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Regional Modeling of Erosion (A Case Study: Torogh Watershed, KhorasanRazavi Province, Iran)

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ABSTRACT

Soil erosion is a serious issue of the human since the early creation yet. This phenomenon threatens and destructs water and soil which are the main bed of the infrastructures of natural resources, environment and production. Therefore, the amount of erosion in the watersheds is necessary to be evaluated and estimated in order to implement erosion control and preservation programs in the watersheds; although, there are several imported models to estimate the amount of erosion which have a different origin to the conditions of Iran. Therefore, considering the specific climatic conditions of Iran as well as the results of conducted researches, a local model which is compatible with the dominant conditions of some watersheds of Iran was provided in Torogh Watershed based on the climatic conditions of KhorasanRazavi Province. To achieve the model, first, work units were prepared using slope, lithology, land use and erosion forms maps in GIS software environment and then, to reduce the number of units, clustering analysis method was used in SPSS software with aim to estimate erosion in homogeneous regions (with lower error). Field activities were conducted in 12 determined homogeneous units by setting up a rainfall simulator and applying a 30-minute rainfall with 10 years return period intensity. Also, the taken soil samples from proximity of each plot at the depth of 0-20 cm were analyzed in the laboratory and those physical and chemical traits were determined there. After accomplishment of statistical analysis in SPSS software, the variables with the maximum impact on erodibility were determined using Kolmogorov- Smirnov, Pearson Correlation and PCA test among 22 variables including land use, coverage percentage logarithm, erosive facies, soil bulk density, permeability and clay percentage. Finally, equations of erosion estimation were determined using linear multi-variable regression by Stepwise and Enter methods. The results of linear multi-variable model with Stepwise method using two variables of coverage percentage logarithm and soil bulk density were selected considering the results of analysis of the residues, lower relative error and root mean square error and higher efficiency as well as lower number of inputs in an equation with explanation coefficient by 0.928.

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INTRODUCTION

Soil erosion and its consequences are considered as one of the most important environmental challenges [20]. In fact, soil erosion is a global challenge which threatens soil and water resources seriously[30].

Separation of soil particles by rain drops and transportation of separated particles by runoff are two fundamental processes in soil erosion [31]. The contact of rainfall drops to the soil surface, a part of soil grains and clods are broken to the fine grains and are absorbed by the soil. By continuing the rainfall, the soil becomes compacted and crusts are generated on the soil surface which cause soil permeability reduction and consequently, creation of surface flow. Kinetic energy of rainfall drops is almost 250 times greater than the kinetic energy of runoff which indicates its critical role in erosion phenomenon. Since measurement of the

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amount of soil erosion under natural conditions of precipitation is time-consuming and costly [33], so, the use of rainfall simulator can help us to monitor the amount of erosion along with its involved processes in addition to generation of rainfall with the considered traits. The use of rainfall simulator has some limitations; for instance, it cannot provide natural conditions completely. The first scientific study on soil erosion was conducted in the late 19th century by Vanley; a German scientist. After that, some scientists such as Miller and Duley attempted to increase public awareness in 1923. H. H. Bennet named erosion as a threat for public welfare and tranquility. The first quantitative experiment was conducted in the US by Forests Organization in heavy grazed pastures in Utah in 1912. Then, in 1917, the first experimental plots of soil erosion were set up in University of Missouri, Colombia (Which are still used). The mentioned plots resulted in publication of the first plot experiments in 1923.

The years 1930 and 1942 are considered as the golden age of soil conservation when the soil conservation stations were established in ten climatic indicator regions of the US.

The pioneer studies in this field were conducted by Baver,Borst, Woodburn and Musgrave separately during 1930 and resulted in the first comparative study by Laws in 1940.

