Chapter 12
Hydrological Parameter Estimation for Water Balance Study Using SWAT Model

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Abstract In recent years water demad has been increased due to a large population base, continued population growth and climate change uncertainties. To deal with issues of water management, quantification and estimation of different hydrological components are important. This study investigates hydrological parameter estimations using a semi-distributed physical-based model, the Soil and Water Assessment Tool (SWAT). The model was tested on a monthly basis for simulating the rate of streamflow, using rainfall and other climatic parameters in the basin. The watershed boundaries, sub-basins, slope, soil and land use maps, and streams were generated using Geographic Information System (GIS). Sensitivity of parameters was checked by p-value and t-stat. To check uncertainty in hydrological parameter, model was calibrated and validated for streamflow using the SWAT-Calibration and Uncertainty Program (SWAT-CUP). Model efficiency for calibration and validation was checked by different statistical parameters. Model uncertainty was analyzed by P factor and R factor. Results indicated R^2, NSE, and PBIAS were 0.62, 0.62, and 3.92, respectively, for the calibration period and also it was satisfactory with performance indicators R^2, NSE, and PBIAS as 0.64, 0.64, and 11.4 for the validation period. The study would be very useful for water resources community to take managerial actions in the watershed area.

Keywords Water balance · SWAT · SWAT-CUP · Sensitivity analysis · Calibration · Validation

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12.1   Introduction

Water is an important natural resource, which needs proper management for the survival of life on the earth, the improper and unmanaged use of water in India has led to decreasing groundwater resources, different land use/land cover planning and management provides the basis for better understanding of ecosystem to take a required decision and to make the decision for policymakers (Gupta et al. 1999). Water balance study is the application of the principle of mass conservation (Ghandhari and Alavi Moghaddam 2011), as there are different hydrological component involved in water budget analysis it is more practical to estimate hydrological component by hydrological modeling (Arnold and Allen 1996) through which water for the different hydrological component is quantified. There are various computer-based hydrological model available which are useful for watershed management (Strauch et al. 2012). To access the influence of climate change, topography and land use hydrologic models are very effective (Patel and Srivastava 2013). There are numerous physical-based watershed models available, among them the SWAT model developed by USDA has been used in this study. The Soil and Water Assessment Tool (SWAT) was developed to predict the effect of managerial practices on water quality, sediment yield, and pollution loading in watershed (Arnold et al. 1998), it has been applied many times in the study of water budget caused by changing climate (Leta et al. 2017; Cuceloglu et al. 2017; Zhou et al. 2011). SWAT model has also been used to study hydrological element in the agricultural area (Cao et al. 2018). Different input parameters were generated in Geographical Information System (GIS), which is a computer-based program which is used to map, analyze, integrate, transform, and manage the spatial or geographic data to solve complex planning and management operations. SWAT-Calibration and Uncertainty Program (SWAT-CUP) is a semi-automated method that has been used for sensitivity analysis, calibration, and validation of the model (Arnold et al. 2012). This model was used for calibration validation and uncertainty analysis of the model.

A good management practice with efficient planning may help for the survival of our water resources, for that computation of different hydrological components is important, hence water balance study has been performed, Andhiyarkore watershed of Chhattisgarh state was selected for the study. About 80% of the watershed area belongs to Kawardha district, which is facing problem of the water scarcity and was declared as a drought-prone area in recent years.

12.2   Materials and Method

12.2.1   Description of the Study Area

The study area is a part of the Sheonath river basin, which tributary of the Mahanadi river basin in Chhattisgarh state, it covers an area of 2268.42 km^2, it extends from
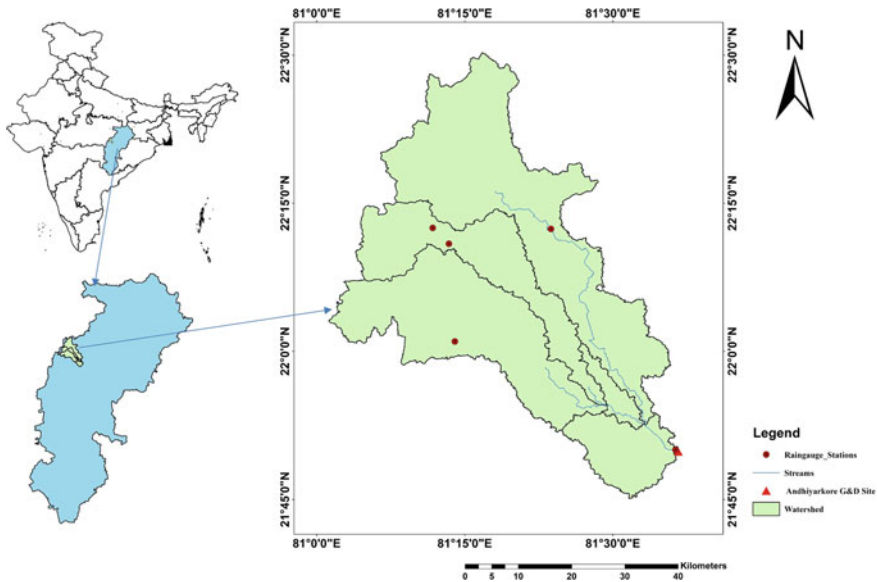
Fig. 12.1 Location of Andhiyarkore watershed in India, Chhattisgarh

