The Sensitivity Analysis and Efficiency of FSM and MPSIAC Models for Estimating Sediment Load

Ali Gholami, and Pezhman Mesri Alamdari

Abstract—This study was conducted in Nahand watershed, two models of MPSIAC, as the most frequently used model in Iran, and FSM as a new model which has less been studied in Iran, have been chosen and their efficiencies and performances were analyzed. Through preparation of the topographic maps, the border of the watershed was determined in a way that the outlet point is located at the location of the hydrometric station of Nahand. The area of the watershed divided into five sub-watersheds and the required information to determine the points of the nine factors of MPSIAC model and five factors of FSM model collected and the points of each factor were determined as per the sub-watersheds and the whole watershed. After determining the points of all the factors, the total sedimentation of the watershed and sub basins were estimated by taking benefit from both models. Based on the same, the special watershed sedimentation as per MPSIAC and FSM models shall be 4.18 and 3.27 tons per hectares, respectively, and according to the results of both of the models, C and A sub-watersheds have the highest and lowest sedimentation, respectively. In order to determine the real sediment of the watershed, the sediment measuring statistics at Nahand Hydrometric Station were used. The sediment throughput equation of the watershed estimated according to the statistics of sediment recorded at Nahand Station and by taking benefit from the one-way measurement curve method, extracted and the real sediment of the watershed found by this equation. According to the general study results, show that the FSM model has more compatibility to the realities of the region in comparison to the MPSIAC model.

Keywords— FSM and MPSIAC Models, Sensitivity Analysis, Sediment, Nahand Watershed

I. INTRODUCTION

The FSM model has been designed and innovated outside Iran and few studies have been made regarding utilization of such model in Iran, while none of these studies have been made in the northeastern Iran and Azerbaijan region, while in none of these studies the efficiency and importance of the factors involved in such model has been considered.[1] Therefore, it is essential that such model is more studied and analyzed in the studies and it is understood whether the FSM model is a suitable model to estimate the level of erosion and sediment in the Iranian watersheds and especially the Azerbaijan region?

Due to the fact that the sediment statistics of Nahand Hydrometric station are available and in this study the level of erosion of Nahand watershed shall be estimated by the MPSIAC model. Therefore, quite suitable conditions are if the results of FSM model are compared to the real sediment statistics and results MPSIAC model and the abstract and relative accuracies of the model (in comparison to the MPSIAC model as the most common model in Iran) are measured. The efficiency of MPSIAC method in five big watersheds in Western Azerbaijan province was studied. In this research, the average statistics of the sediment measured of the river and estimated value of the same by the model within a 20-year model have been compared by taking benefit from the t-student test. The results indicate that the difference of the estimated sediment value in comparison to the measured sediment in four out of five studied watersheds is not significant and the model has the suitable efficiency to calculate the sediment in these four watersheds. In these four watersheds, the difference between the sediment statistics and estimation of the model has been 8.7 to 29.7% [2]. In one research, the application of the semi-quantitative models of estimation of the sediment and value of the sediment accumulated to predict the value of sediment in the Spanish watersheds was studied. In this study, some 60 watersheds were studied and in addition to the estimation of the value of sediment, by taking benefit from the PSIAC and FSM models, the value of real sediment was measured through sediment accumulated in the reserves and compared together accordingly. According to the research data, estimation of the FSM model was in conformity to the reality roughly 72%, while the same for the PSIAC model has been around 58%. Based on the results of this study, the semi-quantitative models may represent a relatively precise and reliable estimation of the level of sediment in the small to medium sized watersheds [3].

