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Simulation of Irrigation and Reservoir Storage in the Develi Basin (Turkey) using Soil and Water Assessment Tool (SWAT)

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Abstract: The efficacy of the Soil and Water Assessment Tool (SWAT) model was evaluated for simulating irrigation and reservoir storage in the Develi Basin in Turkey. Develi Basin is a semi-arid closed basin that hosts an important wetland, called the Sultan Marshes. Surface water flows in the basin are strongly controlled through Ağcaaşar and Kovalı reservoirs, which supply water for irrigating the agricultural lands around the Sultan Marshes. SWAT is a semi-distributed hydrologic model that can be used for simulating irrigation practices and crop development. In this study, the SWAT model was established based on topographic, land use, soil, and meteorological data. Irrigation in the basin is represented with the auto irrigation tool, which determines the timing and amount of irrigation based on plant water stress factor. SUFI-2 algorithm available in the SWAT-CUP program was used for calibration/validation of the model for monthly reservoir storage over the period 2000–2015. This procedure resulted in Kling-Gupta Efficiency (KGE) of 0.69 and 0.70, Nash-Sutcliffe Efficiency (NSE) of 0.36 and 0.60, and coefficient of determination (R^2) of 0.54 and 0.75 for calibration between the simulated and measured water storage. For validation KGE was 0.63 and 0.57, NSE was 0.23 and 0.13, and R^2 was 0.50 for validation. Results indicated that SWAT can provide reasonable predictions for simulating monthly irrigation and reservoir storage in the Develi Basin.

Keywords: SWAT, reservoir storage, irrigation, Develi Basin

Develi Ovası'nda Sulama ve Rezervuar Depolamasının SWAT ile Simülasyonu

Özet: Develi Ovası'nda sulama ve rezervuar depolamasını simüle etmek için SWAT (Soil and Water Assessment Tool) kullanılmıştır. Develi Ovası, önemli sulak alanlarımızdan Sultan Sazlığı'na ev sahipliği yapan yarı kurak iklim özelliğine sahip bir ovadır. Ovadaki yüzeysel akışlar, Sultan Sazlığı çevresindeki tarım arazilerinin sulanması için su sağlayan Ağcaaşar ve Kovalı rezervuarları ile kontrol edilmektedir. SWAT, sulama uygulamalarını ve bitki büyümesini simüle etmek için kullanılabilen bir hidrolojik modeldir. Bu çalışmada model, topografik, arazi kullanımı, toprak ve meteorolojik verilere dayalı olarak geliştirilmiştir. Ovadaki sulama, bitki su stres faktörüne dayalı sulama zamanını ve miktarını belirleyen otomatik sulama aracı ile temsil edilmiştir. SWAT-CUP programında mevcut SUFI-2 algoritması, 2000–2015 dönemi boyunca aylık rezervuar depolama için modelin kalibrasyonu/validasyonu için kullanılmıştır. Bu prosedür ölçülen ve simüle edilen rezervuar depolaması arasında kalibrasyon dönemi için Kling-Gupta Efficiency (KGE) değerini 0.69 ve 0.70, Nash-Sutcliffe Verimliliği (NSE) değerini 0.36 ve 0.60 ve determinasyon katsayısı (R^2) değerini 0.75-0.54 olarak oluşturmuştur. Doğrulama dönemi için KGE = 0.63-0.57, NSE = 0.23-0.13 ve R^2 = 0.50 olarak sonuçlanmıştır. Sonuçlar, SWAT'ın Develi Ovası'nda aylık sulama ve rezervuar depolamalarını simüle etmek için makul tahminler sağlayabileceğini göstermiştir.

Anahtar kelimeler: SWAT, rezervuar depolama, sulama, Develi Ovası

Introduction

Hydrologic models such as Soil and Water Assessment Tool (SWAT) are commonly used for evaluating the effects of agriculture management at various spatial scales. SWAT (Arnold et al., 1998) is a physically-based, continuous-time, semi-distributed hydrological model developed by the United States Department of Agriculture. It has been applied to different size watersheds all over the world for simulating hydrology), erosion, plant growth, nutrient cycling, pesticide dynamics and agricultural management (Guse et al., 2016, Rahman et al., 2013, Neitsch et al., 2011).

