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Journal of Hydro-environment Research 7 (2013) 261–269

Journal of Hydro-environment Research

www.elsevier.com/locate/jher

Research paper

Modeling runoff from an agricultural watershed of western catchment of Chilika lake through ArcSWAT

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Received 23 August 2011; revised 16 April 2013; accepted 19 April 2013

Abstract

Chilika lake is the biggest lagoon in the Indian Eastern coast and is a source of livelihood for peoples of the coastal region surrounding it mainly through fisheries. However, the deposition of sediments in the lake carried through runoff water from its drainage basins may alter this wetland ecosystem in future. Implementation of appropriate soil water conservation measures may reduce the sediment load in runoff water and thus may protect this lagoon ecosystem. Keeping in view these concerns, runoff water from a selected watershed of western catchment of Chilika lagoon was modeled through ArcSWAT with a purpose to estimate future runoff potential from western catchment. Effective hydraulic conductivity of main channel, base flow alpha factor, curve number corresponding to antecedent moisture content II, and roughness coefficient of main channel were found most sensitive parameters in decreasing order. Nash–Sutcliffe coefficient of predicted monthly runoff was 0.72 and 0.88 during calibration and validation period, respectively whereas root mean squared error of predicted monthly runoff was 54.5 and 66.1 mm, respectively. Modeling results indicated that about 60% of rainfall is partitioned to runoff water, which carry significant amount of sediment load and contributes to Chilika lake.

Keywords: Runoff estimation; Hydrological modeling; Lake ecosystem; Tropical watershed; Rainfall–runoff relationship

1. Introduction

The Chilika lake is the biggest lagoon on Indian Eastern coast with a maximum area of 1165 km^2 during the monsoon season and a minimum of 906 km^2 during the summer season (Pattnaik, 2003). Freshwater runoff from the drainage basin, combined with saline water inflows from the ocean result in a wide range of fresh, brackish, and saline water environments supporting an exceptionally productive ecosystem. The Chilika lagoon is well known for several reasons: wintering site for many migratory birds, home to the Irrawady dolphin, source of livelihood of the local people (mainly through fisheries), focus of cultural, religious, and spiritual activities etc. One of the major problems of the Chilika lake is the deposition of sediments carried along with the runoff water from its drainage basins and thus this wetland ecosystem may be altered.

Hydrologically, Chilika is influenced by three subsystems: Mahanadi river system in the North, rivers flowing in the lagoon from the western catchment, and the Bay of Bengal. The western catchment of Chilika lagoon is predominant with laterite soils. Hill streams in this catchment area form gullies and ravines, which are often interspersed with depressions and filled with alluvium. The western catchment contributes an average of 0.3 million ton of sediment per year to the Chilika lake system. Although the rainfall in the region is quite high, the watershed suffers water scarcity also

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1570-6443/$ - see front matter
http://dx.doi.org/10.1016/j.jher.2013.04.005

during prolonged dry spell in summer season and even during monsoon season. Due to undulating terrain in the hillslope, runoff water in the streams is only visible during monsoon season. Water management options like construction of check dams or open wells to store excess water are not fully adopted in the area. Moreover, major changes in land use pattern in the catchment area alter the hydrological set up of the catchment. Rice is main agricultural crop of the area and is totally rainfed. Few farmers grow pulses during *rabi* season on residual soil moisture with suboptimal yield level. Judicious use of rainwater through conservation measures for crop production is totally absent. Few scattered ponds are available to store excess rainwater during monsoon season, which are mainly used to grow rabi crops and vegetables, but are very limited. Therefore, a major portion of rainwater has been contributed to runoff, which ultimately carries top soil as sediment load. It indicates the need for future soil water conservation plan within the western catchment with an aim to use the available water resources in a sustainable way and to reduce the sediment load, which may be achieved through modeling effort.

Over the last few decades, a great stride is made on developing physically-based and distributed-parameter hydrological models (e.g., SWAT, SHE, AGNPS, etc.), which are capable of generating area-wise and hydrologic process-wise outputs over a watershed. Physical laws governing hydrological processes are taken into account in these models. Once parameterized, such models may be directly applied to ungauged basins. Physically-based models are only applied across scales if the parameters and inputs are completely homogeneous, which is not commonly the case. To overcome this constraint, physically-based models are implemented by discretizing the watershed into hydrological response units (HRUs), solving the physically-based governing non-linear hydrological equations for each zone, and by aggregating the outputs (Wood et al., 1988; Kite and Kouwen, 1992; Liang et al., 1994; Flügel, 1995, 1997; Leavesley and Stannard, 1995). The term ‘distributed-parameter’ stems from such segregation of watershed and parameterization of each unit.

