Sensitivity Analysis of MPSIAC Model

Najmeh Behnam[A], Mansoor Parehkar[B], Ebrahim Pazira[C]

[A]M.Sc. Student of Islamic Azad University, Science and Research Branch-Tehran, Iran. Email: najmebehnam@yahoo.com
[B]Faculty member, Research Institute for Water Scarcity and Drought in Agriculture and Natural Resources (RIWSD), Tehran, Iran.
[C]Head of Soil Science Department, Islamic Azad University, Science and Research Branch-Tehran.

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Abstract. MPSIAC is currently known as an appropriate method to measure sediment of Watershed basins of the country while there has not been any sensitivity analysis so far for this method. In this study, required data for MPSIAC model were gathered from six basins; Amame-Kamarkhani, Kand-Golandok, Tang Kenesht (from two different references), Nojian (from three different references), Pegahe sorkh katvand (from one reference) and Ivanaki (authors' research). Eleven sensitivity analyses were conducted and the amount of sediment was calculated using the sum of nine factors. Each input parameter was increased or decreased by 20% using a computer program in Visual Basic in Excel. Then sensitivity of the model for the parameters was analyzed. The less sediment has the basin, the less sensitivity has the input parameters in the model. MPSIAC model has twenty input variables that resulted in nine main factors. Erosion parameter (R) was calculated by adding nine main factors and the quantity of sediment was calculated by an exponential function. By evaluation of nine main factors, it was concluded that land use and Gully development were the most sensitive factors. As a result, based on the area and sensitivity of main factors, more investments must be done on the most sensitive factor to reduce soil erosion. In the assessment of nine main factors occurred errors are reduced due to adding operation. Regarding all items, each factor that has more input quantity has the highest sensitivity. As a result, if score of each factor grows more than six, more attention must be paid to score assignation. If occurred errors in assessment of nine factors did not neutralize each other and have additive or decreasing on the R, by addition of 20% to R, it showed that this factor was the most sensitive factor to run the model. If R is equal to 60 and 20% related to the error occurred in calculation of it, 54% error occurs in estimating the amount of sediment and sensitivity reaches to 2.7. This evaluation indicated that MPSIAC model for evaluation of basins with the amount of sediment more than 2.2 ton/hectare must be used more preciously because the model is so sensitive in this status and possible error may get over 50%.

Keywords: Sensitivity analysis, MPSIAC model, Watershed basin, Erosion, Sediment.

Introduction

Soil erosion and sedimentation are two important problems in Iran, which cause quality reduction of soil and water. Soil erosion causes not only soil distortion, but also sedimentation in channels and rivers, frequent floods, water losses and decreasing the quality of ranges. It also causes filling up the reservoir of dams and levees and reduction of their capacity. These all may damage crop production and have negative effects on the ecosystem especially on the rangelands. In here Iran, there are challenges of lack of enough water and negative effects of erosion water resources and sustainable agriculture. In order to reduce these negative effects, it is necessary to determine current rate of erosion and after identification of critical areas, appropriate plans must be used to reduce erosion rate. Soil erosion rate and sedimentation are predicted by models and measured by two methods; direct and indirect methods. Direct methods have high costs and take time. In addition, lack of enough data in most watersheds, lack of sedimentary station in watershed basins outlets and insufficient data make experimental models useful to prepare the data. Prior to use of any model, these questions should be taken into consideration:

What do we expect from the model?

What are limitations and main assumptions of the model?

What are the required data for the model?

What are the required investments for the model?

How are information gathered by Geographic Information System techniques?

Is it possible to predict the error occurred in the model?

What is sensitivity of the model to input data?

