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Research Article

Derivative Discharge and Runoff Volume Simulation from Different Time Steps with a Hydrologic Simulator

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Abstract: Engineering and water resource management responses to hydrological variability depend on daily, monthly and yearly timeframes. Annual runoff volume and flows are significant for long-term decisions on planning water resources and regulatory programs. The objective of this study was to evaluate the average annual discharge and runoff volume derived from different time steps run by SWAT (Soil and Water Assessment Tool) as hydrologic simulator in order to explore the impact of different time step run simulations on yearly runoff yield. Three scenarios has been performed namely Annual (D), Annual (M) and Annual (Y). Annual (D) and Annual (M) are related with derived average annual flow from daily and monthly run simulations by SWAT. Annual (Y) is yearly simulation run via SWAT. The Nash-Sutcliffe (NS) coefficient, Mean Square Error (MSE) and ratio of the Root-MSE (RSR) on standard deviation of measured data during validation period were 0.73, 6.3 and 0.5 for Annual (D), 0.82, 4 and 0.38 for Annual (M) and 0.81, 4 and 0.38 for Annual (Y), respectively. Also, relative error (%) for validation period obtained 0.97, 0.35 and 0.33 for Annual (D), Annual (M) and Annual (Y) scenarios, respectively. The study concludes that Annual M and Annual Y scenarios obtained closer results in validation period. In regard to relative error for average runoff volume in each year over modeling period, Annual (D) scenario obtained highest contribution with shortest relative errors in comparison with the two other scenarios.

Keywords: Annual flow, hydrology, water resources, water yield

INTRODUCTION

Population growth, industrialization, extended drought, severe floods and possible adverse impacts of climate change are major anthropogenic or climatic related problems impacting hydrological systems worldwide (Singh *et al*., 2014). Arid and semi-arid regions are particularly vulnerable in regard to drought, over-use of groundwater resources and water scarcity, especially in the context of future climate change (Kanae, 2009; Oki and Kanae, 2006; Wang *et al*., 2013; Longe and Balogun, 2010). However, there is a lack of understanding regarding hydrological phenomena and problems in arid and semi-arid areas, pointing to the need for extensive additional research in these regions (Sen, 2008; Buytaert *et al*., 2012).

Climatic conditions vary greatly across Iran, ranging from subtropical conditions along the Caspian coast and the northern forests to arid or semi-arid conditions across much of the central, eastern and southern sub regions of the country. Some areas of the country experience relatively high annual precipitation levels, especially in the northwest where annual average rainfall varies between 680 to 1,700 mm in the eastern and western parts of the plains region, respectively. However, the central basins are arid with less than 200 mm of rain and are characterized by occasional deserts, while annual precipitation ranges from 135 to 355 mm in the coastal plains that lie along the Persian Gulf and Gulf of Oman in southern Iran. Overall, the average annual rainfall is only 250 mm which is just one-third of the world's average rainfall, resulting in water shortages due to the dominant arid and semi-arid climatic conditions.

Recent studies show that water scarcity problems are increasing in Iran which has major implications for maintaining sustainable water resources, agriculture and food production (Faramarzi *et al*., 2010; Paseban and Kaboudvand, 2013). At present, streams in central, eastern and southern Iran are very vulnerable to droughts and food production in these areas can only be sustained via irrigation from stream systems in the respective regions (Faramarzi *et al*., 2009). In addition, Abbaspour *et al*. (2009) reported that wetter regions of Iran will likely receive more rainfall while dry regions will receive less rainfall in future years due to expected climate change, which portends even greater threats for these drier regions. The southern part of Iran further suffers from a lack of in-depth hydrological research,

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due in part to a scarcity of meteorological data and un-gauged watersheds.

A wide variety of hydrological models are being used in many studies to analyze these types of key water resource issues (Daniel *et al*., 2011; Moriasi *et al*., 2012). One of the most widely used models is the Soil and Water Assessment Tool (SWAT) ecohydrological model (Arnold and Fohrer, 2005), which has been applied for a broad spectrum of hydrological and water quality problems worldwide (Gassman *et al*., 2007, 2014; Douglas-Mankin *et al*., 2010; Tuppad *et al*., 2011). SWAT has been applied in Iran for land use change, hydrological cycle analysis, sedimentation, water pollution and agricultural planning for specific watersheds located primarily in the northern, western and central parts of Iran (Rostamian *et al*., 2008; Ghaffari *et al*., 2010; Akhavan *et al*., 2010; Masih *et al*., 2011). The model has also been used to assess water resources, food production and climate change issues on a national scale in Iran (Faramarzi *et al*., 2009, 2010; Abbaspour *et al*., 2009).

