



Adaptation of satellite-based precipitation product to study runoff and sediment of Indian River watersheds

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Abstract

Modeling of hydrological processes plays a vital role in water resources planning and integrated watershed management. Hydrological models have been developed to estimate the streamflow and sediment yield at the sub-basin scale the using the radar precipitation data. In the present investigation, the Soil and Water Assessment (SWAT) model was configured using radar precipitation data of Tropical Rainfall Measuring Mission (TRMM). This setup model was implemented for three watersheds of different hydrological and climatic conditions in India. The observed streamflow and total suspended solids (TSS) in the watershed outlet were used to execute simulation of setup model. The sequential uncertainty fitting technique (SUFI-2) in SWAT-CUP was adopted for sensitivity analysis, calibration, and validation of SWAT model components. Performance of the developed model was assessed by Nash–Sutcliffe model efficiency (NSE) and coefficient of determination (R^2). The result of the streamflow simulation obtained at Mahanadi, Bharathpuzha, and Wunna watershed show NSE values of 0.78, 0.70, and 0.63 while the R^2 values were 0.81, 0.60, and 0.63 respectively. During streamflow, the model was well simulated for Mahanadi and Bharathpuzha watershed and insignificantly for the Wunna watershed, compared to others. During the simulation of TSS, It was only Mahanadi that was well simulated. Higher runoff and sediment yield were observed in Wunna and Mahanadi, respectively, and insignificant response was observed compared to others in Bharathpuzha. The calibrated parameters and obtained results could be implemented for proper land management practices and watershed management.

Keywords Runoff · Sediment · SWAT · SUFI-2 · TRMM · India

Introduction

Every hydrological component varies widely concerning space and time, making it crucial to apprehend and predict the behaviour of the hydrological system. Therefore, the hydrological modeling is reflected as the soul of hydrological studies due to improved understanding of hydrological process (Rosbjerg and Madsen 2006). Rainfall is a fundamental parameter and is input in all hydrological models. Many of the countries do not have rain gauge station data in real-time. Insufficient rainfall input may result in weaker

consequences. Inadequate rain gauge network leads to poor representation of rainfall distribution over the watershed configuration (Yin et al. 2018), errors in the runoff volume estimation (Harmel et al. 2006), and poor model calibration results (Tan and Yang 2021). Overall, The Tropical Rainfall Monitoring Mission (TRMM) is a joint mission of NASA and Japan aerospace to monitor tropical rainfall. This is an effective tool for measuring rainfall from a satellite system (Nhi et al. 2019) that provide series of widely used precipitation product with global coverage on the different time scale (Huffman et al. 2010). Most of the literature studies used ground measure precipitation and very few studies used satellite precipitation data to model SWAT (Li et al. 2018).

Several researchers compared the reliability and error of satellite TRMM precipitation product and gauged information in many regions, including India (Kneis et al. 2014; Prakash et al. 2015), South America (Ochoa et al. 2014), China (Zhang and Tang 2015; Li et al. 2018), Indonesia (As-Syakur et al. 2011), and West Africa (Nicholson et al. 2003). Collischonn et al. (2008) evaluated the performance

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of TRMM rainfall and against rain gauge rainfall in Tapajós river basin of Brazil using the hydrological model, and found that TRMM estimates were very close to the rain gauge estimates in entire basin in terms of rain field comparison. By comparing the streamflow simulations performance statistics, the result demonstrates that satellite estimate product is reliable and can be useful for aberrant rain gauges.

Streamflow/runoff and sediment yield are the two important components for hydrological simulation to understand the behaviour of watershed and accurate simulation require carefully selection of parameters (Douglas-Mankin et al. 2010). Accurate estimation of runoff and sediment is narrowly in India. Therefore, simulations of hydrological processes are very essential (Zade et al. 2005). Strauch et al. (2012) used various precipitation products to estimate the uncertainty on SWAT model in sparse region (Pipiripau River basin). Associated uncertainty ranges of the model were determined using the Sequential Uncertainty Fitting Procedure. They found that lowest uncertainty level in TRMM compared to other and rainfall input could be transferable for other catchments that will increase the level of confidence in simulation. Jain et al. (2010) studied the combined sediment and runoff simulation in Himalayan watershed using SWAT model on daily and monthly time scale. Coefficient of determination was considered for model performance. Both runoff and sediment simulation were given good result in monthly time scale. Daramola et al. (2019) examined the sediment yield variation at the Kaduna Watershed of Nigeria using suspend sedimentation concentration and SWAT model and predicted highest sediment yield on south-west region. Similarly, other studies have been used total suspended solid to predict the soil erosion or sediment yield (Saleh and Du 2004; Khanal and Parajuli 2013).

Past studies indicate that Indian watersheds are facing several both climate and water resource-related issue. Rehana et al. (2021) and Shah and Mishra (2016) studied the hydrological changes in sub-continent Indian basins and found that evapotranspiration and surface water availability were driven by the fluctuations of monsoon rainfall. Groundwater storage has been depleting for many years in Mahanadi and Godavari basin (Singh and Saravanan 2020a).

According to Rishma and Jasima (2015), Wunna watershed has spatially varied runoff throughout the sub-basin and it was stressed the watershed for higher runoff. Wunna watershed is preferentially known for its wetlands. Singh and Saravanan (2020b) applied the four rainfall product (TRMM, GPCP, CFSR, and APHRODITE) on Wunna river watershed using SWAT model. Performance of the study estimated in rainfall characteristics including number of wet day, accumulated rainfall and average rainfall, and streamflow simulation performance by statistical index. Rainfall statistical performance indicates that TRMM and GPCP have same rainfall accumulation.

Because of the low percentage of wet days, APHRODITE is unsuitable for hydrological studies. The GPCP and TRMM precipitation products are ideally suited for streamflow simulation in the Wunna watershed.

Bharathpuzha watershed is very important for the study, because of the changes in rainfall, it might have affected the hydrological characteristics of the Bharathpuzha watershed (Nikhil Raj and Azeez 2012) and also it was affected by seasonal rainfall, flood and water pressure (Kumar and Abraham 2009; Shah and Mishra 2016). The Mahanadi River basin is especially important to study of hydro-climatic changes, causing the basin prone to frequent flooding, droughts, and cyclones (Dilley et al. 2005). Dutta and Sen (2018) studied the soil erodibility in Mahanadi basin using the SWAT and reported that the basin was highly prone for soil erosion. Therefore, regional studies are necessary to understand the hydrological process and response on these regions.

There have been several hydrological models produced and identified as lumped, semi-distributed, and distributed. Lumped model treats each small unit of the sub-basin as a single unit with all average input data (Moradkhani and Sorooshian 2008; Beven 2012), the distributed model gives spatial information of each point on the watershed, and the semi-distributed model is an extension of the lumped model with features of distributed model, dividing the watershed into small sub-watersheds (Rinsema 2014). While addressing complex problems such as streamflow and sediment yield computation, researchers have always preferred physical-based models. In this research, semi-distributed hydrological Soil and Water Assessment Tool (SWAT) model was used to apprehend the behaviour of the watersheds at large scale that is most application model throughout the world for various application (Goff et al. 2000; Moradkhani et al. 2010; Marin et al. 2020). Arnold et al. (1998) developed the SWAT model under the United States Department of Agriculture (USDA) and introduced. Sequential Uncertainty Fitting (SUFI-2) is the widely used optimization algorithm to simulate the parameters of SWAT model to obtain good model performance (Abbaspour et al. 2007; Yang et al. 2008; Zhou et al. 2014).

In India, few studies have been done with the consideration of more than one watershed using TRMM and SWAT, such as in Mula and Mutha River catchment of Western Ghats (Wagner et al. 2011), Marol watershed of Krishna river basin (Himanshu et al. 2018), and Nagavali river basin in between the Mahanadi and Godavari river basins (Setti et al. 2018). However, just a few studies hydrological modeling have been done for using TRMM satellite precipitation products and sub-basin response on various watersheds in India. In this current study, two watersheds were selected from Central India: Wunna (Lower-Godavari), Mahanadi

(Middle-Mahanadi), and Bharathpuzha river watershed from southern India.

Until now, there is not much work that has been carried associated with clearing understanding of water balance on these watershed using satellite precipitation and hydrological modeling in Wunna, Bharathpuzha, and Mahanadi watershed including streamflow and sediment response. We analysed the successful use of satellite-based precipitation as an input in Indian three river watersheds into hydrological model for prediction surface runoff and sediment yield. This study was giving a clear idea about successful applicability of precipitation product by SWAT model.

The main aims of current study are the following: (1) to set up a SWAT model using satellite-based precipitation data to simulate the water balance components and sediment yield, (2) to analyse the sensitivity of discharge and sediment driving parameters, (3) to evaluate the spatial and temporal variation of water balance components using the SWAT.

Study area

Three watersheds, Wunna, Bharathpuzha, and Mahanadi of Indian river basin were considered as study area (Fig. 1).

- (a) Wunna River (also known as Venna) is located in Maharashtra state of Central India and being a part of the Lower-Godavari basin. Wunna River is flowing in the lower-Godavari basin. The watershed of Wunna river is located around 20°30' to 21°16'N latitude and 78°10' to 79°06' E longitude and its cover around total 4512 km² area. It has 1281-mm average annual rainfall with a tropical climate. In the dry season, the temperature touch up to 47°C and minimum temperature around 15°C during the wet season. The elevation of the watershed is varying 169 to 610 m, where the northernmost portion of the study area has the highest elevation. The Central Water Commission (CWC) of India set up hydro-metrological station to measure daily, monthly discharge and sediment rates. Wunna

