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Determination of Monthly Hydrological Erosion Severity and Runoff in Torogh Dam Watershed Basin Using SWAT and WEPP Models

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Abstract Evaluation of runoff and sediment load is the main problem that affects the performance of dams due to the reduction in the storage capacity of their reservoirs and their effect on dam efficiency and operation schedule. Hydrologic models are increasingly used for simulation of spatially varied hydrologic processes with the availability of spatially distributed data to understand and manage natural and activities that affect watershed systems if the continuous field measurements are not available. Soil and water conservation and also quantification of soil loss in watershed basins are a significant issue. In this study, the Soil and Water Assessment Tool (SWAT) and the Water Erosion Prediction Project (WEPP) are applied to estimate runoff volume and sediment load for Torogh dam reservoir area that is located in Kashafrood Watershed Basin in northeastern Iran. Simulated and observed runoff and sediment load are compared with these models. In the calibration period, the Nash–Sutcliffe coefficient (NSE) values for the SWAT and WEPP were 0.698 and 0.854 for runoff, and 0.667 and 0.832 for sediment load, respectively. In the validation period, the NSE values for SWAT and WEPP were 0.678 and 0.824 for runoff, and 0.809 and 0.816 for sediment load, respectively. The results indicate that both models gave reasonable results in comparison with measured values. Simulation with WEPP model was better than SWAT in some cases and with reasonable confidence could be used for soil loss quantification in the watershed basin of Torogh dam.

1 Introduction

Torogh dam reservoir area (TDRA) is one of the sources of water supply in Khorasan Razavi Province (KRP) in Iran. Sediments are one of the major issues of dam operation. They decrease the storage capacity of the reservoir, and they can cause serious problems concerning the operation and stability of the dam (Wang et al. 2013). One of the important factors in reservoirs design and operation is the sedimentation problem. Sediment delivered to the reservoir comes from two main sources. The first is the main river entering the reservoir, and the second is the side valleys on both sides of the reservoir. Therefore, investigation of hydrological components such as runoff and sediment load is a major problem in this area. Due to the importance of the problem, several models were developed and then modeling technique was adopted and various methods were used for estimating the runoff and sediment load. Soil erosion and runoff models can be divided into empirical and physically based models. The empirical models like Universal Soil Loss Equation USLE (Wischmeier and Smith 1965), Modified Universal Soil Loss Equation MUSLE are easy to apply and correlate directly the sediment yield with precipitation and soil properties based on measured values, while the physically based models can describe the physical mechanism of sediment load in detail and can simulate the individual components of the entire erosion process by solving the corresponding equation. Based on this, it is stated that physically based models have a wider range of applicability and are also generally better in assessing both spatial and temporal variability of the

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natural erosion processes. The SWAT and WEPP are physically based models that simulate sediment load and deposition using a spatially and temporally distributed approach. These models were applied with researches in different regions with various conditions (Ashagre 2009; Shawul et al. 2013; Mohammad et al. 2016; Afzali et al. 2015; Akbari et al. 2015; Olotu et al. 2013).

The objective of this study is to evaluate the runoff and sediment load entered to Torogh dam reservoir area (TDRA) based on application of both WEPP and SWAT models. Also, evaluation of the models performance for estimation runoff and sediment load is another objective that has not been studied for this area up to now. These models were selected based on their wide usability, validity and they confer the benefit of having the most up-to-date technology, and also have been tested on many agricultural watersheds. However, there have been few comparisons of the simulations of soil erosion and runoff between these two models; SWAT has been compared to models of the same or relevant module of WEPP to sediment and runoff simulation. This paper will mainly discuss the differences between the empirical and physical modules of the two models that no research in Torogh dam reservoir watershed. It is noteworthy to mention that Iran is suffering from water shortage problems now and it is very important to know the actual capacity of the reservoir to attain prudent management of water resources in the country.

2 Materials and Methods

2.1 Study Area

The Torogh watershed is situated in the south-eastern Mashhad county and one of the subbasins of Kasha-frood Watershed Basin (KWB) in Khorasan Razavi Province of Iran (Fig. 1). The central coordinates of the watershed are 59°34′55″N and 36°34′21″E. The total area of watershed is 163.12 km^2. The mean slope of the watershed area is 37.4%, and the maximum slope of some hilly parts is 51.8%. The mean annual air temperature is 11.4 °C, while the minimum monthly mean temperature is 5.3 °C in January and the maximum is 28.8 °C in July. Mean annual precipitation is 317.4 mm. Main land use types are water tillage, dry farm tillage, pasture and residential field. The models require climate data that include daily values for precipitation, temperature, solar radiation, relative humidity and wind speed. Rainfall data for the site were collected at the Kartian hydrometry station. The other required climate data were collected at the Mashhad county weather station. Management input files were built for watershed from management records of the experimental field investigation. The DEM was developed from the

watershed contour map. Soil and land use information were from interpretation of IRS P6 LISS-4 (5 m resolution) satellite imagery, based on field investigation. The daily runoff and sediment load were measured by the Kartian hydrometry station. Slope data were derived from the contour map.

