Spatio-temporal modeling of surface runoff in ungauged sub-catchments of Subarnarekha river basin using SWAT

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सार – वर्तमान अध्ययन में, सुवर्णरेखा बेसिन के ऊपरी जलग्रहण क्षेत्र में अप्रमापी उप-जलग्रहण क्षेत्र से सतह अपवाह का अनुकरण करने के लिए ArcGIS इंटरफ़ेस के साथ सन्निहित मृदा और जल मूल्यांकन उपकरण (SWAT) का उपयोग किया गया है। SWAT-CUP पैकेज (SWAT अंशांकन अनिश्चितता प्रोग्राम) में निर्मित अनुक्रमिक अनिश्चितता फिटिंग (SUFI-2) की मदद से मॉडल अंशांकन और सत्यापन किया गया। मॉडल को 1996 से 2008 की अवधि के लिए 3 वर्ष की आरंभिक अवधि (1996-1998) के साथ अंशांकित किया गया और 2009 से 2013 तक 5 वर्षों की अवधि के लिए मान्य किया गया। इस मॉडल का मूल्यांकन नैश-सटक्लिफ गुणांक (NSE), निर्धारण गुणांक (R^2) तथा प्रतिशत अभिनति (PBIAS) द्वारा किया गया। अनिश्चितता की डिग्री का मूल्यांकन P तथा R कारकों द्वारा किया गया। मॉडल के कार्य निष्पादन की पुष्टि अंशांकन के दौरान 0.90, 0.90 और -12% के क्रम में क्रमशः R^2, NSE और PBIAS मूल्यों पर आधारित तथा सत्यापन के दौरान 0.85, 0.83 और -15% द्वारा की गई। मॉडल प्राचलों की सभी अनिश्चितताओं को क्रमशः P तथा R कारकों द्वारा अंशांकन के दौरान 0.95 और 0.77 तथा सत्यापन के दौरान 0.82 और 0.87 के क्रम से भली प्रकार लिया गया। आदित्यपुर के 19 उप-जलग्रहण क्षेत्रों की अपवाह प्रवृत्ति वार्षिक वर्षा के 29.2-44.1% तक भिन्न है तथा पूरे जलग्रहण क्षेत्र के लिए अनुकारी औसत सतह अपवाह 545 मि.मी. है। अधिकांश उप-जलग्रहण क्षेत्रों में उत्पन्न सतह अपवाह के रूप में, 30% से अधिक वर्षा होती है। अतः सिंचाई प्रदान करने, भूजल को रिचार्ज करने तथा तलछट और पोषक तत्वों की हानि को कम करने के लिए एवं वर्षा की अतिरिक्त मात्रा को संग्रहित करने के लिए उपयुक्त स्थानों पर पर्याप्त संरचनात्मक हस्तक्षेप की सिफारिश की जाती है।

ABSTRACT. In this present study, Soil and Water Assessment Tool (SWAT) embedded with ArcGIS interface has been used to simulate the surface runoff from the un-gauged sub-catchments in the upper catchment of Subarnarekha basin. Model calibration and validation were performed with the help of Sequential Uncertainty Fitting (SUFI-2) in-built in the SWAT-CUP package (SWAT Calibration Uncertainty Programs). The model was calibrated for a period from 1996 to 2008 with 3 years warm up period (1996-1998) and validated for a period of 5 years from 2009 to 2013. The model evaluation was performed by Nash - Sutcliffe coefficient (NSE), Coefficient of determination (R^2) and Percentage Bias (PBIAS). The degree of uncertainty was evaluated by *P* and *R factors*. Basing upon the R^2, NSE and PBIAS values respectively, of the order of 0.90, 0.90 and -12%, during calibration and 0.85, 0.83 and -15% during validation, substantiate performance of the model. All uncertainties of model parameters have been well taken by the *P* and *R factors* respectively, of the order of 0.95 and 0.77 during calibration and 0.82 and 0.87 during validation. The runoff generation from 19 sub-catchments of Adityapur catchment varies from 29.2-44.1% of the annual rainfall and average surface runoff simulated for the entire catchment is 545 mm. As the surface runoff generated in most of the sub-catchments amounts to above 30% of rainfall, it is recommended for adequate number of structural interventions at appropriate locations in the catchment to store the rainfall excess for providing irrigation, recharging groundwater and restricting the sediment and nutrient loss.

Key words – SWAT, SUFI-2, Streamflow, Surface runoff, Calibration, Validation.

1. Introduction

Water is the most valuable and finite natural resource required for the very existence of life on the earth. It is broadly categorized into surface water and groundwater. Surface water originates from the upper reaches of watersheds in the form of surface runoff and flows downstream wastefully before it joins a river and

ultimately drains to the sea. It is used as a source of freshwater for all terrestrial lives and unfortunately, it occupies only 0.3% of the total water present on the earth's surface (Khatri and Tyagi, 2015). Unless appropriate and strategic measures are taken at watershed level through biological and structural intervention to retain this flow, the growing demand on this finite resource cannot be met with (Cosgrove and Loucks, 2015). Exponentially rising population, rapid industrialization and large scale urbanization coupled with rising demand of food grains are the prime sectors putting more and more pressure on this finite resource and it is in increasing trend. Thus, harnessing of water from both surface and underground has emerged as a national and international concern today. The situation now demands more precision in assessing the potential extent of the resource at spatial and temporal scales, its effective storage and sustainable exploitation to meet the need of the current and future demands of the civilization (Cosgrove and Loucks, 2015).