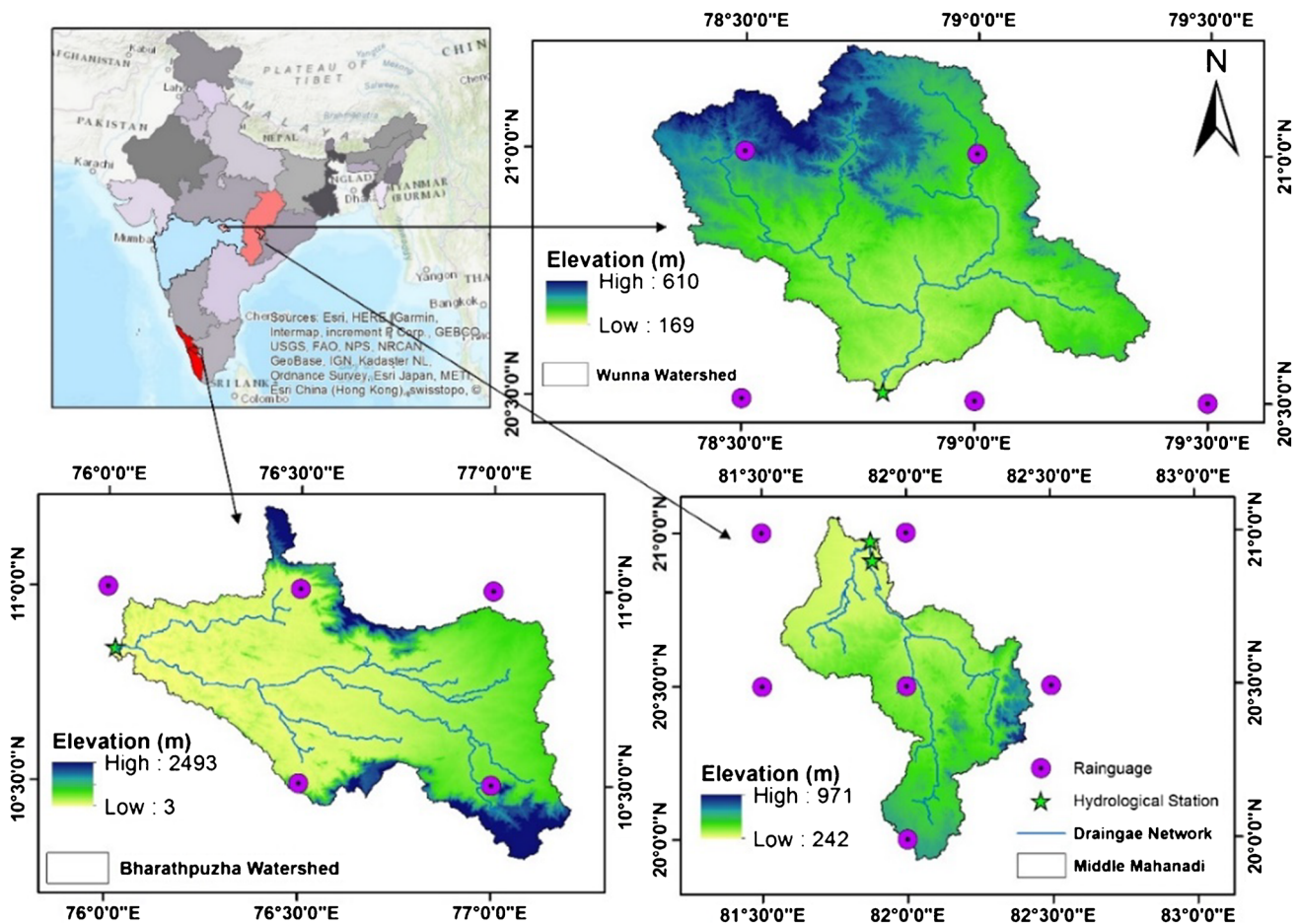


Fig. 1 Study area locations: Wunna watershed, Mahanadi (Middle), and Bharathpuzha

watershed has one streamflow gauging station at Nandgaon (Code-AGG00F2) (Figs. 2, 3, and 4).

- (b) Mahanadi River is situated in Chhattisgarh state of Central-East India. It is originating from Sihawa

mountain of Dhamtari district of Chhattisgarh. This study area falls under Mahanadi basin and it is located around 20°0' to 21°05'N latitude and 81°30' to 82°30' E longitude, and cover around 4533 km² geographical

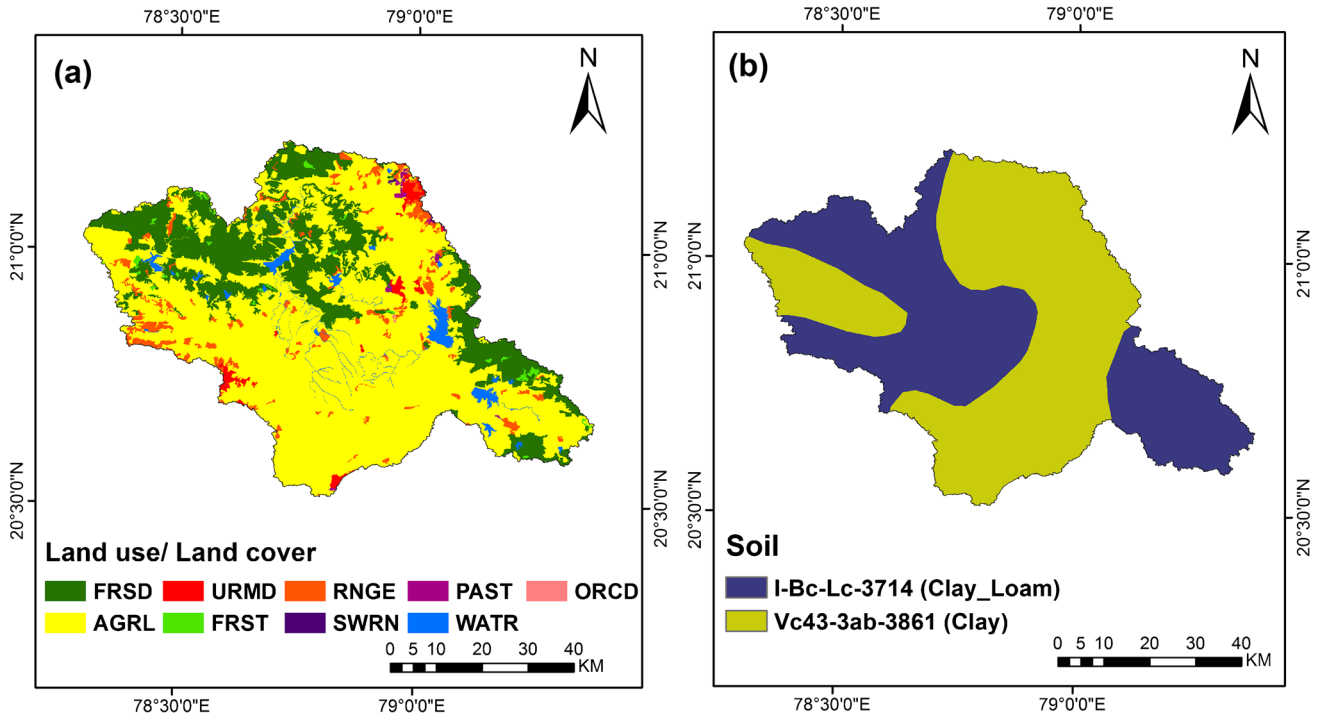


Fig. 2 Selected input raster map of study area: Wunna (Lower Godavari) landuse map (a) and soil map (b)

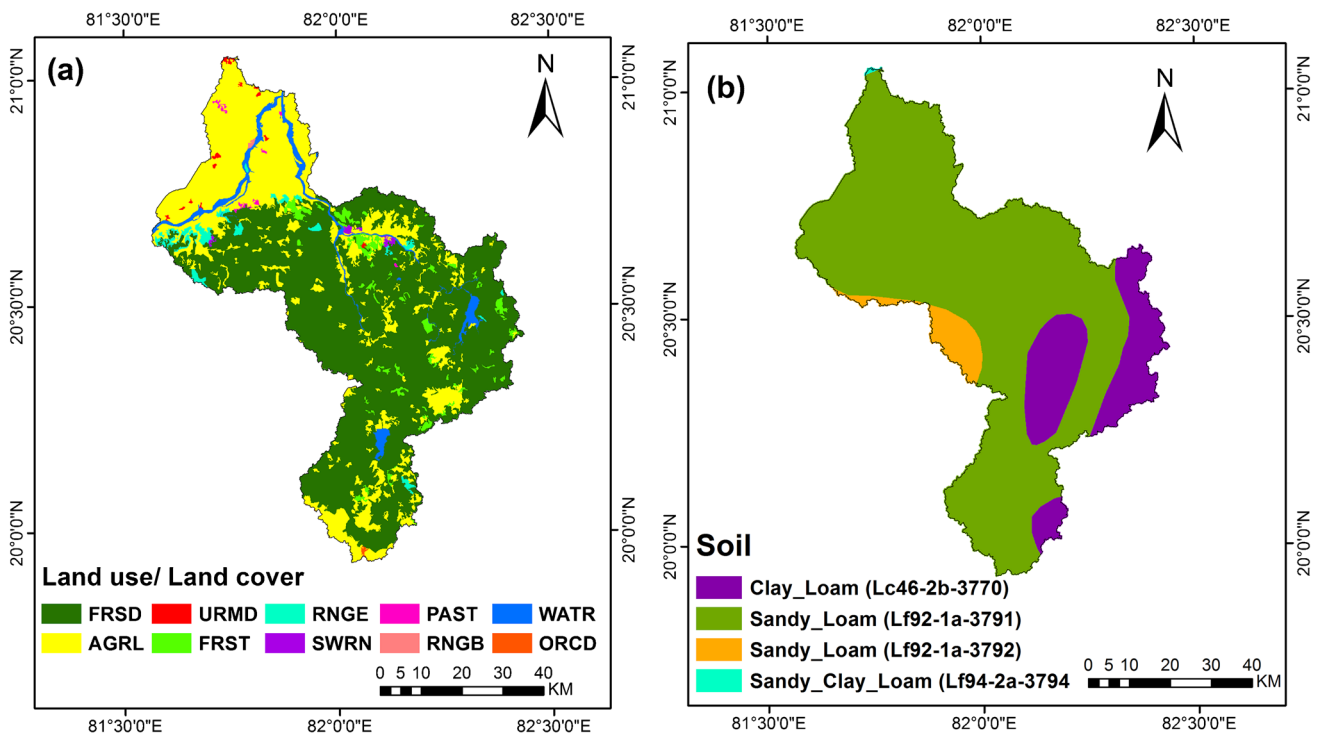


Fig. 3 Selected input raster map of study area: Mahanadi (Middle Mahanadi) landuse map (a) and soil map (b)

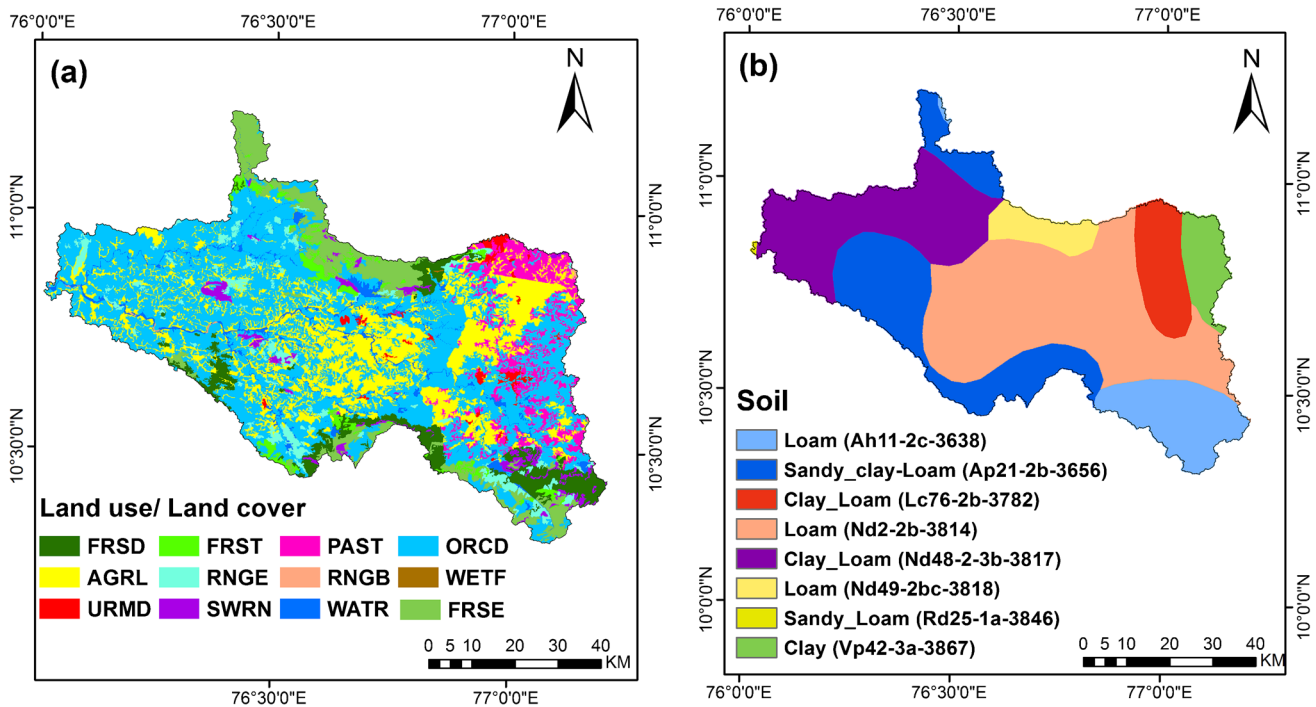


Fig. 4 Selected input raster map of study area: Bharathpuzha Landuse map (a) and soil map (b)