2.2 Description of Applied Models

2.2.1 WEPP Model

Water Erosion Prediction Project (WEPP) is a physically based model to predict deposition and sediment load, flow and soil detachment. It is a continuous simulation model developed by The United States Departments of Agriculture and Interior. The model considers the hydrology, plant growth, flow and erosion and deposition process for hill slopes and relatively small watersheds, and it was publicly released in 1995 (Flanagan et al. 2007). It computes spatial and temporal distribution of sediment load and deposition, based on which conservation measures can be selected to most effectively control soil erosion (Flanagan and Nearing 1995). The continuous simulation of the model requires more detailed data than empirical or single storm simulation models. The topography as DEM, soil properties, land cover and management in addition to climate data are the main input data to the model. The surface runoff which is based on excess rainfall is computed by using kinematic wave equations and approximation to the kinematic wave solution, and infiltration is estimated by Green Ampt Mein Larson (GAML) model in the following form. The GAML equation uses a direct relationship between infiltration and rainfall rate based on physical parameters allowing continuous surface runoff simulation:

$$F_{\mathrm{inf},t} = K_{\mathrm{e}}\left(1 + \frac{\psi_{wf}\Delta\theta_v}{F_{\mathrm{inf},t}}\right) \tag{1}$$

where $F_{inf,t}$ is the infiltration rate at time t (mm h^{-1}), K_{e} is the effective hydraulic conductivity (mm h^{-1}), ψ_{wf} is the wetting front matric potential (m), $\Delta\theta_v$ is the change in volumetric moisture content across the wetting front, and $F_{\mathrm{inf},t}$ is the cumulative infiltration at time t (mm). The sediment load for both hill slope and channel flow consists of detachment, transport and deposition. The steady-state continuity equation for sediment load estimation down a hill slope profile is considered in the following form:

$$\frac{\mathrm{d}G}{\mathrm{d}x} = D_{\mathrm{f}} + D_{\mathrm{i}} \tag{2}$$

where G is sediment load (kg s^{-1} m^{-1}), x represents distance downslope (m), D_{f} is rill erosion rate (kg s^{-1} m^{-2}), and D_{i} is inter-rill sediment delivery to the rill (kg s^{-1} m^{-2}). D_{i} is considered as independent of x, and always >0.
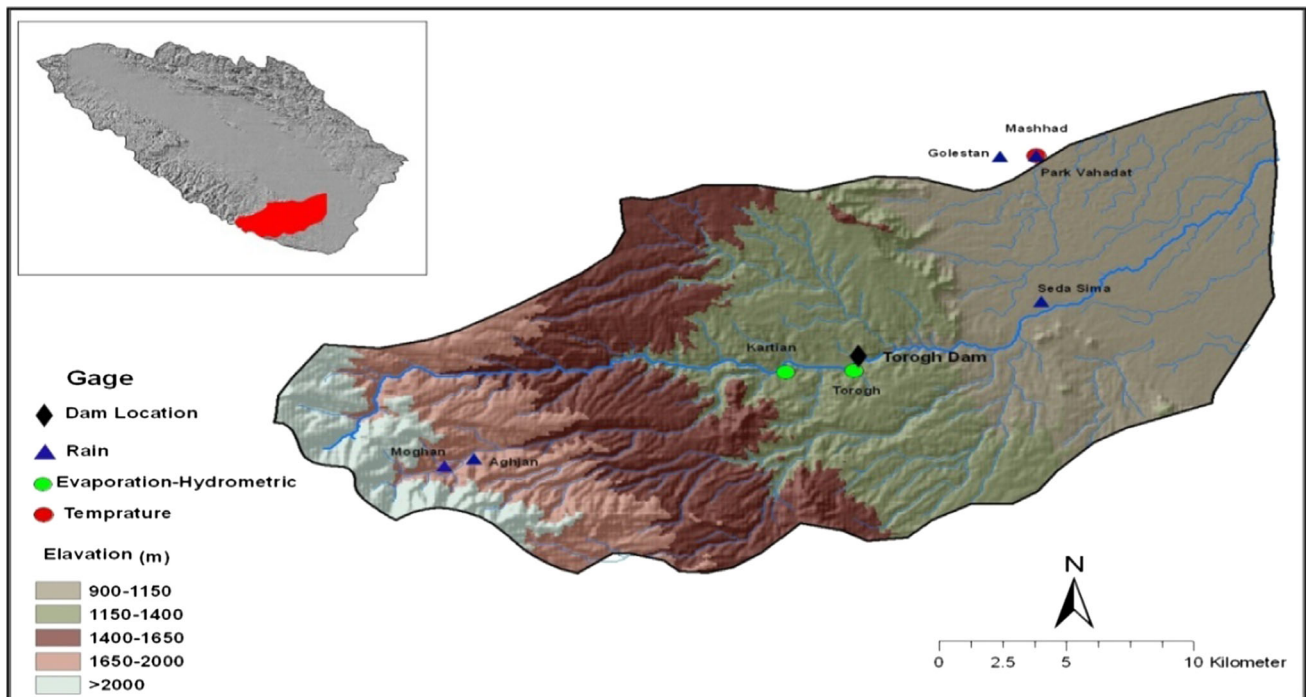
Fig. 1 Location of watershed basin of Torogh dam

