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Comparison of empirical models to estimate soil erosion and sediment yield in micro catchments

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Abstract

Assessment of sediment yield in soil conservation and watershed Project and implementation plan for water and soil resources management is so important. Regarding to somewhere that doesn't have enough information and statistical data such as upper river branches, Empirical models should be used to estimate erosion and sediment yield. However the efficiency and usage of these models before calibration isn't clear. In this research, the measurement of erosion and sediment yield of 10 basins upstream of reservoirshas been estimated by RUSLE and MPSIAC empirical models.In order to compare means between measured and estimated datat-test method was applied.Theresults indicated no significant differences between means of measured and estimated sediment yield in MPSAIC model in 5% level. In contrast, T-test showed contrary results in RUSLE model. Then the applicability and priority of two models were examined by statistical methodssuch as MAE and MBE methods. By regarding to accuracy and precision, MPSIAC model placed in first priorityto estimate soil erosion and sediment yield and has minimum value of MAE=0.79 and MBE = -0.59.

Keywords: Erosion-Sediment models, MPSIAC, RUSLE, Micro Catchments

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Introduction

Soil erosion is the most widely recognized and most common form of land degradation and, therefore, a major cause of falling productivity (Stocking and Murnaghan, 2001). It is a natural process and generally aggravated by human intervention, and exceeds the rate of soil regeneration. Estimating soil erosion and sediment yield needs complete recognize of affected factors, but cognition of these parameters are so difficult because of complexity of soil erosion phenomena.

In recent decades, models have been built (empirical, conceptual, or physically based) in order to represent and to quantify the processes of detachment, transport, and deposition of eroded soil, with the aim of implementing assessment tools for educational, planning, and legislative purposes (Renschler and Harbor, 2002). Since the phenomena are complex and depend on many parameters, calibration of models is difficult, especially because field data are usually not sufficient and relate to small spatial and temporal contexts.

Methods for estimating sediment yieldwere first developedfor the analysis of the effects of agricultural practices using empirical models to evaluate soil erosion and sediment yield in watersheds without statistical data and information is inevitable. Empirical models have been and are still used because of their simple structure and ease of application. One of the most important problems with empirical models of soil

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erosion is its lack of accuracy in processing the huge number of data which should be digitalized by GIS system and analyzed by mathematical models MPSIAC is an empirical model to estimate the quantity and quality of sediment. In fact quantifying and digitalizing the sediment data is an important breakthrough in sediment assessment models development (Nearing et al., 1999). This problem could be partially solved by estimating models (Lufafa et al., 2003). Since soil erosion is a product of few different interacting factors, there is not a simple model to assess all the contributing elements in the same time (Daroussin and King, 2001). The Universal Soil Loss Equation (USLE) is the most widely used empirical erosion model (Wischmeier and Smith, 1965). It estimates soil erosion from an area simply as the product of empirical coefficients, which must therefore be accurately evaluated. Originalvalues of such coefficients were derived from field observations in different areas within the eastern part of the U.S., but they have been expanded with time using information gathered by researchers who have applied the USLE (and derived models) in different countries in the world (Renard et al., 1997). The MPSIAC model (PSAIC, 1986) was developed primarily for application in arid and semi-arid areas in the southwestern USA, and is believed to appropriate for the same environmental conditions in Iran (Sadeghi, 1993). Both the MPSIAC and the RUSLE models are factor-based, which means that a serious of factors, each quantifying one or more processes and their interactions, are combined to yield and overall estimation of soil loss. As a consequence,attention must be paid to the reliability of results whenan application is made outside the range of experimentaland calibration conditions. This research aimed to assess the evaluation of empirical models, MPSIAC and RUSLE, to estimate soil erosion and sediment yield in comparison with measured sediments deposits in basins upstream of reservoirs over West Azerbaijan province, Iran.

Materials and Method

In this study 10 basins upstream of reservoirs were selected in west Azerbaijan province, Iran. All sediment yields from the reservoirs have been caught and they don't have the time to overflow. The properties of micro catchments presented in table 1.