In this study, SWAT has been applied for a hydrologic assessment of the Roodan River watershed, located in Hormozgan province on the Persian Gulf in the southern part of Iran. The Roodan watershed is a stressed hydrological system for several reasons including the depletion of ground water resources, soil erosion resulting from the elimination of natural land cover, decreasing base flow and increased usage of agricultural land without proper management (Shargh, 2009). The province also experiences frequent severe floods resulting in extensive damage in spite of an annual average rainfall of less than 250 mm, most likely due to its location which is influenced by several rain systems, physiographic conditions and lack of vegetation cover (Morid *et al*., 2001).

Water resources planning and management focuses on supplying a steady water supply amid hydrological variability. Such variability occurs at many time scales, from daily to monthly and from seasonal to inter-annual and beyond. Engineering and management responses to hydrological variability depend on the time frame of the variability (Brown *et al*., 2009). Some features of hydraulic infrastructure respond to longer temporal variations and some features at shorter temporal variations. For example, water storage in dams respond to longer time period. Therefore, monthly or annual forecasting is required for reservoir water storage prediction. On the other hand, water release from dams requires daily stream flow forecast.

To date, only limited testing at various time steps due to compare of runoff volume have been reported in the SWAT literature for arid and/or semi-arid regions by Douglas-Mankin *et al*. (2010), Tuppad *et al*. (2011) and Gassman *et al*. (2014) which underscores the need for such an assessment for the Roodan study area.

Therefore, the new contribution of this study is to perform annual hydrological discharge assessment using SWAT at different time steps as supplementary with previously published study for Roodan system (Jajarmizadeh *et al*., 2013). Thus, the specific objectives of this research are:

- Comparison of average annual flow derived from daily and monthly run simulations as well as yearly simulation.
- Comparison of average annual runoff volume behavior which has been derived from daily and monthly time step run simulations as well as yearly simulation for Roodan system.

MATERIALS AND METHODS

Study area: Roodan watershed is located in the south of Iran between Hormozgan and Kerman provinces. Geographically, it lies between northern geographical latitude of 26° 57’ to 28° 31’ and eastern longitude of 56° 47’ to 57° 54’. The location of study area in Iran is shown in Fig. 1. The size of the catchment is 10570 km^2. The average annual precipitation of the study area is 215 mm. The heaviest precipitation is from October to March and warmer months have no substantial precipitation. Average stream flow for Roodan watershed from 1988 to 2008 of 11 m^3/sec has been obtained. The highest record for flow for this period has been obtained from February 1993 corresponding to 4209 m^3/sec. For the same period, the mean daily temperature was 25°C. In addition, the average daily minimum and maximum temperature were 20.6 and 30.2°C, respectively. Dominating land cover of Roodan watershed are range brush and shrub land which cover Roodan watershed 39 and 29% respectively. Minority of land cover is related with residential-medium density (0.2) and residential-low density (0.04). Texture of soil includes mostly clay-loam, which cover around 59% of the watershed. Roodan watershed makes a significant contribution in the production of agricultural products such as citrus and dates and they are considered as a key for development of economy for rural areas.

Data and methodology: Soil Water Assessment Tool (SWAT) was developed in the early 1990s and in the last two decades has undergone various modifications and improvements (Chen and Wu, 2012). The model has been widely used for assessing and predicting the effects of alternative management decisions in water resource allocation, sediment transportation and agricultural chemical yields in watersheds. SWAT divides the watershed into multiple sub-watersheds, which are then further subdivided into Hydrologic Response Units (HRUs) consisting of homogeneous land use, management and soil characteristics. SWAT simulates stream flow through four hydrological processes namely, base flow, surface runoff, groundwater, evaporation and deep aquifer percolation (Neitsch *et al*., 2011). The SWAT simulation module