D_f is >0 for detachment and <0 for deposition. For model calculations, both D_f and D_i are computed on a per rill area basis, and thus, G is solved on per unit rill width basis. After computations, sediment load is expressed as sediment load per unit land area.

2.2.2 SWAT Model

Soil and Water Assessment Tool (SWAT) is a continuous simulation model developed by the USDA-Agricultural Research Service. It is a physically based model to estimate runoff, chemical and sediment transport within the watershed scale for daily time step (Arnold et al. 1998). The surface runoff estimation in the model can be done by two methods, the soil Conservation Service Method (USDA-SCS), Curve Number (CN) method and the Green and Ampt method (Neitsch et al. 2009). The daily precipitation data are required to estimate the surface runoff by SCS curve number method, and the curve number estimation is dependent on certain soil type (permeability), land use and antecedent soil moisture conditions. The Green and Ampt infiltration method required a sub-daily precipitation data to estimate the infiltration rate based on hydraulic conductivity and metric potential of wetting fronts. The SCS curve number method was considered in this study, it is an empirical method to estimate the surface runoff based on studies of different rainfall–runoff relationships for small rural watersheds, and then developed for different types of soils and land use (Neitsch et al. 2009). The equation of

estimating the runoff depth in SCS curve number method is (Williams and Laseur 1976):

$$Q_{\text{surf}} = \frac{\left(R_{\text{day}} - I_a\right)^2}{\left(R_{\text{day}} - I_a + S\right)} \tag{3}$$

where Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm), I_a is the initial abstraction, which includes surface storage, interception and infiltration prior to runoff (mm) and S is a retention parameter (mm) that varies among sub-watersheds according to soil type, land use, management and slope. Retention parameter also varies with time because of changes in antecedent soil water content and is related to CN by the SCS equation below:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \tag{4}$$

The curve number for normal moisture condition is identified based on soil type and land use, and then, it is modified based on antecedent moisture condition. The sediment load estimation in SWAT model was executed for each hydrological response unit (HRU) and divided into two phases, overland phase and channel flow. The Modified Universal Soil Equation (MUSLE) (Arnold et al. 1998) was considered to estimate the erosion and sediment load from rainfall and overland flow in the following form and other factors of the erosion equation are evaluated as described by Wischmeier and Smith (1965):

$$\text{Sed} = 11.8 \left(Q_{\text{surf}} q_{\text{peak}} A_{\text{hru}}\right)^{0.56} K_{\text{usle}} C_{\text{usle}} P_{\text{usle}} L_{\text{usle}} F_{\text{cfrg}}$$

(5)

where Sed is the sediment load (ton) on a given day, Q_{surf} is the surface runoff volume (mm ha^{-1}), q_{peak} is the peak runoff rate (m^3 s^{-1}), A_{hru} is the area of the HRUs (ha), K_{usle} is the USLE soil erodibility factor, C_{usle} is the USLE cover and management factor, P_{usle} is the USLE support practice factor, L_{usle} is the USLE topographic factor, and F_{cfrg} is the coarse fragment factor. Then, the simple form of stream power theory was applied to estimate the channel sediment routing including degradation or deposition. The channel bed and bank erosion will occur when stream flow transport capacity is greater than sediment load (coming from upstream region) at that reach and flow shear stress is greater than the stress required to detach the soil particles. While the deposition will occur in the case that sediment load is greater than transport capacity, the rate of sediment deposition depends on the fall velocity of particles.