II. MATERIALS AND METHODS

A. Study Area

Nahand Dam watershed is the northern part of the Nahand-Chai watershed of the sub branches of Aji-chai (Talkheroud) in the northwest of Iran. This watershed is located at the northeastern of Tabriz City and concerning the state divisions, it is located within the jurisdiction of the Tabriz, Heris and Varzeghan townships. The minimum height of the studied area is 1,600m at site of the Nahand hydrometric station and the maximum height of the same is 2,900m at the northwestern
part of the watershed. The average weighed height of the watershed is also 2,246m. The path of the main waterway is in the northern-southern watershed and the outlet of the watershed is located in the most southern part of the same.

The studied watershed is closed at the Nahand hydrometric station as a hydrological watershed. This station is located at a 3km distance of northern side of Nahand dam. Based on the same, the studied site has an area of 19,800 hectares (198 km²) and is located at latitude of 38°, 09', 05" to 38°, 29', 03"North and longitude 46°, 20', 13" to 46°, 34', 31" East. The common statistical period to measure the climatic parameters (precipitation and temperature), discharge of the river and discharge of the sediment is a 40-year period from 1969 till 2000. In order to estimate the sedimentation by taking benefit from MPSIAC and FSM models, the points of the respective factors have been determined based on the standard equations of these models.

**B. Methods**

Upon determination the points and finding the sedimentation score (R), by taking benefit from the final equation of MPSIAC model, the total sediment of the watershed has been found. Final equation of MPSIAC model:

\[
Q_s = 0.253 e^{0.0335R}
\]

\(Q_s\): value of produced sediment in TonKm\(^2\)

\(R\): sedimentation score

By taking benefit from the following equation as the final equation of FSM model, the total sediment of the watershed was estimated.

Final equation of FSM model:

\[
SSY = 4139A - 0.44 + 7.77 \text{ FSM index} - 310.99
\]

\(A\): area of the watershed in Km\(^2\)

\(SSY\): rate of erodibility at the watershed in Ton.Km\(^2\)

In order to study the efficiency of the FSM and MPSIAC models at the watershed, the estimation resulted from these two models was compared with the real sediment of the watershed. The real sediment of the watershed is the result of measuring the suspended load and load of the bottom of the sediment at the Nahand Hydrometric station. By taking benefit from the statistics of the sediment samples recorded within the statistical period at this station and the sediment one-way measurement curve method, the sediment-throughput equation was extracted. The real sediment of the region has been calculated by using this equation and based on the average monthly throughput of the river. The results of these calculations show that the real sediment of the watershed is 3.50 Ton.ha\(^{-1}\). In order to determine the most important factors involved in estimating the sediment by each of the respective models, the sensitivity analysis technique has been used. The sensitivity analysis is a technique, which is use to estimate and calibrate the model. By such technique, the effecting-proneness of the model and real conditions may be study from the input data. This technique has been carried out based on the following mathematical equations:

**Calculation of Sensitivity Index:**

\[
SI = \frac{Q_s - Q_{sa}}{P - P_a}
\]

Where:

\(p_a\): primary value of the parameter

\(P\): increase/decrease of the input parameters

\(Q_s\): primary value of the calculated sediment

\(Q_{sa}\): value of calculated sediment due to increase/decrease of the input parameter

\(SI\): parameter sensitivity index [4].

The equation of calculating the dependent error percentage:
\[ I_{\text{max}} = \left( \frac{D_{\text{max}}}{Pb} \right) \times 100 \]

\[ D_{\text{max}} = Pm - Pb \]

Where:
- \( I_{\text{max}} \): percentage of dependent error
- \( D_{\text{max}} \): maximum absolute difference
- \( Pm \): estimated value based on modified input value
- \( Pb \): estimated value based on base input value \[4\].

In this study, the value of each of the parameters involved in the final estimation of the models has been increased and decreased for 20%, based on which the sensitivity level and dependent error have been calculated. The higher the level of sensitivity is, that shall mean such parameter plays more important role in sedimentation of the watershed, and the rate of sediment of the watershed is more affected by the changes of such factor. Therefore, by controlling and decreasing such factor more than the other factors, the watershed's sedimentation may be decreased.

