

Estimating hydrologic budgets for six Persian Gulf watersheds, Iran

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Abstract Estimation of the major components of the hydrologic budget is important for determining the impacts on the water supply and quality of either planned or proposed land management projects, vegetative changes, groundwater withdrawals, and reservoir management practices and plans. As acquisition of field data is costly and time consuming, models have been created to test various land use practices and their concomitant effects on the hydrologic budget of watersheds. To simulate such management scenarios realistically, a model should be able to simulate the individual components of the hydrologic budget. The main objective of this study is to perform the SWAT2012 model for estimation of hydrological budget in six subbasin of Persian Gulf watershed; Golgol, Baghan, Marghab Shekastian, Tangebirim and Daragah, which are located in south and south west of Iran during 1991–2009. In order to evaluate the performance of the model, hydrological data, soil map, land use map and digital elevation model (DEM) are obtained and prepared for each catchment to run the model. SWAT-CUP with SUFI2 program was used for simulation, uncertainty and validation with 95 Percent Prediction Uncertainty. Coefficient of determination (R^2) and Nash-Sutcliffe coefficient (NS) were used for evaluation of the model simulation results. Comparison of measured and predicted values demonstrated that each component of the model gave reasonable output and that the interaction among components was realistic. The study has produced a technique with reliable

capability for annual and monthly water budget components in Persian Gulf watershed.

Keywords Iran · Persian Gulf · SWAT model · Water budget

Introduction

In recent decades for the estimation of both water budget components and specifically the outflows of catchments numerous mathematical models and software have been developed. The soil and water assessment tool (SWAT) Model and SUFI2 are professionally linked for estimating water budgets, recently. The main objective of this study is to test the performance and feasibility of the SWAT model for estimating of water budgets in the Persian Gulf watersheds. Hydrologic processes analysis can be carried out thoroughly by the application of both continuous and physical modeling. The prerequisites for such operations are complete and accurate information on soil, land use status and hydro climatology data in catchments which provide desired outputs from quantity and quality components of the water budgets. The use of GIS in many cases can increase the speed and accuracy of calculations, the ability to integrate data with spatial characteristics in terms of providing a comprehensive database. Currently these software are widely used in different parts of the world for simulation of hydrological processes of basins, both quantitatively and qualitatively among them SWAT hydrologic model has found a specific attention. (Arnold et al. 1998).

The soil and water assessment tool (SWAT) is a semi-distributed conceptual model that operates continuously on a daily time step (Arnold et al. 1998). It is a comprehensive tool that enables the impact of land management practices on

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water, sediment and agricultural chemical yields to be predicted over long periods of time for large complex watersheds that have varying soils, land use and management practices (Neitsch et al. 2001). SWAT was developed to simulate the major processes of the hydrologic cycle and their interactions as simply and realistically as possible and to use input data that is readily available for large scale catchments so that it can be used in routine planning and decision making (Ogden et al. 2001). One of the main advantages of SWAT is that it is computationally efficient for very large catchments, which makes it of practical use to land and water resources managers dealing with vast areas. The model is designed for the prediction of long-term yields rather than single flood events (Arnold et al. 1998).

The other advantage of SWAT is the ability to predict water budget components such as surface runoff, interflow, groundwater flow, evaporation; evapotranspiration; soil moisture and sediment yield and present them within GIS platform in a powerful database. Obtaining the spatiotemporal variations of precipitation and runoff is the principal requirement for water resources planning in rather large catchments. Models that are used for investigative purposes tend to be very complex and require a considerable amount of observed data to test the accuracy of the predictions. Grayson et al. (1992) argued that the real uses of such models are to assist in the analysis of data, to test hypothesis in conjunction with field studies, to improve our understanding of processes and their interactions, and to identify areas of poor understanding in our process descriptions.

Hydrological models aim at simplicity by selecting the fundamental aspects of the target system at the expense of incidental details (Anderson and Burt 1985). A number of alternative techniques and modeling approaches have been developed. The first integrated hydrological model, called the Stanford Watershed Model, was reported in the literature in 1966 by Crawford and Linsley (Singh 1995) and was applied on a representative and experimental catchments of southern part of Iran by Ghafouri (1988), for estimation of actual evapotranspiration of oak forests with relatively good results. During following decades, hydrological modeling improved significantly due to the advances in technology and computer hardware. Better hydrological models are becoming available with these technological advances and the continuous improvement in modeling strategies, such as GIS, remote sensing or cellular automata (MacMillan et al. 1993; Beven and Moore 1994). Many of these methods are used in contemporary catchment models, such as TOPMODEL (Beven et al. 1995); KINEROS, a kinematic runoff and erosion model developed by Rovey et al. (1977) and TOPOG_IRM (CSIRO 1993).

Measuring water budget components at the required time intervals is very hard due to both time consumption and costly operations. The water budget is one of the main

principal suites in hydrology to solve theoretical and practical problems. Based on the water budget approach there will be an opportunity to assess the quantity and quality of water resources and their changes that caused by human activities.

