

Chapter 9

Swat Application for Water Balance Assessment of Koyna River Basin, Maharashtra, India



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Abstract Water resources management is very important for the sustainable growth of developing society as it is becoming a crucial resource in the present day. The knowledge of water balance and water yield of a river basin is an indispensable prerequisite in water resources management and sustainable development at basin level scale. The components of water balance are influenced by climate and physical characteristics of the catchment such as morphology, land use, and soil. Therefore, understanding the relationship between these physical parameters and hydrological components is necessary to assess the hydrologic response to climate and land cover variability in determining the water availability. Only after understanding the spatial and temporal variation and the interaction of these hydrologic components, one can scientifically formulate strategies for water conservation. Numerous integrated watershed models are available, but a choice of watershed development model depends upon the hydrologic components to be incorporated in the water balance. In this study, the Soil and Water Assessment Tool (SWAT), an integrated physically based distributed watershed model which uses a water balance equation for simulation of hydrology, has been used to analyze and quantify the water balance in the Koyna river basin, Maharashtra. The model uses DEM, land use, soil, and climate data. The watershed models partition rainfall into various hydrologic processes such as surface runoff, evapotranspiration, percolation, lateral flow, and base flow. with the constraint to account for all water entering, leaving, and being stored in a catchment. The model has been calibrated and validated for discharge at the outlet of the river basin. The calibration and validation efficiency has been tested by the coefficient of regression. Overall, SWAT demonstrated good performance in capturing the patterns and trends of the observed flow series. The model was found to produce a reliable estimate of aggregated monthly runoff which was demonstrated by Nash Sutcliffe; efficiency and coefficient of regression superior to 0.85 for both calibration and validation periods indicate a predictive ability of the model and suggest its appropriateness for

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estimation of water balance components and water yield in the study basin. Time series curves observed and simulated also showed very high similarity. Water balance components simulated by SWAT provided a baseline understanding of the hydrologic processes to deal with water management issues in the basin. The study suggests that the SWAT model could be a promising tool to predict water balance and water yield to support policies and decision-making for sustainable water management at the basin level.

9.1 Introduction

Water resources have become a critical element for socioeconomic development, especially in the arid and semi-arid regions. Water is an extremely essential element to sustain life and the increasing population is raising the demand for water. Availability of water is largely dependent on the rainfall distribution over an area, which again gets distributed into various components of interflow, surface runoff, evapotranspiration, etc. (Kundu et al. 2017; Wang et al. 2003). Water resources management is very important for the sustainable growth of developing society as it is becoming a crucial resource in the present day (Liu et al. 2008). Water resources management and hydrologic modeling studies are intrinsically related to the spatial processes of the hydrologic cycle. Developments in computer technology have revolutionized the study of hydrologic systems. Many computer models have been developed for hydrologic modeling and water resources management applications (Grassman et al. 2007). The knowledge of water balance and water yield of a river basin is an indispensable prerequisite in water resources management and sustainable development at basin level scale (Famiglietti and Rodell 2013).

The components of water balance are influenced by climate and physical characteristics of the catchment such as morphology, land use, and soil. Therefore, understanding the relationship between these physical parameters and hydrological components is necessary to assess the hydrologic response to climate and land cover variability in determining the water availability (White et al. 2011; Muttiah and Wurbs 2002; Arnold et al. 1998). Only after understanding the spatial and temporal variation and the interaction of these hydrologic components, one can scientifically formulate strategies for water conservation. Numerous integrated watershed models are available, but a choice of watershed development model depends upon the hydrologic components to be incorporated in the water balance. In this study, the Soil and Water Assessment Tool (SWAT), an integrated physically based distributed watershed model which uses a water balance equation for simulation of hydrology has been used to analyze and quantify the water balance in the Koyana river basin, Maharashtra.

9.2 Study Area

The Koyna River basin is a head-water basin on the east side of the main ridge of the Western Ghats, locally called the Sahyadri hill ranges, in the district of Satara, Maharashtra state, India (Fig. 9.1).