### III. RESULTS AND DISCUSSIONS

The real produced sediment as per the sediment statistics of Nahand Hydrometric station located at the outlet of the watershed equals to 69368.65 ton per annum and 3.50 ton per hectare per annum that is located within the III sedimentation class with average erosion intensity. The results of this study indicate that the estimated sediment by MPSIAC model is equal to 4.16 ton/hectare per annum, which is 19% more than the real sediment of the watershed. Meanwhile, the FSM model has estimated the watershed's sediment as 3.72 ton per hectare per annum, which is 6% higher than the measured sediment. Notwithstanding the appearance of such differences, the comparison of these results with the results of the previous similar researches indicates the ignorable and acceptable nature of such errors. The sediment estimated by FSM model has a relatively high dependence on the area of the sub watershed. Such correlation is in reversed and exponential manner, in a way that by decreasing the area of the sub watershed the estimated sediment increases. The following chart shows the changes of the value of the estimated sediment by FSM model by changing the area of the watershed. In this chart, the FSM Index is fixed and equals to 35.

In FSM model, the effective-proneness of the sediment estimated from the FSM Index change has a linear trend, so that always the similar error in FSM Index results in similar change in the estimated sediment. Meanwhile, the FSM Index is the product of the point 5 of studied factor in FSM model. Eventually, all have the same weighed affect on the estimated sediment and thus the FSM model estimation with respect to all the input factors have similar and identical sensitivities.

![Fig. 3 Curve of Sediment estimation changes of FSM model by changing of the watershed's area](image1)

![Fig. 4 Trend of estimated sediment changes with FSM Index changes in FSM model](image2)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Area (Km²)</th>
<th>Topo</th>
<th>Veg.</th>
<th>Gully</th>
<th>Litho.</th>
<th>Shape of</th>
<th>FSM index</th>
</tr>
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<tbody>
<tr>
<td>Basin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>30.13</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2.2</td>
<td>2</td>
<td>80.39</td>
</tr>
<tr>
<td>B</td>
<td>20.91</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1.1</td>
<td>2</td>
<td>40.49</td>
</tr>
<tr>
<td>C</td>
<td>47.09</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2.0</td>
<td>1</td>
<td>35.59</td>
</tr>
<tr>
<td>D</td>
<td>59.30</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2.1</td>
<td>2</td>
<td>74.37</td>
</tr>
<tr>
<td>E</td>
<td>40.57</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2.2</td>
<td>1</td>
<td>39.18</td>
</tr>
<tr>
<td>Nahand</td>
<td>198.0</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>36.00</td>
</tr>
<tr>
<td>Basin</td>
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<td></td>
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<td></td>
<td></td>
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</table>

**TABLE I** Points of the FSM model in the studied watershed

The analyzed parameters in sensitivity analysis of MPSIAC model includes the nine factors of MPSIAC, level of sedimentation and factors involved in calculation of the points of such nine factors\[6\]. The sediment in the Nahand watershed and its five sub basins was estimated by taking benefit from MPSIAC model and the points assigned to the nine factors of this model. The three factors indicate of upland erosion (X8), channel erosion, sediment transport (X9) and land uses (X7) have the highest affect on the sedimentation at the watershed. So in all the sub basins and the whole watershed, on average 50% of the sedimentation level was related to these three factors, although the priorities of these three have been different in various sub basins. According to the results of sensitivity analysis in the studied watershed, the sedimentation score has the highest sensitivity in estimation of the sediment by MPSIAC model, so that by decreasing that for 20%, we will face a sensitivity factor of 2.4313, which also results in 28.71% decrease in the sediment estimation. Meanwhile, by increasing 20% in the sedimentation, the sensitivity factor shall become 5.1679 and the estimated sediment shall be more for 103.39% accordingly. It should be note that the sensitivity of such parameter in comparison to the estimated sediment is variable, so that the less sedimentation of the watershed shall
result in less sensitivity of the model to the level of sedimentation. The sediment changes trend with the change of the level of sedimentation at MPSIAC model is complied with an exponential and ascending equation; therefore, the bigger the sedimentation degree, its changes shall result in more change in the sediment estimated by the model. This issue indicates that in MPSIAC model, by increasing the sedimentation the effective-proneness of the estimated sediment exceeds the sedimentation degree. Therefore, in watersheds where there are high sedimentation potential and big sedimentation levels, any minor error in calculating the sedimentation level shall result in appearance of a big error in estimating the sediment.

