Comparison of different targeting methods for watershed management practices implementation in Taleghan dam watershed, Iran

Hamzeh Noor, Mehdi Vafakhah and Majid Mohammady

ABSTRACT

Soil erosion and sediment control is important in watersheds with planned dam construction. For an efficient implementation of watershed management practices, identification of critical areas is vital. Many studies have made an effort to identify and prioritize critical sub-watersheds. But very limited studies have been conducted to rank sub-watersheds in terms of their sediment yield contribution at the watershed outlet. Therefore, the goal of this study is spatial priority of critical sources areas in Taleghan dam watershed based on three methods: (1) SSY-S: specific sediment yield at sub-watershed outlet (sediment yield/area), (2) SY-W: sub-watershed contribution to the sediment yield of the main watershed outlet/reservoir, and (3) SSY-W: specific sediment yield contribution of sub-watershed to the main watershed outlet/reservoir. The results of sub-watershed and prioritization showed that sub-watershed 22 has the highest sediment yield at its own sub-watershed outlet and main outlet of watershed. Also, implementing conservation practices in a high priority area shows a decrease in sediment yield at watershed outlet. However, sediment yield at outlet of watershed decreased about 11%, 15% and 17% from baseline scenario in methods 1, 2 and 3, respectively. The results show that the SSY-W method was more effective at reducing sediments entering the reservoir of Taleghan dam.

Key words | best management practices, hydrologic model, integrated watershed management, sediment yield control, spatial prioritization

Hamzeh Noor (corresponding author)
Soil Conservation and Watershed Management Department,
Agricultural and Natural Resources Research Center of Khorasan Razavi,
AREEO,
Mashhad,
Iran
E-mail: *hamzenor@yahoo.com*

Mehdi Vafakhah
Department of Watershed Management Engineering,
College of Natural Resources,
Tarbiat Modares University,
Noor 46414-356,
Iran

Majid Mohammady
Department of Range and Watershed Management,
Faculty of Natural Resources,
Semnan University,
Semnan,
Iran

INTRODUCTION

Watershed management includes the implementation of practices in order to reduce soil, water and nutrient losses of the watershed and to ensure sustainable natural resources protection in the watershed scale. Understanding the best way to allocate limited resources is a constant challenge for watershed management efforts.

Considering the resource constraints, it is not possible to implement watershed management practices (WMPs) at every sub-watershed in a watershed. Similarly, WMP placement at every field may not be needed, because only a few critical areas in the watershed may potentially contribute disproportionately large amounts of runoff and sediment loads in the watershed (Pai *et al.* 2011; Saghafian *et al.* 2015). When WMPs are implemented in these critical regions, they would achieve maximum efficiency (Tripathi *et al.* 2005; Saghafian *et al.* 2012). Targeting critical source area is more effective and resource efficient than randomly implementing conservation practices throughout a watershed. Preferential implementation of conservation practices on a critical source area is known as the targeting approach (Giri *et al.* 2014). Therefore, identification and prioritization of critical sub-watersheds are essential to sediment reduction. Watershed prioritization is the ranking of different critical sub-watersheds of a watershed according

doi: 10.2166/ws.2016.048

to the order in which they have to be taken up for treatment and WMP implementation (Niraula *et al.* 2013; Sardar *et al.* 2014).

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. But, 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 the implementation of management practices (Mishra *et al.* 2007; Pai *et al.* 2011; Saghafian *et al.* 2012).

Predicted runoff and sediment yield at the sub-watershed outlet have usually been used by researchers as a criterion to prioritize areas (Tripathi *et al.* 2005; Mishra *et al.* 2007; Busteed *et al.* 2009). Sub-watershed prioritization based on sediment yield at sub-watershed outlet has been used for on-site erosion control. Because erosion prone areas are not necessarily those with the highest sediment load contribution at the watershed outlet, when the concern is to control sediment yield at the main watershed outlet, such as reducing sediment entering the reservoir dam (Sardar *et al.* 2014), application of this criterion is not reasonable and does not lead to maximum sediment reduction at watershed outlet. Two factors are important to identify critical source areas (CSAs) at watershed outlet; erodible materials and transport potential or sediment delivery. In a hydrologic model such as SWAT, the simulation of watershed hydrology (runoff and sediment) is divided into two major phases. The first division is the land phase of the hydrologic cycle, which controls the amount of water and sediment loadings to the main channel in each sub-watershed. The second division is the routing phase of the hydrologic cycle, which considers the movement of water, sediments, etc. (Neitsch *et al.* 2011). Therefore, the prioritizing procedure must be inclusion of discharge and sediment routing within the watershed stream network. In other words, the other strategy for watershed management is controlling sediment load of upstream land carrying sediment to the main outlet. To do this, it is essential, first, to simulate the runoff and sediment yield of upstream sub-watersheds and, second, to prioritize them according to their contribution to the main outlet runoff and sediment yield. To recognize the most critical sub-watersheds based on their contribution to the outlet, the unit response approach (URA) may be applied (Saghafian *et al.* 2015). In the URA method, one can set the priority of sub-watersheds based on their share of the outlet runoff and sediment yield by successive omission of each sub-watershed (Saghafian *et al.* 2015).

Finally, it can be concluded that studies to identify and prioritize CSAs have been reported a lot; however, very limited studies have been conducted to prioritize sub-watersheds in terms of their share of the sediment yield of the main outlet watershed, and few studies have evaluated the performance of best management practices (BMPs) based on different CSA identification methods.

Therefore, the overall objective of this study is to develop a decision support for identifying CSAs with respect to sediment yield. To do this, runoff and sediment yield of the watershed were simulated using SWAT. After model calibration and validation, a decision support (SWAT-URA) was developed in MATLAB for prioritizing CSAs at sub-watershed outlets and main outlet of watershed, and finally, conservation practices were implemented in high priority areas. This method was then used in the Taleghan dam watershed.

MATERIALS AND METHODS

Study area

The Taleghan watershed, with drainage area of 900 km^2, located in the Sefidroud basin, which is an important source of water supply for the Tehran Province, Iran, were selected for this study. Design and construction of Taleghan dam were started in the last decade, and water storing in the dam started in 2006. The Taleghan watershed has undergone rapid land use change, urbanization, and water resource system development for agricultural, industry, and domestic water supply (Noor *et al.* 2014). These changes could have devastating impacts on both water balance and water quality of the watershed. Therefore, in the Taleghan watershed, identification of CSA and then implementation of the WMPs in critical areas of the watershed are necessary.

