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Modeling and simulation of watershed erosion: Case study of Latian dam watershed

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The Latian Dam is one of the important drinking water resources of Tehran, and it also has a role in preventing the flood. It is very important to keep the quality of water and preventing the dam from filling. Considering the special aspects of RUSLE model, it was used for estimating the amount of erosion in the watershed of dam including the sub-basins: Jajrood River, Kond River and Afjeh River, and then compared with the actual values measured. The results of modeling show that the degree of erosion is high because of steep slopes, lack of plant coverage. The results of modeling the amount of erosion in The Jajrood basin have been estimated about 1,524 ton/year, in Kond basin about 228.5 ton/year, and in the Afjeh basin about 103.1 ton/year. By using the results of the water samples analyses, the amount of phosphorus entering the reservoir by the rivers were calculated. This research shows that, by using the proper coverage in the basin, the amount of sediment and phosphorus entering the reservoir, decreases considerably.

Key words: Latian Dam, phosphorus, reservoir.

INTRODUCTION

Soil erosion can cause ecological changes in the region. With regard to the role of planning and study of human and natural changes in erosion, assessment and adaptation model applied to each region, it is important. Latian Dam watershed is one of the areas where soil erosion is serious; the study of soil erosion in the area, as one of the water sources of Tehran is very important, particular area, population expansion, land use changed faces (Water and Energy Center of Sharif University, 2003a). Human sewage entering the river increased risk of erosion and sedimentation, pollution and nutrients in the reservoir. Including research done in this area; Quantitative modeling of soil erosion using AHP (Analytic hierarchy process) in the watershed Latian (Maleki et al., 2011), evaluate the accuracy and efficiency of computer models **II SEDIMOT** in estimating runoff and sediment (Sadeghi, 1994), and the application and model evaluation M.P.S.I.A.C. Using satellite imagery, geographic information systems (GIS) in the sub-basin Lavarak (Tahmasebipoor, 1995) and comparison of models RUSLE and SWAT to estimate Erosions in the sub-basin Amameh (Poorabdollah, 2007). In this study, RUSLE model helping GIS system for modeling soil erosion in the watershed Latian was used. And modeling results are

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Table 1. The data used in the model.

S/N	Model inputs	Applied data
1	Slope steepness and slope length	GIS map 1:50,000 Scale
2	Rainfall erosivity	Rainfall intensity got from Tehran's Regional Water Organization for 2 years
3	Meteorology	Temperature and rainfall Values at the different sub-basins
4	Soil erodibility	The soil map (1:50,000), separate reports including: the percentage of silt, sand, organic materials, soil structure and soil.
5	Land-use	1:50,000 maps containing the layers of orchards, pastures and farmlands with the related reports from Iranian National Geography Organization

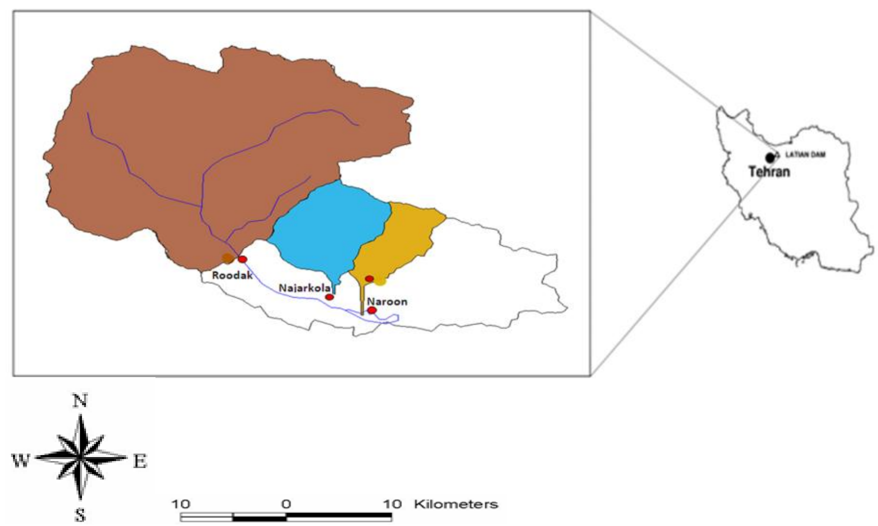

Figure 1. The location of stations and their upstream sub-basins.