In this regard, couple models and GIS are very useful tools for predicting and simulation of water budget components. Soil and water assessment tools (SWAT) is a semi-physical and semi-distributed hydrological model with the ability to run on GIS platform. The ability of the model in simulation of complex hydrological processes with GIS interface has created priorities for it in using relevant lump model for hydrological components simulation (Akbari 2010). This model has the ability to connect with GIS environment and has no restriction for entry of a large amount of data and information and has provided acceptable simulation results in large basins of Mississippi river (Arnold et al., 1998).

For automatic calibration, Abbaspour et al. (2015) developed a set of five different calibration programs as Sequential Uncertainty Fitting (SUFI2), Parameter Solution (ParaSol), Generalized Likelihood Uncertainty Estimation (GLUE), Markov Chain Monte Carlo (MCMC) and Particle Swarm Optimization (PSO) which can be linked to SWAT. Alavinia and Nasiri Saleh (2000) integrated the Curve Number map with SWAT model in Abrou watershed for excess runoff estimation. Rostamian (2008) using SWAT model in Beheshtabad Basin showed good performance for estimation of flow and sediment, but the simulated peak discharges in river had no success. The evaluated results show reasonable ability for sediment load estimation. SWAT model implemented to estimate annually and monthly water budget in Talaghan catchment during 1987 till 2017 (Hosseini 2010). The study has produced a technique with reliable capability and high accuracy for annual and monthly water budget components and suspended sediment yield. Next investigated of this author by SWAT model for water budget simulation in Ghare-Sou river basin indicate reliable results in flow discharge and volume (Hosseini et al. 2012).

In this study, modeling of water budget was carried out to estimate water budget in monthly and annually time steps in a number of catchments for Persian Gulf Watershed with variety of soil and land use in the west and south of the Iran using SWAT model.

Materials and Methods

The study area is located in the Persian Gulf watershed located in South and West of Iran. The area is part of the central Zagros Mountain ranges. It lies within 46°, 6', 20'' to 52°, 20', 52'' eastern longitude and 28°, 10', 10'' to 36°,