Foreign and local researchers have directly and indirectly carried out some studies in this field including: Sidorchuk [34], John Daymond [13], Manuel Vicente Lopez [19], Pepyn [26], Chen [7], Casey [17], Parsakhu [25], Rustaei [30], Kaashi [14], Arman [3] and Mohammadi [21]. Sidorchuk [34] has provided a third generation model to estimate the amount of soil erosion using certain and probable factors. In the mentioned model, some criteria such as soil particle size, cohesion, integration and other erosion controlling factors have been used. Daymond *et al*. provided an erosion model to assess local scenarios of land use. For effective soil conservation, they estimated the mean sediment discharge using mean rate of erosion which depends on three factors including: mean annual rainfall square, coverage factor and erosion coefficient (which depends on the region of erosion), and they provided a model and ultimately, they gave their model' applications to evaluate different states of land use in Motueka Watershed, adjustment of priorities for soil conservation in Manawatu Watershed and determination of the trend of erosion caused by agriculture in a 30-year period. Parsakhoo predicted the soil erosion in forest lands and the amount of sediment yield resulted from roads construction in the mentioned lands using GIS and SED. They used rainfall simulators with various rainfall intensities. AHP was used to determine the risk degree of forest lands for erosion; the results showed that, 47.9% of the forest soil had moderate to high vulnerability potential. Arman [1] could provide a model for the first time to estimate and predict erosion and sediment in wet and semi-wet regions of Iran, by analysis of 21 variables affecting the sediment yield in 27 hydrometric stations of the Northern Alborz using various methods of cluster analysis in three homogeneous regions and finally, 73 work units by accomplishment of field activities using rainfall simulator and sediment rating curve and dynamic systems model (Ithink). Mohammadi provided a regional model of erosion and sediment in Sefidroud Watershed. He studied and evaluated 84 independent variables including 30 physiographic parameters, 16 hydrologic parameters, 16 climatologic parameters, 4 geologic parameters, 5 pedologic parameters and 13 vegetation cover and land use parameters; and various multi-variable statistical analysis methods including hierarchical cluster analysis, principal components analysis and multi-variable regression analysis were used for sediment modelling to compare those results and evaluate the achieved models and finally, achieving the optimal model for sediment prediction of Sefidroud Watershed.

Considering the recent research trend on creation of a local model, the present study intends to do this important task.

MATERIALS AND METHODS

Torogh Dam Watershed is located in TorghabehShandiz city, and is in the areas of Torghabeh, Ahmad Abad and in Torghabe village, 21 km away from the South West of Mashhad city, Iran. The area is 163.12 km^2 of which the smallest sub-basin (T5) has an area by 0.64 km^2 and the largest sub-basin (T14) has an area by 19.3 km^2. Torogh Dam Watershed has 30 sub-basins.

The watershed is located between the Northern latitudes of 36^0 17′ 35" and 36^0 34′ 21" and Eastern longitudes of 59^0 17′ 46" and 59^0 34′ 55". Average elevation of the watershed is 1700 m and the minimum and maximum elevation of the watershed are 1164 and 2687 m respectively. Mean slope of the watershed is 37.5% and the slope direction northern-western. Mean precipitation of Torogh Watershed is 319 mm with mean annual temperature of 11.4 ^{0}C and the climate is cold semi-arid.

Research methodology:

The research procedures were conducted in order of priority as following:

1- Required data collection including slope, lithology, erosive facies and land use maps as well as \meteorological data of the studied area and etc.

2- Determination of homogeneous work units

Providing the homogeneous work units maps and doing field activities as the form of these units are necessary to achieve the areas with same traits. In the present study, work unit is called to an area which is

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different to the areas around, in terms of lithology, slope and type of erosion. To determine homogeneous work units for doing the field activities, clustering was carried out in SPSS software using the maps of slope, lithology, land use and erosion forms with aim to estimate erosion, and then, the homogeneous areas were determined based on the four mentioned factors. It is good to be noticed that, a number of researchers such as Ahmadi [1], Qavami, Nahtani [9], Memarian *et al* and Onagh have mentioned the importance of morphological units in the studies of watershed erosion. After determination of work units, the considered factors were measured by field activities and using rainfall simulator. The use of rainfall simulator has some limitations; for instance, it cannot provide natural conditions completely. It is notable that, field activities of rainfall simulator were conducted only on the slopes less than 50% (due to the limitation of rainfall simulator setting up).

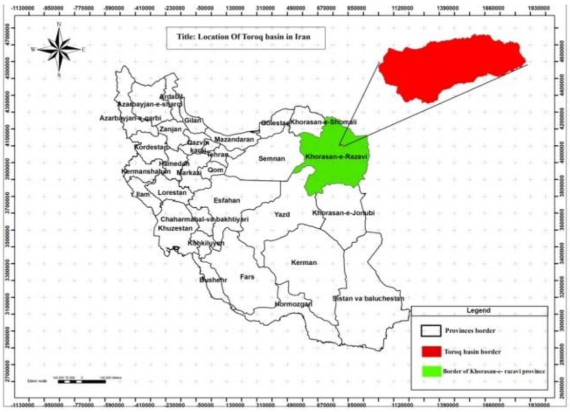

Fig. 1: Location of Torogh Watershed in Iran.