area. It characterised by a tropical climate with average rainfall 1508 mm. The elevation of the watershed is varying 242 to 971 m, where the southernmost portion of the study area has maximum elevation. The majority of the rain falls during the south-west monsoon. In the dry season, the temperature touch up to 42°C and minimum temperature around 13.2°C during the wet season. Streamflow gauging station is located at Baronda (Code-EMR00A4) and Rajim (Code-EM000U7).

- (c) Bharathpuzha River (also known as Nila) is situated in south India of Kerala and located around 10°10' to 11°15'N latitude and 76°0' to 77°20' E longitude. It is originating from Anaimalai hills from the Western Ghats. Its principal tributaries are Gyathripuzha, Kan-nadi, Korayar, and Thuthapuzha, finally deposited in the Arabian Sea at Ponnani on the west coast of Kerala state. The Bharathpuzha watershed has a total area of 5789.49 km² with high annual average rainfall 2340 mm. In the dry season, the temperature touch up to 32.4°C and minimum temperature around 19.2°C during the wet season. The elevation of the watershed is varying 3 to 2493 m, where the eastern part of the study area has maximum elevation. Streamflow gauging station is located at Kumbidi (Code-KR000C9). In Kerala (Palakkad district), recently (September 2018), flood event was occurred due to heavy continuous extreme rainfall.

Materials and methods

Data used

The SWAT model requires soil, landuse, topographical data, and hydro-meteorological data either in raster or geodatabase format for accurate estimation. Landsat Thematic Mapper (TM) 30-m resolution satellite image of 2005 was used to prepare landuse maps and supervised classification done by using GIS Environment software. For soil data, the FAO-UNSECO soil database’s Digital Soil Map of the World (DSMW) was used (FAO 1997, 2003). The global digital elevation model of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) of version 3 with a 30-mresolution downloaded from USGS web portal (<https://earthexplorer.usgs.gov/>) and used for watershed delineation and river network of the watershed.

This study used global daily maximum and minimum temperature data of Climate Prediction Center (CPC) with 0.50 × 0.50 degree resolution as one of the weather input in the model, and it is developed by the National Oceanic and Atmospheric Administration (NOAA) of the USA (<https://www.esrl.noaa.gov>). For Wunna and Bharathpuzha, streamflow and TSS data of 16 years (2001 to 2016) and for Mahanadi 13 year (2001 to 2013) were acquired from the Central Water Commission of India. In this study, one gauging station of Wunna (Nandgaon), two of Mahanadi (Rajim and Baronda), and one of Bharathpuzha (Kumbidi) have been

selected for discharge simulation. According to Hanief and Laursen (2017), SWAT predicts sediment yield by considering bed sediment erosion and deposition. As a result, sediment yield is equal to the amount of bed-load sediment and TSS transported. Therefore, we assumed considered TSS is directly proportional to sediment yield. The description data type shown in Table 1 and LULC and soil type are given in Table 2.

In this study, satellite precipitation product of Tropical Rainfall Measuring Mission (TRMM version-7 3B42) 0.25×0.25 degree daily-based (<https://mirador.gsfc.nasa.gov/>) was used as one of the main weather input (Yong et al. 2014; Huffman et al. 2010). TRMM is the joint mission (launched in 1997) of NASA and Japan Aerospace Exploration Agency (JAXA) to observe the tropical rainfall. TRMM product has been derived by combined instrument (multiple precipitations) estimates from TRMM Microwave Imager, Special Sensor Microwave Imager/Sounder, Special Sensor Microwave Imager, Advanced Microwave Scanning Radiometer for Earth Observing Systems, Advanced Microwave Sounding Unit, and microwave-adjusted merged geo-infrared, and Microwave Humidity Sounder. TRMM (version-7 3B42) used combined instrument to calibrate precipitation measurement obtained from Low Earth Orbit Microwave radiometer (Huffman et al. 2010) (Table 3).

TRMM produces estimates of global precipitation based on the large number of meteorological satellites. TRMM are estimated in four phases. First, microwave precipitations estimates that are calibrated and combined. Second, infrared precipitation estimates that are produced using the calibrated microwave precipitation. Third, microwave and infrared precipitation estimates are combined (Huffman et al. 2010). In this study, we used TRMM 3B42 that combined all above mentioned instrument. It merged all precipitation estimates at 3-h interval and gaps are filled with the help of geostationary earth orbit infrared data. The daily precipitation product has been obtained from the aggregating the 3-h interval precipitation of each 24 h. Each TRMM precipitation field is

interpreted as being the accurate precipitation rate at negligible observation time. The resolution of TRMM and CPC are different. Therefore, pixel-based approach for interpolating data to a particular grid resolution by calculating the average value from the available data for each grid area and assigning it to the grid centre.

SWAT model

The eco-hydrological Soil and Water assessment tool (SWAT) model is one of the open access, most popular, and widely used models in various countries (Wu and Johnston 2007; Bae et al. 2011; Ertürk et al. 2014; Mehdi et al. 2015; Reshmidevi et al. 2018). The SWAT is a physical, continuous, and process-based river hydrological model that simulate and predict the water balance and land management practices on rivers basin on daily time scale in small watershed to large watershed (Arnold et al. 1998; Neitsch et al. 2009; Srinivasan et al. 2010). SWAT 2012 edition setup has been adopted for modeling.

In SWAT, a watershed is divided into numbers of sub-basin using DEM as input. Each sub-basin was further divided into numbers of small unit of sub-basin as Hydrologic Response Units (HRUs) that comprise of homogeneous soil, landuse, and slope unit. Each HRU is a conceptual representation of areas with depended response features. The assumption in HRU is no interaction in between HRUs. Loading (runoff with sediment) from HRUs is aggregated within each sub-basin and then added together to calculate the total loading from the sub-basin. Model simulates the hydrological processes including surface runoff, lateral flow, evapotranspiration, canopy storage, return flow, recharge, and tile drainage (Arnold et al. 2012). SWAT requires input that consists of soil properties, landuse, topography, climate, vegetation, and land management (Gassman et al. 2007). Rainfall and temperature data have been used as a weather input and other weather inputs have been derived from the SWAT model as simulated results.

Table 1 Description of data

Data Type	Description and resolution	Period	Source
Landuse and landcover	Landsat Thematic Mapper (TM), 2005 30-m resolution satellite	2005	https://earthexplorer.usgs.gov/)
Digital Elevation Model	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) global digital elevation model version 3 (GDEM 003)	–	https://earthexplorer.usgs.gov/
Soil	Digital Soil Map of the World (DSMW)	–	FAO-UNSECO soil database
TRMM	The Tropical Rainfall Measuring Mission (TRMM-3B42) of version 7 and 0.25° × 0.25° spatial resolution	2001–2016	https://mirador.gsfc.nasa.gov
CPC	Climate Prediction Center (CPC), 0.50° x.50°	2001–2016	https://www.esrl.noaa.gov
Streamflow	Streamflow at outlet of watershed, Monthly time scale	2001–2016	Central Water Commission of India

Table 2 Summary of LULC and soil type

Watershed	LULC	Area (km ²)	Total (%)	Soil type	Area (km ²)	Total (%)
Wunna	Deciduous forest	1067.20	23.65	I-Bc-Lc-3714 (Clay loam)	2023.00	44.83
	Mixed forest	28.13	0.62	Vc43-3ab-3861 (Clay)	2489.75	55.17
	Agricultural land	3091.78	68.51	–	–	–
	Built-up Land	56.33	1.25	–	–	–
	Shrubland	198.72	4.40	–	–	–
	Barren land	1.20	0.03	–	–	–
	Fallow land	14.36	0.32	–	–	–
	Plantations	0.803	0.02	–	–	–
Mahanadi	Water bodies	54.19	1.20	–	–	–
	Deciduous forest	2841.44	62.89	Lc46-2b-3770 (clay loam)	748.11	16.56
	Mixed forest	119.24	2.64	Lf92-1a-3791 (sandy loam)	3605.22	79.79
	Agricultural land	1301.88	28.81	Lf92-1a-3792 (sandy loam)	162.58	3.60
	Built-up land	12.98	0.29	Lf94-2a-3794 (sandy clay)	228.161	0.05
	Shrubland	71.02	1.57	–	–	–
	Barren land	11.52	0.26	–	–	–
	Fallow land	9.40	0.21	–	–	–
	Wasteland	2.39	0.05	–	–	–
	Plantations	2.39	0.05	–	–	–
Bharathpuzha	Water bodies	145.90	3.23	–	–	–
	Deciduous Forest	334.67	5.78	Ah11-2c-3638 (loam)	560.48	9.68
	Mixed forest	123.46	2.13	Ap21-2b-3656 (sandy clay loam)	1138.49	19.66
	Agricultural land	1204.26	20.80	Lc76-2b-3782 (clay loam)	403.68	6.97
	Built-up land	61.12	1.06	Nd2-2b-3814 (loam)	2088.65	36.08
	Shrubland	259.26	4.48	Nd48-2-3b-3817 (clay loam)	1120.73	19.36
	Barren land	118.76	2.05	Nd49-2bc-3818 (loam)	220.60	3.81
	Fallow land	378.50	6.54	Rd25-1a-3846 (sandy loam)	3.05	0.05
	Wasteland	6.44	0.11	Vp42-3a-3867 (clay)	253.78	4.38
	Plantations	2674.06	46.19	–	–	–
	Water bodies	163.09	2.82	–	–	–
	Wetlands-forested	0.642	0.01	–	–	–
	Forest-evergreen	465.17	8.03	–	–	–

The LULC, soil, and slope maps were reclassified in order to link with the parameters in the SWAT database. The next step is the preparation of hydro-meteorological data and writes the input parameter for the SWAT.