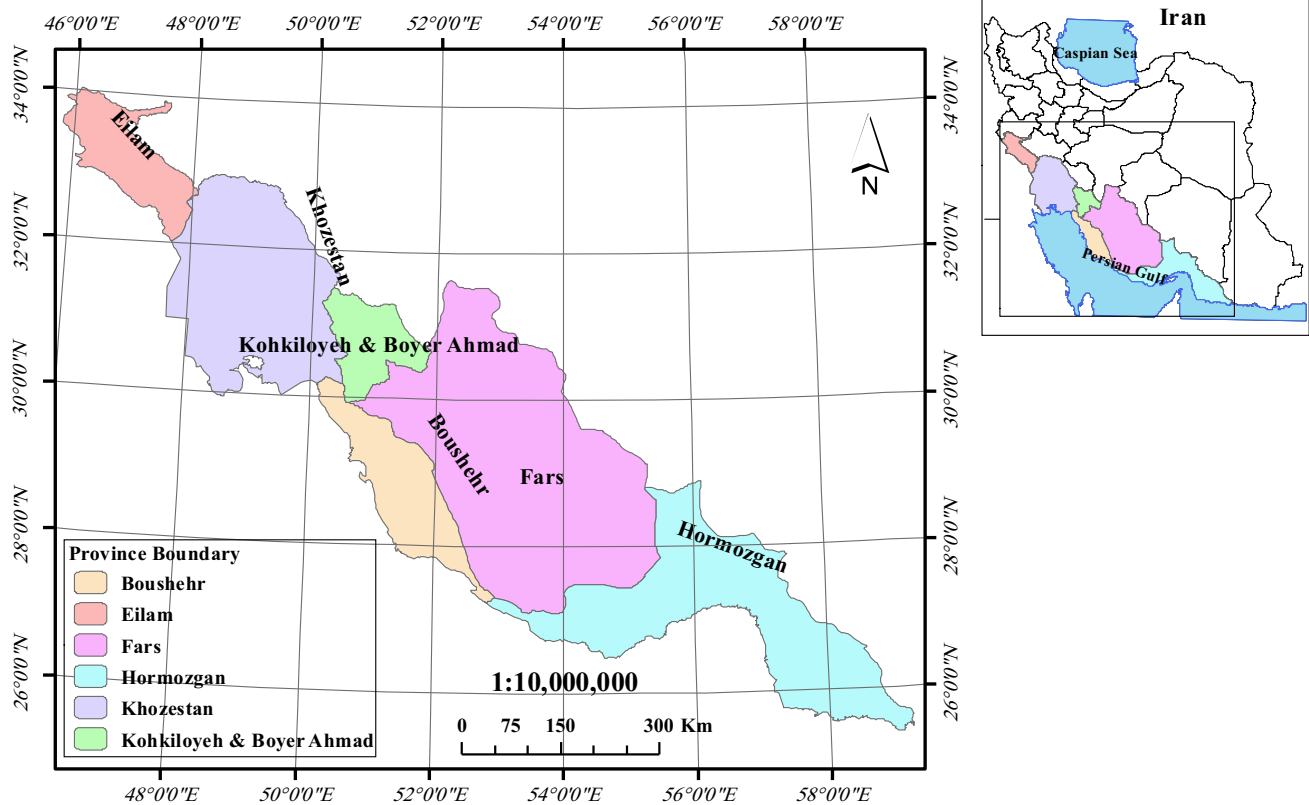


Fig. 1 Location of the simulated basins

4', 12'' northern latitude (Fig. 1). This region with an area of 177,878 km² covers more than 10 percent of the total area of the country. The climate varies from dry and warm in the south to cold and humid in the northern Zagros Mountain Ranges with altitudes from 84 to 3006 (m.a.s.l.). The six subbasins namely; Golgol, Baghan, Marghab Shekastian, Tangebirim and Daragah as representative are located in of Persian Gulf watershed (Fig. 2). The average annual precipitation is 83.4 mm for Daragah in the south and 970.6 mm for Tangebirim in the highest mountainous areas. In the mountains most of precipitation occurs in form of snow. The forest trees in the mountain parts of the catchment mostly include wild pistachio and oak. The general characteristics of each watershed are summarized in Table 1.

Model inputs and calibration

The SWAT hydrologic model requires input on soils (bulk density, available water capacity, sand, silt, clay, organic matter, and saturated conductivity), land use (crop and rotation), management (tillage, irrigation, nutrient, and pesticide applications), weather (daily precipitation, temperature, and solar radiation), channels (slope, length, bank full width and depth), and the shallow aquifer (specific

yield, recession shallow aquifer by deep roots or water that travels from the shallow aquifer to the soil profile and is then lost to soil evaporation or plant root uptake (Arnold et al. 1993). A complete list of inputs has been given by Arnold (1992).

Both synoptic meteorology stations from Iranian Meteorological Organization and also climatology stations from Ministry of Energy in the study area, and in each province of the Persian Gulf basin were included in the research. There are 139 evaporation measurement stations and 327 rain gauge stations in study area. SWAT model requires daily climate data including rainfall, temperature, relative humidity, wind and solar radiation. Daily rainfall data for the rain gauge stations in and around the subcatchments are used. The number of stations used for each study area varies depending on the distribution and the number of active stations within each province. Rainfall data from 40 rain gauges and daily temperature data from 23 stations were prepared and stored in a database for the simulation.

Digital elevation model (DEM) which shows the topography of the land by a cellular network must be used in the model in Raster format with specified geographic coordinate system. The model determines the location of rivers, divides basin to sub basins and extracts physical characteristics of the catchments. The six subbasins of

