMODEL in the Arasbaran forest. Obtained results proposed to achieve appropriate criteria for sustainable development in forest areas while protecting forest soil.

Study area

The study area, Sutanchay, with an area of 14615 hectares is located between longitudes 46°,40′,03” and 46°,53′,19” E, and latitudes 38°,52′,50” and 39°,48′ N. In the natural divisions, the study area includes two sub-basins, namely Sutanchay and Ashegloo from the Aras basin (Figure 1). The highest altitude of the region is 2303m above sea level, and the minimum height is 314m at the basin outlet in the lowland coastal areas of Aras River [16]. The results of slope classification showed that more than 84% of the watershed is located at a slope of >10%. The average annual precipitation in the 10km study area of the basin is 390mm. In the study area, the primary source of precipitation is the incoming air currents from the Mediterranean Sea with low-pressure centers from the west of the country and the inflows from the northwest and the Black Sea. Geologically, pyroclastic rocks with more than 30% and limestone with 20% have the highest rock outcrop in the basin. The mainstream outlet is connected to the Aras River downstream of the Sutan, Ashegloo, and Boydooz villages [17]. The Ashegloo village to Oskloo and Boydooz village to Sutan roads

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are of the third-grade asphalt type. More than 495km of forest access roads are dirt, and the Aras border road, the Ashegloo village-Kalibar access road, and the Ashegloo - Sutan village access road is of second-grade asphalt type with a length of more than 60km (Table 1). In this model, 10km of road, including 3km of asphalt and 7km of dirt from the Aras roads (Sutan to Masjedloo village), are investigated (Figure 2).

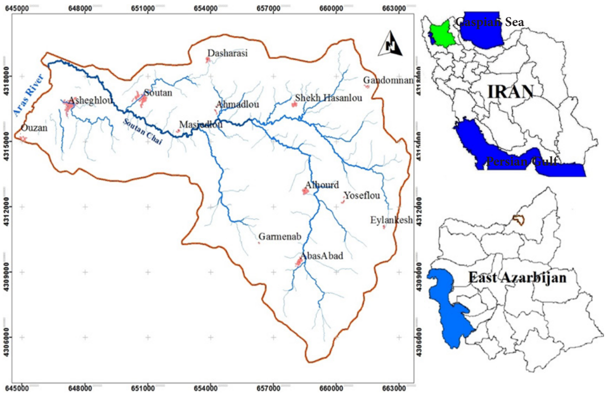

Figure 1) Geographical location of the Sutanchay watershed in East Azarbaijan.

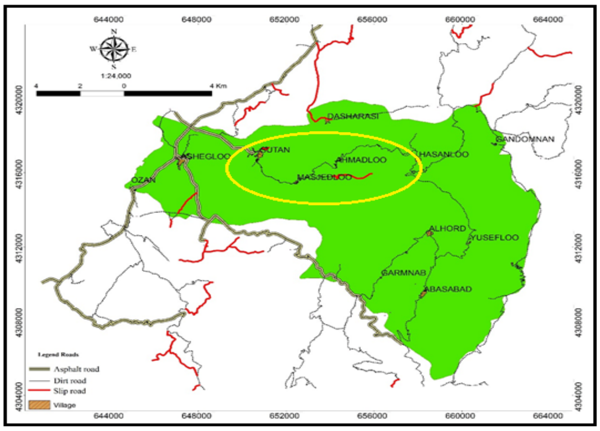

Figure 2) Roads map of the Sutanchay watershed

Table 1) Type and length of access roads to the study area

row	L(Km)	Road Type
1	60	Asphalt
2	495	Dirt road
3	23	Slip road

Materials and methods

The road sedimentation is typically affected by three types of water flow on the road surface, excavation trench and roadside streams. The model used in this study is based on these three factors. Therefore, the total sedimentation ($t.y^{-1}$) from each road section will be calculated based on Eq. (1)[8].