The elevation of this region is from 1,700 to 4,370 m above sea level (a.s.l.) with weighted average of 2,753 m. The highest proportion of the study area belongs to the elevation class of 2,500–3,000 m, with 35% of the total area, while the lowest proportion belongs to the 3,000–4,150 m class, with 6% of the area (Noor *et al.* 2014; Vafakhah *et al.* 2015). Because of orographic effects, the average annual precipitation ranges from about 454 mm at the outlet (Galinak Station) to more than 814 mm at the upper watershed (Dizan Station). The watershed's hydrology is dominated by high volume flows and sediment yield occurring in the spring, with peak flows also occurring due to spring rainfall events (Noor *et al.* 2014; Vafakhah *et al.* 2015).

The land use of the study watershed comprises 90 percent under poor and moderate rangelands, and 10 percent under orchids, agriculture and other land uses. The soil textures of the watershed mainly are silt loam and loamy (FAUT 1993). The locations of the Taleghan watershed, weather stations and dam are shown in Figure 1.

Hydrologic model description

The SWAT model is continuous time, semi-distributed to simulate water, sediment and agricultural chemical transport at river basin scale on a daily time step, developed by the USDA Agricultural Research Service. Sediment yield is predicted using the modified universal soil loss equation, and sediment is routed through the river reaches using a stream power equation (Neitsch *et al.* 2011).

$$Sed = 11.8(Q_{surf} \cdot q_{peak} \cdot Area_{hru})^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG$$

where Sed is defined as Sediment yield (tonnes/day), Q_{surf} is the surface runoff volume (mm/day), q_{peak} is the peak runoff rate (m^3/s), $Area_{hru}$ is the area of the hydrologic response unit (HRU) (ha), K_{USLE} is the USLE soil erodibility factor (0.013 metric ton m^2 h/(m^3-metric ton cm)), C_{USLE} is the USLE crop management factor or cover management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor, and CFRG is the coarse fragment factor. For information about the USLE factor, the reader is referred to (Wischmeier & Smith 1978). The runoff component of the SWAT model supplies estimates of runoff volume and peak runoff rate using the curve number method and modified rational method, respectively, which, along with the sub-watershed area, are used to calculate the runoff erosive energy variable (Neitsch *et al.* 2011). The current version of the SWAT model uses the simplified stream power equation of Bagnold's to route sediment in the channel. Sediment transport in the channel network is a function of two processes, degradation and aggradation (i.e. deposition), operating simultaneously in the reach (Neitsch *et al.* 2011).

Data required

A lot of data are needed for the physical watershed simulation by SWAT. These would be data about topography (digital elevation model (DEM)), climate (daily measured and monthly statistical weather data), and both soil and land use (maps and physical parameters) (Neitsch *et al.* 2011).

Rainfall and temperature (maximum and minimum) data from seven climatology stations located inside the watershed from 2005 to 2010 were collected by the Iranian water resources researches, Tehran. Table 1 shows information about weather stations in the study watershed.

A topography map at a scale of 1:250,000 was produced by National Cartographic Center of Iran, and DEM with a 25×25 m spatial resolution was generated from the topography map (Figure 1).

A land use map for the years of 2008 was prepared by the Soil Conservation and Watershed management Research Institute. The land use map used in this study, is shown in Figure 2.

A 1:50,000 pedological soil map and texture was obtained from the FAUT (1993) as well as some textural soil profiles description for all the major soils. The main soil characteristics of Taleghan watershed are presented in Table 2. Daily stream flow and total suspended sediments data from 2005 to 2010 measured at Galinak hydrometric station were used for the calibration and validation of SWAT.

SWAT model calibration and evaluation

The first step in setting up the SWAT model is the physiographic analysis based on watershed topography. The ArcSWAT automatically delineates a watershed into sub-watersheds based on DEM to account for watershed heterogeneities. The whole watershed was divided into 37

