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Full Length Research Paper

Modeling daily stream flow using plant evapotranspiration method

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In hydrological models, soil conservation services (SCS) are one of the most widely used procedures to calculate the curve number (CN) in rainfall run-off simulation. Recently, another new CN accounting procedure has been mentioned, namely the plant evapotranspiration (ET) method or simply known as the plant ET method. This method is embedded in the Soil and Water Assessment Tool (SWAT) model which has been developed for watersheds covered by shallow soils or soils with low storage characteristics. It uses antecedent climate and plant evapotranspiration for calculation of daily curve number. In this study, the same method had been used to simulate the daily stream flow for Roodan watershed located in the southern part of Iran. The watershed covers 10570 km^2 and its climate is arid to semi-arid. The modeling process required data from digital elevation model (DEM), land use map, and soil map. It also required daily meteorological data which were collected from weather stations from 1988 to 2008. Other than that, the Sequential Uncertainty Fitting-2 (SUFI-2) algorithm was utilized for calibration and uncertainty analysis of daily stream flow. Criteria of modeling performance were determined through the Nash-Sutcliffe and coefficient of determination for calibration and validation. For calibration, the values were reported at 0.66 and 0.68 respectively and for validation; the values were 0.51 and 0.55. Moreover, percentiles of absolute error between observed and simulated data in calibration and validation period were calculated to be less than 21.78 and 6.37 (m^3/s) for 95% of the data. The results were found to be satisfactory under the climatic conditions of the study area.

Key words: Rainfall-runoff, curve number, soil conservation services (SCS), arid region.

INTRODUCTION

Water resource planners have consistently attempted to understand water resource crisis in arid and semi-arid zone (Foltz, 2002). For this matter, hydrological model is undoubtedly a good choice for more effective soil and water development and management (Tombul and Ogul, 2006). Various types of models, ranging from conceptual to lumped and semi-distributed models can be used for hydrological simulation and the same applies to more comparatively complex yet physically based models and fully distributed models. In fact, many researchers have also been developing semi-distributed models with the performance lying between lumped models and fully distributed models (Arnold et al., 1993).

The soil and water assessment tool (SWAT) is a semi-empirical and semi-physical model developed by the United States Department of Agriculture (USDA), Agricultural Research Service in Texas (Neitsch et al., 2005). It uses the soil conservation services (SCS) curve number (CN) for runoff volume estimation (Neitsch et al.,

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2005) and is applicable for different long-term purposes such as prediction of stream flow, sediment yield, impact of land management practices and agriculture management plan for a large and complex watershed (Huang et al., 2009; Oeurng et al., 2011; Junfeng et al., 2005). Recently, a new method has been developed and incorporated into the SWAT model for calculating CN in accordance to antecedent climate, namely the plant evapotranspiration method (plant ET method). This new method in SWAT allows the retention parameter to vary with accumulated plant evapotranspiration. By calculating daily CN as a function of plant evapotranspiration, the value is less dependent on soil storage and more dependent on antecedent climate. Kannan et al. (2008) had done a research on the behavior evaluation of plant ET method for different evapotranspiration regimes to estimate runoff. The results indicated that plant ET method performed better in prediction of stream flow for shallow and low storage soil. However, it gave poor modeling when the average annual precipitation was only 292 mm and the watershed contained 20% shallow soil. Thus, Kannan et al. (2008) suggested that the application of plant ET method needs more to be properly assessed and monitored for area with low annual precipitation by comparing the simulated stream flows with the results from actual observation.

In this study, the daily stream flow of Roodan wastershed situated in the south of Iran had been simulated using the plant ET method. The objectives of this research are: To perform calibration and uncertainty analysis for Roodan watershed modeling; and to determine optimum adjusted value of depletion coefficient (model parameter) for plant ET method with Roodan watershed as a case study.

MATERIALS AND METHODS

SWAT model

SWAT was developed and enhanced from previous earlier models by Arnold for the United States Department of Agriculture in the early 1990s (Krysanova and Arnold, 2009). It was then extended to predict the impact of land management practices on water, sediment, agricultural and chemical yields in large river catchments with varying spatial and temporal aspects. The hydrologic cycle under consideration is based on the following water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \qquad (1)$$

where SW_t is the final soil water content, SW_0 is the initial soil water content on day i, t is the time (days), R_{day} is the amount of precipitation on day i, Q_{surf} is the amount of surface runoff on day i, E_a is the amount of evapotranspiration on day i, w_{seep} is the amount of water entering the vadose zone from the soil profile on day i, and Q_{gw} is the amount of return flow on day i.

Generally, SWAT divides the watershed into sub-basins and these small hydrological parts are termed as hydrological response units (HRUs) which possess unique land-use/management/soil attributes (Neitsch et al., 2005) to help to improve the calculation accuracy (Neitsch et al., 2010).