The methodology flow chart of overall process were shown in Figure 5.

All land surface processes are carried out in each HRU along with water balance.

The hydrological components of the SWAT model are determined using the water balance equation on the daily time step (Eq. 1).

Table 3 Calibrated parameter results for three watersheds

Parameter name	File name	Method	Description	Fitted_Value			Min value	Max value
				W	B	M		
For discharge								
CN2	.mgt	Relative	Curve number	0.07	-0.169	-0.10	-0.20	0.20
ALPHA_BF	.gw	Replace	Baseflow alpha factor	0.0006	0.0851	0.75	0	1
GW_DELAY	.gw		Groundwater delay time (days)	473.66	248.57	0.68	0	450
GWQMN	.gw	Replace	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	102.59	553.42	1416.75	0	1500
ESCO	.hru	Replace	Soil evaporation compensation factor.	0.53	0.294	0.12	0	1
EPCO	.hru	Replace	Plant uptake compensation factor.	1.0	0.599	0.83	0	1
GW_REVAP	.gw	Replace	Groundwater “revap” coefficient	0.16	0.202	0.06	0.02	0.20
REVAPMN	.gw	Replace	Threshold depth of water in the shallow aquifer for “revap” to occur (mm).	65.93	343.335	42.75	0	500
RCHRG_DP	.gw		Fraction of Percolation of deep aquifer	-0.08	-0.051	-0.04	-0.05	0.05
SOL_AWC	.sol	Relative	Available capacity of water	0.26	0.264	0.24	-0.25	0.25
SOL_BD	.sol	Relative	Moist bulk density.	0.16	0.110	-0.25	-0.25	0.25
SOL_K	.sol	Relative	Saturated hydraulic conductivity	0.33	0.118	0.18	-0.25	0.25
SOL_Z	.sol	Relative	Depth from soil surface to bottom of layer.	0.11	0.2207	-0.060	-0.25	0.25
SURLAG	.bsn	Relative	Surface runoff lag time.	0.708	0.4198	-0.052	-0.5	0.5
CANMX	.hru	Replace	Maximum canopy storage	7.30	5.581	8.05	0	100
CH_K2	.rte	Replace	Hydraulic conductivity in major channel alluvium (mm/h)	137.65	132.392	72.30	0	200
CH_N2	.rte	Replace	Manning’s n value for the major channel.	0.01	0.01	0.04	0	0.30
For TSS								
SPCON	.bsn	Replace	Linear parameter for estimating the maximum amount of sediment that can be reentrained during channel sediment routing.	0.0046	0.005	0.0054	0.0001	0.01
SPEXP	.bsn	Replace	Exponent parameter for estimating sediment reentrained in channel sediment routing	1.341	1.085	1.724	1	2
ADJ_PKR	.bsn	Replace	Peak rate modification factor for sediment routing in the sub-basin (tributary channels)	0.134	0.476	0.251	0	1
PRF_BSN	.bsn	Replace	Peak rate modification factor for sediment routing in the major channel	0.152	0.465	0.112	0	2
USLE_K()	.sol	Replace	Soil erodibility factor	0.0194	0.303	0.02	0	0.65
USLE_P	.mgt	Replace	Supportive practice factor	0.0961	0.2006	1.152	0	1
ALPHA_BNK			Baseflow alpha-factor for bank storage	0.749	0.86	0.973	0	1
CH_COV2	.rte		Channel cover factor	1.0	0.001	0.269	-0.0001	1
CH_COV1	.rte		Channel erodibility factor	-0.024	0.484	-0.0183	-0.05	0.65

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$$SW_t = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})_i \quad (1)$$

where SW_t , SW_0 are final and initial soil water content (mm), t is the time (days), R_{day} is precipitation on day i (mm), Q_{surf} is surface runoff on day i (mm), Q_{gw} is return flow i (mm), E_a is evapotranspiration i (mm), and W_{seep} is water entering the vadose zone from the soil profile i (mm).

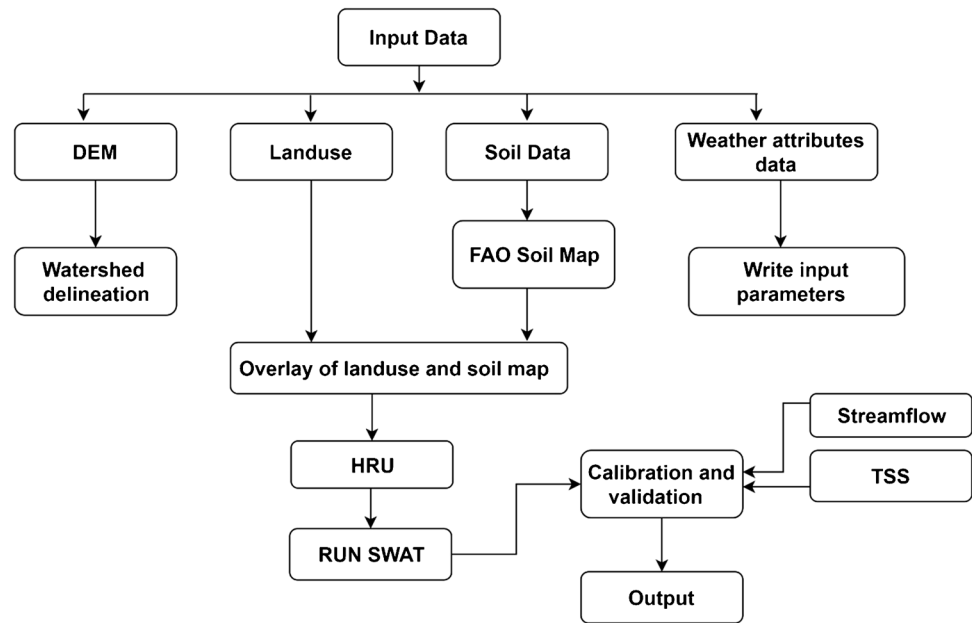
In SWAT model, surface runoff is calculated by either law of the curve number (CN) of the soil conservation service (SCS) (USDA-SCS 1972) using daily rainfall and modified Green and Ampt method using sub-daily rainfall

(Mein and Larson 1973). In this analysis, CN approach has been used assess surface runoff. In CN method, the depth and surface runoff volume are determined for each HRU unit based on the CN values and antecedent moisture condition.

$$Q_{surf} = \frac{(P - I_a)^2}{(P - I_a + S)}; \quad (2)$$

$$I_a = 0.2 * S \quad (3)$$

Fig. 5 Methodology flow chart



$$S = \frac{25400}{CN} - 254 \tag{4}$$

where Q_{surf} is the accumulated runoff or rainfall excess (mm), P is the rainfall depth for the day (mm), I_a is an initial abstraction, CN is the curve number that correspond according to soil, land use and land management, and S is the retention parameter (mm).

To predict lateral flow, a kinematic storage model was adopted, while return flow is simulated by constructing a shallow aquifer (Arnold et al. 1998). Predicted sediment yield are calculated for each HRU by the modified universal soil loss equation (MUSLE) (Eq. 5) (Williams and Berndt 1977):

$$Sed = 11.8(Q_{surf} \times q_{peak} \times A_{hru})^{0.56} \times K_{usle} \times C_{usle} \times P_{usle} \times LS_{usle} \times F_{cfrg} \tag{5}$$

where Sed is the sediment yield (metric tone/day), q_{peak} is the peak runoff rate (cumec), Q_{surf} is the surface runoff volume (mm/ha), A_{hru} is the area of the HRUs (ha), C_{usle} is the USLE cover and management factor, K_{usle} is the USLE soil erodibility factor, LS_{usle} is the USLE topographic factor, P_{usle} is the USLE support practice factor, and F_{cfrg} is the coarse fragment factor.

Penman-Monteith method has been adopted for the modeling out of three widely used methods of estimating potential evapotranspiration: Priestley and Taylor (1972), Hargreaves and Saman (1985), and Penman-Monteith (Monteith 1965).

Calibration, validation, and uncertainty analysis

Prior to model calibration, SWAT model parameter sensitivity analysis was conducted to define and rate parameters that

have a major influence on developed model outputs including streamflow and sediment yield (Saltelli et al. 2000). Calibration and validation were done based on the monthly observed streamflow from 2001 to 2016. Simulation of the study model by observed data has been done into two phase, calibration and validation and it is a goodness of fit observed data with measure data of the model output. Calibration is the adjustment of model parameters based on observations evaluating outcomes to ensure the same response over time interval and validation is the technique of comparing the model outputs and an individual sample without further modification of the parameter values, since the SWAT model

contains a wide variety of input parameters. Calibration and validation are more complex and demanding process.

Streamflow was simulated using seventeen driven parameter for calibration and validation on a monthly period (Arnold et al. 2012; Shivhare et al. 2018; Singh and Saravanan 2020b). Similarly, TSS was simulated using nine driving parameters (Singh et al. 2014; Das et al. 2020). These parameters were carefully chosen based on the previous research that above cited. These studies summarized the detail report of model parameterization for different including parameter range. Since SWAT is a robust model simulating process interactions, several parameters can impact various processes in model. For example, curve number (CN2) influences direct surface runoff; even, surface runoff alters all elements of water balance.

The SWAT-Calibration Uncertainty Programs (CUP) tool is generic interface to execute sensitivity analysis, calibration, and validation by sequential uncertainty fitting-II (SUFI-2) algorithm. All sources of uncertainty are taken into consideration when parameter sensitivity, including conceptual model driving variables, uncertainty, parameters, and measured data (Abbaspour 2015). SWAT-CUP was developed to bring more versatility and efficiency. Therefore, the tool's benefit is its ability to include a wider range of features and interfaces for parameterization and simulation. Five different algorithm technique associate to SWAT such as Particle Swarm Optimization (PSO), Sequential Uncertainty fitting (SUFI-2), Generalized Likelihood Uncertainty Estimation (GLUE), Mark Chain Monte Carlo (MCMC), and Parameter Solution (Para Sol) (Beven and Binley 1992; Kennedy and Everhart 1995; Alamirew 2006; Kassa and Foerch 2007). In our study, we applied SUFI-2 optimization algorithm because it provides most comprehensive marginal parameter uncertainty intervals of model parameter among techniques (Abbaspour et al. 2007).

A multiple regression method with Latin hypercube samples was used to measure the sensitivities of parameters against objective function using the global sensitivity analysis option in SWAT-CUP software (Abbaspour et al. 2007). The significance of the parameter sensitivity of the parameter is assessed by *t*-test and *p*-value. The negative value of *t*-test and closer to zero of *p*-value depict the most sensitivity of parameter.

Since hydrological modeling is under considerable uncertainty, the recent year's quantification and identification of model uncertainty has been a widely discussed topic in recent years. For simulating the individual processes, the efficiency of the model highly depends on precise model calibration.