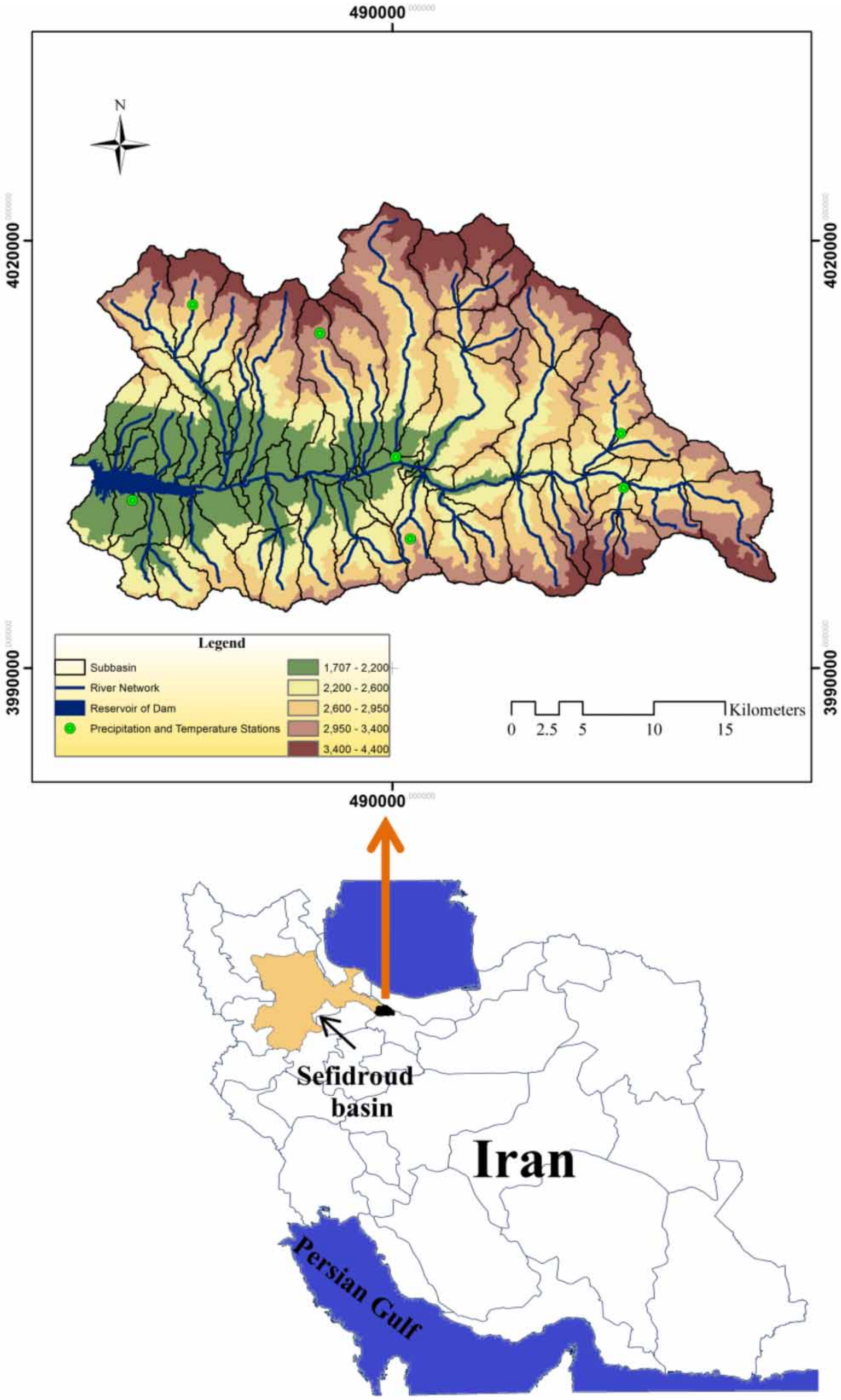

Figure 1 | Locations of study watershed, weather stations and reservoir of Taleghan dam.

sub-watersheds. The land use and soil maps, along with their respective look up tables prepared earlier, were supplied to the model for reclassification according to SWAT coding convention. All three maps were then overlaid to create HRUs with unique land cover/soil class. Finally, location tables of weather data were loaded to link them up with

Table 1 | List of selected weather stations in this Taleghan watershed

Station name	X (UTM)	Y (UTM)	Elevation (m a.s.l.)
Dehdar	506043	4006472	2,800
Garab	506245	4002652	2,600
Joestan	490234	4004812	1,990
Dizan	484904	4013508	1,950
Sekranchal	475977	4015500	2,200
Geliroud	491252	3999080	2,150
Zidasht	471670	4002880	1,750

Table 2 | Soil group classification of the Taleghan watershed

No.	Hydrologic group	Area (%)	Texture
1	C	22.24	Clay-Loam
2	D	32.11	Loam
3	C	1.92	Loam
4	C	4.9	Sandy-Loam
5	C	27.24	Sandy-Loam
6	B	0.9	Sandy-Loam
7	D	2.42	Loam
8	B	0.98	Loam
9	B	4.78	Silty-Loam
10	C	2.51	Clay-Loam

the required files already created for the purpose. The input parameters required in the model were generated from various map themes (DEM, soil and landuse) using the Arc-SWAT interface. After providing required input data, SWAT was run for sediment yield simulation in the Taleghan River. This simulation passed through three consecutive separate periods. These, as well as their durations, were: (i) the setup (also known as warm-up) period (1 year); (ii) the calibration period (3 years); and (iii) the validation period (2 years).

Hydrologic models such as SWAT often contain parameters that cannot be measured directly due to measurement limits and scale issues. Inverse modeling (IM) has in recent years become a very popular method for calibration (Abbaspour 2011). IM is concerned with the problem of making inferences about physical systems from measured output variables of the model (e.g., river discharge, sediment concentration).

In this study, the Sequential Uncertainty Fitting version-2 (SUFI-2) procedure was used to calibrate the SWAT model. It is an inverse optimization approach that uses the Latin hypercube sampling procedure along with a global search algorithm to examine the behavior of objective functions. In SUFI-2, parameter uncertainty accounts for all sources of uncertainties, such as uncertainty in driving variables (e.g. rainfall), conceptual model, parameters, and measured data. The degree to which all uncertainties are accounted for is quantified by a measure referred to as the p-factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). Another measure quantifying the strength of a calibration/uncertainty analysis is the so-called r-factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. 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).

Model performance was evaluated through visual interpretation of the simulated results, and commonly used statistical measures of agreement between measured and simulated data. Several statistical approaches were used to check the model performance, i.e., coefficient of determination (R^2) and Nash–Sutcliffe (NS) efficiency (Moriasi *et al.* 2007). The R^2 value is an indicator of relationship strength between the observed and simulated values. The NS value, which varies from negative infinity to 1, with 1 indicating the perfect fit, works best when the coefficient of variation for the observed data set is large. Furthermore, an NS value equal to zero indicates that the model results are no better estimation than what would result if the average of the observed data were used.

Prioritization methods

The SWAT-URA package was developed in a MATLAB computer program for automatic prioritizing of CSAs in a watershed. Figure 3 describes the methodology followed during sub-watershed prioritization using SWAT-URA. The advantages of SWAT-URA are presented below.

This methodology is user friendly and transferable to other watersheds with different size and number of sub-watersheds.