$$\text{Total Sediment } (t.year^{-1}) = (TS+CS) \times Af \qquad (1)$$

Ts sedimentation caused by road surface and roadside streams

Cs sedimentation caused by excavation trenches

Af the factor related to road operation time

Sedimentation of road surface and roadside streams

The sedimentation caused by the road surface depends on various parameters such as road morphometric characteristics (width, length, and road slope), road type, precipitation, and geology of the area. Based on this factor, the erosion rate can be calculated according to Eq. (2).

$$TS = Lr * GEr * Wr * Sf * Tf * Gf * Pf * Df \qquad (2)$$

Road length (Lr), road width (Wr), road surface material (Sf), road traffic (Tf), road slope (Gf), precipitation (Pf), geological factor (GEr), sediment delivery factor (Df)

Sedimentation caused by excavation trench

Based on Eq. (3), sedimentation caused by excavation trench (CS) is a function of geological erosion factor (GEr), vegetation and rock cover around the road (CSf), excavation trench height (CSh), road length (Lr), and sediment delivery factor (Df).

$$CS = GEr * CSf * CSh * Lr * Df \qquad (3)$$

Sedimentation caused by a road age factor

Road sedimentation is the maximum amount during the first or two years of construction until the excavation trench and embankment are properly stabilized by vegetation. In the SEDMODEL, the road age factor (Af) takes a coefficient of 10 for the first year of construction and 2 for more than two years [8].

Preparation and processing of maps

The required maps, including geology, road, slope, rainfall, and stream network, were digitized in a GIS environment using topography and geology maps, and satellite images. In the next step, the field survey was performed, and the factors of road surface material, traffic, sediment-delivery rate, and trench height were extracted. The streams layer was extracted from the 1:25000 topographic map and compared with the stream network map using Arc Hydro Extension in ArcGIS10.The slope map was extracted using a 10m DEM, and the geological map was extracted from the 1:100000 Varzeqan geo map. The road data were also collected by field survey using GPS, and its digital layer was prepared in the GIS system. Based on the road type and land use, the existing roads were divided into two types of asphalt and earth with forest land use, shown in two classes of 1 and 2. To prepare the annual mean rainfall distribution map, the rainfall gradient was calculated from the relationship between altitude and the average annual rainfall of seven stations in the area. In this study, 10km of road, including 3km asphalt and 7km earth, from the Aras border road to Masjedloo and Sutan was investigated (Figure 3).

Table2) Geological erosion rate based on lithology and formation [8]

Lithology	The geologic age of formation ($t.ha^{-1}.y^{-1}$)				
	Quaternary	**Tertiary**	**Mesozoic**	**Paleozoic**	**Precambrian**
Metamorphic	-	37	37	37	37
Schist	-	148	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	-	-	-
Some of the lithology/ages categories with no occurrence do not have erosion rates (i.e., Soft Sediment and the Mesozoic category does not occur).					

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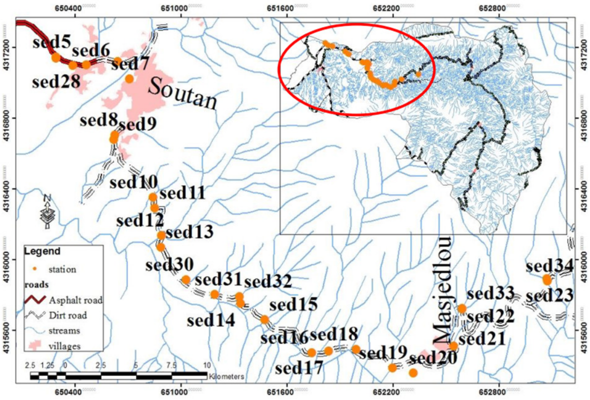

Figure 3) location of model measurement stations

Geological erosion rate(GEr)

The sedimentation potential of a road section is highly dependent on soil and geological characteristics [18]. The erosion rate for different formations was determined using Table2 [10, 19]. Based on the map of geological and lithological formations, the road condition was determined to be in two classes of $37 t.ha^{-1}.y^{-1}$ for hard sediment andesitic and limestone and $74 t.ha^{-1}.y^{-1}$ for sediment (Figure 4).

