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Full Length Research Paper

Evaluation of the effect of watershed characteristics on suspended sediment load using multiple regressions: A case study of Neka river and Gorgan bay

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Having an overall picture of the intensity of erosion and sediment yield in the watersheds of a country is an essential planning criterion for its land and water management. In this study ten suitably distributed hydrometric and sediment stations with availability of enough data were selected and the factors affecting sediment yield were measured to develop a suitable method for estimation of suspended load in sub watersheds of Nekarood and Gorgan Bay, in northern part of Iran. Twenty year average suspended load was calculated using sediment rating curve method. Multiple regressions were carried out using step by step method and by considering sediment load as dependent variable and characteristics of the watershed as independent variables. A total of 104 variables were used in simple linear, second degree and transformed equations. Among them, percentage of Pre-Quartner erosion–sensitive formations (R^2 = 0.996), Gravilius coefficient (R^2 = 0.997), percentage of land use as rangeland and dry land farming use (R^2 = 0.997), percentage of land as intensive and semi-intensive forests (R^2 = 0.993), and mean annual discharge rate (R^2 = 0.610), were effective on suspended sediment yield. Each of these factors describes over 99% of the suspended sediment yield variations in the equations.

Key words: Suspended load, multiple regression, watersheds of Nekarood, Gorgan Bay.

INTRODUCTION

Soil loss is one of the important problems in most countries of the world including Iran. 20 Billion tons of sediment is transported by the World Rivers and deposited in still water. Knowing the influencing factors on sediment yield in a watershed is necessary for reduction of detrimental effects of sediment storage reservoirs, the problems of drinking water treatment, etc. Sediment yield in the watersheds can be used as a direct index in measuring erosion of upper lands and as an easily available and acceptable criterion for ranking of the watersheds. During the past years, different researchers obtained various relations between the amount of sediment and characteristics of the watershed including climate, geology, land use, hydrology, etc. These relations are site specific and cannot be used in other regions (Wlling, 1977).

Jiongxin and Duchene (2002) studied the relationship between erosion and sediment yield zones in Yellow River in China and concluded that sediment yield intensity and the amount deposited at the end of the river can be obtained by regression analysis. The basis for this analysis were runoff and sediment load.

Gert et al. (2003) evaluated specific sediment load variation in 22 Spanish watersheds. Their result showed that among the climatic variables, topography and land use, average slope of watershed, the distance from watershed outlet to the furthest point and index (I) have positive, but the watershed area has negative relationship with the amount of sediment. Phippen and Who (2003) studied the effect of land use and other factors on sediment yield of Riopuerco watershed with 16000 Km^2 area located in north-west part of New Mexico and 17 sub watersheds and found out by multiple regression that there were positive relationship between the watershed suspended sediment load and factors such as topography, percentage of land with low permeability, percentage of areas with poor drainage soils, average grazing intensity, the density of the road without asphalt,

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the percentage of area with fine textured soil and drainage area. Bray and Xie (1993) used regression analysis between geomorphologic and hydroclimatic variables as independent variables and suspended load as dependent variable for 11 stations in Atlantic Canada. They found that the regression model was suitable for evaluation of annual suspended load variations due to changes in land use, drainage and hydrology. The results showed that one-month time basis is too short for use of these equations. Ferraresi (1990) estimated total sediment for 20 watersheds in northern Italy with areas of 90 to 3410 Km^2. The coefficient of determination was 0.996, considering annual rainfall volume, total watershed area and the factor related to sensitivity to erosion and sediment transport. The researches, divided the land into some classes, the factor of sensitivity to erosion and sediment transport was used as percentage of each class in the model. The investigation showed a correlation between annual rainfall volume (in comparison to average annual discharge rate) and total sediment production.