Table 1. The properties of basins upstream of reservoirs

Rows	Micro catchments	Drainage Area(ha)	Basin perimeter(m)	Basin Length(m)	Basin slope	Channel slope	Drainage density
1	Ghaziabad	495.6	4008	4008	39.67	11.3	1.1
2	Emamkandi	181.7	2284	2284	50.61	20.9	2.03
3	Rabat	689.2	5690	5690	23.1	7.02	1.24
4	Kulij	780.9	3025	3025	27.24	6.3	1.30
5	Ashtarmol	344.5	1923	4951	23.76	10.9	1.82
6	Silveh	79	3350	3350	11.5	11.1	2.78
7	Khre	117.5	1923	1923	17.00	10.9	1.88
8	reyhanloo	136	2425	2415	10.80	4.9	1.68
9	gharaaghaj	125.8	1024	1024	25.92	13.7	2.06
10	Gulehguleh	122.7	2880	2880	14.72	10.4	3.00

For estimating soil erosion and sediment yield in micro catchments, MPSIAC and RUSLE empirical models were used and factors affecting sedimentation counted and evaluated.

The RUSLE model

RUSLE was developed to incorporate new research since the earlier USLE publication in 1978 (Wischmeier and Smith, 1978). Agriculture Handbook 703 (Renard et al., 1997) is a guide to conservation planning with the RUSLE.

The underlying assumption in the RUSLE is that detachment and deposition are controlled by the sediment content of the flow. The erosion material is not source limited, 34 but the erosion is limited by the carrying capacity of the flow. When the sediment load reaches the carrying capacity of the flow, detachment can no longer occur. Sedimentation must also occur during the receding portion of the hydrograph as the flow rate decreases. The basic form of the RUSLE equation has remained the same, but modifications in several of the factors have changed. Both USLE and RUSLE compute the average annual erosion expected on field slopes and are shown in equation 1.

$$A = R.K.L.S.C.P \quad \text{(Eq. 1)}$$

Where: R is the rainfall factor, computed on the basis of rainfall energy and the maximum 30-min intensity of a rainfall, K is the soil erodibility factor, which is function of soil characteristics; L is the slope length factor, S is the slope steepness factor; C is the cropping-management factor, that is function of land use type, and P is the erosion-control practice factor (usually contours, strip cropping, or terraces).However, significant changes to the algorithms used to calculate the factors have been made in the RUSLE (Renard et al., 1994). The *R* factor has been expanded to include the Western United States and corrections made to account for rainfall on ponded water. RUSLE to be applied at smaller time scales.

The MPSIAC model

This model was created to estimate the soil erosion according to nine factors consisting of, geological characteristics, soil, climate, runoff, topography, vegetation cover, land use and present soil erosion (PSIAC, 1968).Johnson and Gembhart (1982) improved the original model to have a more accurate estimate of the sedimentation (equation, 2).

$$Qs = 0.253e^{0.036R} \qquad \text{(Eq. 2)}$$

Where: Qs= sedimentation (t/ha/year), R= sedimentation rate, e = 2.718.

The relationship between soil erosion and sedimentation in MPSIAC model and the specific erosion in MPSIAC model is calculated by SDR Coefficient (Sediment Delivery Ratio) by the following equation 3.

$$\text{Log(SDR)} = 1.8768 - 0.14191 \log (10A) \qquad \text{(Eq. 3)}$$

Where: A= the area of watershed (mail^2)

Table2: The effective factors and their points calculation formula in MPSIAC model

The effective factors	The points calculation formula	Explanation Parameter
Geology	Y1=X1	X1: stone sensitive point
Soil	Y2=26.67K	K : erodibility factor in USLE
Climate	Y3=0.2X3	X3 : precipitation intensity with 2 year interval return
Runoff	Y4=0.006R+10Qp	R : annual runoff depth (mm), Qp:annual specific discharge
Topography	Y5=0.33S	S : average watershed slope (%)
Land vegetation cover	Y6=0.2X6	X6 : bare soil (%)
Land use	Y7=20-0.2X7	X7 : canopy cover (%)
Surface erosion	Y8=0.25X8	X8 : points summation in BLM model
Gully erosion	Y9=1.67X9	X9 : point of Gully erosion in BLM model

Sediment yield of basins upstream of reservoirs was determined by mapping. For this purpose, over sediment reservoirs divided to equal networks and depth of sediment in each of the intersection points of the network through the reservoir was measured by borehole and auger. The volume of sedimentation obtained by topography maps. Than to determine the weight of sediments, specific bulk density of sediments was obtained by digging in few points in several depth of soil profile. Finally the weight of deposits obtained from multiplying of specific bulk density and the volume.

