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Full Length Research Paper

Factors controlling suspended sediment yield from catchments in central Ardabil Province, Iran

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Twenty two catchments, which were equipped to hydrometric stations and 9.5 to 7482 km^2, were selected in central areas of Ardabil Province, Iran, and have been a site for collection of suspended sediment yield data since 46 years ago. Various catchment properties were analyzed in order to recognize the effective factors controlling suspended sediment yield. Selected effective factors were mapped and classified in geographic information system (GIS). The mean suspended sediment yield of each catchment was estimated using mean load within discharge classes method and available data. Area specific sediment yield varies from 6.5 to 449.5 t km^{-2} year^{-1} for the selected catchments. Relationships among different geo-environmental and climatic factors and suspended sediment yields using multiple regressions were derived the most effective controlling factors. From these analyses, some regional models were derived for suspended load yields. The results showed that the main factors controlling suspended sediment yield in the study area are: catchment area, mean annual discharge, peak discharge, geological formation susceptibility, mean catchment slope, mean channel slope and mean annual temperature. Moreover, it was concluded that using the values of Napierian Logarithm (LN) of sediment yield and controlling factors can lead to better results in multiple regressions. Furthermore, assessment of the presented models in some eastern catchments of the study areas showed that, a multiple regression model including some catchment properties is a valuable tool to predict total and specific sediment yields in central Ardabil Province. Finally, results showed that a normal multiple regression model can explain 73% of total sediment yield, and a Napierian multiple regression model can explains 78% of specific sediment yield.

Key words: Erosion, sediment, geo-environmental factors, regression models, geographic information system (GIS).

INTRODUCTION

Sediment yield is defined as the total sediment outflow from a catchment, measurable at a point of reference and for a specified period of time (Vanoni, 1975). It can be expressed in absolute terms (e.g. t year^{-1}) or in area specific terms (e.g. t ha^{-1} year^{-1}) (Verstraeten and Poesen, 2001). By considering the problems, which are related to the sediments in land and water management, the estimation of that is a main concern (Anderson, 1975; Verstraeten and Poesen, 2001; Sadeghi et al., 2008). There are many empirical methods and models for sediment estimation (e.g. Sadeghi et al., 2008; Ganju and Schoellhamer, 2009; Bogen, 2009; Cobaner et al. 2009).

Most of these methods and models are based on deriving the affective environmental factors on the sedimentation (Bogen, 2009). For example, Verstraeten and Poesen (2001) reported that in catchments ranging from 7 to almost 5000 ha, the specific sediment yield varies from 0.4 to 20.6 t ha^{-1} year^{-1}. In their study various morphological catchment properties, land use and soil texture were analyzed to explain this large variability in sediment yield. They have concluded that catchment area alone could explain 64% of area specific sediment yield. Tamene et al. (2006) were analyzed the effective factors determining sediment yield variability in the highlands of northern Ethiopia using multiple regression,

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and reported that factors such as terrain steepness, easily detachable slope material, poor surface cover, and gullies accelerate siltation in the reservoirs, and these are the main controlling factors. The main characteristics of the catchment sediment yields are functions of the amount of sediment, time of sedimentation, the size and composition of sediment grains and transition in waterway network, because any change in the mentioned factors cause changing catchment responds (Varvani et al., 2003). Sadeghi et al. (2006) used 49 environmental factors such as physiography, hydrology, land use, geology and climate attributes in the 14 sub-catchments with the record period of 11 years as independent variables versus the mean of daily sediment yield as dependent variable for the analysis of suspended sediment yield in Esfehan and Sirjan catchments. Ali and De Boer (2007) studied the spatial patterns and variation of suspended sediment yield in the upper Indus river basin, northern Pakistan and reported that the effective discharge in the basin ranges from 1.5 to 2.0 to 5.5 to 6.0 times. Zabaleta et al. (2007) studied the factors controlling suspended sediment yield during runoff events in small headwater catchments of the Basque county and reported that linear and curvilinear relationships are exist to estimate the sediment yield. Molina et al. (2008) examined environmental factors controlling spatial variation in sediment yield in a central Andean mountain area and found that an empirical regression model can explains more than 75% of the total variance in the mean annual sediment yield. Haregeweyn et al. (2008) analyzed sediment yield variability in Northern Ethiopia, and reported that a quantitative analysis of its controlling factors showed the best results were obtained with the sediment yield (*SY*) regression model with a high model efficiency (*ME*=0.88). The Suspended Sediment yield (*SSY*) model had a reasonable *ME* of 0.66. Therefore, the *SY* model allows a better prediction of *SY* in the planning phase of new reservoirs in Northern Ethiopia.

In the central area of Ardabil province (Iran) 22 catchments, which are equipped with hydrometric stations, are exist and their sediment and discharge are measuring by Ministry of Energy, and sufficient records of sediment and water discharge up to 46 years are available. By considering the previous study, these areas are the main source of river and infrastructures sediment (Esmali, 2007). Moreover, the erosion state and its acceleration under the effects of land degradation and intensive utilization and derived sediment yield, it is necessary to study the relationships of the amount of sediment yield, and their controlling factors, precisely.