In SWAT, hydrologic model is developed using topographic, soil, land use/cover and meteorological data with data on land management practices. The model is often calibrated and validated with streamflow data collected in the basin (Liu et al., 2014, Masih et al., 2011). For agricultural basins where irrigation and reservoirs play an important role in basin hydrology, it is important that the model is also calibrated for parameters that affect irrigation practices and reservoir storage.

The construction of reservoirs is a widely used strategy for dealing with limited water availability, especially in semi-arid regions. However, reservoirs change the spatiotemporal distribution of water resources in the watershed. Therefore, they affect both the quantity and quality of water in the basin. There are only a few previous studies where SWAT was used for understanding the effects of reservoir storage and irrigation in basin hydrology (e.g., Abera et al., 2018).

This study aims to assess the efficacy of SWAT for simulating irrigation and reservoir storage in the semi-arid Develi Basin in Turkey. Develi Basin (Figure 1) is an agricultural basin in the Central Anatolia region of Turkey, where Develi Irrigation Project constructed in 1980s created significant changes in the basin hydrology. With two large irrigation reservoirs (Kovalı and Ağcaaşar), currently major surface water flows are controlled in the basin and used for irrigation. In this study, the performance and feasibility of SWAT model for simulating the monthly irrigation and reservoir storage was evaluated for Kovalı and Ağcaaşar reservoirs.

Study Area

Develi Basin is a large mountainous basin with a heterogeneous land use/cover structure. The basin is a closed basin that is surrounded by mountains. Erciyes Mountain with 3917 m elevation is located to the northeast of the basin. The central part of the basin hosts a wetland ecosystem called the Sultan Marshes (Figure 1). Sultan Marshes is one of the largest and most important wetland ecosystems in Turkey and it is a Ramsar Site and a National Park and under protection due to these status (Dadaser-Celik et al., 2008). The total area of the catchment is about 3000 km^2, where the Sultan Marshes covers about 176 km^2. Develi Basin has a semi-arid, continental climate. Annual rainfall was 369.5 mm, and annual average air temperature was 11°C during the 2000-2015 period (Figure 2).