For comparison the estimated amount of sediment yield of empirical models with measured in the reservoirst-student test was used. To evaluate empirical models, two MAE and MBE statistical parameters were used. MAE is an indicator of error in the results and MBE indicates the biass of the results obtained through the applied models. When MAE and MBE are 0.00 or near to naught, the applied model simulates the fact well. However, as far as its amount is farther than 0.00, it implies to less precise and more bias. How the parameters MAE and ME are calculated, has been indicated as follow:

$$MBE = \frac{\sum_{i=1}^{n}(Rs - Ro)}{n} \qquad \text{(Eq. 4)}$$

$$MAE = \frac{\sum_{i=1}^{n}|Rs - Ro|}{n} \qquad \text{(Eq. 5)}$$

Where: R_s is the estimated value, R_o is the measured value and N is No. of the data.

Results and Discussion

Shapiro-wilk test conducted to see if the data were of normal distribution, indicated that the data of measured sediment yield were normal and coefficient was less than 0.05 and skewness coefficient less than 1.Results of measured sediment yield in each of basins upstream of reservoirs presented in table 2. Specific sediment yield for all micro catchments showed the minimum sedimentation inKhere micro catchment with 0.274 m^3/ ha/ year and maximum specific sediment yield in Rehanloo micro catchment with 12.04 m^3/ ha/ year.

Table 3. Measured sediment yield in basins upstream of reservoirs

Micro catchments	Total sedimentation (m^3/ha/yr)	Annual sedimentation (m^3/ha/yr)	Specific sediment rate (m^3/ha/yr)
Ghaziabad	3051	399	0.68
Emamkandi	1316	188	1.03
Rabat	6727	1121.2	1.62
Kulij	4183	380.3	0.487
Ashtarmol	4597	574.6	1.67
Silveh	620	77.5	0.98
Khre	355	32.27	0.274
reyhanloo	13100	1637.5	12.04
gharaaghaj	5019	456	3.62
Gulehguleh	1470	210	1.71

The points of effective factors on sedimentation MPSIAC and RUSLE model for micro catchments shown in table 4 and 5.Results of table 3 showed that minimum sedimentation is 1.12 m^3/ ha/ year in Ashtarmol micro catchment and maximum sedimentation is 4.21 m^3/ ha/ year in Rehanloo basin. The correlation coefficient of sedimentation between estimated and measured values in MPSIAC model is 0.91. T-test results between estimated data in MPSIAC model and measured one equal to 0.48 and indicated no significant difference in 5% level. According to RUSLE model, minimum sediment yield equal to 0.79m^3/ ha/ year for Silveh micro catchment and the maximum is 7.52 m^3/ ha/ year in Ghaziabad basin. In RUSLE model the correlation coefficient between measured and estimated data is -.031 and shows negative relation.

Based on the information presented in table 5, it is confirmed that MPSIAC model with the lowest MAE and MBE (MAE=0.79 and MBE = -0.59) would be the most superior model to estimate soil erosion and sediment yield in micro catchments.

Table 4. Evaluation points for nine affecting factors in MPSIAC model in basins upstream of reservoirs