MATERIALS AND METHODS

Study area

The study area is located in central parts of Ardabil province (7482 km^2) in north-west of Iran (48°, 06'N and 38°,20' E) (Figure 1), in which the runoffs of the area are concentrated in Doost Baigloo hydrometric station and finally reach to Aras river in north of Ardabil Province. The average altitude is 1695 m.a.s.l. (ranges from 780 to 4811 m). Mean annual temperature is about 8.8°C and mean annual rainfall is about 550 mm. The bedrock is formed of acidity and basic Igneous, which is covered in narrow strip from east to west. The stratigraphy is includes rocks and sediments faces belong to the Cenozoic and Mesozoic Eras (geology organization of Iran, 2009). Four discernable parts from land use perspective can be classified as: rangelands, forests, agricultural lands as dry farming and irrigated farming lands. Rangelands are dominated by shrub- grasslands and heavily grazed in last half century. Forests with close canopy occupy small parts of the study area (5401 ha; 0.23%), this land use has also over used in last half century. The main crops in irrigated farms are potato and wheat, and on dry farming lands usually wheat and barley have been cultivated. Soil characteristics vary considerably from one land use to other one.

Mean sediment yield estimation

The amount of mean specific suspended sediment of hydrometric stations using mean loads method (Jansson, 1996), were estimated. The relationships of sediment discharge versus water discharge for Doost Baigloo station were calculated using mean loads method. In mean load method groups, initially records of river discharge using groups intervals (if minimum period discharge subtracted from maximum period discharge and divided by the number of recoded years, the interval will be calculated) were classified and mean load calculated. For the amount of mean load discharge, mean sediment discharge in each group using relationships between discharge and sediment, known as one linear or multilinear model, were estimated. This obtained by deriving relationships between discharge– sediment and determination of sediment discharge amount equal to total daily discharge estimated for the given station in the period of data records. Therefore the sediment potential of each station was estimated. By using the estimated potential, yearly sediment and specific for the upland of station were estimated (Mirzaei et al., 2006).

Selection of the effective environmental factors on sediment yield

Twenty one factors including: Mean elevation (H; m); Area (A; km^2); Mean slope (Sw; %); Vegetation index (mean NDVI from Landsat TM 2002); Rangeland area (Ra; %); Agricultural area (Ag; %); Susceptible geological formation to erosion (Se; %) and Resistance of geological formation to erosion (Ps; %) based on Feiznia method (Feiznia, 1996); Mean precipitation (P; mm); Maximum intensity of 30 minutes rainfall (I30; cm hr^{-1}); Mean annual temperature (T; °C); Mean drainage density (DD; km km^{-2}); Mean annual runoff (R; mm); Mean annual discharge (Q; m^3 s^{-1}); Peak discharge (Qp; m^3 s^{-1}) and Specific peak discharge (Qsp; m^3 s^{-1} km^{-1}) based on Dicken's Formula; Catchment length (DL; km); Length of main channel (L; km); Slope of main channel (Sc; m m^{-1}); Catchment form factor (FF) and Time of concentration (Tc; hr) based on Bransby- Williams (1922) formula, which were assumed to be influencing factors in sediment yield on the study area, were selected. The average values of selected factors were calculated for different selected catchments. The calculated values were used for quantitative analyses in relation to effective factors on the sediment yield (Hakimkhani and Arabkhedri, 2006; Lee and Yang, 2010; López-Tarazón et al., 2010).

Figure 1. Position of study area on Ardabil province and Iran.

Examining the relationships between the selected factors versus recorded sediments

There were 22 hydrometric stations in the study area, which were created the possibility of quantitative analyses of the effective factors on sediment yield in different sub-catchments. In the relationship analyses, environmental factors were as independent variables, and specific suspended sediment (t km^{-2} $year^{-1}$) and total suspended sediment yield (t $year^{-1}$) were as dependent variables.

According to the nature and type of data, after overlaying layers in GIS environment and deriving tables, the analyses and interpretation of frequency and the amount of suspended sediment yield in sub-catchment were estimated by regression correlations.

The relationships of environmental factors versus variation of suspended sediment yield in different sub-catchments using simple and multiple regression were examined. A stepwise multiple regressions among the selected effective factors and specific suspended sediment yield (*SSY*) together with total sediment yield (*SY*) were conducted to determine the mutual-effectives of different parameters on sediment yield.

The relationships between each independent variable versus dependent variable, using correlation matrix were investigated. Then by considering the best correlation and their significance, the important influence factors in suspended sediment yield were identified.

Evaluation of multiple regression models efficiency on suspended sediment yield estimation

Nash and Sutcliffe (1970) presented the following equation for Model Efficiency (*ME*) evaluation (Equation 1), which is used in this

Table 1. The estimated average sediments using mean load method.

Catchment		Coordinates		Mean specific suspended sediment yield ($t\ km^{-2}\ year^{-1}$)	Total suspended sediment ($t\ year^{-1}$)
Number	**Hydrometric station**	**Longitude**	**Latitude**		
1	Doost Baigloo	47° -31′	38° -32′	84.3	6307033
2	Arbab Kandi	48° -02′	38° -30′	26.6	126826
3	Samian	48° -15′	38° -23′	79.1	323282
4	Namin	48° -28′	38° -25′	8.5	279
5	Sola	48° -29′	38° -22′	24.1	1024
6	Nane Karan	48° -32′	38° -19′	56.8	540
7	Ala Dizgeh	48° -36′	38° -17′	87.5	1689
8	Iril	48° -35′	38° -13′	17.8	1388
9	Hir	48° -30′	38° -06′	27.3	3615
10	Koozeh Topraghi	48° -22′	38° -07′	116.8	93767
11	Shams Abad	48° -15′	38° -00′	59.4	10591
12	Gilandeh	48° -19′	38° -22′	64.5	77000
13	Pole Almasi	48° -12′	38° -10′	75.3	77973
14	Yamchi	48° -08′	38° -04′	6.5	4646
15	Nir	47° -59′	38° -02′	50.5	8206
16	Lai	47° -54′	38° -07′	31.9	568
17	Nooran	48° -11′	38° -13′	11.4	1488
18	Vila Daragh	48° -04′	38° -11′	97.5	1092
19	Atashgah	48° -03′	38° -13′	7	295
20	Amooghin	48° -12′	38° -14′	10.1	770
21	Baroogh	48° -11′	38° -17′	14.5	1831
22	Pole Soltani	47° -40′	38° -24′	449.5	63964

