ORIGINAL ARTICLE

Evaluation of a physically based model to assess the eco-hydrological components on the basin hydrology

Satiprasad Sahoo[1] · Masjuda Khatun[2] · Sucharita Pradhan[3] · Pulakesh Das[4]

Abstract

The application of geospatial technology in the field of hydrological modeling plays is a crucial role in the proper management of water resources from global to local levels. SWAT (Soil and Water Assessment Tool) is a comprehensive, physically based semi-distributed river basin model. The spatial distribution of the eco-hydrological components was analyzed in the Brahmani River basin, Odisha, India. The sub-watershed-based hydrological parameters were calculated [Evapotranspiration (ET), Potential Evapotranspiration (PET), Surface Runoff (SURQ), Soil Water (SW), and Water Yield (WYLD)] for 15 years from 2000 to 2014. The spatial distribution results show that minimum and maximum ETs were 111.73 mm and 1311.31 mm for the years 2014 and 2010. The results also show that maximum PET (2378.15 mm) was shown in the sub-watershed no. 78 and 100 for the year of 2009. The sub-watershed-based spatial distribution results show that the upstream part of the river basin comes under less ET compared to downstream. For the river discharge, daily streamflow value was used from June to December of 2008 to 2010 data for model calibration and 2011 to 2012 data for validation purpose. The spatial statistical indicators were used for the accuracy of the powerful model. Besides, the results show that streamflow increased in the monsoon season and decreased in the non-monsoon season. Moreover, output maps provide an appropriate guideline for the planning of detailed water resources planning and management related projects.

Keywords Spatial distribution · Streamflow · SWAT · Basin hydrology · Water resource management · GIS

Introduction

Water is the most important natural resource on the Earth's surface. A watershed is an area of land and water boundary by a drainage divide within which the surface runoff collects and stream flows of the watershed through a single outlet into a larger river or lake. The main goal of watershed management is to implant the sustainable management of natural resources to improve the quality of living for the population is to be accomplished by improvement and restoration of soil quality and thus, raising productivity rates, supply and securing of clean and sufficient drinking water for the population, improvement of infrastructure for storage, transport and agricultural marketing. Precipitation, temperature change is mainly responsible for climate variability (Mirza 2003). Accurate hydrological knowledge is important to understand the hydrological behavior of a watershed for effective and efficient management. In the present research, a methodology is proposed for the evaluation of a physically based model to assess the eco-hydrological components on basin hydrology.

A few numbers of researches are available for water resource management in the Brahmani River but large numbers of researches are available for global to regional scale. The semi-distribution of hydrological modeling provides the average behavior of a watershed based on the small homogeneous units which are aggregated for some defined positions (Wilby 1997). Change in hydrological parameters, such as surface runoff, groundwater, ET, PET, soil water content (SW), and water yield (WYLD), of a watershed plays a very important role in climate change on the global scale. An

✉ Satiprasad Sahoo
  satispss@gmail.com

1 Department of Geography, Jadavpur University, Kolkata, West Bengal 700032, India

2 Department of Remote Sensing & GIS, Vidyasagar University, Midnapore, India

3 Department of Agricultural and Food Engineering, Indian Institute of Technology Kharagpur, Kharagpur, India

4 World Resources Institute, New Delhi, India

important goal of semi-distributed hydrological modeling is the estimation of streamflow among the river. The semi-distributed hydrological modeling provides the characteristics of the earth's surface which affects the component of water balance. Jain et al. (2010) evaluated the SWAT model for the estimation of runoff and sediment yield from Suni to Kasol, an intermediate watershed of Saltuj River in the Western Himalaya region. For calibration, daily and monthly surface runoff and sediment yield using observed data of 1993 and 1994 and the mode of validation were carried out for a date set of 3 years from 1995 to 1997. The coefficient of determination (R^2) for the daily and monthly runoff was obtained as 0.53 and 0.90 calibrations and 0.33 and 0.62 for the validation period. Rostamian et al. (2008) used the SWAT model to estimate runoff and sediment in two mountainous basins Beheshtabad and Vanak in Central Iran. They have been used SWAT-CUP (SUFI-2) model for model calibration and uncertainty analysis. They have also used two factors for the goodness of calibration and uncertainty analysis, one is the percentage of data bracketed by 95% prediction uncertainty (*P* factor) and the ratio of average thickness to standard deviation of corresponding measured variable (*D* factor). The result indicates a *P* factor for Beheshtabad ranges from 0.31 to 0.86 while for Vanak 0.71 to 0.80. And the D factor for Beheshtabad ranges from 0.3 to 1.1 and for Vanak 0.77 to 1.16. Arnold et al. (2012) deeply describe how to manually calibrate and automated calibrated using SWAT-CUP (SUFI2) approach. Khoi and Suetsugi (2014) were used the SWAT model to estimate the impact of climate and land-use changes on hydrological processes and sediment yield in Be River catchment in Vietnam. They have used sensitivity analysis, model calibration, and model validation process to indicate accurate land use and climate change. The result indicates the climate and land-use changes increasing the annual streamflow by 28%, sediment load by 46.4% from 1978 to 2000.

Islam et al. (2012) used the Precipitation Runoff Modeling System (PRMS) which is run under the platform of Modular Modeling System (MMS) for assessing the impact of climate change on streamflow of the Brahmani River basin. They have used daily rainfall and streamflow data for calibration from 1980 to 1984 and for validation 1984 to 1986 by matching simulated and observed streamflow. Uniyal et al. (2015) applied the SWAT model for climate change impact water balance components in the Upper Baitarini River basin of Eastern India using the SUFI-2 technique for calibration. Choto and Fetene (2019) used the SWAT model to examine the effects of land-use land cover on the hydrological process of Gojeb Watershed in Ethiopia. The model was evaluated through sensitivity, uncertainty analysis, calibration, and validation. They have used the LULC image to find change analysis in 1989, 2000, and 2013. They have also used streamflow and sediment yield

for analyzing LULC change. The model results show good agreement with observed values of NSE, R^2, PBIAS was 0.75, 0.78 and 0.5. Bhatt et al. (2016) have been used the SWAT model for simulation of runoff in Choe and W3B two micro-watersheds of the lower Himalayan region in India. They have used 1973 to 1978 period for calibration and 1979 to 1981 for the validation purposes. And the result for the W3B watershed the NSE was found 80.2% for calibration and 73.3% for validation.

Ayivi and Jha (2018) applied the SWAT model for the estimation of water balance components in the Reedy Fork-Buffalo Creek Watershed in North Carolina. For the sustainable development of water resource strategy, it is very important to understand the water quality of water resources. The result shows a good relationship between observed and simulated data, both NSE and R^2 was greater than 0.7 for calibration and validation period. The result performs the effect of future land-use change on runoff and water yield 13.9% and 8.32%, respectively. Gashaw et al. (2018) used the SWAT model to evaluate the hydrological impact of land-use land cover changes in the Andassa watershed in Ethiopia. They have analyzed the LULC change on the impacts of a hydrological parameter, such as streamflow, SURQ, lateral flow, groundwater flow, WYLD, and ET, in the period of 1985 to 2015 and predict LULC changes on the hydrological parameter in the year 2045. They have also used Partial Least Squares Regression (PLSR) model to examine the contribution of each of the LULC classes. Anand et al. (2018) show the change in land use due to hydrology for the entire Ganga River basin using the SWAT model. To use water resource sustainability, land-use change and local hydrology play an important role in proper assessment. They have used metrological data from IMD for observed data and compared them with simulated streamflow data. Andrade et al. (2019), they have been used the SWAT model to evaluate the effects of using discharge and soil moisture dataset on uncertainties and predictions in the Mundau watershed in North-eastern Brazil. For streamflow, the calibration phase, the NSE was 0.71 to 0.92 in the annual time step and 0.53 to 0.76 in the monthly time step. In the validation phase, the NSE was 0.53 to 0.76 in the annual time step and 0.62 to 0.72 in the monthly step. The result performs very well and satisfactory for discharge and soil moisture. In a more recent paper, Gong et al. (2019), Roostaee and Deng (2020), Martinez-Salvador and Conesa-Garcia (2020), Jaiswal et al. (2020), Chanapathi et al. (2020) have calculated the streamflow, groundwater, crop yield, and water quality considering climatic parameters by SWAT hydrological model for water resource planning and management purpose. In a more recent paper, Eini et al. (2020), Guug et al. (2020), de Oliveira Serrão et al. (2021), Bizuneh et al. (2021), Shi and Huang (2021), Zeiger et al. (2021), Bal et al. (2021), and Naseri et al. (2021) determined water budget components, soil erosion susceptibility,

water availability, sediment yield, flooding area, soil and nutrient losses, water quantity and quality, runoff estimation, salinity estimation, drought assessment using SWAT hydrological model under changing climate uncertainty.

In the present research, the SWAT model has been performed for a generation of hydrological components considering local climatic conditions in the Brahmani River. This study focuses on the spatiotemporal distribution of hydrological components and estimated the streamflow for four gaging stations. Besides, sub-watershed-based results also focus on future water management and planning purposes.

Study area

Brahmani River basin is the second-largest river in Orissa; this basin is an inter-state river basin (Fig. 1). The total area of this basin is 39,116 sq. km. The Brahmani River is formed by the confluence of Sank and Koel near Rourkela. Sank is origin near the Jharkhand–Chhattisgarh state border near Netarhat Plateau and Koel also originated from Jharkhand, near Lohardaga. Both tributaries' sources are in the Chota Nagpur Plateau. Then, the river flows over the Tamra and Jharbera forests which skirting along National Highway 23. Then, it crosses the Talcher and Dhenkanal and is divided into two streams. The mainstream flows through the town of Jajpur road which is beyond crossed by National Highway 16 and the Kolkata–Chennai main line of East Coast Railway and another stream called Kimiria again meet in the main river at Indupur. The distributary known as Maipara branches off here to join in the Bay of Bengal.

Materials and methods

The SWAT model is required major data sets like LULC, soil, slope, weather data, discharge, and sediment (Fig. 2). The following data are playing a very important role in the assessment of the SWAT model. Deposition of water the way of infiltration, physical and chemical properties of soil is very important especially soil texture, structure, depth, etc. Soil types are also very important for the rate of water movement. For example, it is finely grained soil that consists of small spaces between soil particles, low infiltration and promotes high surface runoff. Coarse soil is consisting of large pore spaces, high infiltration, and low runoff. Watershed slope reflects the rate of elevation change concerning distance along the principal flow path which is calculated as the difference between the endpoints of the main flow path divided by length. The significance of the variation in the slope along the main flow path considers several sub-watersheds and estimates the slope of each sub-watershed.

Change of land use within the watershed especially within the variable source area affects the collection and capacity and consequent runoff behavior of the watershed. Depending on the vegetation and its extent affects the watershed infiltration, erosion, sedimentation, etc. Climate plays a vital role in the watershed. Precipitation provides incoming rainfall temporally and spatially along with its various characteristics like intensity, frequency, etc. The amount of rainfall, temperature, relative humidity, wind speed, solar radiation regulates factors like soil and vegetation. Soil properties reflect the climate of the watershed; similarly, the vegetation type of the watershed depends totally on the climate conditions.