MPSIAC is one of the applicable experimental models which need a broad range of parameters. This model indicated that important errors occurred in the conducted researches and their results were invalid. For instance, using of PSIAC model for estimating R from MPSIAC formulas resulted to a mistake causing two times bigger rate of sedimentation. Evaluation of references indicated that: firstly, there were great mistakes in their results owning to misusing of the model and they must be reviewed. Secondly, none of them conducted sensitivity analysis. Thirdly, the calibration of this model has not been done yet and without calibration, using a model to estimate sedimentation of an area is illogical. Sensitivity analysis of a model is a technique which is used to evaluate and calibrate a model. This technique can be used to evaluate the effectiveness of model and real condition of input data. If variation of input data has a minor effect on output data, it could be concluded that these errors affected the results slightly and thus errors derived from laboratory and field measurements of the parameter could be omitted. In contrast, if they have great effect on output data, that parameter must be measured again more preciously. In addition, there should be given a priority to more sensitive parameters while planning and investing for a basin to reduce soil erosion. This may result in more reduction of erosion by fewer changes in parameters.

Literature Review

Johnson and Gebhardt (1982) changed the PSIAC model to a qualitative model and changed the type scoring. Reynard and Stone (1982) by comparing the calculated sedimentation rate of MPSIAC with some other experimental models revealed that there was a higher correlation between the calculated sedimentation measured by MPSIAC compared to the other models. On the basis of a research in Guam basin, Shade (1986) compared sedimentation of sedimentary station with MPSIAC model and indicated that the model could be applied in tropical areas. Haregeweyn *et al*. (2005) assessed MPSIAC and FSM models by the amount of sediment deposited in the reservoirs of eight dams and concluded that MPSIAC had a good accordance with observed values. Karoon River showed that there was a good correlation between calculated sedimentation rates by MPSIAC with those calculated by sedimentary station. Shah Karami (1995) in a research in Nojian of Lorestan, Iran showed that calculated sediment with MPSIAC had more similarity to output sediment of the basin than EPM model. Sheikh Hasani (1995) in a study at Taleghan dam, Iran showed that calculation of sediment using MPSIAC model was acceptable with 98% reliability. Ghodrati (1996) in a research in the north of Semnan, Iran found that there was a 30% discrepancy between MPSIAC calculated sediment and measured sediment by sedimentary station. Bayat (2000) in Taleghan, Iran showed that there was 98.3% accuracy between the model and measured sediment by the station. Sokoti *et al*. (2001) in a study in five watershed basins of western Azerbaijan, Iran showed that there was an accuracy of 80% between calculated model sediments with measured station ones in four basins. Hashemi (2002) in a research in Semnan, Iran concluded that EPM model was more precious than MPSIAC in calculation of sediment. Parsaee (2005) in a research at three watershed basins in Golestan, Iran showed that results of EPM in Yal Cheshme and MPSIAC in Garmabdasht were similar to the observed results. Rastgoo (2006) at Tang Kansht in north of Kermanshh, Iran found that calculation of MPSIAC was more precious than EPM model. Sensitivity of MPSIAC model and erosion models have not been analyzed so far but sensitivity of other models were done by Lane and Ferria (1982) method. For example, Parehkar (1999) and Asareh (2008) used the technique of sensitivity analysis for LEACHW and LEACHN models for the input parameters in stimulating soil moisture content and the amount of soil Nitrogen.

Materials and Methods

In this study, ten researches project conducted by other researchers as well as a research conducted by authors that was selected and analyzed. The purposes of this study were to compare works done in the country and show the possibility of calculating errors if the input data were not gathered carefully. MPSIAC (Modified Pacific South West International Agency Committee) is an experimental model which uses nine main factors in soil erosion and sedimentation. These factors are Geology, soil, climate, runoff, topography, ground cover, land use, up land erosion and channel erosion. This method assigns a value to each factor depending on its intensity. Then, sedimentation of basin is calculated using the sum of main factors in an exponential equation (equation 1). Affecting factors in MPSIAC and their valuation are shown in (Table 1).

(1) $Q_s = 0.253e^{0.036R}$

Sensitivity Analysis is a technique for Evaluation and Calibration models. This Technique helps to understand the influence of input data on output data. Lane and Ferria method was used to evaluate sensitivity analysis. Input data were increased or decreased 20% with the aim of calculating R and variation of erosion. Sensitivity of twenty input data and nine main factors were calculated using equation (2):

(2) $$\mathrm{SI} = \frac{\frac{Qs - Qsa}{Qsa}}{\frac{P - Pa}{Pa}}$$

Where:
Pa= is initial first parameter
Qsa =is calculated sediment using Pa.
P = is increased or decreased input data.
Qs =Is calculated sediment using P and SI, parameter sensitivity indices?