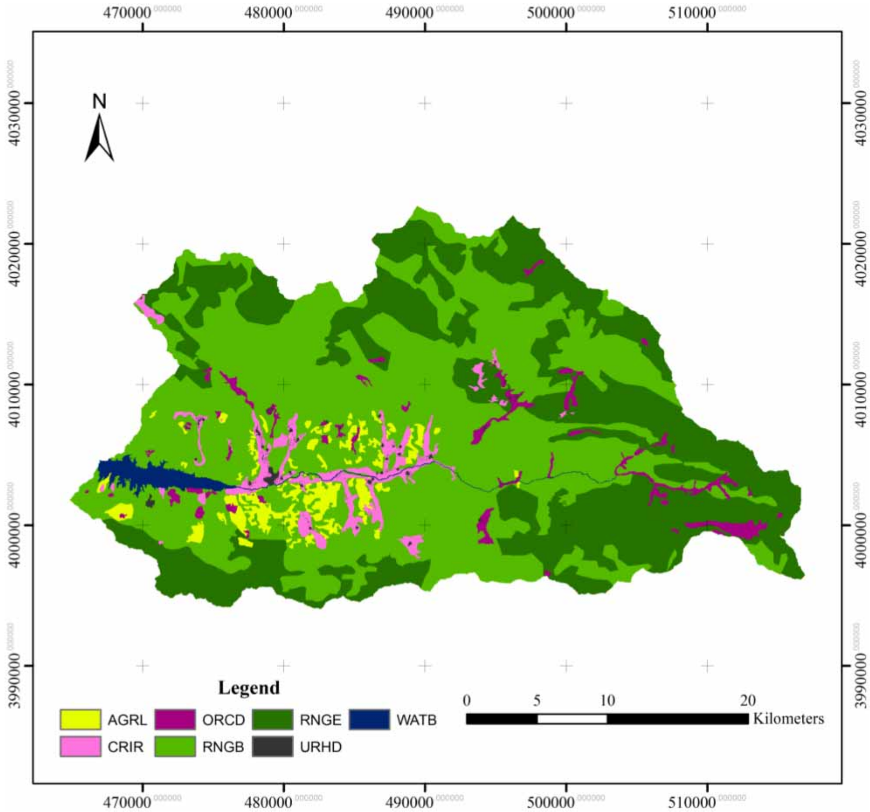

Figure 2 | SWAT land use classification of the Taleghan watershed.

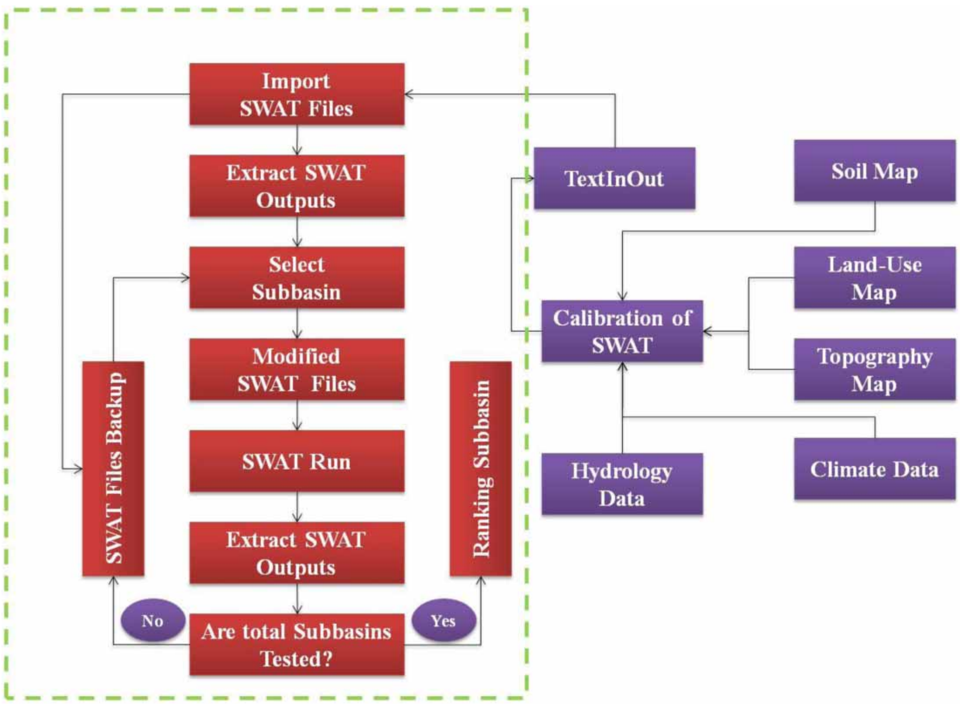

Figure 3 | Flowchart for the different processes during prioritizes of sub-watershed. The boxes within the dashed line denotes the SWAT-URA.

Prioritization of sub-watersheds using different methods. SWAT-URA ranking of sub-watersheds is based on their sediment yield at sub-watershed output and their contribution to main output of watershed.

In SWAT-URA it is possible to represent the watershed into fine spatially discrete units and therefore, realistic sub-watershed dividing. In SWAT-URA, watershed is divided into a number of sub-watersheds that represent the spatially discrete units. In other words, because SWAT-URA automatically prioritizes CSAs, we can represent the watershed into fine discrete area (units).

SWAT-URA prioritizes sub-watersheds in a simple and completely automated way based on three methods:

In method 1 (Specific Sediment Yield at Sub-watershed outlets: SSY-S) for identification of critical sub-watersheds, after the SWAT model is calibrated and validated, specific sediment yields at the outlet of each sub-watershed (sediment yield divided by sub-watershed area) are calculated and then sub-watershed ranking is based on this criterion.

But method 2 (Sediment Yield at Watershed outlet: SY-W) for identification of critical sub-watershed is partially difficult. The URA was applied to prioritize sub-watersheds in terms of their share of sediment yield at the main watershed outlet. The idea behind the URA was derived from the unit response (matrix) approach in groundwater management (Saghafian & Khosroshahi 2005; Saghafian et al. 2015).

The first step in applying URA is to simulate the base state of watershed in which all sub-watersheds contribute to the sediment yield at the main outlet. The result of the base state is then used for comparison with other states resulting from individual removal of sub-watersheds. To remove the effect of each sub-watershed, they should individually be turned off in successive runs, so that the resultant discharge and sediment yield at the main outlet can be obtained by setting the area of the selected sub-watershed equal to zero (Saghafian et al. 2015). This procedure was repeated in each successive run for all sub-watersheds. Finally, changes in sediment values at the main outlet were compared with the base state in which all sub-watersheds were present in the simulation. The following indices can be defined to prioritize sub-watersheds depending on the quantity of their contribution to sediment at the main watershed outlet (Saghafian et al. 2015):

$$\mathrm{SY-W_n = Y_{total} - Y_{total-n}} \tag{1}$$

Also, in order to eliminate area dependency in the sub-watershed's contribution at the outlet sediment yield, the following indices in method 3 (Specific Sediment Yield at Watershed outlet: SSY-W) were defined:

$$\mathrm{SSY-W_n = \frac{Y_{total} - Y_{total-n}}{A_n}} \tag{2}$$

where $\mathrm{SY-W_n}$ is the sediment yield index of the $\mathrm{n_{th}}$ sub-watershed; $\mathrm{Y_{total}}$ is the outlet sediment yield with all sub-watershed units present in the base simulation; $\mathrm{Y_{total-n}}$ is the outlet sediment yield with the $\mathrm{n_{th}}$ sub-watershed; $\mathrm{SSY-W_n}$ is the sediment yield index of the $\mathrm{n_{th}}$ sub-watershed on the basis of unit sub-watershed area; and $\mathrm{A_n}$ is the area of the $\mathrm{n_{th}}$ sub-watershed (ha).