Storage of generated runoff at the upstream of watersheds or along the gully beds with structural intervention requires an accurate estimation of the peak discharge. Empirical formulae associated with high uncertainty are in use in hydrologic design of the structures today. Consequently the structural failures or inadequate storage are widely observed in ongoing watershed development projects (Meshesha, 2015). The main reason attributed to such menace is lack of precisely observed database (Ertiro et al., 2017). Surface runoff data measured at the time of occurrence of the events are the basic and essential information required to plan and design any watershed related project. Intensive data recording is also expensive due to large scale instrumentation and long-term monitoring (Sahoo et al., 2020). Most of the time, these data are not available or collected before commencement of a new watershed project in a particular area (Tegegne and Kim, 2018). Despite continuous efforts and investments made to collect such high resolution hydro-meteorological data over the last century, there are still many catchments left out without any gauging station. In other words, the density of hydrometric gauging stations is inconsistently installed across the river basins of India. In most of the cases, catchment area of the gauging stations in Indian river basins is above 1000 km^2 (CWC, 2006). Under these circumstances, water resources planning in macro-watershed scale or below are quite difficult and inaccurate. Above all, it is not at all a practically feasible proposition to have gauging stations and rain gauges at sub-catchment levels to record the flows and rainfall, respectively.

With advent of newer satellite technologies, the deficiency in data acquisition has been removed and hydrological models have been developed to cope with such technology for simulation of stochastic and deterministic events in time and as per the need in both spatial and temporal scales from catchment to regional scale. Hydrological modeling is a key tool for water resource assessment and management. Several watershed models starting from simple empirical models to more complex physically based distributed models have been developed for the purpose by this time. Applications of these models, however, are not entirely free from various kinds of uncertainties with respect to model structure, parameters, input data and natural randomness. These uncertainties finally lead to a considerable error in model simulation. These uncertainties associated with model outputs are to be eradicated or quantified prior to drawing any conclusion and giving recommendation. Statistical models are also developed to verify these uncertainties. Therefore, researchers now prefer to use stochastic and deterministic model in combination having deterministic core within a stochastic frame (Choudhari et al., 2014).

Now, Soil and Water Assessment Tool (SWAT) is one such model gaining popularity as a joint stochastic and deterministic model due to the newly add-on modules such as SWAT-CUP (SWAT Calibration and Uncertainty Procedures) for uncertainty analysis. Basically, SWAT is a physically based semi-distributed hydrologic model initially developed to simulate streamflow in an un-gauged catchment (Arnold et al., 1998). Now-a-days, it is widely used for simulating streamflow, sediment yield, evapotranspiration, soil moisture, crop yield etc. in watershed scale (Zhang et al., 2010; Yesuf et al., 2016; Kumar et al., 2017). The impact of climate change on streamflow (Faramarzi et al., 2013; Dahal et al., 2016) and estimation of blue and green water resources together (Faramarzi et al., 2009) can also be successfully analyzed using this model. Above all, it stands as a robust model for land, water and agricultural system assessment and management.

Subanarekha basin in the state of Odisha is the largest medium river basin of India and known for its water of golden hue. Now, much of its water is exploited by mining and mineral processing industries. The reduction of water in the river is leading to the decline in the groundwater table. The situation warrants intervention of soil and water conservation measures/structures in order to increase surface storages and recharging phreatic aquifers in the upper part of the basin. Therefore, daily and seasonal assessment of the volume of surface runoff during a water year is essential at mini or micro watershed scale. It is very much helpful in designing the conservation structures and appropriate planning for the effective use of water source. Here, the major challenge is estimation of the surface runoff, a prerequisite for
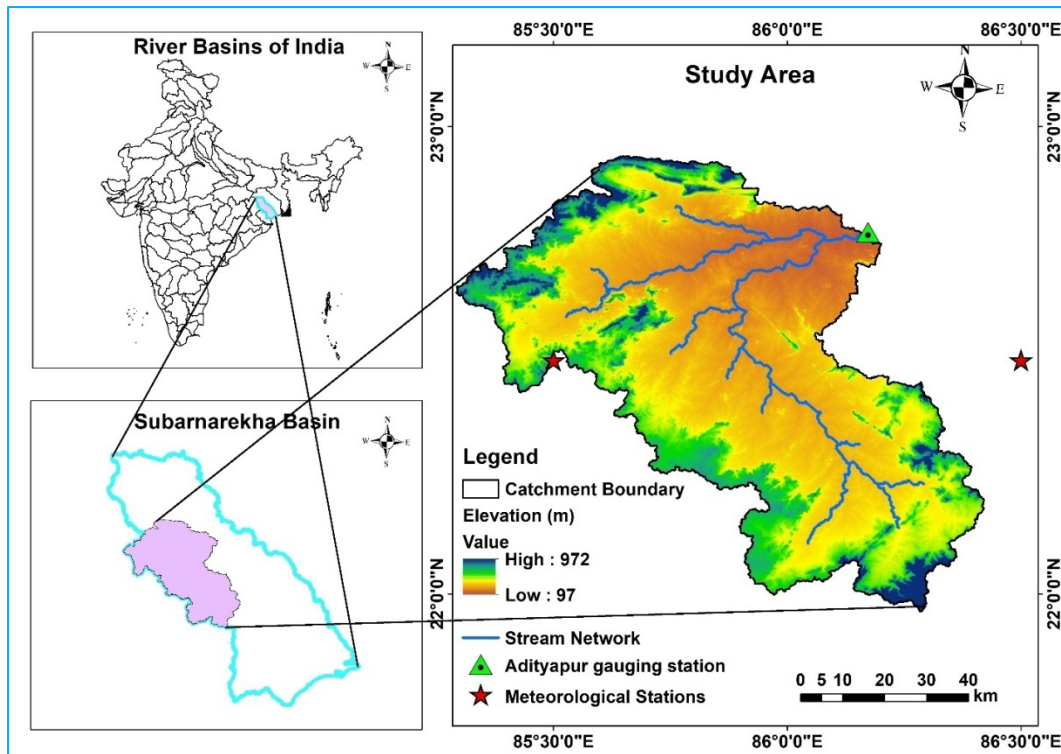
Fig. 1. Location of study area in Subarnarekha River Basin