Data used

The Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) data (Table 1) were used for watershed delineation and slope calculation purposes (https://earthexplorer.usgs.gov/). The Brahmani River basin lays in the coastal plains of Orissa with a slope from north-west to south-east. A major part of the river basin lies less than 300 m elevations. Landsat 8 satellite data are utilized for the generation of LULC classification maps (https://earthexplorer.usgs.gov/). The unsupervised technique was applied for LULC classification purposes. Major classes of land use found in the river basin are agricultural land, evergreen and deciduous forests, pastureland, water bodies, mining area, barren land, and built-up area. A soil map is prepared from the National Bureau of Soil Survey and Land Use Planning. The soil is the main natural resource and plays a very important role in the Brahmani River basin. Based on texture, the soil is divided into four categories which are fine texture, medium texture, coarse texture, and rocky soil. These are very suitable for water demanding crops like rice, sugarcane, etc. The soil in the upper part of the basin is uplands and the lower part of the basin is fertile also some saline patches are found in the coastal part of the basin. Based on formation in the Brahmani River basin soil is divided into two broad categories residual and transported soils. The upper part of the river basin is under the Chhotanagpur plateau which belongs to red gravely and yellow soil. The central part of the river basin belongs to red loamy, mixed red and black soil, and the coastal part of the river belongs to alluvial soil (Table 2).

Climate data are collected (1979–2014) from the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) (https://globalweather.tamu.edu/). About 80% of annual normal rainfall occurred in the 4 months of the south-west monsoon season (June to September). A very little rainfall occurs in December and January, and also during February, some rainfall occurs which is passing due to western disturbances. In the Brahmani River basin, normal annual rainfall varies from 1250 to
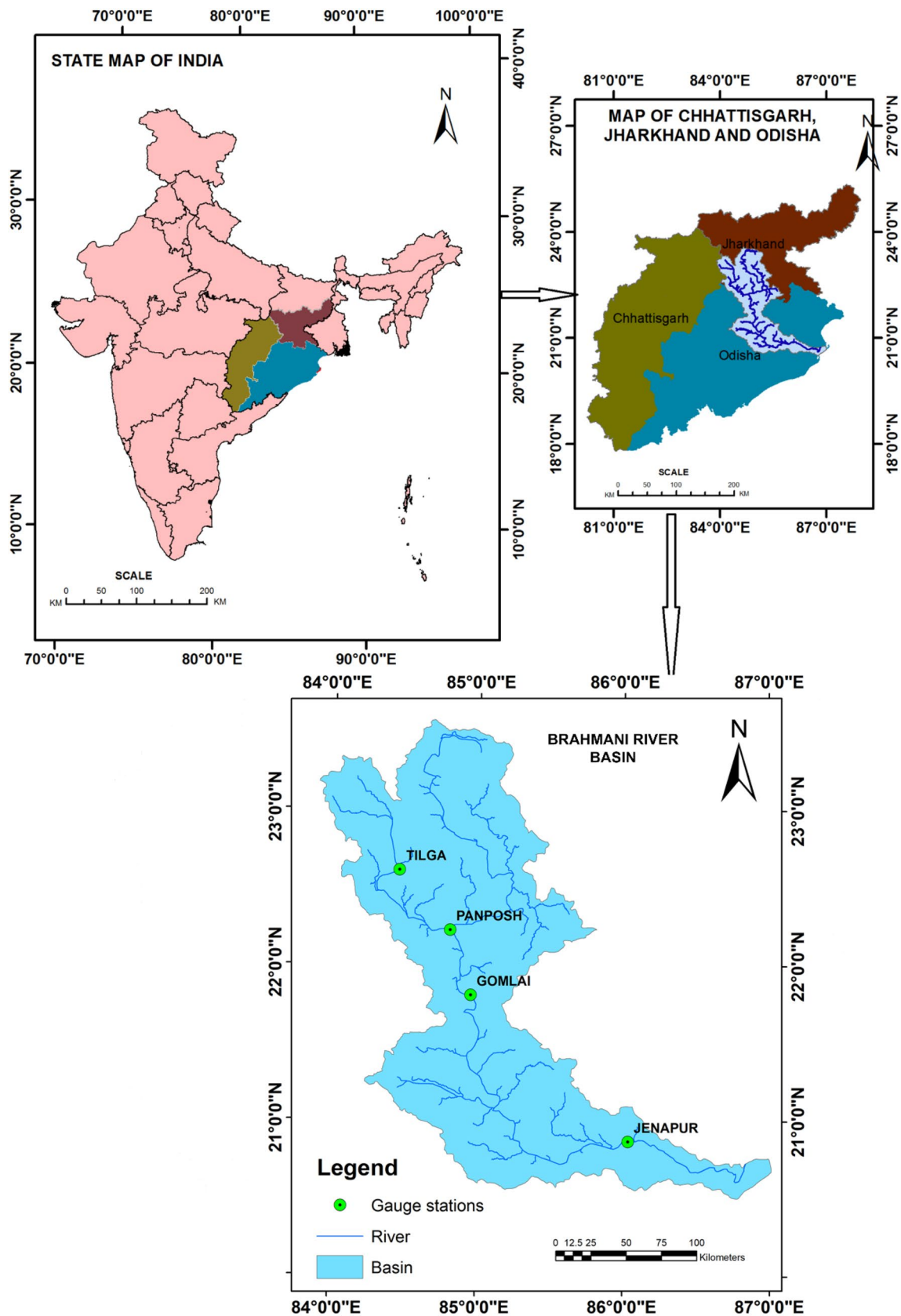
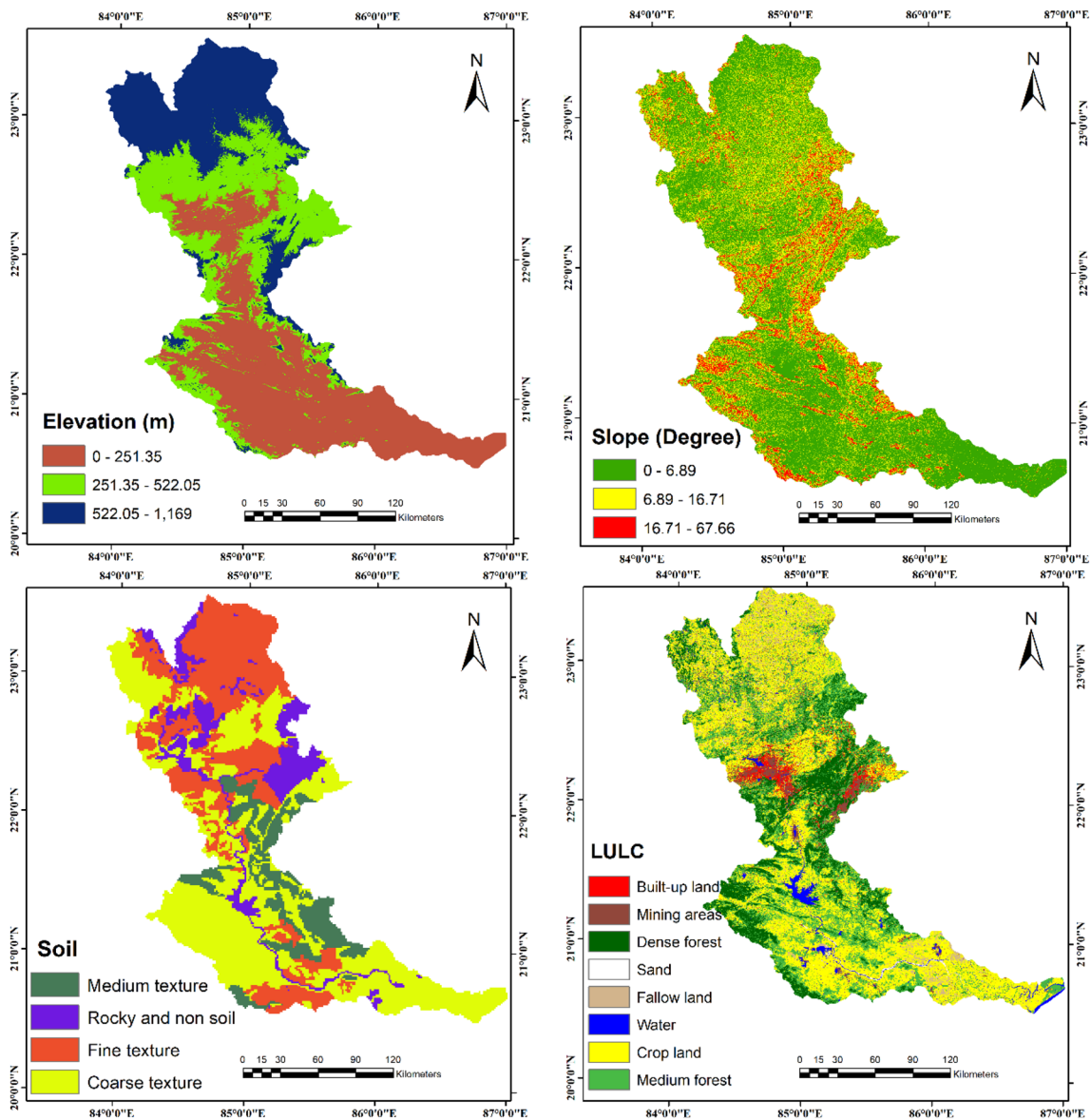**Fig. 1** Location map of study area

Fig. 2 Elevation, slope, soil and LULC maps utilized for SWAT model

Table 1 Sources of input data in SWAT modeling

Type of data	Source of data	Scale or periods of data	Description of data
Topography	SRTM digital elevation data produced by NASA	30 m × 30 m	Digital elevation model
Soil	NBSS & LUP	1:25,000	Soil classification and textural properties
LULC	Landsat 8, USGS	30 m × 30 m	Land use/land cover classification
Climate	CFSR, NCEP (http://globalweather.tamu.edu/)	0.25° × 0.25° (2000–2014)	Daily precipitation and minimum–maximum temperature
Discharge	Central Water Commission (CWC), Bhubaneswar	Daily (2008–2012)	Daily discharge data at selected gauging stations (Tilga, Gomlai, Panpos and Jenapur)

Table 2 Ranges and best-fitted values of streamflow during calibration/validation time periods

Sl. no.	Parameters	Description	Minimum	Maximum	Fitted values
1	CN_2	Curve number	− 0.5	0.5	− 0.035
2	ALPHA_BF	Baseflow alpha-factor	0	1	0.25
3	GW_DELAY	Groundwater delay time	30	350	189
4	GWQMN	Threshold depth water	0	5000	4316.36
5	GW_REVAP	Groundwater revap coefficient	0.02	0.3	0.27
6	ESCO	Soil evaporation compensation factor	0.01	1	0.58
7	CH_K_2	Effective hydraulic conductivity	5	130	105
8	SURLAG	Surface runoff lag coefficient	1	10	5
9	ALPHA_BNK	Base flow alpha-factor for bank storage	− 0.5	0.5	0.34
10	SOIL_AWC	Available water capacity of soil	− 0.2	0.4	0.21
11	SOL_K	Saturated hydraulic conductivity	− 0.8	0.8	0.21
12	HRU_SLP	Average slope steepness	0	0.6	0.43
13	SLSUBBSN	Average slope length	10	150	82.26
14	REVAPMN	Threshold depth of water for revap to occur	6	14	8.39

1750 mm. April, May, and June are the highest temperature and January, December is the lowest temperature. The highest and lowest temperatures are 35.6 °C and 13.4 °C, respectively. The coastal site of the river basin belongs to moderate temperatures and high humidity. The highest temperature recorded in the Kendujhar district of the river basin is 47.40 °C and the lowest temperature recorded in the Jhaspurnagar district of the river basin is 0.70 °C. The discharge data (2008–2012) are collected from the Central Water Commission (CWC), Bhubaneswar, Orissa. Discharge data are very important for the calibration and validation of watershed models focus on the goodness of fit between model predictions and observations.