In order to run a simulation in case of spatial variability, SWAT needs data from digital elevation model (DEM), soil map, and land use map. Meteorological data are also needed in daily or sub daily time steps. SWAT includes two methods for estimation of surface runoff - SCS CN (SCS, 1972) and Green-Ampt infiltration method (Green and Ampt, 1911). The SCS CN method in turn employs two other methods to account for the retention parameter in surface runoff estimation (SCS, 1972): (1) The traditional method that allows the retention parameter to vary with soil profile water content; and (2) An alternative method that allows the retention parameter to vary with accumulated plant evapotranspiration in SWAT (Neitsch et al., 2005). For the estimation of evapotranspiration, SWAT uses three different methods: Priestley and Taylor, Penman–Monteith, and Hargreaves and Samani (Ghaffari et al., 2010). Finally, the stream flow is routed in each sub-basin and contributes to the Network River, then incorporated into the outlet of watershed. SWAT also considers the snow volume, soil profile, shallow and deep aquifers, precipitation, interception, evapotranspiration, surface runoff, infiltration, percolation, and subsurface runoff (Schuol et al., 2008). A more cognitive and detailed description of the SWAT is available in its manual and user guide (Neitsch et al., 2005; 2010; Winchell et al., 2011; Arnold et al., 1998).

Plant evapotranspiration method

Using the plant ET method, the daily CN value is calculated as a function of plant evapotranspiration, thus the CN value becomes less dependent on soil storage and more dependent on antecedent climate. In comparison with the tradition method, namely the soil moisture condition II which is based on water content and produces too much runoff in simulation of low and high stream flows in SWAT model (SCS, 1972; Neitsch et al., 2005), plant ET method produces moderate runoff particularly for watershed with low storage and shallow soils (Neitsch et al., 2005, 2010). The retention parameter is calculated using the plant ET method in SWAT as follows:

$$S_t = S_{t-1} + PET_t \exp\left(\frac{-BS_{t-1}}{S_{\max}}\right) - p + Q \qquad (2)$$

where S_t is the retention at the present time step, S_{t-1} is the retention at the previous time step, PET_t is the potential evapotranspiration for the day t, B is the depletion coefficient (theoretically varies from 0 to 2), P is the rainfall depth at the previous time step, Q is the runoff depth at the previous time step, and S_{max} is the maximum value of the retention. A comprehensive description of plant ET method is available in the literatures by Neitsch et al. (2005, 2010) and Kannan et al. (2008).

Sequential uncertainty fitting-2 (SUFI-2) algorithm

Sequential Uncertainty Fitting (SUFI-2) of inverse modeling (IM) is used for calibration and validation of SWAT model. SUFI-2 performs the parameter uncertainty analyses by determining all sources of uncertainties, namely uncertainty in driving variables, conceptual model, parameters and measured data. Two factors are used as indices for evaluation performance of the model. 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 95% prediction uncertainty (95PPU). Another factor that shows the strength of a calibration and uncertainty analysis is the R-factor, which is the mean thickness of the 95PPU band. Theoretically, the value for P-factor ranges between 0 to 100%, while that of R factor should be between nil to infinity. If the P-factor is equals to 1 and the R-value is 0, then the simulation has corresponded exactly to the observed data, ideally (Abbaspour et al., 1997, 2004, 2007).

In addition to the R and P factors, accuracy of SWAT model can also be evaluated using coefficient of determination (R^2) and coefficient of Nash-Sutcliffe (NS). These two coefficients are used to evaluate the error between the observed and simulated stream flow (Nash and Sutcliffe, 1970). Krause et al. (2005) stated that R^2 close to 1 indicates a complete harmony between observed and simulated stream flow and the same applies to the NS value when it is 1.

The R^2 value is estimated as in the following Equation 3:

$$R^2 = \left\{ \frac{\sum_{i=1}^{n} (Q_{obsi} - Q_{obsave})(Q_{simi} - Q_{simave})}{\left[\sum_{i=1}^{n} (Q_{obsi} - Q_{obsave})^2 \sum_{i=1}^{n} (Q_{simi} - Q_{simave})^2 \right]^{0.5}} \right\}^2 \quad (3)$$

where n is the number of events, Q_{simi} and Q_{obsi} are simulated and observed runoff at event i ,and Q_{simavg} and Q_{obsavg} are the average simulated and observed runoff over the simulation period respectively. The NS coefficient can be calculated as in the following Equation 4:

$$NS = \left\{ \frac{\sum_{i}^{n} (Q_{simi} - Q_{obsi})^2}{\sum_{i}^{n} (Q_{obsi} - Q_{avg})^2} \right\} \quad (4)$$

where n is the number of time steps, Q_{simi} and Q_{obsi} are the simulated and observed stream flow at time step I respectively, and Q_{avg} is the average observed stream flow over the simulation period.

Case study

The study area is located in the south of Iran between Hormozgan and Kerman provinces, namely the Roodan watershed. The area of catchment is 10570 km^2 and lies between northern geographical latitude of 26° 57' to 28° 31' and eastern longitude of 56° 47' to 57° 54'. The mean elevation of the Roodan watershed is 781 m above sea level (Figure 1). From 1978 to 2008, the average annual precipitation was 215 mm. Most of the precipitation fell between October to March and during warm months, there were no substantial precipitation. From 1978 to 2008, the mean daily temperature was 25°C. The predominant soil type at the watershed is a heterogeneous mix of clay, silt, and sand at the northern and center part, whereas the soils at the southern and eastern part are mostly silt and a little bit of clay. According to the soil reports of Roodan watershed from an agricultural organization at the Hormozgan province in Iran, this area is covered with low storage soil to nearly 30% of the watershed area, which is commonly a mixture of sand and silt texture (Ab Rah Saz Shargh, 2009). Generally, the climate of Roodan is arid to semi-arid with short and high intensity rainfall. Some important and dominating land cover types of Roodan watershed are shrub land (range brush), mix grassland with shrub land, and rock. The patches of irrigated agriculture and orchard are located in low land with a distribution of dry land and grassland. The urban areas (cities and villages) are only a minority land cover type. The Esteghlal dam that has an important role in collecting the surface waters for development of downstream areas is located at the outlet of watershed.