planning and design of structures, in the un-gauged sub-catchments at the upper reaches of the basin.

In this present study, an attempt has been made to simulate the streamflow in sub-catchments at the upper reach of Subernarekha basin above Adityapur gauging station by using SWAT model integrated with uncertainty quantifying sub-models like SWAT-CUP. The main aim of the study is to quantify the runoff generated from the un-gauged sub-catchments which will be subsequently referred by the water resource planners, managers and also extension officials involved in watershed development.

2. Materials and method

2.1. *Study area and data collection*

The present study is carried out in the upper catchment of Subarnarekha basin (Fig. 1) which spreads over two districts of Jharkhand namely, Sarikela Kharsawan and Paschima Singhbhumi and one district of Odisha namely, Mayurbhanj (Fig. 1). The catchment covers an area of 6029.2 square kilometers with geographical spread from 21° 53′ 48″ to 22° 59′ 13″ N latitude and 85° 11′ 42″ to 86° 30′ 50″ E longitude. There is only one gauging station in the catchment situated at Adityapur in Sarikela-Kharsawan district. The resultant slope of the catchment moves along south to north-west

direction. The elevation of the catchment ranges from 160 m to 651 m from the mean sea level. Major land use pattern in the catchment includes agricultural land of 54%, followed by deciduous forest land of 30%. Major crops grown in this catchment are rice, maize, millets, groundnut, sugarcane and vegetables. The average annual precipitation received is 1332 mm. Peak summer is felt during the month of May with a maximum temperature, as recorded, of 46.4 °C and chilling winter temperature goes down to the level of 5 °C during the month of December. The third order stream network of the catchment is illustrated in Fig. 1.

2.2. *SWAT model*

The Soil and Water Assessment Tool (SWAT) is a continuous, long term, physically based conceptual model (Arnold *et al*., 1998, 2001). This model operates at basin scale on daily time step (Neitsch *et al.*, 2011). It is a hydrologic model developed by the USDA-ARS and the Blackland Research and Extension Centre and enabled to work in GIS interface (Arnold *et al.*, 1998). Simulation of surface runoff by the model is based on United States Department of Agriculture, Natural Resources Conservation Services-Curve Number Method, 1972 (USDA, NRCS-CN). The water balance equation as shown in Eqn. 1 has been used for simulating other hydrological components (Neitsch *et al.*, 2011).
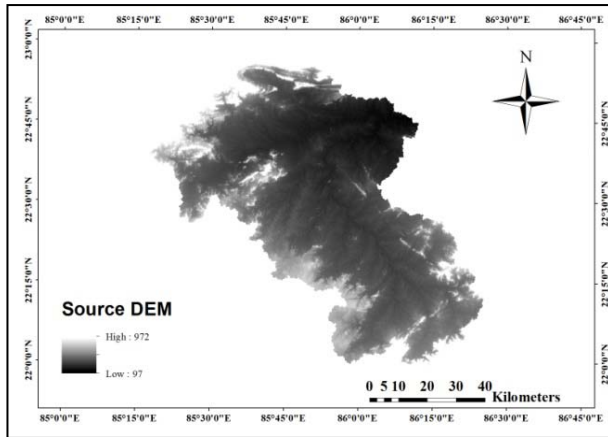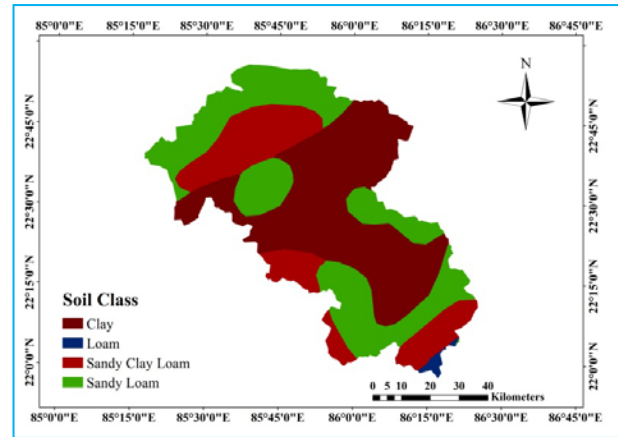
Fig. 2. DEM of the study area