The watershed loading/water quality model, Soil Water Assessment Tool (SWAT), developed by the United States Department of Agriculture-Agriculture Research Service (USDA-ARS), is used by many users for simulating stream flow and sediment load due to its capability of handling GIS-based inputs and other user-friendly options. A detailed description of SWAT is given in Neitsch et al. (2005) and Arnold et al. (1998). In the recent version of SWT interface, ArcSWAT, HRUs are delineated by overlaying land use, soil and slope grid. During last decade, SWAT has been used for many watershed applications in India (Tripathi et al., 2003, 2004, 2005, 2006; Kamble et al., 2003, 2005; Kaur et al., 2003a, 2003b, 2004; Gosain et al., 2006; Mishra et al., 2007; Immerzeel et al., 2008; Garg et al., 2012). Specifically, Garg et al. (2012) showed through modeling of water balance components using SWAT that adoption of agricultural water management interventions e.g. checks dams or in situ water management practices helped in increased water availability by 10–30% and better crop yields compared to no-intervention. Therefore, in the present study, an attempt was made to model the water balance components in a micro-watershed from western catchment of Chilika lake using ArcSWAT with the final aim to reduce sediment load into Chilika lake through runoff water.

2. Materials and methods

2.1. Description of study area

The present study was carried out at the Dengei Pahad Watershed (DPW), which is a part of the western catchment of Chilika lake system in Orissa, India and falls within the North–Eastern Ghat agro-climatic zone under hot and sub-humid climate (Fig. 1). It is located between 19°49′48″–19°52′8.4″ N and 85°13′55.2″–85°14′34.8″ E. Detailed description of the DPW watershed is given in Santra and Das (2008). The average annual rainfall of the study area is 1130 mm, of which major portion occurs during monsoon season from June to September. The area is a hilly terrain with the mean sea level varying from 5 to more than 451 m. The hills and isolated rocky knobs break the watershed into small but well cultivated fields. Discharge of several gauging stations at western catchment was measured by Chilika Development Authority, Bhubaneswar as a part of regular monitoring of runoff and sediment load in Chilika lake. The measured daily flow data ($m^3\ s^{-1}$) at the ‘Badanai’ gauging station during 2004–2006 was collected and used in the present study. Discharge from the catchment was generally measured during monsoon season only. For remaining periods of the season, negligible amount of flow exists in the stream.

2.2. Model input

ArcSWAT version 1.0.7 was used to prepare the input database for SWAT run. The SWAT model requires three GIS data layers (digital elevation model (DEM), soils, and land use) and the weather data of the study area.

2.2.1. Elevation grid

The DEM of the study area was downloaded from http://srtm.csi.cgiar.org/, where elevation data at 90 m resolution acquired through shuttle radar topographic mission (SRTM) is available for the globe (Rabus et al., 2003). The model calculates sub-basin parameters such as slope and slope length as well as the definition of the stream network using the DEM. The delineated stream network of the watershed from ArcSWAT interface exactly matches with the observed stream network both in the toposheet of the area and as identified from remotely sensed image. The resulting stream network was used to delineate the entire watershed into a reasonable number of sub-basins. Before the DEM was used for modeling, it was projected to Universal Transverse Mercator (UTM) under appropriate zones. The study area falls in the UTM zone number 45. The DEM of the delineated watershed is shown in Fig. 2a.