Colove et al. (1997) found regression equations for estimation of average annual runoff and suspended sediment load of the watershed with areas of 5 to 1100 Km^2 in plain, mountain and coastal region of North Carolina. They proposed separate equations for each region due to changes in annual suspended sediment in different hydrographic regions. Valikhojinin et al (1998) studied the sedimentation by annual simultaneous sampling of water and sediment discharge rates in Golink station and 7 sub watersheds in Taleghan Rood River and showed that the average transported suspended sediment for each Km^2 of watershed was 920 tons. This is high and needs watershed management practices in Taleghan watershed to control erosion. They also showed that there is a harmony between the variations in mean monthly concentration of sediment. Ghadimi arosmahalleh (1998) compared mean specific sediments of three zones of Sanandaj- Sirjan, Central Iran and Central Alborz in Salt Lake watershed, and concluded that there are significant differences in sediment yield in the three zones so that Central Iran has the highest and Sanandaj- Sirjan zone the least sediment yield. Ghadimi arosmahalleh and Ghoddosi (1999) proposed a regression model between the suspended load of 21 stations and geomorphologic, hydrologic, climatic and geologic factors. Among 30 influencing factors, 7 factors which include total length of channel, alluvium area percentage, density of second order channel, density of faults, sensitivity to stone erodibility, average temperature and weighted average elevation had the highest correlation with the suspended sediment.

Sekoti and Oskoii (2001) investigated the efficiency of modified MPSIAC in sediment estimation of 5 watersheds of western Azarbaijan Province. There were 20 measured and one estimated data and the significance of differences among the means were compared by student t-test. The result showed that except in one watershed, the differences among the means were not significant at 95% level of significance. It is possible to estimate the sediment productions of similar watersheds using this model. Faiznia (1995) stated that among different geological variables, the lithological characteristics and sensitivity of units to erosion are the controlling factors of erosion and sediment yield, especially in small watersheds. As other geological factors such as tectonic, volcanic, etc, are constant to some extent in these watersheds. One the other hand, stone erosion is not known completely without considering the environmental conditions. For example the limestone behavior in humid region is completely different from arid region. Even in humid area, the behavior of limestone is different in different elevations. Vervani et al. (2002) concluded in their study in Gorgan rood watershed that average annual water discharge rate has higher correlation (0.82) with sediment yield than with other factors. Among other dependent variables, total percentage of Pre-Quartner resistant and relatively resistant to erosion formation, total percentage of semi and low intensive forest lands or undisturbed forest lands and mean annual water discharge rate are effective on suspended sediment of selected sub watersheds. In this research the relationships among the suspended load and characteristics of Nekarood and Gorgan Bay watershed are obtained using regression methods and will be used in areas without station or in regression with short-term data.

MATERIALS AND METHODS

Nekarood and Gorgan Bay watersheds are located in southern coast of Caspian Sea. The watersheds are located in longitudes of 53º 13´ 9˝ to 54˚44´20˝ east and latitudes of 36˚27´36˝ to 36˚59´12˝ north. The watershed is a part of Caspian Sea watershed and is bordered by Gorgan rood watershed in the north, Gorgan Bay and Caspian Sea in south to Semnan Province, watershed of Gorgan rood in east and in west by Darabkola river watershed. The climate is temperate humid, temperate semi-humid, temperate semi-arid and cold semi-humid. The rainfall decreases from west to east, but the temperature increases in this direction (Figure 1).

To investigate the effect of watershed characteristics on suspended sediment load, 10 suitably distributed stations were selected among the available hydrometry and sediment measuring stations where enough data are available and are suitably distributed. The average 20 year (1981-2001) suspended sediment was calculated from sediment rating curve. Among the geological parameters, percentage of classes of erosion of geological unit was calculated using the existing maps. The percentage of different classes of land was also calculated with the help of the existing maps. Physiographic features like, watershed area, circumference of the region, maximum elevation, average elevation, minimum elevation, Gravilius coefficient, equivalent diameter of equal area circle, length of main channel, slope of main channel and average slope of watershed were also determined (Table 1).

