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Effect of spatial resolution of climatological data on streamflow simulations using the SWAT : A case study

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सार — **डेटा की गुणवत्ता हमेशा मॉडल आउटपुट की सटीकता को प्रभावित करती है। हाइड्रोलॉजिकल मॉडलिंग में वर्षा आवश्यक बुनियादी डेटा है क्योंकि वर्षा से अपवाह रूपांतरण सभी मॉडलों का मूल है। क्षेत्रीय मॉडलिंग अध्ययनों के लिए उच्च विभेदन स्थानिक-कालिक डेटा की आवश्यकता होती है और उचित विभेदन पर डेटा की उपलब्धता भी मॉडलिंग परिणामों को बहुत प्रभावित करती है। इसलिए, जलवायु परिवर्तन को बेहतर विभेदन पर रिकॉर्ड करने के प्रयास शुरू किए गए हैं ताकि वे ब्लॉक स्तर और ग्राम पंचायत स्तर के अध्ययन के लिए उपयोगी हों। इस अध्ययन में, महानदी नदी बेसिन के केसिंगा जलग्रहण क्षेत्र में धारा प्रवाह अनुकरण पर विभिन्न विभेदन जलवायु डेटा का उपयोग करने के प्रभाव की पहचान करने का प्रयास किया गया है। भारत मौसम विज्ञान विभाग से** 0.25° × 0.25° **और** 1° × 1° **के स्थानिक विभेदन के साथ और विशेष राहत आयुक्त (एसआरसी), ओडिशा सरकार द्वारा मृदा और जल मूल्यांकन उपकरण** (SWAT) **का उपयोग करके केसिंगा वर्षामापी स्टेशन पर दर्ज किए गए वर्षा आंकड़ों के तीन सेट का उपयोग भारत मौसम विज्ञान विभाग के** 1° × 1° **ग्रिडेड तापमान के साथ संयोजन से धारा प्रवाह को सिमुलेट करने के लिए किया गया है। एनएसई, आर**^{2}**, आरएमएसई, पीबीआईएएस, पी-फैक्टर और आर-फैक्टर का उपयोग करके तीन अनुकरण का विश्लेषण किया गया। प्राप्त परिणामों से पता चलता है कि भारत मौसम विज्ञान विभाग ग्रिडेड वर्षा डेटा सेट ने एसआरसी द्वारा अभिलेखित वर्षा डेटा के समान प्रवाह का पूर्वानुमान दिया है जो ब्लॉक स्तर पर दर्ज वर्षा डेटा के बराबर भारत मौसम विज्ञान विभाग के ग्रिडेड डेटा की समानता साबित करता है।**

ABSTRACT. Data quality always affects the accuracy of model output. Rainfall is the basic data required in hydrological modelling as rainfall to runoff conversion is the core of all such models. Regional modelling studies required high resolution spatio-temporal data and availability of data at appropriate resolution also greatly affect the modelling results. Therefore, efforts have been started to record climatic variables at finer resolution so that they will be useful for block level and gram Panchayat level studies. In this study, an effort has been made to identify the effect of using various resolution climatic data on streamflow simulation in the Kesinga catchment of the Mahanadi river basin. Three types of rainfall sets with spatial resolution of 0.25° × 0.25° and 1° × 1° from IMD and one set of recorded rainfall data of the Special Relief Commissioner (SRC), Govt. of Odisha is used in combination with IMD 1° × 1° gridded temperature to simulate streamflow at the Kesinga gauging station using the Soil and Water Assessment Tool (SWAT) keeping other parameters constant. The three simulations were analyzed using NSE, R^2, RMSE, PBIAS, P-factor and R-factor. The results depicted that IMD gridded rainfall data sets predicted similar flows compared to the SRC recorded rainfall data which proves the fairness of IMD gridded data is at par with the recorded rainfall data of SRC, Govt. of Odisha.

Key words – Hydrological modelling, SWAT, Data resolution, Streamflow.