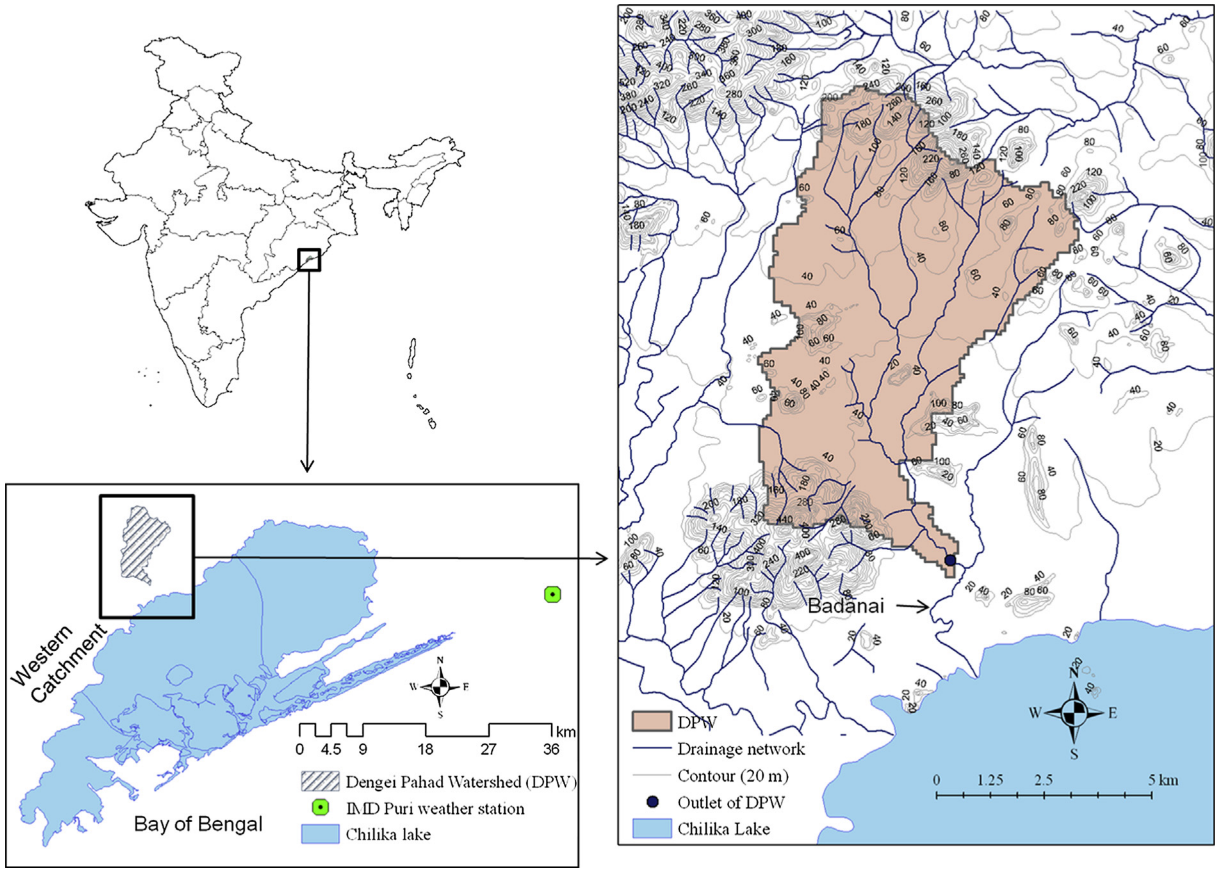

Fig. 1. Location of Dengei Pahad Watershed (DPW) in western catchment of Chilika lake, Orissa, India.

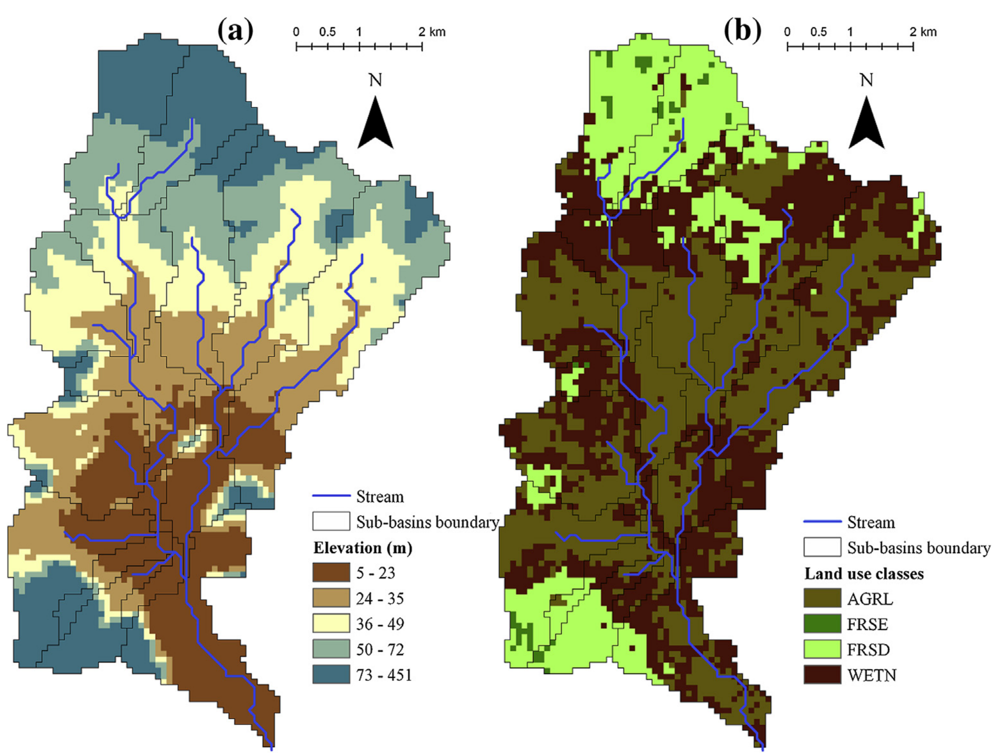

Fig. 2. GIS-based grids of the watershed used in SWAT simulation; (a) Digital elevation model and (b) Land use class grid of the watershed.

2.2.2. Land use grid

Land use grid was prepared from the AWiFs image acquired by IRS-P6 satellite. Raw image was classified into land use classes with the help of ground truth data using ERDAS IMAGINE version 8.0. The classified land use map of the watershed is given in Fig. 2b. The land use classes of the watershed are agricultural land (41.65%), forested area with evergreen and deciduous trees (21.72%), and wetlands with natural shrubs (36.63%). In agricultural land, rice is mainly grown during *kharif* season, which is totally rainfed and followed by fallow. Rabi crops are rarely grown in the area.