Using SAS software, the correlation coefficient among the suspended sediment load and 102 dependent variables were investigated in the form of simple linear, logarithmic and transformed equations. The statistical relationships between the suspended sediment load and characteristics of watershed were obtained using step by step multiple regression analysis. The used variables in this study were based on the watershed constant

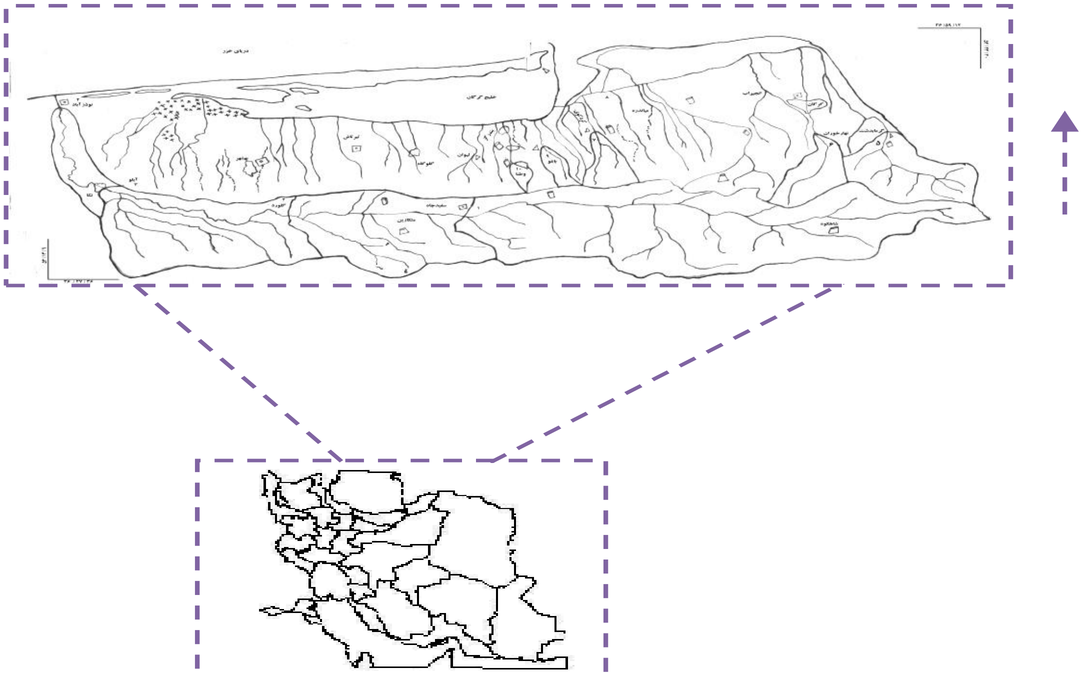


Figure 1. The map of the region of the hydrometric stations.

characteristics such as geometric and also the temporal properties of the watershed which are changing during the time.

RESULTS

To investigate the relationship between sediment discharge rate as a dependent variable and all observed dependent variables, the dependent variables were entered into SAS software in different forms and the different equations of linear, logarithmic and transformed forms were used. The correlation coefficient between dependent variable and other variables which have been defined in simple and logarithmic forms in the program were calculated using simple Pearson correlation method. Mean annual discharge rate, Gravilius coefficient, percentage of rangeland use and dry land farming had the highest correlation coefficient with dependent variable at over 99% level of significance.

After preparation of data related to physiographic variables, vegetation and land use classes, classes of sensitivity to erosion, climatic and hydrologic factors, at first the linear relationship was investigated. For factors with mean error of 5%, the regression equations were selected. The equations which had an acceptable statistical meaning were selected. To investigate the correctness of statistical relationship, the effective parameters were used as inputs to the model and suspended sediment load was estimated. Then the estimated sediment load was drawn against the measured values. These curves show that the obtained model can be used in for estimation of average suspended sediment of the sub watershed (Figures 2, 3, 4, 5 and 6).

DISCUSSION

The results of this research show the relationships between the dependent variable, that is, suspended sediment and the independent variables such as physiography, geology, hydrology and land use. After regression and statistical analysis, the regression models for estimation of suspended sediment of watershed are presented. In model 1, log FA (log of percentage of Pre-Quartner formations sensitive to erosion) was recognized as effective on suspended sediment. This model shows the relationship of dependent and independent variables in a linear from. If percentage of the areas of these formations increases in a watershed the suspended sediment load also increases (cv = 7% R^2_{adj-} = 0.995).