RESULTS AND DISCUSSION

SWAT calibration and baseline scenario

Calibration is carried out in two steps: flow is calibrated first and then the sediment load. In the first step, during flow calibration, the parameters identified as impacting sediment load are kept constant (average values of their range); and in the second step, during sediment calibration, the parameters found from flow calibration are kept constant to search for the optimal values of sediment parameters.

The calibration process began with 35 parameters in the SUFI-2 algorithm, but in the last iteration only 18 parameters were found to be sensitive to discharge and sediment. The model was run for 500 iterations. The parameter ranges and calibrated values are presented in Table 3.

p-factor, r-factor, coefficient of determination (R^2) and NS are calculated for performance evaluation of SWAT. In discharge calibration, 67% of measured data were bracketed by the 95PPU, whereas for sediment calibration, 56% of measured data fell in the 95PPU band (Table 4).

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

Parameter	Min–max value	Optimum value
Discharge calibration		
r-CN2.mgt	(0.08)–(−0.15)	−0.05
v-SMFMN.bsn	(2)–(6)	4.20
r-SOL-K.sol	(−20)–(20)	−0.12
v-SNOCOVMX.bsn	(200)–(300)	288.00
v-SNO50COV.bsn	(0.4)–(−0.6)	0.52
v-SMFMX.bsn	(3)–(7)	4.91
r-SOL-AWC.sol	(−0.2)–(−0.2)	−0.08
v-ALPHA-BF.gw	(0.03)–(−0.07)	0.056
v-GW-DELAY.gw	(5)–(15)	7.50
v-CH-N2.rte	(0.1)–(−0.2)	0.12
v-CH-K2.rte	(45)–(55)	0.51
v-SURLAG.bsn	(4)–(11)	7.51
Sediment calibration		
v-SPCON.bsn	(0.001)–(0.005)	0.003
v-SPEXP.bsn	(1.00)–(1.50)	1.10
v-CH_EROD.rte	(0.10)–(0.40)	0.21
v-CH_COV.rte	(0.20)–(0.70)	0.32
v-ADJ_PKR.bsn	(0.50)–(2.00)	1.13
v-PRF.bsn	(0.10)–(1.00)	0.31

Table 4 | Results of calibration and uncertainty analysis in SUFI-2

	Runoff		Sediment	
Criteria	Calibration	Validation	Calibration	Validation
NS	0.77	0.80	0.61	0.64
R^2	0.82	0.85	0.61	0.66
r-factor	0.76	0.73	0.85	0.81
p-factor	0.64	0.67	0.52	0.56

Also, comparisons of the estimated and measured data are compared in Figures 4 and 5. As can be seen in Figure 4, the monthly observed and simulated flow match well; however, the simulated peak flows are lower than the observed peak flows in almost all cases. The NS coefficients for calibration and validation periods were 0.80 and 0.77, respectively.

The results showed that SWAT consistently underestimated streamflow. This finding is in agreement with Akhavan et al.'s (2010) findings, which showed that SWAT consistently underestimated streamflow in a region where snowmelt plays

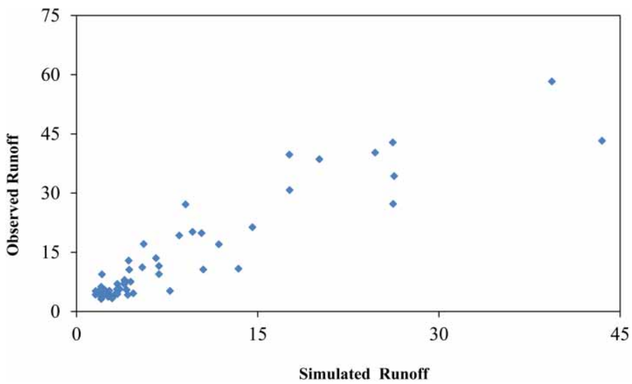

Figure 4 | Correlation between SWAT simulated and observed monthly runoff (m^3/s) in Taleghan River.

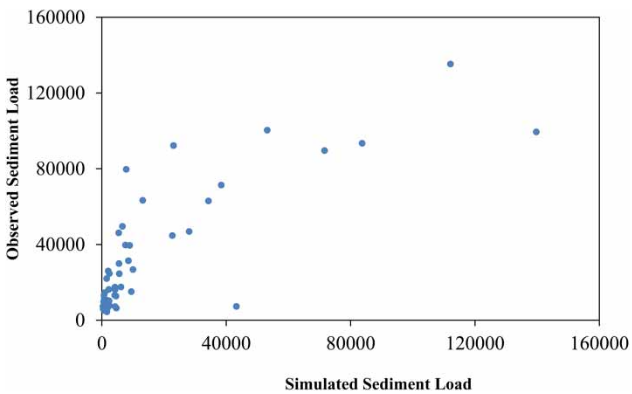

Figure 5 | Correlation between SWAT simulated and observed monthly sediment yield (tons) in Taleghan River.

a key role in streamflow, similarly to the Taleghan watershed (Vafakhah et al. 2015). Also, this could be due to one or more of the other uncertainties: errors in input data, errors in the observed data, or errors in the model itself (Kaini et al. 2012).

In the case of sediment calibration and validation, the graphical plot shows more differences in the simulated and measured data. Insufficient observed sediment data and other uncertainties (as in the case of flow calibration) are expected to be the causes of lower performance of sediment calibration (Kaini et al. 2012).

In the Taleghan watershed, the predicted runoff values were much better than those for sediment. The NS coefficients 0.64 and 0.61 were obtained for calibration and validation data sets. The weakness of the model to simulate sediment was due to the improper peak runoff simulation and the nature and accuracy of the measured sediment data.