compared with the actual values measured. The application of the RUSLE model has some advantages: (i) the data required are not very complex or unavailable in a developing country; (ii) this model is compatible properly with GIS software (Blonn, 2001), (iii) the use of this model is simplified by the presence of a graphical environment. Using this model with GIS information in raster format, the potential erosion can be found in any cell (Cox and Madramootoo, 1998). Also in regards to land use, based on management decisions, simulated erosion and its impact on the amount of sediment and phosphorus transport into the reservoir is shown. Study and modeling of the sub-basin Jajrood, and sub-basins kond and Afjeh is performed.

METHODS AND MATERIALS

The base equation of RUSLE model is as follows (Yazidhi, 2003):

$$A = LS \times R \times K \times C \times P$$

Where: A = the average annual soil loss (ton/ha/year); LS = the combination of the slope steepness and slope length (the factor without dimension); R = the rainfall erosivity factor; K = the factor of soil erodibility; C = the coefficient of plant coverage, and P = the coefficient of support practice.

The definition and application of every one of the above mentioned coefficients have been presented (Wischmeier and Smith, 1978; Desmet and Govers, 1996; Wischmeier et al., 1971).

The collected information about the watershed of Latian Dam is shown in Table 1. These stations together with their upstream sub-basins are shown in the Figure 1 and characterized in Table 2.

Input data

Figure 2 shows map of the river and its subdivisions, watershed boundaries and sub basins. Figure 3 shows the digital elevation map of the watershed (DEM) and the average slope values for each region. Figure 4 shows the type of vegetation in the watershed. Coefficients related to the vegetation which should be used in RUSLE model are shown in Table 3 and the values have been obtained from studies conducted in the region (Tehran's Agricultural Organization, 2002a).

Table 2. The specifications of measuring stations in the watershed of Latian dam.

Basin area (km^2)	Sub-Basin	Elevation (m)	Latitude	Longitude	River	Station
403	Garmabdar, Meygoon, Ahar, Emameh and Roodak	1700	35-53	51-32	Jajrood	Roodak
58	Kond	1670	35-49	51-38	Kond	Najarkola
31	Afjeh	1790	35-50	51-40	Afjeh	Naroon

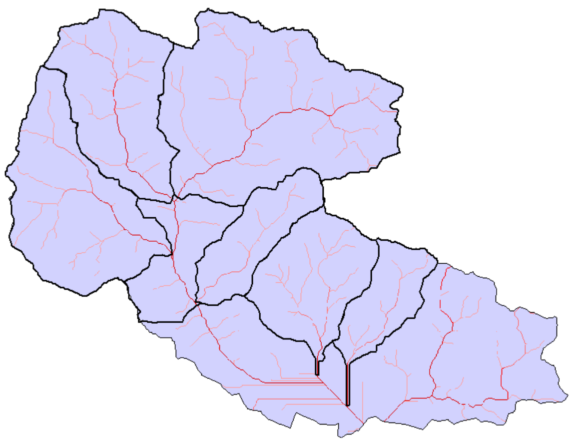

Figure 2. Distinguishing the boundaries of sub-basins with the help of arc view.

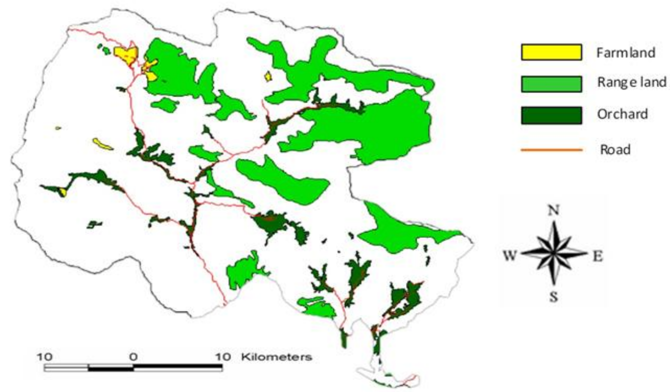

Figure 4. The map of plant.