SWAT model operates on the principle of water balance equation (Eq. 1) and three different watersheds separately simulated from 2001 to 2013/2016. Bharathpuzha and Wunna were simulated from 2000 to 2016 and Mahanadi was from 2001 to 2013 depending upon the availability of discharge data. This analysis was executed to identify the instability of sensitivity parameters within the watershed for relative modification of SWAT input parameters. Daily streamflow data was used for all outlets of each watershed considered for model evaluation by using SUFI-2. In order to simulate the observed and simulated data, a thirteen-year monthly discharge was used. The entire period was simulated, the first three periods were considered as the warm-up period for equalising the pools and another period divide into calibration and validation. During the simulation (both calibration and

validation), two iterations have been performed with 1700 numbers of simulations for each watershed.

The degree to which SUFI-2 provides for all uncertainties is assessed using a formula defined as the *p* and *r* factors that are the proportion of calculated data bracketed by the 95% uncertainty prediction (95PPU) and Mean 95PPU band thickness divided by standard deviation of calculated results, respectively. If the acceptable *p*-factor and *r*-factor values are satisfied, the parameter uncertainties must be the appropriate parameter ranges. The reliability of the calibration and the uncertainty of the prediction are determined by the similarity of the *p*-factor to 100% whereas at the same time have an *r*-factor close to zero. SUFI-2 algorithm has been adopted to identify the sensitive parameters. Parameter sensitivity and uncertainty were evaluated using the several regression analyses that yields the parameters produced by Latin hyperbolic compared to the objective function values. Global sensitivity analysis results represent the ranking of different parameters with *p*-value and *t*-test. A large *p*-value and small value indicate the more sensitivity of the parameter (Neitsch et al. 2009).

Model performance evaluation

Model performance evaluation is the main component for the accuracy and it was evaluated with statistical methods, i.e., percentage of bias (PBIAS), Nash–Sutcliffe model efficiency coefficient (NSE), and coefficient of determination (R^2). The following is the Nash–Sutcliffe model efficiency coefficient (Nash and Sutcliffe 1970) model statistical equation (Eq. 6).

$$NSE = 1 - \frac{\sum_{i=0}^n (X_i^{obs} - X_i^{sim})^2}{\sum_{i=0}^n (X_i^{obs} - \overline{X_i^{obs}})^2} \quad (6)$$

where *X* is variable, *n* is a number of observation, X^{obs} is observed, and X^{sim} is simulated value of *i*th.

The NSE varying between $-\infty$ and 1 and its optimal value is 1. The value from 0.50 to 1 is generally acceptable importance of performance and 0 value indicates unacceptable performance that means observed data is an enhanced predictor than simulated data. The percent of bias (PBIAS) is a numerical error-index that is commonly used to assess model output performance. It assesses the proclivity of simulated data being smaller or larger than the observed data. A negative value indicates overestimation and positive value indicates underestimation and better simulation, and its optimal value is zero (Eq. 7) (Gupta et al. 1999).

$$PBIAS = 100 * \frac{\sum_{i=0}^n (X_i^{obs} - X_i^{sim})}{\sum_{i=0}^n (X_i^{obs})} \tag{7}$$

Model performance was assessed based on the criteria. Moriasi et al. (2007) suggest that model simulation is “satisfactory” if NSE>0.50. PBIAS ±15 to ±25 is “satisfactory,” ±10 to ±15 is “good,” and 0 to ±10 is “very good.” During the simulation, NSE was selected as objective function.

Estimation of hydrological components

Water balance components (runoff), water yield, and sediment yield of the SWAT model were generated from fitted values of parameters on the SWAT model. In this model, runoff is estimated by the SCS curve number method (Eq. 4). The MUSLE was used to simulate the soil erosion that combine the soil, runoff, landuse, topography, and land management practices (Eq. 5). The amount of eroded and transported through HRU to each sub-basin can be calculated by SWAT (Neitsch et al. 2009).

Results and discussion

Streamflow and TSS simulation were done with selected sensitive parameter (Abbaspour et al. 2007) with the help of SWAT-CUP software documentation (Neitsch et al. 2009).

Sensitivity analysis of SWAT models parameters

From flow simulation, sensitivity analysis suggests that curve number (CN2), base flow alpha-factor (ALPHA_BF), and moist bulk density (SOL_BD) parameters were most sensitive parameter in all watersheds. For Wunna watershed, ALPHA_BF, CN2, CH_N2, SOL_BD SOL_Z, SOL_AWC, and CH_K2 were highly sensitive that rejecting the null hypothesis and CANMX is least sensitive. For Bharathpuzha, CN2, ALPHA_BF, SOL_BD, ESCO, REVAPMN, SOL_K, CH_N2, and CH_K2 are highly sensitive, and GW_DELAY is least sensitive (Table 4). Similarly, Mahanadi, ALPHA_BF, CN2, SOL_BD, and GW_DELAY were highly sensitive, and SOL_K is least sensitive. For TSS, the sensitivity parameters are SPCON, USLE_P, PRF_BSN, and ADJ_PKR. For Bharathpuzha, only PRF_BSN is significant. For Mahanadi, SPCON, USLE_K, and PRF_BSN are significant (Table 5).

Sensitivity ranks were assigned for all the watersheds, on the basis of *p*-value and *t*-stat results. High rank assigns nearly zero *p*-value and negative *t*-stat value (Abbaspour et al. 2007). Bharathpuzha watershed was most sensitive compared to others and less sensitive parameter in Middle-Mahanadi watershed due to most of the parameter *p*-values are nearly zero. Table 4 shows the global sensitivity analysis results are based on SWAT-CUP documentation (Neitsch et al. 2009) in the form of *p*-value and *t*-stat that define the sensitivity of the parameters.

Table 4 Sensitivity rank for the discharge of three watersheds using SUFI-2

Rank	Wunna watershed			Bharathpuzha watershed			Mahanadi watershed		
	Parameter	<i>t</i> -stat	<i>P</i> -value	Parameter	<i>t</i> -stat	<i>P</i> -value	Parameter	<i>t</i> -stat	<i>P</i> -value
1	ALPHA_BF	-41.77	0.00	CN2	-34.23	0.00	CN2	7.78	0.00
2	CN2	-30.20	0.00	ALPHA_BF	-15.07	0.00	ALPHA_BF	13.03	0.00
3	CH_N2	3.47	0.00	SOL_BD	-9.57	0.00	SOL_BD	2.52	0.01
4	SOL_BD	2.87	0.00	ESCO	-8.77	0.00	GW_DELAY	-2.40	0.02
5	SOL_Z	3.11	0.00	REVAPMN	-4.10	0.00	CH_N2.	-1.83	0.07
6	SOL_AWC	3.27	0.00	SOL_K	-3.48	0.00	CH_K2	-1.75	0.08
7	CH_K2	18.93	0.00	CH_N2	-2.94	0.00	RCHRG_DP	1.66	0.10
8	RCHRG_DP	2.56	0.01	CH_K2	2.45	0.01	SOL_AWC	1.29	0.20
9	REVAPMN	-1.84	0.07	RCHRG_DP	1.87	0.06	SURLAG	-1.19	0.23
10	ESCO	-1.11	0.27	GWQMN	17.90	0.00	GW_REVAP	-0.94	0.35
11	GW_REVAP	0.96	0.34	GW_REVAP	8.79	0.00	REVAPMN	-0.75	0.46
12	GWQMN	0.85	0.4	SOL_AWC	6.14	0.00	ESCO	-0.63	0.53
13	EPCO	-0.41	0.68	SOL_Z	5.31	0.00	SOL_Z	0.61	0.54
14	SOL_K	0.38	0.7	EPCO	1.57	0.12	EPCO	-0.25	0.81
15	SURLAG	0.32	0.75	CANMX	-0.53	0.60	CANMX	0.10	0.92
16	GW_DELAY	-0.32	0.75	SURLAG	-0.41	0.68	GWQMN	-0.09	0.93
17	CANMX	0.04	0.97	GW_DELAY	0.31	0.76	SOL_K	0.09	0.93

Table 5 Sensitivity rank for TSS of three watersheds using SUFI-2

Rank	Wunna watershed			Bharathpuzha watershed			Mahanadi watershed		
	Parameter	<i>t</i> -stat	<i>P</i> -value	Parameter	<i>t</i> -stat	<i>P</i> -value	Parameter	<i>t</i> -stat	<i>P</i> -value
1	SPCON	−6.70	0.00	PRF_BSN	−2.89	0.00	SPCON	−2.96	0.00
2	USLE_P	−4.98	0.00	ADJ_PKR	1.65	0.10	USLE_K(..)	5.93	0.00
3	PRF_BSN	−3.25	0.00	CH_COV2	−1.25	0.21	PRF_BSN	−2.26	0.02
4	ADJ_PKR	2.03	0.04	SPCON	0.57	0.57	SPEXP	0.93	0.35
5	USLE_K(..)	−1.98	0.05	USLE_P	−0.53	0.60	ADJ_PKR	−0.82	0.41
6	CH_COV1	−0.74	0.46	SPEXP	−0.51	0.61	CH_COV1	0.82	0.42
7	CH_COV2	0.73	0.47	ALPHA_BNK	0.44	0.66	ALPHA_BNK	−0.34	0.74
8	ALPHA_BNK	0.52	0.61	USLE_K(..)	−0.32	0.75	CH_COV2	0.14	0.89
9	SPEXP	−0.29	0.78	CH_COV1	−0.22	0.83	USLE_P	0.00	1.00

Calibration and validation

For calibrating the default parameters, important watershed driving parameters have been selected in this study, since effective calibration was achieved for discharge fitted value for three watersheds (Table 3).

SUFI-2 technique has been carried out for both streamflow and TSS for all the three watersheds between observed and simulated valued. The calibration and validation results are shown in Fig. 6 and 7, respectively. Calibration of streamflow at the outlet of Wunna watershed was quite good $NSE=0.63$, $R^2 = 0.63$, very good $PBIAS = 7.2$ with larger uncertainty (r -factor = 1.45) and p -factor = 0.89. The percentage of data observed bounded by 95PPU during calibration was 89%, indicating good model performance.

The model calibration at the outlet of Mahanadi watershed was quite good $NSE= 0.64$, 0.78, satisfactory $PBIAS = -24.8$, -14.1 with less uncertainty (r -factor = 0.71, 1.10) and p -factor = 0.85, 0.93 respectively at two outlets. In addition, the first outlet of Mahanadi at Rajim gives “satisfactory” ($NSE>0.60$) and Baronda outlet provides “very good” ($NSE>0.75$) results during calibration.

The model calibration provides at the outlet of Bharathpuzha watershed very good $NSE = 0.70$, satisfactory $PBAIS = -24.3$ and p -factor = 0.62 with larger uncertainty (r -factor = 1.51). The percentage of data observed bounded by 95PPU during calibration was 62%, indicating average model performance.

The model validation at the outlet of Wunna watershed provides good $NSE = 0.51$ and satisfactory $PBIAS = 23.2$.

Mahanadi watershed at two outlets was $NSE (0.54, 0.54)$ with $PBIAS (-30.0, -24.0)$ respectively. Bharathpuzha watershed provides 0.72 (NSE) and -16.6 ($PBAIS$) as shown in Table 6.

