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# Spatial Prioritization of Sediment Source Areas at Watershed Scale

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## Abstract

Identification and prioritization of critical sub-watershed is essential to sediment control at watershed scale. Many studies have been carried out on the topic of identifying and prioritizing the critical source areas (CSAs); however, only few researches have been conducted to prioritize sub-watersheds in terms of their contributions to the sediment yield of the main watershed outlet. In fact, observations alone are not enough for CSAs prioritization; hence, hydrological models may be applied for prioritization of sub-watershed. Therefore, in the present study, prioritization of sub-watershed was considered based on (1) on-site effects of soil erosion: specific sediment yield at sub-watershed scale (sediment yield/area), (2) offsite effect of soil erosion: sub-watershed contribution to the sediment yield of the main watershed outlet. In this study, Soil and Water Assessment Tool (SWAT) was applied for prediction of runoff and sediment load at sub-watershed scale and the main watershed outlet. The Unit Response Approach (URA) has also been applied to prioritize sub-watersheds in terms of their contributions to the sediment yield at the watershed outlet. The proposed model was applied in Mehran watershed, in West of Tehran (capital of Iran). The study watershed was divided into 37 sub-watersheds. The results showed that the contribution of sub-watershed No.14 and No. 17 had the largest sediment contribution into the main outlet of watershed. The results of this ranking can differ entirely from those based on single sub-watershed sediment production at the sub-watershed outlet. Targeting the placement of Best Management Practices, based on the CSAs concept, will assist sediment control in watersheds.

**Keywords:** CSAs, Spatial Prioritization, Hydrologic Model, Watershed Management

## 1. Introduction

Soil erosion and sediment yield provide an important index of land degradation and they reflect the characteristics and history of a watershed. Soil erosion has on- and off-site effects. The primary on-site effect is the reduction of topsoil thickness, which results in reduced crop yields (Noor et al., 2013). But, off-site causes pollution, sedimentation, and silting of water resources.

Numerous studies have been conducted to quantify the effectiveness of Best Management Practices (BMPs) in the sediment reduction at watershed scale (Tripathi et al., 2005; Strauss et al., 2007; Panagopoulos et al., 2011; Seppelt et al., 2013; Yazdi et al., 2013; Skardi et al., 2013). Based on the literature and considering the resource constraints, it is not possible to implement BMPs at every sub-watershed in a watershed. Similarly, BMPs placement at every field may not be needed because only a few critical areas in the watershed may potentially contribute disproportionately to large amounts of runoff and sediment loads in the watershed (Arabi et al., 2006; Strauss et al., 2007; Karamouz et al., 2010; Kaini et al., 2012; Saghafian et al., 2015).

When BMPs were selected for implementation in critical sub-watershed, they would achieve maximum efficiency (Srinivasan et al., 2005; Tripathi et al., 2005; Sardar et al., 2012; Kumar and Mishra, 2015). In other words, identification of these critical areas based on targeting methods is essential for an efficient implementation of BMPs in a watershed management program (Niraula et al., 2013; Saghafian et al., 2015). A specific prioritization strategy should be chosen based on the goals of watershed management project (WMP). For example, when the goal of WMP is to protect water quality or prevent sedimentation of a reservoir, it may be useful to employ sub-watershed contribution to the sediment yield of the main watershed outlet.

These critical areas can be identified through sub-watershed level hydrologic gauge monitoring or hydrologic modeling (Niraula et al., 2013). Direct hydrologic monitoring and field studies are usually costly and labor intensive. Recently, mathematical models of watershed hydrology and transport processes have been employed to address a wide spectrum of environmental and water resources problems. The use of watershed models, such as Soil and Water Assessment Tool (SWAT), can avoid most limitations associated with field studies and can help in prioritizing sub-watersheds for implementation of management practices (Tripathi et al., 2005; Niraula et al., 2013; Sardar et al., 2014; Kumar and Mishra., 2015).

Srinivasan et al. (2005) used the SWAT to identify critical source runoff areas for phosphorus transport and compared the results with the Soil Moisture Distribution and Routing (SMDR) physically based model. White et al. (2009) used SWAT to identify CSAs and quantify sediment and total phosphorus loads generated from five watersheds in Oklahoma. They reported that just 5% of the land area yielded 50% of the sediment load and 34% of the phosphorus load. Schilling and Wolter (2009) used SWAT to evaluate nitrate load reduction in the Des Moines River in Iowa using four targeting methods. Tuppad et al. (2010) implemented various BMPs (reduced tillage, edge of field vegetative filter strips, and contoured terraced) on 10%, 26%, 52%, and 100% of total targeted cropland and compared the pollutant reduction efficiency at the outlet of the watershed using targeting and random placement. Giri et al. (2012; 2014) evaluated four targeting methods for implementation of the best management practices in the Saginaw River Watershed using the SWAT. Niraula et al. (2013) identified critical source areas of nonpoint source pollution with SWAT and GWLF. Sardar et al. (2014) used SWAT model to identify and manage critical erosion-prone areas for improving reservoir life in Barakar watershed. Kumar and Mishra (2015) prioritized critical erosion area based on hydrological response unit level to reduce Sedimentation in Damodar watershed.