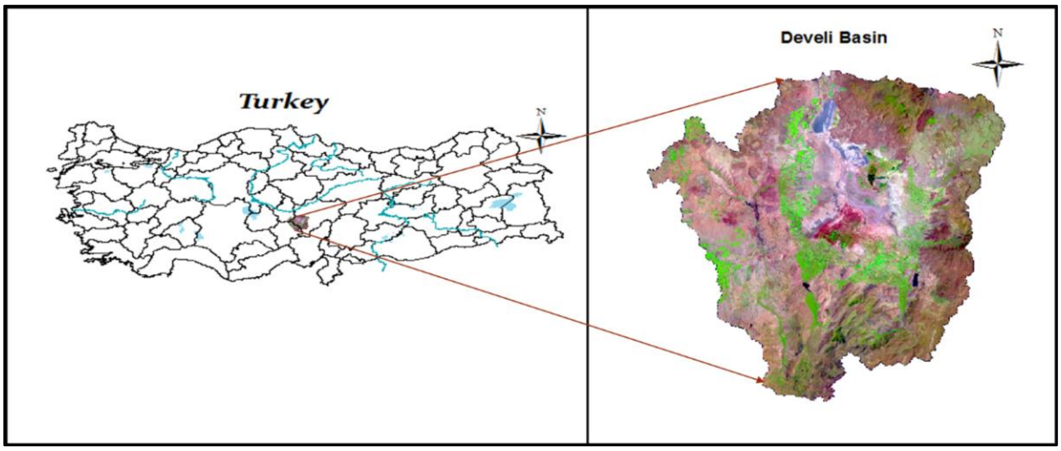

Figure1: Location of Develi Basin

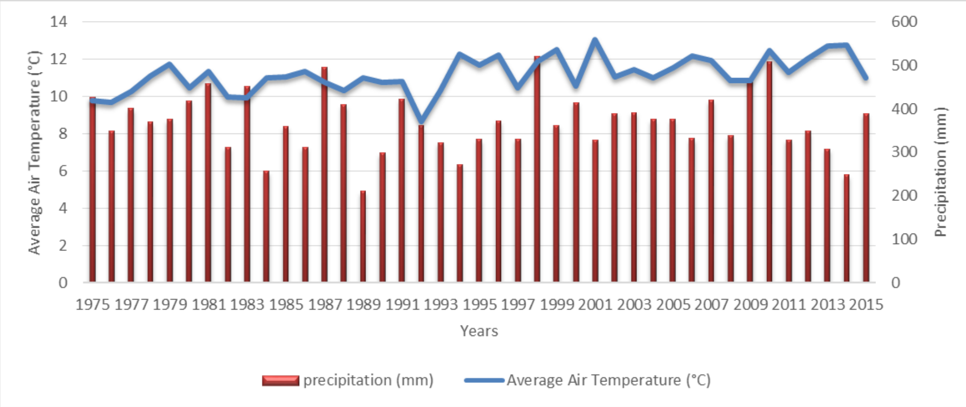

Figure 2. Annual precipitation and annual average air temperature at the Develi Basin during the 1975-2015 period.

Agriculture is the major economic activity in the region. Most of the basin around the Sultan Marshes is covered by agricultural areas, where both irrigated and non-irrigated agriculture take place. About 40% of the basin is agriculture (125000 ha). And about half of the agricultural area is irrigated. The stream flow is not monitored at the outlet of the basin and the amount and timing of water extracted from reservoirs, wells, and reaches for irrigation are unknown. After the construction of Develi Irrigation Project, hydrologic, physical, and biological characteristic of Sultan Marshes ecosystem have been affected due to the changes in timing and the magnitude of flows (Dadaser-Celik et al., 2008).

Materials and Methods

SWAT was applied for simulating irrigation and reservoir storage in the Develi Basin.

Data Used

SWAT's input database includes spatial and climate data i.e., digital elevation model (DEM), data for land use/cover, soils, land management practices and meteorological data. SWAT also requires stream flow data and reservoir storage data for model calibration and validation. Detailed information about the data used in this study, including the data type, resolution and their source, is presented in Table 1 and shown in Figure 3. The land use/cover data for the basin was obtained by classification of a Landsat 8 imagery. Eight land use classes were considered for simlification purposes: Urban, Marshes, Water, Dry Lake, Steppe/Shrubs, Winter Wheat, Sugar Beet, Apple Orchards. The soil map was obtained from FAO-UNESCO World Soil Map, which shows that the area is dominated by clayey and loamy soils.

Table 1.Data used for hydrology modelling of Develi Basin

Data	Spatial/Temporal Resolution	Data Source
Digital Elevation Model (DEM)	30 m × 30 m	United States Geological Surveys (USGS)
Land use/cover	30 m × 30 m	Landsat 8 (OLI) image classification.
Soils	1/5.000.000	FAO-UNESCO World Soil Map
Climate (precipitation, maximum and minimum air temperature, relative humidity, solar radiation, wind speed)	Daily	State Meteorology Service
Management Operations	-	Local Agricultural Experts
Streamflow	Monthly	State Hydraulic Works
Reservoir Storage	Monthly	State Hydraulic Works