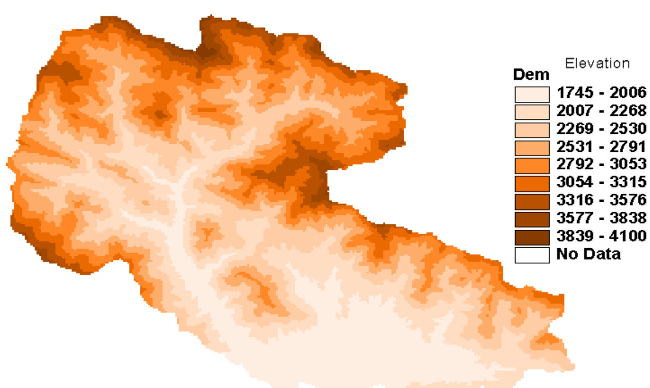

Figure 3. The DEM of the Latian Dam watershed.

The necessary inputs for the RUSLE model are: Average monthly temperature, the average amount of rainfall in month, the erosivity factor (R) and were obtained by studying the measured data in the stations (Tehran's Agricultural Organization, 2002b).

Soil types in this area include: Loamy, sandy loam, and clay loam. Types of Watershed soils are: 1 – Mountains; 2-hills; 3- flats and upper terraces; 4- Plains. Watershed land units, as part of the soil types are mentioned and Have the same physical characteristics, as of 1.1, 1.2, 1.3, 1.4, 2.1, 2.2, 3.1, 4.1 as shown in Figure 5 (Water and Energy center of Sharif University, 2003b).

The existing hydrological groups are shown in Table 4.

RESULTS AND DISCUSSION

The amounts of erosion, obtained from the model for any type of soil and any type of Land cover were presented for every sub-basin in Table 5. So, the whole amount of erosion per year in the basins of Roodak, Afjeh and Kond can be calculated by adding up the results of erosion in their sub-basins.

Due to the global equation erosion between any two regions with similar characteristics, whatever the place, the slope is greater or less vegetation or soil permeability is less, The amount of erosion in the area further. The result shows due to high slope and low vegetation in most areas, soil erosion is high.

Comparison with actual amounts and determining the model precision

A part of the eroded soil is transferred to downstream area by the flowing water in the form of sediment. This proportion is defined in the following way:

$$\text{Sediment delivery ratio (SDR)} = \frac{\text{The amount of sediment delivered to a point}}{\text{The amount of eroded soil at upstream of the point}}$$

To determine SDR and estimation of suspended load, the formulas proposed in this regard has been used (Foster, 2003).

Table 3. RUSLE input parameters for plant coverage.

Kind of plants	Canopy cover (%)	Falling height (m)	Residue	Canopy shape	Rock cover
Range land	50	0.2	Range litter	Rectangle	30
Farmland	30	0.3	The roots and branch residue	Rectangle	30
Orchard	35	2.1	Bushes and branches and leaves	Rectangle	30
barren land	-	-	-	-	30