As was mentioned, for prioritizing the area to targeting of BMPs, the researchers have used simulated sediment yield at the sub-watershed outlet, which has been used for on-site erosion control. However, these studies do not provide any information about that specific part of the watershed that is susceptible to sediment yield and contribute more sediment to the outlet. Therefore, when the concern is to off-site control of soil erosion (i.e. sediment yield at the main watershed outlet, such as reducing sediment load entering rivers, dams, reservoirs, and other water bodies), this approach is not very useful for the managers. This is because the most erodible sub-watersheds are not necessarily those with the highest sediment load contribution at the main basin outlet. Therefore, another strategy for identification of CSAs is based on contribution of sub-watershed to the sediment yield of the main outlet watershed is required.

Therefore, this study was conducted to design a framework for identifying the spatial patterns of erosion and sediment yield hazard at watershed scale. The problem that was addressed in this paper is how to identify and prioritize CSAs on the basis of their contribution to the sediment yield at the sub-watershed (onsite effects) and watershed outlet (offsite effects).

## 2. Materials and Methods

### 2.1. Study Area

Mehran watershed with an area of 97 km$^2$ is located in the Sefidroud basin, in Alborz province, west of Tehran, Iran (Fig.1). The topographical elevation of the study area varies between 1989 m a.sl. and 4363 m a.sl. With weighted average of 2948 m. Design and construction of Taleghan dam was started in the three decades ago and water storing in the dam started in 2006. The Mehran watershed has undergone rapid land use change (Noor et al., 2014), these changes could have devastating impacts on both water balance and water quality of the watershed. Therefore, in Mehran watershed identification of CSAs and then implementation of the BMPs in critical areas of the watershed is necessary. The watershed's hydrology is dominated by high volume flows and sediment yield in the spring, due to spring rainfall events (Hosseini et al., 2012; Noor et al., 2014).

The land use of the study watershed comprises 90 percent of low and high density rangelands, 10 percent of orchard, farming and other land uses. Mainly, the soil textures of the watershed are silt loam and loamy and clay loam (FAUT, 1993). The locations of Mehran watershed in Sefidroud basin and Iran are shown in Fig. 1.

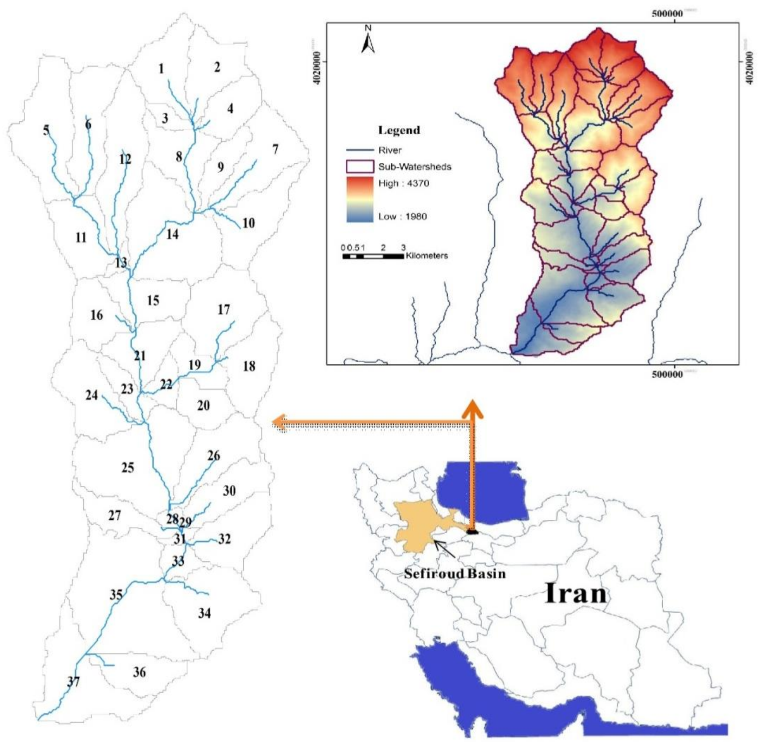


**Fig. 1.** Mehran SWAT watershed delineation with 37 sub-watersheds, stream networks and the digital elevation model.

### 2.2. Watershed Simulation Model and Data Collection

The SWAT model is developed to simulate long-term effects of various watershed management plans on hydrology and water quality response at daily, monthly, and annual time scales. Stream network and user defined outlets are used to divide the watershed into sub-watersheds. Land use, soil, and slope maps are used by the SWAT model to further divide a sub-watershed into hydrologic response units (HRUs). HRU is the smallest geographic area for which flow and transport of sediment are performed by the model.

The SWAT model needs a lot of data to be defined for the watershed. The input data are DEM (Digital Elevation Model), climate data (daily and monthly), and soil and land use layers (maps and physical parameters) (Neitsch et al., 2011). Daily Runoff, rainfall and temperature (maximum and minimum) data were collected from the Iranian water resources researches organization for the period 2005-2010. Table 1 shows information about weather stations in the study watershed.