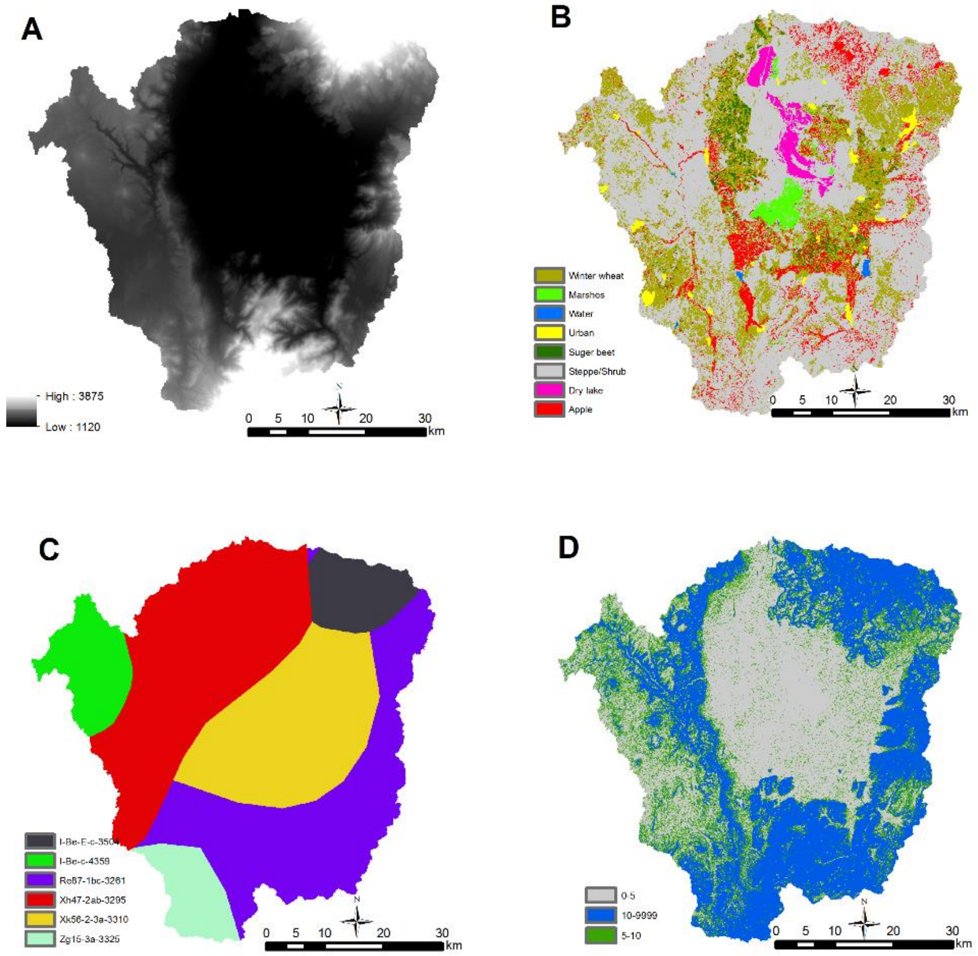

Figure 3. Spatial input data in the SWAT model A) DEM, B) Land use/cover, C) Soil properties D) Slope.

SWAT model setup

For model setup, the first step was to delineate the catchment using the DEM into several connected subbasins. The subbasins were further divided into smaller units called hydrologic response units (HRUs). HRUs are lumped land areas within each subbasin that are comprised of a unique land cover, soil, slope and management combinations (Neitsch et al., 2011).

A total of 37 subbasins and 404 HRUs were created (Figure 4). The HRUs were created by defining the thresholds of land use over subbasin area at 5%, soil class over land use area at 5% and slope class over soil area at 5% using the multiple HRUs definitions. Curve number method was used in SWAT to calculate the runoff based on daily precipitation and Penman-Monteith method was used to calculate the potential evapotranspiration.

The management operations data for planting, harvest, irrigation applications, nutrient applications, pesticide applications, and tillage applications were added. First, for irrigation applications, irrigation type was selected depending on the agricultural land area and the water resource available in the subbasin. There were three irrigation sources in Develi Basin: Reservoirs, reach and ground water.

In this study, the amount and frequency of actual irrigation in agricultural lands were unknown. Therefore, auto-irrigation option was selected. Auto irrigation selects the timing and amount of irrigation based on plant water stress factor.