The gross storage capacity Koyna dam is of $2797.15 \times 106 \text{ m}^3$. The Koyna project is a multi-purpose project, but primarily designed as a hydro-electric project that supplies hydro-electric power to Maharashtra state, India with an installed capacity of 1920 MW. Koyna dam watershed has an elongated leaf shape, about 64 km in length and about 13 km in width with an area of 891.78 km^2 . The water spread area at full reservoir level is 115.36 km^2 which is about 13% of the total catchment area. Nearly 99% of the annual rainfall in this basin occurs during the south-west monsoon (June–October) and varies from 3000–5500 mm annually over the valley. The water released from the dam has been mainly utilized for agriculture and drinking purposes and simultaneously hydropower is generated during release (Naik et al. 2001).

Therefore, understanding the water balance is very important for studies on the operational management of reservoirs and river basins. Moreover, water balance studies provide an evaluation of an unknown water balance component from the difference between the known components (Dor et al. 2011).

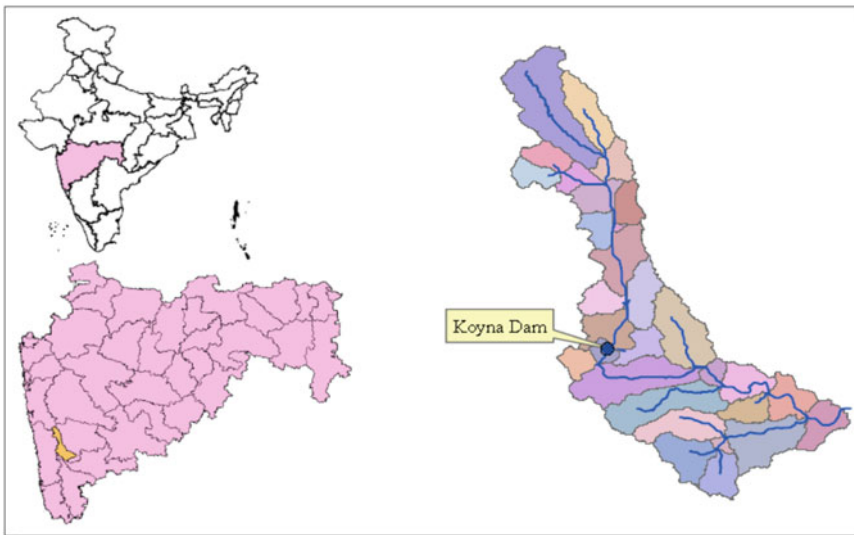


Fig. 9.1 Location of Koyna River Basin

9.3 Data

SWAT input data included elevation, soil, LULC, temperature, precipitation, and streamflow. These data were constructed using the Arc SWAT graphical user interface that runs in ArcGIS. Elevation data were obtained from the Digital Elevation Model (DEM) created using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data of Earth Observing System of United States. The LULC map that was used in the study was developed based on LANDSAT satellite images. The daily temperature and precipitation data were acquired from Indian Meteorological Department. The soil-related data were obtained from the FAO map and the daily streamflow data was collected at one gauge and discharge station from Central Water Commission. The gridded meteorological data used for hydro-meteorological parameters estimation was obtained from Global Weather Generated data (Figs. 9.2, 9.3, 9.4 and 9.5).

9.4 Methodology

The Soil and Water Assessment Tool (SWAT) was developed by Arnold et al. (1998) for the Agricultural Research Service (ARS), United States Department of Agriculture (USDA). SWAT model which is a physically based model was developed for application to large and complex watersheds over long periods of time. SWAT is a physically based model and hence it requires extensive physical parameters to represent the real hydrological processes in the catchment scale. From topography data, the watershed is divided into a number of sub-catchments. The use of sub-catchments in a simulation is particularly beneficial when different areas of the catchment are dominated by land uses or soils dissimilar enough in properties to impact hydrology. Every sub-catchment is then subdivided into Hydrologic Response Units (HRUs). Every HRU is a unique combination of land use, soil, and management practices in a sub-catchment. Input information for each sub-catchment is grouped into the following categories: climate; hydrologic response units or HRUs; groundwater; and the main channel or reach, draining the sub-catchment. The final result of the entire basin is then obtained at the main outlet.