Methodology

The methodology focused on the estimation of hydrological components using the Soil and Water Assessment Tool (SWAT) considering climatic parameters in the small watershed by the GIS environment. The SWAT is a physically based sub-watershed model used for measuring the quality and quantity of surface water and groundwater. The model has various components, such as weather parameters, SURQ, groundwater recharge, ET, PET, WYLD, return flow, percolation, reservoir storage, sediment flow, crop growth, irrigation, nutrient, reach routing, water transfer. It can predict the long-term environmental impacts of land management practices considering climate change impact in the small watershed to the large complex river basin. It can also be used for soil loss estimation and control, non-point source pollution control in watersheds. First, a watershed or a river basin is divided into multiple sub-watersheds. After that, the sub-watersheds are divided into Hydrological Response Units (HRU) based on land use, soil, and slope; then inputs the weather parameter data, such as

precipitation, maximum–minimum temperature, wind speed, relative humidity, and solar radiation. An all-weather parameter is not essential but precipitation and temperature data must be being required for the preliminary run of the SWAT model. After that, the updated model database will be utilized for simulation purposes; then used simulated data for different purposes for calibration and validation through the manual/SWAT-CUP.

The hydrologic water balance of a watershed or river basin refers to the total amount of input water, output water and storage of water in that watershed or river basin. The water balance equation can be expressed as (Arnold et al. 2013):

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{dayi} - Q_{surfi} - E_{ai} - W_{seepi} - Q_{gwi}) \quad (1)$$

The detailed expression is discussed in the Sahoo et al. (2018, 2019).

The source of input of water is from groundwater, precipitation, and glacial melt. The major source of the output of water is evaporation, PET; soil moisture storage consists of an amount of water in the soil depends on the soil properties like soil texture and organic matter. Water balance is a driving force that is divided into two major components: (i) the land phase of the hydrologic cycle and (ii) the routing phase of the hydrologic cycle. The overall methodological framework is shown in Fig. 3.

Results

This section deals with the results of the SWAT model spatial distribution of hydrological parameters, such as ET, PET, SURQ, SW, and WYLD. This part also consists of
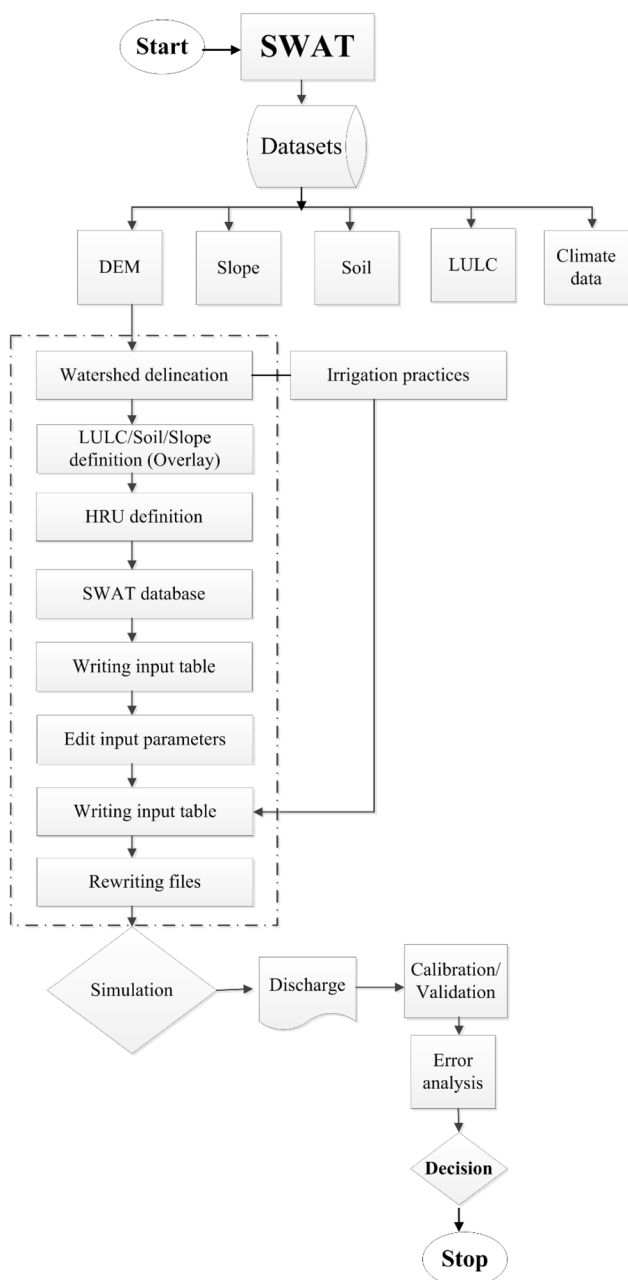
Fig. 3 Overall methodological framework

SWAT model calibration, validation for the prediction of streamflow compare with the simulated and observed value (Table 2).

Spatial distribution of hydrological components

The SWAT model has divided the watershed into 123 sub-watersheds during the watershed delineation stage for easy and accurate modeling. The sub-watershed-based results are important for watershed management and planning purposes. It is protecting water quantity and quality that focus on the entire watershed. Thus, we discuss sub-watershed-based spatial distribution of the hydrological parameters following sections.

Evapotranspiration (ET)

ET plays a very important role in the water cycle. It is a long-term process; it should be an increasingly warmer climate. It is an impact in a major river basin due to an imbalance of rainfall and runoff.

The ET result shows the actual ET in the watershed for the year (Figs. 4 and 5). During these 15 years of the spatial distribution of ET, it is found that the minimum ET value was 199.06 mm which belongs to the year 2002 and the maximum ET value was 1311.31 mm which belongs to the year 2010 (Table 3). In 2014, minimum and maximum ETs were 111.7 and 796.19 mm because this year has only 7 months' value due to no availability of whole year data. The result shows the maximum sub-watershed belongs to medium range of ET. The sub-watershed nos. 10, 39, 43, 48, 58 have been found always lowest ET in whole 15 years. Similarly, the sub-watershed nos. 77, 78, 84, 97, 100, 104, 105, 107, 109, 123 belong always to the highest range of ET value except 2009. In the year 2009, there are only 78 and 100 nos. of sub-watershed belonging to the maximum ET value. It also affected sub-watershed which belongs to a minimum and maximum value in the years 2000 to 2014.

Potential evapotranspiration (PET)

PET is important for the measurement of water demand based on ET in a region. The results showing 15 years of the spatial distribution of PET have found the minimum PET value was 1453.19 mm for the year 2011 and the maximum PET value was 2378.15 mm which belongs to the year 2009 (SF 1–2). Year 2014 consists minimum and maximum PETs 1071.53 mm and 1484.25 mm. The sub-watershed nos. 3, 4, 5, 7, 8, 13, 14, 25, 104 have been found always lowest PET and the sub-watershed nos. 78 and 100 maximum PET in whole 15 years (Table 4).

Surface runoff (SURQ)

SURQ is very important for changing the landscape when it flows over the surface. Runoff carries nutrients from agricultural land to the river. During these 15 years of the spatial distribution of SURQ, it has been found the minimum surface runoff value was 0 which belongs to the maximum year, few years consist of less than 1 mm surface runoff and the maximum surface runoff value was 593.63 mm which belongs to the year of 2007 (Figs. 6 and 7). The result shows maximum sub-watershed belonging to lower range of surface runoff. The sub-watershed nos. 32, 39, 46, 47, 48, 55,
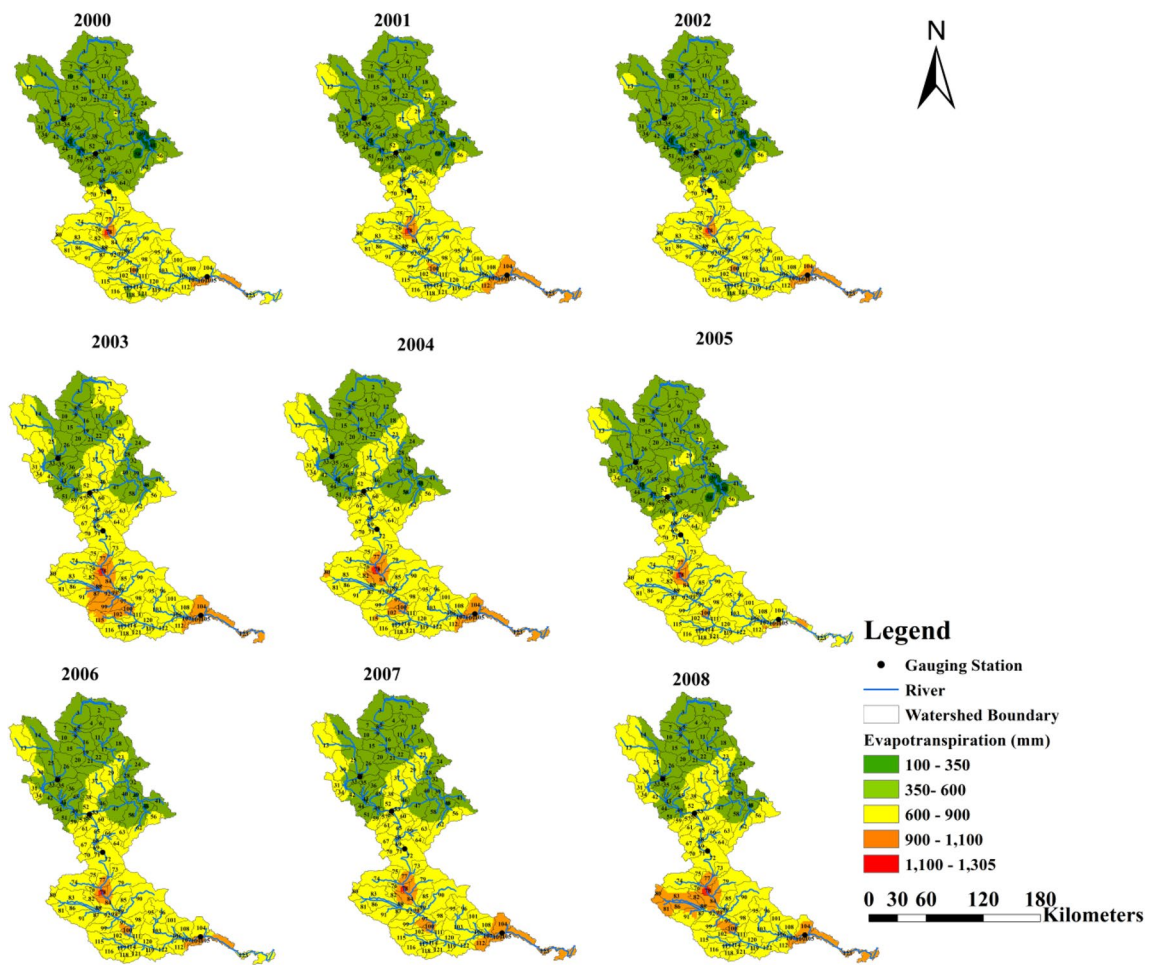
Fig. 4 Sub-watershed-based spatiotemporal changes for ET in the whole river basin from 2000 to 2008
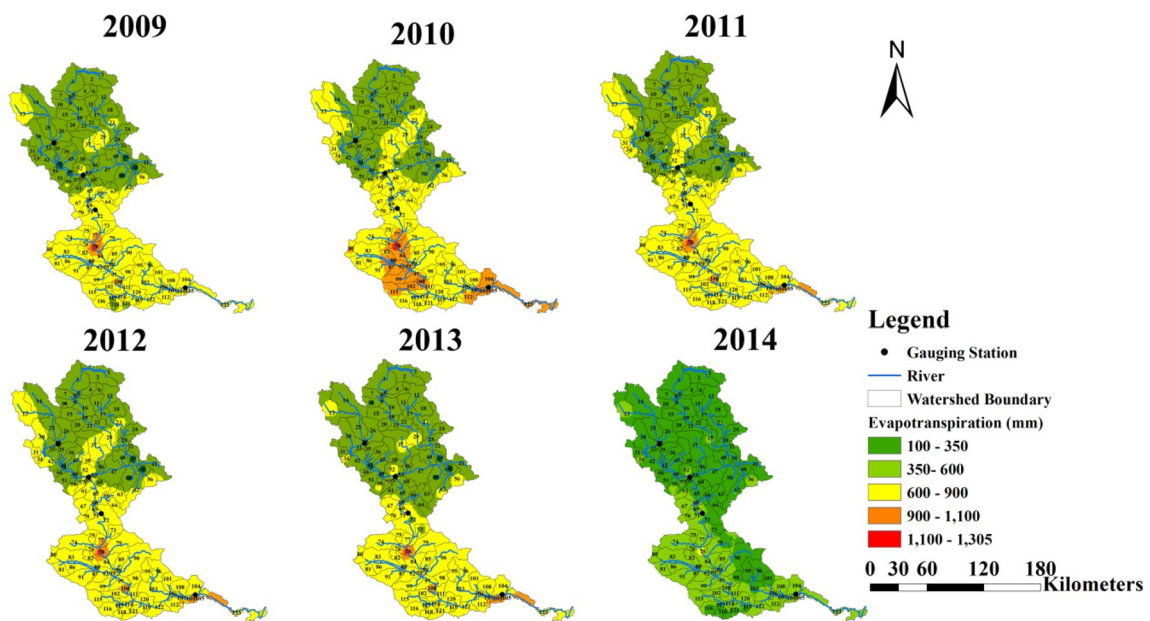