2.3 Sensitivity Analysis, Calibration and Validation

In recent years, hydrological models have been increasingly used by hydrologists and water resources managers to understand and manage natural and human activities that affect watershed systems. These models can contain parameters that cannot be measured directly because of measurement limitations and scaling issues (Beven 2000). For practical applications in solving water resources problems, model parameters are calibrated to produce model predictions that are as close as possible to observed data. When calibrating a hydrological model, one or more objectives are often used to measure the agreement between observed and simulated values. To calibrate the models, sensitivity analyses were performed for 2004 and 2005 by changing the value of a parameter within an acceptable range and observing the runoff and sediment load output. Sensitivity analysis evaluates the relative magnitudes of changes in the model response as a function of relative changes in the values of model input parameters. The sensitivity ratio, Sen was determined as (McCuen and Snyder 1986):

$$\text{Sen} = \frac{(Y_2 - Y_1)/\overline{Y}}{(X_2 - X_1)/\overline{X}}$$

(6)

where X_1 and X_2 are the least and greatest values of input used, $\overline{X}$ is the average of X_1 and X_2, Y_1 and Y_2 are the corresponding outputs for the two input values, and $\overline{Y}$ is the average of the two outputs. The parameter Sen is a function of the chosen range for nonlinear response. The parameter that produced the maximum sensitivity was adjusted first, followed by the other parameters. The input parameters

that showed negligible variation were not calibrated and were taken as model default values. Thus, the calibration process focused mainly on input parameters that control runoff and sediment production. Once the model was calibrated, it was run with the calibrated parameters, and the runoff and sediment load values predicted for the validation period. The simulated values by different models were evaluated by visual inspection of plots of the range of observed and simulated values. The root-mean-square-error (RMSE), deviation (R_e) and Nash–Sutcliffe (NSE) were computed as criteria for goodness-of-fit. The model efficiency (NSE) is expressed as (Nash and Sutcliffe 1970):

$$E_{\text{NS}} = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O}_i)^2}$$

(7)

where $\bar{O}_i$ is the mean of observed values. The range of NSE values is from $-\infty$ to 1, with 1 indicating a perfect fit. However, a shortcoming of the Nash–Sutcliffe statistic is that it does not perform well in periods of low flow. If the daily measured flow approaches the average value, the denominator of the equation tends to zero and NSE approaches negative infinity, with only minor prediction errors of the model. This statistic works well when the coefficient of variation for the data set is large (Pandey et al. 2008). The deviation of runoff and sediment values is given by the following equation (Yen 1993):

$$R_e = \left(\frac{P_i - O_i}{O_i}\right) \times 100$$

(8)

The smaller the absolute value of R_e is, the better the model results are. The RMSE is defined as (Thomann 1982):

$$\text{RMSE} = \left(\frac{\sum_{i=1}^{n} (O_i - P_i)^2}{n}\right)^{1/2}$$

(9)

where O_i and P_i are the observed and predicted values for the ith pair, and n is the total number of paired values. The smaller the RMSE, the closer simulated values are to observed values.

3 Results and Discussion

The models were run to perform sensitivity analyses after the input files were created. For the SWAT model, CN2 (initial SCS runoff curve number for moisture condition II), ESCO (soil evaporation compensation factor), SOL_AWC (available water capacity of the soil layer) were the most sensitive parameters for runoff, and CN2, ESCO and SPCON (linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel

sediment routing) were the most sensitive for soil erosion. For the WEPP model, K_e (effective hydraulic conductivity) was found to be the most sensitive parameter for runoff, and baseline K_i (inter-rill erodibility), K_e (effective hydraulic conductivity), K_r (rill erodibility) and τ_c (critical hydraulic shear stress) values were most sensitive for soil erosion. In the present study, the models were calibrated with measured data at the watershed level. The Torogh watershed data from May 2004 to December 2005 were used for the calibration. The calibration SWAT and WEPP models were then used to simulate monthly runoff and sediment load for the years 2006 and 2007; the measured monthly runoff and sediment load values were compared with simulated values to evaluate the model validation performance. The simulated monthly mean runoff values of the WEPP and SWAT models for the calibration and validation periods were compared with observed values (Fig. 2). The observed and simulated monthly mean runoff values along with 1:1 line for the calibration and validation periods are shown in Fig. 3. The simulated peak values matched consistently well with the measured peak values for runoff throughout all years for both models (Fig. 2). The high coefficient of determination (Table 1) indicates a positive relationship between the measured and simulated runoff for most months, except for the SWAT runoff validation (Fig. 3). Furthermore, reasonably high NSE values for the calibration and validation periods (0.698 and 0.678 for SWAT and 0.854 and 0.824 for WEPP) indicated satisfactory performance of both models (Table 1). The R_e values between the simulated and observed monthly mean runoff values for the SWAT and WEPP models were −3.7 and 8.6% for the whole calibration period, and 10.8 and 10.3% for the whole validation period, respectively. These results along with other criteria indicate satisfactory overall prediction of monthly mean runoff by the WEPP and SWAT models during the calibration period. For the SWAT model, the performance for runoff in the validation