study to evaluate the efficiency of derived multiple regressions.

$$ME = 1 - \frac{\sum_{i=1}^{n}(Oi - Pi)^2}{\sum_{i=1}^{n}(Oi - Omean)^2} \quad (1)$$

Where, n is the number of observations, O_i is the observed value, O_{mean} is the mean observed value and P_i is the predicted value. The ME value can range from $-\infty$ to 1 and represents the proportion of the initial variance accounted for by the model. The closer the value of ME approaches 1, the more efficient the model is. Values of $ME \leq 0$ mean that the model produces more variation than could be observed so the model is inefficient. All statistical analyses were conducted using SPSS ver. 16.

RESULTS AND DISCUSSION

The amount of mean specific suspended sediment of hydrometric stations using mean loads method for the study area are presented in Table 1. As can be seen from Table 1, mean specific suspended sediment yield vary from 6.5 $t\ km^{-2}\ year^{-1}$ (almost in the middle of the study area with 714.8 km^2) to 449.5 $t\ km^{-2}\ year^{-1}$ (almost in the west of the study area with 142.3 km^2)

Figure 2 shows the relationships of sediment discharge versus water discharge for Doost Baigloo station using mean loads method. The average values of selected factors are presented for different catchments in Table 2.

One by one analysis/ results of simple and Napierian logarithmic regression

The relationship between each independent variable versus dependent variable, using correlation matrix were presented as examples in Figures 3 and 4. As can be seen from these figures, high relationship exist between catchment areas and discharge versus total suspended sediment (A) but low relationship exist between catchment areas and discharge versus specific suspended sediment (B).

Tables 3 and 4 show the simple correlation matrix and Napierian logarithmic between controlling factors versus the amount of sediment yield. In these tables the significance of relationships ($p = 0.01$ and $p = 0.05$)

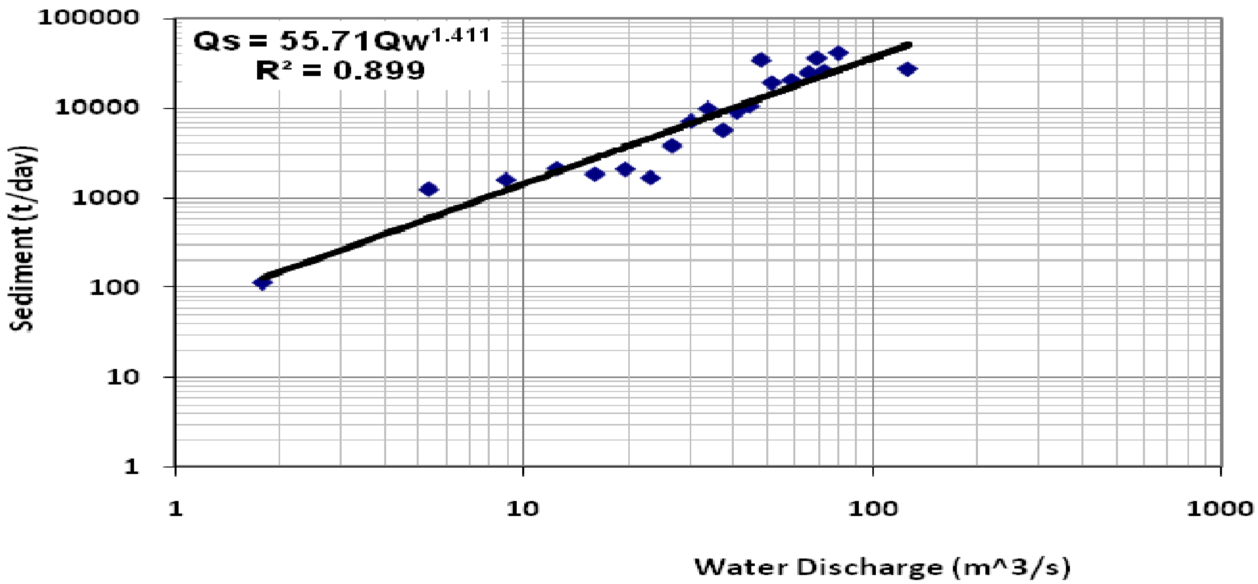

Figure 2. Relationship between sediment discharges versus water discharge (Doost Baigloo St.) using mean load method.