Modeling implementation

In this study, the SWAT version 2009 was used for modeling the Roodan watershed. As mentioned before, data required for SWAT modeling includes DEM, land-use map, soil map and meteorological data in daily or sub-daily scale (Winchell et al., 2010). Chaplot (2005) suggested a mesh size of between 50 to 90 m for DEM and so for this study, the DEM was prepared with the 90 m resolution from 1:25000 topographic maps provided by the Iran topography organization. Nevertheless, to achieve more accurate simulation, digital river network burning on DEM can be applied to find out the minimum area for delineation of sub basins (Arabi et al., 2006).

The soil map was obtained from the global soil map of the United Nations Food and Agriculture Organization (FAO) (FAO, 1995). FAO soil map was used as the required soil properties information were more accessible (Setegn et al., 2010; Faramarzi et al., 2009; Schuol et al., 2008). Other than this map, some geology maps and satellite images of Landsat7 had also been used. Meanwhile, the properties of soil (e.g. texture, soil water content, hydraulic conductivity, bulk density, clay content, silt, and sand) were obtained from available soil samples through collaboration with the agricultural organization of Hormozgan province, Iran.

Land use maps of Roodan watershed for three periods had been prepared (1988-1992, 1993-2002 and 2002-2008). For the past 21 years, the watershed's land use type had changed mainly due to agricultural activities. Although the changes were not considerably significant (1% for 21 years), the trend had to be noted for better modeling (Pai and Saraswat, 2011). Therefore, an effort had been made to collect the statistics of developed agricultural area from an agricultural organization in the Hormozgan province for those three periods. This means that the land use map in SWAT was continuously updated for different periods using the statistics and also by definition of lup.dat files for land use map within the input table file. However, to generate the current land use map, the SWAT model needed more data. This data collection was done through other sources such as a satellite image taken by Landsat 7, results collected from site visits in the year 2007 to 2008, and available land use maps.

Daily rainfall and temperature data were collected from 12 and five stations, respectively. Hargreaves method was applied for calculation of potential evapotranspiration. In addition to that, the daily CN value of plant ET method was chosen to account for volume runoff by adjusting the depletion coefficient as a parameter of SWAT model (Kannan et al., 2008). Finally, reach evaporation coefficient (EVRCH.bsn) was adjusted for Roodan watershed based on measured values of daily stream flow and by considering the contribution of base flow to main channels. The reach