**Table 1.** List of selected weather stations in the Taleghan watershed.

| Station Name | X (UTM) | Y (UTM) | Elevation (m a.s.l.) |
|---|---|---|---|
| Dehdar | 506043 | 4006472 | 2800 |
| Joestan | 490234 | 4004812 | 1990 |
| Dizan | 484904 | 4013508 | 1950 |

Digital elevation model (DEM) with a 25 m ×25 m spatial resolution was generated from topography map (Topography map at a scale of 1:250,000 was produced by National Cartographic Center of Iran). A land use map for the year 2008 was prepared by the Soil Conservation and Watershed Management Research Institute (Fig. 2). Measured daily stream flow and total suspended sediments (TSS) data from 2005 to 2010 at Mehran hydrometric station were used for the calibration and validation of the SWAT model. Also, the input parameters required in the model were generated from various map themes using the Arc-SWAT interface. Various input files, i.e., sub-watershed (.bsb), soil (.sol), routing (.rte), weather generator (.wgn), management (.mgt), groundwater (.gw), and chemical (.chm) were also generated through the interface.

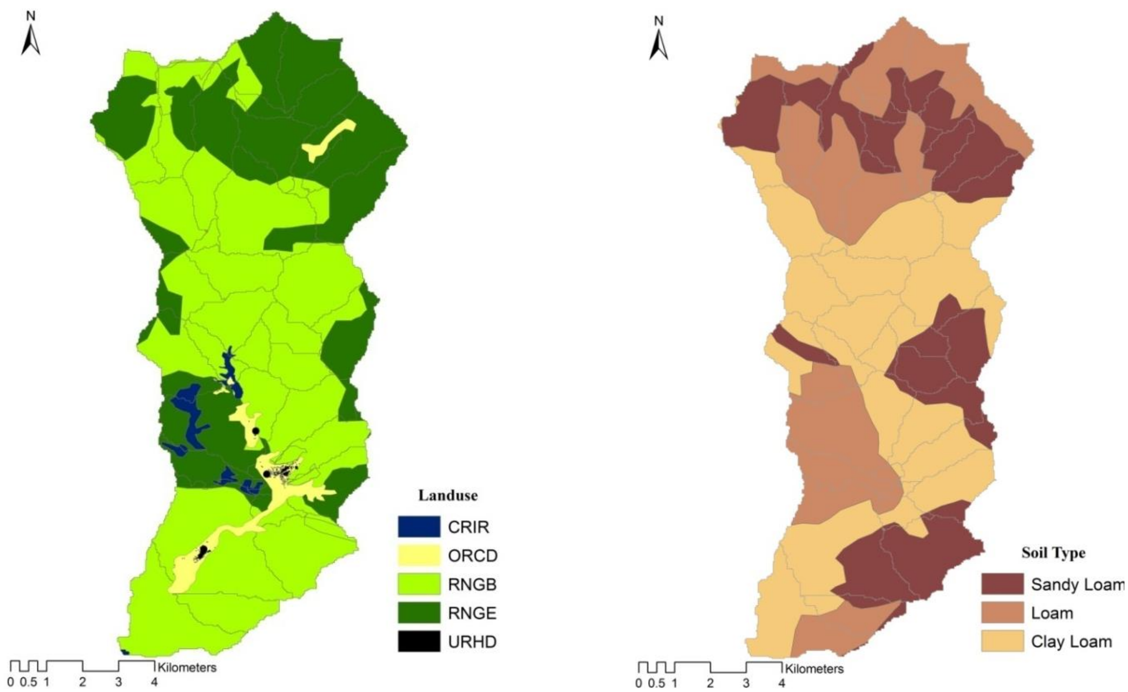


Fig. 2. SWAT land use classification soil type map of the Mehran watershed.

A 1:50000 pedagogical soil map and texture was obtained from the FAUT (1993) as well as some textural soil profiles description for all the major soils (Fig. 2). Summary of land use and soil texture of sub-watersheds is presented in Table 2. Finally, in this study, The Sequential Uncertainty Fitting version-2 (SUFI-2) procedure was used to calibrate the SWAT model (Abbaspour, 2011). Uncertainty in SUFI-2 is calculated based on all sources of uncertainties by r- and p- factors. SUFI-2, searches to bracket most of the measured data (p-factor approaching the maximum value of 1) with the smallest possible uncertainty band (r-factor approaching the minimum value of zero) (Abbaspour, 2011).