9.5 Results and Discussion

In the practical application of hydrologic models, modelers often select a single model among the several choices that are assumed to best represent the hydrologic system (Zhang et al. 2009). Therefore, before calibrating the water balance and streamflow, we need to have a profound understanding of the actual watershed characteristics and

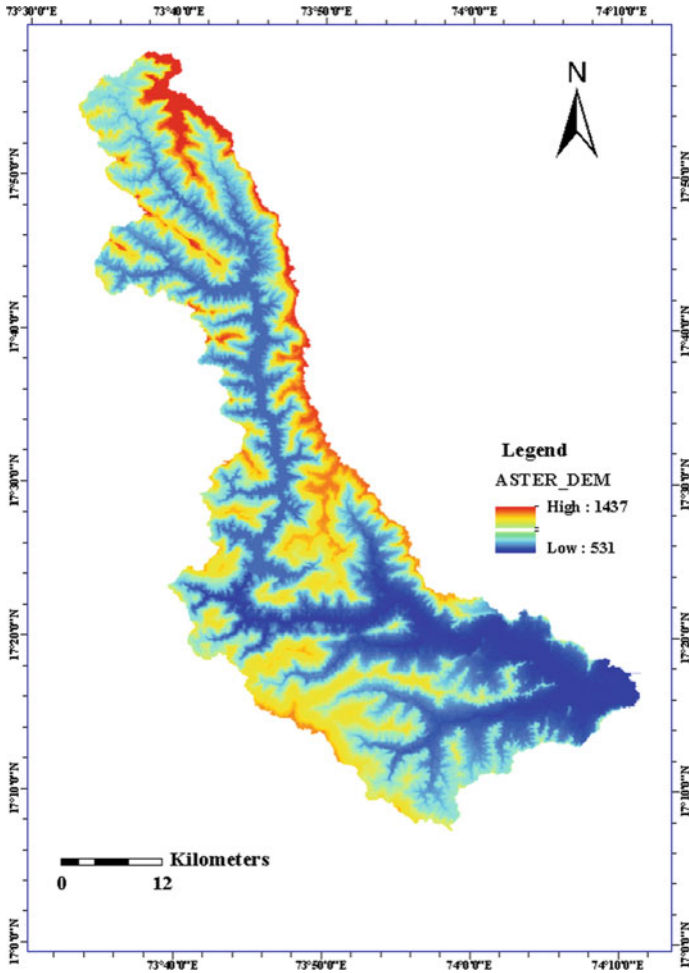


Fig. 9.2 Koyna Basin DEM

the information provided in previous SWAT literature (Neitsch et al. 2005) (Figs. 9.6 and 9.7).

In this study, the periods from 2001 to 2003, 2004 to 2010, and 2011 to 2013 were taken as warm-up period, calibration period, and validation period, respectively. The calibration carried out with the flow data from 2004 to 2010 shows the R^2 value of 0.84 and the validation shows R^2 value of 0.82 between the observed and the simulated flow. Validation is carried out with the flow data from 2011 to 2013. The accuracy assessment of the model has been carried out with the coefficient of determination (R^2) (Legates and McCabe 1999). According to Figs. 9.6 and 9.7, the curves of the observed and simulated monthly values of Warunji gauge and discharge matched well, and the evaluation coefficients of the simulated monthly discharge were very