between some parameters and the amount of total and specific sediment yield were estimated which overall results show that the amount of total sediment are more than specific sediment. Moreover, the results of Napierian logarithmic show the improvement of the significance (p = 0.01, p = 0.05). In the next step, initially data (the values of each parameters and sediment yield); transferred to the Napierian logarithm and then a multiple regression were conducted with the new data. In the simple regression (bi-variate), the best results for the estimating the amount of total suspended sediment yield (SY) were taken under the effects of mean annual discharge; time of concentration; specific peak discharge; peak discharge; catchment area; length of main channel and length of catchment, respectively with the amount of 85, 80, 80, 80, 80 and 79% (the percentages are R^2 values that exchanged to 0-100%). Moreover, some of the other parameters such as slope of main channel; mean NDVI value; mean drainage density and the mean slope of catchment had found effective in the next level with the amount of 44, 35, 34, and 26%, respectively. The derived relationships for different perimeters were as Equations 2 to 12:

$$SY = 12071\,Q^{1.478} \qquad R^2 = 0.85 \quad n = 22 \tag{2}$$

$$SY = 29.42\,Tc^{2.614} \qquad R^2 = 0.83 \quad n = 22 \tag{3}$$

$$SY = 4.545\,Qsp^{-4.38} \qquad R^2 = 0.8 \quad n = 22 \tag{4}$$

$$SY = 36.65Qp^{1.463} \qquad R^2 = 0.8 \quad n = 22 \tag{5}$$

$$SY = 21.75A^{1.097} \qquad R^2 = 0.8 \quad n = 22 \tag{6}$$

$$SY = 3.12L^{2.239} \qquad R^2 = 0.8 \quad n = 22 \tag{7}$$

$$SY = 1.395\,DL^{2.675} \qquad R^2 = 0.79 \quad n = 22 \tag{8}$$

$$SY = 24582Sc^{-2.33} \qquad R^2 = 0.44 \quad n = 22 \tag{9}$$

$$SY = 23139\,NDVI^{-25.6} \qquad R^2 = 0.35 \quad n = 22 \tag{10}$$

$$SY = 6E+09\,DD^{-13.8} \qquad R^2 = 0.34 \quad n = 22 \tag{11}$$

$$SY = 2E+09\,Sw^{-4.34} \qquad R^2 = 0.26 \quad n = 22 \tag{12}$$

Table 2. Defining of dependent and independent variables for statistics relationships of sediment yield.

Watershed		Independent Variables (X)																					Dependent Variables (Y)	
No.	***Station***	***H***	***A***	***Sw***	***NDVI***	***Ra***	***Ag***	***Se***	***Ps***	***P***	***I30***	***T***	***DD***	***R***	***Q***	***Qp***	***Qsp***	***DL***	***L***	***Sc***	***FF***	***Tc***	***SSY***	***SY***
1	Doost Baigloo	1695.4	7482	13.08	0.99	29.5	65.1	5.2	25.5	403.5	1.46	8.68	2.4	144.6	9.13	563.1	0.075	113.75	223.57	1.58	1.44	49.41	84.3	630732.6
2	Arbab Kandi	1773	4767.9	12.99	1.01	25.1	70	8.1	30.6	418.3	1.47	8.29	2.4	157.6	4.37	401.6	0.084	80.91	152.51	2.09	1.45	33.33	26.6	126826.1
3	Samian	1777.8	4087	12.58	1.02	24.2	70.3	9.5	29.5	419.2	1.48	8.27	2.32	157.6	7.93	357.8	0.088	67.41	116.78	2.59	1.48	24.83	79.1	323281.7
4	Namin	1700	32.8	19.58	1.02	44.5	53.6	0	5.4	404.3	1.46	8.65	3.01	154.7	0.13	9.6	0.293	10.5	10.81	10	1.33	3.15	8.5	278.8
5	Sola	1548.5	42.5	16.67	1.08	18.7	64.2	0	28.3	375.5	1.43	9.41	3.3	126.6	0.31	11.7	0.274	12.76	15.83	3.43	1.4	5.02	24.1	1024.3
6	Nane Karan	1435.4	9.5	16.72	1.22	0	53.9	0	58.2	353.9	1.41	9.8	2.76	110.9	0.1	3.8	0.399	6.63	7.72	2.05	1.54	3.16	56.8	539.6
7	Ala Dizgeh	1484.1	19.3	18.41	1.2	0	59.1	0	98.3	363.2	1.42	9.62	2.58	119.3	0.24	6.4	0.334	8.94	10.2	2.86	1.46	3.63	87.5	1688.8
8	Iril	1638	78	20.13	1.08	17.9	64.2	0	95.2	392.5	1.45	8.95	2.43	144.8	0.47	18.4	0.236	12.1	14.97	6.5	1.39	4.64	17.8	1388.4
9	Hir	2489.5	132.4	25.03	1.05	79.3	16.4	0	74.7	555	1.62	4.71	2.6	356.0	0.29	27.3	0.206	17.3	24.48	6.53	1.56	6.1	27.3	3614.5
10	Koozeh Topraghi	1754.7	802.8	13.42	0.97	30.4	67.2	31.4	5	414.8	1.47	8.38	2.78	155.2	1.48	105.6	0.132	41.85	48.06	1.48	1.48	13.45	116.8	93767.0
11	Shams Abad	1840.2	178.3	15.45	0.98	39.9	57.9	46.8	0.4	431.1	1.49	7.96	2.82	174.1	0.52	34.2	0.192	24.4	27.19	3.04	1.47	7.66	59.4	10591.0
12	Gilandeh	2033.2	1193.8	15.95	1.02	26.9	65	9.6	8.8	467.9	1.53	6.99	2.44	214.2	4.23	142.2	0.119	66.15	93.42	3.22	1.76	21.51	64.5	77000.1
13	Pole Almasi	2119.7	1035.5	17.34	1.02	31	63.9	9.1	6.6	484.4	1.54	6.56	2.57	236.7	3.93	127.8	0.123	43.25	65.2	4.34	1.48	14.34	75.3	77973.2
14	Yamchi	2161.6	714.8	17.65	1.03	34.8	61.3	7.9	6.3	492.4	1.55	6.35	2.63	247.4	2	96.8	0.135	31.98	48.99	7.01	1.5	10.58	6.5	4646.2
15	Nir	2516.1	162.5	22.49	1.07	50.9	47.2	0.4	4.6	560.1	1.62	4.58	2.99	358.7	1.28	31.9	0.196	28.46	37.41	7.25	1.8	8.94	50.5	8206.3
16	Lai	2821.4	17.8	27.32	1.07	82.8	17.2	0	0	618.3	1.68	3.05	3.16	483.6	0.11	6.1	0.341	10	10.4	13.64	1.66	2.73	31.9	567.8
17	Nooran	1944	130.5	16.33	1.05	24.7	71.9	0	0	450.9	1.51	7.44	2.56	196.1	0.37	27.0	0.207	23	26.18	8.63	1.34	6.17	11.4	1487.7
18	Vila Daragh	2090.9	11.2	17.27	1.04	30.2	69.8	0	0	478.9	1.54	6.69	3.2	230.0	0.07	4.3	0.383	8.71	8.82	8.51	1.62	2.67	97.5	1092.0
19	Atashgah	2428.9	42.2	31.34	1.08	62.9	37.1	0	0	543.4	1.61	5.01	2.86	348.7	0.11	11.6	0.275	11.1	12.76	14.63	1.19	3.03	7	295.4
20	Amooghin	2229	76.2	21.84	1.08	55.1	44.9	0	0	505.3	1.57	6.01	2.93	273.1	0.31	18.1	0.237	24.25	27.2	8.18	1.71	6.84	10.1	769.6
21	Baroogh	2469.1	126.3	25.76	1.09	62.1	33.2	0	11.4	551.1	1.61	4.81	2.58	351.0	0.3	26.4	0.209	25.5	31.69	7.21	1.55	7.68	14.5	1831.4
22	Pole Soltani	2677.3	142.3	33.84	1.04	79.2	17.1	0	0	590.8	1.66	3.77	2.89	441.1	0.97	28.8	0.203	23	28.73	6.81	1.61	6.84	449.5	63963.9