21° 45′ 5.83″ N to 22° 30′ 14.73″ N latitude and 81° 1′ 14.12″ E to 81° 36′ 38.87″ E longitude as shown in Fig. 12.1, Andhiyarkore is a Gauge and discharge measuring station of Central Water Commission (CWC), situated in the Bemetara district of Chhattisgarh state, which was used as an outlet for the study. The watershed covers parts of Kawardha, Bemetara, and Mungeli districts of Chhattisgarh state. The area receives an average annual rainfall of 895.46 mm. The mean annual temperature in the area is 33 °C, the climate in the area is dry sub-humid, the altitude varies from 224 to 979 m above MSL. There are mostly agricultural and forest area. In recent years, majority of the districts in Chhattisgarh state has been declared as drought-affected areas. There are 21 districts among 27 districts of Chhattisgarh facing the drought problem. Figure 12.1 is representing location map for the study area.

12.2.2   Data Used

Digital elevation model, Land use—land cover, soil, and meteorological data such as rainfall, temperature, wind speed, relative humidity, and observed discharge datasets were collected from different sources and used for hydrological modeling in SWAT. Details of data sets are listed in Table 12.1.

Table 12.1 Description of spatial datasets used for Andhiyarkore basin

| Data	Description	Source
DEM	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) of 30 m resolution	NASA and Japan's Ministry of Economy, Trade, and Industry (METI)
LULC	Scale 1:50,000	Bhuvan, ISRO (2011–12)
Soil	Scale 1:5,000,000	Food and Agriculture Organization (FAO), U.N.
Metrologic data	Daily data	Precipitation—State Data Center, Raipur, C.G. (1985–2013) Wind speed, relative humidity, temperature and solar radiation—CFSR (1985–2013)
Discharge	Daily data	Central Water Commission, Bhubaneswar, Orissa (1985–2013)

12.2.2.1 Digital Elevation Model

DEM is a three-dimensional representation of the terrain, which represents elevations of the surface. The Digital Elevation Model (DEM) helps to understand catchment response, it helps to understand flow behavior and flow pattern in the watershed. In this study, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) of 30 m resolution, released by NASA and Japan's Ministry of Economy, Trade, and Industry (METI) has been used to analyze topography and to delineate watershed (Fig. 12.2). Watershed was divided into 5 number of sub-basins, and 40 number of Hydrological Response Units (HRUs). Percentage Slope was calculated using DEM, it was classified into four classes as shown in Fig. 12.3.

12.2.2.2 Land Cover/Land Use

For hydrological study land use play an important role, land use data shows that how much region is covered by agricultural practice, forest, urbanization, etc., which is important to find runoff from that area. LULC data is downloaded from BHUVAN (LISS-III), National Remote Sensing Centre (NRSC). Most of the watershed is an agricultural and forest area (Fig. 12.4; Table 12.2).

Soil data are collected from the Food and Agriculture Organization of United Nations. Data is provided at 10 km spatial resolution soil database is a 30 arc-second raster database contained within 1:5,000,000 scale. Attribute data included with raster maps are different soil parameters like organic carbon, PH, water storage, soil,
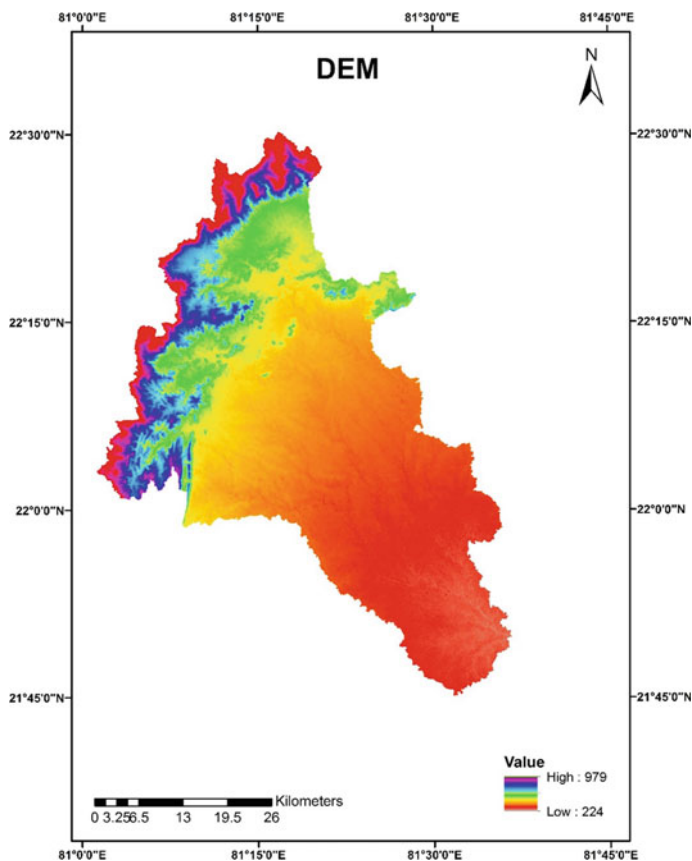
Fig. 12.2 Digital Elevation Model of study area (ASTER Global Digital Elevation Model)

and clay fraction, etc. 3 groups of soil fall in this area, namely I-Bc-Lc-3714, I-bc-3735, and Lf92-1a-3791, in which basic variant is chromic vertisols and Lithosols (Fig. 12.5).