period was slightly degraded compared to the calibration data, but it was still acceptable. The absolute R_e values for the SWAT model were higher than those of the WEPP model. The NSE value for WEPP was higher than that of the SWAT model. An important reason for this phenomenon is the different runoff calculating methods in the models. The WEPP model uses the GAML equation, while the SWAT model has two methods for estimating surface runoff: the SCS curve number procedure and the Green–Ampt infiltration method. The GAML method considers rainfall duration as a time step in solving the infiltration equation. When infiltration rate is greater than rainfall intensity, no excess rainfall is calculated. Therefore, when the GAML method is used for rainfall–runoff modeling, more water is held in the soil profile. In the SCS runoff equation, CN is a dimensionless index determined by hydrologic soil group, land use, land treatment, hydrological conditions and antecedent moisture condition. The main criticism of the SCS-CN method is that the amount of simulation runoff is not sensitive to rainfall intensity. Thus, the method would compute the same amount of runoff, given the same amount of total rainfall, independent of even duration or the distribution of rainfall intensity during the event. In the calibration process, WEPP responded well for relatively lower runoff than SWAT, whereas SWAT performed better than WEPP for simulated runoff above $0.4 \, \text{m}^3 \, \text{s}^{-1}$. At this point validation, results show the superiority of the WEPP model throughout (Fig. 2).

The reason for the worse performance of SWAT may be that the empirical parameters, such as CN2 and ESCO, resulted in relatively large uncertainty in simulating low runoff. These parameters were among the most sensitive parameters for SWAT, and they could significantly affect the runoff process. For example, canopy interception is calculated according to above ground biomass in the WEPP model (Flanagan and Nearing 1995), while it is lumped into the term of CN2 in the SWAT model (Neitsch
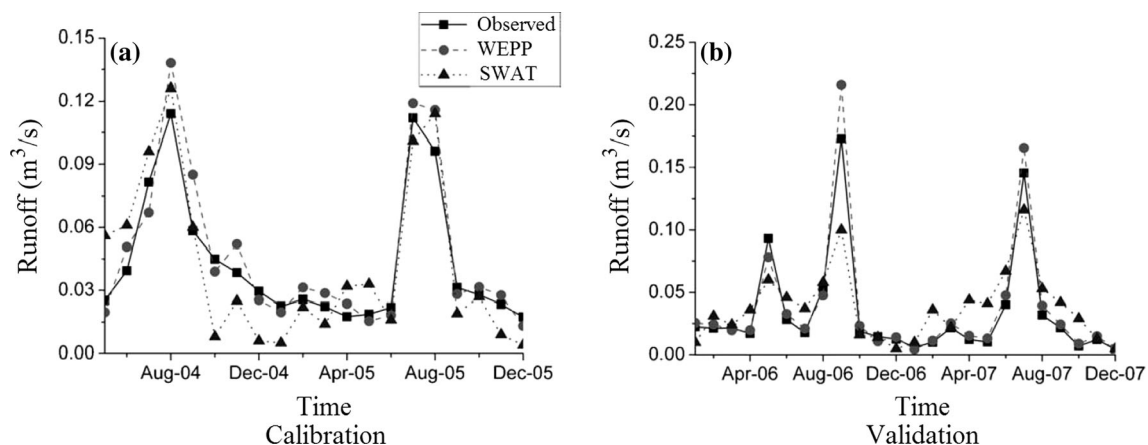

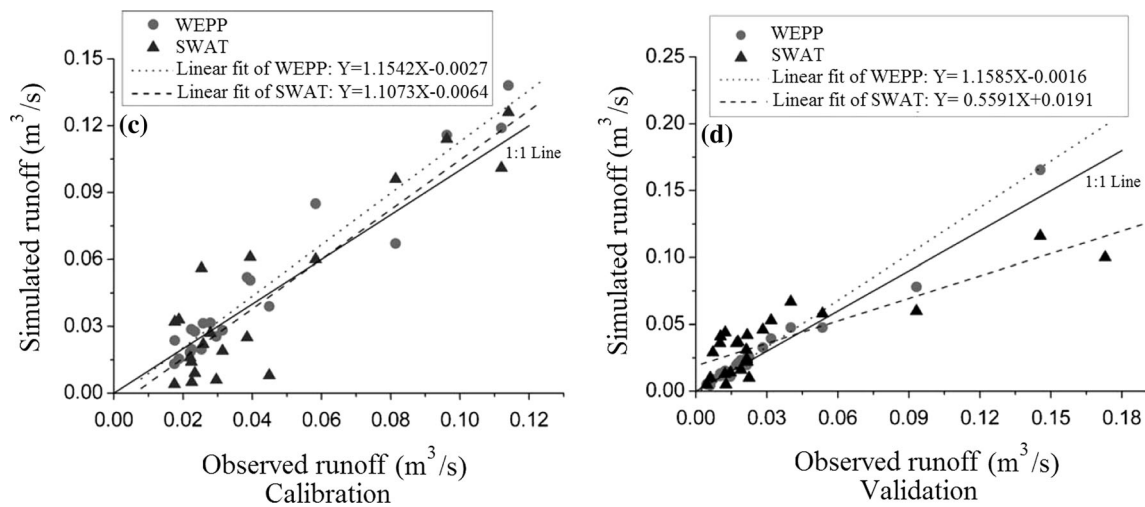Fig. 2 Observed and simulated runoff for watershed basin of Torogh dam