Fig. 5 Sub-watershed-based spatiotemporal changes for ET in the whole river basin from 2009 to 2014

Table 3 Maximum–minimum value of ET and effected sub-watershed from 2000 to 2014

Sl. no.	Year	Min (mm)	Max (mm)	Effected minimum ET (no. of sub-watershed)	Effected maximum ET (no. of sub-watershed)
1	2000	252.81	1270.49	10, 24, 33, 36, 39, 48, 58	77, 78, 84, 97, 100, 104, 105, 107, 109, 123
2	2001	248.39	1248.65	10, 39, 43, 48, 58	77, 78, 84, 97, 100, 104, 105, 107, 109, 112, 123
3	2002	199.06	1253.68	10, 24, 33, 36, 39, 43, 48, 58	77, 78, 97, 100, 104, 105, 107, 109, 123
4	2003	326.38	1257.56	10, 39, 43, 48, 58	77, 78, 84, 86, 87, 88, 91, 92, 93, 97, 99, 100, 102, 104, 105, 107, 109, 111, 112, 115, 123
5	2004	279.32	1292.58	10, 39, 43, 48, 58	77, 78, 84, 97, 100, 104, 105, 107, 109, 123
6	2005	237.16	1250.83	10, 24, 39, 43, 48, 58	77, 78, 80, 82, 83, 84, 87, 88, 92, 93, 97, 99, 100, 102, 104, 105, 107, 109, 111, 112, 115, 123
7	2006	296.20	1245.54	10, 39, 43, 48, 58	77, 78, 80, 82, 83, 84, 87, 88, 92, 93, 97, 99, 100, 102, 104, 105, 107, 109, 111, 112, 115, 123
8	2007	309.41	1249.49	10, 24, 39, 43, 48, 58	77, 78, 84, 97, 100, 105, 107, 109, 123
9	2008	322.02	1286.34	10, 24, 39, 43, 48, 58	77, 78, 80, 81, 82, 83, 84, 86, 87, 88, 92, 93, 97, 99, 100, 102, 104, 105, 107, 109, 111, 115, 123
10	2009	237.77	1296.21	10, 39, 43, 48, 58	78, 100
11	2010	297.96	1311.31	10, 39, 43, 48, 58	77, 78, 84, 97, 100, 102, 105, 107, 109, 115, 123
12	2011	275.85	1257.50	10, 39, 43, 48, 58	77, 78, 80, 81, 82, 83, 84, 86, 87, 88, 92, 93, 97, 99, 100, 102, 104, 105, 107, 109, 111, 115, 123
13	2012	264.42	1264.06	10, 24, 39, 43, 48, 58	77, 78, 84, 97, 100, 104, 105, 107, 109, 123
14	2013	270.97	1245.54	10, 24, 39, 43, 48, 58	77, 78, 80, 82, 83, 84, 86, 87, 88, 91, 92, 93, 97, 99, 100, 102, 104, 105, 107, 108, 109, 111, 112, 115, 123
15	2014	111.73	769.19	10, 24, 32, 36, 39, 43, 48, 58	77, 78, 80, 82, 83, 84, 88, 97, 100, 105, 107, 109, 123

Table 4 Maximum–minimum value of PET and effected sub-watershed from 2000 to 2014

| Sl. no.	Year	Min (mm)	Max (mm)	Effected minimum PET (no. of sub-watershed)	Effected maximum PET (no. of sub-watershed)
1	2000	1758.69	2347.70	1, 3, 4, 5, 7, 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 25, 79, 85, 90, 95, 96, 101, 103, 104, 108	78, 100
2	2001	1761.18	2249.23	7, 13, 14, 79, 85, 90, 95, 96, 101, 103, 104, 108	34, 42, 44, 48, 49, 51, 78, 100
3	2002	1834.62	2340.64	3, 4, 5, 7, 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 25, 79, 85, 90, 95, 96, 101, 103, 104, 108	34, 38, 42, 43, 44, 45, 49, 51, 52, 55, 77, 78, 81, 84, 93, 97, 100, 123
4	2003	1709.25	2212.65	3, 4, 5, 7, 8, 9, 10, 13, 14, 25, 79, 85, 90, 95, 96, 101, 103, 104, 108	34, 42, 44, 48, 51, 78, 93, 97, 100, 123
5	2004	1770.94	2306.83	3, 4, 5, 7, 8, 13, 14, 25, 62, 79, 85, 90, 95, 96, 101, 103, 104, 108	78, 100
6	2005	1740.35	2279.81	3, 4, 5, 7, 8, 9, 10, 13, 14, 15, 16, 19, 20, 21, 25, 79, 85, 90, 95, 96, 101, 103, 104, 108	78, 100
7	2006	1686.07	2229.99	3, 4, 5, 7, 8, 13, 14, 25, 71, 72, 73, 79, 85, 90, 95, 96, 101, 103, 104, 108	34, 42, 44, 48, 51, 77, 78, 93, 97, 100, 123
8	2007	1653.27	2212.73	3, 4, 5, 7, 8, 13, 14, 25, 104	34, 42, 44, 48, 51, 77, 78, 84, 93, 97, 100, 123
9	2008	1686.68	2254.68	3, 4, 5, 7, 8, 9, 10, 13, 14, 15, 16, 19, 20, 21, 25, 79, 85, 90, 95, 96, 101, 103, 104, 108	78, 100
10	2009	1880.62	2378.15	7, 13, 62, 79, 85, 90, 95, 96, 101, 103, 104, 108	78, 100
11	2010	1819.23	2344.03	3, 4, 5, 7, 8, 9, 10, 13, 14, 15, 16, 19, 20, 21, 25, 71, 72, 73, 79, 85, 90, 95, 96, 101, 103, 104, 108	78, 100, 123
12	2011	1453.19	2259.79	3, 4, 5, 7, 8, 13, 14, 25, 41, 56, 74, 76, 82, 83, 104, 108	78, 97, 100
13	2012	1606.75	2289.74	3, 4, 5, 7, 8, 13, 14, 25, 41, 70, 74, 75, 76, 82, 83, 102, 104, 111, 114, 115, 116, 117, 118, 119, 120, 121	78, 97, 100
14	2013	1506.14	2275.35	3, 4, 5, 7, 8, 13, 14, 25, 74, 76, 82, 83	78, 97, 100
15	2014	1071.53	1484.25	3, 4, 5, 7, 8, 13, 14, 25, 70, 74, 75, 76, 82, 83, 86, 104, 108	34, 42, 44, 51, 78, 97, 100
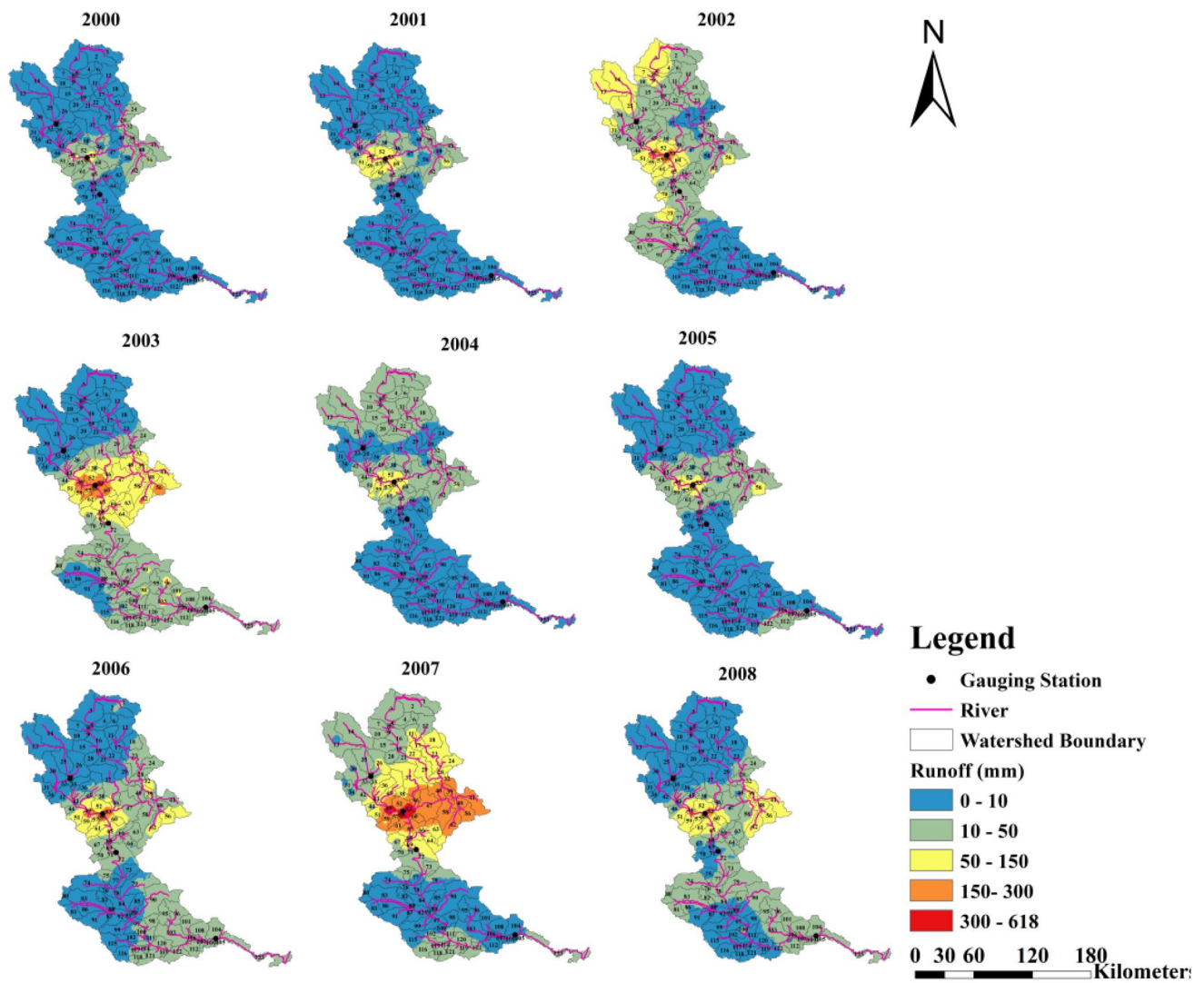
Fig. 6 Sub-watershed-based spatiotemporal changes for SURQ in the whole river basin from 2000 to 2008

56, 58, 60, 62, 65 have found always medium and the sub-watershed nos. 53 and 55 belonging always to the highest range of SURQ value over the years (Table 5).