12.2.2.3   Hydrometeorological Data

Daily rainfall data of six stations are used from 1985 to 2013 for hydrological modeling in SWAT many hydrological parameters as rainfall, temperature, wind speed, relative humidity, and solar radiation, are used, using these data weather generator database is prepared and used. Daily rainfall data of 6 stations are used from 1985 to 2013 which is collected from the state data center, Department of Water Resources, Raipur (CG) and other hydrological data are downloaded from the climate forecasting system reanalysis (CFSR) database which is simulated by National Centers for Environmental Prediction (NCEP) and Texas A & M University, United States.
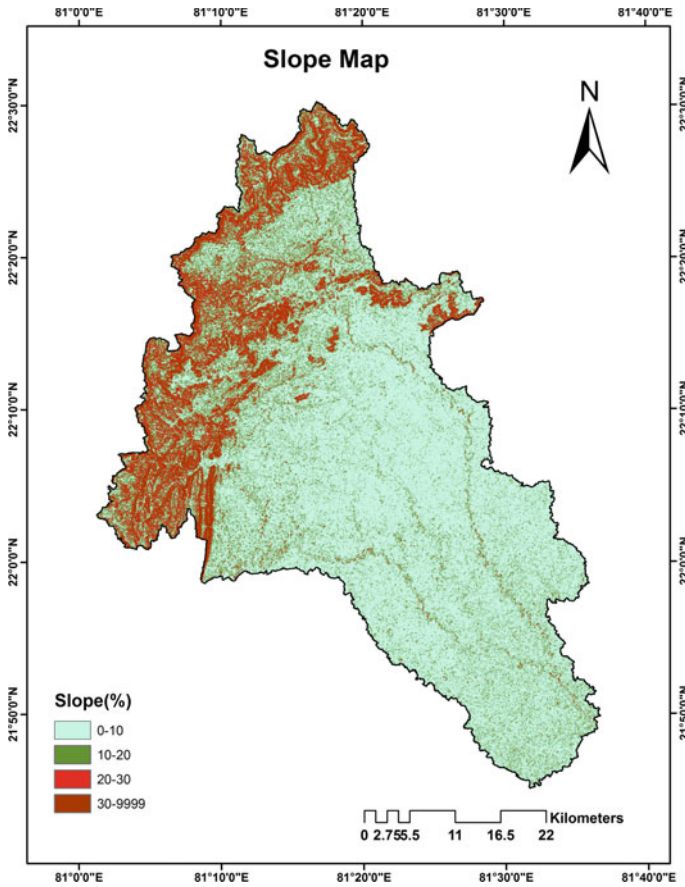
Fig. 12.3 Percentage slope map of study area (ArcSWAT)

No of CFSR stations present in the Andhiyarkore watershed is 4. Daily discharge data (1985–2013) were collected from the Central Water Commission, Bhubaneswar, Orissa for Andhiyarkore gauging station.

12.2.3 SWAT Model Description

Soil and water assessment tool (SWAT) is a physical-based, basin-scale continuous model and can be used to predict agricultural land management impacts on the hydrological regime of a watershed through simulation of variable soil, land use, and management conditions over long periods (Rahman et al. 2013). SWAT is a useful Geographic Information System (GIS) based decision support tool which has been used successfully for many watersheds around the world (Addis et al. 2016).
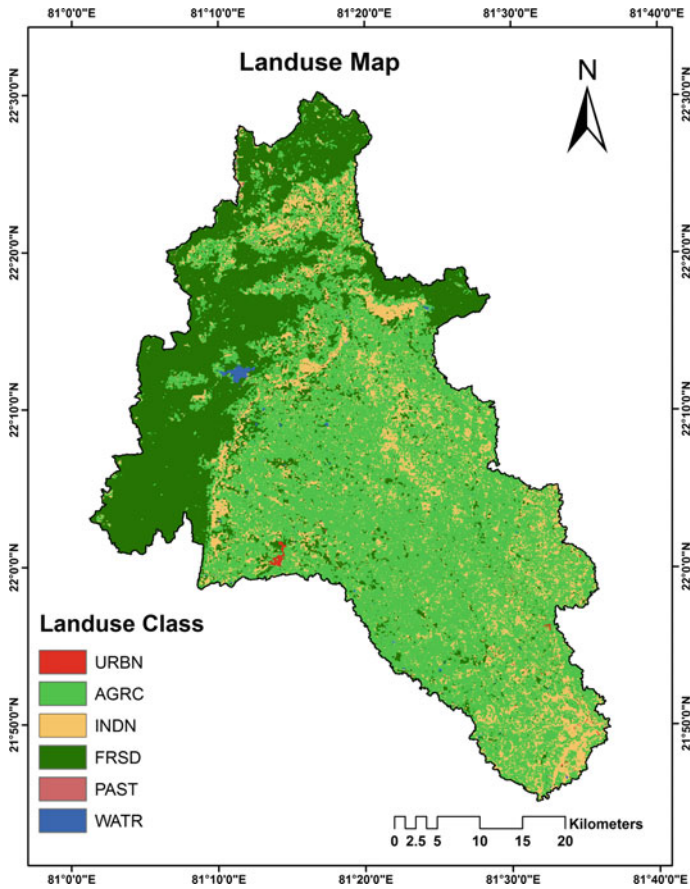
Fig. 12.4 Land use map of study area (Bhuvan, ISRO (2011–12))