Finally, sensitivity index for different values of R was evaluated. A computer program in Visual Basic Using Excel was prepared to do the calculation.

Table 1. The effective factors and their point's calculation formula in MPSIAC model

The effective factors	The points calculation formula	Explanation parameter
Geology	Y1=X1	X1: Stone Sensitivity Point
Soil	Y2=16.67K	K: Erodibility Factor in USLE
Climate	Y3=0.3X3	X3: Six hours Precipitation Intensity with 2 Year Interval Return
Water runoff	Y4=0.006R+10QP	R: Annual Runoff Depth (mm), QP: Annual Specific Discharge (cm/s/km2)
Topography	Y5=0.33S	S: Average Watershed Slop (%)
Ground cover	Y6=0.2X6	X6: Bare Soil (%)
Land use	Y7=20-0.2X7	X7: Canopy Cover (%)
Upland erosion	Y8=0.25X8	X8: Points Summation in BLM Model
Channel erosion	Y9=1.67X9	X9: Points of Gully Development in Model

After Rafahii (1997)

Results and Discussion

As it was shown in Table 2, there were great differences in calculating input data for a basin among different researchers. For instance, 8th and 12th references reported the basin sedimentation of Amame-Kamarkhani as 1.075 and 7.887 ton/ha, respectively. This model depends more on expert ideas than the reality of nature. Ignoring human errors in calculating input data, sensitivity analysis of **e**leven basins were conducted. Modelling of Ivanaki Watershed basin was done by authors. Therefore, the graphs obtained from this analysis were selected and shown as a sample (Figs. 1-5). Considering (Table 3), R was observed as the most sensitive factor. Between nine main factors of MPSIAC model, land use in five basins (Ivanaki, Amame-12, Kand-12, Tang Kenesht-1, Tang Kenesht-2), channel erosion in three basins (Nojian-1, Nojian-2, Nojian-3), up land erosion in two basins (Kand-8, Amame-8) and finally topography factor in one basin (Peghak Sorkh Katvand) showed the highest sensitivity. It could be concluded that among nine main factors, land use, channel erosion and up land erosion had the highest sensitivity in accomplishment of the model. Evaluation of all input data showed that Gully development in three cases was the most sensitive factor. Moreover, Gully development must be evaluated more preciously since it affects channel erosion and up land erosion instantaneously. Among all soil factors (in all basins except one), infiltration rate was not sensitive since the variation of infiltration was not large enough to change the class of infiltration. Therefore, if the estimated infiltration rates are in the middle range of infiltration class, this factor affects the results obtained from model slightly and occurred errors of measuring in laboratory or field could be omitted. Soil structure class had the highest sensitivity indicating that most attention should be paid to the estimation of this parameter; otherwise it causes a major error. In case of runoff, annual runoff depth had small sensitivity; specific discharge had high sensitivity which indicated that more attention must be paid to estimate specific discharge. In case of SSF, Gully development had a high sensitivity which shows that it should be calculated more preciously. Farrow in ten cases and mass movement in two cases showed the least sensitive. Some parameters like infiltration classes at borderline values are sensitive. Infiltration classes vary by small changes. For example, infiltration of 0.5-0.125 cm/hour is placed in class of five while less than 0.125 is placed into another class. Considering Fig.5, it can be seen that R was more sensitive to increase than decrease. Errors in estimation of R cause errors in the amount of sediment progressively (Fig. 6). Initial R being more than 60 is not recommended. When R is greater than 60, 20% error in R causes 54% error of estimated sediment rate and sensitivity of the model could be 2.7. This evaluation indicated that MPSIAC model

for evaluation of basins with more than 2.2 ton per hectare per year, sediment quantity is not appropriate. In other words, it would be so sensitive with more than 50% of a potential error.
In order to decrease the soil erosion, it is suggested that more investments on Land use and then Gully development and conservative action must be done to modify these factors. So, based on the area and sensitivity of main factor, there must be more investment on the sensitive factors to decrease the soil erosion.