1. Introduction

Liquid water is the symbol of life in this universe. Role of water in the environment has sparked debate about its management and utilisation. Limited fresh water availability and its fluctuations necessitate its appropriate management for sustainable use. Nowadays, fresh water quantity and quality are the major concerns because both are declining at alarming rate (Padhiary *et al*., 2019). Hydrological models are used to predict various components of the natural hydrological cycle (Patil *et al*., 2019). However, input data availability, its resolution and

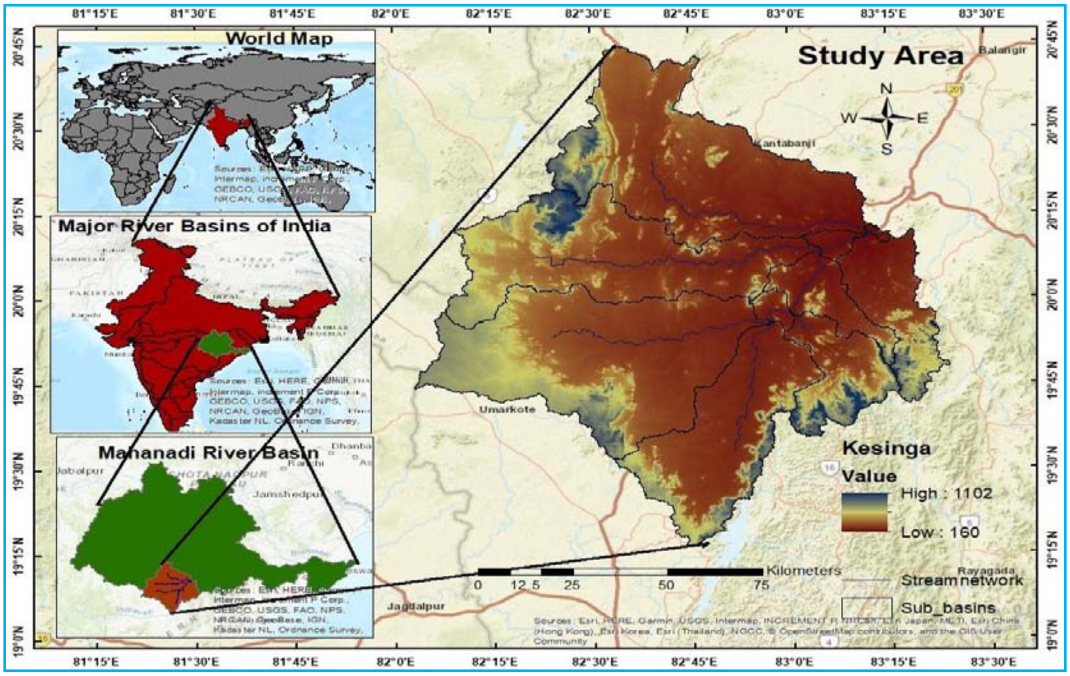

Fig. 1. The location map of study area

accuracy are mainly responsible for better model output (Camargos *et al*., 2018). The SWAT model is a widely accepted hydrological model used for rainfall-runoff analysis, surface and groundwater quality and quantity investigation, sediment yield prediction and other agricultural applications like irrigation scheduling, crop yield modelling and nutrient flow from crop lands etc. (Panda *et al*., 2021, Narsimlu *et al*., 2015). Historic climatic data is required for continuous simulation of hydrological fluxes at various time steps like daily, monthly and annually (Srivastava *et al*., 2009, Uniyal *et al*., 2015). The lack of observed climatic data records sometimes impels researchers to use average data base like WGEN weather generators to run the model (Vesely *et al*., 2019).

Rainfall is the major component for the hydrological cycle and source of interception, infiltration, seepage, percolation and runoff process (Narsimlu *et al*., 2015). Hence, rainfall data is the bare minimum requirement in any type of hydrological model. The SWAT being a physically based semi-distributed hydrological model requires climatic data like precipitation, solar radiation, wind speed, relative humidity, maximum and minimum temperature of climate stations or in gridded form for hydrological simulation from an ungauged catchment (Arnold *et al*., 2012). High spatio-temporal variation in climatic data creates a similar trend in estimation of hydrological process. Therefore, all climatic agencies are putting their efforts to record climatic data at higher spatial resolution (Oruc *et al*., 2022). In the current study, an effort has been made to simulate the streamflow at Kesinga gauging station using the high resolution IMD gridded rainfall data and SRC, Govt. of Odisha observed rainfall data.