The simulation was also analysed by comparing monthly observed and measured TSS. The Wunna watershed model validation produces unsatisfactory NSE value during calibration and validation with $NSE = 0.36, 0.30$ and large

uncertainty respectively. Bharathpuzha also provided unsatisfactory $NSE = 0.37, 0.31$, and larger uncertainty, respectively during calibration and validation. However, Mahanadi watershed at the outlet of Rajim performed well with $NSE = 0.52, 0.50$, respectively, during calibration and validation and at the outlet Baronda it was very good with $NSE = 0.52, 0.60$.

This analysis shows that Wunna watershed has a larger uncertainty and average 95PPU brackets for streamflow simulation and except Mahanadi both Wunna and Bharathpuzha were not captured good observation during both calibration and validation of TSS. According to Moriasi et al. (2007), the assessment of the streamflow rate of the model fitted shows excellent performance of simulated parameters.

Assessment of surface runoff, sediment yield, and water yield

The temporal statistics of water balance components surface runoff (SURFQ), water yield, and sediment yield of all watershed were shown in Fig. 8, where remarkable temporal variations of the hydrological components have been detected.

Temporal variability

In Wunna watershed, it was observed that there was a higher surface runoff in 2005, 2007, 2012, 2013, and 2015 (Fig. 8). Results of higher runoff may be due to higher rainfall on particular year and landuse changes throughout the watershed and also it generated a higher runoff on a higher slope. In the monsoon season (June to September), the monthly runoff and water yield were high (Table 7). However, in the dry season (October to February), both the runoff and water yield were less in the early season of dry and decreased in the late season of dry. In 2004 and 2014, there was very low water yield due to drought year that the year groundwater contribution is not significant for streamflow. The water

Fig. 6 Streamflow simulated performance for calibration and validation of Wunna watershed (a), Mahanadi watershed (two outlet) (b, c), and Bharathpuzha (d). The statistics R^2 , NS, P -factor, and R -factor are for calibration period only

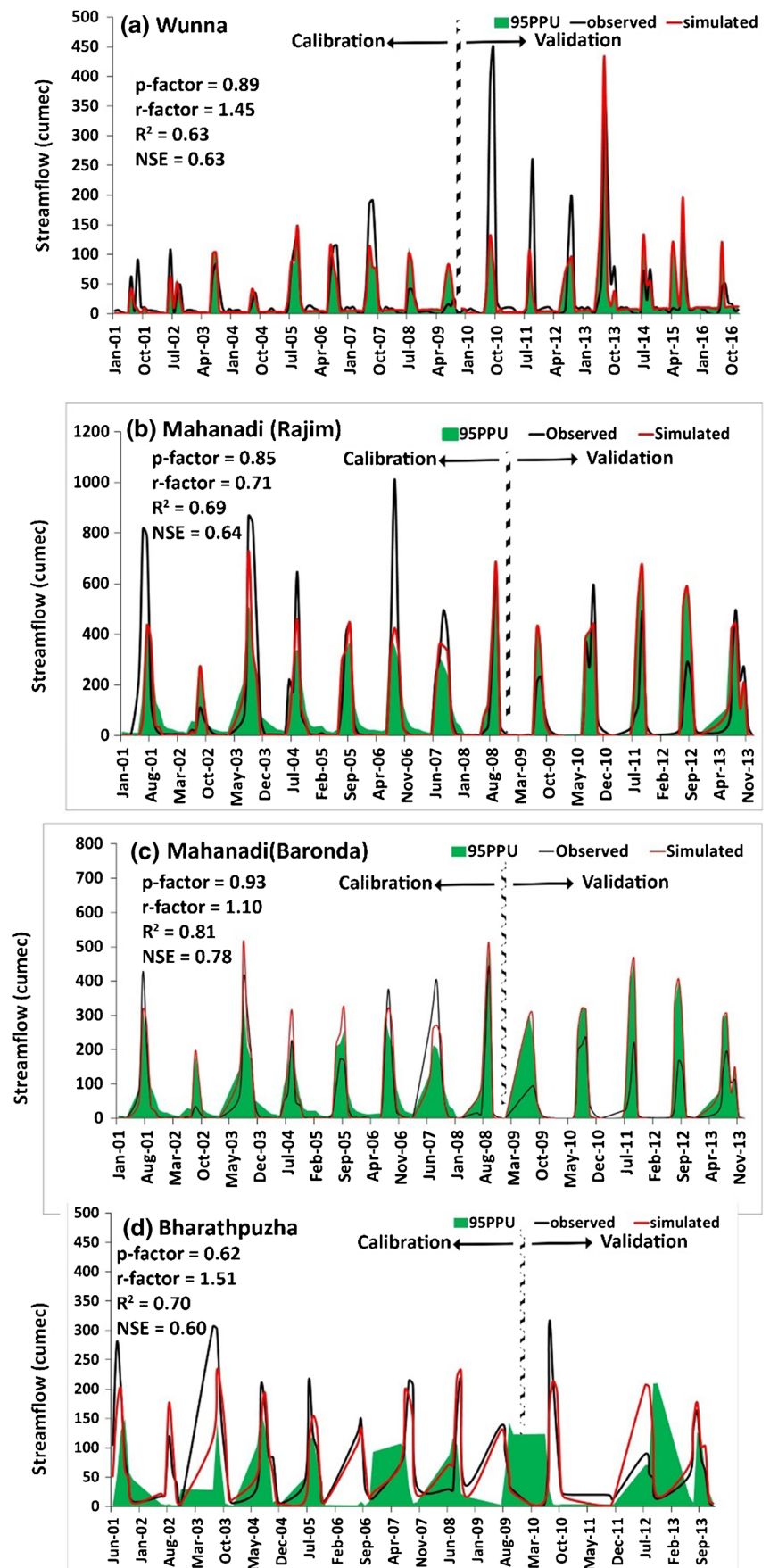


Fig. 7 Total suspended solid (TSS)-simulated performance for calibration and validation of Wunna watershed (a), Mahanadi watershed (two outlets), (b, c), and Bharathpuzha (d) The statistics R^2 , NS, P -factor, and R -factor are for calibration period only

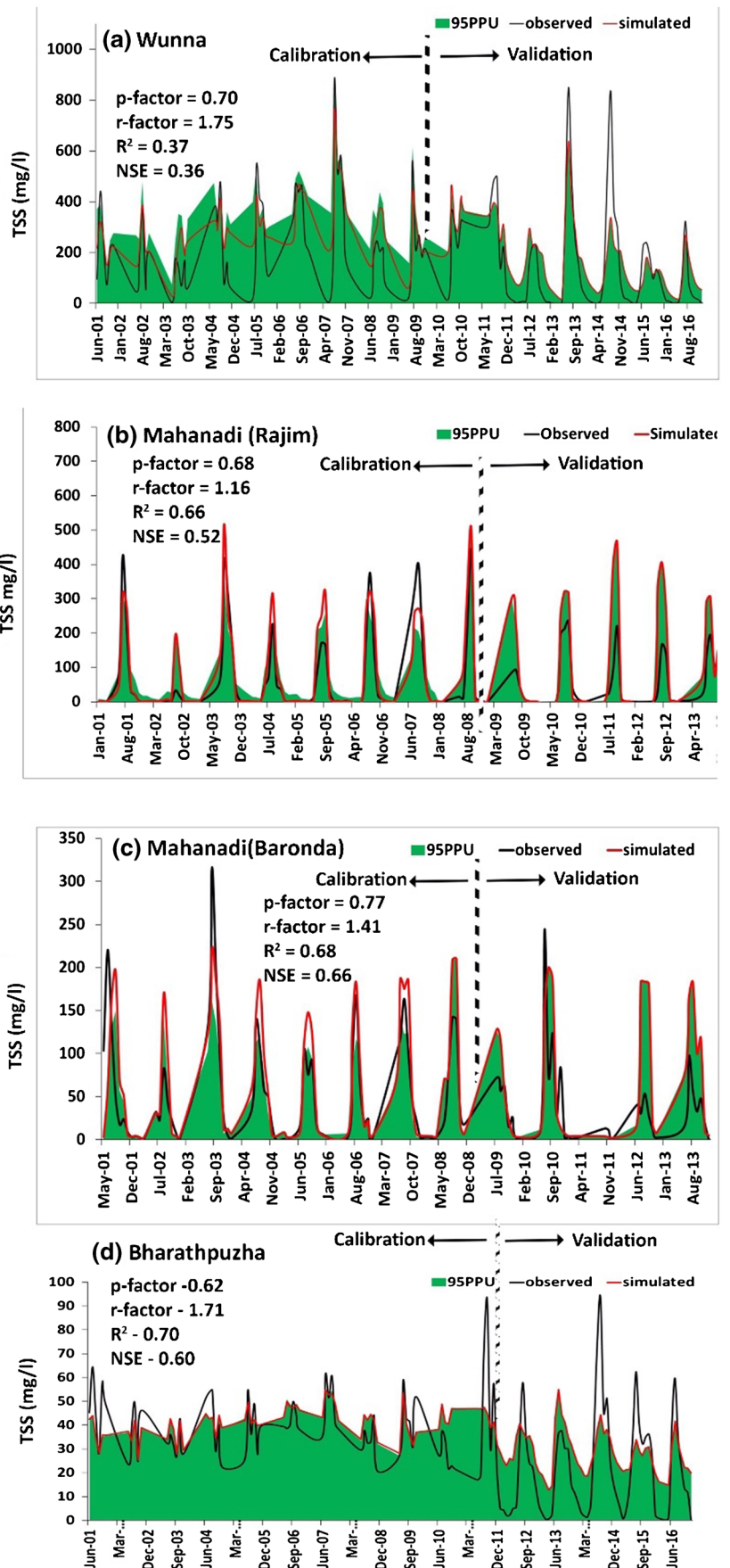


Table 6 Assessment of SWAT model performance

		Calibrated			Validated		
Discharge							
Watershed	Station	PBIAS	R ²	NSE	PBIAS	R ²	NSE
Wunna	Nandgaon	7.2	0.63	0.63	23.2	0.50	0.51
Bharathpuzha	Kumbidi	-24.3	0.60	0.7	-16.6	0.62	0.72
Mahanadi	Rajim	-24.8	0.69	0.64	-30	0.75	0.54
	Baronda	-14.1	0.81	0.78	-24	0.75	0.51
TSS							
Wunna	Nandgaon	6.2	0.37	0.36	42	0.39	0.30
Bharathpuzha	Kumbidi	-0.9	0.38	0.37	-27.7	0.46	0.31
Mahanadi	Rajim	-15.5	0.62	0.52	-33.1	0.51	0.5
	Baronda	11	0.68	0.66	-23.3	0.61	0.52

