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Impact of Behaviour of New Accounting Curve Number Method using SWAT Model on Stream Flow

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Abstract. Soil and water assessment tool (SWAT) model is a semi-distributed model, which is applied in different aspects such as quantifying the land management practices on water, sediment, and agricultural chemical yields in a large and complex watershed in light of changing soil, land use and management condition over long period. SWAT simulates runoff volume by SCS curve number procedure. Recently, a curve number accounting procedure, the plant evapotranspiration method (plant ET method), has been developed for SWAT model and is suggested for watersheds covered with low storage soils. In this study, Roodan watershed area located in southern part of Iran has been simulated by SWAT using the plant ET method. The climate of Roodan is arid to semi-arid and the area covers 10570 km^2. Roodan watershed is 30% covered with low storage soils. For modeling, Roodan watershed area digital elevation map, land use map and soil map were prepared. Meteorological data were collected for 21 years from 1988 to 2008. Then, SUFI-2 algorithm was performed for calibration and uncertainty analysis of daily stream flow. Besides that, depletion coefficient (parameter model or CN_{coef}) for calculation of daily curve number in plant ET method was set to 2 as the best value for Roodan watershed. Nash-Sutcliffe and coefficient of determination of 0.66 and 0.68 for calibration as well 0.51 and 0.55 for validation were obtained in this study. The results show that plant ET method can give satisfactory simulation for arid to semi-arid regions with low annual precipitation in southern part of Iran. Moreover, adjustment of depletion coefficient shows that a decrease in this value leads to reduction in runoff and causes SWAT to predict lesser stream flow.

Keywords: Plant ET method, Stream Flow, SWAT, SUFI-2

1. Introduction

Water resources management and modelling have recently become an important research topic especially for arid and semi-arid hydrology. Moreover, water resource planners are looking and searching seriously for solutions into water resource crisis in arid and semi-arid zone [1]. Hydrological models are significant instruments for water resource managements, development and future planning [2]. Among the various types of models, semi-distributed models are efficient tool for hydrological simulation as they are able to overcome the difficulties with the fully-distributed models and lumped models. Not only that, researchers have started improving semi-distributed models as a trade off between fully distributed models and lumped models [3]. Soil and Water Assessment Tools (SWAT) as a semi-distributed model is developed by the U.S. Department of Agriculture (USDA), Agricultural Research Service in Texas [4]. SWAT is applied in different subjects such as in the prediction of stream flow, sediment yield, impact of land management practices and in agricultural management planning of large and complex watershed. In SWAT model, the soil conservation services (SCS) curve number (CN) method is used for estimating the runoff volume [4]. This method is more dependent on antecedent climate and it is called the plant evapotranspiration method (plant ET method). In fact, the one-parameter accounting procedure which is based on evapotranspiration and precipitation continuous soil moisture is developed for the application of the

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Soil Conservation Services (SCS) curve number(CN) method for hydrological simulation [5].In one study, the behaviour of the plant ET method by combining different evapotranspiration procedures was evaluated to determine the runoff [5]. However the results showed a poor modelling for area under low precipitation condition (292 mm), as such it was suggested that the application of plant ET method should be considered for area under low precipitation to fully find out the behaviour of this developed method through matching of observed and simulated stream flow [5][6].

In this study, daily stream flow was simulated for the Roodan watershed to the south of Iran by using the plant ET method accounting for daily CN value in the SWAT model. The objectives of this research were (1) to evaluate the behaviour of plant ET method on low precipitation area; (2) and to suggest the depletion coefficient value (model parameter) for Roodan watershed using plant ET method.

2. Material and methods

2.1. SWAT model

SWAT was developed from several earlier models by Arnold for the United States Department of Agriculture in the early 1990s [7]. It was extended to predict the impact of land management practices on water, sediment, agricultural and chemical yields in large river basins with varying spatial and temporal features. In addition, SWAT is a watershed scaled, continuous time model and it is suitable for studying long-term results on large and complex catchments. Meanwhile, it is not appropriate to model single flood events or to study characteristics of watersheds in short period. In fact, SWAT model is a semi-physically and semi-empirical based model. It employs mathematical equations approximating the physical performance of the hydrologic structure [4]. In accordance to the plant ET plant method, CN value is a function of 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. In contrast with soil moisture condition II method ,which produces too much stream flow in modelling, plant ET method (new method) creates moderate runoff, especially for watersheds with low storage and shallow soils [4,9]. The model parameter (Depletion coefficient or CN_{coef}) developed based on evapotranspiration and precipitation while it varies from 0.5 to 2.0. A complete description about SWAT and plant ET method can be found in literatures [5,8,9,10].