India Meteorological Department (IMD) established in the year 1875, is the premier body in the country responsible to install new climate data recording stations, keep climate data records, provide an early warning system for climatic extremes etc. In addition to this, state government departments, state agricultural universities, Indian council of Agricultural Research (ICAR) are the other agencies to record climate data on their own periphery. IMD developed 0.25 × 0.25° rainfall and 1 × 1° gridded maximum-minimum temperature data is the finest resolution data available for the entire country which can be used for micro scale research. IMD on its official website has given two types of rainfall data at 0.25 × 0.25 degree and 1 × 1 degree spatial scale. Both the rainfall data sets are available from 1901 to till date in daily time step. The 0.25 × 0.25 degree data product is considered as a very high - spatial resolution gridded rainfall data in the India. The unit of rainfall data is in millimeter (mm). Data is arranged in 135 × 129 grid points over the entire country. High resolution (1° × 1°) gridded maximum and minimum temperature (in °C) data is available from 1951 to till date and arranged into 31 × 31 grid points for the entire country in daily time step. The yearly data file consists of 365 days and 366 days of data records

TABLE 1

Input data for the SWAT model in the Kesinga river basin

S. No.	Data	Sources
1.	DEM	The Digital Elevation Model (DEM) was collected from Shuttle Radar Topography Mission (SRTM 30) of USGS (http://srtm.csi.cgiar.org/)
2.	Soil	Soil map at 1:50,000 was collected from NBSS&LUP-ICAR
3.	Land Use	The land use map at 1:50000 was collected from the National Remote Sensing Centre (https://www.nrsc.gov.in/)
4.	Rainfall and Temperature	Gridded rainfall (2000-2020) data at 1 degree and 0.25 degree, and Gridded temperature data at 1 degree on a daily basis were collected from the Indian Meteorological Department (IMD), Pune. Observed rainfall(SRC data, Spatial scale: Block wise, Temporal scale :daily) (https://srcodisha.nic.in/rain_fall.php/)
5.	Discharge	Daily discharge data of the Kesinga catchment for the period from 2000-2020 was collected from Water Resources Information System of India (India WRIS). (https://indiawris.gov.in/)

corresponding to non-leap and leap years, respectively. Block-wise daily observed rainfall data is available in the SRC Govt. of Odisha website, from 1988.

The objective of this study is to run the SWAT model using two high resolution IMD gridded rainfall data (0.25° and 1°) and observed rainfall data from SRC with 1° × 1° maximum minimum temperature data. The resulted streamflow from the three sets of data are then compared with the observed streamflow to screen out the most suitable rainfall product for streamflow simulation. The Kesinga catchment of the Mahanadi basin has been selected for the study because of its natural diversity and availability of all types of data required for the SWAT modelling. This study includes different types of data to provide a theoretical and methodological foundation for the hydrological dynamics for the catchment. It will also assist researchers, watershed planners and managers to tackle climatic data issue for hydrological modelling.

2. Materials and methods

2.1. *Study area*

The study was conducted in the Kesinga sub-catchment of the Mahanadi river basin. The Kesinga sub-catchment is spread between 19.15° - 20.44° N latitude and 82.21° - 83.24° E longitude (Fig. 1). The sub-catchment includes Kalahandi, Nuapada, Balangir and Nabarangpur district of Odisha and Gariabad district of Chhattisgarh. Due to the continual flow of water streams, the region has fine and medium grained soil. These fertile soils are ideal for agriculture. Upstream of the Kesinga gauging station has three minor streams : Harol, Udanti and Under.

2.2. *SWAT model*

It is a physically based semi-distributed model created by the Agricultural Research Service of the US (USDA-ARS). SWAT requires daily precipitation, temperature, solar radiation, wind speed and relative humidity. The climate data can be used either from measured sources and/or generated internally in the model using SWAT's weather generator (Uniyal *et al*., 2015). On a daily, monthly and yearly timeframes, the SWAT model simulates stream flow, erosion in planes and channels and nutrient and pesticide transport. In the hydrological model, equation 1 is used for water balance.