Second, the agricultural land area was splitted into 3 types: winter wheat, sugar beets, and apple trees. Each agricultural type was assigned a management schedule based on information from local agricultural experts.

Reservoir Management

Reservoir water balance contains different components such as rainfall, runoff, groundwater, evaporation, infiltration, water consumption and discharge. In this study, the runoff to the reservoirs was estimated from simulated streamflow data. Infiltration was simulated based on hydraulic conductivity which depends on the soil type at the bottom of the reservoir. Evaporation was estimated based on potential evaporation and evaporation coefficient factor. Water consumption was based on human activities such as irrigation. Reservoir discharge was controlled by the reservoir operation based on irrigation water requirements.

Surface water flows in the basin are strongly controlled through Ağcaaşar and Kovalı reservoirs, which release water as the reservoir storage exceeds the maximum reservoir storage and used to supply water for irrigating the agricultural lands around the Sultan Marshes in the Develi Basin. All 12 monthly target volumes set equal to the principal volume. The number of days to reach target storage from current reservoir storage (ND targ) was set to 1 as default.

Figure 4 shows the reservoirs in the Develi Basin and the reservoir properties is presented in Table 2. When this table was created, area and volume information was used at normal water level obtained from State Hydraulic Works (DSI). Maximum level area and volume levels were estimated to be 10% greater than normal area and volumes. The operation years of the reservoirs were obtained from DSI and it has been accepted that they are in operation from the first month of the year. Area and volume information for marshes and lakes was obtained from DSI.

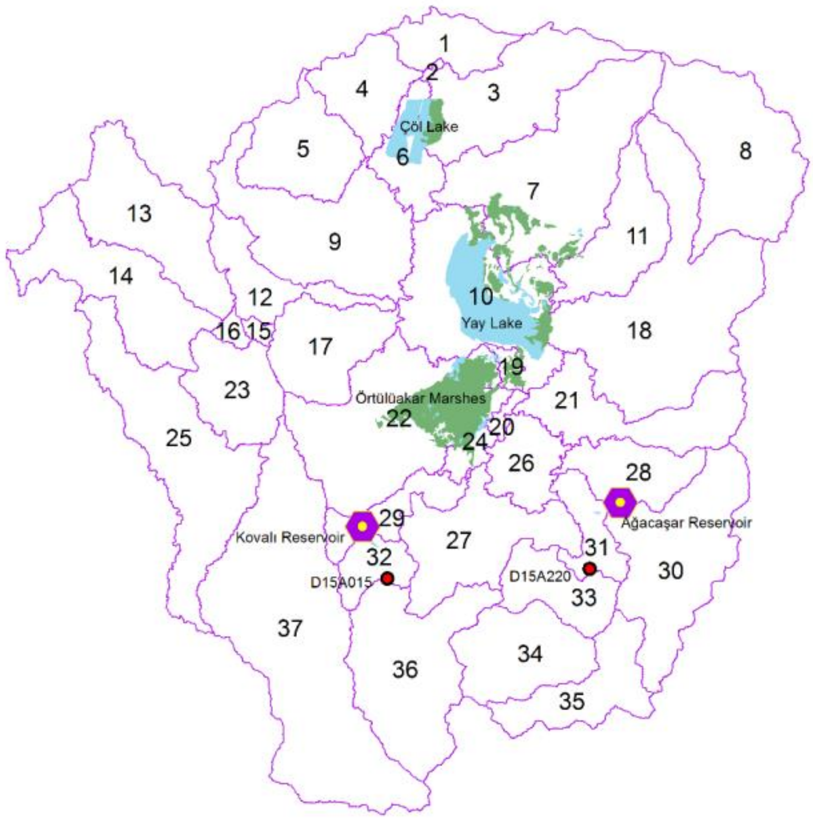

Figure 4. Subbasins and locations of reservoirs, lakes and marshes.