2.2.3. Soil grid

Soil series map at 1:250,000 scale for Orissa state, published by National Bureau of Soil Survey & Land Use Planning (NBSS and UP, 2005), was used as the source of soil database and soil grid. Detailed soil data from this report are given in Table 1. Soil hydraulic data, which are unavailable in the report, were estimated by pedotransfer functions developed from this study (Santra and Das, 2008). According to soil series map, 69% of the watershed is under a single soil series, Nuagarh.

2.2.4. Weather data

SWAT requires daily values of weather data as an input. These data are precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed. To run SWAT one can either prepare a file that contains observed data, or use daily values simulated by the SWAT model weather generator. In the present study, daily weather data including rainfall, maximum temperature, minimum temperature, relative humidity, and wind speed were collected for 11 years (1996–2006) from Puri weather station of Indian Meteorological Department (IMD), which is marked in Fig. 1. Measured meteorological data within the watershed was searched but it was unavailable except few observations on rainfall events for a location. The best available meteorological data near to watershed was from IMD Puri weather station, which was collected and used in the present study. Moreover, physiographic similarity (both are very near to coast) of the DPW and the IMD Puri weather station had prompted us to select this weather station as the source of weather data. Moreover, available few rainfall data within the DPW was compared with the rainfall data of IMD Puri station and close proximity was observed. Therefore, in spite of expected loss in accuracy of model performance, weather data outside the watershed was used. Observed solar radiation data was not available for IMD Puri station and therefore was calculated from maximum and minimum temperature (Hargreaves and Samani, 1985). Monthly averages of these data were calculated for this weather station and included in the weather generator database (Table 2). It is noted here that the annual potential evapotranspiration (PET) of the study area is about 1400–1500 mm. We have used observed daily weather data for the simulation of SWAT. In case of missing data, weather generator was used to estimate that data.

2.3. Sub-basin delineation

A total of 17 subbasins were delineated using a default minimum value of sub-watershed area as 116 ha. Each subbasin contains at least one HRU. Each HRU has uniform

Table 1
Soil database of the watershed obtained from the soil series map of Orissa at 1:250,000 scale, published by NBSS and LUP (2005).

Soil series	Horizon depth (cm)	Soil properties						
		Organic carbon (%)	Sand (%)	Silt (%)	Clay (%)	Coarse frag. Vol (%)	pH	EC (dS m^{-1})
Singarazu	0–13	0.36	66.9	14.4	18.7	–	5.3	0.08
	13–28	0.28	50	23.5	26.5	–	5.6	0.08
	28–60	0.17	50.5	19.1	30.4	–	5.8	0.04
	60–90	0.20	50.1	18.2	31.7	4	5.8	0.03
	90–127	0.12	55.6	17.3	27.1	7	5.8	0.03
Tarlakota	0–9	0.26	64.4	20.7	14.9	4	5.4	0.10
	9–41	0.20	60.3	21.1	18.6	12	5.8	0.08
	41–83	0.20	58.2	19.3	22.5	18	6	0.09
	83–102	0.16	57.1	18.1	24.8	25	6.3	0.05
Jamguda	0–18	1.82	33	37.7	29.3	–	6	0.95
	18–42	1.07	27	31.3	41.7	–	6	0.47
	42–68	0.67	26.8	30	45.2	–	6.1	0.38
	68–96	0.58	43.1	22.8	34.1	–	6.1	0.35
	96–124	0.47	45.3	23.1	31.6	–	6.2	0.27
	124–152	0.33	22.2	32	45.8	–	6	0.21
Nuagarh	0–21	0.6	14.4	48.5	37.1	–	7.3	0.42
	21–48	0.54	13.6	43.5	42.9	–	7.6	0.27
	48–82	0.35	35.6	15.4	49	–	7.9	0.13
	82–105	0.36	38.7	15.2	46.1	–	8	0.95
	105–155	0.2	40.2	14.8	45	–	8.2	0.76
Bandhadwar	0–14	0.80	47.6	15.6	36.8	50	5	0.05
	14–31	0.60	42.5	12.6	44.9	65	5	0.05
	31–69	0.40	44.5	10.0	45.5	75	4.9	0.05

Table 2
Weather parameters for Puri weather station of Indian Meteorological Department.