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

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

2.2. *Data requirement*

Five basic data sets, *i.e*., digital elevation model (DEM), land use, soil, weather and discharge data is required for model set up and calibration and validation as shown in Table 1. Climate stations for rainfall are shown in Fig. 2. SWAT generates 146 hydrological response unit (HRUs) using uniform land use, soil and slope to simulate the hydrological components.

TABLE 2

Calibration parameters and their fitted values

Sensitivity Rank	Calibration parameters	Qualifier	Minimum value	Maximum value	Fitted Parameters
1	CN2.mgt	R	-0.163	0.112	0.065
2	ALPHA_BF.gw	V	-0.364	0.545	0.245
3	GW_DELAY.gw	A	170.396	451.253	319.250
4	GWQMN.gw	V	1568.576	4706.423	1976.49
5	ESCO.hru	V	0.298	0.894	0.626
6	SOL_AWC(..).sol	R	-0.045	0.364	0.262
7	CH_K2.rte	V	62.132	186.417	83.260
8	SOL_K(..).sol	R	-0.408	0.030	-0.193
9	SURLAG.bsn	V	2.294	5.883	5.703
10	CH_N2.rte	V	0.118	0.336	0.312

(i) A represents the fitted value is added to the existing parameter value; (ii) R represents the existing parameter value is multiplied by (1+the given value); (iii) V represents the existing value for the parameter is to be replaced by the fitted value.

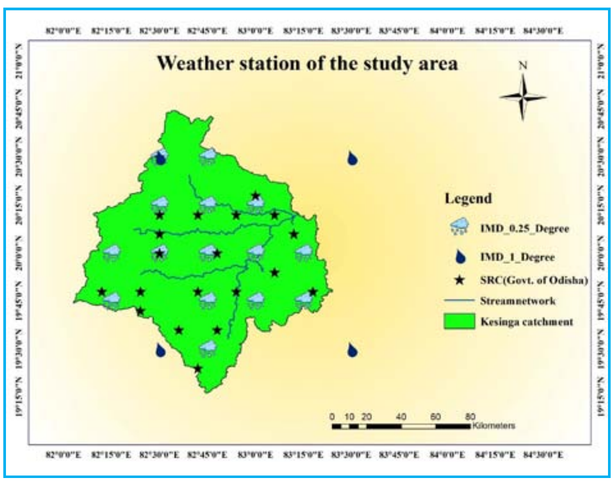

Fig. 2. Location of weather stations under various spatial rainfall data resolution

2.3. *Scenario Generation, Model Calibration and Validation*

Three scenarios has been formulated using the rainfall products of three spatial resolution, *i.e.*, Scenario-I (S-I) = 0.25° × 0.25°, Scenario-II (S-II) = 1° × 1° and Scenario-III (S-III) = SRC observed rainfall. The SWAT model was simulated thrice on a monthly time step from the year 2000 to 2020 using the three spatial resolution rainfall data. First three years of model simulation, *i.e.*, 2000-2002 used as the warm up period to set-up the model. Monthly, time step was selected to reduce the computational time because the objective of the study was to study the effect of various data resolution on streamflow. Many researchers have also identified monthly SWAT simulation gives better insight than other time step (Khan *et al*., 2022). Then, from the year 2003-2012, was used for model calibration and 2013-2020 was used for model validation. Model calibration validation and uncertainty analysis were carried out in SWAT Calibration and Uncertainty Programs (SWAT-CUP) 2019 v.5.1.6.2 software (Abbaspour *et al*., 2007) using SUFI-2 auto-calibration technique. The optimised model parameters influencing the streamflow were chosen for the study which is presented under Table 2. Parameter sensitivity analysis was also carried out during calibration and parameters in Table 2 are ranked as per their sensitivity towards streamflow simulation. The parameters were optimised 5 iterations with 500 simulations each using SUFI-2 algorithm in SWAT-CUP which were used to simulate streamflow for each of the scenario of the study.