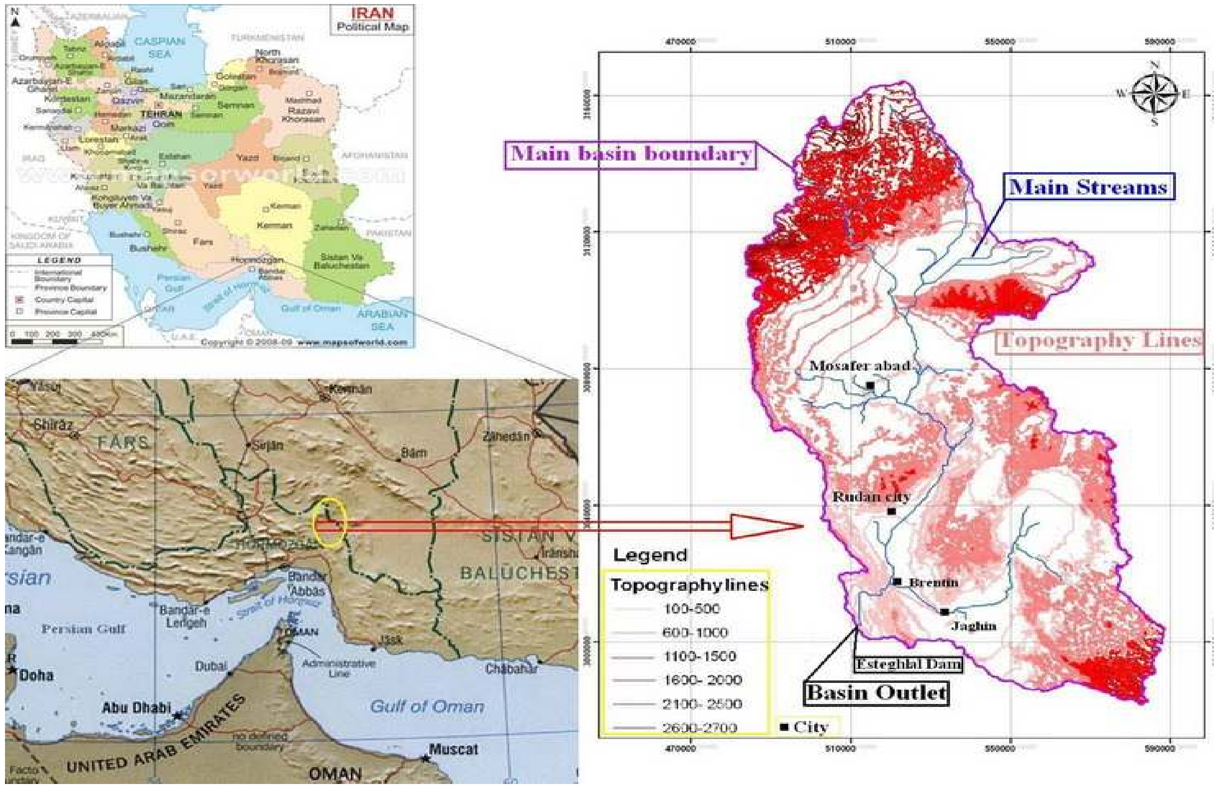


Fig. 1: Location of study area in Iran

includes hydrology, land management, weather, plant growth, soil temperature and properties, bacteria and pathogens, pesticides and nutrients.

The data required for the SWAT model development include DEM, land use map, soil map and meteorological data in daily or sub-daily scale (Winchell *et al*., 2010). A mesh size between 50-90 m is suggested for DEM (Chaplot, 2005). In Roodan watershed, the DEM was prepared with a 90 m resolution from 1:25000 topographic maps developed by the Iran topography organization. The digital river network burning technique was applied on the DEM by considering the minimum area for delineation of sub basins (Arabi *et al*., 2006). Considering the availability of soil information needed, Nations Food and Agriculture Organization soil map was used in the present study. Available information was utilized to evaluate the essential soil properties in relation to the soil type map of Roodan watershed such as available geology maps and sample soils. The land use of Roodan was prepared from Landsat image of the study area collected in 2007. Daily rainfall and temperature data were collected from 12 and 5 stations, respectively. Hargreaves method was used for the calculation of potential evapotranspiration. After setting up SWAT for Roodan watershed, it was run in daily, monthly and yearly time step simulation scenarios namely Annual (D), Annual (M) and Annual (Y), respectively.

Calibration and validation: Sequential Uncertainty Fitting (SUFI-2) is one such procedure available with original SWAT model. In the present study SUFI-2 was used for calibration and sensitivity analysis of model (Abbaspour *et al*., 2007). A comprehensive description on SUFI-2 algorithm can be found in Abbaspour *et al*. (1997). The accuracy of the model was evaluated by comparing the observed and simulated data. In the present study, Nash-Sutcliffe coefficient (NS), Mean Square Error (MSE) and ratio of the RMSE (RSR) on standard deviation of measured data have been used as suggested by Arnold *et al*. (2012). Details on equations related with NS, MSE and RSR can be found comprehensively in Moriasi *et al*. (2007) and Parajuli *et al*. (2009).