Table 2. Reservoirs properties added to SWAT

Name	Subbasin	Reservoir Construction Date (Month/Year)		Reservoir Area at Maximum Water Level (ha)	Reservoir Volume at Maximum Water Level (*104 m^3)	Reservoir Area at Normal Water Level (ha)	Reservoir Volume at Normal Water Level (*104 m^3)
Agcaşar	20	1	1987	459	7267	417	6606
Kovalı	32	1	1987	183	2761	167	2510

Model calibration, validation and performance evaluation

The model was run on monthly time step for a period of 26 years from 1990 to 2015 with a warm-up period of ten years.

Calibration was accomplished by comparing the output of the SWAT model with the observed data. For calibration and validation, the semi-automated Sequential Uncertainty Fitting (SUFI-2) calibration method within the SWAT Calibration and Uncertainty Procedures (SWAT-CUP) was used (Abbaspour et al., 2007). SWAT-CUP can use the SWAT outputs directly to perform calibration, validation, sensitivity, and uncertainty analyses, and visualize the results with high-quality graphics. The SUFI2 algorithm is the most commonly used method and it considers all sources of uncertainties; such as model structure, observation data error, and model input (Abbaspour et al., 2007).

The model was first calibrated and validated for streamflow measured at three streamflow gauging stations (Jouma and Dadaser-Celik, 2017). However, streamflow gauging stations were located in the higher elevations in the basin (Figure 4). Flows from streams are accumulated in the reservoirs and used for irrigation of the lands downstream. To be able to analyze irrigation and return flows correctly in the central parts of the basin, calibration and validation of the model for reservoir storage was necessary.

The observed monthly reservoir storage data for the 2000-2007 period were used to calibrate the model for Kovalı and Agcaaşar Reservoirs. Data from the 2008-2015 period were used for model validation.

To evaluate the model performance and compare the simulated versus the observed results, statistical measures, as well as graphical representations at a monthly time step, were used. Three objective functions were employed: Coefficient of determination (R^2), Nash–Sutcliffe efficiency (NSE) (Nash and Sutcliffe, 1970) and Kling-Gupta efficiency (KGE) (Gupta, 2009).

As shown in Table 3, for calibration, the parameters that can affect reservoir water balance and irrigation operation were selected.

Table 3. The parameters used for model calibration for reservoir storage

Parameters	Definition	Initial Range (min/max)		Calibrated value (Ağcaaşar)	Calibrated value (Kovalı)
v_EVRES.res	Lake evaporation coefficient	0	1	0.7865	0.0068
v_RES-K.res	Hydraulic conductivity of the reservoir bottom that controls the infiltration mm/hr	0	1	0.8135	0.0921
v_IRR_EFF.mgt	Irrigation efficiency	0	1	0.3885	0.266
v_AUTO-WSTRS.mgt	Water stress factor of cover/plant which triggers	0	1	0.1142	0.0625
v_GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0	5000	2983	42.3165

Results and Discussion

The SWAT model calibrated and validated previously for streamflow was used to simulate irrigation and reservoir storage.

As shown in Figure 5, reservoir storage (and irrigation water use) is variable at the Develi Basin as it is affected by climatic and antropogenic factors. Simulating the water storage at reservoirs for multiple years, where water accumulation and use patterns show seasonal and annual changes, is a major challenge. For Develi Basin lack of data pose another challenge. There was account of the frequencies and amounts of actual irrigation water use and there were uncertainities about reservoir operation.

In this study, calibration and validation were based on comparison of observed reservoir storage and simulated ones. The performance of the calibration/validation process was evaluated using R^2, NSE, KGE.

The model performance indicators during model calibration and validation were presented in Table 4. The graphical representation of the simulated and observed values were given in Figure 5.