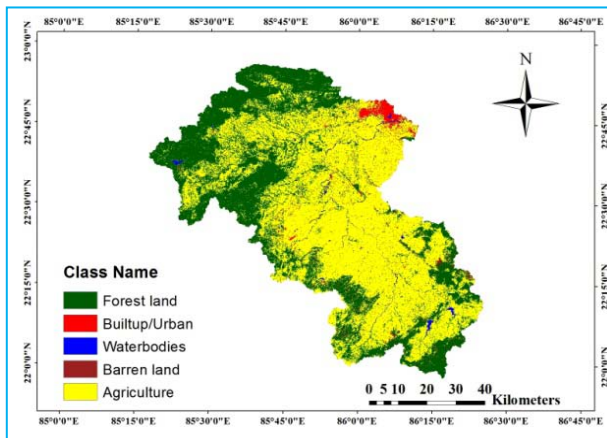**Fig. 4.** Soil map of the study area

Fig. 3. Land use/land cover map of the study area

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day,i} - Q_{surf,i} - E_{a,i} - W_{seep,i} - Q_{gw,i}) \qquad (1)$$

where, SW_t = Final soil water content (mm), SW_o = Initial soil water content on day i (mm), R_{day} = amount of precipitation on day i (mm), Q_{surf} = Amount of surface runoff on day i (mm), $E_{a,}$ = Amount of evapotranspiration on day i (mm), W_{seep} = Amount of water entering the vadose zone from the soil profile on day i (mm), Q_{gw} = Amount of return flow on day i (mm) and t = time interval in day.

2.3. *Model input data*

SWAT needs various field data to set-up the model for simulating streamflow. The basic input datasets required to run the model include the digital elevation model (DEM), land use/cover (LULC), soil, slope and climatic data. The climatic data includes gridded data of rainfall, maximum and minimum temperature at $(1° \times 1°)$ exposure. Data type and their sources of availability are discussed in subsequent sections.

2.3.1. *Digital Elevation Model (DEM)*

DEM is a pre-requisite and critical input to the SWAT model for delineating the catchment area and further division of the large unit into sub-catchments. DEM of the study area has been extracted from ASTER GLOBAL DEM of 30×30 m resolution and downloaded from USGS Earth Explorer as shown in Fig. 2.

2.3.2. *Land use/land cover data*

LULC maps with 1:250000 scale for Odisha and Jharkhand were collected from NRSC, ISRO, Hyderabad. Agricultural land covers the major part of the watershed (54%) followed by forested area (30%) which is mainly dominated by deciduous forests. The barren land (8%), built up area (6%) and water bodies (2%) are the other categories of land use/ land cover of the watershed as portrayed in Fig. 3. It shows that the north and north-west of the watershed is mostly covered with forests and the central part is used for agricultural purposes.

2.3.3. *Soil data*

The soil map was obtained from Food and Agriculture Organization of the United Nations (FAO-UNESCO) at a scale of 1:5000000. The Global soil map was clipped to obtain the required soil map of the study catchment. It is observed that the study area comprises four major types of soil and among them clay soil has the maximum spread (42%) followed by sandy loam soil (36%). The soil types with their spatial extent are presented in Fig. 4.

2.3.4. *Slope data*

After delineation of the watershed boundary, the slope of the watershed is obtained directly from the DEM

using ArcGIS spatial analysis tool. In this particular study, the slope of the watershed is categorized into 5 different classes such as 0-2, 2-7, 7-15, 15-30 and greater than 30% as depicted in Fig. 5. It is observed from the map that more than two third areas (75.5%) of the catchment are lying below 15% slope, 16% area within 15-30% slope and 8.5% area is above 30% slope in the study catchment.

2.3.5. *Meteorological data*

Meteorological data play a vital role in hydrological modeling for drawing a fruitful conclusion. While rainfall is the primary source of water, the other climatic variables such as temperature, relative humidity, wind speed and solar radiation are necessary for accurate estimation of evapotranspiration. Weather station-based gridded climatic data such as rainfall, maximum and minimum temperature were collected from Indian Meteorological Department (IMD), Pune at $1° \times 1°$ scale for 18 years from 1996 to 2013 in daily time step. Other meteorological data required for modeling such as wind speed, relative humidity and solar radiation were simulated using the SWAT Global database downloaded from the SWAT website. It represents average climatic variable data for entire India. SWAT model has an internal capability to interpolate the input station data to generate meteorological data at sub-catchments and HRU level to simulate the hydrological fluxes.

2.3.6. *Hydrological data*

Daily discharge data at Adityapur gauging station recorded by Central Water Commission (CWC) were collected from Water Resource Information System of India (India-WRIS) website for the period from 1996 to 2013.

2.4. *Model calibration and validation*

The model SWAT has been calibrated and validated for monthly streamflow by comparing the observed streamflow at Adityapur outlet with the simulated discharge. The model was run for a period of 18 years (1996-2013) by considering the first 3 years from 1996 to 1998 as the warm-up period. Streamflow data from 1999 to 2008 were used for calibration whereas, the remaining 5 years of the dataset from 2009-2013 were used for validating the model. While the SWAT-CUP has been applied for calibration of the model, the SUFI-2 technique has been used for uncertainty analysis.