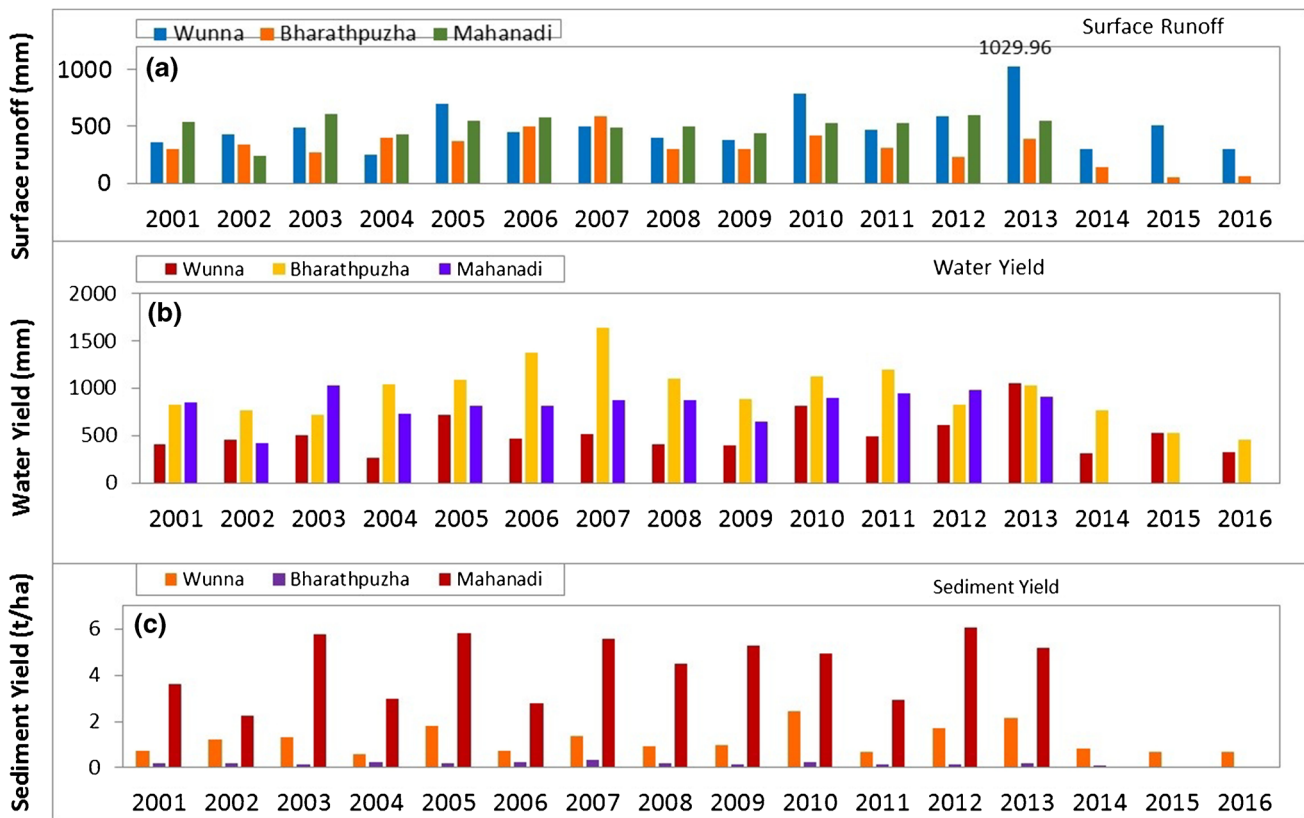


Fig. 8 Comparison among three watersheds: **a** surface runoff, **b** water yield, and **c** sediment yield

yield of Wunna was a high concentration in July and August. It was observed that a higher sediment yield in 2010 and 2013 and monthly sediment were at peak during monsoon season. It was found that it was most sensitive in 2010 and July. The higher concentration of runoff and sediment yield indicates the condition of watershed with no soil conservation service. It might be an increasing fragile agricultural land and less percolation indicating the higher runoff.

It was observed that in Bharathpuzha, there was high surface runoff in 2006, 2007, and 2010, and low in the 2015

and 2016. Similarly, water yield was highest in 2006 and 2007 and less in 2015 and 2016. The sediment yield of the watershed is not significant in all the years. However, it was observed maximum in 2007 and minimum in 2015 and July and August were the maximum loading months. It was observed that in Mahanadi watershed, there was a high surface runoff in 2003 and 2012 and low in 2002, similar in the case of water yield. Sediment yield of the watershed was maximum in 2003, 2005, 2009, 2012, and 2013 and minimum in 2002, and July and August were the maximum

Table 7 Monthly statistics of water balance components

Month	Surface runoff (mm)			Water yield (mm)			Sediment yield (t/ha)		
	W	B	M	W	B	M	W	B	M
Jan	1.29	0.01	1.78	2.39	38.02	5.05	0.01	0.0	0.01
Feb	0.24	0.02	0.36	1.3	27.57	1.72	0.0	0.0	0.0
Mar	0.40	0.21	0.38	1.51	24.81	1.49	0.0	0.0	0.0
Apr	0.14	1.14	0.32	1.09	26.54	1.36	0.0	0.0	0.0
May	0.04	6.18	0.05	0.9	34.6	0.92	0.0	0.0	0.0
Jun	51.7	65.74	42.28	53.21	121.3	45.86	0.1	0.02	0.28
Jul	187.6	94.8	182	189.8	180.7	198.2	0.42	0.04	1.42
Aug	159.92	57.43	164.1	164.9	141.7	226.8	0.36	0.03	1.29
Sep	82.72	27.29	96.97	86.8	103.5	186.7	0.23	0.02	1.02
Oct	12.4	43.42	16.33	14.49	121.5	98.35	0.04	0.03	0.17
Nov	1.42	14.81	0.98	2.61	90.17	46.69	0.01	0.01	0.01
Dec	0	0.15	1.11	0.99	52.11	19.44	0.0	0.0	0.0

W Wunna, M Mahanadi, B Bharathpuzha

loading months. Based on the results, during monsoon season, high erosion was observed in Mahanadi and Wunna, and there was very less observed erosion in Bharathpuzha. Higher and lower surface runoffs and were generated on higher and lower rainfall, respectively (Fig. 9).

Spatial variability

The spatial variation of sediment yield, surface runoff, and water yield was generated for all watersheds at sub-basin scale and shown in Fig. 10, Fig. 11, and Fig. 12. It was observed that in Wunna watershed, surface runoff was higher on the north, south, and Southeast regions and two sub-basins of the north-west were less. Wunna was less potential for generating water yield and around 9% watershed under low water yield, the backrest 4% of the southeast region was under moderate condition. The highest runoff rates were located in built-up land and agricultural land. The quantity of sediment yield of Wunna watershed was supplied with higher concentrations in the southern, south-western, and south-eastern regions and north region with moderate (Fig. 10). The higher sedimentation rate was located in agricultural land, clay soil, and downstream region. The higher concentration of both runoff and sediment yield will probably create problems such as urban flood and downstream reservoir sedimentation that may be caused by landuse dynamics.

In Bharathpuzha, the southernmost region had more surface runoff and low on easternmost region. Water yield was very high in the eastern region (around 60%) backrest 30% under moderate and 10% in low on northeast region. The highest runoff rate was located in agricultural land, shrubland, and built-up land. Sediment yield of the watershed was poor in the northern region with 0.03–0.1 t/ha and rest of the region under low sediment yield (Fig. 11). The higher sediment yield rate

was located in agricultural land, loamy soil, and both moderate and high slopes. Bharathpuzha was affected by higher runoff due to high rainfall, and there is much probability of flood due to extreme rainfall and hilly terrain.

In Mahanadi, northernmost region had more surface runoff and lower in the central and southernmost regions. Water yield of the watershed was moderate on the northern and eastern regions and only one sub-basin indicate under low water yield of the north-west region and water yield capacity of watershed indicating the groundwater contribution. Sediment yield was higher in the northern region, and few sub-basins were shallow sediment concentration, and two in the west and one in the eastern region (Fig. 12). The higher sediment yield was located in agricultural, sandy loam soil, and low slope region. This is the highly erosive watershed, and much probability of trend will affect the agricultural activity.

Bharathpuzha and Mahanadi generated moderate runoff than Wunna, while Wunna watershed was generating higher runoff due to low groundwater potential in soil and decrease in evapotranspiration, canopy interception, and percolation. The outcome of the SWAT model shows that approximately 60% of the Mahanadi watershed erosion is vulnerable to and leads to higher sediment yield; approximately 8% of the Wunna watershed erosion is sensitive and almost under control erosion from Bharathpuzha. Bharathpuzha has a large potential of water yield, which is the indication of very enrichment of water yield; Mahanadi also has on average significant potential of water yield, while Wunna does not have enough potential of water yield and this will may create a huge impact on agricultural and groundwater uses. Several studies have already shown that the greatest sediment yields occurred after a larger precipitation event (Endale et al. 2014; Kiani-Harchegani et al. 2019; Jia et al. 2020).

There are some of the limitations in this study. First, due to the low performance of TSS in Wunna and Bharathpuzha.