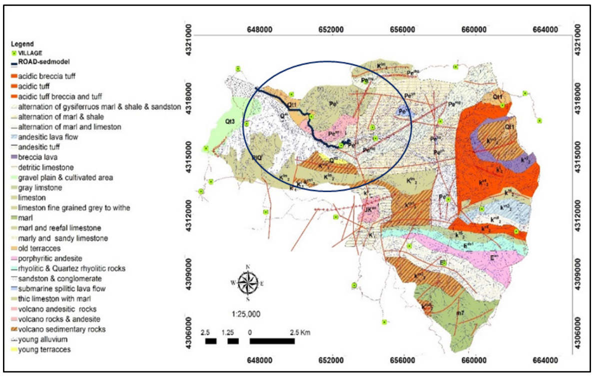

Figure 4) Geological map of the study area [20]

Tread surfacing factor(Sf)

The quality of road surface material directly impacts the amount of sedimentation (sedimentation rate). In the model used, the road surface erosion rate for different classes is according to (Table 3) [21]. The erosion rate for this factor in the region from the source of measurement, which is the intersection of the Aras border road with Sutan village road, is 0.03 for the asphalt section to the Sutan village (3 km) and 0.5 for the earth section (7 km).

Table 3) Road tread surfacing factors for various common road types

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

Traffic factor(Tf)

The sedimentation of road surface depends on the type of use and traffic situation. (22) introduced the traffic factor (Tf) as one of the influential factors in sediment production. The erosion rate of the traffic factor is presented in Table4 for different road classes. The study of the road traffic factor in the Sutanchay watershed showed that the traffic situation was light during the year since the road is sometimes used as timber and recreational routes with light vehicles, and only in summer, the traffic is moderate due to the arrival of passengers and the villagers, who live in cities like Tehran and Tabriz. Therefore, for all stations surveyed, the road class was considered a secondary road with an erosion coefficient of 2.

The road grade factor (Gf.)

The slope map of the area was prepared using DEM in ArcGIS10, and the coefficient of the road grade erosion was 0.2, 1, and 2.5 for the slopes less than 5, 5 to 10 %, and more than 10 percent, respectively [23]. The slope map of the Sutanchay watershed was prepared in three classes(Figure 5). Table 5 shows the area of each of the slope classes. The slope classes study area results show

Table 4) Erosion rate of road traffic factor for various classes

Road classes	Road descriptions	Traffic factor
Highway	Main highway	120
Main Haul	Heavily used by log truck traffic throughout the year; usually, the main access road in a watershed that is being actively logged	120
County Road	The wide, county-maintained road that receives heavy residential and/ or log truck use Receives	50
Primary Road	heavy to moderate use by log trucks throughout all or most of the year	10
Secondary Road	Receives light log truck use during the year. May occasionally be heavily used to access a timber sale. Receives car/pickup or recreational use	2
Spur Road	The short road was used to access a logging unit. Used to haul logs for a brief time while the unit is logged. On average receives little use	1
Abandoned/blocked	The road is blocked by a tank trap and boulders or is no longer used by traffic.	0.1

that more than 84% of the watershed is located at a slope of >10% and has a high erosion coefficient.

Table 5) Slope classes and erosion coefficients in the watershed

Erosion Coefficient	Area(ha)	Slope class
0.2	722	5<
1	1567	5-10
2.5	12326	>10

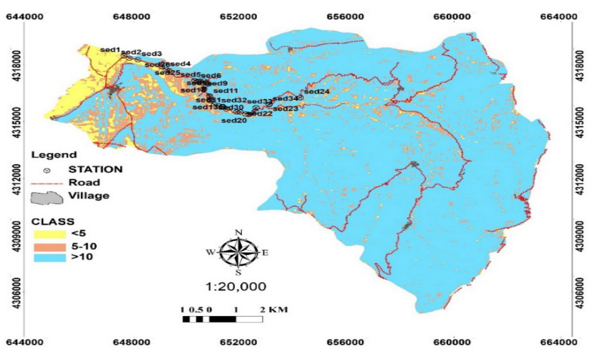

Figure 5) slope map of the study watershed

Precipitation factor (Pf)