Table 12.2 Land use/land cover (LULC) % area distribution (Bhuvan, ISRO (2011–12))

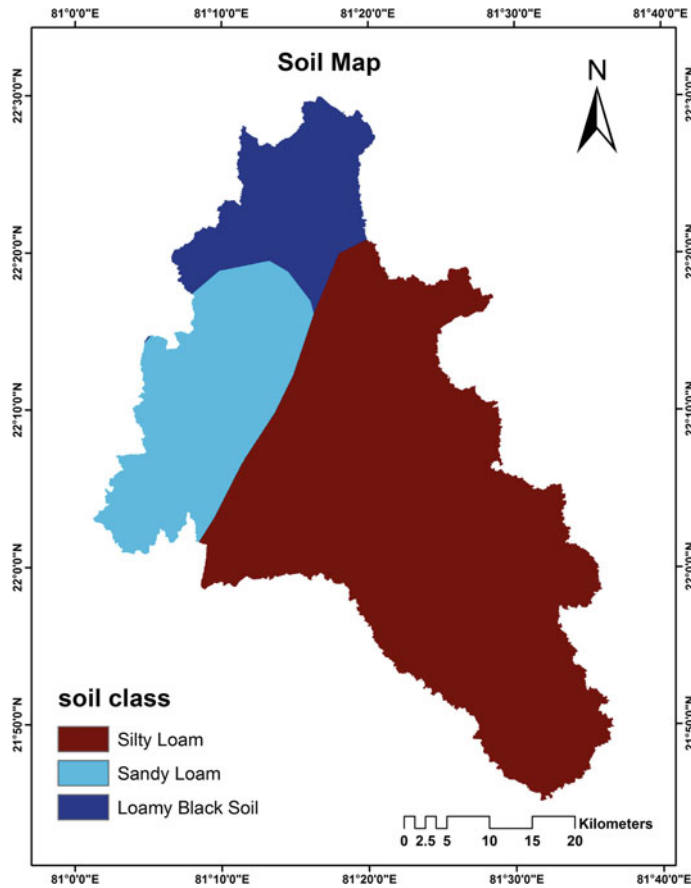| S. No.	LULC type	Percentage of total area
1	Urban area	0.13
2	Agricultural area	51.89
3	Grass	16.47
4	Water	0.33
5	Pasture	0.12
6	Deciduous forest	31.06

Fig. 12.5 Soil map of study area (Food and Agriculture Organization (FAO), U.N.)

In the current study DEM was used for watershed delineation and also to draw drainage patterns of the land. Watershed was divided into five sub-basins. SWAT divides hydrology into two phases, the first phase land phase includes all vertical exchanges such as evaporation, infiltration, transpiration, percolation, and horizontal exchange as horizontal hypodermic flows. The watershed was divided into sub-basins which were further divided into Hydrologic Response Units (HRUs) according to similar soil, land use, and slope (Arnold et al. 1998). HRU is the smallest unit in the modeling. SWAT model simulates hydrological parameters for each HRU using the water balance equation. The water balance equation is as follows (Kundu et al. 2017)

$$\mathrm{SW}_t = \mathrm{SW}_o + \sum_{t=1}^{t}(R_t - Q_t - \mathrm{ET}_t - P_t - \mathrm{QR}_t) \qquad (12.1)$$

To calculate SW_t and SW_o = soil water content at the beginning and end of the time period for which water balance equation is used (mm), R_t = Rainfall for that day (mm), Q_t = Surface Runoff for the day (mm), ET_t = Evapotranspiration on day (mm), P_t = Percolation on the day (mm), QR_t = Lateral flow on the day (mm).

SWAT default method to calculate surface runoff is Soil Conservation Service Curve Number (SCS-CN) method has been used for this study. Potential evapotranspiration has been calculated by Hargreaves method. SWAT provides two methods for estimating runoff into the river system: the variable storage method developed by Williams (1969) and the method developed by Muskingum method by McCarthy (1938). In this study, the Muskingum method was chosen, which is the most commonly used routing mechanism in the literature.

12.2.4   Calibration and Uncertainty Analysis

SUFI-2 Algorithm in SWAT-CUP has been used for model calibration and uncertainty analysis SWAT-CUP is specially developed by Abbaspour et al. (2007) to interface with the SWAT model (Abbaspour et al. 2007), it is capable of analyzing a large number of parameters. t-test and p-value are used to check the sensitivity of parameters. The higher the absolute value of t-stat and the smaller the value of p-value, the more sensitive is the parameter (Abbaspour et al. 2007). For calibration and validation semi-automated method SUFI-2 algorithm in SWAT-CUP was used (Abbaspour 2013). The model was calibrated for streamflow at one discharge gauging station Andhiyarkore, of Central Water Commission. Model calibration was performed for the year 1988–2008 (21 years) and validation for the year 2009–2013 (5 years).

12.2.5   Performance Indices

The model performance for calibration and validation is checked by various statistical parameters p factor, r factor, Standard deviation, NSE, R^2, and PBIAS. Formulations to find these indices are described below

- Bias determination

$$PBIAS = 100 \times \frac{\sum_{i=1}^{n}(X_m - X_s)_i}{\sum_{i=1}^{n} X_{m,i}} \tag{12.2}$$

- Coefficient of determination

$$R^2 = \frac{\left[\sum_i \left(X_{m,i} - \overline{X}_m\right)\left(X_{s,i} - \overline{X}_s\right)\right]^2}{\sum_i \left(X_{m,i} - \overline{X}_m\right)^2 \sum_i \left(X_{s,i} - \overline{X}_s\right)^2} \tag{12.3}$$

- Nash Sutcliff efficiency

$$\text{NSE} = 1 - \frac{\sum_i (X_m - X_s)_i^2}{\sum_i \left(X_{m,i} - \overline{X}_m \right)^2} \tag{12.4}$$

where,

X = Variable value,

m and s = Measured and Simulated values,

i = ith number of measured value and bar shows the average value.