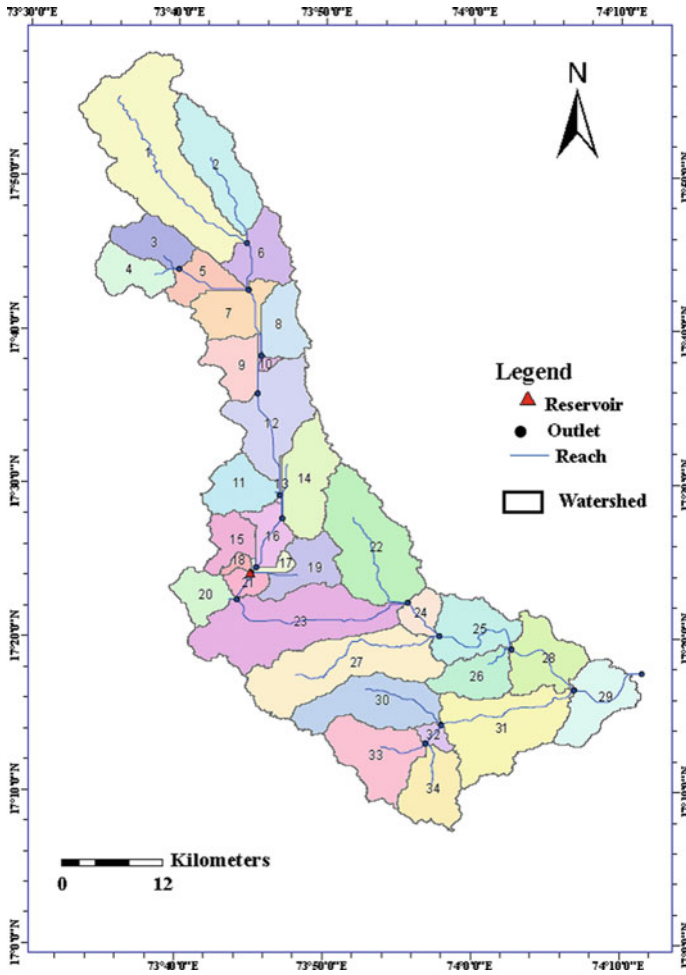


Fig. 9.3 Koyna River Sub-basins

good and listed in Table 9.1. In the validation process, the model was operated with input parameters set during the calibration process without any change and the results were compared to the remaining observational data to evaluate the model prediction. The monthly simulated and observed discharge of the Koyna River basin fitted well, which also could be indicated by the evaluation coefficients (Tables 9.1 and 9.2).

The input and output of water of the whole basin were quantified and the average monthly discharge was determined. On the monthly scale, considering the rainy and dry season, the related parameters were adjusted such as Cn2, Sol_Awc, Sol_K, and Alpha_Bf to calibrate the proportion of surface runoff, lateral flow, and baseflow to total discharge. Because precipitation controls the water balance, it is critical that the

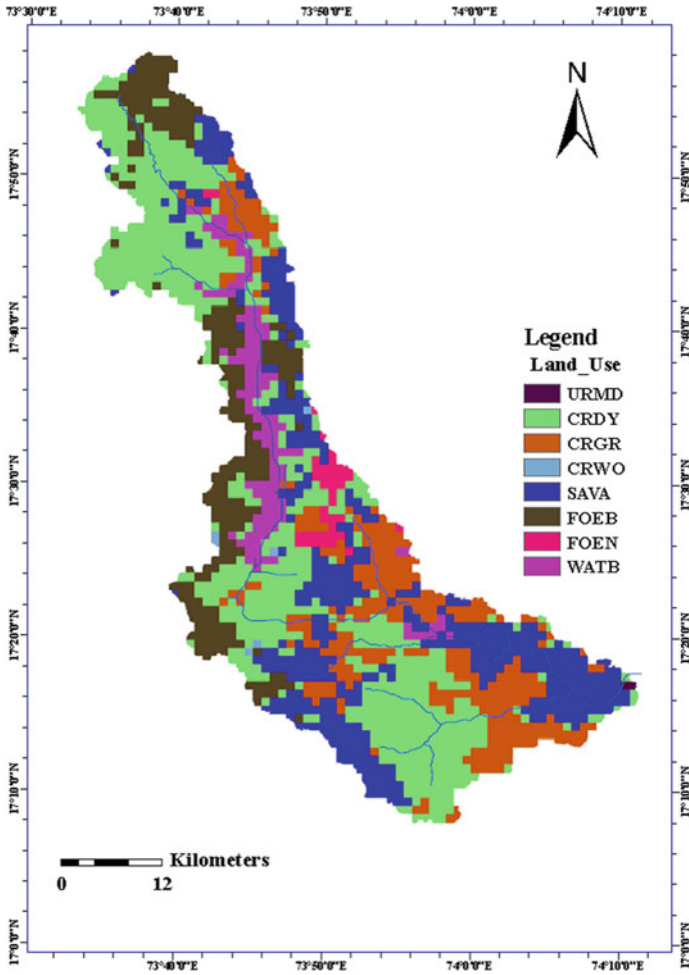


Fig. 9.4 LULC map

amount and distribution of precipitation in space and time are accurately simulated (Arnold et al. 1998).