3- Field activities of rainfall simulator:

The field activities were conducted in 12 homogeneous units by setting up the rainfall simulator and applying a 30-minute rainfall with 10 years return period intensity. The output runoff was collected from the plot and the samples were transmitted to the laboratory after reading the runoff volume by graduated cylinders.

3-1- The properties of rainfall simulator:

The rainfall simulator used in the present study is portable with an initial velocity of the falling droplets is zero. This device has been made by Institute of Soil Conservation and Watershed Management in accordance to the climatic conditions of Iran. The device is plexiglass with 120*89 dimensions and 1 m^2 area with adjustable bases with a height of at least 5.1 m which can be set up on various slopes. Properties of the device have been given in Table 1:

Table 1: Properties of the used rainfall simulator.

120*84*160 cm	Dimensions
1.45 m	Height of drops falling at upstream
0.66 mm	Mean diameter of the pores
4.8 mm	Mean diameter of drops
0.106 gr	Mass of drop
0	Initial speed of drop
5.24 m/s	Estimated speed at the time of collision with Earth
204	The number of capillary tubes
8 mm	Pipes length
1.008 m^2	Plot area
12 v	electric motor voltage of the device
80 L	Tank volume of the device
110 Kg	Weight of the device with empty tank

3-2- Steps of rainfall simulator installation and doing rainfall simulation:

Selection of the considered rainfall intensity and calibration of the device:

By adjusting the length of air pressure adjustment pipe which has been installed on the tank, the rainfall intensity can be adjusted. To conduct the present study, a 30-minute rainfall with 10 years return period intensity was used. This rainfall intensity is much important due to higher occurrence frequency and runoff and sediment production threshold. Therefore, in the studied watershed, the rainfall data with various durations were analyzed and ultimately, 31.5 mm rainfall in 30 minutes with 30-year return period was estimated. Before starting the experiment and applying the device in a field activity, it was calibrated by adjusting the adjustment air pressure pipe to apply the considered rainfall intensity.

Fig. 2: Rainfall simulator.

After installation of the device in the determined work units and after 30 minutes, the rainfall was stopped and the generated runoff was collected at the device outlet by a graduated cylinder and was transmitted to the laboratory along with the taken soil samples from proximity of each plot at the depth of 0-20 cm. in the laboratory, the runoff was passed through a filter paper and the remaining sediments were dried under 105 ^{0}C temperature for 24 hours in an oven, and then, the amount of sediments was measured and its concentration was calculated. Considering the obtained sediment volume and concentration, the produced sediment by the plot was calculated. Also, the soil samples were analyzed in the laboratory and several parameters were determined including: Soil moisture, electrical conductivity, bulk density, the pH of soil, the amount of lime (TNV), organic carbon, sand, silt, clay, soil texture, and cations in the soil containing the ions of sodium (Na +), magnesium (Mg ++) and calcium (Ca ++).

Statistical analysis:

After doing field and laboratory activities and recording the data in Excel software environment, SPSS 22 software was used for statistical analysis. At the first stage, the qualitative data were converted to quantitative data and then, being normal of the data was checked using Kolmogorov- Smirnov test. Then, the amount of impact and significance of each measured variable on the amount of erosion was investigated. Finally, linear multi-variable models were developed to estimate soil erosion using the variables affecting the amount of erosion. Since consistency of the achieved results with the real results is the required provision to determine the validity of a model, the following indices were used to determine the best model: Residual Analysis, Relative Error (RE), Root Mean Square Error (RMSE) and Coefficient of Efficiency.

Results:

The results of field and laboratory activities and estimated erosion as homogeneous units have been given in Tables 2 and3. Pearson correlation analysis was carried out among the measured variables including elevation, slope, land use, geology, erosive facies, vegetation cover logarithm, percentage of sand and gravel, percentage of bare soil, and pedologic parameters including soil moisture, electrical conductivity, bulk density, pH, logarithm of the amount of lime (TNV), amount of organic carbon, percentage of sand, silt and clay, soil cations containing sodium (Na+), magnesium (Mg ++) and calcium (Ca ++), permeability and erosion. The results have been presented in Table 4.