2.5. *Model performance evaluation indices*

Five parameters, namely coefficient of determination (R^2), Nash - Sutcliffe Efficiency (NSE), Percentage BIAS (PBIAS), *P-factor* and *R-factor* have been chosen for
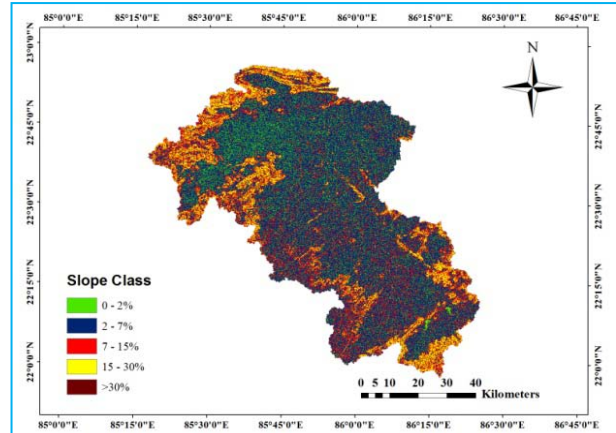

Fig. 5. Slope map of the study area

evaluation of model performance. The coefficient of determination (R^2), Nash-Sutcliffe Efficiency (*NSE*) and Percentage BIAS (*PBIAS*) are expressed mathematically as presented through Eqns. 2, 3 and 4, respectively.

$$R^2 = \frac{[\sum_{i=1}^{n}(S_i-\bar{S})(O_i-\bar{O})]^2}{\sum_{i=1}^{n}(S_i-\bar{S})^2 \sum_{i=1}^{n}(O_i-\bar{O})^2} \qquad (2)$$

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i-S_i)^2}{\sum_{i=1}^{n}(O_i-\bar{O})^2} \qquad (3)$$

$$PBIAS = \frac{\sum_{i=1}^{n}(O_i-S_i)}{\sum_{i=1}^{n}O_i} \times 100 \qquad (4)$$

where, O_i is the observed data on i^{th} day; S_i the predicted/simulated value on i^{th} day; $\bar{O}$ the mean of measured/observed data; $\bar{S}$ the mean of predicted data and n the total number of data.

The *P-factor* (percentage of measured data bracketed by the 95% prediction boundary) was used to quantify all the uncertainties associated with the SWAT model. The range of the *P-factor* varies from 0 to 1 with values closer to 1 indicating a very high model performance and efficiency.

The *R-factor* is the average width of the 95 PPU band divided by the standard deviation of the observed variable and it varies within the range of 0 to ∞ (Abbaspour *et al.*, 2007; Yang *et al.*, 2008). The *P-factor* and the *R-factor* are expressed mathematically as presented in Eqns. 5 and 6 (Abbaspour *et al.*, 2007; Yang *et al.*, 2008).

$$P\text{-}factor = \frac{ny_{t_i}}{N} \qquad (5)$$

where, ny_{t_i} the number of measured values bracketed by the 95 PPU and N the total number of measured values.
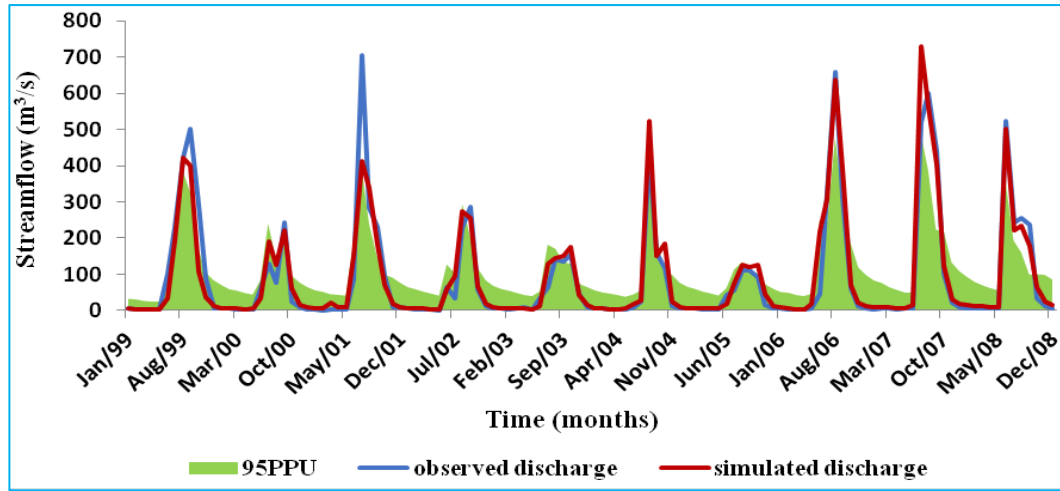
Fig. 6. Time series plot of simulated *versus* observed streamflow with 95PPU band during calibration period

TABLE 1

Summary statistics of calibration performance indicators

	Performance Indicators				
Method	*P-factor*	*R-factor*	R^2	NSE	PBIAS
SUFI-2	0.95	0.77	0.90	0.90	-0.12

TABLE 2

Summary statistics of validation performance indicators

	Performance Indicators				
Method	*P-factor*	*R-factor*	R^2	NSE	PBIAS
SUFI-2	0.82	0.87	0.85	0.83	-0.15

$$R-factor = \frac{\frac{1}{n}\sum_{t_i}^{n} {}_{=1}\left(y_{t_i,97.5\%}^{M} - y_{t_i,2.5\%}^{M}\right)}{\sigma_{obs}} \qquad (6)$$

where, $y_{t_i,97.5\%}^{M}$ and $y_{t_i,2.5\%}^{M}$ are the upper and lower boundaries of the 95 UB (Uncertainty Band), respectively and σ_{obs} is the standard deviation of the observed data.