Soil water content (SW)

The soil water content (SW) means the amount of water absorbs into the soil at a time. It plays a very important role in plant growth mostly in agriculture. SW refers to the amount of water stored in the soil profile in the watershed for the year. During these 15 years of the spatial distribution of SW, it was found that the minimum and maximum values were 0.01 mm and 385.07 mm of the year 2011 and 2014 (SF 3–4). The results show that the maximum sub-watershed belongs medium range of SW. The sub-watershed nos. 10, 24, 36, 39, 48, 58, 60, 96 have been found always the lowest

SW in the whole 15 years. Similarly, the sub-watershed nos. 13, 56, 77, 80, 82, 83, 84, 100, 102, 104, 105, 109, 111, 112, 114, 115, 123 belong always to highest range of SW value. There is no sequential range increase or decrease of SW in the sequential year (Table 6).

Water yield (WYLD)

The WYLD indicates the amount of freshwater flow over the watershed. It plays a very important role in a watershed for water management. It refers to WYLD to streamflow from HRUs in the watershed for the year. Here, the model test run was used in the year of 1 January 2000 to 31 July 2014. Within 15 years' distribution, lots of variations in some watersheds were found (SF 5–6). During these 15 years of the spatial distribution of water yield, it has been found
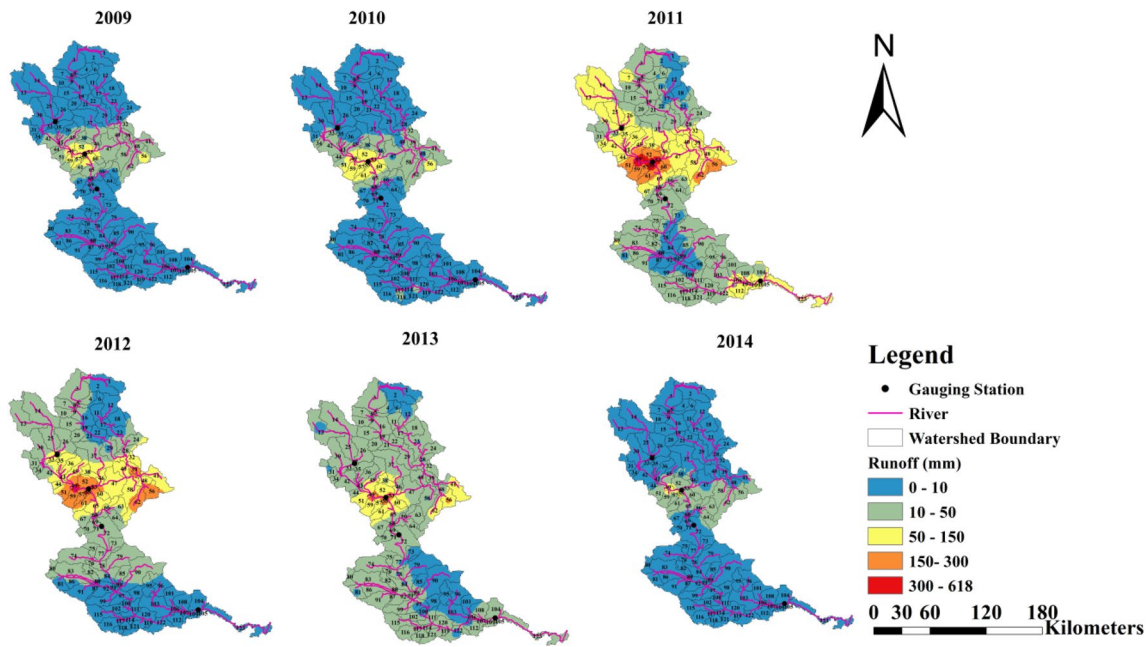
Fig. 7 Sub-watershed-based spatiotemporal changes for SURQ in the whole river basin from 2009 to 2014

Table 5 Maximum–minimum value of SURQ and effected sub-watershed from 2000 to 2014

Sl. no.	Year	Min (mm)	Max (mm)	Effected minimum SURQ (no. of sub-watershed)	Effected maximum SURQ (no. of sub-watershed)
1	2000	0	104.43	23, 24, 28, 32, 39, 41, 49, 51, 52, 57, 58, 59, 60, 61, 62, 65	53, 55, 56
2	2001	0	200.03	11, 17, 18, 22, 32, 39, 41, 49, 51, 52, 56, 59, 60, 61, 62, 65	53, 55
3	2002	0.38	292.89	3, 4, 5, 7, 8, 13, 14, 25, 31, 49, 51, 52, 56, 57, 59, 60, 61, 70, 75	53, 55
4	2003	0	434.95	39, 52, 56, 57, 59, 60, 61, 62, 65	53
5	2004	0	150.59	49, 51, 52, 56, 57, 58, 59, 60, 61, 62	53, 55
6	2005	0	136.73	32, 39, 41, 42, 43, 44, 45, 49, 52, 57, 59, 60, 61, 62	53, 55, 56
7	2006	0.03	305.62	32, 39, 51, 52, 57, 59, 60, 61, 62, 65	53, 55, 56
8	2007	0.25	593.63	32, 39, 46, 47, 48, 55, 56, 58, 60, 62, 65	53
9	2008	0.01	290.98	32, 39, 41, 48, 51, 52, 57, 58, 59	53, 55, 56
10	2009	0	168.53	32, 52, 57, 58, 59, 60, 61, 62	53
11	2010	0	204.37	51, 52, 56, 57, 58, 59, 60, 61, 62	53, 55
12	2011	0.88	622.22	51, 52, 56, 57, 59, 60, 61, 62	53, 55
13	2012	0.04	531.15	39, 48, 51, 52, 56, 57, 58, 59, 60, 61, 62	53, 55
14	2013	2.47	279.38	41, 51, 52, 57, 59, 60, 61	53, 55, 56
15	2014	0	114.78	32, 39, 40, 41, 60, 65, 66	51, 52, 53, 55, 56, 57, 58, 59, 61, 62, 63, 64

that the minimum WYLD value was 9.51 mm in the year 2000 and the maximum WYLD value showed 1476.98 mm which belongs to the year 2011. Year 2014 consists of lowest value minimum 13.06 mm and the maximum value showed 213.12 mm because this year has only 7 months' value due to no availability of whole year data. It was observed that the maximum sub-watershed belongs to medium range of WYLD. The sub-watershed nos. 30, 31, 34, 42, 56, 81, 86, 87, 88, 89, 91, 92, 93, 97, 99, 100, 102, 104 have been found always lowest WYLD in whole 15 years. Similarly, sub-watershed nos. 22, 23, 24, 28, 58, 62, 63, 64, 65, 73, 75, 80, 96, 110 belong always to highest range of water yield value

Table 6 Maximum–minimum value of SW and effected sub-watershed from 2000 to 2014

Sl. no.	Year	Min (mm)	Max (mm)	Effected minimum SW (no. of sub-watershed)	Effected maximum SW (no. of sub-watershed)
1	2000	17.35	287.74	10, 24, 36, 39, 58, 60, 96	13, 56, 77, 80, 82, 83, 84, 100, 102, 104, 105, 109, 111, 112, 114, 115, 123
2	2001	17.00	319.36	10, 24, 36, 39, 48, 58, 60, 96	13, 56, 80, 81, 82, 83, 86, 87, 88, 91, 92, 93, 99, 100, 102, 104, 105, 109, 111, 115, 123
3	2002	0.45	310.00	10, 24, 36, 39, 48, 58, 60, 96	13, 29, 56, 77, 80, 81, 82, 83, 84, 86, 87, 88, 91, 92, 93, 99, 100, 102, 104, 105, 109, 111, 115, 123
4	2003	7.08	358.63	10, 39, 43, 48, 53, 56	13, 29, 56, 80, 81, 82, 83, 86, 87, 88, 92, 93, 99, 100, 102, 104, 105, 109, 111, 115, 123
5	2004	18.92	287.62	10, 24, 36, 39, 48, 58, 60, 96	13, 29, 56, 80, 81, 82, 83, 86, 87, 88, 92, 93, 99, 100, 102, 104, 105, 109, 111, 115, 123
6	2005	19.56	306.52	10, 24, 36, 39, 48, 58, 60, 96	13, 29, 56, 77, 80, 81, 82, 83, 84, 86, 87, 88, 91, 92, 93, 99, 100, 102, 104, 105, 109, 111, 115, 123
7	2006	19.35	310.32	10, 36, 39, 48, 58, 60, 96	13, 29, 56, 80, 81, 82, 83, 86, 87, 88, 92, 93, 99, 100, 102, 104, 105, 109, 111, 115, 123
8	2007	21.03	300.73	10, 36, 39, 48, 58, 60, 96	13, 29, 56, 80, 81, 82, 83, 84, 86, 87, 88, 92, 93, 99, 100, 102, 104, 105, 109, 111, 115, 123
9	2008	19.29	290.57	10, 36, 39, 48, 58, 60, 96	13, 29, 56, 80, 81, 82, 83, 84, 86, 87, 88, 92, 93, 99, 100, 102, 104, 105, 109, 111, 115, 123
10	2009	0.53	326.91	10, 36, 39, 48, 58, 60, 96	13, 29, 56, 80, 81, 82, 83, 86, 87, 88, 92, 93, 99, 100, 102, 104, 105, 109, 111, 115, 123
11	2010	2.71	352.51	10, 36, 39, 48, 58, 60, 96	13, 29, 56, 80, 81, 82, 83, 84, 86, 87, 88, 92, 93, 99, 100, 102, 104, 105, 109, 111, 115, 123
12	2011	0.01	297.70	10, 24, 36, 39, 48, 58, 60, 96	13, 29, 56, 80, 81, 82, 83, 86, 87, 88, 92, 93, 99, 100, 102, 104, 105, 109, 111, 115, 123
13	2012	20.73	319.22	10, 24, 36, 39, 48, 58, 60, 96	13, 29, 56, 80, 81, 82, 83, 86, 87, 88, 92, 93, 99, 100, 102, 104, 105, 109, 111, 115, 123
14	2013	20.02	312.44	10, 24, 36, 39, 48, 58, 60, 96	13, 29, 56, 80, 81, 82, 83, 86, 87, 88, 92, 93, 99, 100, 102, 104, 105, 109, 111, 115, 123
15	2014	13.00	385.07	10, 24, 28, 32, 39, 48, 58	13, 30, 34, 52, 58, 59, 67, 70, 80, 82, 83, 102, 104, 105, 109, 123

(Table 7). It was observed that ET, PET, SURQ, SW, and WYLD results of 2014 showed abrupt because weather data were missing after July.

The impact of climate change and LULC during the study period on ET and PET was analyzed through the SWAT model. The maximum value of ET ranging from 299.5 to 1304.3 mm was observed during the year 2010, whereas this range reduced from 112.15 to 763.84 mm during 2014. However, most sub-watershed experienced a gradual increment of ET over the years. The range of PET was maximum during 2009 (1881.4–2372.4 mm) and 2010 (1820.4–2338.4 mm) which decreased in subsequent years. Sub-watershed 78 indicated the maximum amount of ET and PET in all the years. Although the temperature is increasing over time, the change in LULC has affected the pattern of PET of the watershed. The highest amount of SURQ was observed in Panposh gauging site in all the years. In 2011, the maximum value of surface runoff 300 to 600 mm was observed in sub-basin 45, 49, 51, 53, 55, 57, and 60. In all the years except during 2011, the lower part of the basin has generated less than 50 mm of runoff. The water yield

in all the sub-basin during the year 2000 ranged from 10 to 386.8 mm. In 2011, the range of water yield in most of the sub-basin increased 500–1500 mm as compared to 2000. The highest amount of WYLD was observed in the middle part of the watershed. This is due to the transition from forest land cover to agricultural and urban areas. However, the WYLD was less than 800 mm in most of the downstream sub-basins. A constant increase in soil water throughout the watershed is observed. In 2000, most of the sub-basin in the upper part indicated less than 150 mm of soil water storage which increases from 250 to 350 mm during the study period. Sub-basins 104, 105, 107, 109, and 123 which are in the downstream area have experienced maximum soil water storage in all the years.