According to the correlation matrix given in Table 5, it is found that, the variables of land use, erosive facies, vegetation cover logarithm, percentage of sand and gravel, moisture, permeability, percentage of clay, bulk density and the amount of calcium show a higher correlation to the amount of erosion in the watershed. After making Pearson correlation matrix, the principal components were chosen using PCA test and applying it on the factors with high correlation. The results of PCA test are given in Table 5. Finally, the linear multi-variable model was provided to estimate erosion using the parameters affecting the amount of erosion. In regression analysis, the amount of erosion was considered as dependent variable and the variables of land use, cover logarithm, erosive facies, bulk density, permeability and clay percentage were considered as independent variables.

Enter stepwise regression analysis methods were tested. According to the results of residual analysis about the stepwise method (Fig. 1, 2), the cloud of the residuals do not follow any certain pattern and are scattered. Also, relative error and root mean square error is lower and higher coefficient of efficiency and lower number of inputs led to choose the equation obtained from stepwise method.

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Table 2: Results of the field and laboratory activities of rainfall simulator in each homogeneous unit in Torogh watershed.

Sand %	Silt %	Clay %	P.D gr/cm^3	B.D gr/cm^3	moisture %	pH	EC ds/m	O.C %	permeability	Erosive facies	Geology	Slope	Land use	Sample
24	65	11	2.54	1.63	1.32	7.9	0.62	0.25	5	SR	Qt1,Qt2	8%	DF	1
52	41	7	2.58	1.78	0.98	7.8	1.02	1.10	4	SRG	J1q, J1sh, R3J1, gr2, SD	21%	Ra	2
64	29	7	2.62	1.80	0.94	7.7	1.07	0.81	4	S	J1q, J1sh, R3J1, gr2, SD	50%	Ra	3
64	29	7	2.65	1.89	0.95	8.0	0.66	0.46	4	SR	J1q, J1sh, R3J1, gr2, SD	29%	Ra	4
62	27	9	2.29	1.46	1.31	7.9	0.65	0.42	5	SRG	J1q, J1sh, R3J1, gr2, SD	5%	DF	5
48	37	15	2.61	1.53	1.30	7.8	0.65	0.47	5	SRG	J1q, J1sh, R3J1, gr2, SD	44%	DF	6
46	39	15	2.60	1.50	1.33	7.8	0.65	0.45	5	SR	J1q, J1sh, R3J1, gr2, SD	23%	DF	7
30	59	11	2.48	1.61	1.47	7.8	2.71	0.50	3	SR	Ptu	47%	Ra	8
36	53	11	2.54	1.68	1.53	7.7	1.90	0.85	4	SR	Ptu	7%	Ra	9
53	38	9	2.60	1.73	1.24	7.8	1.14	1.37	4.5	SRG	Qc	11%	DF	10
36	48	16	2.48	1.51	0.87	8.0	0.75	1.35	3	SRG	Db	43%	Ra	11
51	32	17	2.55	1.54	1.17	7.9	0.78	1.95	5	SRG	Db	41%	DF	12

Table 3: The rest of results of the field and laboratory activities of rainfall simulator in each homogeneous unit in Torogh watershed.

Plot erosion (g)	Erosion of homogeneous unit)y/ton(	Sediment concentration (gr/lit)	Runoff volume (cc)	TNV %	Ca meq/lit	Mg meq/lit	Na meq/lit	elevation	Percentage of vegetation cover	Percentage of bare soil	Percentage of sand and gravel	sample
4.20	90.2	3.5	1200	24.5	3.2	2.2	0.9	1383	40	50	10	1
9.75	1249.0	7.8	1250	6.6	6.5	2.2	1.6	1474	12	33	55	2
18.48	2009.4	13.2	1400	5.4	7.1	1.9	1.6	1461	**8**	4**2**	50	3
7.92	1782.2	7.2	1100	3.2	3.9	1.8	0.9	1487	8	32	60	4
1.03	65.1	7.9	130	5.2	3.9	1.7	1.1	1526	30	35	35	5
5.50	428.0	8.6	640	5.0	3.8	1.6	1.2	1543	35	40	25	6
3.84	79.2	8.0	480	5.1	3.9	1.6	1.4	1538	35	3**5**	30	7
83.20	53305.3	26.0	3200	14.0	14.6	10.3	1.9	1221	12	72	16	8
11.44	1068.3	5.2	2200	17.6	8.1	9.0	2.2	1190	15	73	12	9
3.08	95.7	2.2	1400	11.5	6.2	3.8	1.1	1224	45	45	10	10
15.80	985.4	10.0	1580	16.4	4.5	1.9	0.9	1923	10	50	40	11
4.814	39.6	5.8	830	17.2	4.3	2.5	1.2	1941	40	35	25	12

Table 4: Results of Pearson correlation matrix (variables with a correlation greater than 0.5).