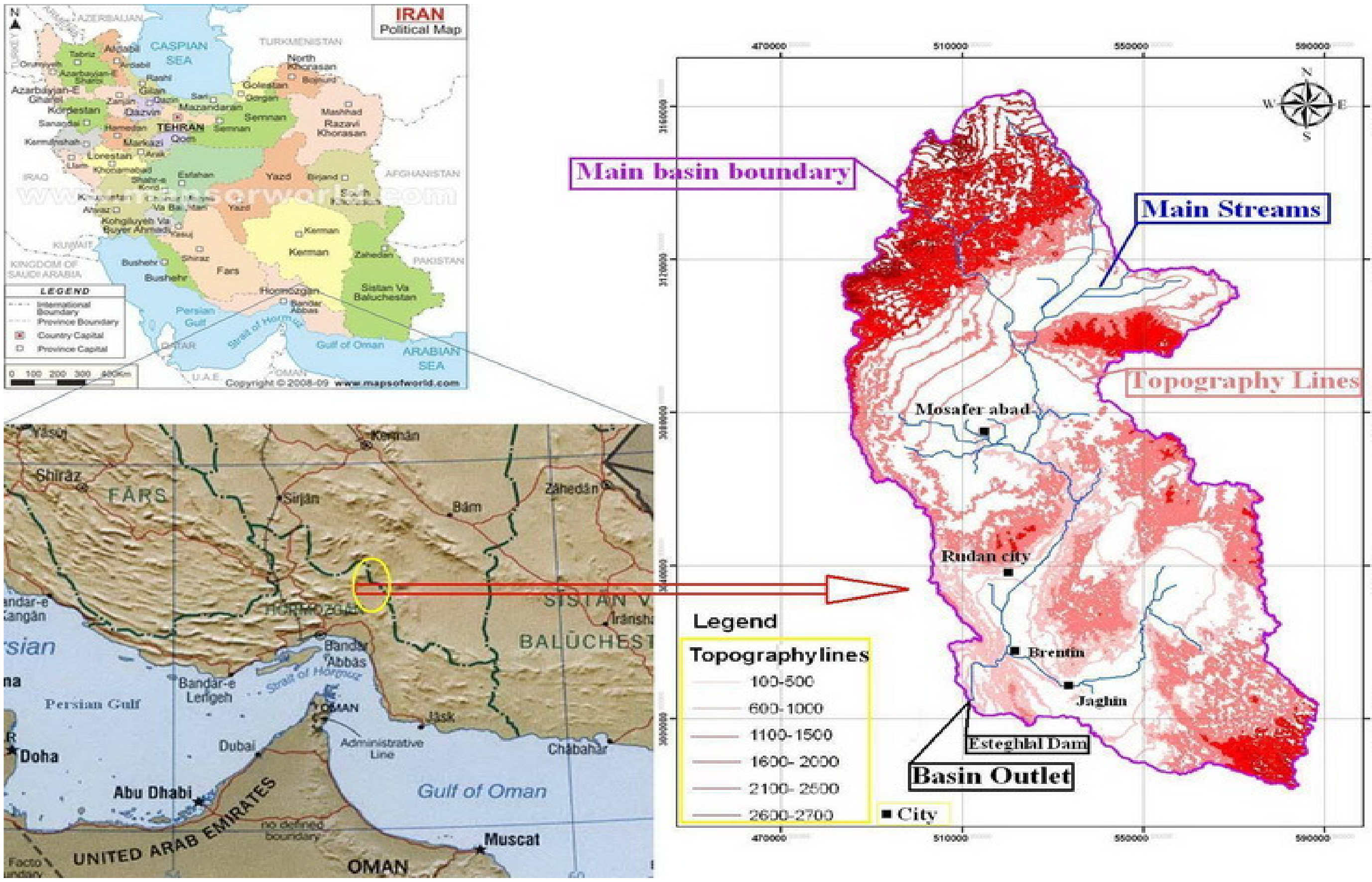

Figure 1. Location of Roodan watershed in Iran according to Ab Rah Saz Shargh (2009).

evaporation adjustment factor in existing equation tends to overestimate the reach evaporation in arid areas. Therefore, it is recommended that the EVRCH.bsn is to be adjusted to protect overestimation of reach evaporation in modeling stream flow in such area (Neitsch et al., 2010).

Calibration and sensitivity analysis

Calibration and validation were performed using data set from the year of 1989 to 2002 and from 2003 to 2008, respectively. 26 parameters were selected for sensitivity analysis with all of them playing an important role in estimation of daily stream flow (Van Griensven et al., 2006; Winchell et al., 2010). These sensitive parameters were chosen for calibration and uncertainty analysis according to sensitivity analysis result; cognition of case study; and review on the related literatures (Kannan et al., 2008; Ghaffari et al., 2010; Faramarzi et al., 2009). After that, a more in depth sensitivity analysis was performed using the SUFI-2 algorithm in the calibration procedure (Schuol, et al., 2008). To make a hydrological cycle fully operational, an equilibration period of one year (1988) was chosen as a warm-up period. Adequate calibration and validation are needed to ensure that a good model has been simulated. Therefore, other than determining the P and R factors, the R^2 and NS coefficients were also calculated as those done by Schuol et al. (2008), Krause et al. (2005) and Yang et al. (2008).

RESULTS AND DISCUSSION

Sensitivity analysis

After sensitivity analysis, 14 parameters that significantly influenced the rainfall-runoff model for Roodan watershed were established. The research outcomes showed that these sensitive parameters are important in representing channel routing, direct runoff, base flow, and infiltration processes. Aside from that, Table 1 shows the most sensitive parameters on stream flow process were generated by the SUFI-2 algorithm. Two values, namely t-stat and p-value show a measure and significance of sensitivity by SUFI-2 algorithm, respectively. These values represent the importance of the other parameters; a sensitive parameter will have a larger absolute value for t-state and p-value close to zero (Abbaspour, 2007). The

Table 1. Parameter sensitivity in Roodan watershed by SUFI-2 in accordance to plant ET and CN methods.

Parameter	Definition	t-stat	P-value
v*_ESCO.hru	Soil evaporation compensation factor	0.00	1.00
v_GW_REVAP.gw	Deep aquifer percolation fraction	0.31	0.75
r**_SOL_K.sol	Soil conductivity	-0.44	0.66
r_SOL_AWC.sol	Soil available water capacity	-0.55	0.58
v_EPCO.hru	Plant evaporation compensation factor	-0.72	0.47
v_REVAPMN.gw	Threshold depth of water in the shallow for percolation to the deep aquifer	-0.77	0.44
v_EVRCH.bsn	Reach evaporation coefficient	0.92	0.36
v_GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur	-1.64	0.10
v_CANMX.hru_MIGS	Maximum canopy index for mix grassland shrub-land	-1.65	0.10
v_SURLAG.bsn	Surface runoff lag coefficient	2.93	0.00
v_CN2.mgt_SHRB	SCS runoff curve number for Shrub land based on plant ET method	13.63	0.00
v_CH_N2.rte	Manning coefficient for channel	-20.54	0.00
v_CN2.mgt_MIGS	SCS runoff curve number for Mixing Grassland and Shrub land based on plant ET method	35.52	0.00
v_CH_K2.rte	Effective hydraulic conductivity of main channel	-55.08	0.00

*, Parameter value is replaced by given value or absolute change; r**: parameter value is multiplied by (1 + a given value) or relative change.