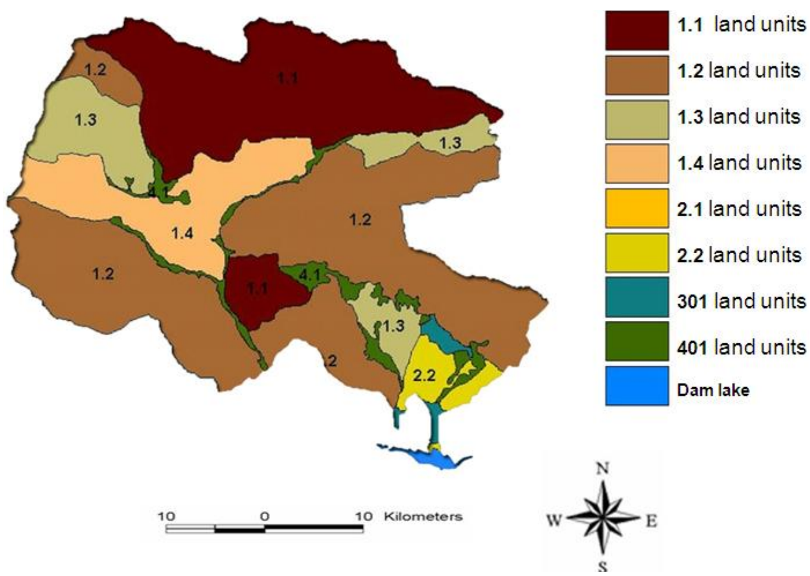

Figure 5. The map of evaluating the sources and the capability

Table 4. Hydrological groups of soil in the Latian Dam watershed.

Hydrological group	Minimum permeability (cm/h)	Runoff generation potential
A	7.5 - 11.5	Low
B	3.5 - 7.5	Low to moderate
C	1.5 - 3.5	Relatively high
D	< 1.5	High

The summary of the results (Including sediment calculated values and measured values and Model precision) are shown in Table 6.

Estimating the phosphorus load entering the water due to erosion

Total phosphate in the water consists of dissolved phosphorus and particulate phosphorus. The phosphorus existing in the sediments from soil erosion is particulate phosphorus. The amount of phosphorus in the unit of suspended sediment load is calculated from dividing particulate phosphorus load by suspended sediment load. This amount can be used for estimating the particulate phosphorus load entering the water after using the management procedures for preventing the erosion (the change of land-use) and investigating the change of the amount of phosphorus using these procedures. For calculating the phosphorus load, the results of the tests done by Sharif University of Technology were used. Figure 6 shows the variation of phosphorus-discharge at the mentioned stations.

The amounts of particulate phosphorus are shown in Table 7 based on the results of existing data.

Table 5. The results of erosion modeling in the sub-basins.

Sub-basin	The type of soil	Permeability (cm/h)	Land cover	Slope (degree)	Area (km^2)	Erosion (ton/ km^2/year)	Erosion (ton/year)
Garmabdar	SL (1.1)	1.5	P	23.7	25.8	3362	86833
			F-L	23.6	0.173	425.8	73.67
			B-L	26.7	52.8	4482	236844
	L (1.3)	5.5	P	22.2	10.0	3138	31376
			O	16.4	1.16	2465	2860
			B-L	19.8	3.49	3138	10950
	L (1.2)	2.5	P	23.7	23.6	3810	89953
			B-L	26.2	19.4	4931	95701
	SL (4.1)	5.5	O	18.1	0.76	2241	1703
			B-L	17.7	1.52	2241	3407
	SL (1.4)	2.5	O	15.8	0.871	2465	2147
			B-L	22.6	15.4	3586	55093
			P	27.9	2.75	3810	10481
Meygoon	SL (1.1)	1.5	F-L	18.3	1.94	336.2	650.8
			P	20.3	8.50	2913	24773
			B-L	25.7	21.5	4482	96531
	L (1.2)	2.5	F-L	20.7	0.331	358.6	118.7
			P	14.2	0.217	1860	403.7
			B-L	21.9	8.19	3586	29350
	L (1.3)	5.5	B-L	24.8	18.4	3362	61822
			O	18.5	0.600	2465	1479
	SL (4.1)	5.5	B-L	18.4	1.96	2465	4832
			O	11.5	1.23	1345	1655
	SL (1.4)	2.5	O	18.5	0.917	2914	2672
			F-L	24.6	0.283	403.4	114.2
			B-L	25.0	12.6	3810	48173
Ahar	L (1.3)	4	B-L	27.8	10.2	3810	38679
	SL (1.4)	5.5	B-L	25.2	24.7	3362	83169
			F-L	20.7	0.041	448.2	18.38
	SL (4.1)	5.5	B-L	19.1	1.57	2465	3878
			O	13.2	0.520	1569	815.8
	L (1.2)	2.5	O	14.8	1.76	2241	3940
			F-L	10.4	0.162	269	43.57
			B-L	23.9	55.2	3810	21085
Roodak	SL (1.4)	2.5	O	11.1	0.612	1591	973.8
			B-L	22.0	4.78	3586	17155
	SL (4.1)	5.5	O	10.4	0.290	1233	357.5
			B-L	22.4	1.79	3138	5626
	L (1.2)	2.5	P	22.5	1.19	3362	4000
			O	14.9	0.085	2465	210
			B-L	22.8	4.88	3810	18574
	SL (1.1)	1.5	B-L	27.2	7.58	4931	37378
	L (1.2)	2.5	O	5.7	0.212	672.3	142.5
			B-L	19.3	15.4	3138	48260
Emameh	L (1.2)	2.5	P	29.9	5.81	4483	26042
			O	26.8	0.472	4706	2221