Table4. Performance of model during calibration and validation

	Kovalı Reservoir			Ağcaaşar Reservoir		
	KGE	NSE	R^2	KGE	NSE	R^2
First, run		0.24	0.46		-1.60	0.46
Calibration	0.69	0.36	0.54	0.70	0.60	0.75
Validation	0.63	0.23	0.50	0.57	0.13	0.50

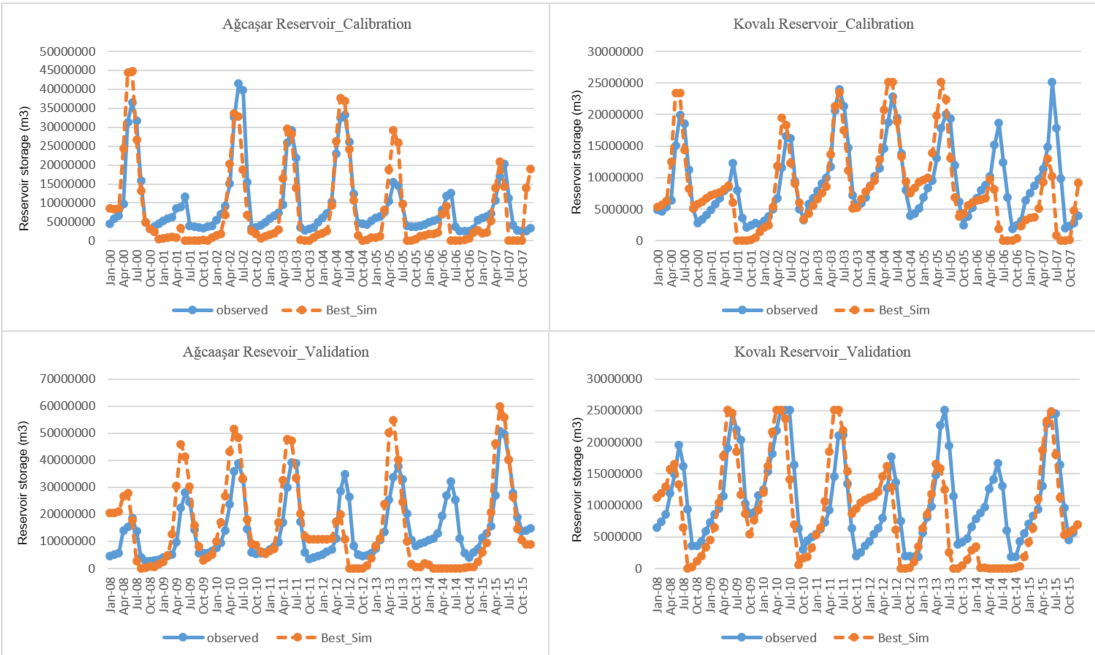

Figure 5. Simulated and observed monthly water storage at Ağcaaşar and Kovalı Reservoirs during calibration and validation processes

Results show that in terms of R^2 and KGE satisfactory results were obtained during calibration and validation. R^2 value was 0.75 for Ağcaaşar reservoir and 0.54 for Kovalı reservoir. The KGE value was 0.70 for Ağcaaşar reservoir and 0.69 for Kovalı reservoir that indicates that there is a strong relationship between measured and simulated reservoirs storages. However, the NSE values for the monthly calibration indicate relatively poor correspondence of measured values versus simulated values. In general, NSE is used for stream flow calibration and validation and it determines the similarity of the peaks in oberved and simulated values. NSE is sensitive measure to extreme stremflow values as is it evaluated based on the differences between the observed and simulated values where the differences are calculated as squared values (Legates and

McCabe 1999). In a basin such as Develi Basin where there is uncertainities in irrigation amounts, methods and sources, NSE values can also be acceptable.

Conclusions

This study contributes important insights into the efficacy of the Soil and Water Assessment Tool (SWAT) model for simulating reservoir storage. In this study, irrigation was simulated using the auto-irrigation function.

The SWAT model was successful in reproducing the reservoir storage in the two reservoirs in Develi Basin. The lack of information on reservoir management and agriculture management data availability affected the model performance. However, despite these limitations, the results were acceptable in terms of NSE, R^2, KGE.

With the calibrated and validated model, we plan to analyze the relationships between reservoir operation and water resources availability in the Develi Basin. We also plan to understand the effects of expected climatic changes on basin hydrology.

Acknowledgments

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