		Landuse	ErosionFaces	BD	Moisture	Ca	clay	LogCover	Stone	Penetrability	Erosion
Landuse	Pearson	1	-.354	.611*	-.556	.581	-.416	-.965**	.612*	-.878**	.911**
	Sig. (2-tailed)		.285	.046	.076	.061	.203	.000	.045	.000	.000
	N	12	12	12	12	12	12	12	12	12	12
ErosionFaces	Pearson	-.354	1	-.458	.036	-.282	.364	.344	-.163	.100	-.527
	Sig. (2-tailed)	.285		.157	.916	.401	.271	.300	.632	.771	.096
	N	12	12	12	12	12	12	12	12	12	12
BD	Pearson	.611*	-.458	1	-.405	.485	-.765**	-.581	.417	-.391	.733*
	Sig. (2-tailed)	.046	.157		.217	.131	.006	.061	.202	.234	.010
	N	12	12	12	12	12	12	12	12	12	12
Moisture	Pearson	-.556	.036	-.405	1	.015	.221	.664*	-.793**	.632*	-.616*
	Sig. (2-tailed)	.076	.916	.217		.966	.513	.026	.004	.037	.044
	N	12	12	12	12	12	12	12	12	12	12
Ca	Pearson	.581	-.282	.485	.015	1	-.413	-.401	.003	-.462	.502
	Sig. (2-tailed)	.061	.401	.131	.966		.207	.222	.992	.153	.115
	N	12	12	12	12	12	12	12	12	12	12
clay	Pearson	-.416	.364	-.765**	.221	-.413	1	.439	-.402	.187	-.538
	Sig. (2-tailed)	.203	.271	.006	.513	.207		.177	.220	.582	.088
	N	12	12	12	12	12	12	12	12	12	12
LogCover	Pearson	-.965**	.344	-.581	.664*	-.401	.439	1	-.753**	.845**	-.935**
	Sig. (2-tailed)	.000	.300	.061	.026	.222	.177		.008	.001	.000
	N	12	12	12	12	12	12	12	12	12	12
Stone	Pearson	.612*	-.163	.417	-.793**	.003	-.402	-.753**	1	-.456	.721*
	Sig. (2-tailed)	.045	.632	.202	.004	.992	.220	.008		.159	.012
	N	12	12	12	12	12	12	12	12	12	12
Penetrability	Pearson	-.878**	.100	-.391	.632*	-.462	.187	845**	-.456	1	-.710*
	Sig. (2-tailed)	.000	.771	.234	.037	.153	.582	.001	.159		.014
	N	12	12	12	12	12	12	12	12	12	12
Erosion	Pearson	.911**	.527	.733*	-.616*	.502	-.538	-.935**	.721*	-.710*	1
	Sig. (2-tailed)	.000	.096	.010	.044	.115	.088	.000	.012	.014	
	N	12	12	12	12	12	12	12	12	12	12

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Table 5: Principal components of PCA analysis.

	Component	
	1	2
Landuse	-.925	-.339
ErosionFaces	.078	.720
BD	-.380	-.824
clay	.164	.857
LogCover	.910	.341
Penetrability	.970	.019

Table 6: Regression models of erosion estimation by stepwise and Enter methods.

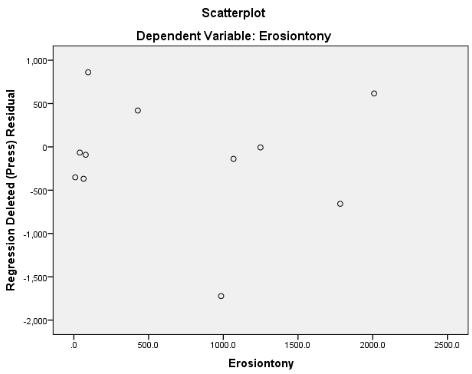
Explanation coefficient	Coefficient of Efficiency	Root Mean Square Error	Relative Error	Multi-variable erosion model	No.
0.928	0.83	148.2	2.8	E=869.8-1929.6(Log Cover)+1467.2(B.D)	1
0.956	0.8	167	16.2	E=808.06+6.94(Land use)-153.4(erosion faces)+1407.6(B.D)+16.57(clay)-2215.5(log cover)+163.2(penetrability)	2

Table 7: Variance analysis of equation No.1.