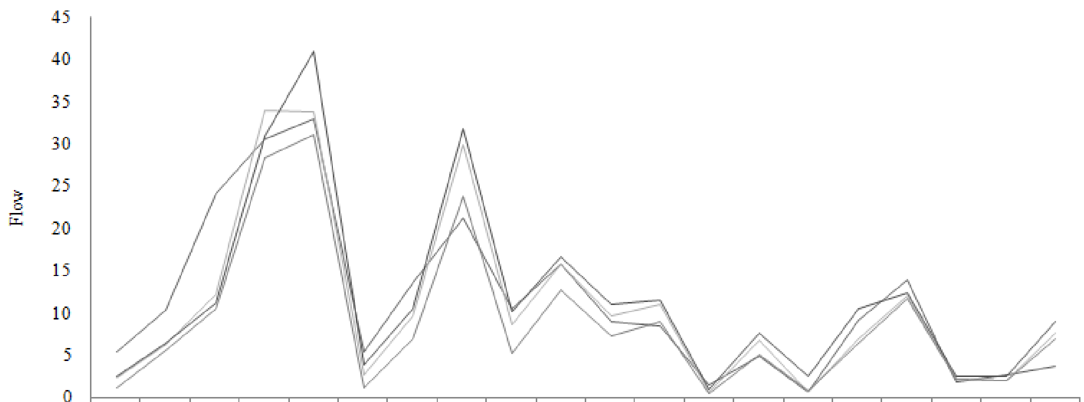
RESULTS AND DISCUSSION

Roodan watershed has been assessed via SWAT model by contribution of base and high flows that include calibration and related discussion by Jajarmizadeh *et al*. (2013) in a previous study. Therefore, this study only discusses the new contributions according to the newly mentioned objectives in the introduction. Details on calibration and validation can be found in Jajarmizadeh *et al*. (2013).

In this study, three scenarios are under presentation and evaluation:

Table 1: Model performance examination criteria for calibration and validation periods

	Annual (D)	Annual (M)	Annual (Y)
Criteria	Calibration-validation	Calibration-validation	Calibration-validation
NS %	68-73	75-82	76-81
MSE	28.50-6.3	24.7-4	21-4
RSR	0.54-0.5	0.5-0.38	0.46-0.38



	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Observed*	5.3	10.3	24.1	30.5	32.8	5.3	13.5	21.0	10.4	15.7	8.9	8.3	1.5	4.8	0.5	9.1	13.8	1.7	2.5	3.5
Annual (Y)*	2.2	6.1	12.2	34.0	33.7	2.6	9.6	29.8	8.5	15.6	9.6	10.9	0.6	6.6	0.5	6.8	12.0	2.1	1.8	7.5
Annual (M)*	1.1	5.4	10.4	28.3	31.1	1.1	6.9	23.7	5.2	12.7	7.2	8.9	0.4	5.0	0.7	6.4	11.7	2.0	1.9	6.9
Annual (D)*	2.6	6.4	11.2	30.9	40.9	3.8	10.6	31.7	10.2	16.7	11.0	11.5	1.0	7.6	2.5	10.5	12.4	2.6	2.5	9.0

Fig. 2: Comparison of predicted average annual flows (m^3/sec) and average annual observed flows over modeling period (1989-2008)

Observed: Average observed annual flow; Annual (Y): Predicted yearly flow with SWAT in yearly run simulation; Annual (M): Derived yearly flow with SWAT from monthly run simulation; Annual (D): Derived yearly flow with SWAT from daily run simulation

- Yearly simulation run presented as Annual (Y)
- Average annual flow, which is derived from monthly simulation run indicated as Annual (M)
- Average annual flow derived from daily simulation run via SWAT known as Annual (D) in the following figures and tables

Table 1 shows model performance criteria for three simulations (scenarios). In calibration, NS coefficient for Annual (Y) and Annual (M) are very close to each other, obtaining 76 and 75%, respectively. Also, they can be classified as very good values as reported by Parajuli *et al*. (2009). For Annual (D) the NS of 68% has been classified as good quantity (Parajuli *et al*., 2009). In validation, the study also shows the same quality of NS for three scenarios as very good for Annual (M) and Annual (Y). Also, NS is good for Annual (D) in regard to simulation quality. For MSE two scenarios namely Annual (M) and Annual (Y) have closer values to each other in calibration. Also, these two scenarios obtained the same MSE value for validation period. In calibration, RSR values demonstrate a decreasing trend of 0.54, 0.5 and 0.46 for Annual (D), Annual (M) and Annual (Y), respectively. In validation, Annual (M) and Annual (Y) follow the same values for quality accuracy.