12.3 Results and Discussions

12.3.1 SWAT Model Calibration

SWAT is a physically based semi-distributed model, calibration of SWAT can be performed for gauged watersheds (Arnold and Allen 1996). The monthly flow rate at Andhiyarkore gauge and discharge station of CWC Bhubaneshwar was collected for the period 1988–2009 were used for model calibration. To achieve a certain level of model performance, calibration is important. Andhiyarkore was selected as an outlet and was taken for consideration to assign parameters of sub-basins. Rainfall data for six rain gauge stations were used and a rainfall data file was prepared. The weather generator database was generated using all meteorological data as was used as an input for SWAT model simulation. Priestley–Tayler's method was used to compute Evapotranspiration. SWAT default SCS-CN method was used for the estimation of Runoff.

12.3.1.1 Simulation of Streamflow Rate Using Pre-calibrated ArcSWAT Model

Initially, pre-calibrated ArcSWAT outputs were compared with observed discharge at Andhiyarkore station. The hydrograph shows that model was overpredicting values of streamflow. Results indicate that model performance is not satisfactory for pre-calibration run and adequate calibration is required (Fig. 12.6).

12.3.1.2 Parameters Used for Model Calibration

Sensitivity analysis was performed for calibration and validation of the model on monthly time steps. SWAT-CUP model was used for sensitivity analysis. Many parameters affect the performance of watershed sensitivity analysis is performed for 13 parameters, which are selected according to the objective function of streamflow
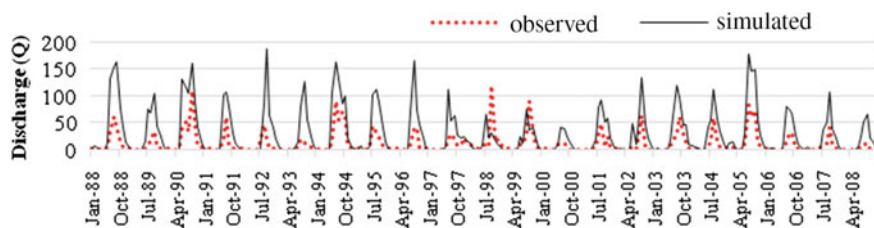
Fig. 12.6 Graphical comparison of observed and simulated monthly flow before calibration of model for calibration period (1988–2008)

Table 12.3 Results of sensitivity analysis (SWAT-CUP)

Parameters	Description	P-value	t-stat	Rank
CN2	Curve number for moisture condition 2	0	32.69	1
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	0	11.07	2
GW_DELAY	Groundwater delay	0.01	2.42	3
SURLAG	Surface runoff lag time	0.16	1.40	4
SLSUBBSN	Average slope length	0.24	1.18	5
ALPHA_BF	Baseflow alpha factor	0.43	−0.78	6
SOL_AWC	Available water capacity of the soil layer	0.44	0.77	7
SOL_K	Saturated hydraulic conductivity	0.46	−0.76	8
ESCO	Soil evaporation compensation factor	0.56	0.58	9
SOL_BD	Moist bulk density	0.61	0.51	10
CH_K2	Effective hydraulic conductivity in main channel alluvium	0.66	0.44	11
GW_REVAP	Groundwater "revap" coefficient	0.80	−0.26	12
HRU_SLP	Average slope steepness	0.98	−0.02	13

measurement sensitivity of the model is checked by p-value and t-stat, the parameters are more sensitive for larger t-stat values. P-values are used to determine the significance of the sensitivity where the parameter becomes significant if the p-values is close to zero (Khalid et al. 2016). CN2, GWQMN, and GW_DELAY were found the most sensitive parameters for the watershed (Table 12.3).

12.3.1.3　Simulation of Monthly Streamflow Rate

ArcSWAT model was calibrated against monthly streamflow at Andhiyarkore gauging station for years 1988–2013 with consideration of 3 years (1985–87) as a warm up period. P-factor and R factor were found 0.65 and 0.43, respectively, for the calibrated model. It can be observed in Fig. 12.7. The time to peak for observed
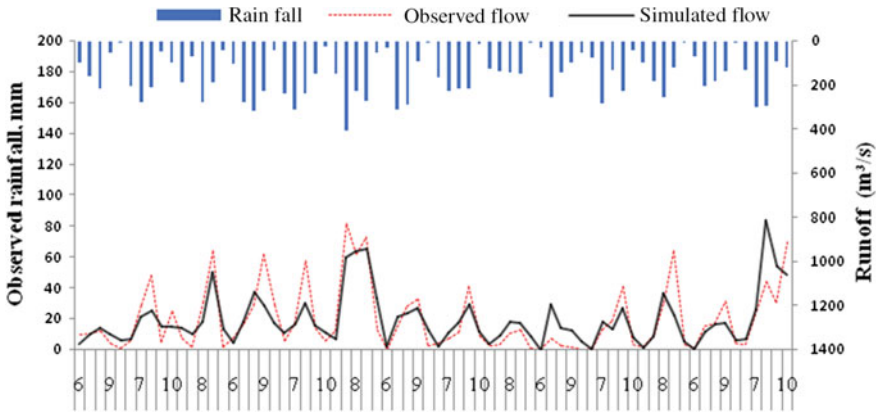
Fig. 12.7 Graphical comparison of observed and simulated discharge with rainfall

and simulated flow matches well with peaks of rainfall in the watershed. Figure 12.8 is representing a scattered plot of observed flow and simulated flow for the watershed, with a coefficient of correlation as 0.62.