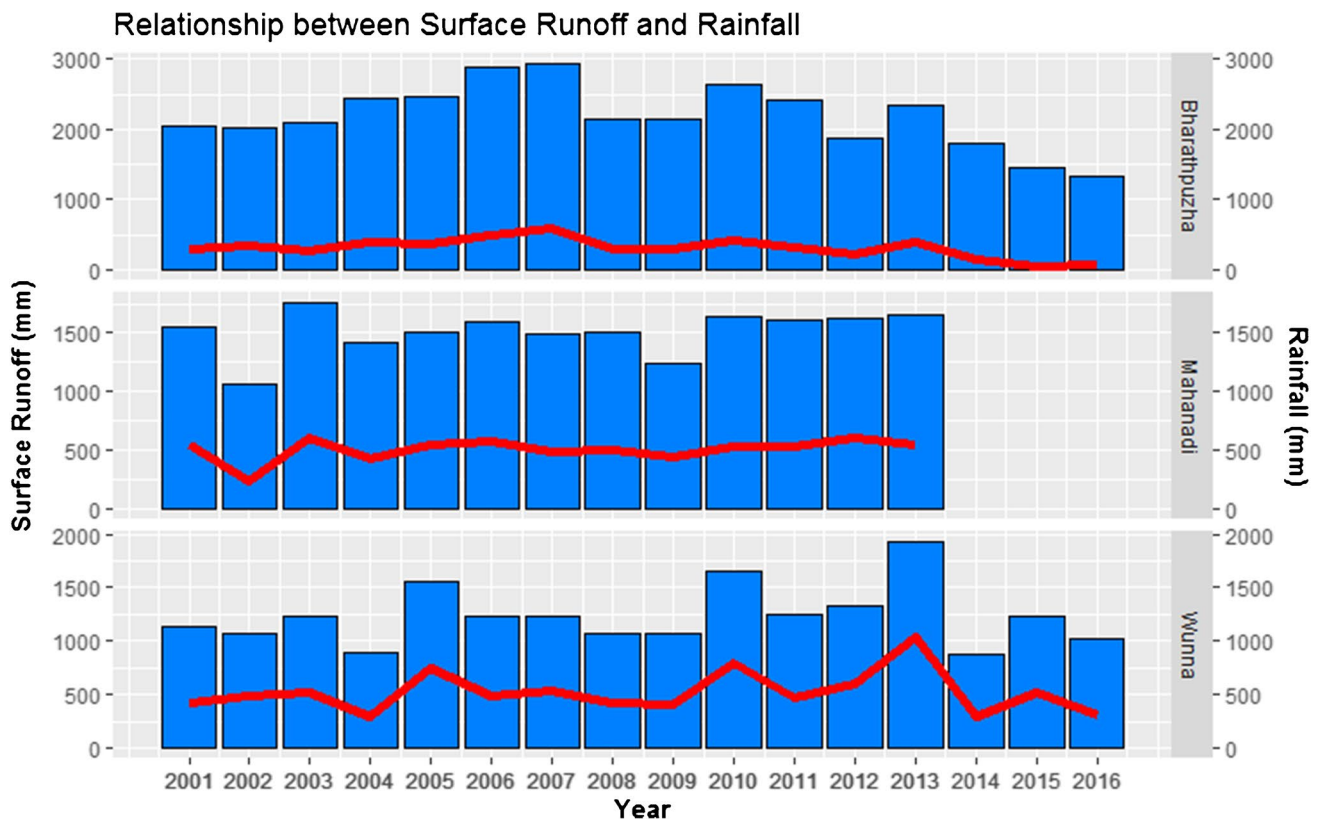


Fig. 9 Relationship between surface runoff and rainfall

Second, less hydro-metrological monitoring gauge stations in Wunna and Mahanadi. Presently, our result generated sediment yield from the land surface and transported into stream. Further assessment is needed using the higher resolution of soil data. It can also be improved by considering land management practices and more hydro-meteorological gauge station installation. Improvement could be possible by calibrating sediment yield instead of TSS. Providing adequate observations of loss of sediments from the soil surface by which evaluating the validity of our results would assist to rectify errors, since water yield is controlled by largely by runoff. Therefore, it can be control by runoff reduction measures. Model rates of runoff, water yield, and sediment yield values may be used as a reference for further hydrological research. The obtained observed values of these processes are definitively would assess the precision of our model predictions. The result may be lead to a sub-basin scale water resources management and soil conservation improvement for sustainable development.

Conclusion

This study has been supported out to assess the hydrological components with satellite product-based rainfall in Indian watersheds using the SWAT model.

Sensitivity analysis indicates common sensitive parameters for both streamflow and TSS simulation. These sensitive parameters are acquired to focuses on further studies about land management of the watershed. Streamflow simulation was given excellent results compared to TSS. Particular attention has been paid to precisely calculate and show the 95% prediction uncertainty of the outputs. Bharathpuzha performed well with larger model 95% prediction uncertainty (higher r -factor) in streamflow simulation, and Mahanadi (Baronda) performed excellent. During monsoon, surface runoff was higher for all watersheds. The southernmost area of Wunna was more vulnerable with sediment yield. Mahanadi was severely affected by sediment yield. Bharathpuzha was influenced by considerably low sediment concentrations spatially during the study period.

From the simulated results performance, it was concluded that TRMM precipitation product was most appropriate for monthly streamflow modeling in Indian watersheds. The performance of the mode for TSS simulation was not satisfactory. Therefore, there were some of the limitations for improper simulation of TSS in Wunna and Bharathpuzha but it was well simulated under Mahanadi. Further, improvement was possible by considering land management practices. The obtained model results provide the base for future development. Further

Fig. 10 Spatial variations of surface runoff in three watersheds at sub-basin scale

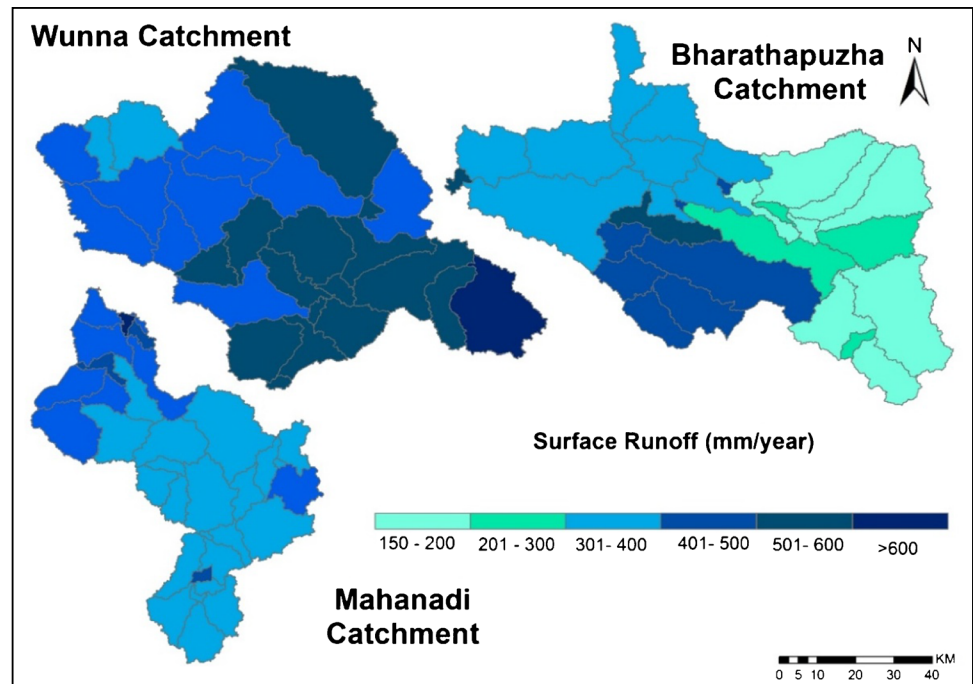
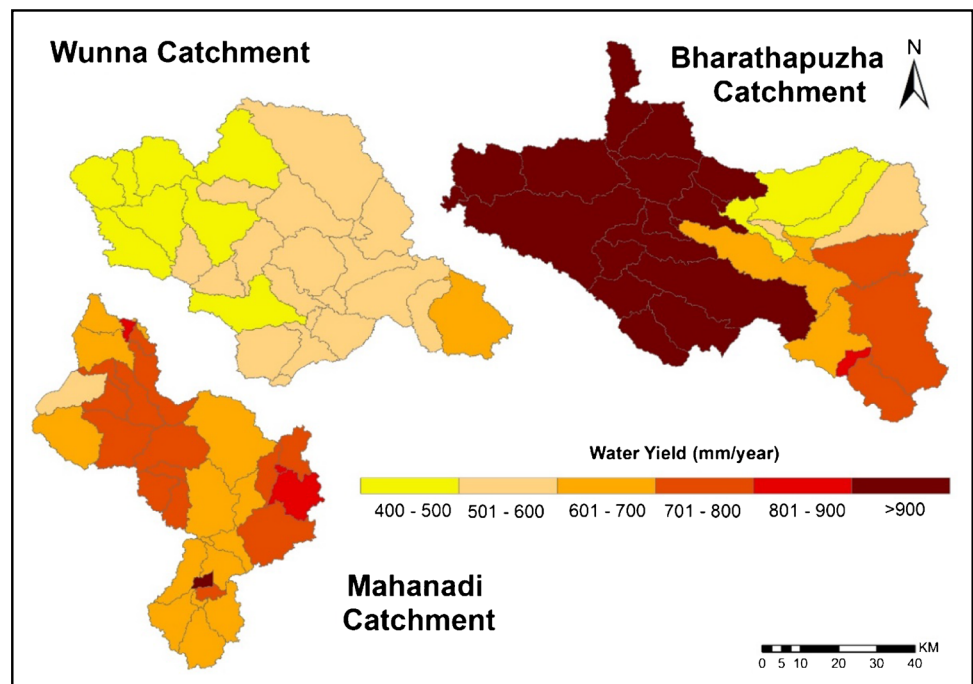


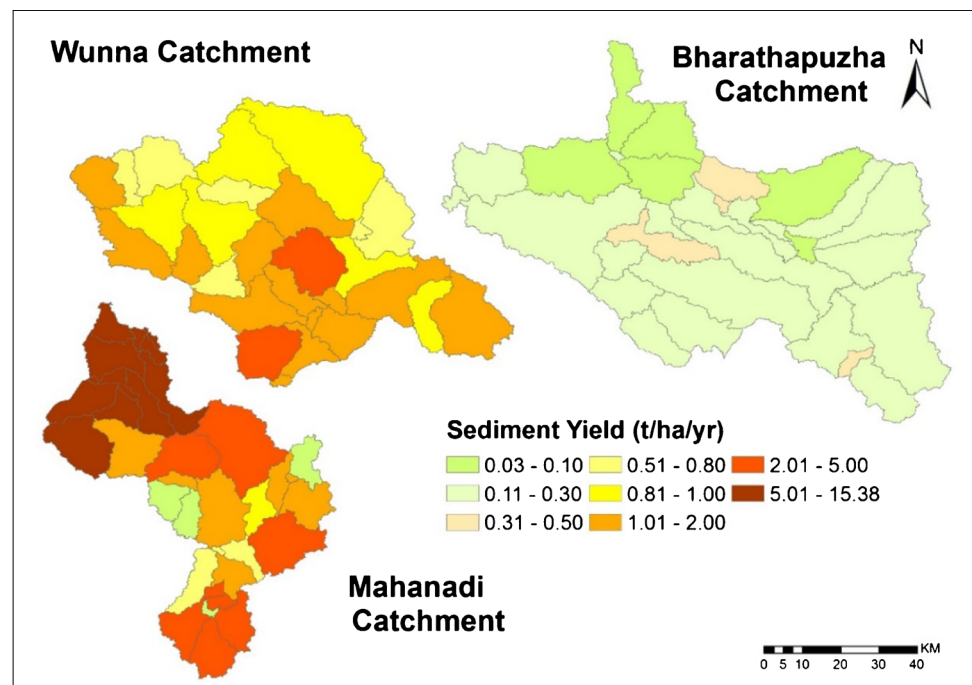
Fig. 11 Spatial variations of Water yield in three watersheds at sub-basin scale



research is also required to assess the effect of landuse or climate change on main hydrological process and reduce the uncertainty of model performance. Overall, it was concluded that the performance of the model was successfully simulated using TRMM; simulated hydrological balance could be guideline tool for watershed management and conservation. Before making general conclusions, inherent uncertainty must be

considered. Model improvement could be possible with incorporation of high-resolution landuse, soil data, and multiple site calibration for better spatial variability and sediment yield simulation instead of TSS data. This approach considers the understanding of hydrological process on watersheds. It will enable the future irrigation development and it will help decision makers to reconsider the impact of hydrological components

Fig. 12 Spatial variations of sediment yield in three watersheds at sub-basin scale



for watershed conservation. For example, irrigation and stream maintenance, and water security (flood and drought).

Finally, we were not considered any future improvements in land use or vegetation cover. Therefore, we suggest a comprehensive analysis of the combined effects of changes in climate, land use and vegetation on hydrological process stability, water quality, and water resources and also the insecurity of the water supply network would increase.

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Author contribution Leelambar Singh Designed and performed the experiments, analysed the data, and all authors of this research wrote the paper. Subbarayan Saravanan supervised the research.

Declarations

Competing interests The authors declare no competing interests.

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