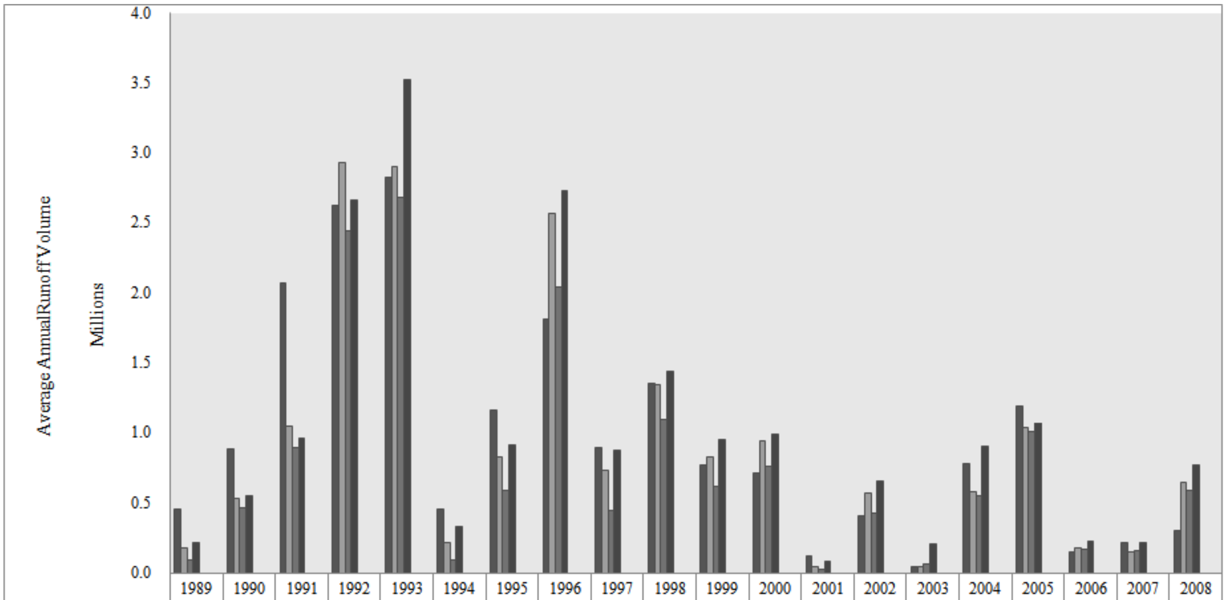
In general, all scenarios are satisfactory but Annual (M) and Annual (Y) obtained greater accuracy with regard to NS, MSE and RSR values.

Figure 2 presents average annual flow according to different time step run simulations via SWAT labelled previously as Annual (D), Annual (M) and Annual (Y). In general, observed data is in good agreement with average annual flow for Annual (D) and Annual (M). Also, Annual (Y) shows acceptable trend against observed data. The highest recorded observations were in 1993 where Annual (Y) scenario follows a fair prediction; however Annual (M) suffers from underestimation.

In contrast, model has obvious overestimation trend in Annual (D). Discrepancy of scenarios is related with various time scale run simulation. In Annual (D), every single day contributed to yearly flow production. As well, monthly simulation run (Annual (M)) included only 12 months of flow production per year. Hence, results for estimation of average annual flow include such differences via SWAT.

Some events show SWAT model has similar trend consistency (i.e., all scenarios have been overestimated in 1996 and 2008 and all scenarios have been underestimated in 2001 and 2005) for flow prediction in different time step run simulations.