Model performance for calibration was checked by other statistical parameters, and it was found as standard deviation, coefficient of correlation (R^2), Nash–Sutcliffe efficiency (NSE), index of agreement, and (d) and percentage of bias (PBIAS) summary of statistics are tabulated in Table 12.4, model performance was found good with R^2 0.62, NSE 0.62, PBIAS 3.92, and index of agreement as 0.991.
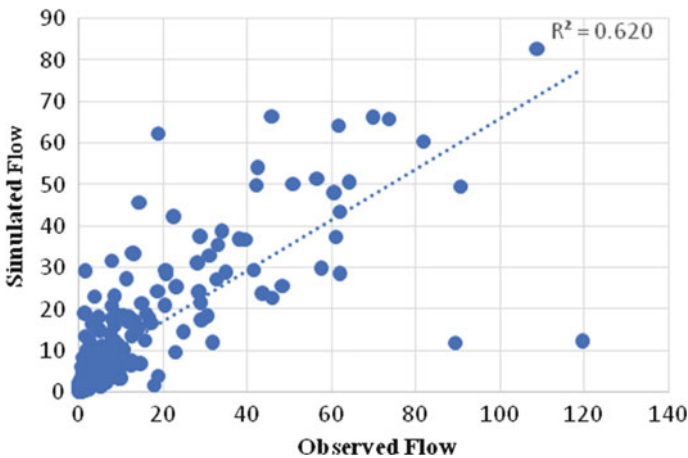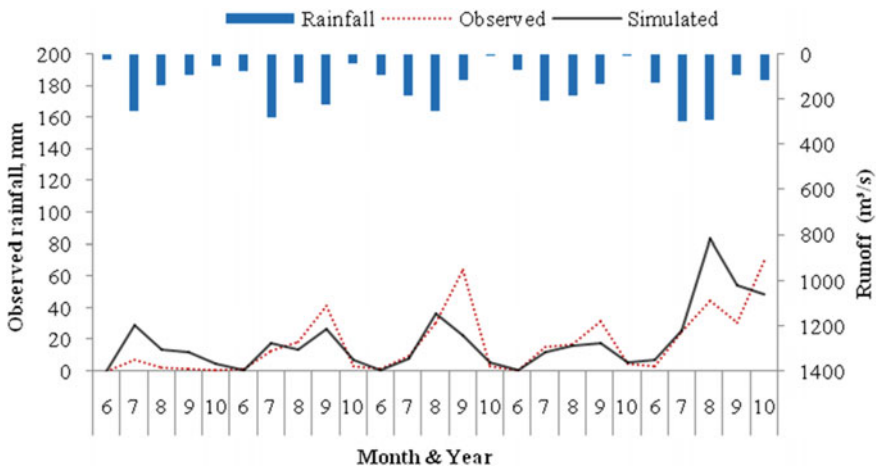

Fig. 12.8 Scattered plot of observed and simulated monthly streamflow rate for model calibration period (1988–2008)

Table 12.4 Summary of statistics for observed and simulated streamflow for calibration and validation period

	Pre-calibrated		Calibrated		Validated	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
Count	252	252	252	252	60	60
Mean (m³/s)	11.49	30.27	11.49	11.94	8.29	9.04
Maximum (m³/s)	119.53	188	119.53	82.68	69.73	83.89
SD	19.74	43.23	19.74	15.32	15.34	15.42
R^2	0.60		0.62		0.64	
NSE	−2.3		0.62		0.65	
d	0.927		0.991		0.90	
PBIAS	163.31		3.92		11.4	
RSR	1.56		0.45		0.54	

12.3.2 Model Validation

After calibrating the model, validation of the model has been performed for five years (2009–2013). Validation results show that the modeled monthly flow of stream matches well with observed stream flows. Figure 12.9 is representing the relation between the peak event of modeled and observed streamflow with rainfall, it matches well. Magnitude of the simulated monthly streamflow rate was lower for the years 2010, 2011, and 2012 and higher for the years 2009 and 2013.

Fig. 12.9 Graphical comparison of observed and simulated monthly stream flow rate for model validation (2009–2013)
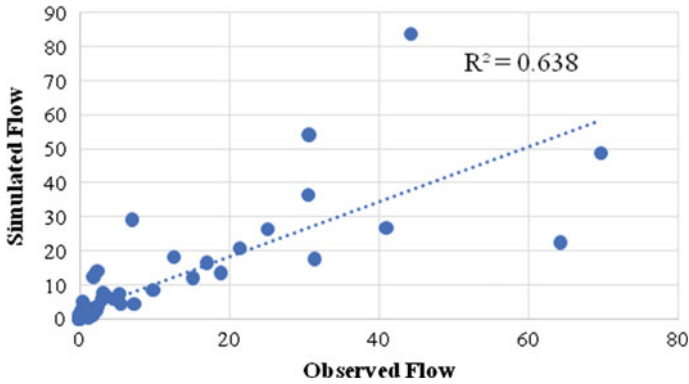
Fig. 12.10 Scattered plot of Simulated and observed monthly flow during validation period (2009–2013)

Figure 12.10 is representing a scattered plot between observed and simulated streamflow for the validation period, they show good co-relation with the coefficient of variation as 0.64, NSE 0.65, and PBIAS 11.4 with the index of agreement as 0.9. Other statistics for the validation period are listed in Table 12.4.