2.4. *Model performance evaluation*

The model performance and uncertainty were evaluated using NSE, R^2, RMSE, PBIAS, P-factor and R-factor (EI-Sadek *et al*., 2011; Neitsch *et al*., 2011; Kannan *et al*., 2007). The mathematical formulation of these statistical indices are presented in Eqns. 2, 3, 4, 5, 6 and 7.

$$R^2 = \frac{\left[\sum_{i=1}^{n} (S_i - \underline{S})(O_i - \underline{O})\right]^2}{\sum_{i=1}^{n} (S_i - \underline{S})^2 \sum_{i=1}^{n} (O_i - \underline{O})^2} \quad (2)$$

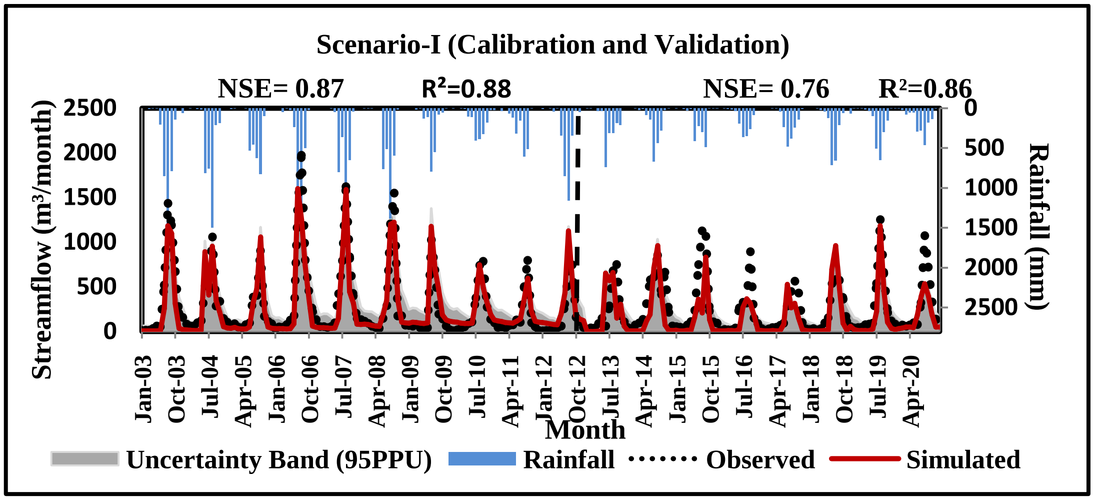

Fig. 3. Time Series Plot of Streamflow under Scenario-I

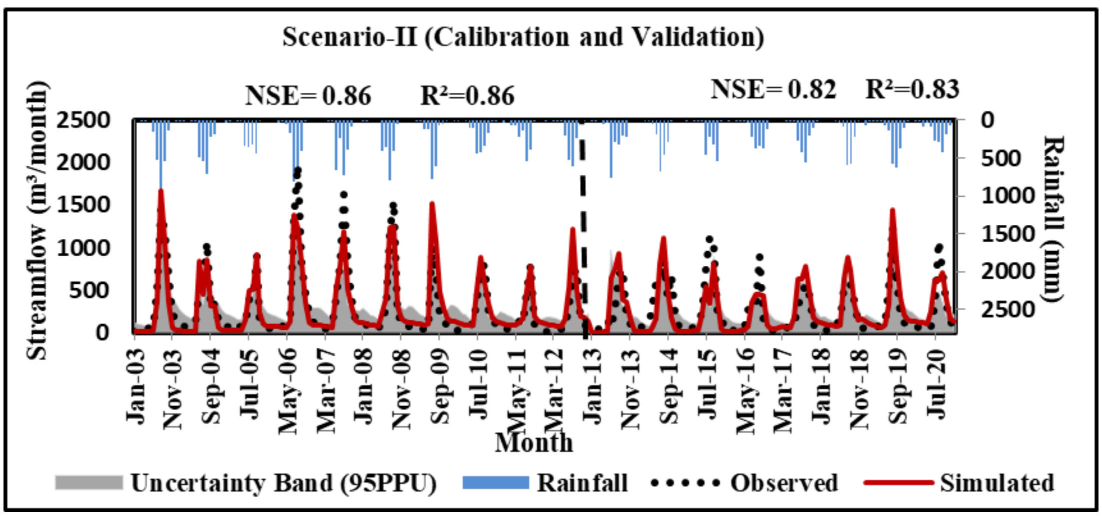

Fig. 4. Time Series Plot of Streamflow under Scenario-II

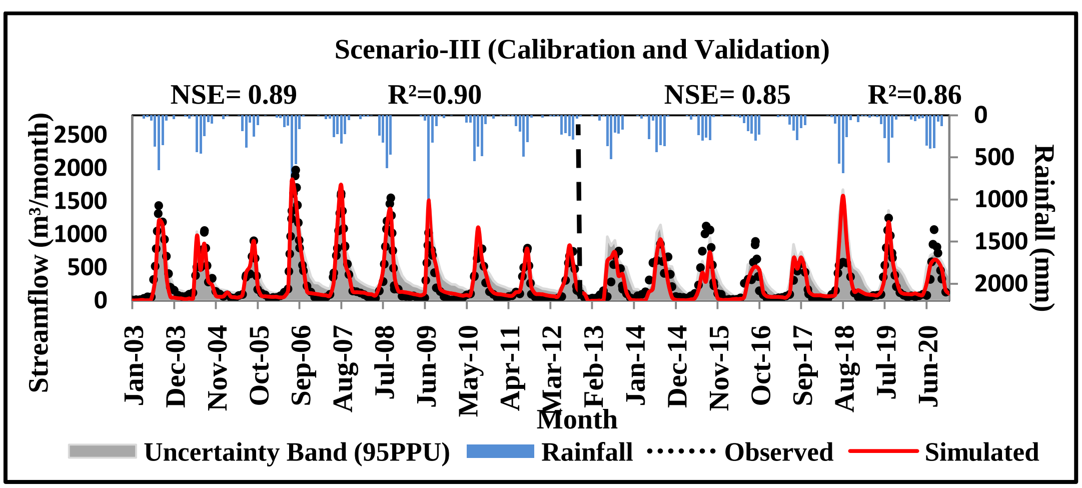

Fig. 5. Time Series Plot of under Scenario-III

TABLE 3

Model performance and Weightage assignment to scenarios during calibration

S. No.	Scenario	NSE	R^2	PBIAS	R-FACTOR	P-FACTOR	RMSE (m^3/s)	Total Weightage
1.	S-I	0.87 (2)	0.88 (2)	-4.7 (2)	1.03 (2)	0.89 (2)	138.2 (2)	12
2.	S-II	0.86 (1)	0.86 (1)	-19(1)	0.90 (1)	0.85 (1)	148.2 (1)	6
3.	S-III	0.89 (3)	0.90 (3)	-3.8 (3)	1.04 (3)	0.90 (3)	130.5 (3)	18

TABLE 4

Model performance and Weightage assignment to scenarios during validation

S. No.	Scenario	NSE	R^2	PBIAS	R-FACTOR	P-FACTOR	RMSE (m^3/s)	Total Weightage