Estimation of streamflow

Streamflow consists of the amount of water move over the surface at a given time and it is expressed as a cubic meter per second (m³/s). The streamflow is related to the volume of water flows in the watershed by the stream channel. Rainfall,

Table 7 Maximum-minimum value of WYLD and effected sub-watershed from 2000 to 2014

Sl. no.	Year	Min (mm)	Max (mm)	Effected minimum WYLD (no. of sub-watershed)	Effected maximum WYLD (no. of sub-watershed)
1	2000	9.51	387.79	30, 31, 34, 42, 44, 51, 81, 86, 87, 88, 89, 91, 92, 93, 97, 99, 100, 102, 104, 111	24, 28, 39, 48, 58, 63, 64, 65, 72, 73, 75, 96, 110
2	2001	38.03	552.92	30, 31, 34, 56, 81, 86, 87, 88, 89, 91, 92, 93, 97, 99, 100, 102, 104, 111, 115, 123	11, 17, 18, 22, 23, 24, 28, 39, 48, 58, 63, 64, 65, 73, 80, 96, 110
3	2002	90.00	831.31	34, 56, 87, 88, 89, 92, 93, 97, 99, 100, 102, 104, 109, 111, 114, 123	63, 64, 65, 70, 72, 73, 74, 75, 80
4	2003	181.90	1306.17	30, 31, 34, 42, 43, 44, 49, 51, 87, 88, 89, 91, 92, 93, 97, 99, 100, 102, 104, 111, 123	63, 64, 65, 73, 80, 96, 110
5	2004	50.47	618.74	30, 31, 34, 42, 56, 81, 86, 87, 88, 89, 91, 92, 93, 97, 99, 100, 102, 104	22, 23, 63, 64, 73, 75, 96, 112
6	2005	57.58	563.85	30, 31, 34, 38, 42, 43, 44, 45, 46, 49, 51, 53, 81, 87, 88, 89, 92, 93, 99, 100, 102, 104, 111, 123	24, 39, 48, 58, 63, 64, 73, 80, 95, 96, 101, 110
7	2006	82.55	789.77	30, 31, 34, 42, 43, 44, 81, 87, 88, 89, 91, 92, 93, 97, 99, 100, 102, 104, 111, 115, 117, 123	23, 24, 28, 39, 48, 58, 60, 63, 64, 65, 67, 73, 75, 80, 95, 96, 101, 110
8	2007	95.42	1134.36	31, 34, 87, 88, 89, 92, 93, 97, 99, 100, 102, 104, 109, 111, 123	24, 28, 39, 48, 58, 60, 62, 63, 64, 65, 66, 68, 73
9	2008	140.88	1110.06	30, 31, 33, 34, 42, 43, 44, 45, 46, 48, 51, 52, 87, 88, 89, 92, 93, 97, 99, 100, 102, 104, 111, 123	63, 64, 65, 72, 73, 74, 75, 80, 96
10	2009	62.81	652.10	30, 31, 33, 34, 42, 43, 44, 45, 49, 51, 52, 56, 87, 88, 89, 92, 93, 97, 99, 100, 102, 104, 111, 123	22, 23, 24, 28, 58, 62, 63, 64, 65, 73, 75, 80, 96, 110
11	2010	65.70	725.81	30, 31, 33, 34, 42, 43, 44, 45, 49, 51, 52, 56, 87, 88, 89, 92, 93, 97, 99, 100, 102, 104, 111, 123	22, 23, 24, 28, 58, 62, 63, 64, 65, 73, 75, 80, 96, 110
12	2011	97.42	1476.98	31, 77, 78, 84, 87, 88, 89, 92, 93, 97, 99, 100, 102, 104, 111, 123	26, 39, 48, 57, 59, 61, 62, 67, 69, 70, 74, 75, 80, 95, 96, 101
13	2012	49.06	1074.22	77, 78, 84, 87, 88, 89, 92, 93, 97, 99, 100, 102, 104, 111, 123	26, 39, 48, 57, 59, 61, 62, 67, 69, 70, 74, 75, 80, 96
14	2013	43.79	586.41	1, 2, 31, 33, 34, 77, 78, 84, 87, 88, 89, 92, 93, 97, 99, 100, 102, 104, 111, 123	24, 26, 39, 48, 57, 59, 61, 62, 67, 69, 70, 74, 75, 80, 96, 116
15	2014	13.06	213.12	31, 46, 78, 84, 87, 88, 89, 92, 93, 97, 99, 100, 102, 104, 111, 123	58, 59, 61, 62, 67, 74, 75, 80, 96

snowmelt, groundwater discharge, groundwater recharge, evaporation, transpiration, surface runoff, sedimentation are the natural mechanisms which affect the streamflow. It is also affected by changing climatic conditions. In the present study, SWAT hydrological model was applied for the estimation of streamflow considering climatic parameters by GIS environment. The calibration and validation have been performed with observed river discharge at gaging stations.

Model calibration and validation

The calibration and validation process is very important to know properly the accuracy of results which is used to make a decision. The model calibration and validation were considered from June to December of 2008 to 2010 and 2011 to 2012. The statistical technique evaluates some criteria, such as Coefficient of Determination (R^2), Nash–Sutcliffe Efficiency (NSE), and Percentage Bias (PBIAS). The four gaging station data were used for model calibration and validation purposes, namely Tilga, Gomlai, Panpos and Jenapur.

For the Tilga gauge station, model calibration has been performed for June to December of 2008 to 2010 data. The results show that R^2, NSE, and PBIAS were 0.77, 0.79, and 4.21% for 2010 (Fig. 8). For the validation process, river discharge data were used from June to December of 2011 to 2012. It was observed that very good results of R^2, NSE, PBIAS showed 0.78, 0.81, and − 7.19% for 2011. For the Gomal gauge station, in the year 2008 shows, R^2, NSE, and PBIAS were 0.79, 0.50, and − 59.02%. In 2009, R^2, NSE, and PBIAS were 0.89, 0.46 and − 58.33% under calibration observation (Fig. 9). In the year 2011 shows, R^2, NSE, and PBIAS were 0.80, 0.79, and 17.39% and in the year 2012, R^2, NSE, and PBIAS were 0.89, 0.75, and − 44.54% under validation observation. For Panpos gauge station, in the year of 2008 shows, R^2, NSE, and PBIAS were 0.86, 0.57, and − 68.47%. In 2009 and 2010, R^2, NSE, and PBIAS were 0.82, 0.44 and − 60.23% and 0.87, 0.42 and − 44.07% due to the calibration phase (Fig. 10). In the years of 2011 and 2012 shows, R^2, NSE, and PBIAS were 0.87, 0.62 and − 82.13% and 0.88, 0.74 and − 56.13%
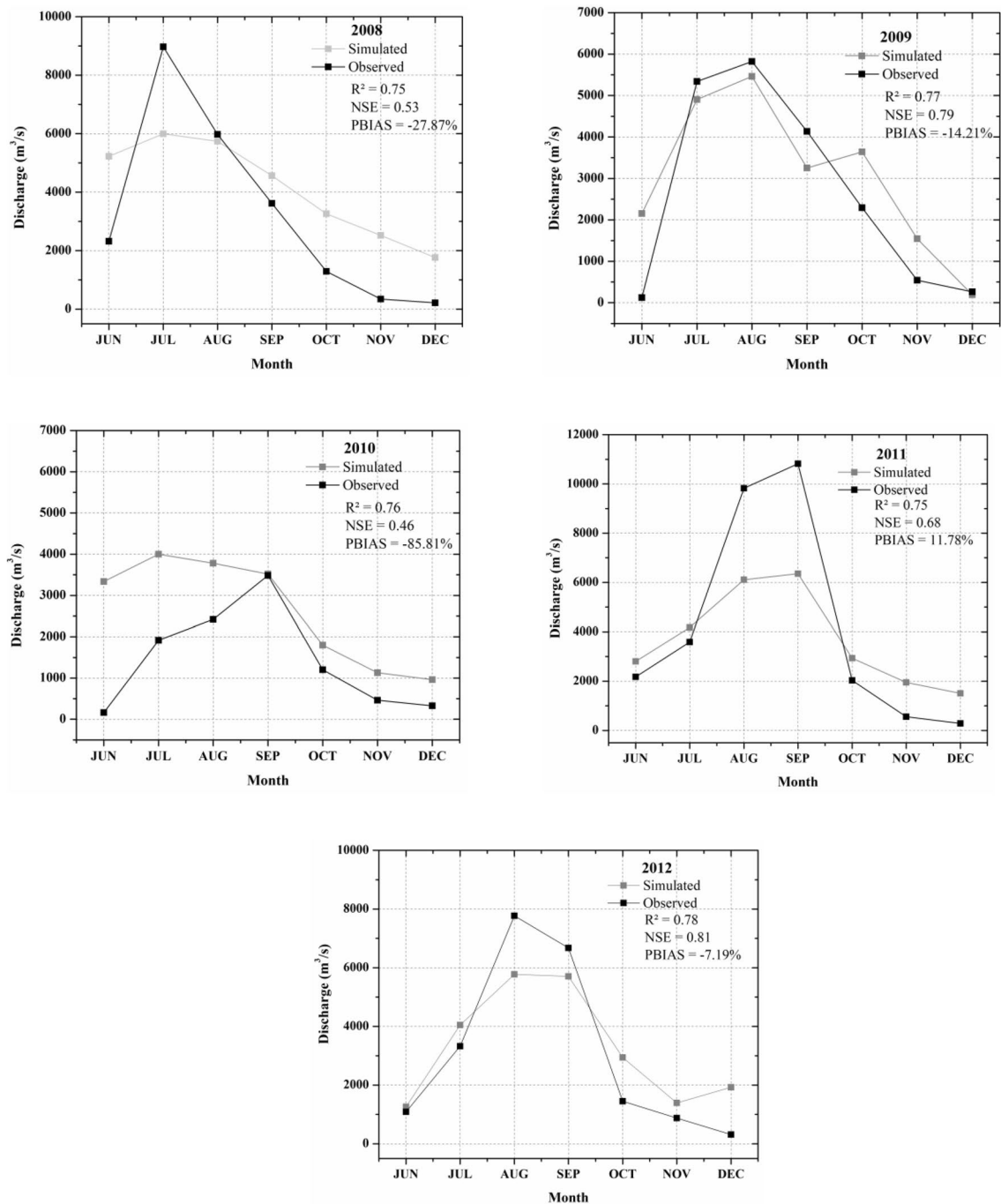
Fig. 8 Calibration for 2008–2010 and validation for 2011–2012 at Tilga gauging station

under validation phase. For the Jenapur gauge station, in the years 2009 and 2010 shows, R^2, NSE, and PBIAS were 0.81, 0.51, − 46.52% and 0.89, 0.41, and − 27.43% for calibration periods (Fig. 11). In the years 2011 and 2012 shows, R^2, NSE, and PBIAS were 0.79, 0.61 and − 66.53% and 0.89, 0.68 and − 49.24% for validation periods.