12.3.3 Evaluation of Model Performance

Model performance in calibration and validation has been tabulated in Table 12.4 which is representing a summary of all statistical parameters obtained. Moriasi et al. (2007) have given criteria for model evaluation for streamflow on monthly time steps, which is summarized in Table 12.5.

Model performance was found very good while analyzing PBIAS and RSR for model calibration, it was found good for PBIAS and RSR for model validation. While analyzing NSE model behavior was found satisfactory for calibration and good for validation.

Table 12.5 General performance rating for monthly time step (Moriasi et al. 2007)

Model performance	RSR	NSE	PBIAS
Very good	0 < RSR < 0.5	NSE > 0.75	PBIAS < ±10
Good	0.5 < RSR < 0.6	0.65 < NSE < 0.75	±10 < PBIAS < ±15
Satisfactory	0.6 < RSR < 0.7	0.50 < NSE < 0.65	±15 < PBIAS < ±25
Unsatisfactory	RSR > 0.7	NSE < 0.50	PBIAS > ±25

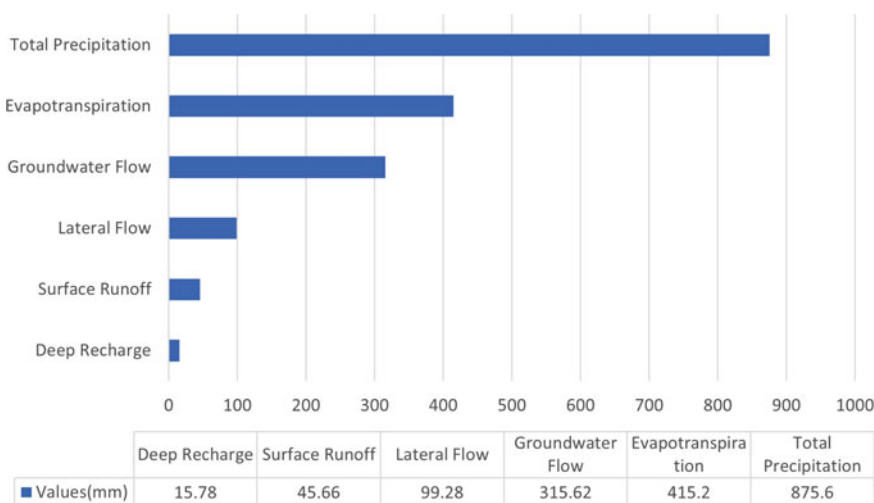**Table 12.6** Parameters representing uncertainty associated with the model prediction

| Parameters	After calibration	Validation
P factor	0.65	0.62
R factor	0.43	0.44

12.3.4   Uncertainty Analysis

There were total 6 iterations of SUFI-2 algorithm with 500 number of simulations for each iteration. *P* factor and *R* factor are important to analyze uncertainty for the model prediction, Table 12.5 represent parameters which represent uncertainty associated with model prediction using *P* factor and *R* factor. *P* factor was found 0.65 and *R* factor was found 0.43 for the calibrated model. During validation, *P* factor was 0.62 and *R* factor was 0.44. It is observed that *p*-value closer to 1 and *R* factor closer to 0 gives good relation between observed and simulated model result (Bekele and Nicklow 2007). It is observed that uncertainty is not very high in model prediction (Table 12.6).

12.3.5   Hydrological Parameter Estimation

Calibration ensures that good correlation exists between observed and model-predicted flow, it also ensures that hydrological parameters associated with water budget are also in a reasonable range. Figure 12.11 shows the average annual value of all hydrological elements obtained from the calibrated model. It is observed that

	Deep Recharge	Surface Runoff	Lateral Flow	Groundwater Flow	Evapotranspiration	Total Precipitation
■ Values(mm)	15.78	45.66	99.28	315.62	415.2	875.6

Fig. 12.11 Average annual values of hydrological elements in mm for period 1988–2013

Fig. 12.12 Percentage of
hydrological component
relative to precipitation
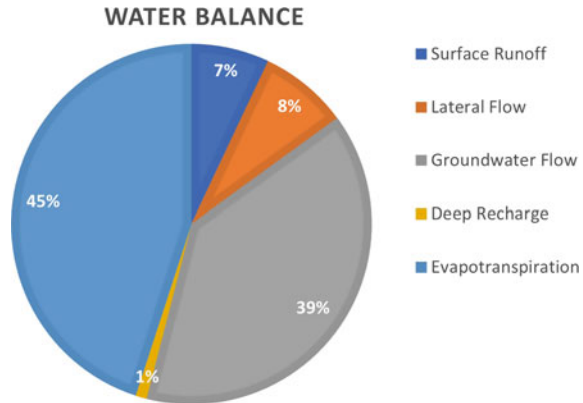
the average annual rainfall in the area was 875.6 mm. Figure 12.12 is representing
the percentage distribution of all hydrological components. It is can be observed
that a major portion of precipitation is distributed to evapotranspiration (45%) and
Groundwater Flow (39%), whereas there is very least amount of water contributing
to deep recharge and surface runoff.