Table 5 | Runoff and sediment yield at sub-watershed outlet

Sub-watershed	Area (ha)	Area (%)	Ranking SSY-S	Ranking SY-W	Ranking SSY-W
1	1,564.5	1.75	22	26	26
2	2,471.0	2.75	25	16	22
3	2,369.2	2.64	5	12	13
4	2,026.4	2.26	18	22	25
5	1,980.2	2.20	15	19	18
6	829.0	0.92	19	27	7
7	7,276.2	8.11	8	2	14
8	200.0	0.22	24	37	16
9	5,944.2	6.63	16	9	35
10	66.3	0.07	38	40	11
11	2,574.2	2.87	7	8	9
12	971.2	1.08	17	28	19
13	2,650.6	2.95	4	5	6
14	6,138.6	6.84	13	6	31
15	4,828.7	5.38	21	13	36
16	1,331.6	1.48	12	7	2
17	114.3	0.13	6	38	8
18	8.7	0.01	37	41	3
19	348.8	0.39	36	36	30
20	324.1	0.36	2	31	5
21	2,576.4	2.87	20	18	27
22	3,701.4	4.13	1	1	1
23	2,490.6	2.78	27	11	12
24	764.8	0.85	31	33	32
25	491.7	0.55	39	35	39
26	3,091.7	3.45	9	3	4
27	2,304.8	2.57	33	15	17
28	156.3	0.17	40	39	37
29	312.7	0.35	23	34	20
30	1,515.6	1.69	30	32	41
31	1,563.3	1.74	14	17	10
32	1,457.1	1.62	10	29	33
33	5,633.0	6.28	28	4	21
34	2,467.1	2.75	35	20	28
35	1,948.2	2.17	34	30	40
36	2,799.9	3.12	26	14	23
37	1,503.2	1.68	29	25	24
38	2,736.2	3.05	32	23	34
39	2,640.2	2.94	11	10	15
40	2,643.8	2.95	3	21	29
41	2,896.4	3.23	41	24	38

Figure 5 depicts the correlation between monthly sediment yield simulated and observed for the Taleghan watershed.

Moriasi *et al.* (2007) recommended threshold values of NS for model calibration. When NS is greater than 0.5 for stream flow and 0.55 for sediment, calibration is considered satisfactory (Moriasi *et al.* 2007). The results obtained here showed that NS coefficients are equal to 0.80 and 0.77 for streamflow calibration and validation, respectively, which are higher than the generally acceptable minimum NS value (0.5) for streamflow calibration (Moriasi *et al.* 2007). NS coefficients for sediment calibration and validation obtained are 0.64 and 0.61, respectively, which are within the acceptable range. Also, sediment calibration in the Taleghan watershed was higher than reported in the previous study. Kaini *et al.* (2012), Saghafian *et al.* (2012) and Artita *et al.* (2013) obtained NS values for sediment calibration of 0.50, 0.44 and 0.44, respectively.

Sub-watershed prioritization

After calibration and validation of the model, average annual sediment yield for each sub-watershed was determined for the calibration and validation periods (2006–2010). This output of the model served as an indicator of prioritization in the base state. The results of Table 4 indicate that sub-watershed 22 is the most critical one in terms of sediment yield at sub-watershed outlet (SSY-S).

Ranking source areas at sub-watershed outlet will be needed for on-site erosion control. Sub-watershed ranking based on SSY-S can be effectively used in decision making for priority management of critical areas that require conservation measures. Therefore, as can be seen from Table 5, sub-watershed 22 is a critical area in respect of soil degradation, soil compaction, nutrient depletion, loss of soil organic matter, poor seedling emergence, and reduced crop yields. On the other hand, sub-watersheds 25 and 41 produce the lowest SSY-S. Analysis of sub-watershed soil and land cover maps clearly indicates that the first rank of sub-watersheds in soil erosion and sediment yield has clay loam texture and with low vegetation cover. Soils differ in their susceptibility to erosion (erodibility) based on texture; a soil with a high percentage of silt and clay particles has a greater erodibility than other soils under the same conditions. This implies that the amount of clay loam texture soils in the watershed positively affects the soil erosion and therefore, sediment load at watershed outlet. Saghafian *et al.* (2015) found a relationship between sub-watersheds' ranking based on sediment load and the clay loam contents in their soils. Also, landuse and land cover (LULC) have significant impacts on the generation of runoff, forms of water fluxes, and soil erosion and sediment transport to water bodies. The results showed that with expansion of the low density rangelands in sub-watersheds, the value of the sediment yield index has been increased.

As previously described, sub-watersheds' priority based on their share of the main outlet sediment yield (SY-W) is determined using the URA. In successive runs each sub-watershed is eliminated by setting its area equal to zero. Then, sediment indict was calculated. The results are presented in Table 5.

The lower the value of indict, the less contribution to the outlet sediment yield. Overall, sub-watershed 18, the smallest sub-watershed in the Taleghan watershed, has the least contribution to the outlet's sediment load. However, this does not necessarily mean that larger sub-watersheds always contribute more to the outlet's sediment load.

Based on SY-W, sub-watersheds 22, 7, 26, 33, 13 and 14 rank highest, respectively. These areas include 20% of the watershed area, while 45% of the sediment loads are produced in these sub-watersheds. These results indicate that upstream steep sub-watersheds with higher runoff production have the most determining contribution to the outlet sediment yield. However, the findings of the current study do not support the previous research indicating that the nearest sub-watershed has the largest contribution to the watershed sediment yield (Kaini *et al.* 2012). The results of this study show that this hypothesis is not generally valid. In the Taleghan 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.

The implementation of conservation practices in these areas is more effective because they have the opportunity to control sediment yield and thus will improve the effectiveness of water quality programs.

As can be seen from column 6 in Table 4, the rankings of sediment per unit area of each sub-watershed (SSY-W) contributions generally differ from those of sediment load contributions (SY-W). According to sediment load ranking, sub-watersheds 22, 16 and 18 have the highest rank, whereas the smallest rank belongs to sub-watershed 30. Panagopoulos *et al.*'s (2012) findings showed that the size of sub-watersheds may affect their contribution to the sediment yield at the watershed outlet, but it may be that a small sub-watershed has a high specific sediment yield (sediment yield/area). Therefore, in the SSY-W method area dependency of CSA's sediment yield sharing at the watershed outlet is eliminated.

Prioritization of sub-watersheds based on sediment per unit area is very useful for implementation of BMPs. The rankings indicate that with BMPs in these areas, maximum performance per unit area can be obtained.