The water balance was estimated based on the principle of conservation of mass (i.e., the water entering an area must leave the area or be stored within the area) and the annual partitioning of precipitation into ET and runoff, which is controlled by the temporal distribution of water supply (precipitation) and demand (ET) and is balanced by water storage in the soil.

Thus, the water balance can be expressed as follows:

$$R = P - ET + TWS$$

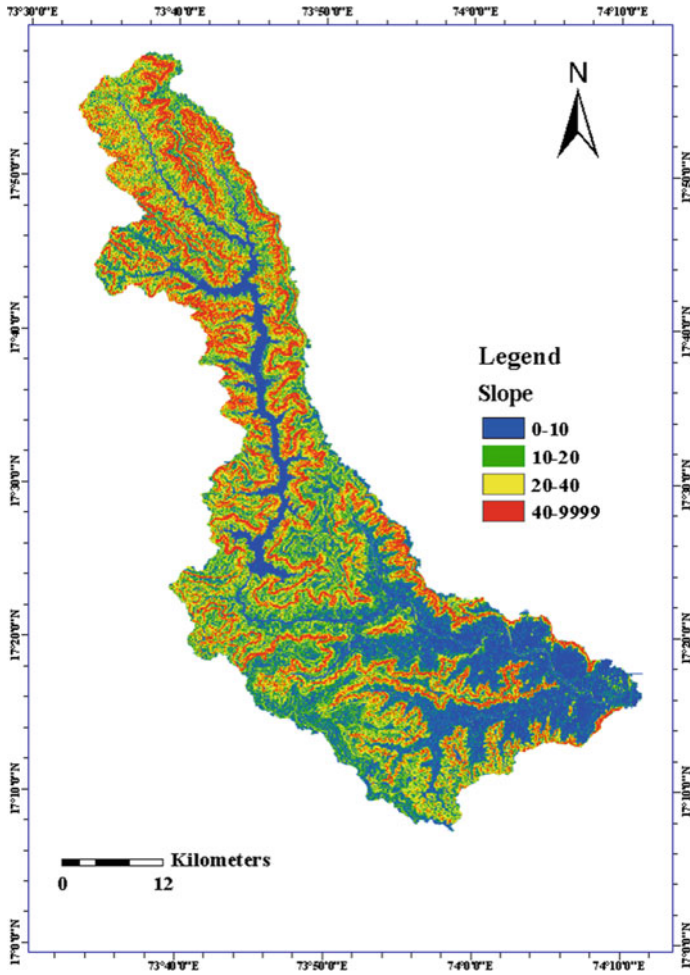


Fig. 9.5 Slope map

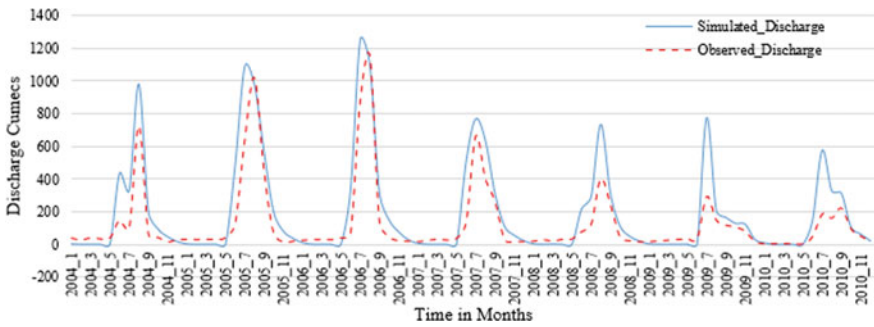


Fig. 9.6 Calibration for Discharge

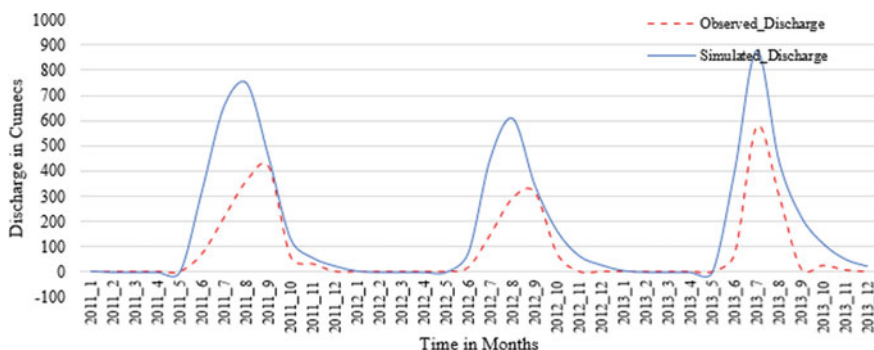


Fig. 9.7 Validation for Discharge

Table 9.1 Objective measures achieved by SWAT at Warunji

Parameters	Calibration	Validation
Coefficient of determination (R^2)	0.84	0.82

Table 9.2 Average monthly values of water balance components

Months	Rain (mm)	SURF Q (mm)	LAT Q (mm)	Water Yield (mm)	ET (mm)	PET (mm)
1	1.84	0.05	0.22	11.01	9.95	132.33
2	0.76	0.08	0.09	2.55	6.78	142.27
3	2.85	0.30	0.13	2.05	44.30	185.90
4	16.67	0.60	0.62	2.38	24.74	187.08
5	23.90	1.10	1.29	3.27	20.26	201.97
6	540.86	287.19	18.51	307.84	54.77	103.37
7	1,170.99	852.78	39.88	940.71	37.06	43.36
8	838.66	563.45	42.02	740.44	37.82	48.25
9	308.60	151.30	24.21	334.95	54.61	100.70
10	116.87	45.67	10.31	181.51	47.14	127.96
11	30.98	6.84	2.62	81.40	29.18	130.74
12	6.45	1.40	0.82	37.47	16.35	129.36

where R is river runoff, P is precipitation, ET is evapotranspiration, and TWS is total water storage (vegetation, surface detention, soil, and groundwater).

The estimated values from the models of all of the components should be reasonably accurate to determine the water availability in the different components of the hydrological cycle. In reality, there are always discrepancies between the observed values and model predictions due to measurement errors, inadequate data capture networks, and the difficulty of representing real-life complex spatial heterogeneity in

the model. Observed precipitation data that had been adequately checked for continuity and consistency were used in the simulations. River runoff was estimated using the model and compared to observed runoff. The groundwater and surface water withdrawals for consumptive and non-consumptive uses are not considered in this study. Based on the measured precipitation data and observed PET, the percentage runoff generation (runoff fraction) and conversion of PET to ET were estimated.