Table 2. Criteria for evaluation of model accuracy for calibration and validation.

Criteria	Calibration (1989-2002)	Validation (2003-2008)
NS	0.66	0.51
R^2	0.68	0.55
p-factor	0.57	0.50
R-factor	0.16	0.06

reach evaporation coefficient (EVRCH.bsn) gave little contribution to the increase in stream flow; it should have been able to improve the estimation of evaporation in channels.

Calibration and uncertainty analysis

Calibration of models at a large basin scale is an elaborate task due to possible uncertainties. Uncertainties are outcome of process simplification - processes that are not considered for by the model and processes in the watershed that are unknown to the modeler (Abbaspour et al., 2007). In this study, the calibration and validation results showed reasonable P and R factors, as presented in Table 2. P and R factors were obtained as 57% and 0.16, respectively for calibration, and 50% and 0.06, respectively for validation period. It should be noted that if results are of high quality, then 80 to 100% of the data should be bracketed by the 95PPU (P-factor), while a low quality results may contain many outliers and it may be sufficient to account for only 50% of the data in the 95PPU (Abbaspour et al., 2007). For calibration and validation periods, the P factors (measured data bracketed in 95PPU) were in satisfactory range. The stability of model is achieved by the R-factor, which is the average distance between the upper and the lower 95PPU and should be smaller than the standard deviation of the measured data. Generally, an R-factor that is close to zero indicates lower uncertainties and that the model has a good consistency. Some reasons that cause low uncertainty can be that the catchment area has little development and human activities (Faramarzi, et al., 2009). Nevertheless, there are other important reasons like the application of plant ET method in the simulation of daily stream flow. Basically, such method results in better modeling of low flows as it tends to reduce overestimation of runoff (Kannan et al., 2008; Neitsch et al., 2005, 2010). Therefore, stream flows of Roodan watersheds, which are more perennial for three-fourth of a year, get better simulation at the expense of losing peak flow simulation in winter season (Figure 2).

For SWAT model, values of NS and R^2 greater than 0.4

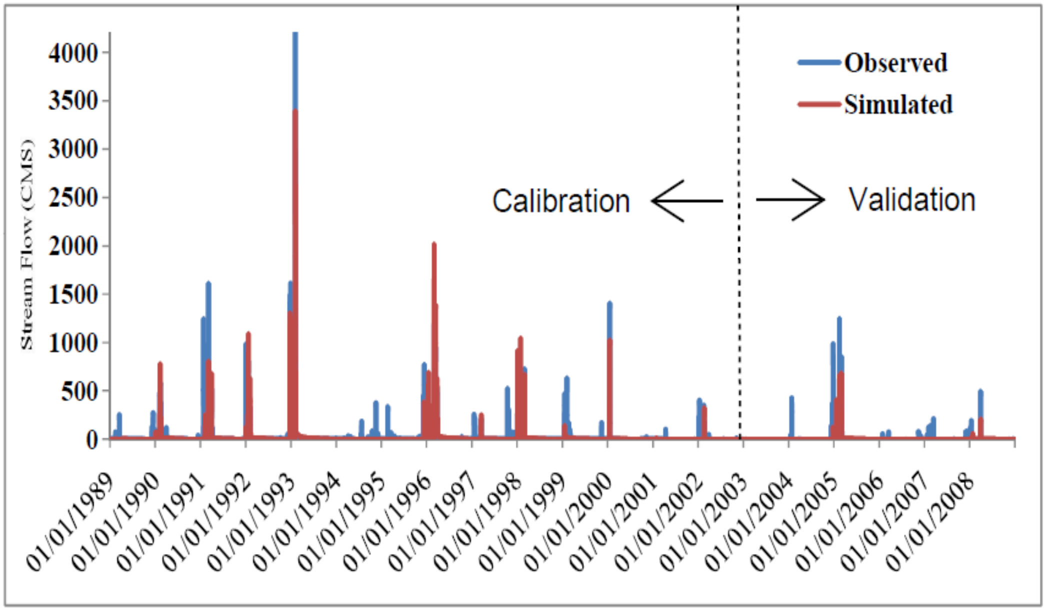

Figure 2. Simulated and observed daily stream flow(m^3/s) for calibration (1989-2003) and validation (2003-2008) periods.

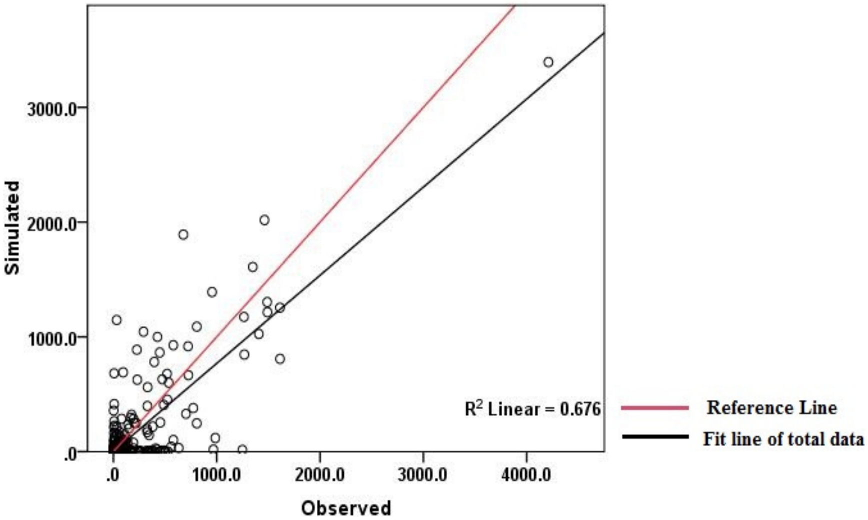

Figure 3. Scatter plot of simulated versus observed flows (m^3/s) for calibration period.