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	5147674.758	2	2573837.379	51.917	.000[c]
Residual	396607.034	8	49575.879		
Total	5544281.791	10			

Table 8: Variance analysis of equation No.2.

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	5300953.175	6	883492.196	14.523	.011[b]
Residual	243328.616	4	60832.154		
Total	5544281.791	10			



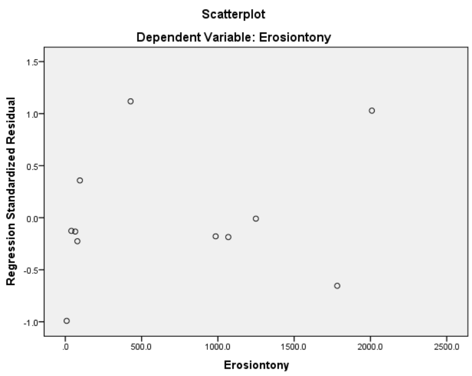


Fig. 3,4: Residuals analysis for validation of the equation.

Discussion and conclusion:

According to the results of correlation matrix (Table 4), among the variables having significant relationship to the amount of erosion, the variables of vegetation cover percentage, moisture, clay percentage and permeability have a negative relationship to the amount of soil erosion. About the impact of vegetation cover on the amount of erosion, it can be mentioned that, vegetation cover causes increase of soil permeability, runoff reduction, prevention of linear motion of runoff and increase of organic matter of the soil which are so important in soil conservation. About the effect of moisture on the amount of soil erosion, the studies conducted by the military of the US show that, the amount of soil erosion in moist slopes is 20-30% less than the dry slopes with inadequate moisture. Clay particles act like cement in the grains and cause increase of the soil particles' stability as well as reduction of erosion. About negative relationship of permeability and erosion it should be stated that, by increasing the infiltration rate in the soil, the amount of runoff and erosion would be lower; therefore, the soil permeability should be increased to reduce erosion. Stability of the soil particles and permeability are two important traits depending on the soil in terms of erodibility which are affected by mineral particles, organic matter and lime. The soil properties which cause increase of permeability or soil particle stability, cause to reduce erodibility. According to the results of PCA test which have been given in Table 5, two effective components on erosion were recognized; the first component includes the variables of land use, logarithm of vegetation cover percentage and permeability, and the second component includes the variables of erosive facies, soil bulk density, and clay percentage. Vahabi and Mahdian investigated the erosion in Taleghan watershed using rainfall simulator and introduced the factors of vegetation cover percentage and soil moisture as the factors affecting soil erodibility. Kavian *et al*. investigated a number of soil variables affecting the soil erosion and runoff in two research bases located in Sari city, Iran. They found that, percentage of organic matter, soil moisture and silt have had the highest impact on the forest lands. Abdinezhad *et al*. studied and evaluated the amount of runoff production in the units of geological formations of Zanjan province using rainfall simulator. They believe that, the impact of slope and climate on runoff volume and coefficient is significant. Nahtani showed that, among independent variables, only four factors including slope, cation exchange capacity, amount of dissolved calcium and the amount of silt have a determining role in production of runoff and sediment of loess and the mentioned factors control 80% of erodibility variations of the watershed. Arman in soil erosion modeling by rainfall simulator in the northern Alborz basin, reported the factors of runoff coefficient, the percentage of bare land, the rocks sensitivity to erosion, stones and pebbles percentage, mean annual precipitation, rainfall intensity, waterways length, soil moisture, average basin slope, land use type and soil texture as the factors affecting the erosion of the northern Alborz basin. Mohammadi in soil erosion modeling for arid and semi-arid climate of Iran in Sefidroud Watershed reported that, the factors of susceptibility of geological formation to erosion, canopy cover, percentage of stone and pebble, the percentage of bare soil, soil moisture, soil electrical conductivity, soil organic carbon content, gypsum content, silt percentage and soil carbon ions affect erosion. The results of the present study are consistent with the findings of Vahabi, Kavian. Nahtani, Arman and Mohammadi in some parameters.

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