Weather parameters[a]	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
TMPMX	27.36	29.25	31.01	31.84	33.10	32.22	31.62	31.42	32.09	31.88	30.37	28.18
TMPMN	17.84	21.63	25.15	26.71	27.81	27.55	27.02	26.91	27.02	25.55	21.68	17.77
TMPSTDMX	1.29	1.49	1.00	1.00	1.09	1.71	1.67	1.59	1.62	1.93	1.52	1.39
TMPSTDMN	2.54	2.71	1.69	1.63	2.00	1.72	1.49	1.25	1.22	1.56	2.25	1.75
PCPMM	13.10	37.97	26.72	26.72	55.71	410.95	394.91	347.55	259.50	206.29	45.75	17.79
PCPSTD	3.07	8.03	4.38	4.61	7.48	50.00	35.27	24.00	20.86	20.53	7.74	6.13
PCPSKW	7.00	7.00	6.59	6.69	6.54	6.97	5.13	4.31	4.47	4.94	6.38	7.00
PR_W1	0.04	0.06	0.08	0.1	0.15	0.29	0.36	0.51	0.36	0.2	0.06	0.02
PR_W2	0.32	0.18	0.28	0.26	0.2	0.63	0.71	0.73	0.69	0.58	0.44	0.4
PCPD	1.73	2.00	3.27	3.82	5.00	13.18	18.09	21.27	16.82	10.91	3.55	1.36
RAINHHMX	15.00	15.00	20.00	25.00	30.00	35.00	35.00	40.00	40.00	25.00	20.00	15.00
SOLARAV	15.72	15.76	15.82	16.10	16.86	15.96	15.70	15.22	15.05	14.97	15.35	15.71
DEWPT	18.42	22.00	24.94	25.00	25.00	25.00	25.00	25.00	25.00	25.00	21.10	17.55
WNDAV	2.21	2.38	3.14	3.64	3.58	3.45	2.96	2.90	2.40	1.76	1.43	1.76

TMPMX = Average maximum temperature for a month (°C), TMPMN = Average minimum temperature for a month (°C), TMPSTDMX = Standard deviation for maximum temperature in month, TMPSTDMN = Standard deviation for minimum temperature in month, PCPMM = average amount of precipitation (mm H_2O), PCPSTD = Standard deviation of daily precipitation in month, PCPSKW = Skew coefficient of daily precipitation in month, PR_W1 = Probability of a wet day following a dry day, PR_W2 = Probability of a wet day following a wet day, PCPD = Average number of days of precipitation in month, RAINHHMX = Extreme half-hour rainfall for month, SOLARAV = Average daily solar radiation for month (MJ m^{-2}).DEWPT = average dew point temperature for month (°C), WNDAV = Average wind speed in month (m s^{-1}).

[a] Details description of each weather parameter is available in SWAT manual (Neitsch et al., 2005).

land cover and soil type. The smaller the area assigned to each sub-basin, the more the number of subbasins and the more detailed the drainage network (Di Luzio et al., 2002). A less detailed watershed can be delineated by choosing few but larger size sub-basins. The total number of HRUs was 60. Bingner et al. (1997) evaluated sub-watershed size dependency of the SWAT erosion model and reported that runoff volume is not appreciably affected by the number and size of sub-watersheds.

2.4. Calibration and validation of SWAT

The SWAT model was calibrated with the observed monthly runoff from the DPW during the year 2004 and 2005. Calibrated parameters were then validated in the year 2006 to simulate monthly runoff. During calibration, 8 years of daily weather data from 1996 to 2003 were used for stabilization of SWAT model set up. Before calibration, sensitive parameters were identified through sensitivity analysis. During sensitivity analysis, sum of square on residual (SSR) was used as objective function. Sensitive parameters were calibrated with PARASOL optimisation method using auto-calibration option. Detailed description on this optimization algorithm is given in advanced manual on ArcSWAT. Briefly, in the PARASOL algorithm as implemented with Neitsch et al. (2005), parameters affecting hydrology or pollution can be changed either in a lumped way (over the entire catchment), or in a distributed way (for selected sub-basins or HRUs). They can be modified by replacement, by addition of an absolute change or by a multiplication of a relative change. A relative change means that the parameter or several distributed parameters simultaneously, are changed by a certain percentage. However, a parameter is never allowed to go beyond the predefined parameter ranges. Out of eight selected sensitive parameters, except SURLAG, all are HRU related parameters. SURLAG is the watershed parameter and only one value for the total watershed is calibrated. Except SCS curve number for moisture condition II (CN2), all the HRU related parameters were changed in a lumped way (Table 3). To keep the relative physical difference in CN2 along HRUs, this parameter was changed by multiplication of a value.

The efficiency and performance of the SWAT model calibration and validation was assessed according to Nash—Sutcliffe coefficient (Nash and Sutcliffe, 1970) which is given by

$$\mathrm{NSC} = 1 - \frac{\sum_{i=1}^{n} (M_i - O_i)^2}{\sum_{i=1}^{n} \left(O_i - \overline{O}_i\right)^2} \tag{1}$$

where, M_i is the modeled or simulated runoff, O_i is the observed runoff, $\overline{O}_i$ is the mean of observed runoff, and n is the number of observations. The value ranges between $-\infty$ to 1 and the higher the value the more efficient is the prediction. Value of N—S coefficient can range from $-\infty$ to 1. A value of N—S coefficient of 1 corresponds to a perfect match of modeled runoff to the observed data. N—S coefficient of 0 indicates that the model predictions are as accurate as the mean of the observed data, whereas a coefficient less than zero occur when the observed mean is a better predictor than the model. Besides, N—S coefficient, root-mean-squared error (RMSE) was also calculated *o* evaluate the magnitude of error in predicted monthly runoff as follows:

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}(M_i - O_i)^2} \tag{2}$$

Table 3
Sensitive parameters for daily simulation of flow in the watershed using SWAT set up with hydrologically classified soil map (SWAT-Hydro) and SWAT set up with soil series map (SWAT-Series).