In model 2, log FG (log of percentage of Pre-Quartner formations relatively sensitive to erosion) was recognized as effective on suspended sediment. This model shows the linear relationship between the dependent and independent variables. If percentage of the areas of these formations increases in a watershed, the suspended sediment also increases (cv = 7% R^2_{adj}=0.995). In model 3, log RD (percentage of range land and dry land farming use) was recognized as effective independent variable on suspended sediment. This equation shows that if range land and dry land

Table 1. Variables used in regression equations.

Kind of variable			
Land use	**Climate and hydrology**	**Geology**	**Physiography**
Dry farming- PD	**Mean rainfall - P**	**Sensitive -FA**	**Watershed area-PHA**
Intensive range-R1	Spring - PSP	Relative s. - FB	Watershed
Semi-intensive range-R2	Summer PSU	Moderate - FC	Circumference - PHP
Total range -R	Autumn - PAT	Relative m.- FD	Length of channel-PHLW
Dry farming and rangeland - RD	Winter – PW1	Resistant -FE	Maximum elevation-H1
Intensive forest – F1	Mean discharge rate-Q	Relative r. - FF	Mean elevation- H2
Semi-intensive forest-F2	Spring - QWSP	Relative s.- FG	Minimum elevation –H3
Total forest - F	Summer - QWSU	FABC	Gravilius coefficient-PHG
Forest and garden-FO Limited irrigated cultivation- I1	Autumn - QWAT	FDE	Diameter of equivalent circle-PHD
Irrigated cultivation-I2	Winter – QWW1	FFG	Slope of watershed-PHSB
Agriculture and garden- IO	Specific discharge rate- QWS		Channel slope-PHSW
Tree complex- O			
Garden and agriculture -OI Without vegetation-B City - U Equipments – U2 Other used - SA18	Discharge volume - VQ Runoff depth - HR Runoff coefficient - CR 14	10	10 total

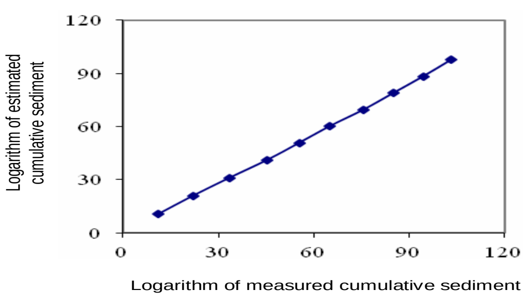
farming use increases in a watershed, the suspended sediment also increases. The range land and dry farming are created due to destruction of natural environment. These lands are not used for cultivation after few years. So in case of increases in the mixed use of range and dry land farming, the amount of suspended sediment load also increases (cv=7% R^2_{adj}=0.996). In model 4, logarithm of water discharge rate is effective on sediment yield of Nekarood and Gorgan Bay watershed (cv=7% R^2_{adj}=0.5). In model 1, the logarithm of percentage of Pre-Quartner sensitive to erosion formation in model 2, the logarithm of percentage of Pre- Quartner relatively sensitive to erosion formations, in model 3, the logarithm of range land and dry farming uses show 99% variations of sedimentation in Nekarood and Gorgan Bay watershed. In model 4, logarithm of water discharge rate shows 52% of variations in sediment yield.

Vervani et al. (2002) studied sediment yield in Gorganrood watershed and presented a regression model in which 3 factors, namely, total percentage of area of Pre-Quartner resistant formations and relatively resistant formations (GR), total percentage of area of low land semi-intensive forest (FD) and average annual water discharge rate (Q_w) were recognized as the effective variables on suspended sediment. The logarithm of sediment discharge rate was found to have positive relation with FD and Q_w and negative relation with GR.