2.2. SUFI-2 algorithm

SUFI-2 algorithm is applied as an inverse modelling for calibration models that have parameters as those in SWAT [11,12,13]. In this research, two stop criteria were used to evaluate the results. The degree to which all uncertainties were accounted for was quantified by a measure referred to as the P-factor, which was the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). Another factor that showed the strength of a calibration and uncertainty analysis was the R-factor, which was the mean thickness of the 95PPU band and was divided by standard deviation of the observed data. Ideally, P factor of 1 and R factor of zero would show that the simulation corresponded exactly to observed data. In addition, accuracy of SWAT model can be judged by two coefficients, namely coefficient of determination (R^2) and Nash-Sutcliffe coefficient (NS) between the observations and the final simulation [14].

2.3. Study area

Roodan watershed is located in the southern part of Iran between Hormozgan and Kerman providences (Fig.1). 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′. In the period of 1978 to 2008, the average annual precipitation was 215 mm. The predominant soil types in the north and center parts are heterogeneous mixture of clay, silt and sand. The southern and eastern parts of Roodan watershed include mostly silt, sand and little clay that has a good drainage. 30% of Roodan is covered with low storage soil. Generally, the climate of Roodan is arid to semi-arid with short rainfall but high intensity. The most important and dominant land-use types of Roodan watershed are shrub land, mixed grassland /shrub land.

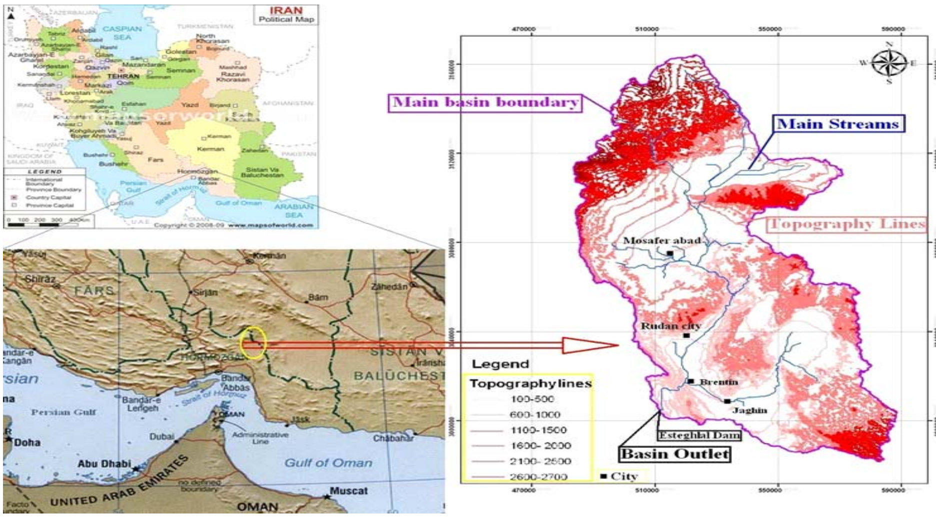

Fig. 1: Location of Roodan watershed in Iran

3. Modelling implementation

SWAT model requires digital elevation map (DEM), land-use map, soil map and meteorological data in daily scale [9]. DEM was prepared with 90-m resolution from 1:25000 topographic maps. In this study, for more accurate simulation, digital river network burning technique had been applied on the DEM by considering the minimum area for delineation of sub basins [15]. The soil map was obtained from the global soil map from the Food and Agriculture Organization of the United Nations [16]. Land use of Roodan was prepared from satellite of Landsat7, observation of various part of case study (2007-2008), available land use map (1:25000) image and statistic recorded by agriculture organization of Hormozgan province [17]. Then, daily precipitation and temperature served as input for the model within the period of 1988-2008. Potential evapotranspiration was calculated using Hargreaves method and daily rainfall-runoff curve number was chosen for the plant ET method to calculate surface runoff. Finally, reach evaporation coefficient (EVRCH.bsn) was adjusted for Roodan watershed. In fact, reach evaporation adjustment factor in original equation tends to overestimate evaporation from riches in arid areas [8].

4. Calibration and sensitivity analysis

In this study, to find the sensitive parameters in Roodan watershed Latin hypercube simulation, the One At-a-Time (LH-OAT) method was used before calibration [16]. 26 parameters were selected for sensitivity analysis which were identified as having important roles in estimation of daily stream flow [8,18]. According to sensitivity analysis cognition of case study and literature reviews [5], sensitive parameters were chosen for calibration and uncertainty analysis. Then, a more in depth sensitivity analysis by SUFI-2 algorithm was performed during the calibration [19]. In this study, year 1988 was chosen as the starting date for warm-up period as it had a complete hydrological cycling. The period from 1989 to 2002 was defined for calibration and the period from 2003 to 2008 was used for validation. In order to have a perfect evaluation of modelling as well as P and R factor which is specified for SUFI-2 algorithm in calibration and uncertainty analysis, R^2 and (NS) had been chosen for accuracy of modelling [20].