and 0.5 respectively are considered to be satisfactorily by Green et al. (2008). In this study, criteria of R^2 and NS obtained were 0.66 and 0.68 (calibration); and 0.55 and 0.51 (validation), respectively, as shown in Table 2.

The performance of modeling is satisfactory but the SWAT model tends to underestimate the simulation of high stream flow for both calibration and validation periods (Figures 3 and 4). This may be attributed to the application of plant ET method that reduces an overestimation of runoff for high flows and leads to better simulation for perennial flows. Moreover, precipitation duration and intensity are not being considered by the SCS method for simulation of stream flow in SWAT model as reported by Nie et al. (2011). This limitation is

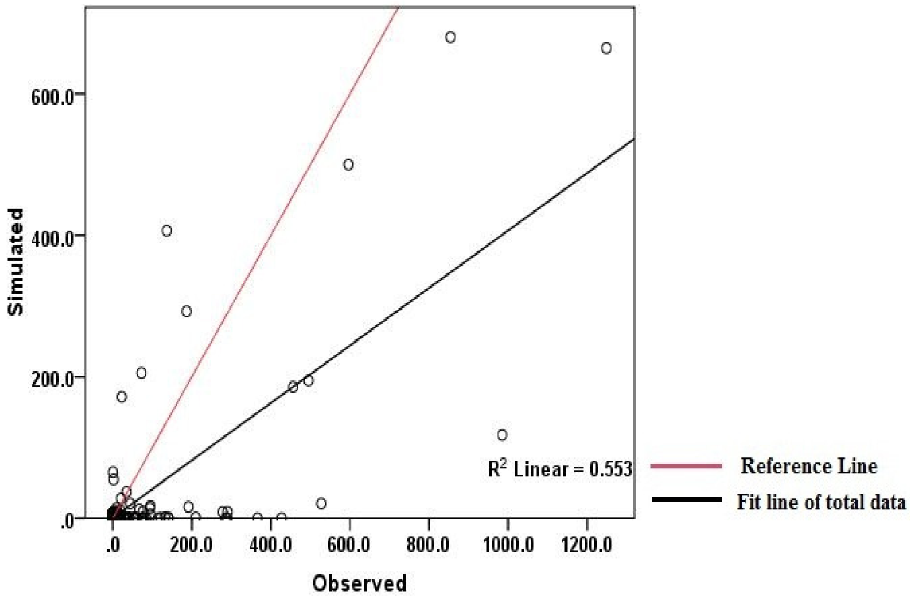

Figure 4. Scatter plot of simulated versus observed flows (m^3/s) for validation (right side) period.

Table 3. Percentiles of absolute error between observed and simulated flows (m^3/s).

Percentiles (%)	5	10	25	50	75	90	95
Calibration error (m^3/s)	0.24	0.44	0.93	1.77	3.68	9.33	21.78
Validation error (m^3/s)	0.05	0.10	0.30	0.50	1.12	3.78	6.37

more profound for watersheds that are located in arid and semi arid area where the climate is always hot with high precipitation intensity, for example in the south of Iran.

As shown in Figure 2, there is an underestimation that corresponded to the ending of 1994 and beginning of 1995 (between the 2100th to 2200th day) for calibration period. In addition, for validation period in earlier days of 2004 (day 400), 2006 (day 1097) and 2007 (1462), an underestimation of stream flow had been observed. Generally, simulation of stream flows under 500 m^3/s resulting in an underestimation of daily peak flows. The simplified simulation of rainfall-runoff modeling during low precipitation period is one of the sources that caused underestimation, as reported by Hantush and Kalin (2005). This is being more significant for simulation of stream flows in arid and semi-arid regions. In comparison with our study, Kannan et al. (2008) reported unsatisfactory stream flow simulation for 20% shallow soils covering and 292 mm average annual precipitation in upper Colorado catchment using the plant ET method. However, our study showed that plant ET method gives satisfactory results in arid and semi arid regions, meanwhile low annual precipitation can be a possible reason which causes the results to deprive from good simulation of peak flows.

Behavior of depletion coefficient on stream flow

In order to evaluate error distributions in detail, the absolute error percentiles of estimates were calculated and shown in Table 3. The results showed that error of calibration was higher than validation in all percentiles. However, 95% of the errors in validation had an absolute error of less than 6.37 m^3/s, whereas 95% of errors in calibration were less than 21.78 m^3/s.