**Table 2.** Land use and soil type of sub-watersheds in Mehran watershed

| Sub-watershed | Area under Soil Type (%) | | | Area under land cover (%) | | | | |
|---|---|---|---|---|---|---|---|---|
| | Sandy Loam | Loam | Clay Loam | Low Density Rangeland | High Density Rangeland | Orchard | Irrigated agriculture | Residential |
| 1 | 28.61 | 71.39 | | 27.53 | 72.47 | | | |
| 2 | 28.87 | 71.13 | | | 100.00 | | | |
| 3 | 46.30 | 53.70 | | 28.04 | 71.96 | | | |
| 4 | 51.52 | 48.48 | | | 100.00 | | | |
| 5 | 58.52 | 20.19 | 21.29 | 41.51 | 58.49 | | | |
| 6 | 25.90 | 74.10 | | 66.84 | 33.16 | | | |
| 7 | 63.96 | 36.04 | | | 100.00 | | | |
| 8 | 54.28 | 45.72 | | | 100.00 | | | |
| 9 | 76.83 | 17.70 | 5.46 | 11.86 | 62.40 | 25.74 | | |
| 10 | 40.66 | | 59.34 | 14.99 | 85.01 | | | |
| 11 | | 13.22 | 86.78 | 79.16 | 20.84 | | | |
| 12 | 27.10 | 72.90 | | 46.00 | 54.00 | | | |
| 13 | 0.00 | 33.72 | 66.28 | 100.00 | | | | |
| 14 | 6.18 | 39.16 | 54.65 | 74.09 | 25.91 | | | |
| 15 | | | 100.00 | 100.00 | | | | |
| 16 | | | 100.00 | 72.87 | 27.13 | | | |
| 17 | 12.22 | | 87.78 | 100.00 | | | | |
| 18 | 70.90 | | 29.10 | 28.15 | 71.85 | | | |
| 19 | 51.23 | | 48.77 | 100.00 | | | | |
| 20 | 100.00 | | | 100.00 | | | | |
| 21 | | 11.00 | 89.00 | 92.00 | 8.00 | | | |
| 22 | 10.58 | | 89.42 | 90.00 | 10.00 | | | |
| 23 | | 14.51 | 85.49 | 85.16 | | | 14.84 | |
| 24 | 20.10 | 30.44 | 49.46 | 62.57 | 37.43 | | | |
| 25 | 3.39 | 67.47 | 29.15 | 31.04 | 56.92 | | 12.04 | |
| 26 | 40.98 | | 59.02 | 84.23 | 15.77 | | | |
| 27 | | 100.00 | | | 80.61 | | 19.39 | |
| 28 | | 75.43 | 24.57 | | 34.49 | 51.61 | | 13.90 |
| 29 | | 90.00 | 10.00 | | | 100.00 | | |
| 30 | 19.69 | | 80.31 | 100.00 | | | | |
| 31 | | 60.73 | 39.27 | | 28.70 | 56.80 | 14.50 | |
| 32 | 12.07 | | 87.93 | 40.01 | 43.74 | 16.26 | | |
| 33 | 9.98 | 19.22 | 70.80 | 52.85 | 21.53 | 25.62 | | |
| 34 | 100.00 | | | 100.00 | | | | |
| 35 | 33.16 | 17.21 | 49.63 | 86.19 | | 13.81 | | |
| 36 | 23.20 | 56.69 | 20.11 | 100.00 | | | | |
| 37 | | 33.80 | 66.20 | 100.00 | | | | |

Model performance was evaluated through visual interpretation of the simulated results and common statistical criteria of agreement between measured and simulated data. Several statistical approaches were used to assess the model performance, coefficient of determination ($R^2$) and Nash-Sutcliffe efficiency (NS) (Moriasi et al., 2007). The $R^2$ value is the indicator of the relationship strength between the observed and simulated values. Values of the NS coefficient, ranged from negative infinity to 1. NS coefficients greater than 0.75, are considered ‘‘good,’’ whereas the values between 0.5 and 0.75 are considered ‘‘satisfactory’’ (Moriasi et al., 2007). Therefore, p-factor, r-factor, $R^2$ and NS are calculated for performing the evaluation of SWAT.

### 2.3.CSAs Identification Method

The SWAT model was applied for the prediction of sediment yield at sub-watershed and the main outlet. The Unit Response Approach (URA) has been applied to prioritize sub-watersheds. URA was initially proposed to identify the flood source (Saghafian and Khosroshahi, 2005), but it can be extended to other aspects, such as sediment yields.

Sub-watersheds are individually turned off in successive runs to remove their effects by assigning zero for the area of the selected sub-watershed (Saghafian and Khosroshahi, 2005; Saghafian et al., 2015). In fact, this procedure was repeated in each successive run for all sub-watersheds. Finally, sediment yields changes at the watershed outlet were compared with the baseline (all sub-watersheds were presented in the simulation). The following index can be defined to prioritize sub-watersheds depending on the quantity of their contribution to the sediment at the main watershed outlet (Saghafian et al., 2015), where $X_n$ is sediment yield index of the $n_{th}$ sub-watershed, $Y_{total}$ is the outlet sediment yield with all sub-watershed units presented in the base simulation, $Y_{total-n}$ is the outlet sediment yield with having $n_{th}$ sub-watershed removed:

$$X_n = Y_{total} - Y_{total-n} \quad (1)$$

The entire process is done in MATLAB program (mfile) which is developed in this study. Fig. 3 describes the methodology employed during sources area prioritization using SWAT-URA.

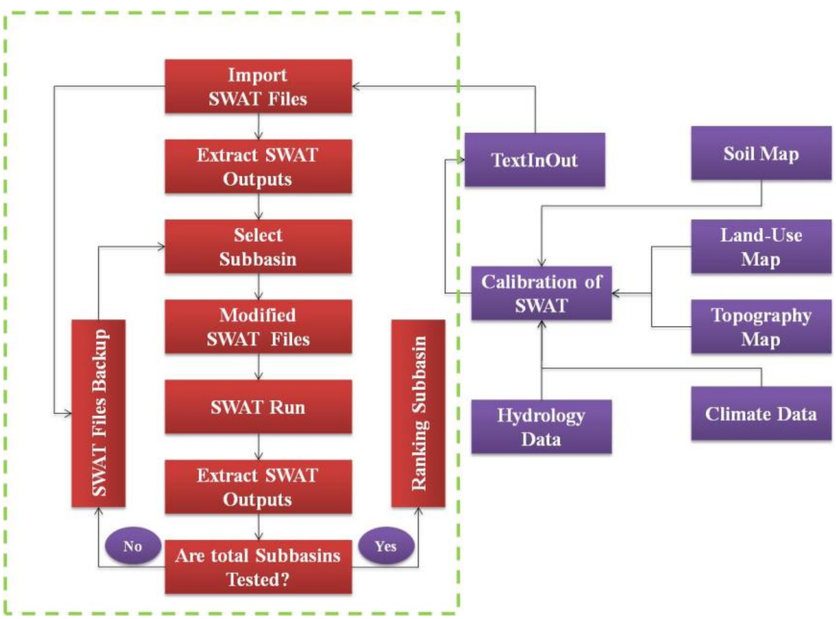


**Fig. 3.** Flowchart for different processes during prioritization of the sub-watershed. The boxes within the dashed line denote the SWAT-URA.