5. Results and conclusion

In this study, five parameters, namely Effective hydraulic conductivity of main channel (CH_K2.rte); SCS runoff curve number for mix grassland/shrub land (CN2.mgt_MIGS); manning coefficient of channel (CH_N2.rte); SCS runoff curve number for shrub land (CN2.mgt_SHRB); and surface runoff lag coefficient (SURLAG.bsn) were found as the most sensitive parameters for Roodan watershed. The research outcomes showed that these sensitive parameters have important roles in representing channel routing, runoff, and lastly groundwater characteristic respectively. P and R factors were obtained satisfactory by 57% and 0.16 (calibration), and 50% and 0.06 (validation) [12]. The uncertainties are reasonable as the Roodan watershed is of low development and human activities [21]. The other reason can be the effect of using plant ET method as it has been suggested that the model protects runoff overestimation thus leads to better modelling of low flows (perennial) [5]. Therefore, stream flows that are perennial get better simulation at the expense of loosing peak flows simulation in winter season. The criteria of R^2, NS obtained 0.68, 0.66 (calibration), and 0.55, 0.51 (validation) respectively with setting value of 2 for depletion coefficient (CN_{coef} in SWAT). It was the best modelling between observed and simulated data (Fig.2) according to R^2 and NS and considering the uncertainty band (P and R factor)[19,22]. Kannan *et al* [5] reported an unsatisfactory stream flow simulation in upper Colorado catchment by application of plant ET method due to low annual precipitation (292 mm). However, this study showed that plant ET method could give satisfactory results in arid and semi-aired region under condition of 30% low storage soil and 215 mm annual precipitation. Therefore, low annual precipitation with short duration and high intensity can be neglected as a reason that hinders good simulation of peak flows in arid area. Area of low storage soil, which is covered in a watershed area, should be significant factor. Table 1 shows impact of behaviour for depletion coefficient (CN_{coef}) on daily stream flow. Absolute error percentile evaluation between observed and simulated stream flow (m^3/s) revealed that a decreasing in CN_{coef} leads to reducing in simulated flow. Although the absolute error percentile decreases between observed and simulated flows when decreasing the depletion coefficient, it affects the simulation quality of moderate and peak flows; in addition, accuracy of modelling has been reduced by index R^2 and NS coefficient. In conclusion, the plant ET method was satisfactory in Roodan watershed and ongoing research can offer a good cognition from the method.

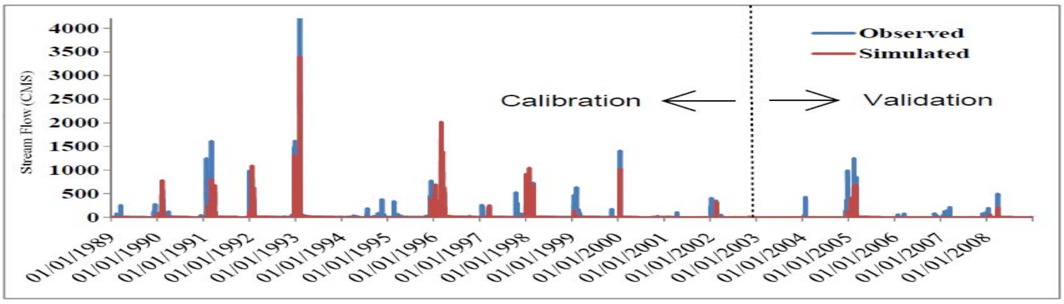

Fig. 2 Simulated and measured stream flow (m^3/s) in daily time scale over calibration(1989-2003) and validation (2003-2008) period by CN_{coef} setting 2

Table 1: Percentile of absolute error between observed and simulated flow (m^3/s) for CN_{coef} between 2-1.7

	Percentiles (%)						
	5	10	25	50	75	90	95
Observed - CN_{coef} (2)	.1233	.2450	.5351	1.3500	3.1098	7.3234	16.9240
Observed - CN_{coef} (1.9)	.1102	.2377	.5422	1.3030	3.1355	7.5204	16.5870
Observed - CN_{coef} (1.8)	.0821	.2333	.5278	1.2970	2.9230	7.2264	16.2280
Observed - CN_{coef} (1.7)	.0809	.2320	.5325	1.3030	2.8650	7.0321	16.0210

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