The sedimentation potential from each road section is related to the average annual precipitation. According to the model used, the precipitation factor (Pf) is calculated based on the average annual precipitation in the basin according to Eq. (4) [24]. In this equation, P_{avr} is the average annual precipitation.

$$Pf = \left({}^{Pavr}/_{1542}\right)^{0.8} \qquad (4)$$

According to the isohyet map of the Sutanchay watershed, shown in Figure 6, the average annual precipitation in the 10km study area of the basin varies from 340mm - 390mm [25]. The average precipitation at each station was extracted by overlapping the station location with the isohyet map in ArcGIS10, and then the precipitation factor of each station was prepared using Eq. (1).

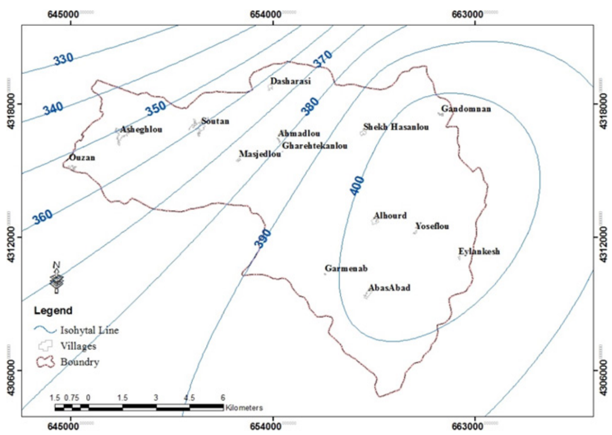

Figure 6) Isohyetal map of the Sutanchay watershed

Delivery factor (Df)

The extraction of sediment delivery factor (Df) data is one of the most complex parts of the estimating model of sedimentation percentage from a road

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section to a stream [24]. Parts of the road that are further away from the streams usually bring a small percentage of the sediment to the streams. However, much of the sediment produced on forest roads is controlled by high vegetation cover and does not reach the streams [26]. In this model, the sediment delivery rate for each road section is measured based on the distance of the middle point of the road from the nearest stream [27]. According to the model guide [8], the sediment delivery rate is 100% for the road sections that have direct sediment to the stream and cut it off, 35 and 10% for the sections that are at a distance of 30m, 60m from the stream, and zero (0) for the sections that are at a distance more than 60m, due to the filtering of sediments by vegetation.

Cut-slope cover factor(CSf)

This factor is defined as a percentage of the undamaged or repaired stone or plant cover of the road surface, excavation trench, and embankment trench [27]. Table 6 shows the Cut-slope cover factor based on the vegetation and rock cover percentage of the areas around the road [8]. Based on this, the CSf of the access road of the Sutanchay watershed was extracted in the measurement stations (Table 7).

Table 6) The erosion rate of the cut-slope cover factor

Vegetation or rock cover (%)	Cover factor
0	1.0000
10	0.7700
20	0.6155
30	0.5222
40	0.4435
50	0.3742
60	0.3116
70	0.2540
80	0.2003
90	0.1500
100	0.1023