Discussion

SWAT is a physically based popular hydrological model for the calculation of water balance within a basin (Martinez-Retureta et al. 2020). Large numbers of parameters like LULC, Soil, Slope, weather data are required
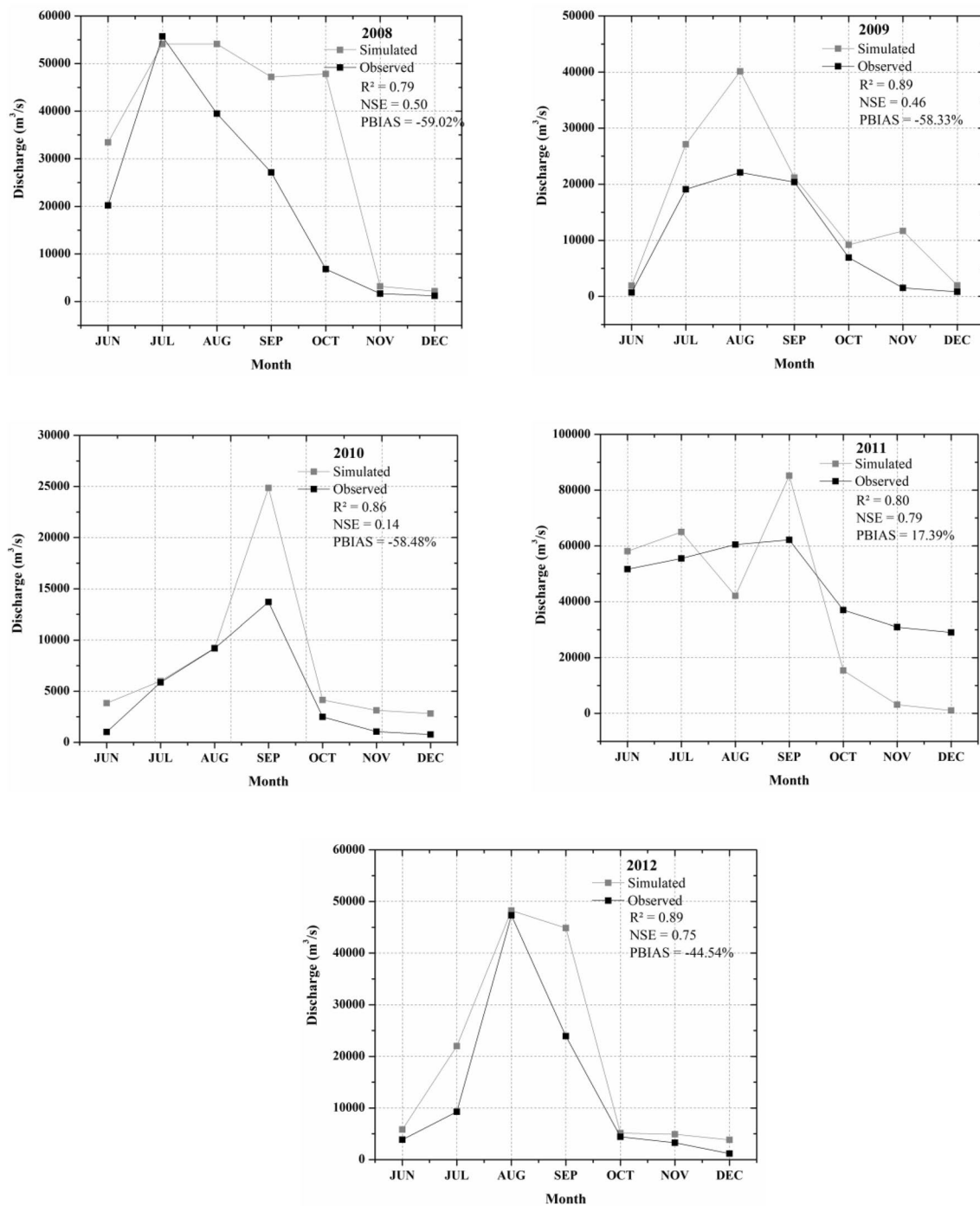
Fig. 9 Calibration for 2008–2010 and validation for 2011–2012 at Gomlai gauging station

for SWAT modeling. Notably, it can be modeled on the hydrological impacts of human activity considering climatic conditions (Musie et al. 2020). The LULC and climate variability can be affected in the hydrological responses of a watershed. However, sub-watershed-based analysis is very significant for prioritization of basin for water resources management. Sahoo et al. (2019) studied

sub-watershed-based groundwater recharge change from 2030 to 2080 considering LULC and bias-corrected precipitation and temperature data through a hydrological model in the Dwarakeswar–Gandherswari River basin. This study also focuses on long-term streamflow prediction under different RCPs data. The present study also calculated sub-watershed based on five hydrological components (ET,
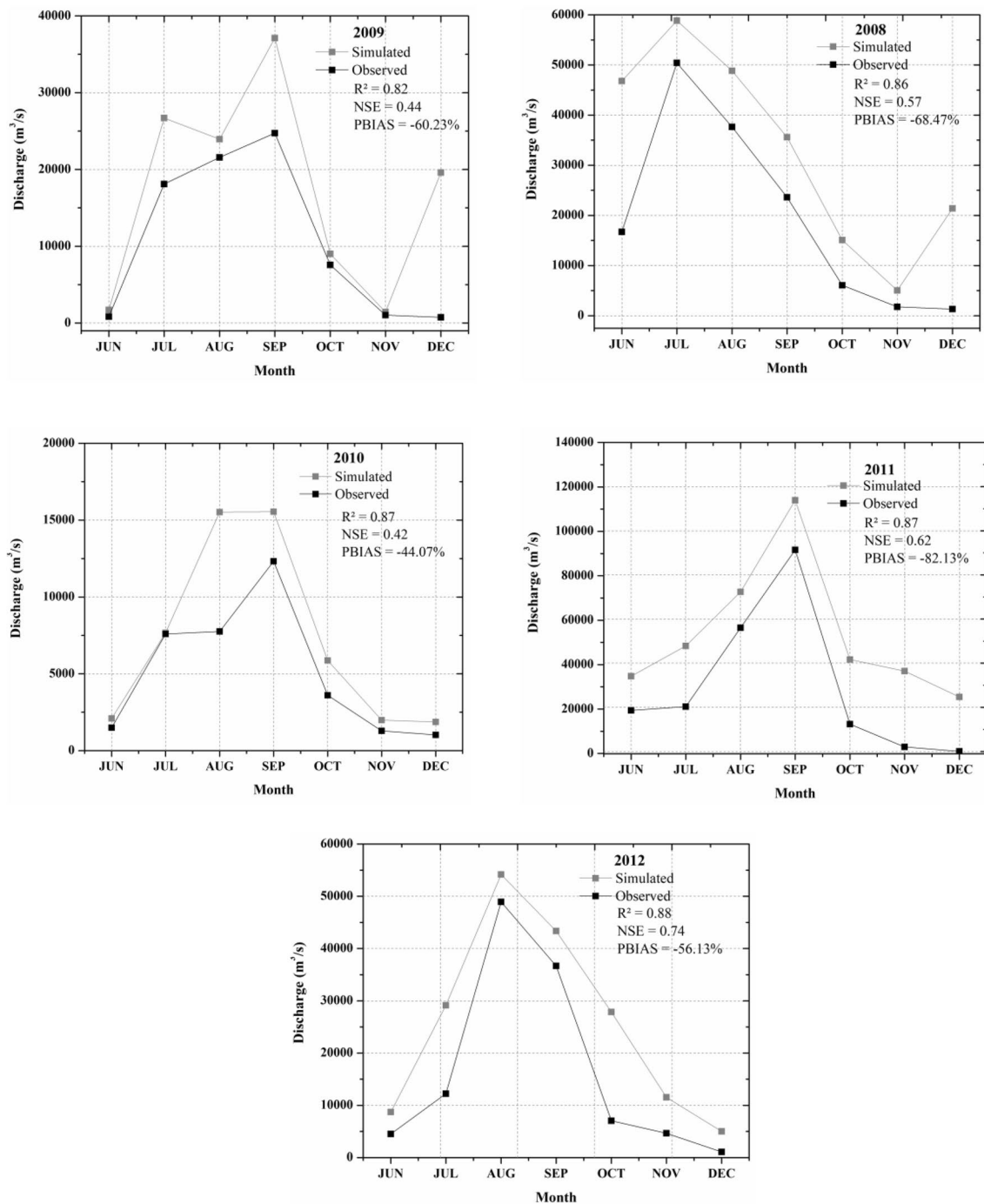
Fig. 10 Calibration for 2008–2010 and validation for 2011–2012 at Panpos gauging station

PET, SURQ, SW, and WYLD) from 2000 to 2014. Das et al. (2019) evaluate two multisite performances of the SWAT model and validations have been done for 2009 to 2013 in the Gomti River basin. It was observed that the most sensitive parameter showed the curve number for moisture condition II. Our study also considering four multi-gaging sites for calibration and validation purposes. Begou et al. (2016) studied hydrological modeling and

calibration by the Generalized Likelihood Uncertainty Estimation approach. It was notified that ET and biomass were considered for the accuracy of the model output. Swain and Patra (2017) performed SWAT modeling for thirty-two catchments to analyze continuous streamflow estimation and Sequential Uncertainty Fitting (SUFI-2) applied for uncertainty analysis in an ungauged basin. It was perceived that inverse distance weighted, kriging,
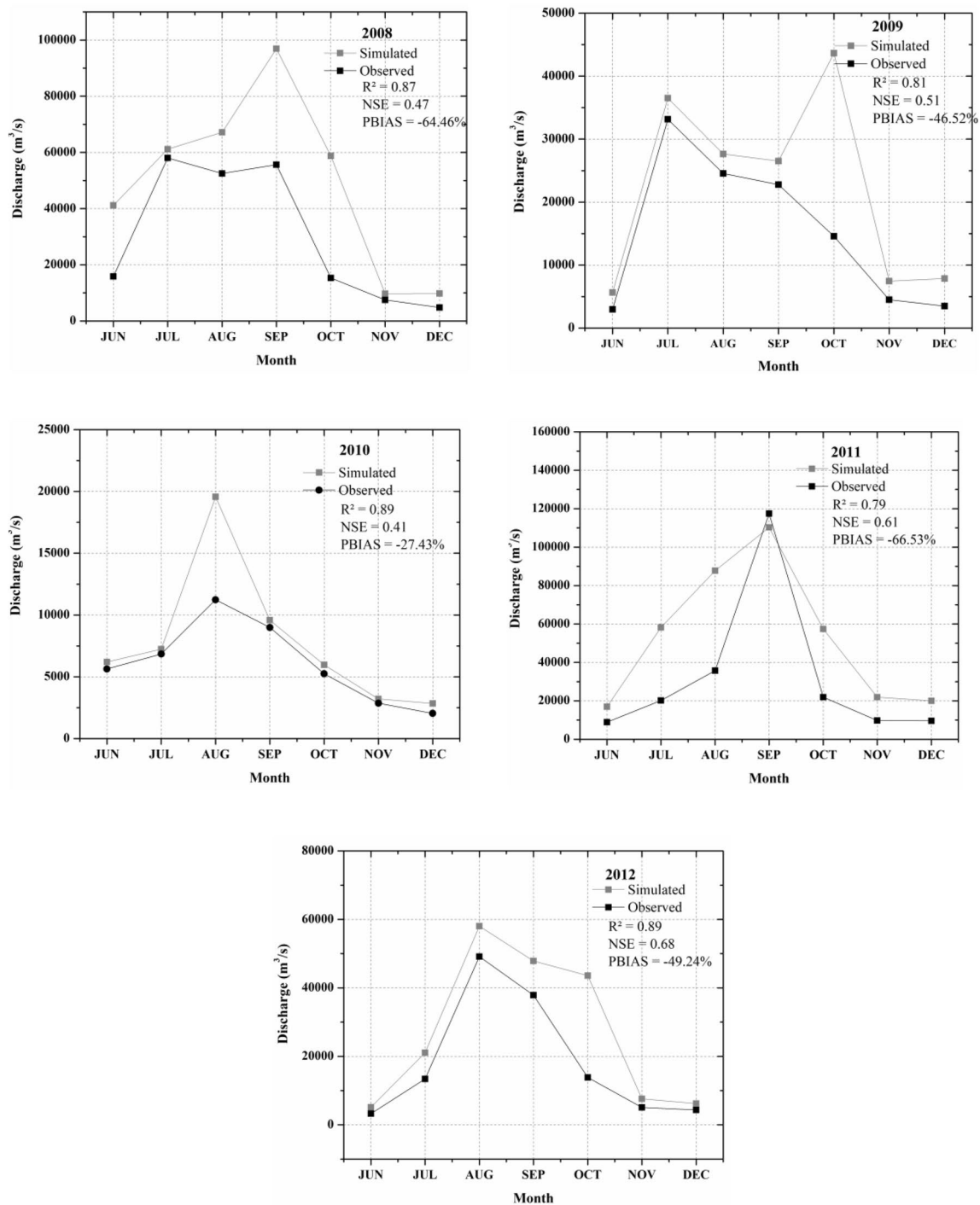
Fig. 11 Calibration for 2008–2010 and validation for 2011–2012 at Jenapur gauging station