Fig. 3 Comparison of simulated runoff between WEPP and SWAT

Table 1 Statistical analysis of observed and simulated runoff

Models	Periods	Mean runoff (m³/s)		R_e (%)	RMSE	R^2	NSE
		Observed	Simulated				
SWAT	Calibration	0.0429	0.0411	−3.7	0.017	0.8127	0.698
	Validation	0.338	0.0377	10.8	0.023	0.7671	0.678
WEPP	Calibration	0.0426	0.0465	8.6	0.011	0.9374	0.854
	Validation	0.0338	0.0367	10.3	0.011	0.9765	0.824

et al. 2009). Unsaturated flow between soil layers is indirectly estimated by the distributions of plant water uptake and soil water evaporation through two parameters: ESCO and EPCO (the plant uptake compensation factor). For the WEPP model, most simulated runoff values were greater than the observed values. For the SWAT model, there were more underestimates of peak flow than overestimates. One possible cause may be that CN is updated using changes in soil moisture. In SWAT, the CN value is updated using available water content of the entire soil profile. However, it is probably more appropriate to update the CN values in accordance with soil water content of the topmost soil layer, which would more closely reflect the process of surface saturation during heavy rainfall events. Analysis of results showed that WEPP predicted runoff slightly better than SWAT. Given a choice, the WEPP model is recommended to simulate runoff for the Torogh watershed. The simulated monthly mean sediment load values by the WEPP and SWAT models for the calibration and validation periods were compared with observed values (Fig. 4). The observed and simulated monthly mean sediment loads for the calibration and validation periods along with 1:1 line are shown in Fig. 5. The simulated peak values match consistently well with the measured peak values for sediment in all years for both models (Fig. 4). The high coefficient of determination (Table 2) indicated a positive

relationship between the simulated and measured sediment loads (Fig. 5). Reasonably high NSE values for the calibration and validation periods (0.667 and 0.809 for SWAT and 0.832 and 0.816 for WEPP) showed that the models performed satisfactorily (Table 2). During calibration, the R_e between the mean simulated and observed sediment values for the SWAT and WEPP models was −23.7 and 5.6%, respectively (Table 2). The NSE value of the WEPP model was higher than the SWAT model. However, the overall predictions of monthly mean sediment by the WEPP and SWAT models during the calibration period were satisfactory and so used for further analysis. For the SWAT model, the performance for sediment load in the validation period was slightly better compared to the calibration period (Table 2).