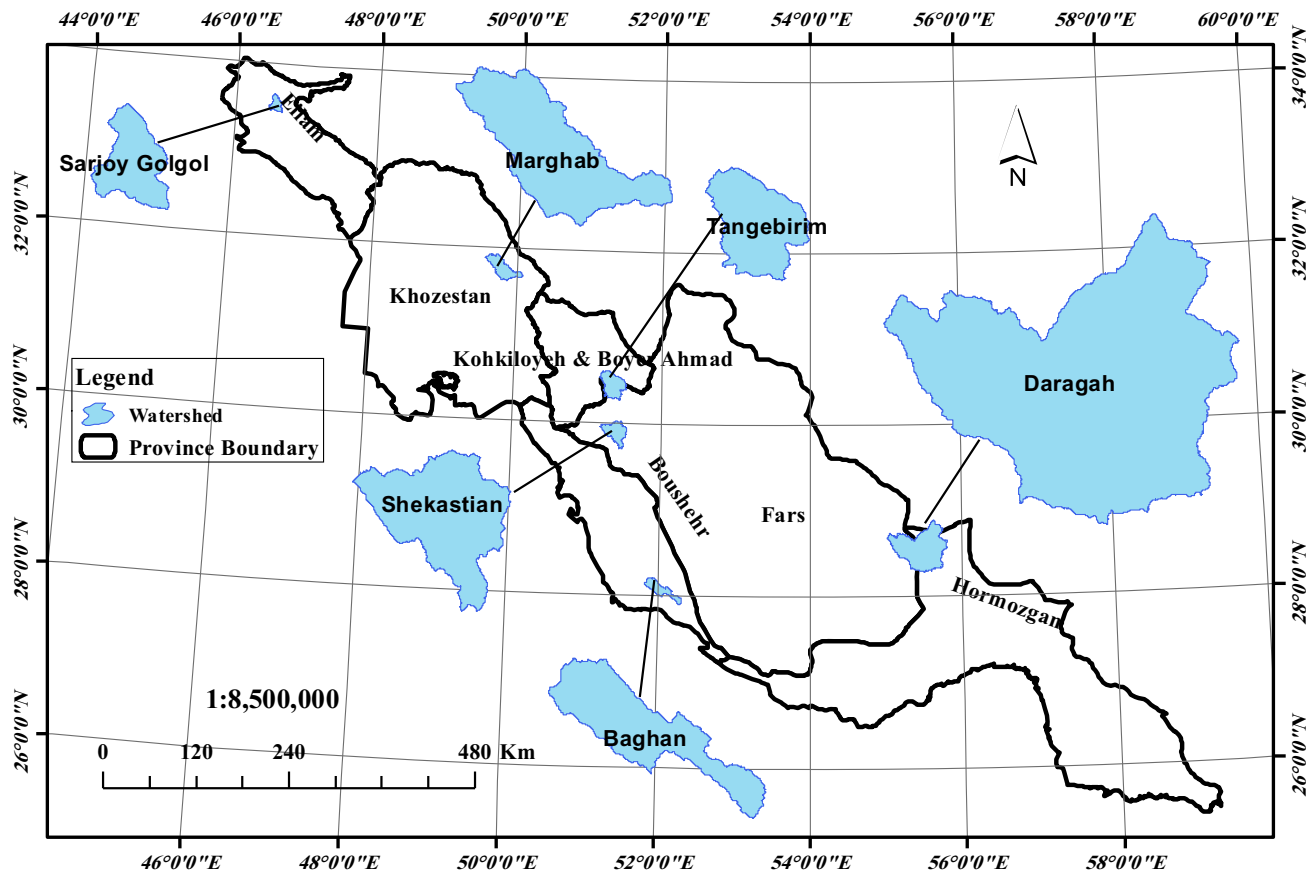


Fig. 2 Location of the subbasin in six provinces of Persian Gulf watershed

Table 1 Comparison of characteristics of basins

Characteristics	Golgol	Baghan	Marghab	Shekastian	Tangebirim	Daragah
Min. elevation (m.a.s.l)	1066	84	462	660	730	1040
Max. elevation (m.a.s.l)	2729	1351	2992	2033	3006	2892
Mean elevation (m.a.s.l)	1667	527	1012	1121	1477	1729
Elevation at outlet (m.a.s.l)	1100	85	478	714	748	1106
Ave. annual precipitation (mm)	502	189	646	510	708	90
Soil Texture	Loam	Silty loam	Silty clay	Loam	Silty clay	Clay loam
Mean annual temperature (°C)	16.8	14.5	16.5	17.8	16.7	22.4
Area (km ²)	219.7	492.6	679.2	613.3	796.9	2894.2

watersheds were subdivided to account for differences in soils and land uses (Figs. 3, 4). Soil map prepared by the FAO with scale of 1: 1,000,000 and their attributes provided in the database of the model. Land uses in Raster format are obtained from Soil Conservation and Watershed Management Institute (SCWMRI) country databases. Hydrologic response units (HRU) are lumped land areas within the subbasin that are comprised of unique land cover, soil, and management combinations (Neitsch et al. 2005). While individual fields with a specific land use, soil, and management may be scattered throughout a subbasin,

these areas are lumped together to form one HRU. The HRUs are used in most SWAT runs since they simplify the particular run by lumping all similar soil and land use areas into one response unit. It is often not practical to simulate individual fields. The HRU assumes that there is no interaction between HRUs in one subbasin. Loading variables such as runoff and sediment from each HRU are estimated separately then summed together to determine the total loadings from the subbasin. Land use maps available in SCWMRI are prepared using data from Landsat satellite images in 2005 by supervised classification and visual