12.4   Conclusion

The present study used the SWAT model to successfully simulate streamflow on a
monthly scale for the Andhiyarkore watershed. All statistical parameters indicate
the model was satisfactory calibrated and validated. *R* factor and *P* factor were
satisfactory which indicates less uncertainty was associated with model simulation.

By analyzing twenty years model output data annual average contribution to
different hydrological parameters was quantified. Evapotranspiration, groundwater
flow, Lateral flow, surface runoff, and deep recharge were found 415.2 mm, 315.2 mm,
99.28 mm, 45.66 mm, and 18.78 mm, respectively out of annual average precipitation
of 875.6 mm. It is observed that a major amount of water is contributed to evapo-
transpiration and groundwater flow as most of the part of catchment is agricultural
land and forest area. These results for hydrological parameter estimation could be
valuable for water resources management of the Andhiyarkore watershed.

References

Abbaspour KC (2013) Swat-cup 2012. In: SWAT calibration and uncertainty program—a user manual

Abbaspour KC, Vejdani M, Haghighat S, Yang J (2007) SWAT-CUP calibration and uncertainty programs for SWAT. In: MODSIM 2007 international congress on modelling and simulation, modelling and simulation society of Australia and New Zealand, pp 1596–1602

Addis HK, Strohmeier S, Ziadat F, Melaku ND, Klik A (2016) Modeling streamflow and sediment using SWAT in Ethiopian Highlands. Int J Agric Biol Eng 9(5):51–66

Arnold JG, Allen PM (1996) Estimating hydrologic budgets for three Illinois watersheds. J Hydrol 176(1–4):57–77

Arnold JG, Srinivasan R, Muttiah RS, Williams JR (1998) Large area hydrologic modeling and assessment part I: model development 1. JAWRA J Am Water Resour Assoc 34(1):73–89

Arnold JG, Moriasi DN, Gassman PW, Abbaspour KC, White MJ, Srinivasan R, Santhi C, Harmel RD, Van Griensven A, Van Liew MW, Kannan N (2012) SWAT: model use, calibration, and validation. Trans ASABE 55(4):491–1508

Bekele EG, Nicklow JW (2007) Multi-objective automatic calibration of SWAT using NSGA-II. J Hydrol 341(3–4):165–176

Cao Y, Zhang J, Yang M, Lei X, Guo B, Yang L, Zeng Z, Qu J (2018) Application of SWAT model with CMADS data to estimate hydrological elements and parameter uncertainty based on SUFI-2 Algorithm in the Lijiang river basin, China. Water 10(6):742

Cuceloglu G, Abbaspour KC, Ozturk I (2017) Assessing the water-resources potential of Istanbul by using a soil and water assessment tool (SWAT) hydrological model. Water 9(10):814

Ghandhari A, Alavi Moghaddam SMR (2011) Water balance principles: a review of studies on five watersheds in Iran. J Environ Sci Technol 4:465–479

Gupta HV, Sorooshian S, Yapo PO (1999) Status of automatic calibration for hydrologic models: comparison with multilevel expert calibration. J Hydrol Eng 4(2):135–143

Khalid K, Ali MF, Rahman NFA, Mispan MR, Haron SH, Othman Z, Bachok MF (2016) Sensitivity analysis in watershed model using SUFI-2 algorithm. Procedia Eng 162:441–447

Kundu S, Khare D, Mondal A (2017) Individual and combined impacts of future climate and land use changes on the water balance. Ecol Eng 105:42–57

Leta OT, El-Kadi AI, Dulai H (2017) Implications of climate change on water budgets and reservoir water harvesting of Nuuanu area watersheds, Oahu, Hawaii. J Water Resour Plann Manag 143(11):05017013

McCarthy GT (1938) The unit hydrograph and flood routing, Conference of North Atlantic Division. US Army Corps of Engineers, New London, CT. US Engineering

Moriasi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, Veith TL (2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans ASABE 50(3):885–900

Patel DP, Srivastava PK (2013) Flood hazards mitigation analysis using remote sensing and GIS: correspondence with town planning scheme. Water Resour Manage 27(7):2353–2368

Rahman K, Maringanti C, Beniston M, Widmer F, Abbaspour K, Lehmann A (2013) Streamflow modeling in a highly managed mountainous glacier watershed using SWAT: the Upper Rhone River watershed case in Switzerland. Water Resour Manage 27(2):323–339

Strauch M, Bernhofer C, Koide S, Volk M, Lorz C, Makeschin F (2012) Using precipitation data ensemble for uncertainty analysis in SWAT streamflow simulation. J Hydrol 414–415:413–424

Williams JR (1969) Flood routing with variable travel time or variable storage coefficients. Trans ASAE 12(1):100–103

Zhou G, Wei X, Wu Y, Liu S, Huang Y, Yan J, Zhang D, Zhang Q, Liu J, Meng Z, Wang C, Chu G, Liu S, Tang X, Liu X (2011) Quantifying the hydrological responses to climate change in an intact forested small watershed in Southern China. Glob Change Biol 17(12):3736–3746