Table7) The cut-slope cover factor of the study area access road

Station	Lr(m)	Vegetation or rock cover (%)	CSF
sed1	1	60	0.3116
sed2	200	50	0.3742
sed3	550	60	0.3116
sed25	1450	70	0.2540
sed4	1700	60	0.3116
sed26	1800	60	0.3116
sed5	3050	60	0.3116
sed27	3050	30	0.5222
sed6	3100	60	0.3116
sed28	3170	30	0.5222
sed29	3660	0	1.0000
sed7	3700	100	0.1023
sed8	4100	30	0.5222
sed9	4300	30	0.5222
sed10	4550	50	0.3742
sed11	4600	30	0.5222
sed12	4800	50	0.3742
sed13	5100	50	0.3742
sed30	5250	20	0.6155
sed31	5300	20	0.6155
sed32	5460	50	0.3742
sed14	5500	60	0.3116
sed15	5600	50	0.3742
sed16	6000	50	0.3742
sed17	6100	60	0.3116
sed18	6300	60	0.3116
sed19	6500	50	0.3742
sed20	6700	100	0.1023
sed21	7000	60	0.3116
sed22	7300	60	0.3116
sed33	7300	60	0.3116
sed23	8100	50	0.3742
sed34	8100	60	0.3116
sed24	10000	60	0.3116

Findings

Cut-slope height factor (CSh)

As the cut-slope height factor increases, the sedimentation rate from these areas increases by landslide and soil leaching into the side stream channels [27]. Figure 7 shows this factor along the Arasbaran forest road. It is challenging to measure this factor; thus, we can use the slope map classified into different classes. Based on this model, the slope map of the study area is divided into four classes: 0-15, 15-30, 30-60, and more than 60%. The erosion rate for each class is 0.75, 1.5, 3, and 7.5, respectively [8,26]. Figure 8 shows the slope map of the excavation trench factor, and Table8 shows the excavation trench factor (cut-slope) in the watershed in the asphalt and earth sections of the road. Based on this map, the average slope of 0-15 and 15-30% was predominant in measurement stations, so the Cut-slope values were considered to be 0.75 and 1.5. Then using the Pearson correlation test, the effect of the factors influencing the erosion rate and statistical characteristics were investigated.

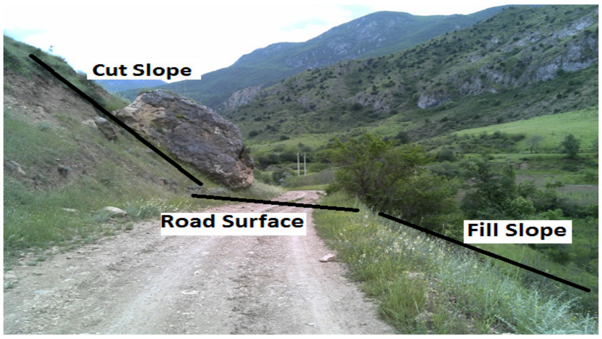

Figure 7) Forest road sample in the earth section

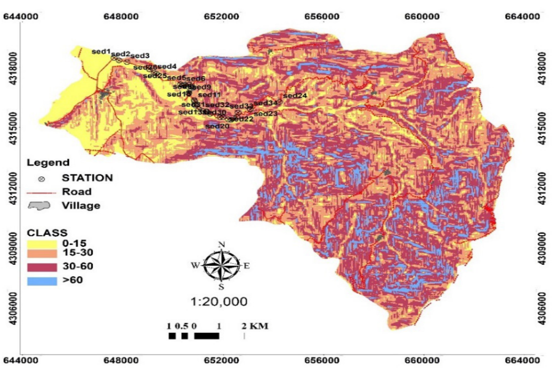

Figure 8) Slope map of the excavation trench factor (cut slope)

Table 8) excavation trench factor of the Sutanchay watershed access road

STATION	Lr(m)	SLOP%	CSh
sed1	1	0-15	0.75
sed2	200	0-15	0.75
sed3	550	15-30	1.5
sed4	1700	15-30	1.5
sed5	3050	15-30	1.5
sed6	3100	0-15	0.75
sed7	3700	15-30	1.5
sed8	4100	0-15	0.75
sed9	4300	0-15	0.75
sed10	4550	15-30	1.5
sed11	4600	15-30	1.5
sed12	4800	15-30	1.5
sed13	5100	15-30	1.5
sed14	5500	15-30	1.5
sed15	5600	15-30	1.5
sed16	6000	15-30	1.5
sed17	6100	15-30	1.5
sed18	6300	15-30	1.5
sed19	6500	15-30	1.5
sed20	6700	15-30	1.5
sed21	7000	15-30	1.5
sed22	7300	15-30	1.5
sed23	8100	15-30	1.5
sed24	10000	15-30	1.5
sed25	1450	0-15	0.75
sed26	1800	0-15	0.75
sed27	3050	15-30	1.5
sed28	3170	15-30	1.5
sed29	3660	0-15	0.75
sed30	5250	15-30	1.5
sed31	5300	15-30	1.5
sed32	5460	15-30	1.5
sed33	7300	15-30	1.5
sed34	8100	15-30	1.5