In developed program (mfile), the procedure for identification and prioritization of sediment source areas is simple and entirely automated as described below:

Copy “TxtInOut” file in SWAT project directory and paste in SWAT-URA directory path, and then, in user-inputs file insert some information about project, including the NSUB number of sub-watersheds), OUTLET (sub-watershed number where outlet of the watershed is), IVARS (output variables# sediment=10), NMONT (number of months) and NYEAR (number of years).

## 3. Results and Discussions

### 3.1.SWAT Performance Evaluation

The calibration process began with 18 parameters found to be sensitive to discharge and sediment. Five hundred model runs were performed in each iteration. The parameter ranges and calibrated values are presented in Table 3.

Table 3. Calibrated parameters of SWAT model with their ranges and calibrated values

| parameter | Min – Max Value | Optimum value |
|---|---|---|
| | Discharge calibration | |
| r-CN2.mgt | (0.1)-(-0.15) | -0.06 |
| v-SMFMN.bsn | (1)-(7) | 3.80 |
| r-SOL-K.sol | (-20)-(20) | -0.15 |
| v-SNOCOVMX.bsn | (200)-(380) | 320.00 |
| v-SNO50COV.bsn | (0.4)-(-0.7) | 0.58 |
| v-SMFMX.bsn | (3)-(8) | 5.12 |
| r-SOL-AWC.sol | (-0.2)-(-0.2) | -0.10 |
| v-ALPHA-BF.gw | (0.01)-(-0.09) | 0.062 |
| v-GW-DELAY.gw | (1)-(15) | 5.50 |
| v-CH-N2.rte | (0.1)-(-0.2) | 0.12 |
| v-CH-K2.rte | (35)-(55) | 40.00 |
| v-SURLAG.bsn | (1)-(10) | 6.51 |
| | Sediment calibration | |
| v-SPCON.bsn | (0.001)-(0.005) | 0.003 |
| v-SPEXP.bsn | (1.00)-(1.50) | 1.15 |
| v-CH_EROD.rte | (0.10)-(0.40) | 0.24 |
| v-CH_COV.rte | (0.20)-(0.70) | 0.35 |
| v-ADJ_PKR.bsn | (0.50)-(2.00) | 1.02 |
| v-PRF.bsn | (0.10)-(1.00) | 0.28 |

In discharge calibration, 67% of the measured data fell in the 95PPU, whereas for sediment calibration, 56% of the measured data fell in the 95PPU band (Table 4).

**Table 4.** Results of the calibration and uncertainty analysis in SUFI-2.

| Criteria | Runoff | | Sediment | |
|---|---|---|---|---|
| | Calibration | Validation | Calibration | Validation |
| NS | 0.71 | 0.66 | 0.64 | 0.60 |
| $R^2$ | 0.73 | 0.67 | 0.64 | 0.61 |
| r-factor | 0.81 | 0.85 | 0.92 | 0.95 |
| p-factor | 0.59 | 0.56 | 0.53 | 0.50 |

Comparisons of the estimated and measured runoff and sediment yield data are compared in Fig 4. In case of runoff, the NS coefficients for calibration and validation of the SWAT were 0.71 and 0.66, respectively. Results showed that SWAT consistently underestimated stream flow. The same results were reported in region where snow hydrology plays a key role in stream flow (Akhavan et al. 2010).

In the Mehran watershed, the predicted runoff values were better accuracy than those for sediment. The NS coefficients 0.64 and 0.60 were obtained for calibration and validation data sets, respectively. The results showed that, NS equal to 0.71 for flow calibration and 0.66 for flow validation, are acceptable because minimum NS value is 0.5 for flow calibration (Moriasi et al. 2007). NS values obtained for sediment calibration and validation are 0.64 and 0.60, respectively, which are within the acceptable limits too (Moriasi et al. 2007).