In the developed bi-variate regression, which can explain the amount of specific suspended sediment yield (*SSY*) are limited. Only a little some parameter such as slope of main channel; catchment form factor; mean slope of catchment with the amount of 26, 16 and 11%, respectively can explain the amount of specific suspended sediment yield. The derived relationships for these parameters were as Equations 13 to 15:

$$SSY = 128.8\,Sc^{-0.8} \qquad R^2 = 0.26 \quad n = 22 \tag{13}$$

$$SSY = 5.858\,FF^{4.443} \qquad R^2 = 0.16 \quad n = 22 \tag{14}$$

$$SSY = 5.317\,Sw - 40.26 \qquad R^2 = 0.11 \quad n = 22 \tag{15}$$

Multiple analysis/ regressions

Normal regression

The results of stepwise multiple regressions among selected effective factors and specific suspended sediment yield (*SSY*) together with total sediment yield the(*SY*) presented the significant in p = 0.01, 0.05 and 0.1. The derived

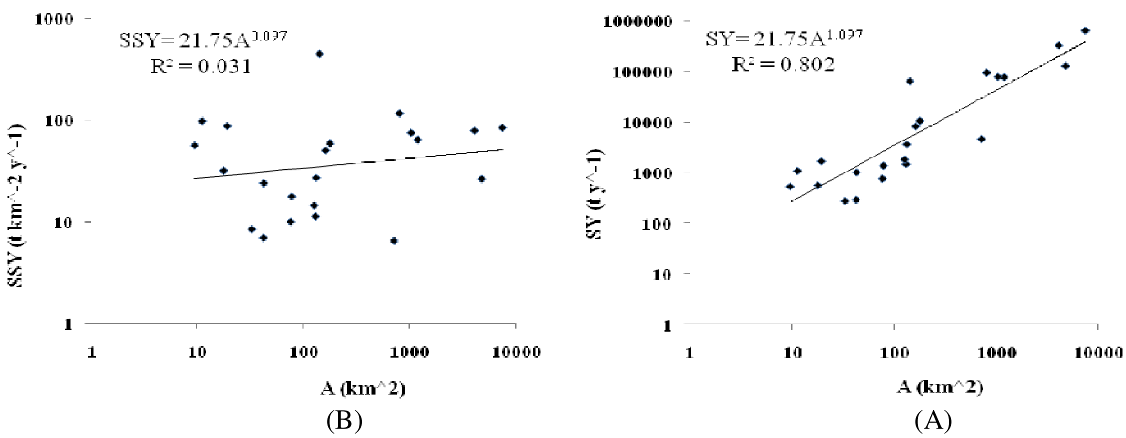

Figure 3. Relationship between catchment areas versus total suspended sediment (A) and specific suspended sediment (B).