Table 9 shows the statistical characteristics of the parameters measured in the region—

Table 9) Statistical calculations of some of the parameters evaluated in the region

Descriptive Statistics							
Variablel	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Wr	34	7.0	5.0	12.0	6.60	1.71	2.93
Lr	34	200.0	0.0	200.0	29.63	33.72	1137.59
CSF	34	0.8977	0.102	1.00	0.38	0.16	0.025
CSH	34	0.75	0.75	1.50	1.32	0.32	0.104
Gf	34	2.3	0.20	2.5	1.85	0.92	0.847
Valid N (listwise)	34						

the maximum Std. The deviation is for the length of the road, and the minimum is for the cut-slope cover factor.

sedimentation due to the road surface and
Side streams (TS)

According to Eq. (2), sedimentation caused by road surface and side streams (TS) depends on various parameters such as road morphometric characteristics (width, length, slope), road type, precipitation, and geology of the area. Factors related to these parameters were calculated in the Sutanchay watershed, and finally, the road surface sedimentation was extracted from Eq. (2) for stations. Accordingly, the total annual sedimentation of the study 10km route is estimated to be more than 19,000 tons, of which 240 tons are related to 3 km of asphalt road, and the rest are related to 7 km of earth road.

Estimation of sedimentation caused Cut Slope Sediment (CS)

The sedimentation caused by excavation trench (CS) depends on the (GEr), (CSf), (CSh), (Lr), and (Df), and its data are extracted using Eq. (3) for measurement stations in the Sutanchay watershed. The total annual sedimentation of the study 10-km route is 3130 tons, of which 378 tons are related to 3 km of asphalt section, and the rest is related to 7 km of the earth road. Figure 9 was shown Soil mass movements in soil-type road trenches.

Figure 9) Soil mass movements in soil-type road trenches.

The total sedimentation estimated by the results of maps and field visits showed that out of 10000m of the road length, 1008 m had the highest impact on the sediment delivery rate to the stream. Based on 34 measurement stations, 15% of the total road length, i.e., 151m, is related to the asphalt section and its role in the sediment delivery rate to the stream, and the rest, with a share of 85%, is related to the earth road. The study of outlet sediment of the watershed showed that out of the total road length (1008 m) effective in sedimentation, 391 m was less than 30 m away from the mainstream, of which only 30 m was related to the asphalt route, and 31 meters of the asphalt road was 30-60 meters away. The maximum length of the route, 586 meters, is related to the distance of more than 60 meters, which due to the zeroing of the sediment delivery parameter, the sediment rate along this route, with 58% of the road length, is zero. Regarding the indicators effective in sediment

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production, the earth part of the road played a significant role (36%) in sediment delivery from the basin to the stream. Finally, using the parameters measured in the model, the sediment production rate in the forest road of the region was obtained. The results of the calculations using are presented in Tables 5 and 6.

Sedimentation due to road construction results from the sum of sedimentation caused by road surface and side streams (TS) and sedimentation caused by the cut slope (CS), which is multiplied by the value of road age factor (Af) (Eq. 1). According to this, the sedimentation rate caused by the road surface and stream is 19000 tons, and the sedimentation rate due to the excavation trench is 3130 tons. According to Table 10, the total sediment resulting from the road in the 10km route of the watershed is estimated to be 46,000 tons.