Taking the validation period as a whole, the mean R_e values for the SWAT and WEPP models were −30.6 and −2.8%, respectively. There was a trend in the present study that illustrates the greater the amount of eroded sediment, the smaller the R_e values for both the SWAT and WEPP models were and vice versa. The result is also reasonable since a given R_e value by either model will result in a greater relative effect on smaller erosion values. For both the WEPP and SWAT results, most simulated peak values were less than the observed values. For non-peak situations, WEPP simulated values were often larger than
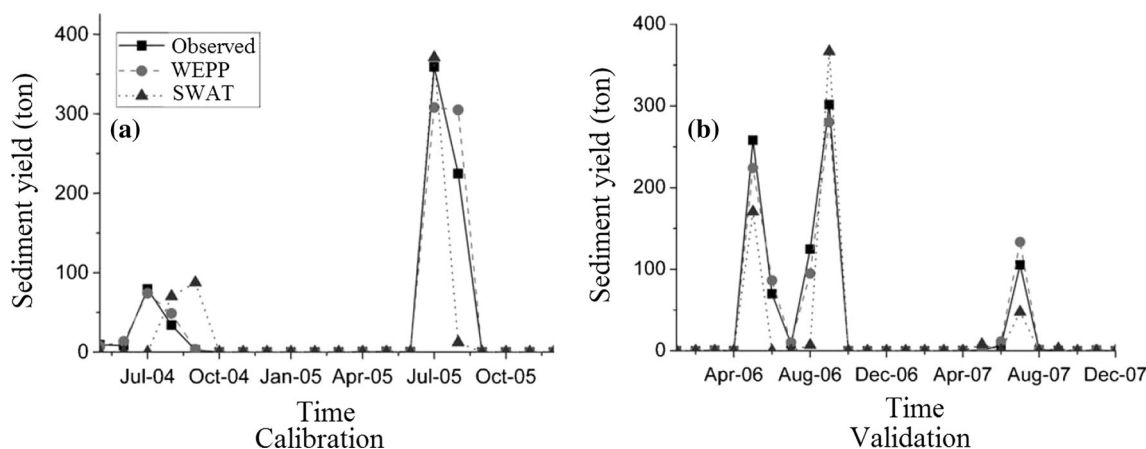
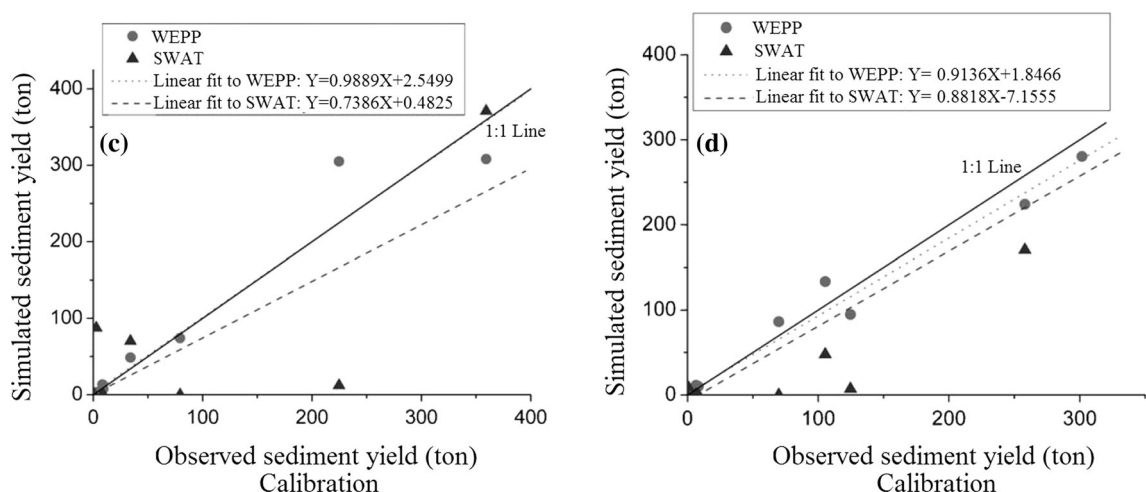**Fig. 4** Observed and simulated sediment load for watershed basin of Torogh dam

Fig. 5 Comparison of simulated sediment load between WEPP and SWAT

Table 2 Statistical analysis of observed and simulated sediment load

Models	Periods	Mean sediment load (ton)		R_e (%)	RMSE	R^2	NSE
		Observed	Simulated				
SWAT	Calibration	35.85	26.91	−23.7	54.901	0.6486	0.667
	Validation	36.65	24.95	−30.6	37.971	0.8077	0.809
WEPP	Calibration	35.84	37.90	5.6	21.608	0.9448	0.832
	Validation	36.63	34.31	−2.8	12.543	0.9817	0.816

observed values, but SWAT simulation had the opposite result. The deviations may be attributed to errors associated with manual measurement and calculation in estimating runoff from the measured cross-sectional area and runoff velocity at the watershed outlet. The sediment loads were only measured on rainfall days, when there was little or no rain, then sediment load was zero by default. This measurement error results in lower sediment load than in reality for non-peak situations. However, the sediment load of the overestimated part was relatively small for non-peak situations. Therefore, to some degree, WEPP simulation could

well represent the reality for these situations. The analysis showed the WEPP simulated sediment load better than SWAT. For the calibration and validation periods, all criteria of the WEPP model including R_e, and NSE were better than those of the SWAT model. WEPP uses the steady-state sediment continuity equation to predict soil loss, while in SWAT the sediment load simulation is performed using the MUSLE module, a modified version of USLE. In MUSLE, the rainfall energy factor is replaced with a runoff factor and optimizes hydrologic process of sediment load and thus allows the equation to be applied to

individual storm events and improve the sediment load prediction. However, in the present study, monthly mean sediment load was predicted and no storm event was simulated, so the advantages of using MUSLE instead of USLE to MUSLE was not obvious, i.e., the outcomes of MUSLE were similar to those of USLE. Some studies have explained the defects of USLE; USLE is an empirical model, developed to assess field-scale sediment load, not sediment detachment and transport at the watershed scale (Morgan 1995). Limitations of the SWAT simulation can be attributed to its dependence on many empirical and semi empirical parameters, but is probably not well suited to conditions of the Torogh watershed. Additionally, the rather poorer runoff simulation in SWAT affected its sediment load simulation.