It has been noticed that by increasing the depletion coefficient (close to 2) in plant ET method, the stream flow increases in prediction and decreases the depletion coefficient (close to 0.5), thus resulting in low simulated stream flow. Figure 5 shows the behavior of plant ET method on stream flow simulation when the depletion

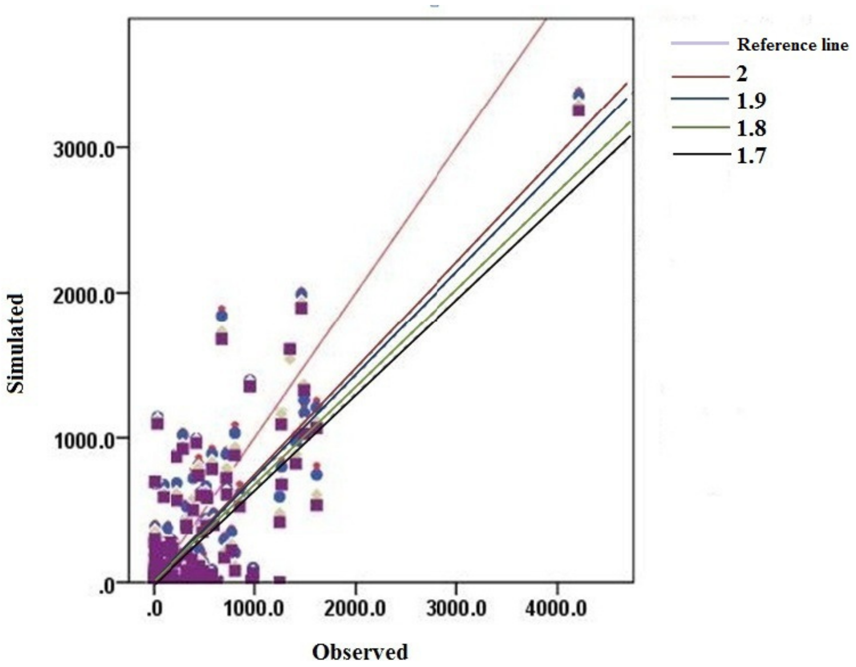

Figure 5. Scatter plot of behavior of plant ET method on simulated versus observed flows (m^3/s) from 1989-2008 for depletion coefficient values of 2-1.9-1.8-1.7.

coefficient value was decreased during the modeling (1989-2008) and the results indicated more underestimation and lower accuracy criteria (R^2 and NS). In this study, depletion coefficient was set to two to give the best accuracy for R^2, NS and uncertainty band using SUFI-2. This value can also be applied for arid and low precipitation regions if the plant ET method is to be used.

Conclusion

In this study, a new method, namely the plant ET method was used for calculation of daily stream flow simulation for Roodan watershed, Iran. This method tends to reduce overestimation of runoff and thus is suggested for watersheds covered by low storage or shallow soil. Using this approach, calculation of stream flows is based on antecedent climate and evapotranspiration of catchment. Hence, the model is more dependent on evapotranspiration and precipitation in calculation of stream flow. In comparison with this approach, the SCS CN method is more related to soil moisture by application of tradition approach, namely soil moisture condition II for calculation of stream flow (SCS, 1972). Results of this study showed that simulation for Roodan watershed was satisfactory; even though there was an underestimation of stream flows. One of the main reasons that a good consistent modeling (R-factor) was obtained is because the plant ET method gave better adjustment for low, perennial flow at the Roodan watershed. For future studies, it is suggested that two methods, namely the plant ET and soil moisture condition II, are applied for estimation of runoff by SWAT model and their behavior should be evaluated in arid and semi-arid region. Moreover, behaviors of these methods have not been fully discovered for tropical area that has low storage and shallow soil; and this can be an objective for future research on SWAT model.

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REFERENCES

Ab Rah Saz Shargh (2009). Comprehensive studies of water resource management for Roodan watershed, Synthesis report of Roodan. Consulting Water Resource Engineering Corporation, register code 1400. Mashhad, Iran. (In Persian)[Accessible web site: www.Abrahsaz.com]

Abbaspour KC (2007). User Manual for SWAT-CUP, SWAT Calibration and Uncertainty Analysis Programs. Swiss Federal Institute of Aquatic science and Technology. Eawag, Duebendorf, Switzerland, p. 93.

Abbaspour KC, Genuchten MTV, Schulin R, Schlappi, (1997). A sequential uncertainty domain inverse procedure for estimating

Abbaspour KC, Johnson A, van Genuchten MTh (2004). Estimating uncertain flow and transport parameters using a sequential uncertainty fitting procedure. Vadose Zone J., 3(4): 1340-1352.

Abbaspour KC, Yang J, Maximov I, Siber R, Bogner K, Mieleitner J, Zobrist J, Srinivasan R (2007). Modeling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. J. Hydrol., 333: 413-430.

Arabi M, Govindaraju RS, Hantush MM, Engel BA (2006). Role of watershed subdivision on modeling the effectiveness of best management practices with SWAT. J. Am. Water Resour. Assoc. 42(2): 513-528.

Arnold JG, Allen PM, Bernhardt G (1993). A comprehensive surface-ground water flow model. J. Hydrol., 142: 47-69.

Arnold JG, Srinivasan R, Muttiah RS, Williams JR (1998). Large area hydrologic modeling assessment. PartI. Model development. J. Am. Water Resour. Assoc., 34: 73-89.