Parameters	Rank of parameters in sensitivity analysis	Replacement method[a]	Calibrated values
Alpha_Bf	2	1	0.1269
CH_K2	1	1	491.10
CH_N	4	1	0.0300
CN2	3	3	+22.48
ESCO	6	1	0.0226
GWdelay	13	1	480.69
GWqmn	17	1	5000
Surlag	5	1	18.563

Alpha_Bf = Base flow alpha factor (days); CH_K2 = Effective hydraulic conductivity in main channel alluvium (mm/hr); CH_N = Manning's roughness coefficient value for the main channel; CN2 = Initial SCS runoff curve number for moisture condition II; ESCO = Soil evaporation compensation factor; GWdelay = Groundwater delay time (days); GWqmn = Threshold depth of water in the shallow aquifer required for return flow to occur (mm H_2O); Surlag = Surface runoff lag coefficient.

[a] If replacement method is 1 then parameters were replaced by value and if it is 3 then, parameters were multiplied by value (%) during calibration.

Both these indices measure the goodness of fit of the predicted runoff with observed runoff, however, N–S coefficient indicates that how much predicted data matches with observed data whereas RMSE indicates the magnitude of error in predicted data.

3. Results and discussion

3.1. Rainfall–runoff relationship in the watershed

Rainfall–runoff relationship in the watershed is depicted in Fig. 3. During summer months and initial period of monsoon, rainwater does not significantly contribute to runoff since major portion of rainwater is utilized to wet the soil profile. However, subsequent rainfall events significantly contribute to runoff because soil profile and vadose zone almost reaches to saturation stage at that time. Runoff from the watershed was generally observed during July to November in a year. During rest of the periods, stream remains dry. Overall, it was found that runoff flow rate was higher during 2006 than during 2004 and 2005. This was mainly due to higher rainfall (2115.6 mm) during 2006 than during 2004 and 2005 (1161.2 mm and 1669.2 mm, respectively).

3.2. Sensitive parameters for flow

Sensitive parameters for simulation of the mean daily flow for a month are given in Table 3. Out of 26 parameters included in SWAT for flow simulation, six parameters are related with snow melt and therefore not important for this tropical watershed. Six most sensitive parameters were selected for calibration purpose. Other than these six, two groundwater related parameters, such as GWqm and GWdelay were also selected because of their comparatively high sensitivity. The selected parameters are mentioned below according to their physical significance.

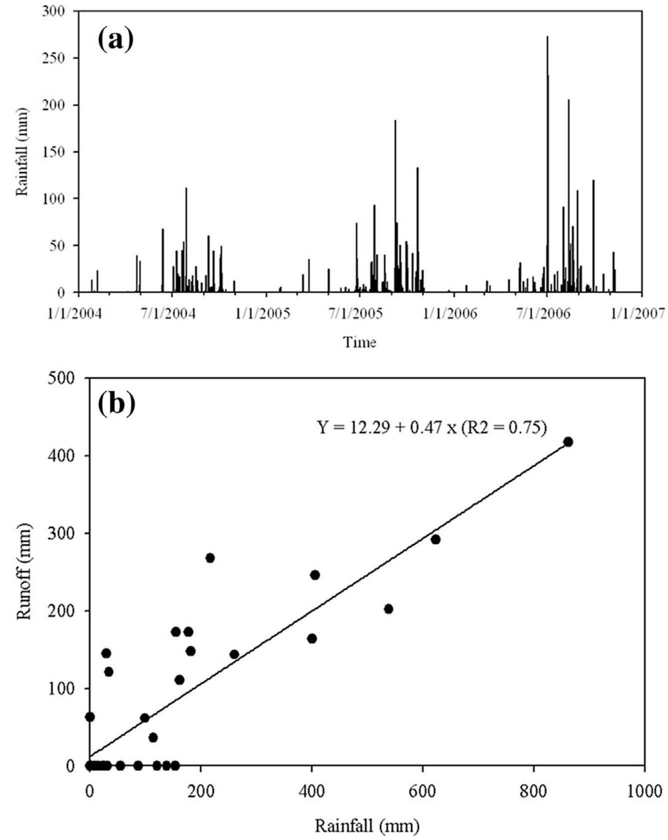

Fig. 3. Rainfall–runoff relationship of Dengei Pahad Watershed (DPW), (a) Daily rainfall frequency during 2004, 2005 and 2006, (b) Rainfall–runoff relationship in DPW watershed.

i) ALPHA_BF: Base flow alpha factor (days),
ii) CH_K2: Effective hydraulic conductivity in main channel alluvium (mm h^{-1}),
iii) CH_N: Manning's roughness coefficient for the main channel,
iv) CN2: Initial SCS runoff curve number for moisture condition II,
v) ESCO: Soil evaporation compensation factor,
vi) GW_DELAY: Groundwater delay time (days).
vii) GWQMN: Threshold depth of water in the shallow aquifer required for return flow to occur (mm H_2O), viii) SURLAG: Surface runoff lag coefficient.