4 Summary and Conclusion

In this study, the prediction capabilities of WEPP and SWAT were tested on a semiarid watershed in Khorasan Razavi in Iran (Torogh dam reservoir area). The sensitivity analysis showed that in SWAT model and for runoff the CN2, ESCO and SOL_AWC parameters and for sediment load CN2, ESCO and SPCON were the most sensitive parameters and also in the WEPP model for runoff K_e and for sediment load K_e, K_i, K_r and τ_c were the most sensitive parameters. Results of calibration and validation indicated that sediment load and runoff outputs are relatively well simulated with both models. In WEPP model, the high values of NSE and R^2 and the low values of RMSE in relationship with SWAT model indicate that the WEPP model provided better prediction than the SWAT model for both runoff and sediment load. Runoff and sediment yield were simulated with constant soil and land use data for this region. The effects of climate and land use changes on runoff and sediment load on this region in different future time periods will be investigated by SWAT and WEPP models.

References

Afzali SF, Baqeri E, Amin S, Namdari Ghareghani E, Soltani E (2015) Comparison of WEPP, ANSWERS and MPSIAC for evaluating the runoff, soil erosion and sediment at Khosroshirin region Fars province Iran. Int J For Soil Eros (IJFSE) 5(3):76–85

Akbari A, Sedaei L, Naderi M et al (2015) The application of the water erosion prediction project (WEPP) model for the estimation of runoff and sediment on a monthly time resolution. J Environ Earth Sci 24(7):5827–5837. doi:10.1007/s12665-015-4600-7

Arnold JG, Srinivasan R, Muttiah R, Williams J (1998) Large area hydrologic modeling and assessment part I: model development. J Am Water Resour Assoc 34:73–89

Ashagre B (2009) SWAT to identify watershed management option: (Anjeni watershed, Blue Nile Basin, Etiopia). Master thesis, Cornell University, New York

Beven KJ (2000) Rainfall-runoff modelling: the primer. Wiley, New York

Flanagan DC, Nearing MA (1995) USDA-water erosion prediction project: HillsplopeProfile and watershed model documentation. NSERL Report No. 10. USDA-ARS National Soil Erosion Research Laboratory, West Lafayette

Flanagan DC, Gilley JE, Franti TG (2007) Water erosion prediction (WEPP): development history, model capabilities and future enhancements. Trans Am Soc Agric Biol Eng 50:1603–1612. doi:10.13031/2013.23968

McCuen RH, Snyder WM (1986) Hydrologic modeling: statistical methods and applications. Prentice Hall, Englewood Cliffs

Mohammad ME, Al-Ansari N, Knutsson S (2016) Annual runoff and sediment in Duhok reservoir watershed using SWAT and WEPP models. J Eng 8(7):410–422. doi:10.4236/eng.2016.87038

Morgan RPC (1995) Soil erosion and conservation. Longman, Harlow

Nash JE, Sutcliffe JV (1970) River flow forecasting through conceptual models. Part I. A discussion of principles. J Hydrol 10(3):282–290

Neitsch SL, Arnold JG, Kiniry JR, Srinivasan R, Williams JR (2009) Soil and water assessment tool theoretical documentation version. Blackland Research Center-Texas SA TR, 406

Olotu Y, Akanbi OP, Ahanmisi E, Adeniyi EA (2013) Simulation of runoff and sediment load for reservoir sedimentation of river ole dam using SWAT and WEPP model. Global J Sci Front Res 13(13):7–12

Pandey A, Chowdary VM, Mal BC, Billib M (2008) Runoff and sediment load modeling from a small agricultural watershed in India using the WEPP model. J Hydrol 348(3–4):305–319

Shawul AA, Alamirew T, Dinka MO (2013) Calibration and validation of SWAT model and estimation of water balance components of Shaya mountainous watershed, Southeastern Etiopia. Hydrol Earth Syst Sci 10:13955–13978. doi:10.5194/hessd-10-13955-2013

Thomann RV (1982) Verification of water quality models. J Environ Eng Div 108(5):923–940

Wang X, White M, Tuppad P, Lee T, Srinivasan R, Zhai T, Andrews D, Narasimhan B (2013) Simulating sediment loading into the major reservoirs in Trinity river basin. J Soil Water Conserv 68(5):372–383

Williams JR, LaSeur WV (1976) Water load model using SCS curve numbers. J Hydraul Div 102(9):1241–1253

Wischmeier WH, Smith DD (1965) Predicting rainfall-erosion losses from cropland east of the Rocky Mountains—a guide for selection of practices for soil and water conservation. USDA Agricultural Handbook, No, p 282

Yen B (1993) Criteria for evaluation of watershed models. J Irrig Drain Eng ASCE 119(3):429–442