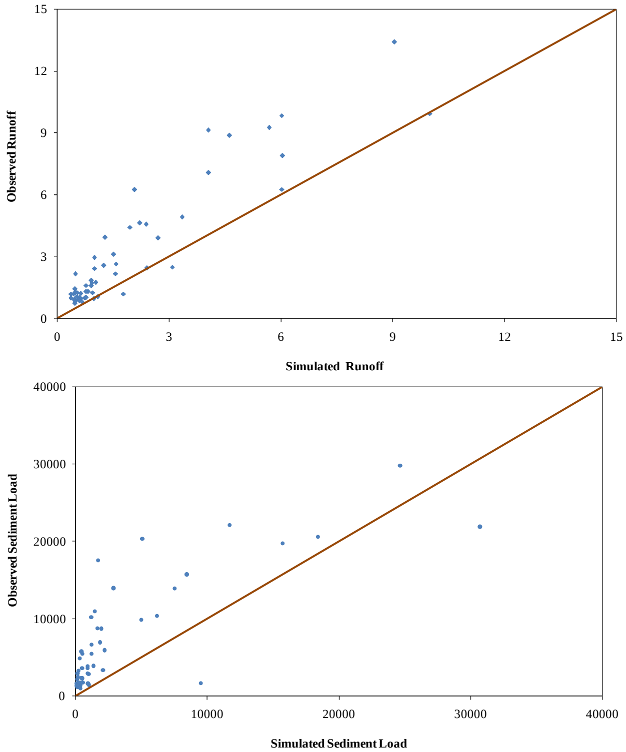


**Fig. 4** Comparison between measured and SWAT simulated monthly runoff (above) and sediment load (below).

### 3.2.Sub-watershed Prioritization

After calibration and validation of the SWAT model, the URA was applied to prioritize sub-watersheds based on their contribution to the sediment yield at the main outlet. As previously described, in each run of the model, Sub-watersheds alternately are eliminated by setting its area equal to zero. In the next step, the mean annual sediment yield of the watershed (all sub-watersheds – sub-watershed$_n$) simulated by the SWAT model that it was used to calculate the sediment index (Eq. 1). Results of the contribution of all sub-watersheds to the main outlet sediment yield are presented in Fig. 5.

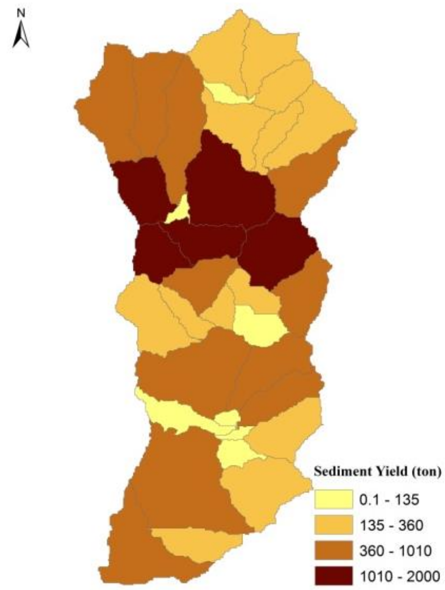


**Fig. 5.** Sediment load map of the Mehran sub-watersheds based on the SWAT simulations.

Ranking sub-watersheds based on runoff and sediment yield at their outlets and their contributions to the corresponding values at the watershed outlet can be compared in Table 5. Fig. 6 showed comparing the rankings of sub-watersheds with respect to their area and sediment yield contribution on main watershed outlet.

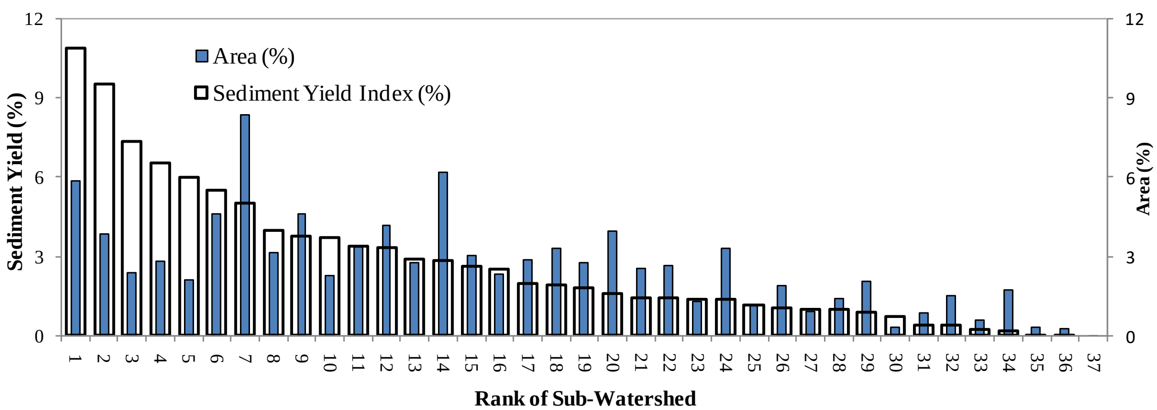


**Fig. 6.** Area (in percent of total area) and outlet sediment contributions of sub-watersheds.

**Table 5.** Ranking of the area based on runoff and sediment yield at sub-watershed and contribution to watershed outlet.