Chaplot V (2005). Impact of DEM mesh size and soil map scale on SWAT runoff, sediment, and NO3-Nloads predictions. J. Hydrol. 312(1-4): 207-222.

Faramarzi, M., Abbaspour, K. C., Schulin, R., and Hong, Y (2009). Modeling blue and green water resources availability in Iran. Hydrol. Process., 23: 486-501.

Foltz RC (2002). Iran's Water Crisis: Cultural, Political, and Ethical Dimensions. J. Agric. Environ. Ethics, 15: 357-380.

Food and Agriculture Organization (1995). The digital soil map of the world and derived soil properties. CD-ROM, Version 3.5, Rome.

Ghaffari, G., Keesstra, S., Ghodousi, J., and Ahmadi ,H .(2010). SWAT-simulated hydrological impact of land-use change in the Zanjanrood Basin, Northwest Iran. Hydrol. Process., 24: 892–903.

Green CH, Van Griensven A (2008). Autocalibration in hydrologic modeling: Using SWAT2005. Environmental modeling and software, 22: 422-434.

Green WH, Ampt GA (1911). Studies on soil physics, 1. The flow of air and water through soils. J. Agric. Sci. 4:11-24.

Hantush MM, Kalin L (2005), Uncertainty and sensitivity analysis of runoff and sediment yield in a small agricultural watershed with kineros2. Hydrol. Sci. J., 50(6): 1151-1172.

Huang Z, Xue B, Pang Y (2009).Simulation on stream flow and nutrient loadings in Gucheng Lake, Low Yangtze river basin, based on SWAT model. Quat. Int., 208: 109-115.

Junfeng C, Xiubin L, Ming Z (2005). Simulation the impacts of climate variation and land cover changes on basin hydrology: Acase study of the Suomo basin. Sci. China Ser. D Earth Sci., 48(9): 1501-1509.

Kannan N, Santhi C, Williams JR, Arnold JG (2008). Development of a continuous soli moisture accounting procedure for curve number methodology and its behavior with different evapotraspiration methods. Hydrol. Process., 22: 2114-2121.

Krause P, Boyle DP, Base F (2005). Impact of DEM mesh size and soil map scale on SWAT runoff, sediment, and NO3-N loads predictions. J. Hydrol., 312(1-4): 207-222.

Krysanova V, Arnold JG (2009). Advances in ecohydrological modeling with SWAT-a review. Hydrol. Sci. J., 53(5): 939-947.

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

Neitsch SL, Arnold JG, Kiniry JR, Srinivasan R, Williams JR (2010). Soil and Water Assessment Tool, Input/Output File Documentation. Version 2009. Grassland, Soil and Water Research Laboratory, Agricultural Research Service, Blackland Research Center, and Texas AgriLife Research, Texas water resources institute technical report No.365.

Neitsch SL, Arnold JG, Kiniry JR, William JR (2005). Soil and Water Assessment Tool Theoretical Documentation (Version 2005). Grassland, Soil and Water Research Laboratory, Agricultural Research Service, Blackland Research Center, and Texas Agricultural Experiment Station: Temple, Texas 76502, USA, p. 494.

Nie W, Yuan Y, Kepner W, Nash MS, Jackson M, Erickson C (2011).assessing impact of land use and land cover changes on hydrology for the upper San Pedro watershed. J. Hydrol., 407: 105-114.

Oeurng C, Sauvage S, Sanchez Perez JM (2011). Assessment of hydrology, sediment and particulate organic carbon yield in a large agricultural catchment using the SWAT model. J. Hydrol., 401: 145-153.

Pai N, Saraswat D (2011). SWAT 2009_LUC: A tool to activate the land use change module in SWAT 2009. Soil Water Div. ASABE, 54(5): 1649-1658.

Schuol J, Abbaspour KC, Srinivasan R, Yang H (2008). Estimation of freshwater availability in the west African sub-continent using the SWAT hydrologic model. J. Hydrol., 352:30-49.

Setegn SG, Srinivasan R, Melesse AM, Dargahi B (2010). SWAT model application and prediction uncertainty analysis in the lake Tana basin, Ethiopia. Hydrol. Process., 24:357-367.

Soil Conservation Service. (1972). Section 4: Hydrology In National Engineering Handbook. SCS.

subsurface flow and transport parameters. Water Res., 33(8): 1879-1892.

Tombul M, Ogul E (2006). Modeling of rainfall-runoff relationship at semi-arid small catchments using artificial neural networks. Lecture notes in control and information sciences (LNCIS), Intell. Control Autom., 344: 309-318.

Van Griensven, A., Meixner, T., Grunwald, S., Bishop, T., Diluzio, M., and Srinivasan, R. (2006). A global sensitivity analysis tool for the parameters of multi- variable catchment models. J. Hydrol., 324: 10-23.

Winchell M, Srinivasan R, Di Luzio M, Arnold J (2010). Arc SWAT interface for SWAT 2009. Users'guide. Grassland, Soil and Water Research Laboratory, Agricultural Research Service, and Blackland Research Center, Texas Agricultural Experiment Station: Temple, Texas 76502, USA, p. 495.

Yang J, Reichert P, Abbaspour KC, Xia J, Yang H (2008). Comparing uncertainty analysis use for a SWAT application to Chaohe basin in china. J. Hydrol., 358: 1-23.