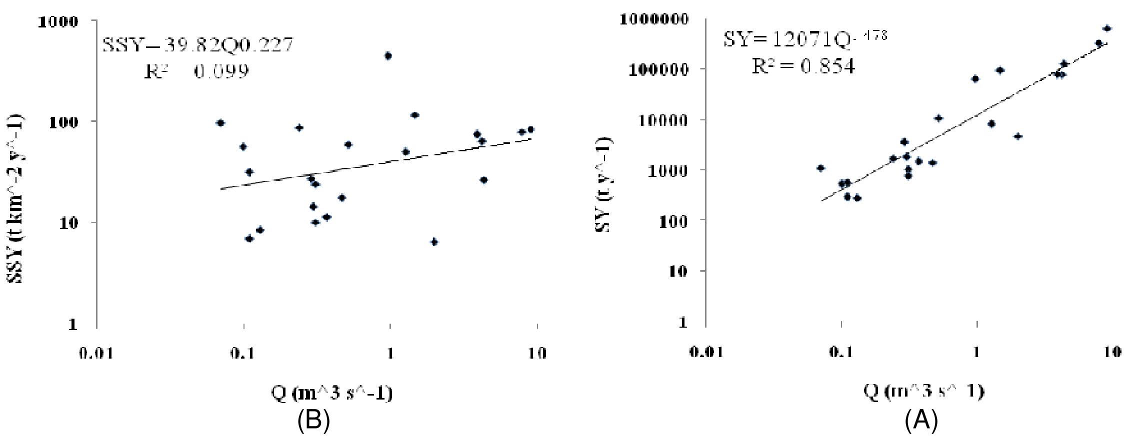

Figure 4. Relationship between discharge versus total specific suspended sediment (A) and specific suspended sediment (B).

equations in normal regressions express that the catchment area (*A*) explains the distribution of *SY* (p=0.01). Other parameters were not significant in this level. The derived formula is as Equation 15.

$$SY = 70.271A - 2917.54 \quad R^2 = 0.86 \qquad (15)$$

However, catchment area (*A*), mean annual discharge (*Q*), specific discharge (*Qp*) and susceptibility of the formation (*Se*) parameters were significant in lower level (p = 0.1). The derived equation is as Equation 16.

$$SY = 266.65A + 53360.94Q - 3398.86Qp + 1588.58Se + 22428.75 \quad R^2 = 0.96 \qquad (16)$$

Moreover, multiple regressions express that factors such as mean slope of catchment (*Sw*), mean slope of main channel (*Sc*) and resistance of geological formation (*Ps*) are the main effective factors controlling *SSY*. The derived equation is as Equation 17:

$$SSY = 16.15Sw - 25.51Sc - 1.05Ps - 76.74 \quad R^2 = 0.56 \qquad (17)$$

Napierian regression

According to Equation 18 in the Napierian logarithm, only mean annual discharge (*Q*) was highly significant (p = 0.01) with *SY*, and other factors such as mean slope of main channel (*Sc*), maximum intensity of rainfall in 30 min (*I30*), *NDVI2* and the percentage of agricultural area(*Ag2*) were significant (Equation 19) in lower level (p = 0.1).

With regard to removing minus values entered

Table 3. Simple correlation matrix between controlling factors versus the amount of sedim

Variable	SSY	SY	H	A	Sw	NDVI	Ra	Ag	Se	Ps	P	I30	T	DD	R	Q	Qp	Qsp	DL	L	Sc	FF	Tc
SSY	1	0.15	0.227	0.019	0.339	-0.104	0.222	-0.284	0.046	-0.124	0.227	0.241	-0.23	0.074	0.28	0.08	0.023	-0.071	0.056	0.036	-0.163	0.227	0.039
SY		1	-0.239	0.928**	-0.406	-0.389	-0.161	0.284	0.111	0.001	-0.239	-0.238	0.245	-0.474*	-0.262	0.908**	0.91**	-0.579**	0.862**	0.896**	-0.444*	-0.088	0.897**
H			1	-0.277	0.77**	-0.15	0.904**	-0.768**	-0.217	-0.463*	1**	0.999**	-1**	0.266	0.984**	-0.223	-0.268	-0.001	-0.18	-0.208	0.656**	0.428	-0.236
A				1	-0.495*	-0.409	-0.218	0.368	0.111	0.026	-0.277	-0.283	0.284	-0.556**	-0.315	0.918**	0.994**	-0.652**	0.931**	0.973**	-0.478*	-0.113	0.969**
Sw					1	0.251	0.78**	-0.881**	-0.425*	-0.128	0.77**	0.78**	-0.775**	0.361	0.841	-0.507*	-0.522*	0.356	-0.509*	-0.493*	0.717**	0.098	-0.514*
NDVI						1	-0.267	-0.204	-0.542**	0.543**	-0.15	-0.143	0.133	0.121	-0.04	-0.448*	-0.453*	0.697**	-0.54**	-0.478*	0.084	0.038	-0.481*
Ra							1	-0.856**	-0.122	-0.42	0.904**	0.906**	-0.901**	0.316	0.909**	-0.237	-0.225	-0.007	-0.175	-0.187	0.64**	0.25	-0.207
Ag								1	0.292	0.05	-0.768**	-0.775**	0.775**	-0.312	-0.847**	0.406	0.396	-0.286	0.388	0.37	-0.538**	-0.264	0.384
Se									1	-0.237	-0.217	-0.221	0.224	-0.121	-0.273	0.153	0.158	-0.391	0.237	0.159	-0.438*	-0.05	0.19
Ps										1	-0.463*	-0.457*	0.456*	-0.391	-0.385	-0.036	0.001	0.187	-0.12	-0.05	-0.353	-0.167	-0.039
P											1	0.999**	-1**	0.266	0.984**	-0.223	-0.268	-0.001	-0.18	-0.208	0.656**	0.428	-0.236
130												1	-0.999**	0.266	0.984**	-0.225	-0.275	0.007	-0.187	-0.215	0.659**	0.427	-0.243
T													1	-0.268	-0.986**	0.23	0.275	-0.011	0.188	0.216	-0.656**	-0.432	0.244
DD														1	0.317	-0.614**	-0.595**	0.648**	-0.614**	-0.601**	0.468*	0.16	-0.594**
R															1	-0.281	-0.316	0.102	-0.252	-0.267	0.672**	0.403	-0.293
Q																1	0.941**	-0.744**	0.932**	0.935**	-0.509*	0.01	0.926**
Qp																	1	-0.716**	0.954**	0.983**	-0.507*	-0.092	0.978**
Qsp																		1	-0.822**	-0.76**	0.443*	-0.009	-0.758**
DL																			1	0.987**	-0.535*	0.061	0.988**
L																				1	-0.511*	0	0.998**
Sc																					1	-0.092	-0.542**
FF																						1	0.002
Tc																							1