Implementing conservation practices

After prioritization of sub-watersheds based on three prioritization methods, i.e. SSY-S, SY-W and SSY-W, the conservation practices were implemented on 25% of the watershed area based on high priority areas. High priority areas were obtained from three prioritization methods

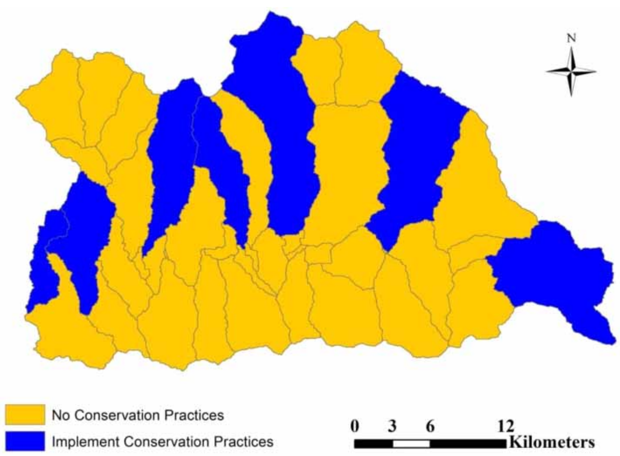

Figure 6 | Selected sub-watershed for implementation of conservation practices based on prioritization method 1.

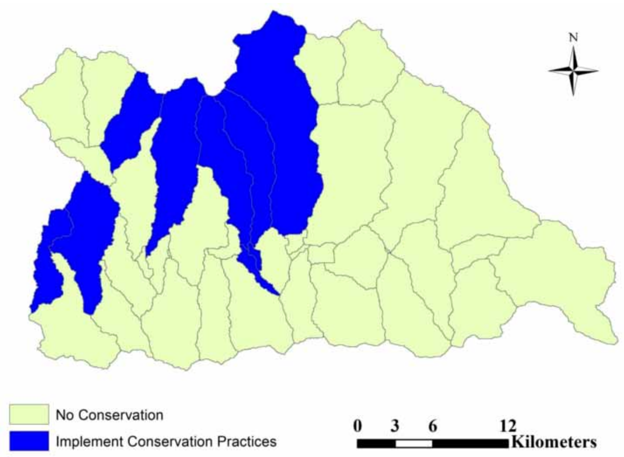

Figure 7 | Selected sub-watershed for implementation of conservation practices based on prioritization method 2.

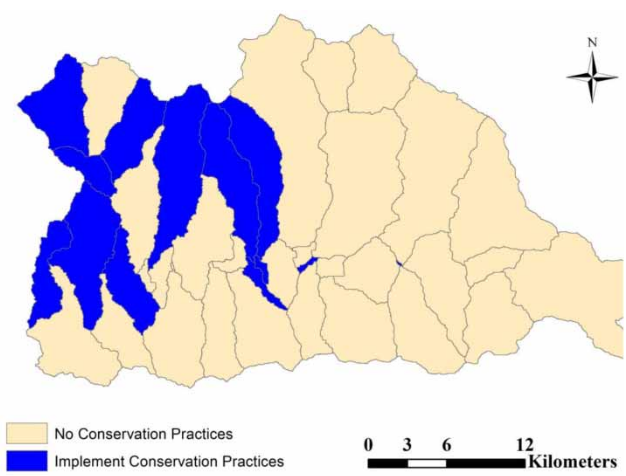

Figure 8 | Selected sub-watershed for implementation of conservation practices based on prioritization method 3.

(Figures 6–8). After implementing conservation practices (scenarios), the efficiency of each scenario was compared in sediment reduction entering Taleghan dam. The conservation practices were represented through the curve number (CN) and USLE support practice factor ($USLE_p$) in the model (Sardar *et al.* 2014). These model parameters affect sediment loss from the CSA. In other words, 25% of the watershed area was selected in each prioritization method where it has higher rank in sediment yield. Then the conservation practices were simulated within the selected sub-watersheds through decreasing the value of CN and $USLE_p$.

Implementing conservation practices in three prioritization methods will decrease sediment yield and its transportation to the watershed outlet/reservoir and thereby will increase the life of the Taleghan Reservoir. But comparison of results demonstrated that the sediment yield at outlet of the watershed decreased about 11%, 15% and 17% from baseline scenario (current condition) in prioritization methods 1, 2 and 3, respectively. These sediment yield change were determined considering the prevalent hydrologic conditions during the study period. However, it may alter in the future if there is any change in the hydrologic conditions of the study area.

Using various CSA identification methods demonstrated that different areas of a watershed can be selected as high or low priority based on targeting technique. When applying BMPs to the priority areas based on the three targeting methods, varying results were observed. Comparing targeting methods, method 3 was the most effective for reducing sediment yield at the watershed outlet when BMPs are applied on high priority areas. Therefore, apart from type of conservation practices, placement in the watershed also plays a vital role in the sediment yield reduction, as the contribution of sediment is disproportionate in the watershed (Maringanti *et al.* 2009).

In this study, three prioritization methods have offered different priority maps and as a result, the same implementing conservation practices have different sediment reduction. These results are due to using different criteria in the prioritization methods. For example, the criterion in method 1 for prioritization of CSAs was sediment yield at the sub-watershed outlets. Therefore, high priority area was related to the sub-watersheds with high sediment yield at their outlets. But in method 3, the sub-watershed contribution to specific sediment yield at the watershed outlet was used as the criterion. So, the results obtained in these methods were different. This result may be explained by the fact that the most erodible sub-watersheds are not necessarily those with the highest sediment load contribution at the watershed outlet.

As mentioned earlier, 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 (Blanco & Lal 2008; Noor *et al.* 2010). But, off-site causes pollution, sedimentation, and silting of water resources (Blanco &

Lal 2008). Therefore, for watershed management goals, prioritization of sub-watersheds based on their share of sediment yield to the different spatial scale (sub-watershed and watershed outlet) will be needed. Based on the results of Giri *et al.* (2014), no single method was found to be significantly better or worse for priority area selection and pollutant type, although each method produced different high and low priority areas. In addition, utilization of a specific targeting method should be based on the goals stated in a BMP implementation project (Giri *et al.* 2012). For example, when preventing sedimentation of a reservoir is the goal of a watershed management project, selecting the targeting method that focuses on sediment load reduction at watershed outlet may be more appropriate.