3.3. Calibration

The calibrated parameters obtained from auto-calibration are presented in Table 4. The value of Alpha_Bf for the SWAT set up was 0.1269, which indicated a slow response of recharge to groundwater flow. High value of hydraulic conductivity (CH_K2) and roughness coefficient (CH_N) for main channel was observed. Presence of sand and gravels in the main channel of this hilly watershed leads to such high value. Specifically the bed materials of channels at higher elevations with steep slopes mainly consist of sand and gravels. The main channels of sub-basins near to the outlet are high in silt and clay content and therefore, low value of hydraulic conductivity

Table 4
Nash–Sutcliffe coefficient (NSC) and root mean square error (RMSE) of the predicted monthly runoff (mm) using SWAT set up in the watershed.

Time period	Season	NSC	RMSE (mm)
Calibration			
2004	Total year	0.69	54.8
	Monsoon	0.24	76.1
2005	Total year	0.81	54.3
	Monsoon	0.55	69.0
2004–05 (pooled)	Total year	0.76	54.5
	Monsoon	0.45	72.6
Validation			
2006	Total year	0.88	66.1
	Monsoon	0.76	91.4

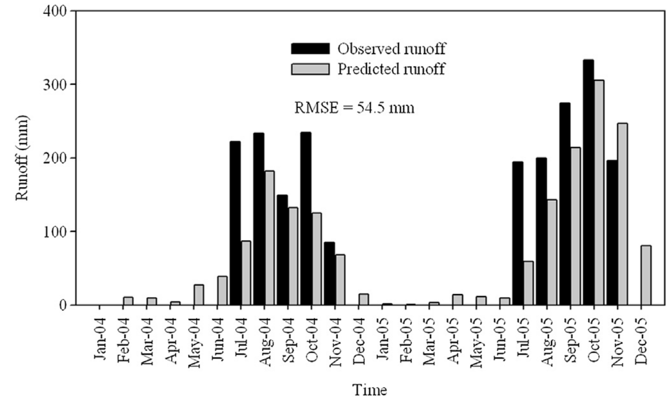

Fig. 4. Observed and simulated runoff in Dengei Pahad Watershed (DPW) during the calibration period (2004–2005).

and roughness coefficient are expected for this zone. We used only one value of these two parameters for all sub-basins and hence represent the average for all sub-basins. The SCS CN was the distributed parameter in SWAT and hence each HRU was assigned with different CN2 number. Overall, after calibration CN2 was increased from its initial value by 22%. The final calibrated CN2 values ranged from 76 to 95. In case of agricultural land under Nuagarh and Bandhadwar soil series, CN2 was 95 whereas it was 88 under Jamguda soil series. CN2 value of forested land was 76 under Tarlakota, Jamguda and Singarazu soil series, whereas it was 88 under Nuagarh and Bandhadar soil series. The ESCO value was very low, which indicated that most of the evaporative demand was extracted from deeper soil. The lag time to move water from the bottom of the soil profile to shallow aquifer, i.e. GW_delay was high. Therefore, deeper groundwater table and low contribution of groundwater to stream flow was expected. This was clearly visible from the high GWqmn value (Table 3). The value of SURLAG was high, which indicated less amount of water held in storage, and a high portion of runoff was contributing to the stream.

3.4. *Observed vs simulated monthly runoff*

3.4.1. *Calibration period*

Calibration of the SWAT set up showed that the model performance was improved from its pre-calibrated set up. Observed and simulated monthly runoff during the calibration period is shown in Fig. 4. It was found that the predicted monthly runoff was higher than the observed runoff in most of the months, which may be due to the under prediction of runoff flow during high intensity rainfall events during a month. Daily rainfall data was used for simulation purpose in the present study because sub-daily rainfall data was unavailable, use of which might have improved the simulation of rainfall–runoff process in a better way specifically in case of high intensity rainfall events.

N–S coefficient and RMSE values of predicted monthly runoff during calibration period are mentioned in Table 4. Simulation performance for calibration period considering whole period of a year was better (N–S coefficient = 0.76) than if only monsoon months (June–November) were considered (N–S coefficient = 0.45). RMSE of predicted runoff during calibration period was 54.5 mm whereas for monsoon months of calibration period, it was 72.6 mm. Among two years of calibration period, N–S coefficient and RMSE were better in 2005 than 2004. In the year 2004, significant amount of runoff was predicted by the model during pre-monsoon months (Jan–May) whereas measured data was unavailable and thus resulted in lower N–S coefficient and higher RMSE. Even during monsoon months except September, predicted runoff was quite higher than observed runoff.