Table 5. Contd.

			B-L	24.0	12.3	4706	57969
	SL (4.1)	5.5	O	8.9	2.18	1009	2197
			B-L	13.1	0.711	1726	12267
	SL (1.1)	2.5	O	16.1	0.073	2465	180.0
			B-L	22.2	8.35	3586	29952
	L (1.2)	2.5	P	26.6	2.82	4034	11380
			B-L	22.2	4.38	4482	19641
Afjeh	L (1.2)	2.5	O	22.0	0.307	3586	1101
			P	29.3	3.08	4258	13128
			B-L	25.3	15.0	4931	73894
	SL (3.1)	5.5	O	12.7	0.27	1569	423.6
			B-L	18.2	1.37	2465	3375
	SL (4.1)	5.5	O	10.2	1.68	1188	1990
			B-L	8.7	1.39	1031	1427
	CL (2.2)	2.5	B-L	12.5	4.53	1031	4672
			O	11.3	0.984	874.1	860.1
	CL (2.2)	2.5	B-L	14.7	1.68	1233	2075
			O	10.6	0.09	806.8	72.61
	SL (3.1)	5.5	O	2.30	0.34	150.2	51.50
			B-L	2.00	0.336	145.7	48.95
Kond	L (1.2)	2.5	P	31.3	6.46	4931	31827
			O	19.5	0.094	3362	316.00
			B-L	29.4	14.4	6051	87166
	SL (4.1)	5.5	O	11.0	1.24	1390	1716
			B-L	13.5	4.01	1860.	7465
	SL (3.1)	5.5	B-L	22.1	1.38	3138	4330
	L (1.3)	5.5	O	12.6	2.21	2062	4563
			B-L	13.5	8.5	2241	19050
	CL (2.2)	2.5	B-L	15.1	3.09	1345	4155
	L (1.2)	2.5	O	12.0	0.536	1927	1033
			P	22.8	1.93	3586	6921
			B-L	21.5	13.4	4482	59929

SL=Sandy loam, L= Loamy, CL= Clay loam; F= Farm land, Barren land, Pasture=P, Orchard=O.

Table 6. The results of calculated sediment load by the model and measurement.

Station	Soil loss (ton/year)	SDR (%)	Estimated total sediments (ton/year)	Calculated suspended load (ton/year)	Actual suspended load (ton/year)	Model precision (%)
Roodak	1524	16	243.8	187.6	216.0	86.8
Najarkola	228.5	24.7	56.49	43.38	50.09	86
Naroon	103.1	28	288.9	22.22	40.64	55*

*In Afjeh because the lack of actual suspended load data, this number (40637) in the above table is not a good indicator for this parameter. Therefore the obtained precision is not a suitable value for model in Afjeh basin.

The change of land-uses and estimating the erosion variation

Now, with the change of the land-uses in the basin according to the Figure 7, erosion modeling was performed. The results of running the model again are presented in Table 8. The compared results are presented in Table 9.