The extracted results of this research shows that the average annual discharge rate and percentage of range and dry farming land use have direct relationship with the sediment load, but as per the studies conducted by Vervani total percentage of areas of low and semi-intensive forests have direct relation with suspended sediment. From the present study it is seen that in addition to geological, land use and hydrological variables, the physiographic variable of Gravilius coefficient was also effective on sediment yield. The results of this research show that in a long watershed with high Gravilius coefficient, the sedimentation rate increases. This variable has the same effect as average discharge rate. Arabkhederi et al. (1995) studied northern Alborz watersheds and by regional analysis of sediment, found multiple relationships between the amount of annual suspended sediment and characteristics such asdischarge rate, climate, vegetation and physiography by multi-variable regression method. The results showed that the most suitable model of sedimentation has correlation with variables such as area, slope and maximum daily flow rate with a return period of 2 years.

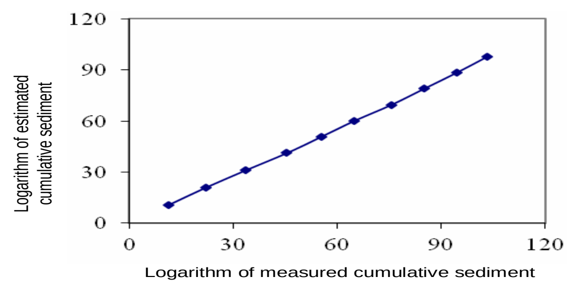
Comparison of this research with the above study confirms the obtained relationships. Although the previously used models are different, but since in all the studies, the effective variables influencing suspended sediment are selected from geological, hydrological, land

A



$CV = 7$ and $R^2_{adj} = 0.995$ $\log Q_S = 3.132(\log FG_G) \pm 0.073$

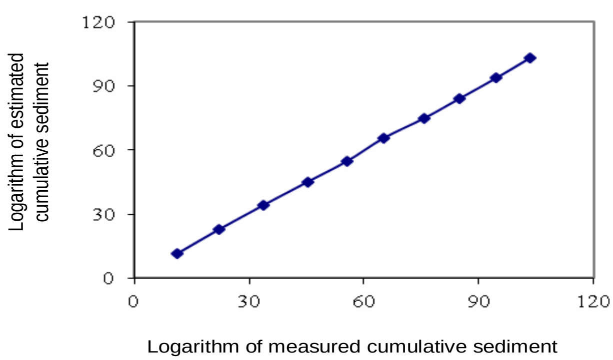
B



$CV = 7$ and $R^2_{adj} = 0.995$, $\log Q_S = 3.137(\log FA_1) \pm 0.068$

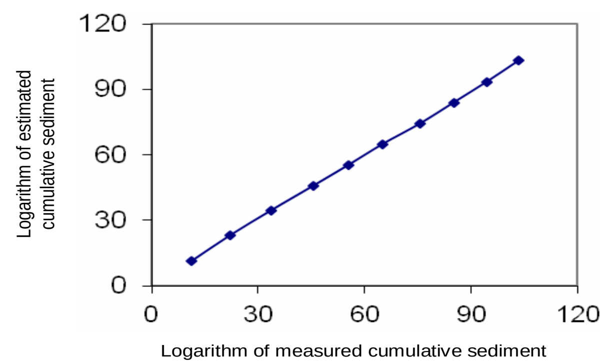
Figure 2. Logarithm of measured versus estimated sediment (A and B are from models 1and 2 in Table 2).