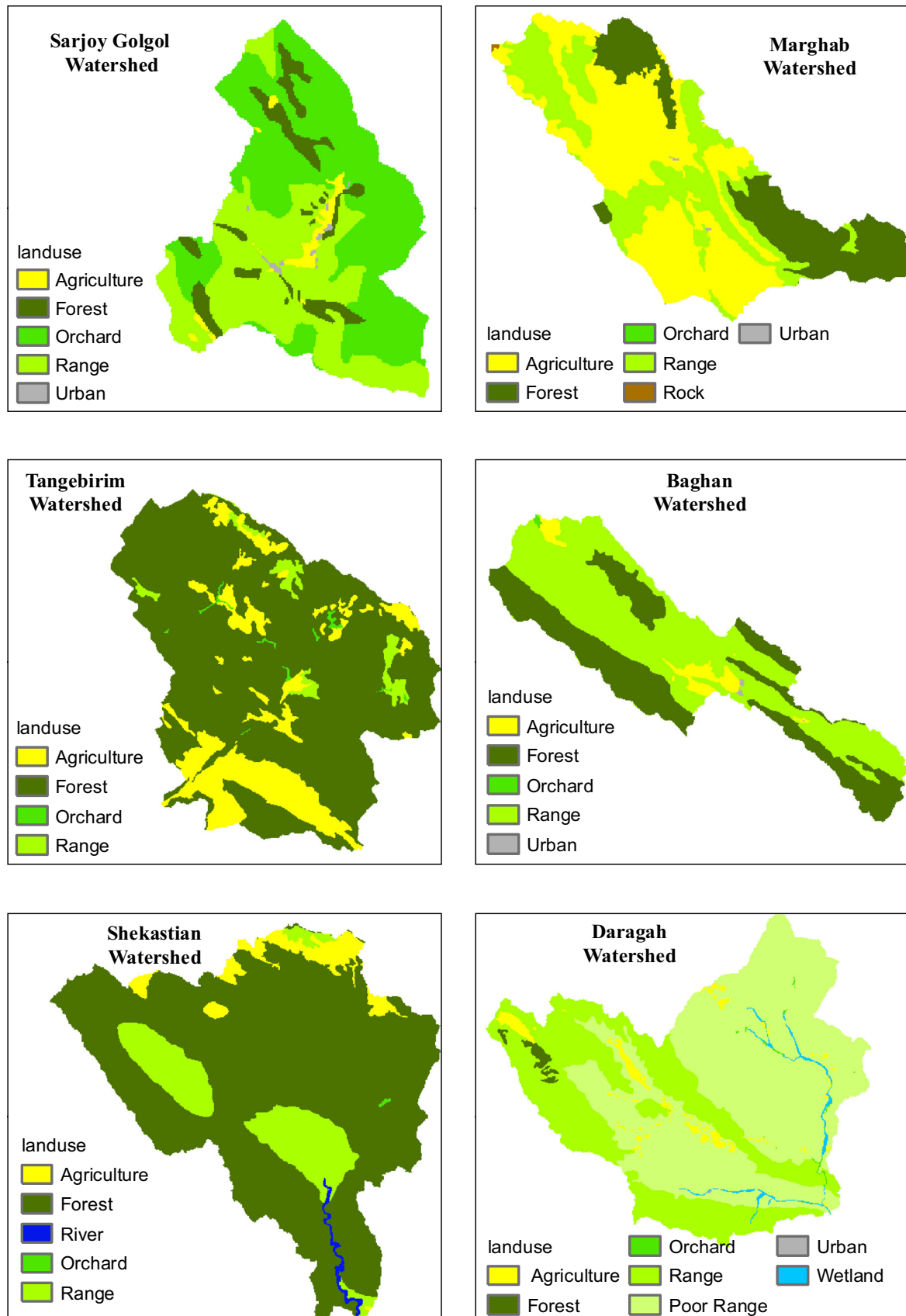


Fig. 3 Land use map of the selected catchments

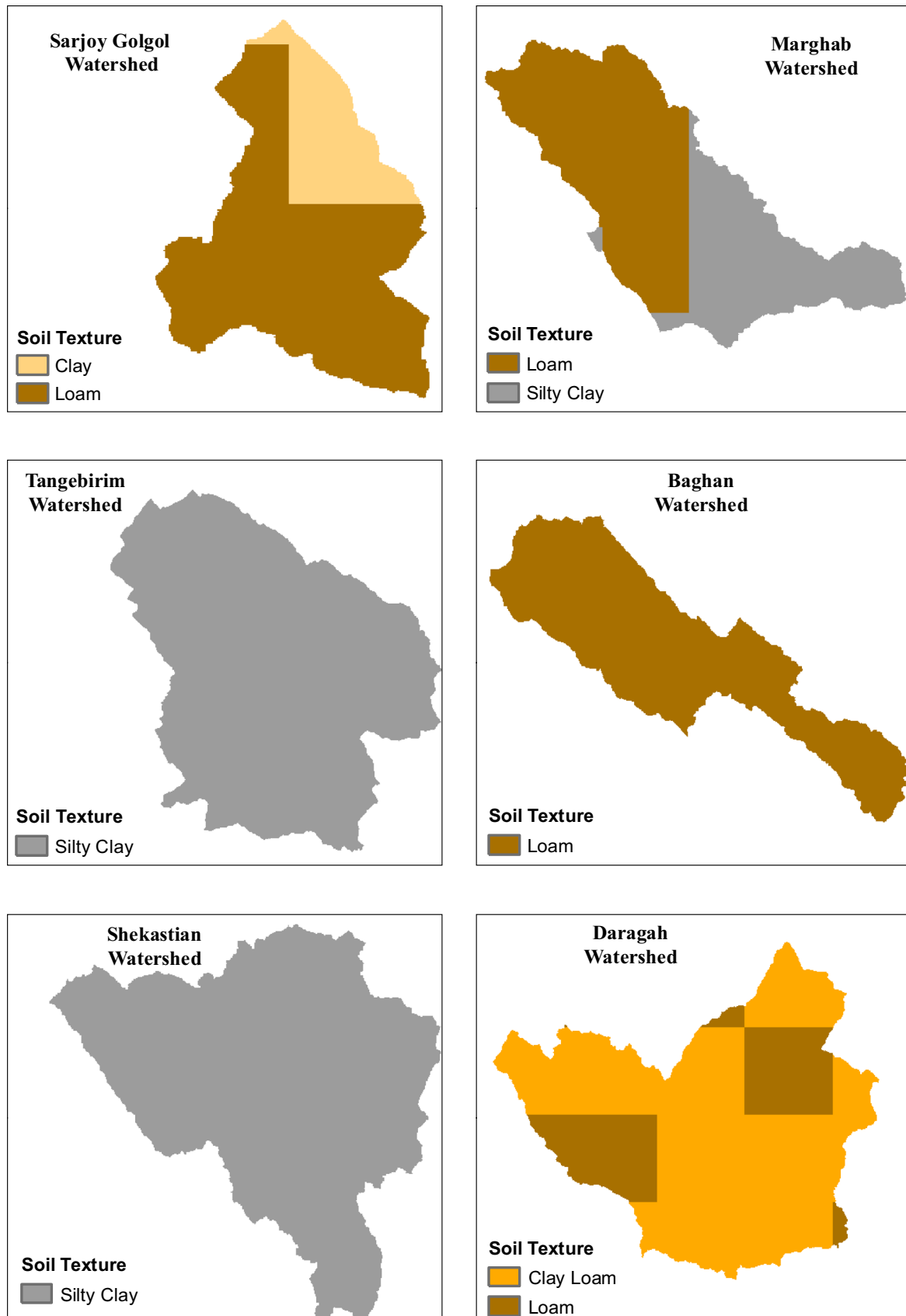


Fig. 4 Soil map of the selected catchments

interpretation. Given the large number of parameters, for successful and fast calibration, sensitivity analysis using a “one parameter at a time” (OAT) built in the model was used to identify factors with important and sensitive impacts on river flow simulation. Calibration, validation and uncertainty analysis were performed by using SUFI2 algorithm (Abbaspour et al. 2004,2007).

Results and discussion

Evaluation of the water budget components in this study entailed employment of the pertinent parameters optimized by SUFI2 to test the performance SWAT in both the model calibration and validation for the period January, 1995, to August, 2004. The water budget components encompass surface runoff, lateral flow, groundwater flow, evapotranspiration and soil water content.

The results of the statistical evaluation of model performance on the monthly discharge in the calibration and validation periods at outlets of six subbasins stream gauge stations are summarized in Table 2. Statistical criteria shows that SWAT model successfully implemented in both calibration and validation periods at outlets. The values of