Factor	Micro catchments									
	Ghaziabad	Emamkandi	Rabat	Kulij	Ashtarmol	Silve	Khre	Reyhanloo	Gharaaghaj	Gulegule
Geology	4.5	4.80	5.5	4.00	4.10	4.00	4.50	7.40	6.60	5.50
Soil	5.33	5.00	5.17	6.83	4.67	6.83	5.67	6.67	5.83	7.17
Climate	0.61	0.72	0.65	0.65	0.65	0.65	0.72	0.37	0.72	0.47
Runoff	8.98	10.84	6.86	8.29	9.95	10.19	10.96	11.09	10.86	7.72
Topography	13.06	16.70	5.38	8.97	7.82	3.79	5.61	2.61	8.54	4.85
Land vegetation cover	13.00	11.80	8.20	11.00	8.00	8.00	13.00	15.00	16.00	12.00
Land use	5.00	9.34	6.60	4.40	5.40	6.00	5.00	9.00	11.00	6.00
Surface erosion	7.75	9.00	11.00	7.75	10.25	9.00	8.25	17.25	13.25	11.00
Present soil erosion	1.68	1.67	6.68	3.34	1.67	6.68	1.67	20.04	6.68	5.01
Sediment rate	5.93	69.86	59.03	55.24	52.50	55.15	55.38	89.04	79.48	59.72
Sediment yield (m3/ha/yr)	1.46	2.09	1.27	1.23	1.12	1.22	1.24	4.21	2.95	1.45
Sediment yield (t/ha/yr)	2.18	3.13	1.9	1.84	1.67	1.84	1.86	6.3	4.42	2.17

Table 5. Evaluation points of six factors in RUSLE model in basins upstream of reservoirs

Factors	Micro catchments									
	Ghaziabad	Emamkandi	Rabat	Kulij	Ashtarmol	Silve	Khre	Reyhanloo	Gharaaghaj	Gulegule
R	27.09	24.45	49.85	24.75	50.56	24.22	30.80	26.55	25.19	24.93
K	5.33	5.00	5.17	6.83	4.67	6.83	5.67	6.67	5.83	7.17
LS	26.35	24.75	18.30	16.23	21.88	10.90	17.50	12.64	18.13	10.91
C	0.45	0.4	0.2	0.23	0.2	0.2	0.44	0.4	0.56	0.35
P	1	1	1	1	1	1	1	1	1	1
Erosion rate (m^3/ha/yr)	13.19	9.31	7.25	4.86	7.94	2.78	10.34	6.88	11.48	5.25

Based on the information presented in table 6 and 7 has been indicated that the correlation coefficient between measured and estimated data obtained 0.91 in MPSIAC model and the t-test results become 0.48, indicated there was no significant difference in 5% level. In contrast, T-test showed contrary results in RUSLE model.

Table 6. The correlation coefficient and significant difference test in MPSIAC and RUSLE models

Pairs	Models	N	Correlation	Sig.
Pair 1	MEAS & PSIAC	10	0.91	0.000
Pair 2	MEAS & RUSLE	10	0.13	0.972

Table 7. The t-test results in MPSIAC and RUSLE models

pairs	Models	Paired Differences Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Pair 1	MEAS - PSIAC	0.62	2.73	0.86	0.72	9	0.480
Pair 2	MEAS - RUSLE	-3.66	4.38	1,33	-2.64	9	0.027

According to the information presented in table 8, it is confirmed that MPSIAC model with an error rate -.59 and bias rate 0.79 is more preciseness for the estimation of sediment yield, while RUSLE model is more bias compared to MPSIAC model, therefore considering the preciseness and bias in MAE and MBE, MPSIAC model would be the most superior model. The rate of bias and preciseness has been shown in table 8 and 9.

Table 8. The error and bias values in MPSIAC model to estimate sediment yield

Micro catchments	Measured sediment yield	Estimated sediment yield	MAE	MBE
Ghaziabad	0.68	3.15	0.78	0.78
Emamkandi	1.03	4.64	1.06	1.06
Rabat	1.62	2.85	0.16	-0.35
Kulij	0.49	2.72	0.74	0.74
Ashtarmol	1.67	2.62	0.38	-.055
Silveh	0.98	2.62	0.24	0.24
Khre	0.27	2.59	0.97	0.97
reyhanloo	12.04	8.97	3.30	-7.83
gharaaghaj	3.62	4.73	0.22	-0.67
Gulehguleh	1.71	3.13	0.04	-0.26
Total results of MAE and MBE value			0.79	-0.59