A



$CV = 4$ and $R^2_{adj} = 0.520$, $\log Q_S = 10.307 + 0.525 \log QW$

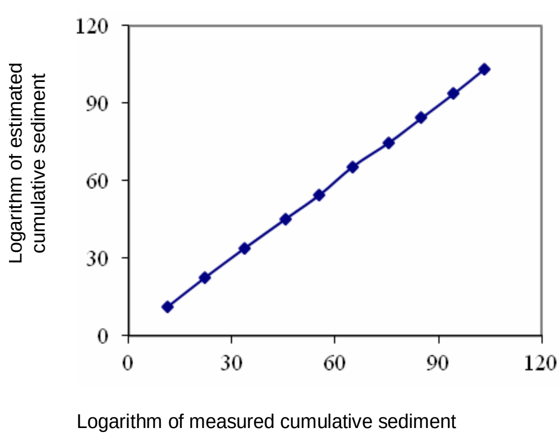
B



$CV = 6$ and $R^2_{adj} = 0.996$ $\log Q_S = 4.145(\log RD_1) \pm 0.077$

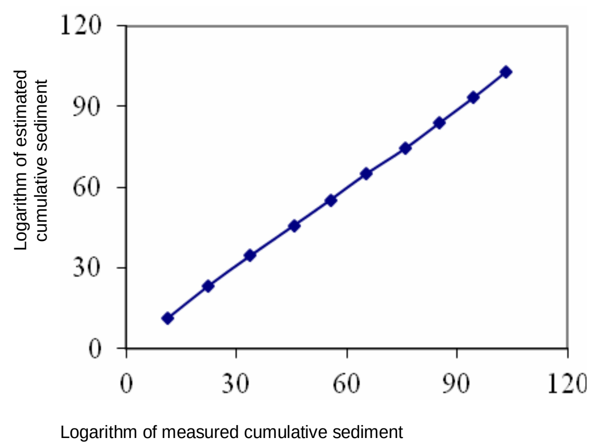
Figure 3. Logarithm of measured versus estimated sediment (A and B are from models 3 and 4 in Table 2).

A



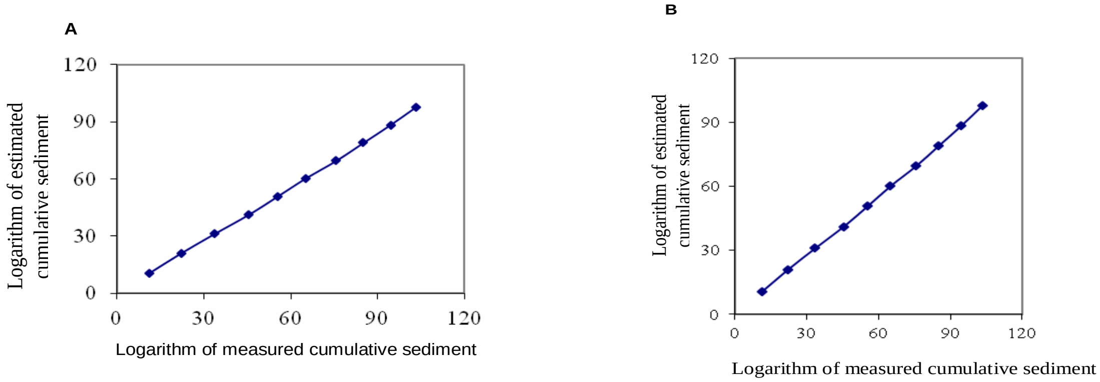
$CV = 6.6$ and $R^2_{adj} = 0.996$, $\log Q_S = 0.091(FG) + 3.223(\log FG_1)$

B



$CV = 7$ and $R^2_{adj} = 0.996$, $\log Q_S = -0.020(FA) + 3.191(\log FA_1)$

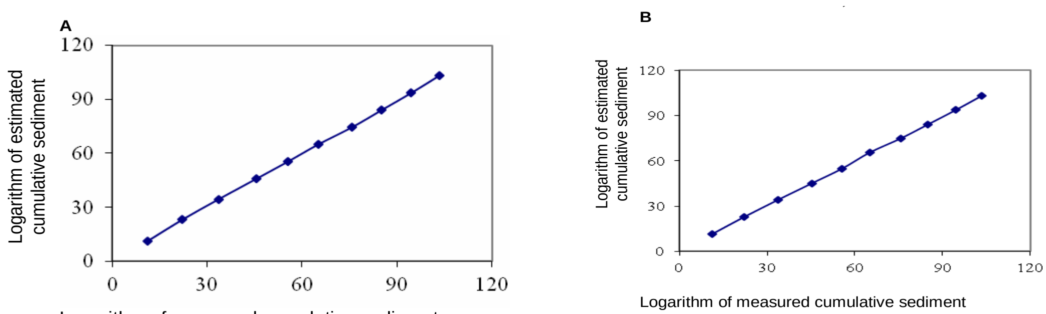
Figure 4. Logarithm of measured versus estimated sediment (A and B are from models 5 and 6 in Table 3).