3.4.2. *Validation period*

Observed and predicted monthly runoff during validation period is presented in Fig. 5. Overall, predicted monthly runoff matched well with observed runoff except during the month of July and August. During these two months, observed monthly runoff was 396 and 566 mm, respectively, whereas predicted runoff was 288 and 384 mm. Few high intensity rainfall events were observed during these two months of validation period with an occurrence of 273 mm and 232 mm during July 1 and 2, 2006, respectively and 206 mm during Aug 12, 2006, which might have resulted in under prediction of monthly runoff amount.

N–S coefficient and RMSE values for predicted monthly runoff during validation period are mentioned in Table 4. N–S coefficient of predicted monthly runoff during total validation year was 0.88, whereas RMSE was 66.1 mm. If only monsoon months (June–November) are considered, N–S coefficient and RMSE was found 0.76 and 91.4 mm, respectively. Notably, the N–S coefficient was found higher during validation period (0.88) than calibration period (0.76). However, the RMSE of predicted monthly runoff was higher during validation period than calibration period. This indicates that although the model performance in terms of explaining the percent variation in observed runoff data was better during validation period as shown by N–S coefficients but the magnitude of error (RMSE) in predicted runoff is higher during validation period than calibration period.

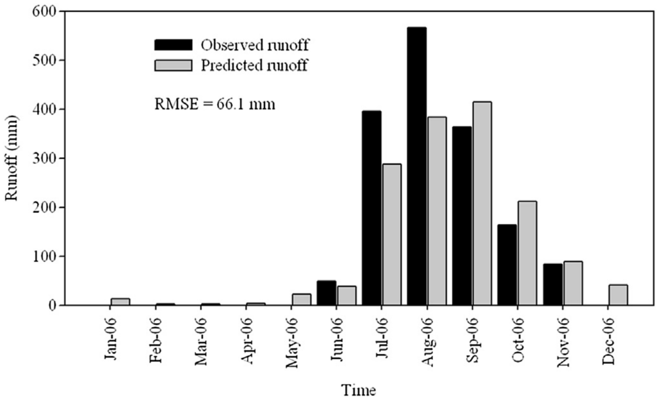

Fig. 5. Observed and simulated runoff in Dengei Pahad Watershed (DPW) during the validation period (2006).

3.5. Predicted runoff and other water balance components in DPW

Other than surface runoff, other hydrological components like ET and groundwater recharge was also checked during SWAT simulation. On an average, annual ET was observed as 30−35% of total rainfall, whereas GW recharge was about 8% and runoff was about 60−65% of total rainfall. In our study, observed runoff was 53−59% of total rainfall, and simulation slightly overestimated the annual runoff. It has been observed that during 2004, with low annual rainfall (1161.2 mm), contribution of annual ET was 42% of total rainfall, whereas during excess rainfall year with occurrence of high intensity rainfall events (Fig. 3a), contribution of ET to total rainfall was only 21%. Contribution of surface runoff was 71% of rainfall during excess rainfall year.

Runoff water generated from the DPW watershed directly contributes to Chilika lake through ‘Badanai’ stream as indicated in Fig. 1. From the modeling result, the predicted total runoff water from DPW during monsoon months (June−November) was found 635, 980, and 1426 mm during 2004, 2005 and 2006, respectively whereas corresponding observed total runoff was 925, 1199, and 1622 mm, respectively.

4. Conclusion

Monthly runoff water from Dengei Pahad Watershed (DPW) located at Western catchment of Chilika lake, Orissa, India was simulated using ArcSWAT in the present study. Measured runoff data at the outlet of the DPW located at the existing torrential stream locally known as ‘Badanai’ during 2004−2006 was used for calibration and validation of SWAT model. Sensitivity analysis revealed that effective hydraulic conductivity of main channel (CH_K), base flow alpha factor (Alpha_bf), curve number corresponding to antecedent moisture content II (CN2), and roughness coefficient of main channel (CH_N) were most sensitive parameters for runoff prediction among 8 identified parameters. All these sensitive parameters were calibrated using observed monthly runoff during 2004−2005 and validated during 2006. Nash−Sutcliffe coefficient of predicted monthly runoff during calibration period was 0.76. Model performance in prediction of runoff was even better during validation period with a N−S coefficient of 0.88. However, the RMSE of predicted monthly runoff was higher during validation period than the calibration period. Total estimated runoff water from the DPW during 2006 was 1509 mm corresponding to an annual rainfall of 2115.6 mm. Modeling results revealed that mean monthly runoff from western catchment may be estimated with reasonable accuracy. The calibrated ArcSWAT model in the selected watershed from the western catchment may help to estimate the total runoff and sediment generation potential in future and thus will help to formulate proper soil water conservation plan to protect this biggest lagoon in India.

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