3.   Results and discussion

   3.1. Model calibration

   It is observed that the simulated streamflow through the outlet of Adityapur gauging station is at the proximity of the observed streamflow during the period of calibration as shown in Fig. 6. The fact has been substantiated by high R^2 value of 0.90. During calibration, the percent bias of (-) 0.12 suggests that the model under-predicts to the degree of 12% only which is well within
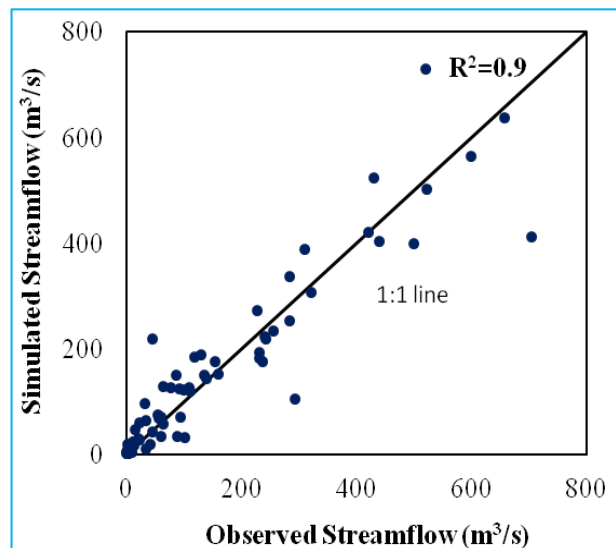

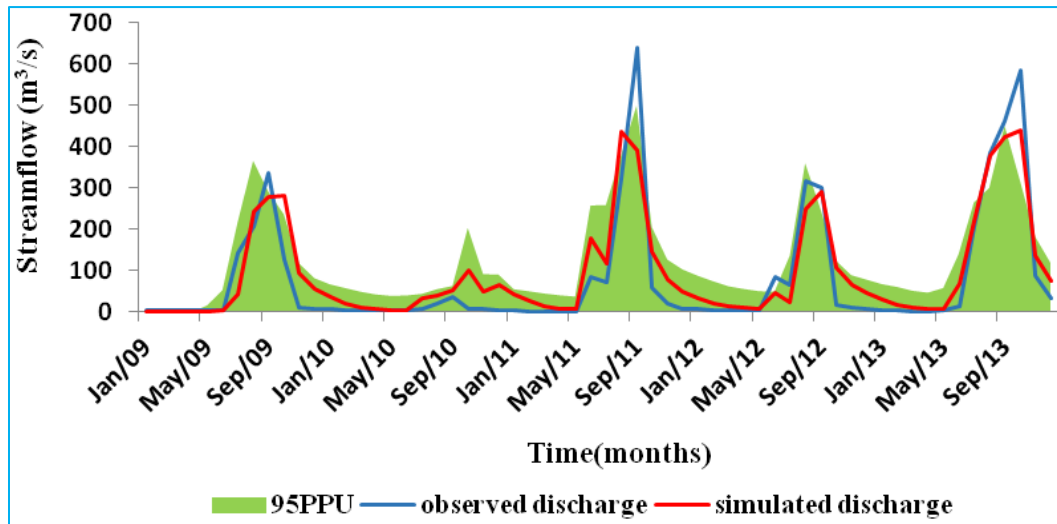**Fig.7.** Scatter plots of observed *versus* simulated streamflow during calibration

Fig. 8. Time series plot of simulated vs. observed streamflow with 95PPU band during validation
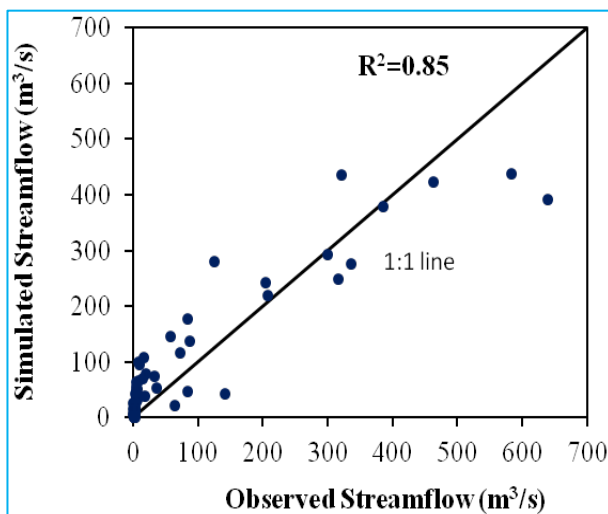

Fig. 9. Scatter plots of observed *versus* simulated streanflow by SUFI-2 during validation

the allowable range as mentioned by Moriasi *et al.* (2007). Again, a scatter plot of both the variables in Fig. 7 depicts the closeness of distribution of the discharges indicating that the simulated discharge is in good agreement with the observed values. The predicting ability of the model has been established through high Nash Sutcliffe Efficiency (NSE) values to a magnitude of 0.90 which suggests that the model calibration is satisfactory. The values of *P and R factors* are obtained to be 0.95 and 0.77, respectively during the calibration period, shown in Table 1. From Fig. 6 it is also observed that most of the model simulated values lie within the shaded region of the 95PPU band, which indicates the model capability to simulate the stream-flow quite satisfactorily even under parameter uncertainty.