By considering all the input parameters of the model, the three parameters of the gully erosion development, SSF factor and erosion status throughout the watershed are of highest sensitivities and more carefulness in valuing such parameters is mandatory. It should be note that the gully erosion development parameter as a secondary input parameter is addressed as the most sensitive input parameter and the reason of such issue is the affecting of such parameter on grading two out of nine factors of MPSIAC model. On the other hand, the three parameters of depth of annual runoff, soil mass movement and rock parts compacted into the area of the watershed have the lowest sensitivities at the result of the model. The sensitivities of these three parameters are so low that the error resulted from their measurement may be neglected. From amongst the parameter affective on the point of the runoff factor (X4), the special peak discharge is more sensitive in comparison to the depth of annual runoff. From amongst the seven parameters involved in calculating the SSF factor, the gully erosion development factor is the most sensitive parameter with the high difference, so that such parameter is deemed as the most sensitive input parameter of the model and any error in measuring the same shall result in appearing to a big error in estimated sediment of the model. The results of the sensitivity analysis indicate that at the studied watershed, the most sensitive factors are those through which the modifying actions may be taken to decrease the erosion. Therefore, by carrying out the modifying mechanical and biological actions an important step may be taken to decrease the gully erosion. While assisting in stabilization of the waterway basis and controlling the expansion of the gully erosion as the most sensitive input parameter of the model, carrying out the mechanical operations shall result in decreasing SSF, as the third sensitive input parameter. Decreasing such two parameters also results in controlling the surface and river erosions as the first and second sensitive factors from amongst the nine factors thereof. Implementation of the biological operations and especially the stacking operations shall result in an increase in the vegetation crown and affects the points of the land use factor as the third sensitive factor of MPSIAC model.

![Graph](image1.png)

**Fig. 5** Trend of changes of the estimated sediment with R changes in MPSIAC model

From amongst the nine factors, the factors of climate (X3) and run off (X4) have the lowest sensitivities. The three factors of upland erosion (X8), channel erosion and sediment transport (X9) and land use (X7) have the highest sensitivities; therefore, in grading of these factors, high precision should be apply and the controlling and modifying actions to decrease the erosion in the watershed shall be focused on parameters relevant to these three factors [7].

**TABLE II**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Sensitivity Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runoff</td>
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<tr>
<td>Channel erosion</td>
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</tr>
<tr>
<td>Upland erosion</td>
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<tr>
<td>Soil compaction</td>
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</tr>
<tr>
<td>Sedimentation</td>
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</tr>
<tr>
<td>Climatic change</td>
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<tr>
<td>Erosion status</td>
<td>0.25</td>
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<tr>
<td>Land use</td>
<td>0.20</td>
</tr>
</tbody>
</table>

![Graph](image2.png)

**Fig. 6** Histogram the sensitivity factor of the nine factors of MPSIAC model
IV. CONCLUSION

This study indicates that both MPSIAC and FSM models enjoy good efficiency and accuracy in estimating the sedimentation of the Nahand Dam watershed. Although the estimation made by the FSM model is more compatible to the real sediment of the watershed, but as the MPSIAC model uses more parameters to estimate the sediment and incorporates more characteristics of the watershed in estimating the sediment, it is considered as a more suitable model to estimate the sediment at Nahand watershed and its similar watersheds and utilization of the same is recommended.

REFERENCES