Table 9. The error and bias values in RUSLE model to estimate sediment yield

Micro catchments	Measured sediment yield	Estimated sediment yield	MAE	MBE
Ghaziabad	0.68	3.29	3.97	2.12
Emamkandi	1.03	3.10	1.77	1.4
Rabat	1.62	9.07	1.61	7.27
Kulij	0.49	6.45	1.34	5.83
Ashtarmol	1.67	3.95	4.65	1.56
Silveh	0.98	2.58	0.72	0.72
Khre	0.27	2.60	8.61	1.55
reyhanloo	12.04	12.73	3.04	-3.04
gharaaghaj	3.62	9.42	1.19	3.58
Gulehguleh	1.71	6.61	5.49	2.94
Total results of MAE and MBE value			3.24	2.39

The results obtained with the present investigation, namely the selection and recommendation of MPSIAC empirical model are agreed with those published by Renard et al., (1997) and Rahmani et al., (2006). Studying on soil erosion and sediment yield in micro catchments showed Khre and Rehanloo sub basins have minimum and maximum annual sediment yield respectively. Khre sub basin with pasture land use and sandstone lithology has minimum sediment yield (0.247 m^3/ha/yr) and Rehanloo with land use under cultivation and Marn lithology has maximum sediment yield(12.04 m^3/ha/yr). This variation of sediment yield based on land use and lithology, they are two base factors affected soil erosion and sediment yield. This results are Compatibility with those published by Rastgoo(2007) and Rahmani et al.,(2006). Essential performances to control soil erosion in micro catchments are forest and pasture reclamation, accurate tillage, restricts burning herbaceous leftovers and terracing gradient area. The relation between estimated sediment yield in MPSIAC model and measured one (%91) indicated MPSIAC model has high capability to assess soil erosion and sediment yield in basins upstream reservoirs

This research totally showed MPSIAC empirical model has the capability to estimate soil erosion and sediment yield in micro catchments. The results of this model can be used for schematization and watershed project with high accuracy and precision.

References

Daroussin, J., King D., 2001. Mapping erosion risk for cultivated soil in France, *Catena* 46, 207-220.

Jhonson, C. W., Gembhart, A.C., 1982. Predicting sediment yield from Sagerbrush range lands. *USDA SEAARM Western Series* 26, 145-156.

Lufafa, A., Tenywa, M.M., Isabirye, M., Majaliwa, M.J.G., Woomer., P.L., 2003. Prediction of soil erosion in alake victoria basin catchment using a GIS- based universal soil loss model. *Agricultural Systems* 76, 883-894.

Nearing, M. A., Govers, G., Norton., L.D., 1999. Variability in soil erosion data from replicated plots. *Soil Science Society America Journal* 63, 1829-1835.

Rahmani, M., Hadian Amri, M,E., Mollaaghajanzadeh., S., 2004. Application satellite data and GIS to estimate soil erosion and sediment yield in MPSIAC model (case study: Shrafkhane watershed, Shabestar). *Collection of erosion and sediment papers*, 2004.

Rastgoo Ghahreman, S., Senayeenejad, H., Daavari, K., Khodashenas, S. 2006. Estimating soil erosion and sediment yield in Tang Konasht watershed with MPSIAC , EPM and GIS. *Agriculture and Natural Resources Journal* 91-104

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE), *USDA-ARS, Agricultural Handbook No*. 703.

Renschler, C.S., Harbor, J., 2002. Soil erosion assessment tools from point to regional scales-the role of geomorphologists in land management research and implementation. *Geomorphology* 47, 189–209.

Sadeghi, H., 1993. Comparison of some erosion potential and sediment yield assessment models in Ozon-Dareh sub-catchment. Proceedings of the National Conference on Land Use Planning, Tehran, Iran 1993.

Stocking, M., Murnaghan, N., 2001. Handbook for the Field Assessment of Land Degradation. London: Earthscan Publication, UK.

Wischmeier, W.H., Smith, D.D., 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains: guide for selection of practices for soil and water conservation, *USDA Agricultural Handbook*, No. 282.

Wischmeier W.H., Smith D., 1978. Predicting rainfall erosion losses: a guide to conservation planning. *USDA Agriculture Handbook* No. 537.