CONCLUSIONS

WMPs are widely accepted as effective control measures for floods and sediment loads at a watershed before they enter the receiving water body. 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 conservation practices, prioritization of sub-watersheds is vital. Distributed hydrologic models serve as useful tools to prioritize sub-watersheds that need immediate attention to implement conservation practices. In this study, the SWAT-URA package was developed in the MATLAB computer program for automatic prioritizing of source area with different criteria (sediment yield at sub-watersheds outlet and main outlet of watershed). This study evaluated three targeting methods for implementation of conservation practices to reduce sediment entering Taleghan dam. The results revealed that sub-watersheds producing the highest or lowest absolute sediment load at their own outlet may not essentially rank first and last in contributing to the total sediment ranking. We can conclude that sediment contributions to the outlet of a watershed are generally a nonlinear function of many factors, such as soil characteristics, LULC, size of the sub-watershed, distance to river, etc. Therefore, no single method was found to be significantly better or worse for priority area selection, although each method produced different priority areas.

ACKNOWLEDGEMENTS

Data for stream flow calibration of SWAT were supported by the Tarbiat Modares University.

REFERENCES

Abbaspour, K. C. 2011 SWAT-CUP user manual, Federal Institute of Aquatic Science and Technology (Eawag). Switzerland.

Akhavan, S., Abedi-Koupai, J., Mousavi, S. F., Afyuni, M., Eslamian, S. S. & Abbaspour, K. C. 2010 Application of SWAT model to investigate nitrate leaching in Hamadan–Bahar Watershed, Iran. *Agriculture, Ecosystems and Environment* **139**, 675–688.

Artita, K. S., Kaini, P. & Nicklow, J. W. 2013 Examining the possibilities: generating alternative watershed-scale BMP designs with evolutionary algorithms. *Water Resources Management* **27**, 3849–3863.

Blanco, H. & Lal, R. 2008 *Principles of Soil Conservation and Management*. Springer Science, The Netherlands. p. 617.

Busteed, P. R., Storm, D. E., White, M. J. & Stoodley, S. H. 2009 Using SWAT to target critical source sediment and phosphorus areas in the Wister Lake Basin. USA. *American Journal of Environmental Sciences* **5** (2), 156–163.

Faculty of Agriculture, University of Tehran (FAUT) 1993 General Investigation of Taleghan Basin: Hydrometeorology and Climatology Report (in Persian).

Giri, S., Nejadhashemi, A. P. & Woznicki, S. A. 2012 Evaluation of targeting methods for implementation of best management practices in the Saginaw River Watershed. *Journal of Environmental Management* **103**, 24–40.

Giri, S., Nejadhashemi, A. P., Woznicki, S. & Zhang, Z. 2014 Analysis of best management practice effectiveness and spatiotemporal variability based on different targeting strategies. *Hydrological Processes* **28** (3), 431–445.

Kaini, P., Artita, K. & Nicklow, J. W. 2012 Optimizing structural best management practices using swat and genetic algorithm to improve water quality goals. *Water Resources Management* **26**, 1827–1845.

Maringanti, C., Chaubey, I. & Popp, J. 2009 Development of a multiobjective optimization tool for the selection and: placement of best management practices for nonpoint source pollution control. *Water Resources Research* **45**, 1–15.

Mishra, A., Kar, S. & Singh, V. P. 2007 Prioritizing structural management by quantifying the effect of land use and land cover on watershed runoff and sediment yield. *Water Resources Management* **21**, 1899–1913.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D. & Veith, T. L. 2007 Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the American Society of Agricultural and Biological Engineers* **50** (3), 885–900.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R. & Williams, J. R. 2011 Soil and water assessment tool theoretical documentation version 2009, Texas Water Resources Institute, College Station, TWRI Report TR-406, Texas.
Niraula, R., Kalin, L., Srivastava, P. & Anderson, J. 2013 Identifying critical source areas of nonpoint source pollution with SWAT and GWLF. *Ecological Modeling* **268**, 123–133.
Noor, H., Mirnia, S. K. H., Fazli, S., Raisi, M. B. & Vafakhah, M. 2010 Application of MUSLE for the prediction of phosphorus losses. *Water Science and Technology* **62** (4), 809–815.
Noor, H., Vafakhah, M., Taheriyoun, M. & Moghadasi, M. 2014 Hydrology modeling in Taleghan mountainous watershed using SWAT. *Journal of Water and Land Development* **20**, 30–37.
Pai, N., Saraswat, D. & Daniels, M. 2011 Identifying priority subwatersheds in the Illinois river drainage area in Arkansas watershed using a distributed modeling approach. *Transactions of the ASABE* **54** (6), 2181–2196.
Panagopoulos, Y., Makropoulos, C. & Mimikou, M. 2012 Decision support for diffuse pollution management. *Environmental Modelling and Software* **30**, 57–70.
Saghafian, B. & Khosroshahi, M. 2005 Unit response approach for priority determination of flood source areas. *Journal of Hydrologic Engineering* **10** (4), 270–277.
Saghafian, B., Sima, S., Sadeghi, S. & Jeirani, F. 2012 Application of unit response approach for spatial prioritization of runoff and sediment sources. *Agricultural Water Management* **109**, 36–45.
Saghafian, B., Meghdadi, A. R. & Sima, S. 2015 Application of the WEPP model to determine sources of run-off and sediment in a forested watershed. *Hydrological Processes* **29** (4), 481–497.
Sardar, B., Singh, A. K., Raghuwanshi, N. & Chatterjee, C. H. 2014 Hydrological modeling to identify and manage critical erosion-prone areas for improving dam life: case study of Barakar Basin. *Journal of Hydrologic Engineering* **19**, 196–204.
Tripathi, M. P., Panda, R. K. & Raghuwanshi, N. S. 2005 Development of effective management plan for critical subwatersheds using SWAT model. *Hydrological Processes* **19**, 809–826.
Vafakhah, M., Nouri, A. & Alavipanah, S. K. 2015 Snowmelt-runoff estimation using radiation SRM model in Taleghan watershed. *Environmental Earth Sciences* **73** (3), 993–1003.
Wischmeier, W. H. & Smith, D. D. 1978 *Predicting rainfall losses: a guide to conservation planning*. USDA Agricultural Handbook No. 537. US Gov. Print. Office, Washington, DC.

First received 8 October 2015; accepted in revised form 21 March 2016. Available online 29 April 2016