mean absolute relative error (MARE) and standard error reported in the stations are generally low and close to zero. R^2 and NS coefficient are two important statistical analyses for evaluation of the results. According to Norusis (1999), when R^2 equal to 1, the regression equation model considered as a perfectly fit model, meanwhile if the R^2 is lower than 0.5 (near to zero), the model would be considered as not suitable. Otherwise, the values for the coefficient of efficiency (NS) can range from extreme negative values to 1, with 1 indicating a perfect fit between the observed and predicted runoff. Motovilov et al. (1999) stated that according to common practice, the simulation of a model is considered good for values greater than 0.75 and acceptable for values between 0.36 and 0.75. Values less than 0.36 indicate a poor model performance.

In this research R^2 values corresponding to the relationships between the observed and predicted average monthly discharges were between 0.51 till 0.84 during the calibration and validation periods. Coefficient of efficiency (NS) at outlet of subbasins ranged between 0.36 till 0.78 for periods (Table 2). These ranges were adopted in this study for interpretation of model performance.

Table 3 gives hydrologic budget components for selected years at the outlets of subbasins. The water budget components including of surface flow, lateral flow,

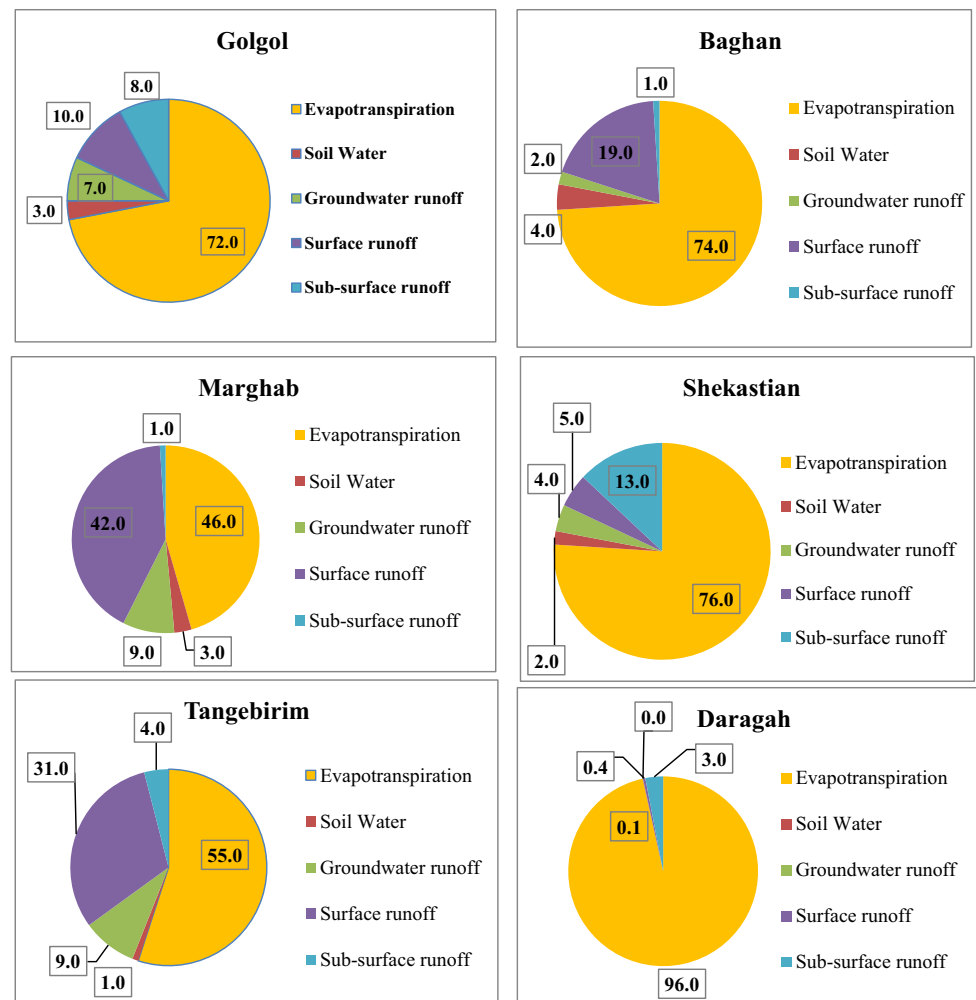
Table 2 Evaluation of performance model and the results of the calibration and validation in study area