$CV = 6$ and $R^2_{adj} = 0.997$, $\log Q_S = 9.621(PH_G) - 11.061(\log PH_G)$

$CV = 6$ and $R^2_{adj} = 0.997$, $\log Q_S = -.052(RD) + 4.201(\log RD_1)$

Figure 5. Logarithm of measured versus estimated sediment (A and B are from models 7 and 8 in Table 3).



$CV = 6.6$ and $R^2_{adj} = 0.996$, $\log Q_S = -.073(F) + 3.567(\log F_2)$

$CV = 6.6$ and $R^2_{adj} = 0.996$, Log Qs=9.881+0.176Qw+0.213 Log Qw

Figure 6. Logarithm of measured versus estimated sediment (A and B are from models 9 and10 in Table 3).

Table 2. Linear models obtained from step by step regression method.

Model no.	Kind of independent variable	Equation	Coefficient of variation (CV)	Corrected coefficient of determination
1	Geology	Log Qs = 3.137(logFA_1) ±0.068	6.86	0.995
2	Geology	Log Qs = 3.132(log FG_G) ±0.073	6.94	0.995
3	Use	Log Qs = 4.145(logRD_1) ±0.077	5.89	0.996
4	Hydrology	Log Qs = 10.307 + 0.525logQw	3.54	0.520

Table 3. Non-Linear models obtained from step by step method.

Model no.	Kind of independent variable	Equation	Coefficient of variation (CV)	Corrected coefficient of determination
5	Geology	Log Qs = -0.20(FA) + 3.191(logFA_1)	7.10	0.996
6	Geology	Log Qs = 0.91(FG) + 3.223(logFG_1)	6.61	0.996
7	Physiography	Log Qs = 9.621(PH_G) - 11.061(log PH_G)	5.78	0.997
8	Use	Log QS = -0.052(RD) + 4.201(logRD_1)	6.06	0.997
9	Use	Log Qs = -0.073(F) + 3.567(logF_2)	9.21	0.992
10	Hydrology	Log Qs = 9.881 + 0.176Qw + 0.213logQw	7.14	0.500

use factors and parameters such as mean annual discharge rate. The results of this research show that in non-linear relationships also some physiographical, hydrological and land use factors have impact on sediment yield in Neka Rood and Gorgan Bay watersheds. A comparison of linear and nonlinear models shows that in nonlinear models, in addition to linear model variables (Gravilius coefficient, percentage of range and dry farming land use, average annual water discharge rate, percentage of area of Pre-Quartner sensitive erosion formations and percentage of area of Quartner relatively resistant to erosion formation) other variables such as average watershed slope and percentage of areas in intensive and semi-intensive forest land use are also effective on suspended sediment load.

Gert et al. (2003) used climatic, topographic and land use variables in their studies in Spain. Their results showed that specific sediment loads has positive relation with average watershed slope, the watershed outlet distance to the furthest point of the watershed and index (I) but has negative relationship with the watershed area. The present research corroborates the same findings. The gained results from different subwatershed and comparison of the models show that in models with intercept of zero (b = 0, as in y = ax + b), using step by step in linear and non linear are significant over 99% of suspended load. The comparison of the findings of this research with that of others confirms the validity of these models and they may be used for estimation of suspended sediment load.

The results showed that the models can be classified based on:

1. Linearity or non-linearity
2. Kind of factors appearing in the model (physiography, geology, hydrology and land use)

The advantage of these models on previous ones is that one can estimate suspended sediment load by using one kind of variable (physiography, geology, hydrology and land use).

Conclusion

The extracted results from the used models are showing a significant relationship between suspended load and Gravilius coefficient. The regression analysis showed that type of geological formations affect the suspended sediment in the study area. Therefore the critical area (Pre-Quartner sensitive to erosion formations and Quartner relatively resistant to erosion formation) are recognized as effective variables. The regression analysis showed that the kind of land use and percentage of area are effective on sediment yield of watershed.

Also, the flow rate can be used for estimation of mean sediment yield of a watershed.

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