Table 2. Information about sedimentation rate and sedimentation in MPSIAC model for research basins

Name of basin	Area (ha)	Amount of R	Amount of Qs (ton/ha)	Reference
Amame-Kamarkhani	37200	40.204	1.075	8
Amame-Kamarkhani	37200	95.509	7.887	12
Kand-Galandok	5900	54.98	1.831	8
Kand-Galandok	5900	99.56	9.115	12
Nojian	34000	97.55	8.478	1
Nojian	34000	93.77	7.4007	2
Nojian	34000	115.24	16.027	3
Peghah Katvand	4600	66.24	2.746	4
Tang Kenesht	14348	58.32	2.065	1
Tang Kenesht	14348	59.75	2.174	2
Ivanaki	83500	71.79	3.44	Producers

Table 3. The amount of sensitivity analysis factors in MPSIAC model for different basins

Factors	Effective parameters	Ivanaki	Nojian (3)	Nojian (2)	Nojian (1)	Tang kenesht1	Tang kenesht2	Peghah	Kand (12)	Kand (8)	Amame (12)	Amame (8)
	Surface Geology	0.21	0.31	0.33	0.15	0.24	0.27	0.24	0.33	0.18	0.30	0.17
	Soil	0.22	0.10	0.14	0.09	0.16	0.16	0.12	0.24	0.09	0.11	0.09
	Climate	0.14	0.15	0.15	0.15	0.22	0.23	0.34	0.15	0.12	0.16	0.12
	Run Off	0.29	0.27	0.27	0.29	0.18	0.15	0.16	0.2	0.24	0.22	0.15
Main factors	Topography	0.25	0.60	0.5	0.53	0.43	0.30	0.50	0.50	0.12	0.51	0.11
	Ground Cover	0.39	0.61	0.09	0.16	0.14	0.16	0.20	0.60	0.32	0.63	0.21
	Land Use	0.56	0.66	0.53	0.61	0.47	0.48	0.33	0.63	0.26	0.66	0.24
	Up Land Erosion	0.48	0.84	0.66	0.76	0.27	0.32	0.33	0.61	0.38	0.58	0.24
	Chanel Erosion	0.12	0.87	0.84	0.99	0.10	0.10	0.27	0.50	0.32	0.44	0.12
	Fine Sand %	0.18	0.04	0.08	0.03	0.10	0.10	0.06	0.18	0.03	0.05	0.03
	Silt (%)	0.05	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.02	0.02	0.02
	Clay (%)	0.03	0.004	0.01	0.003	0.01	0.009	0.005	0.02	0.03	0.004	0.004
Soil factor	Organic Matter%	0.04	0.01	0.03	0.01	0.02	0.02	0.01	0.04	0.01	0.01	0.01
	Soil Structures Class	0.06	0.04	0.04	0.03	0.04	0.039	0.039	0.04	0.04	0.04	0.04
	Infiltration Rate (ch/hour)	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff factor	Run Off (mm/year)	0.002	0.01	0.016	0.005	0.003	0.004	0.004	0.014	0.004	0.003	0.004
	Specific Discharge(m3/s/Km^2)	0.28	0.26	0.26	0.28	0.17	0.14	0.151	0.18	0.24	0.22	0.15
	Mass Movement	0.12	0.45	0.29	0.38	0.06	0.09	0.063	0.29	0.14	0.3	0.02
	Leaf Cover	0.09	0.06	0.06	0.05	0.04	0.06	0.06	0.06	0.04	0.05	0.05
	Stone Cover	0.09	0.07	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.05	0.05
SF Factors	Stone	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02
	Farrow	0.05	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	Bed Morphology	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	Gully Development	0.14	1.02	0.93	1.16	0.12	0.11	0.30	0.58	0.36	0.51	0.14
SSF Factor	SSF Factor	0.48	0.84	0.66	0.76	0.27	0.32	0.33	0.61	0.38	0.58	0.24
R	R	4.36	8.81	6.40	6.97	3.19	3.20	3.70	6.76	3.12	6.35	2.07