Gauging station	Period	MARE	SE	R^2	E_{NS}	Result
Golgol	Calibration (1997–2003)	0.73	0.65	0.66	0.66	Satisfy
	Validation (2004–2009)	1.03	0.82	0.51	0.49	Satisfy
Baghan	Calibration (2001–2005)	0.27	0.58	0.65	0.40	Satisfy
	Validation (2006–2008)	0.40	0.67	0.61	0.40	Satisfy
Marghab	Calibration (1992–2002)	0.27	0.58	0.65	0.40	Satisfy
	Validation (2003–2009)	0.40	0.67	0.61	0.40	Satisfy
Shekastian	Calibration (1991–2001)	1.68	0.88	0.64	0.36	satisfy
	Validation (2002–2008)	0.46	0.85	0.66	0.45	Satisfy
Tangebirim	Calibration (1992–2002)	0.39	0.35	0.74	0.73	Satisfy
	Validation (2003–2008)	2.26	0.50	0.67	0.48	Satisfy
Daragah	Calibration (2002–2006)	0.53	0.67	0.84	0.78	Good
	Validation (2007–2009)	1.23	0.31	0.62	0.62	Satisfy

Table 3 Comparison of hydrologic budgets for the Persian Gulf basin

Subasins	Golgol	Baghan	Marghab	Shekastian	Tangebirim	Daragah
Evapotranspiration (%)	72	74	46	76	55	96
Soil Water content (%)	3	4	3	2	1	0.06
Groundwater flow (%)	7	2	9	4	9	0.01
Surface runoff (%)	10	19	42	5	31	0.4
Sub surface flow (%)	8	1	1	13	4	3
Average precipitation (mm)	502	189	646	510	708	90

Fig. 5 The mean annually water balance components in Persian Gulf watershed



groundwater flow, evapotranspiration and soil water content.

Stream flow is separated into surface runoff and groundwater flow, and ET is divided into surface and soil ET and groundwater ET. In SWAT, soil ET is the sum of soil evaporation and plant root uptake from the crop root zone (approximately 2 m). Groundwater ET is plant root uptake (trees and shrubs) from soil and rock layers below the crop root zone or water loss that occurs as the water from the shallow aquifer re-enters the soil zone. Groundwater recharge is the amount of water that percolates past the soil accurately monthly or annual hydrologic parameters.