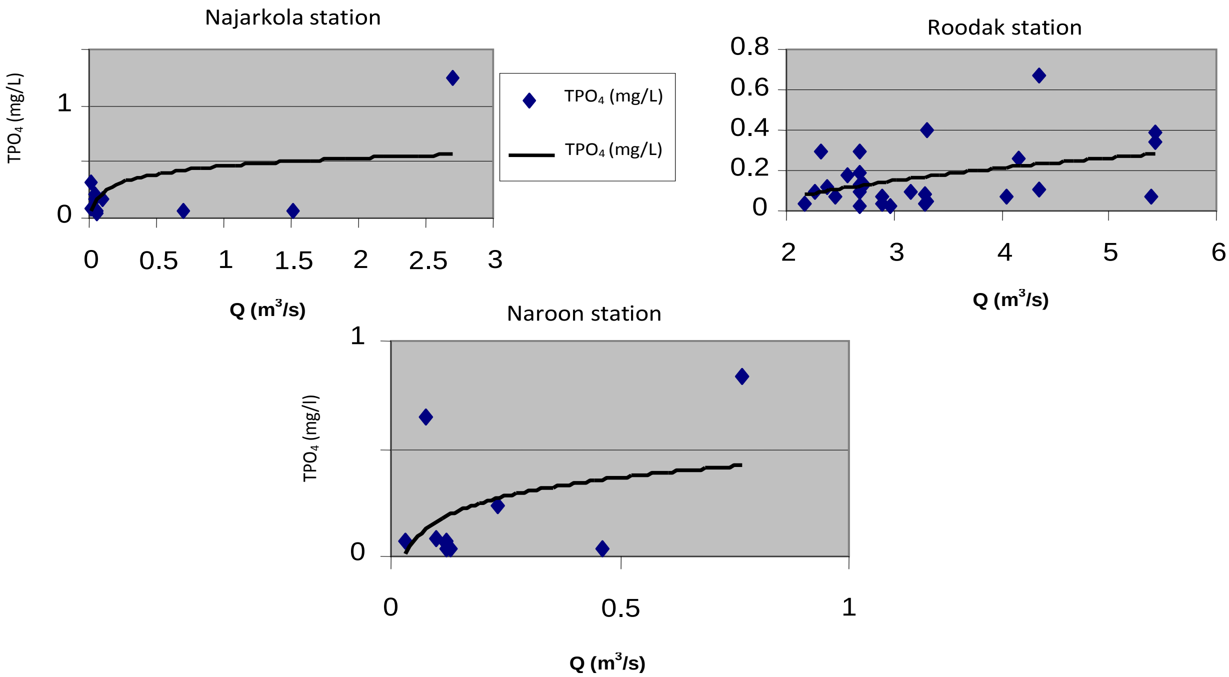

Figure 6. Variation of total phosphate (TPO_4) and river discharge (Q) at the Najarkola, Roodak and Naroon stations.

Table 7. The amounts of particulate phosphorus due to erosion in the stations.

Basin	The particulate phosphorus resulted from erosion (ton/year)	The amount of phosphorus in the suspended sediment load (g/ton)
Roodak	12.10	56.21
Kond	1.587	31.7
Afjeh	0.295	7.3*

* In Afjeh because the lack of actual suspended load data, this number in the above table is not a good indicator for this parameter.

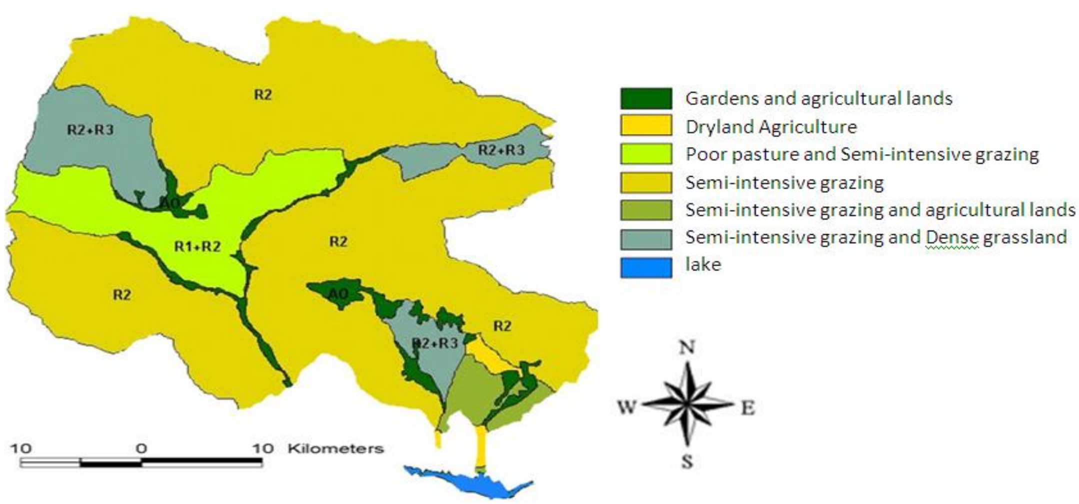

Figure 7. The map of present land use.