Table 10) Total sediment rates in the study road

Station	CS	TS	Total Sediment (t)
sed1	1.73	0.21	3.88
sed2	145.38	185.11	660.98
sed3	60.53	18.97	159.00
sed4	51.88	40.65	185.07
sed5	0.00	0.00	0.00
sed6	0.00	0.00	0.00
sed7	0.00	0.00	0.00
sed8	0.00	0.00	0.00
sed9	0.00	0.00	0.00
sed10	363.44	242.58	1212.04
sed11	0.00	0.00	0.00
sed12	145.38	1617.20	3525.15
sed13	218.07	1819.35	4074.82
sed14	242.11	516.54	1517.31
sed15	290.75	2066.17	4713.85
sed16	363.44	197.62	1122.12
sed17	84.74	707.52	1584.53
sed18	302.64	1010.75	2626.78
sed19	145.38	422.30	1135.35
sed20	39.74	84.46	248.41
sed21	121.06	422.30	1086.71
sed22	181.58	1583.62	3530.42
sed23	0.00	0.00	0.00
sed24	0.00	0.00	0.00
sed25	0.00	0.00	0.00
sed26	0.00	0.00	0.00
sed27	0.00	0.00	0.00
sed28	0.00	0.00	0.00
sed29	0.00	0.00	0.00
sed30	119.56	826.47	1892.06
sed31	263.03	1590.95	3707.97
sed32	123.57	1053.75	2354.64
sed33	181.58	3167.25	6697.66
sed34	157.37	2195.96	4706.66

Discussion

The results of the Pearson test As mentioned, to study the role and extent of the effect of the measured parameters on the erosion rate, the Pearson correlation test was used, and its results were presented in Table 11. According to the results, the CSh and road traffic factors affecting road erosion showed the highest correlation values. Also, the relationship between the geological formations factor and the sediment delivery rate from the road to the stream is significant at the level of 5%.

Estimation of erosion based on a metric method

The volume of erosion forms was estimated for each section of the Sutanchay watershed during 10Km of the road to validate the model due to the lack of discharge-sediment measurement systems. This estimate was measured at all 34 stations. Table 12 shows its quantitative calculations.

Comparison of and observational estimation values

The statistical method of F distribution or Fisher distribution was used to compare the model estimation and observation values. Distribution F is a continuous probability distribution mainly used for assumptions related to the analysis of variance (ANOVA). Analysis of erosion assessment variance

[DOR: 20.1001.1.23222700.2021.9.4.2.4]

Table 11) Correlation coefficients of factors affecting erosion rate

		CSh100%	Tf100%	Gf100%	%Df
CSh100%	Pearson Correlation	1	0.923**	-0.180	0.721**
	Sig. (2-tailed)		0.000	0.435	0.000
	N	21	21	21	21
Tf100%	Pearson Correlation	0.923**	1	-0.192	0.718**
	Sig. (2-tailed)	0.000		0.405	0.000
	N	21	21	21	21
Gf100%	Pearson Correlation	-0.180	-0.192	1	0.528*
	Sig. (2-tailed)	0.435	0.405		0.014
	N	21	21	21	21
Df%	Pearson Correlation	0.721**	0.718**	0.528*	1
	Sig. (2-tailed)	0.000	0.000	0.014	
	N	21	21	21	21

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

between the two methods of sediment delivery model and metric method is presented in Table 13. The standard error of the mean of the metric method was presented in Table 14. Statistical analysis of the data showed no significant difference between the two sediment delivery models and the Metric method in the erosion assessment resulting from access roads. The Standard Error of Mean erosion- sediment was calculated to be 1.34× 10-3 and 1.37× 10-3 in the Metric and SEDMODEL, respectively.