1.	S-I	0.76 (1)	0.86 (3)	-7.5 (2)	1.03 (3)	0.89 (3)	207.6 (1)	13
2.	S-II	0.82 (2)	0.83 (2)	-17.5(1)	0.69 (1)	0.82 (2)	191.8 (2)	10
3.	S-III	0.85 (3)	0.86 (3)	1.9 (3)	0.75 (2)	0.79 (1)	137.6 (3)	15

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

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

$$\mathrm{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (S_i - \underline{S})} \qquad (5)$$

$$\mathrm{P-factor} = \frac{no_{t_i}}{N} \qquad (6)$$

where, no_{t_i} is the number of measured values bracketed by the 95PPU and N is the total number of measured values.

$$\mathrm{R-factor} = \frac{\frac{1}{n} \sum_{t_i=1}^{n} \left(o_{t_i,97.5\%}^{M} - o_{t_i,2.5\%}^{M} \right)}{\sigma_{\mathrm{obs}}} \qquad (7)$$

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

The range of R^2 and NSE varies from 0-1. Value R^2 and NSE are close to 1 and lower value of PBIAS and RMSE represents good simulation. P-factor and R-factor represents the uncertainty in the model simulation. The P-factor represents % of observed data bracketed within the 95PPU band and R-factor represents the width of the 95PPU band. Higher the value of both factors represents trustable simulation under model parameters uncertainty (Padhiary *et al*., 2019).