3.2. *Model validation*

A calibrated model usually passes through a validation process at different time step for checking the efficiency of the model using the calibration parameters. The simulated and observed streamflow during validation period from 2008 to 2013 show a good correlation as portrayed in Fig. 8. The fact is evidenced by the value of coefficient of determination ($R^2 = 0.85$) as shown in Table 2. The percent bias is further increased to (-) 0.15 from the mean indicating that the model under-predicts the discharge to a degree of 15% only and this is again within the allowable range of prediction (-20% to +20%). Furthermore, a scatter plot of both the variables in Fig. 9 depicts an overestimation of the flow during the initial period which has been underestimated towards the end. However, the overall simulation of the streamflow is found to be satisfactory. The values of *P* and *R factors* during the validation period to the tune of 0.82 and 0.87, respectively indicate overall satisfactory performance of the model. The predicting ability of the model has been established through Nash Sutcliffe efficiency (*NSE*) values of 0.83. It amply suggests that the model validation is satisfactory (Table 2). It is also shown in Fig. 8 that most of the model simulated values lie within the shaded region of the 95PPU band, which indicate the model capability to simulate the streamflow quite satisfactorily even under parameter uncertainty.

3.3. *Spatial variation of average annual surface runoff*

The calibrated and validated model simulates water balance components at sub-catchment and Hydrological Response Unit (HRU) scale. Sub-catchment wise average
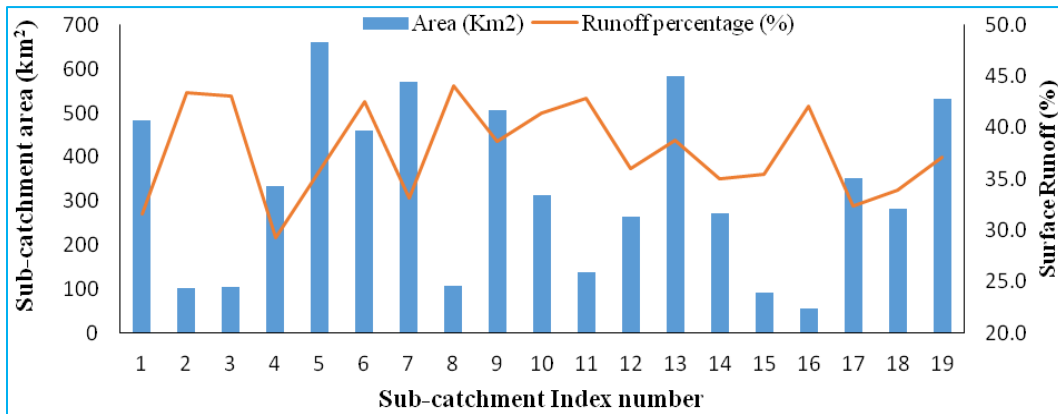
Fig. 10. Sub-catchment area *versus* percentage of surface runoff generated

TABLE 3

Rainfall-runoff transformation in sub-catchments

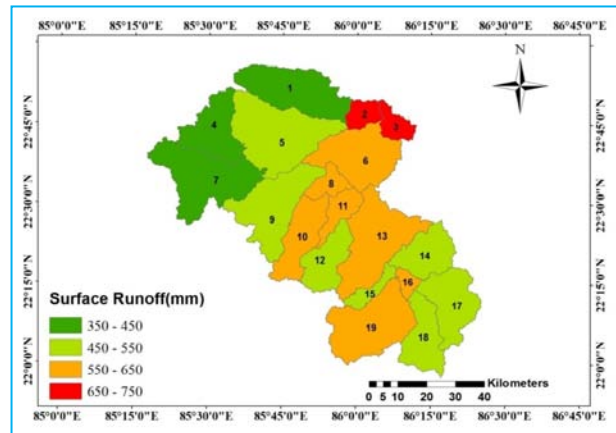| Sub-catchment index No.	Area (km²)	Avg. Rainfall (mm)	Simulated Avg. Runoff (mm)	Runoff percentage (%)
1	483.32	1351	426	31.5
2	100.88	1526	662	43.4
3	105.01	1526	657	43.1
4	333.93	1351	395	29.2
5	660.68	1351	484	35.9
6	460.46	1526	649	42.5
7	570.68	1351	448	33.2
8	107.42	1351	596	44.1
9	505.43	1351	523	38.7
10	312.06	1351	559	41.4
11	136.89	1351	579	42.8
12	263.13	1351	487	36.0
13	584.50	1526	591	38.7
14	272.20	1526	534	35.0
15	91.62	1526	541	35.4
16	54.43	1526	642	42.1
17	352.33	1526	494	32.4
18	282.19	1526	517	33.9
19	532.05	1526	566	37.1
Average		1443	545	37.7

Fig. 11. Spatial distribution of annual average runoff

process. Fig. 10 represents the relation between catchment area and surface runoff produced from them and implies that the smaller sub-catchments reproduce higher surface runoff as compared to the larger ones. It may have happened due to low drainage network. The average surface runoff produced from the entire catchment is 545 mm which is 37.7% of the average rainfall received by the entire catchment area. The highest percentage of surface runoff (44.1%) obtained from the sub-catchment 8. The runoff conversion percentage ranges from 29.2-44.1% in 19 sub-catchments of the study area.