**Significant at the 0.01 level; *significant at the 0.05 level.

in the Napierian logarithm, the *NDVI* values summed with number 2 and defined as *NDVI2* ranging from 1 to 3. Also for removing zero value, the *Ag* percents subtracted from 101 and defined as *Ag2* ranging from 100 to 1. These new values will convert to original values when calculating the *SY* after determining the equation.

According to Equation 20 in the Napierian logarithmic factors mean slope of main channel (*Sc*) and mean annual temperature (*T*) were highly significant (p = 0.01) with SSY:

$$\ln SY = 1.478 \ln Q + 9.4 \quad R^2 = 0.85 \tag{18}$$

$$\ln SY = 0.9 \ln Q - 1.806 \ln Sc + 170.97 \ln I30 - 19.415 \ln(NDVI2) - 1.451 \ln(Ag2) + 254.51 \quad R^2 = 0.96 \tag{19}$$

Table 4. Napierian logarithmic correlation matrix between controlling factors versus the amount of sediment yield.

Variable	*SSY*	*SY*	*H*	*A*	*Sw*	*NDVI*	*Ra*	*Ag*	*Se*	*Ps*	*P*	*I30*	*T*	*DD*	*R*	*Q*	*Qp*	*Qsp*	*DL*	*L*	*Sc*	*FF*	*Tc*
SSY	1	0.6	-0.06	0.176	-0.157	-0.112	-0.012	-0.072	0.269	-0.008	-0.057	-0.039	-0.005	-0.043	-0.062	0.315	0.176	-0.176	0.21	0.201	-0.509*	0.397	0.252
SY		1	-0.068	0.896**	-0.510*	-0.595**	-0.296	0.225	0.792**	-0.145	-0.073	-0.094	0.134	-0.583**	-0.126	0.924**	0.896**	-0.896**	0.980**	0.894**	-0.663**	0.191	0.910**
H			1	-0.05	0.721**	-0.186	0.895**	-0.723**	-0.126	-0.328	1**	0.997**	-0.968**	0.25	0.995**	-0.094	-0.05	0.05	0.029	0.003	0.671**	0.395	-0.111
A				1	-0.538**	-0.667**	-0.379	0.315	0.822**	-0.179	-0.058	-0.094	0.167	-0.690**	-0.12	0.958**	1**	-1**	0.974**	0.984**	-0.531*	0.015	0.974**
Sw					1	0.33	0.797**	-0.823**	-0.638**	0.106	0.728**	0.757**	-0.789**	0.415	0.781**	-0.531*	-0.538**	0.538**	-0.504	-0.508*	0.768**	0.098	-0.584**
NDVI						1	0.279	-0.151	-0.644**	0.591*	-0.175	-0.133	0.044	0.138	-0.114	-0.556**	-0.667**	0.667**	-0.666**	-0.623**	0.135	0.037	-0.580**
Ra							1	-0.88**	-0.367	-0.25	0.861**	0.869**	-0.867**	0.351	0.874**	-0.413	-0.379	0.379	-0.314	-0.324	0.549*	0.28	-0.381
Ag								1	0.455*	-0.173	-0.732**	-0.764**	0.831**	-0.292	-0.770**	0.344	0.315	-0.315	0.29	0.285	-0.491*	-0.261	0.345
Se									1	-0.572*	-0.134	-0.172	0.234	-0.445*	-0.199	0.831**	-0.822**	0.822**	0.804**	0.793**	-0.590**	0.142	0.806**
Ps										1	-0.321	-0.291	0.228	-0.345	-0.284	-0.147	-0.179	0.179	-0.254	-0.171	-0.104	-0.164	-0.137
P											1	0.998**	-0.972**	0.255	0.996**	-0.101	-0.058	0.058	0.02	-0.005	0.672**	0.397	-0.119
I30												1	-0.982**	0.271	0.999**	-0.13	-0.094	0.094	-0.016	-0.04	0.677**	0.4	-0.151
T													1	-0.321	-0.982**	0.186	0.167	-0.167	0.094	0.112	-0.658**	-0.408	0.214
DD														1	0.224	-0.662**	-0.690**	0.690**	-0.618**	-0.654**	0.454*	0.143	-0.669**
R															1	-0.156	-0.12	0.12	-0.044	-0.067	0.698**	0.379	-0.178
Q																1	0.958**	-0.958**	0.939**	0.952**	-0.573**	0.142	0.955**
Qp																	1	-1**	0.974**	0.984**	-0.531*	0.015	0.974**
Qsp																		1	-0.974**	-0.984**	0.531*	-0.015	-0.974**
DL																			1	0.993**	-0.504*	0.156	0.981**
L																				1	-0.521*	0.131	00.991**
Sc																					1	-0.023	-0.627**
FF																						1	0.135
Tc																							1