9.6 Summary and Conclusions

Based on the available geospatial and hydro-meteorological data, a SWAT model was developed for the Koyna River basin. The performance indicators R^2 values in the model showed good performance for runoff simulation. There was close agreement between the monthly observed and calibrated runoff at the river basin scale, and the models accurately captured the flow patterns for most seasons. The calibration and validation procedures estimated water balance components and monthly streamflow that generally showed “satisfactory” model performance, though the model underestimated some peak flow events, including the low flows of a certain period. At the same time, the model simulated some peak flows that happened during intensive rainfall while the corresponding observed flows showed low values.

The calibration efficiency has been tested by the coefficient of regression. Overall, SWAT demonstrated good performance in capturing the patterns and trends of the observed flow series. The model was found to produce a reliable estimate of aggregated monthly runoff which was demonstrated by the coefficient of regression superior to 0.80 for both calibration and validation periods which indicate a predictive ability of the model and suggest its appropriateness for estimation of water balance components and water yield in the study basin. Time series curves observed and simulated also showed very high similarity. Water balance components simulated by SWAT provided a baseline understanding of the hydrologic processes to deal with water management issues in the basin. The study suggests that the SWAT model could be a promising tool to predict water balance and water yield to support policies and decision-making for sustainable water management at the basin level. Therefore, understanding the water balance will be useful for studies on the operational management of reservoirs and river basins.

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