| Sub-watershed | Area (km$^2$) | Area (%) | Rank based on sediment at sub-watershed outlet | Rank based on runoff at sub-watershed outlet | Rank based on sediment at watershed outlet |
|---|---|---|---|---|---|
| 1 | 2.88 | 2.94 | 20 | 21 | 17 |
| 2 | 2.53 | 2.58 | 24 | 22 | 21 |
| 3 | 0.59 | 0.60 | 32 | 17 | 33 |
| 4 | 1.88 | 1.93 | 25 | 15 | 26 |
| 5 | 4.60 | 4.70 | 8 | 8 | 6 |
| 6 | 3.36 | 3.44 | 14 | 16 | 11 |
| 7 | 3.32 | 3.40 | 31 | 26 | 24 |
| 8 | 2.64 | 2.71 | 26 | 18 | 22 |
| 9 | 1.42 | 1.45 | 19 | 14 | 28 |
| 10 | 3.13 | 3.20 | 9 | 7 | 8 |
| 11 | 2.81 | 2.88 | 4 | 3 | 4 |
| 12 | 4.18 | 4.28 | 18 | 20 | 12 |
| 13 | 0.34 | 0.34 | 6 | 6 | 30 |
| 14 | 5.86 | 6.00 | 5 | 4 | 1 |
| 15 | 2.41 | 2.46 | 1 | 1 | 3 |
| 16 | 2.14 | 2.19 | 3 | 2 | 5 |
| 17 | 3.85 | 3.94 | 2 | 5 | 2 |
| 18 | 2.76 | 2.82 | 11 | 11 | 13 |
| 19 | 1.32 | 1.36 | 13 | 25 | 23 |
| 20 | 1.51 | 1.55 | 33 | 34 | 32 |
| 21 | 2.25 | 2.31 | 7 | 9 | 10 |
| 22 | 0.89 | 0.91 | 10 | 10 | 27 |
| 23 | 1.15 | 1.17 | 15 | 12 | 25 |
| 24 | 3.32 | 3.40 | 23 | 27 | 18 |
| 25 | 6.20 | 6.34 | 28 | 30 | 14 |
| 26 | 3.05 | 3.12 | 16 | 23 | 15 |
| 27 | 1.73 | 1.77 | 36 | 36 | 34 |
| 28 | 0.32 | 0.33 | 34 | 33 | 35 |
| 29 | 0.01 | 0.01 | 37 | 37 | 37 |
| 30 | 2.36 | 2.41 | 12 | 13 | 16 |
| 31 | 0.27 | 0.28 | 35 | 35 | 36 |
| 32 | 2.74 | 2.80 | 21 | 19 | 19 |
| 33 | 0.87 | 0.89 | 27 | 28 | 31 |
| 34 | 3.94 | 4.04 | 30 | 32 | 20 |
| 35 | 8.38 | 8.57 | 22 | 29 | 7 |
| 36 | 2.08 | 2.13 | 29 | 31 | 29 |
| 37 | 4.64 | 4.74 | 17 | 24 | 9 |

The lower value of sediment yield index, the less contribution in the outlet sediment load. Overall, sub-watershed 29, 31 and 28, which the smallest sub-watersheds in the Mehran, have the least sediment yield contribution at the watershed outlet. However, precise analysis of Table 5 and Fig. 6 shows that in addition to the area of sub-watersheds, other factors affect these results. For example, sub-watershed with ranks 32 (sub-watershed 20) and 34 (sub-watershed 27) have medium size (area) in the Mehran watershed. To clarify this result, simultaneous analysis of columns 4 (Rank Based on Sediment yield at sub-watershed), 5 (Rank Based on runoff at sub-watershed) and 6 (Rank Based on Sediment yield at watershed outlet) and Table 5 is needed. Accordingly, these sub-watersheds have the lowest participation in watershed outlet sediment load, due to low soil erosion and runoff production at their outlet despite having moderate area. In other words, it occurs due to low erodible material in these sub-watershed and also, due to their small runoff production capability which in turn leads to lower sediment carrying capacity. Therefore, it is not correct that always the larger sub-watersheds contribute more to the watershed sediment yield.

Sub-watershed 15, 17, and 14 are respectively the most participation in the outlet's sediment yield. These results indicated that sub-watersheds located in the middle part of watershed have the highest contribution to the sediment yield of the entire watershed. While occupying 11% of the watershed area, these sub-watersheds produce more than 27% of the sediment.

According to the prioritization map, middle and upstream sub-watersheds have generally higher sediment yield index and thus higher contributions to the outlet sediment load. Some pervious researches indicated that the nearest (to watershed outlet) or the largest sub-watershed has the largest contribution to the watershed sediment yield (Kaini et al., 2012; Panagopoulos et al., 2012).

The results of this study show that these hypotheses are not generally valid. Ranking of sub-watershed based on sediment and runoff at sub- watershed is shown in Table 5. To interpret this finding, it is necessary to analyze Table 5, especially columns 4 and 5. In Mehran watershed, critical sediment source areas have high soil erosion and runoff at their outlets. Therefore, those areas produce high volume of runoff and particularly higher sediment load. This can be attributed to the increased flow carrying capacity. Therefore, it can be concluded that the amount of sediment contribution to the watershed outlet are generally a nonlinear function of many factors, such as soil characteristic, land use and land cover (LULC), size of the sub-watershed, distance to the river, etc.

Table 2 and Fig. 2 clearly indicate that the first rank of sub-watershed in soil erosion and sediment yield has clay loam textures and with low vegetation cover. In this regard, Nosrati et al. (2011) suggest that soil and land use maps provide a useful framework for assessing soil erosion in Taleghan region. The erodibility of soils differs; a soil with a high percentage of silt and clay particles has a greater erodibility than other soils under the same conditions.

Landuse and land cover (LULC) have significant impacts on the generation of runoff and soil erosion and sediment transport to water bodies. During the last two decades, Taleghan basin and especially Mehran watershed have been intensively influenced by land use changes. The dense rangelands, have gradually decreased since the approval of the dam construction (Hosseini et al., 2012).