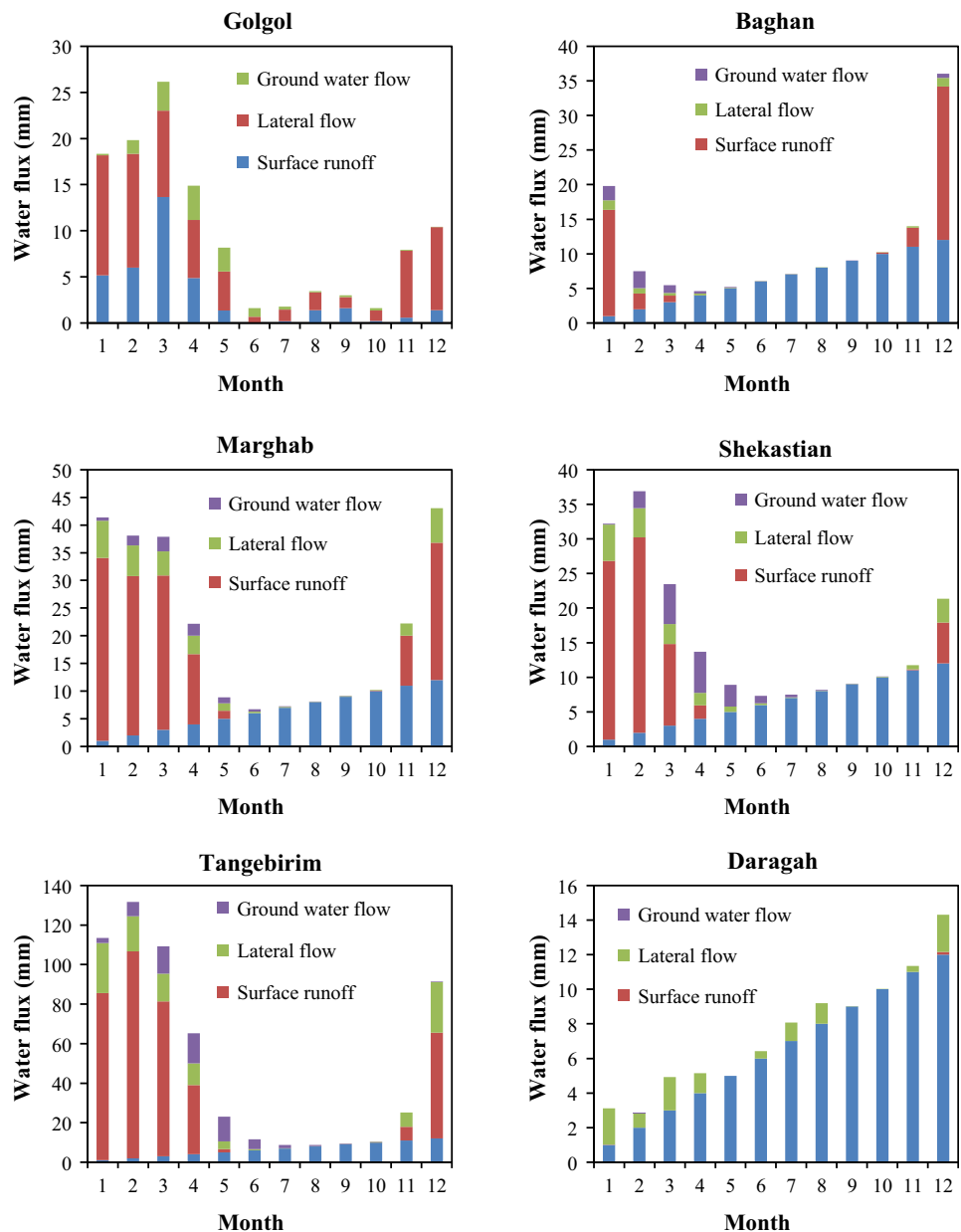
Annual interpretation indicates most losses take place by actual evapotranspiration in study area (Fig. 5). High values with 96 percent belong to Daragah subcatchment with 1729 (m.a.s.l) and 90 mm mean annual precipitation. Lowest value occurred in Marghab subbasin with 46 percent with 1012 (m.a.s.l) and 646 mm mean annual precipitation. The Marghab subbasin produces 42 % surface runoff. It's led engineers to planning of utilize the water for

spring season. The lowest surface runoff belongs to Daragah subbasin with heavy soil texture with 0.4 %. Shekastian subbasin with 13 percent produced the highest subsurface flow during study period. This subbasin located in Fars province with 1121 (m.a.s.l) and 510 mm mean annual precipitation. The ranges of ground water flow changes from 0.01 in Daragah to 9 percent in Marghab and Tangebirim subbasins. The study area has an irregular mean annual precipitation with high coefficients of variation; the minimum (90 mm) takes place at Daragah whereas the maximum (708 mm) occurs at Tangebirim subcatchments.

The average evaporation in Iran is equal to 73 percent. On the other hand, the study area located between 28° and 37° northern latitude with high evaporation. Therefore, evaporation in this area is relatively high. On the other hand soil texture is heavy with majority of clay at surface. In this reasons the runoff coefficient in this area is very low.

The monthly proportions of different water pathways of input to the river flow are shown in Fig. 6 for outlets of subbasins. It can be seen that from April to the end of May,

Fig. 6 The mean monthly proportions of different water flux in Persian Gulf watershed



most of the river flow originates from surface runoff due to the intense storms and snow melt occurring during that period. Most of the surface runoff in June depends on snow melt that takes place at high elevation areas.

Climate of study area is influenced by both Caspian Sea and Persian Gulf. In general, the precipitation regime of the study area is the result of the Mediterranean regime with one main maximum precipitation episode at the end of winter and early spring followed by one long dry season in the summer. In fall there is another rainy period wherein precipitation is influenced by moist air in contact with northern Siberian air masses. The influence of the monsoon from the Indian Ocean is very rare during the year.

Conclusion

A multicomponent water budget model (SWAT) has been tested for six subbasins in Persian Gulf watershed during 1991 to 2009. The model simulates all components of the water budget within acceptable limits on both an annual and monthly time step. In this research SWAT optimized water budget components reasonably well to create database for managing water resource in study area. This database system of the Persian Gulf watershed, with dispersed datasets in GIS environment was successfully developed to be used not only for modeling purposes but also for decision making by many government agencies

and other stakeholders in time. Comparison of the modeled results with measured water budgets allows comparison of the accuracy of the different components of the model. In this particular study, it demonstrates that each components of the model gives reasonable output. This should allow more realistic appraisal of various land use management practices on a large watershed. It should also better pinpoint exactly how each alternative will affect the water budget, thus allowing for more innovative management practices to test a priori and their effects traced through each hydrologic component of the watershed.

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