3. Results and discussion

The time series plot of simulated streamflow under scenario-I, II and III are presented under Figs. 3, 4 and 5, respectively. IMD gridded data of 0.25 and 1 degree are used under scenario-I and II, respectively and SRC observed rainfall data is used under scenario-III. Location of climate station data used under scenario-I, II and III are 15, 4 and 19, respectively as shown in Fig. 2. From the time series plot it is observed that simulated streamflow under all scenarios are well matched with the observed streamflow but scenario-III has a better agreement with the observed streamflow. Under scenarios-I and II the peak of the simulated streamflow was under predicted than the observed flow during the monsoon period. Streamflow is under predicted in the years 2003, 2006, 2008, 2011, 2015, 2016 and 2020 for scenario-I and in the years 2004, 2006, 2007, 2008, 2015, 2016 and 2020 for scenario-II, respectively. Under scenario-III the streamflow is under predicted 2003, 2008, 2015, 2016 and 2020. So, it is concluded that the SWAT is not very efficient in predicting the peak flow in most of the cases. This may be due to the SCS curve number method used in the SWAT model to simulate surface runoff which does not take care of peak flow. This is one of the limitations of SWAT model, so it is not very popular in flood simulation and routing.

The 95PPU band represents the uncertainty in model simulation due to uncertainty in model parameterization. The auto calibration in SWAT-CUP generates a series of simulated data that forms a band and model prediction is said to be better if the maximum number of observed data is bracketed inside the 95PPU band. In this study, it is seen that expect some peak points most of the observed data is bracketed within the 95PPU band.

3.1. *Model performance evolution*

SWAT model performance under scenario-I, II and III are evaluated using NSE, R^2, PBIAS, RMSE and uncertainty was evaluated using P-factor and R-factor. The results from the different scores obtained for all scenarios during calibration and validation period is presented under Table 3 and Table 4, respectively. To identify the best scenario weights have been assigned to all the scores on 1 to 3 scales in the order of their superiority among all scenarios. From Tables 3 and 4, the best SWAT model simulation was observed under scenario-III followed by scenario-I and scenario-III, respectively. The total weightage score is highest in scenario-I followed by scenario-II and III, respectively during both calibration and validation periods. The weightage was assigned to various model evaluation parameters under different scenarios as per the order of their values. Then the individual score weightage were summed to find out the total weightage of different scenarios during calibration and validation periods. However, difference in weightage is higher in calibration period rather than validation period. It reveals that a distinguished variation in model simulation results was observed during calibration rather than validation. Higher value of P-factor and R-factor represent the model is well at predicting the streamflow under parameter uncertainty for all the three scenarios. The lowest root mean square (RMSE) error was obtained under scenario-III during both calibration and validation periods. However, higher variation in RMSE values are observed during validation period which represent higher disagreement between observed and simulated streamflow during the validation period rather than the calibration period.

4. Conclusions

SWAT model was simulated using three rainfall products of varying spatial resolution. IMD gridded rainfall data of 0.25° and 1° are used under scenario-I and scenario-II, respectively. SRC Govt. of Odisha observed rainfall data is under scenario-III. From the analysis of model output under all the scenarios revealed that the scenario-III with 19 climatic stations within the Kesinga catchment depicted the highest model performance rather than the other two scenarios. Scenario-I using high resolution IMD rainfall data of 0.25° × 0.25° grid having 15 climatic stations inside the catchment stood second and scenario-III using 1° × 1° gridded data stood third for streamflow prediction. The performance indicators like NSE, R^2, PBIAS and RMSE depicted that the IMD gridded rainfall products are well responding to hydrological models and simulating streamflow in an acceptable range. Hence, it is concluded that the gridded rainfall products can be used for hydrological simulations in ungauged catchments of the India with satisfactory accuracy compared with the observed rainfall products.

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

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