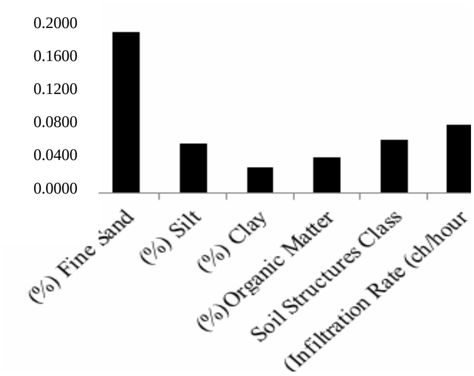

Fig. 2. Sensitivity analysis of soil factors

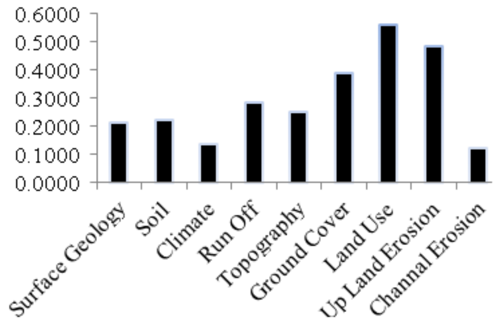

Fig.1. Sensitivity analysis of nine main factors

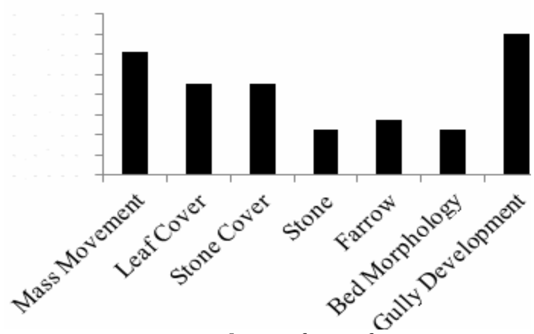

Fig. 4. Sensitivity analysis of SSF factor

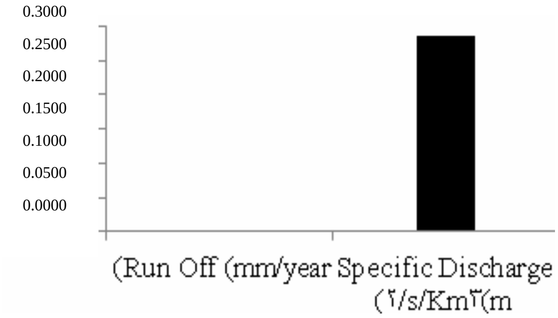

Fig. 3. Sensitivity analysis of runoff

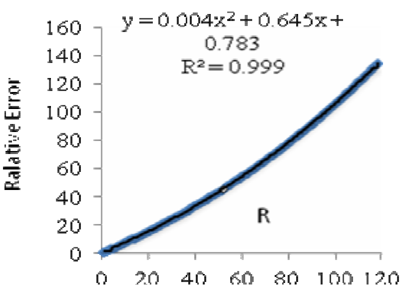

Fig. 6. Relation between relative error and R

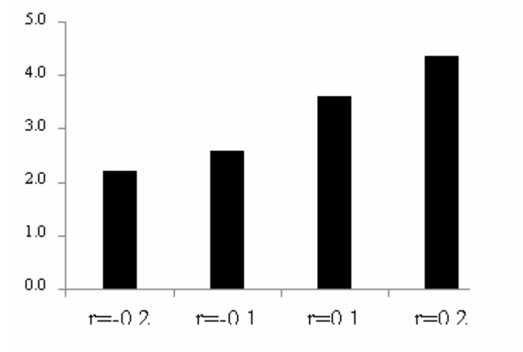

Fig. 5. Sensitivity analysis of R factor

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