and global mean were used in a hydrological model for streamflow estimation. Yu et al. (2018) developed LULC planning scenarios based on land suitability and impact on eco-hydrological responses in the Huaihe river basin, China. The surface runoff and groundwater were considered to land use planning scenarios because they more sensitive parameters compared to other parameters for eco-hydrological responses. It was beneficial to terrestrial and aquatic ecosystems. Jin et al. (2019) considered multi-year LULC data in the SWAT model for the impact of the hydrological process by interception, infiltration, evapotranspiration, and groundwater recharge. It was observed that multi-year LULC data may better improve the hydrological model compared to single-year LULC data. The

present study was considered single-year LULC data in the SWAT model because no variability of LULC features for multi-year LULC data.

Conclusion

The present research is an estimation of river streamflow using SWAT hydrological modeling considering climate change impact for the small river basin. The objective is to focus on the sub-watershed-wise spatial distribution of hydrological parameters in the Brahmani River basin by the GIS platform. However, five hydrological variables were estimated namely ET, PET, SURQ, SW, and WYLD from 2000 to 2014. The spatial distribution results show that minimum and maximum ETs are 111.73 and 1311.31 mm for the years 2014 and 2010. It was observed that maximum PET (2378.15 mm) showed in the sub-watershed nos. 78 and 100 for the year of 2009. The results also show that the highest SURQ (622.22 mm) showed in the sub-watershed nos. 53 and 55 for the year of 2011. It was also observed that minimal SW (0.01 mm) showed in the sub-watershed nos. 10, 24, 36, 39, 48, 58, 60, 96 for the year 2011. The main goal of this study is the use of the hydrological model to estimate streamflow and assess their impacts on water resources. The calibration and validation have been performed for the year 2008 to 2010 and 2011 to 2012. The four gauge stations, namely Tilga, Gomlai, Panpos, and Jenapur, were used for calibration and validation purposes. The results also show that streamflow increased in the monsoon season and decreased in the non-monsoon season. It is a general condition of any river system. However, SWAT model-generated data can utilize for flood and drought modeling (e.g., runoff, streamflow, ET, water yield), groundwater modeling (e.g., discharge, ET), water evaluation and planning system (e.g., streamflow, recharge, ET), and watershed management (e.g., runoff, streamflow, ET, PET, water yield,) purposes (Sahoo et al. 2020). Moreover, the resulting maps provide a suitable guideline for the planning of detailed water resources planning and management. The major drawback of the research is coarse spatial resolution data utilized for setting up the physically based hydrological model. The results obtained are quite satisfactory. This model is flexible and can be implemented as per the availability of data in different small to large basins. It can be considered as a hydrological transport model on a watershed scale.

Declarations

References

Anand J, Gosain AK, Khosa R (2018) Prediction of land use changes based on land change modeler and attribution of changes in the water balance of Ganga basin to land use change using the SWAT model. Sci Total Environ 644:503–519

Andrade CW, Montenegro SM, Montenegro AA, Lima JRDS, Srinivasan R, Jones CA (2019) Soil moisture and discharge modeling in a representative watershed in northeastern Brazil using SWAT. Ecohydrol Hydrobiol 19(2):238–251

Arnold JG, Moriasi DN, Gassman PW, Abbaspour KC, White MJ, Srinivasan R, Kannan N (2012) SWAT: model use, calibration, and validation. Trans ASABE 55(4):1491–1508

Arnold JG, Kiniry JR, Srinivasan R, Williams JR, Haney EB, Neitsch SL (2013) SWAT 2012 input/output documentation. Texas Water Resources Institute

Ayivi F, Jha MK (2018) Estimation of water balance and water yield in the Reedy Fork-Buffalo Creek Watershed in North Carolina using SWAT. Int Soil Water Conserv Res 6(3):203–213

Bal M, Dandpat AK, Naik B (2021) HHydrological Modeling with respect to Impact of Land-Use and Land-Cover Change on the Runoff Dynamics in Budhabalanga River Basing using ArcGIS and SWAT Model. Remote Sens App Soc Environ 23:100527

Begou JC, Jomaa S, Benabdallah S, Bazie P, Afouda A, Rode M (2016) Multi-site validation of the SWAT model on the Bani catchment: model performance and predictive uncertainty. Water 8(5):178

Bhatt VK, Tiwari AK, Sena DR (2016) Application of SWAT model for simulation of runoff in micro watersheds of lower Himalayan region of India. Indian J Soil Conserv 44(2):133–140

Bizuneh BB, Moges MA, Sinshaw BG, Kerebih MS (2021) SWAT and HBV models' response to streamflow estimation in the upper Blue Nile Basin, Ethiopia. Water-Energy Nexus 4:41–53

Chanapathi T, Thatikonda S, Keesara VR, Ponguru NS (2020) Assessment of water resources and crop yield under future climate scenarios: a case study in a Warangal district of Telangana, India. J Earth Syst Sci 129(1):1–17

Choto M, Fetene A (2019) Impacts of land use/land cover change on stream flow and sediment yield of Gojeb watershed, Omo-Gibe basin, Ethiopia. Remote Sens Appl: Soc Environ 14:84–99

Das B, Jain S, Singh S, Thakur P (2019) Evaluation of multisite performance of SWAT model in the Gomti River Basin, India. Appl Water Sci 9(5):134

de Oliveira Serrão EA, Silva MT, Ferreira TR, de Ataide LCP, dos Santos CA, de Lima AMM, Gomes DJC (2021) Impacts of land use and land cover changes on hydrological processes and sediment yield determined using the SWAT model. Int J Sediment Res

Eini MR, Javadi S, Delavar M, Gassman PW, Jarihani B (2020) Development of alternative SWAT-based models for simulating water budget components and streamflow for a karstic-influenced watershed. CATENA 195:104801

Gashaw T, Tulu T, Argaw M, Worqlul AW (2018) Modeling the hydrological impacts of land use/land cover changes in the Andassa watershed, Blue Nile Basin, Ethiopia. Sci Total Environ 619:1394–1408

Gong X, Bian J, Wang Y, Jia Z, Wan H (2019) Evaluating and predicting the effects of land use changes on water quality using SWAT and CA–Markov models. Water Resour Manag 33(14):4923–4938

Guug SS, Abdul-Ganiyu S, Kasei RA (2020) Application of SWAT hydrological model for assessing water availability at the Sherigu

catchment of Ghana and Southern Burkina Faso. HydroRes 3:124–133

Islam A, Sikka AK, Saha B, Singh A (2012) Streamflow response to climate change in the Brahmani River Basin, India. Water Resour Manag 26(6):1409–1424

Jain SK, Tyagi J, Singh V (2010) Simulation of runoff and sediment yield for a Himalayan watershed using SWAT model. J Water Resour Prot 2(03):267

Jaiswal RK, Lohani AK, Tiwari HL (2020) Development of framework for assessment of impact of climate change in a command of water resource project. J Earth Syst Sci 129(1):58

Jin X, Jin Y, Yuan D, Mao X (2019) Effects of land-use data resolution on hydrologic modelling, a case study in the upper reach of the Heihe River, Northwest China. Ecol Model 404:61–68

Khoi DN, Suetsugi T (2014) Impact of climate and land-use changes on hydrological processes and sediment yield—a case study of the Be River catchment, Vietnam. Hydrol Sci J 59(5):1095–1108

Martínez-Retureta R, Aguayo M, Stehr A, Sauvage S, Echeverría C, Sánchez-Pérez JM (2020) Effect of land use/cover change on the hydrological response of a Southern Center Basin of Chile. Water 12(1):302

Martínez-Salvador A, Conesa-García C (2020) Suitability of the SWAT model for simulating water discharge and sediment load in a karst watershed of the semiarid mediterranean basin. Water Resour Manag 34(2):785–802

Mirza MMQ (2003) Climate change and extreme weather events: can developing countries adapt? Clim Policy 3(3):233–248

Musie M, Sen S, Chaubey I (2020) Hydrologic responses to climate variability and human activities in Lake Ziway Basin, Ethiopia. Water 12(1):164

Naseri F, Azari M, Dastorani MT (2021) Spatial optimization of soil and water conservation practices using coupled SWAT model and evolutionary algorithm. Int Soil Water Conserv Res

Effects of Digital Elevation Model Resolution on Watershed-Based Hydrologic Simulation. Water Res Manage Int J Published for the European Water Resources Association (EWRA) 34:2433–2447

Rostamian R, Jaleh A, Afyuni M, Mousavi SF, Heidarpour M, Jalalian A, Abbaspour KC (2008) Application of a SWAT model for estimating runoff and sediment in two mountainous basins in central Iran. Hydrol Sci J 53(5):977–988

Sahoo S, Dhar A, Debsarkar A, Kar A (2018) Impact of water demand on hydrological regime under climate and LULC change scenarios. Environ Earth Sci 77(9):341

Sahoo S, Dey S, Dhar A, Debsarkar A, Pradhan B (2019) On projected hydrological scenarios under the influence of bias-corrected climatic variables and LULC. Ecol Ind 106:105440

Sahoo S, Dhar A, Debsarkar A, Pradhan B, Alamri AM (2020) Future water use planning by water evaluation and planning system model. Water Resour Manag 34(15):4649–4664

Shi W, Huang M (2021) Predictions of soil and nutrient losses using a modified SWAT model in a large hilly-gully watershed of the Chinese Loess Plateau. Int Soil Water Conserv Res 9(2):291–304

Swain JB, Patra KC (2017) Streamflow estimation in ungauged catchments using regionalization techniques. J Hydrol 554:420–433

Uniyal B, Jha MK, Verma AK (2015) Assessing climate change impact on water balance components of a river basin using SWAT model. Water Resour Manag 29(13):4767–4785

Wilby RL (1997) Non-stationarity in daily precipitation series: implications for GCM down-scaling using atmospheric circulation indices. Int J Climatol 17:439–454

Yu D, Xie P, Dong X, Su B, Hu X, Wang K, Xu S (2018) The development of land use planning scenarios based on land suitability and its influences on eco-hydrological responses in the upstream of the Huaihe River basin. Ecol Model 373:53–67

Zeiger SJ, Owen MR, Pavlowsky RT (2021) Simulating nonpoint source pollutant loading in a karst basin: a SWAT modeling application. Sci Total Environ 785:147295

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.