Table 8. The result of erosion modeling in the basin with new land.

Basin	Area	The recommended land-use	Slope (degree)	Area (km^2)	Erosion (ton/km^2 /year)	Erosion (ton/year)
Garmabdar	1.1	R2	25.98	78.90	1569	123700
	1.3	R2+R3	22.39	14.60	538	7864
	4.1	AO	15.58	2.28	1569	3773
	1.4	R1+R2	24.32	19.00	2465	46840
	1.2	R2	25.58	42.90	1726	73980
Meygoon	1.1	R2	25.42	31.90	1524	48554
	1.2	R2	21.10	8.73	1345	11739
	1.3	R2+R3	24.93	19.00	650	12348
	1.4	R1+R2	22.65	13.80	2174	30043
	4.1	AO	17.43	3.19	1905	6077
Ahar	1.2	R2	24.15	57.11	1905	108793
	1.3	R2+R3	28.08	10.15	1053	10691
	1.4	R1+R2	25.22	24.77	2689	66616
	4.1	AO	21.28	2.09	2465	5457
Roodak	1.1	R2	29.10	7.55	1927	14556
	1.2up	R2	23.03	6.15	1905	11721
	1.2down	R2	21.18	15.60	1726	26921
	1.4	R1+R2	22.50	5.41	2465	13344
	4.1	AO	20.26	2.08	2465	5428
Emameh	1.1	R2	23.73	8.46	1793	15161
	1.2up	R2	26.90	18.61	2241	41708
	1.2down	R2	24.97	7.15	2107	15054
	4.1	AO	12.25	2.89	1277	3688
Kond	1.2up	R2	29.78	20.96	2465	51672
	1.2down	R2	21.33	15.86	1748	27725
	4.1	AO	12.88	5.25	1412	7413
	1.3	R2+R3	13.25	10.71	426	4562
	3.1	DF	21.93	1.37	538	739
	2.2	R2+F	15.10	3.06	359	1098
Afjeh	1.2	R2	25.91	18.37	1121	20582
	4.1	AO	9.43	3.06	874	2674
	2.2up	R2+F	12.02	5.53	269	1488
	2.2down	R2+F	14.55	1.75	336	588
	3.1up	DF	16.72	1.65	381	627
	3.1down	DF	2.49	0.679	29.1	19.8

Table 9. The comparison of the results of erosion modeling in the present condition with the suggested land-use conditions.

Basin	The erosion with new land-use (ton/year)	The erosion with the former land-use (ton/year)	The calculated suspended load with new land-use (ton/year)	The percentage of erosion reduction	The particulate phosphorus entering after the new land-use (ton/year)
Roodak	703.5	1524	86.58	54	4.87
Kond	93.21	228.5	17.71	59	0.56
Afjeh	25.98	103.1	5.595	75	0.041

Conclusion

By comparing the results of sediment load calculated by the model with the actual values, the precision of the model in estimating the erosion and the sediment yield for the upstream basins of Roodak, Kond and Afjeh was respectively of 86.8, 86 and 55%, although depend on the percentage assumed valid for SDR. These results show the suitable precision of the model for Roodak and Kond basins (if in the basin of Afjeh, more measuring data for suspended load could be gathered, the more precise outputs of the model can be obtained in this basin).

The results show that the use of vegetation to areas without coverage and use of appropriate vegetation density appropriate land, the amount of erosion and the phosphorus load are reduced considerably. As a result, by using the suggested methods of land-uses for the basins discussed so far, the degree of erosion reduction in the upper basins of Roodak is about 54%, for Kond basin is about 59% and in the basin of Afjeh is about 75%.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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