The results showed that the value of the sediment yield index has been increased in sub-watersheds with the expansion of the low density rangeland. This implies that the increased contribution of the sub-watersheds with low density rangeland cover played a key role on sediment production at the main outlet of the watershed. However, an accurate interpretation of the interaction of the mixed land uses on the sediment yield of the whole watershed is difficult because of the interaction between LULC, soil type and topography.

Therefore, sub-watersheds located in the middle part of watershed with high soil loss and runoff generation have determined the contribution in the watershed sediment yield. Therefore, to control the sediment yield at the watershed outlet, the implementation of some BMPs, such as rangeland management and rangeland improvement, etc. for such areas is necessary.

Finally, Mehran sub-watersheds were classified in 4 groups based on sediment yield production. Group 1 represents the area of the Mehran watershed which correspond with 25% of sediment yield at watershed outlet. According to this, sub-watersheds belonging to the groups 2, 3 and 4 represent the areas of the Mehran watershed which correspond with 25-50%, 50-75% and 75-100% of sediment yield at watershed scale, respectively. Fig. 7 represented 4 groups in Mehran watershed.

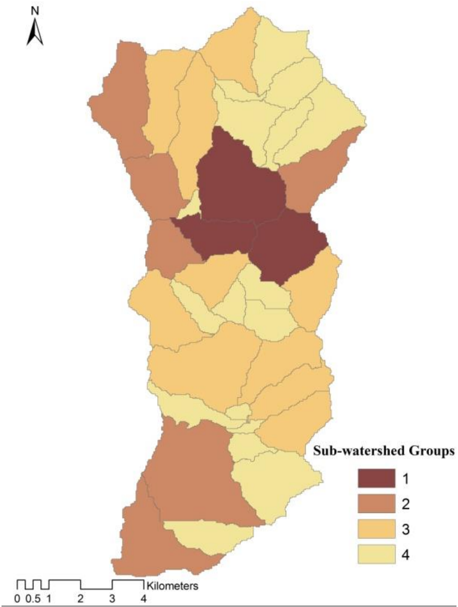


**Fig. 7.** Spatial distribution of 4 groups of sub-watersheds.

Fig. 7 is very important to implement BMPs for sediment yield reduction with the minimum cost and maximum efficiency. Hence, in the first time, watershed management programs should introduce at sub-watersheds in group 1. The results showed that 11%, 30% and 57% of the watershed area respectively contributed 27%, 50% and 75% of the total sediment yield at the main outlet of watershed (Fig. 8). These findings confirm the concept of CSAs, and agree with the previous studies (White et al., 2009, Winchell et al., 2011; Jha et al., 2010; Tuppad et al., 2010; Giri et al., 2012 and 2014).

## 4. Conclusion

A few areas in a watershed might be more critical and responsible for high amount of runoff and sediment yield. For an effective and efficient implementation of BMPs, prioritization of the sub-watersheds is vital.

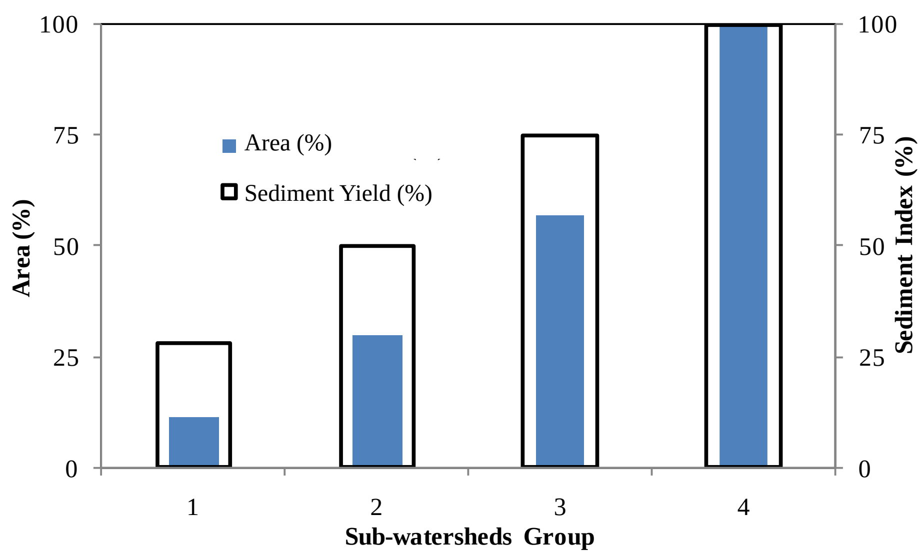


**Fig. 8.** Area (in percent of total area) and outlet sediment contributions of each group of sub-watersheds.

In this study, priority of areas was considered based on their sediment yield contribution to the main outlet of the watershed. The following conclusions were drawn from this study:

- For determining sediment hotspots based on the sediment yield contribution at the watershed outlet, land cover, soil properties, area, and distance from the outlet are important.
- Results revealed that first rank of sub-watersheds based on absolute sediment load at their respective outlet may not be essentially first rank in the sediment yield at watershed outlet ranking.
- For watershed management goals, priority of sub-watersheds based on their contribution of runoff and sediment yield to the different spatial scale (sub-watershed and watershed outlet) will be needed. Priority of CSAs at sub-watershed outlets will be used for on-site sediment control. On the other hands, source area priority based on contribution of

sediment load at main river outlets was used for off-site control strategies.

## 5. Disclosure statement

No potential conflict of interest was reported by the authors

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