**Significant at the 0.01 level; *significant at the 0.05 level.

$$\ln SSY = -1.433 \ln Sc - 1.997 \ln T + 9.644 \quad (20)$$
$$R^2 = 0.54$$

Evaluation of multiple regression models efficiency on suspended sediment yield estimation

In this research, some of catchments, such as Namin, Sola, NaneKaran, AlaDizgeh, and Iril, which are small catchments, were selected for the evaluation of the model. The amount of *ME* in Equation 16, 17, 18, 19 and 20 were used for these catchments and results of those are presented in Table 5. By considering Table 5, efficiency of the model for estimating the amount of total sediment yield (*SY*) using normal multiple regressions was calculated 73%. From this result it can be concluded that the efficiency of the model is acceptable.

However, using normal multiple regression for estimating specific suspended sediment yield (*SSY*) shows that the efficiency of the model was poor, which is estimated about 35%.

In Napierian multiple regression models, the amount of the efficiency for estimating total sediment yield (*SY*) and specific suspended sediment

Table 5. The result of applying ME factor for evaluating the efficiency of the multiple regression models in estimating suspended sediment yield in five small catchments.

Reg. type	Normal multiple regression		Napierian multiple regression	
Total/ specific Sd.	***SY***	***SSY***	***SY***	***SSY***
Mean ME Pct.	73	35	77	78

yield (*SSY*) calculated 77 and 78%, respectively, which were evaluated as acceptable models for those variables. Moreover it shows the importance of using the Napierian logarithm for estimating sediment yield.

Conclusion

The knowledge of sediment yield from catchments is very important in order to understand the linkage between soil erosion processes on hillslopes and suspended sediment transport in large rivers. In the past, this spatial scale has often been neglected in soil erosion studies. In this study, data on sediment yield for catchments in central Ardabil were collected, mostly using sediment data from recorded hydrometric stations. Various physiographical catchment characteristics, land use, climate, geology, etc were analyzed to explain this large variability in sediment yield.

The study showed that the main factors controlling suspended sediment yield in central Ardabil included: catchment area, mean annual discharge, peak discharge, geological resistance of formation to erosion, mean slope of catchment, mean slope of main channel and mean annual temperature.

Analysis of multiple regression showed that using Napierian logarithm of the amount of sediment yield and value of controlling factors could lead to better results. These results are supported by the results of Verstraeten and Poesen (2001).

Like Arabkhedri et al. (2004) expressions, the results showed that although multiple regression models express the condition of sediment yield in relation with controlling factors, but intensive use of them can be affected by selecting different factors and the precision of their calculation. Thus, using multiple regressions for estimating sediment is not reliable.

The multiple regression models, which were established using a number of catchments, could not be suitable to evaluate the sediment yield in a given catchment; even it is possible to gain negative values. It is because of the selection of factors is a function of statistical patterns. In this process, the lower and upper values were adjusted by considering the variance of the data and significant coefficient is calculated according to the mean of values of several catchments.

According to the results of this research, which were fluctuated for 5 evaluated catchments in the stage of testing models, it can be concluded that the multiple regression models are not suitable for estimating sediment yield in central Ardabil. However it can be used for recognizing the sediment yield controlling factors on a specific area. In addition to improving the efficiency of the Napierian regression models, which were used in this research, it is suggested that, we should examine different types of data values (logarithm, roots, power, etc) for developing the best regression models for estimating the sediment yield.

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Abbreviations: A, Area (km^2); **Ag,** agricultural area (%); **Ag2;** the Ag percents subtracted from 101; **DD,** mean drainage density (km km^{-2}); **DL,** catchment length (km); **FF,** form factor (dimensionless); **H,** mean elevation (m); **I30,** maximum intensity of 30 min rainfall (cm hr^{-1}); **L,** length of main channel (km); **ME,** model efficiency (dimensionless); **n,** number of observations; **NDVI,** normalized difference vegetation index (dimensionless); **NDVI2,** The NDVI values summed with number 2; **O_i,** observed values; **O_{mean},** mean observed values; **P,** mean precipitation (mm); **P_i,** predicted values; **Ps,** resistance of geological formation to erosion (%); **Q,** mean annual discharge (m^3 s^{-1}); **Qp,** peak discharge (m^3 s^{-1}); **Qsp,** specific peak discharge (m^3 s^{-1} km^{-1}); **R,** mean annual runoff (mm); **R^2,** squared correlation coefficient (dimensionless); **Ra,** rangeland area (%); **Sc,** slope of main channel (m m^{-1}); **Se,** susceptibility of geological formation to erosion (%); **SSY,** specific suspended sediment yield (t km^{-2} year^{-1}); **Sw,** catchment mean slope (%); **SY,** total suspended sediment yield (t year^{-1}); **T,** mean annual temperature (°C); **Tc,** time of concentration (h).

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