All the sub-catchments are reclassified into 4 categories based on the depth of annual average surface runoff produced as shown in Fig. 11. Among 19 sub-catchments, 2 and 3 sub-catchments are coming under the highest category of the surface runoff class (650-750 mm) although they are situated in the lower reach of the catchment close to the outlet of Adityapur gauging station. This may be due to the fact that these sub-catchments have more built-up area within their drainage boundary having higher opacity and lower infiltration rate suitable

simulated surface runoff is shown in Table 3. It is observed that the highest runoff of 662 mm is generated from sub-catchment 2 and the lowest of value 395 mm is generated from sub-catchment 4 against same rainfall but of different geographical situation. The highest percentage of rainfall to runoff transformation has occurred in sub-catchment 8. Sub-catchments 2 and 3 ranked 2nd and 3rd in rainfall to runoff transformation
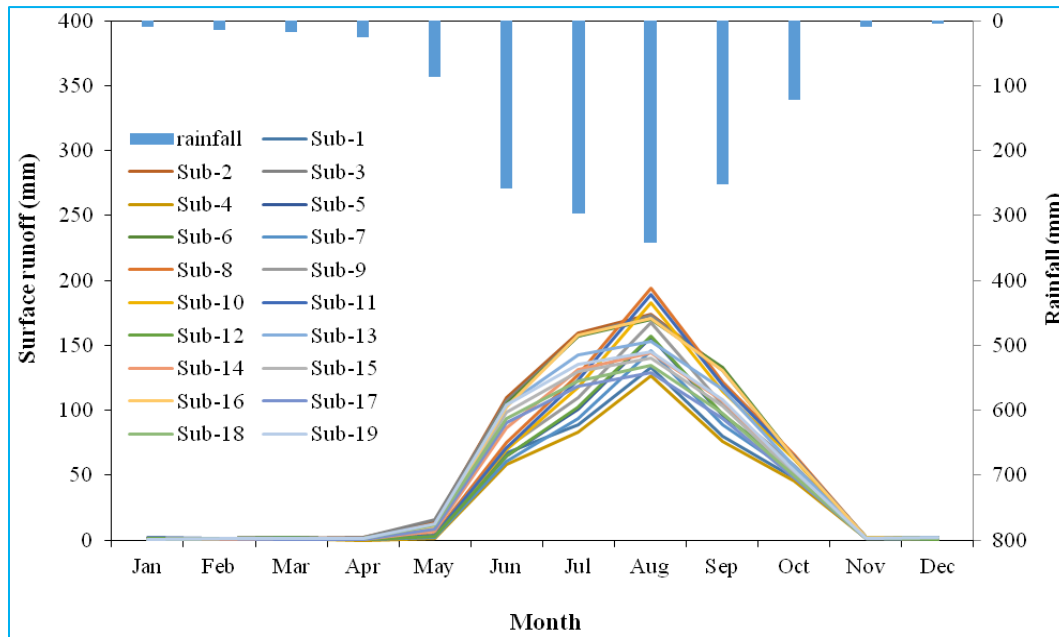
Fig. 12. Temporal variation of runoff in different sub-catchments

for production of higher runoff (Fig. 3). The next higher runoff producing sub-catchments are 6, 8, 10, 11, 13, 16 and 19 mostly covered with agricultural crops produce runoff in the range of 550-650 mm. It may be due to more clay content in the soil having relatively less infiltration capacity. The least runoff producing sub-catchments 1, 4 and 7 (350-450 mm) are mostly covered with forests and the soil type is mostly sandy loam to loam textured having higher infiltration capacity.

3.4. *Temporal variation surface runoff*

Temporal variation of surface runoff is portrayed in Fig. 12. In each of the sub-catchments, as evidenced from the Fig. 12, high surface runoff with peak discharges has been generated during the monsoon season (June to September). For most of the cases, the rise in the ascending limb of runoff hydrograph starts from the month of May, attains peak during August and then descends and becomes asymptotic in the month of November. It reveals that excess surface runoff produced during May to November can be suitably stored in water harvesting structures for reuse during rest of the 7 non-monsoon months of the year. Thus, it may be concluded that the simulation results of SWAT model in sub-catchment scale are well responding to the rainfall pattern, soil and slope of the catchment.

4. Conclusions

The present study demonstrates the application of SWAT model in un-gauged sub-catchments under upper catchment of Subarnarekha River Basin, India for simulating the spatio-temporal variation of surface runoff. The model performance during streamflow calibration by SUFI-2 was evaluated and found to be excellent as supported by *NSE*, R^2 and *PBIAS* values of 0.90, 0.90 and (-) 0.12, respectively for the monthly flow stream simulation. During validation, the model performance is convincingly acceptable as indicated by the *NSE*, R^2 and *PBIAS* values of 0.83, 0.85 and (-) 0.15, respectively. The *P and R factor* values of the order of 0.95 and 0.77 during calibration and 0.82 and 0.87 during the validation period, respectively indicate that the model performance is quite satisfactory under the parameter uncertainty.

Basing upon the calibration and validation results, it may be inferred that the average surface runoff produced from the entire catchment is 545 mm which amounts to 37.7% of the average rainfall received in the entire catchment area. The percentage of runoff generation varies from 29.2 - 44.1% of annual rainfall in 19 sub-catchments under Adityapur catchment. The highest surface runoff of 662 mm is generated from sub-catchment 2 and the lowest surface runoff of 395 mm is from sub-catchment 4. The fact is also supported by the geomorphologic parameters of the sub-catchments. Further, the smaller sub-catchments are observed to produce higher surface runoff as compared to larger ones. The existing stream order and prevailing land slope support the finding. Irrespective of the size, location and shape of the sub-catchments, high to peak surface runoff is observed during the month of May and November.

As the surface runoff generated in most of the sub-catchments under the upper catchment of Subarnarekha is above 30%, a blank recommendation may be issued for structural as well as biological interventions or both in adequate number and at appropriate locations in different parts of the catchment in order to restrict the sediment and nutrient losses from the catchment and increase storage of runoff water for supplemental irrigation, recharging groundwater and evading flash floods in the downstream areas.

Disclaimer

The contents and views expressed in this research paper are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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