Conclusion

Road construction is one of the causes of various forms of erosion and sedimentation due to the destruction of vegetation, increasing the velocity of runoff, and destabilization of the slope. This is especially important in forest watersheds due to environmental, ecological, and economic impacts. As the results of this study show, the model has a high ability to identify areas sensitive to erosion and estimate the rate of sedimentation caused by forest roads so that the asphalt part of the road, which has high strength in terms of road material, has a low slope factor, moderate vegetation factor, and low Cut-slope height (Csh). Akay stated that the increase in the slope and Cut-slope factor, along with the decrease in vegetation cover, is considered adequate, increasing sedimentation[8]. In practice, the asphalt section accounted for less than 15% of the erosion and sedimentation caused by road construction, while the earth section accounted for more than 85% of erosion and sedimentation due to the high slope of the road and deep trenches with mass movements. The study access road with a share of 0.05 of the total area of the Sutanchay watershed basin has more than 46000 tons of sediment production and 22000 tons of sediment delivery to the stream, which is consistent with the results of similar research in northern forest areas [12] and Zagros forest areas [14]. In other words, it can be said that, due to the percentage of the area of the watershed that these roads include, the amount of sediment produced is far more significant than the area of the watershed. This ratio highlights the importance of adhering to proper road construction principles, proper network

Table 12) Estimation of erosion forms of metric method measurement stations

Station	Type of erosion	L(m)	W(m)	h(m)	V(m^3)	Total sediment (t)
sed1	-	-	-	-	-	0
sed2	excavation trench	20	4	4	320	704
sed3	-	-	-	-	-	0
sed4	-	-	-	-	-	0
sed5	excavation trench	30	12	8.5	3060	6732
sed6	excavation trench	30	4	5	600	1320
sed7	-	-	-	-	-	0
sed8	-	-	-	-	-	0
sed9	excavation trench	3800	1	0.3	1140	2508
sed9	debris flows	8	1	4	66	145.2
sed10	channel erosion	40	8	1	320	704
sed11	excavation trench	20	9	4	720	1584
sed12	channel erosion	55	8	3	1320	2904
sed13	-	-	-	-	-	0
sed14	-	-	-	-	-	0
sed15	Rockfall $ debris	40	1	4	160	352
sed16	Surface erosion	50	50	0.3	750	1650
sed17	debris flows	14	1	4	203	446.6
sed18	Rockfall $ debris	25	1	8	176	387.2
sed19	Surface erosion	100	100	0.3	3000	6600
sed19	excavation trench	10	6	2	120	264
sed20	-	-	-	-	-	0
sed21	debris flows	20	1	12	1244	2736.8
sed22	channel erosion	430	8	1	3440	7568
sed23	-	-	-	-	-	0
sed24	-	-	-	-	-	0
sed25	channel erosion	9	5.6	1	50.4	110.88
sed26	channel erosion	4.9	9	1	44.1	97.02
sed27	excavation trench	39	12	8.5	3978	8751.6
sed28	-	-	-	-	-	0
sed29	-	-	-	-	-	0
sed30	channel erosion	10	8	0.6	48	105.6
sed31	-	-	-	-	-	0
sed32	-	-	-	-	-	0
sed33	-	-	-	-	-	0
sed34	-	-	-	-	-	0

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Table 13) Analysis of erosion between and metric method

VAR00002			ANOVA		
VAR00001	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	16978.996	1	16978.996	0.004	0.951
Within Groups	2.990E8	66	4529889.324		
Total	2.990E8	67			

Table 14) standard Error of Mean of the and the metric method

VAR00002		
VAR00001	Mean	Std. Error of Mean
1 metric	1.3433E3	413.85587
2	1.3749E3	308.52455
Total	1.3591E3	256.17470

design such as protection of excavation slopes such as mesh networks and planting, minimizing road length, and proper road management to decrease erosion and sedimentation in these areas. Based on Aky's studies, the highest soil erosion rate is related to the excavation trench, which was also an influential factor in the present study [8]. Therefore, according to the results of this study and other similar studies, control measures and engineering operations are necessary to be performed upstream of roads that have a high potential for erosion due to the greater slope, compared to the downstream, as well as in areas that are close to the stream and have a high sediment transport conditions as the most sensitive points to erosion.

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