In terms of relative error (%), all scenarios have close values in accuracy. However, Annual (D) and



	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Observed*	454892	889223	207802	263320	283651	455495	116793	181727	898312	135720
Annual(Y)*	185760	530496	105321	293328	291340	222048	832896	257817	736992	135043
Annual (M)*	92137	467885	895258	244888	268540	92549	592906	205027	445920	109914
Annual (D)*	223939	551253	969691	267226	353124	330688	913778	273866	881636	144173
RE%(AY)	0.59	0.40	0.49	0.11	0.03	0.51	0.29	0.42	0.18	0.00
RE%(AM)	0.80	0.47	0.57	0.07	0.05	0.80	0.49	0.13	0.50	0.19
RE%(AD)	0.51	0.38	0.53	0.01	0.24	0.27	0.22	0.51	0.02	0.06

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Observed*	770642	716327	126440	411190	47328	784843	119456	150062	220189	305427
Annual(Y)*	828576	940896	47520	569376	44928	584064	103680	177120	155520	648000
Annual (M)*	623830	765461	31140	431233	62432	551138	100727	173501	162663	596136
Annual (D)*	954190	990982	87685	655492	213046	908219	107510	225943	216097	775879
RE%(AY)	0.08	0.31	0.62	0.38	0.05	0.26	0.13	0.18	0.29	1.12
RE%(AM)	0.19	0.07	0.75	0.05	0.32	0.30	0.16	0.16	0.26	0.95
RE%(AD)	0.24	0.38	0.31	0.59	3.50	0.16	0.10	0.51	0.02	1.54

Fig. 3: Comparison of predicted average annual runoff volume (m^3) over modeling period
Observed: Observed average annual runoff volume; Annual (Y): Average yearly runoff volume with SWAT in yearly run simulation; Annual (M): Derived average yearly runoff volume with SWAT from monthly run simulation; Annual (D): Derived average yearly runoff volume with SWAT from daily run simulation; RE% (AY): Relative error for annual (Y); RE% (AM): Relative error for annual (M); RE% (AD): Relative error for annual (D)

Annual (Y) were better, respectively in calibration. On the other hand, Annual (Y) and Annual (M) obtained better values in validation. Annual (D) obtained an obvious high relative error. The reason can be related with event 2003 where the model has an obvious over prediction. Figure 2 also shows this overestimation in 2003. This high overestimation created a bias for relative error in Annual (D) scenario. Consistency can be seen from Table 2 for relative errors in calibration and validation periods for both Annual (Y) and Annual (M).

In Fig. 3, average runoff volume has been presented for each year over modeling for scenarios namely, Annual (D), Annual (M) and Annual (Y). Also Relative Error (RE%) for each annual runoff volume has been indicated in Fig. 3. Shortest RE% is for Annual (Y) for 1998 that shows a good prediction of runoff volume. Largest relative error is that of Annual (D) for event 2003. In regard to the number of events (20 years simulation) Annual (D) scenario involved the highest number of events including shorter relative errors (10 years). Figure 3 indicates that all scenarios usually have 9 years under prediction. Also, they have 5 years over prediction in the same events.

Table 2: Relative Error (RE %) for flow prediction in calibration and validation periods

	Calibration	Validation
Scenario	RE %	RE%
Annual (D)	0.30	0.97
Annual (M)	0.36	0.35
Annual (Y)	0.31	0.33

It can be concluded that SWAT provides fair estimation for annual runoff volume including all scenarios. It is clear that different time scale run simulations have their own contribution for average annual runoff. In this study, all scenarios obtained acceptable estimation for average annual runoff.

In general, the importance of runoff volume via modeling is related with maximizing the use of water resources, planning annual operations of water-resource infrastructure, quota allocations for supplemental water for irrigation and domestic use, etc. Yearly forecasting of stream flow is highly important for long-term water resource planning and regulatory programs. Thus, conservative decisions to use accurate model results for management and planning should be taken and significance and cost of projects should also be considered.

CONCLUSION

SWAT model was applied for estimating average annual runoff volume in southern part of Iran. Three scenarios have been performed with daily, monthly and yearly run simulations via SWAT. The average annual runoff volumes were derived from daily and monthly simulations and compared with yearly simulation run via SWAT simulator to approximate accuracy and analysis. Results showed that Annual (M) and Annual (Y) agree in annual average flow comparison. However, Annual (D) scenario is satisfactory. Evaluation of trend analysis for annual flow presents general agreement for all scenarios during modeling. Relative Error (RE%) for yearly simulation run (Annual (Y)) showed better results compared to Annual (M) and Annual (D) scenarios. Runoff volume analysis showed that largest relative error value included Annual (D) scenario, however Annual (D) scenario has shortest relative errors for 10 years compared to Annual (M) and Annual (Y) over a modeling period of (20 years). Results showed that SWAT tool can be suitable for use in the southern part of Iran for management and planning in regard to annual runoff flow and volume. Further assessments are suggested in the southern part of Iran or other arid to semi-arid climates to obtain a comprehensive view.

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