

Simulation of runoff in Baitarani basin using composite and distributed curve number approaches in HEC-HMS model

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सार – वर्तमान अध्ययन ओडिशा के बैतरणी बेसिन में आनंदपुर गेजिंग स्टेशन तक 8603.7 कि.मी² के क्षेत्र में किया गया था। डिजिटल एलीवेशन मॉडल (DEM) से बेसिन का पूर्व संसाधन HEC-Geo-HMS एक्सटेंशन और स्थानिक विश्लेषक यंत्र द्वारा किया गया। इसके बाद इन पूर्व संसाधित फाइलों को अपवाह बढ़ाने के लिए HEC-HMS में भेजा गया। प्रस्तुत अध्ययन में अपवाह अनुकरण दो विधियों नामतः संयुक्त और वितरित वक्र संख्या उपगमन द्वारा किया गया। अपवाह की मात्रा की गणना के लिए SCS वक्र संख्या विधि, प्रत्यक्ष अपवाह के लिए SCS-UH विधि, मूल अपवाह के लिए स्थिर-मासिक परिवर्ती मूल प्रवाह मॉडल और प्रवाह के मार्ग के लिए मसकिंगम विधि का प्रयोग किया गया। संयुक्त और वितरण CN विधियों द्वारा मॉडल का अंशांकन किया गया और मान्यता दी गई। अंशांकन के लिए 1 जनवरी 2007 से 31 दिसम्बर 2013 तक के आँकड़ों तथा मान्यता प्रदान करने के लिए 1 जनवरी 2014 से 31 दिसम्बर 2016 तक के आँकड़ों का उपयोग किया गया। संयुक्त CN विधि के दौरान सांख्यिकीय प्राचल जैसे नैश सटाक्लिफ एफिशिएन्सी (NSE) निर्धारण गुणांक (R^2) प्रतिशत बायस (PBIAS) और RMSE प्रक्षेप मानक विचलन अनुपात (RSR) क्रमशः 0.53, 0.63, 12.82 और 0.7 पाए गए और मान्यता के लिए ये क्रमशः 0.53, 0.54, -19.73 और 0.7 रहे। वितरित वक्र संख्या उपगमन के मामले में NSE, R^2 , PBIAS और RSR जैसे सांख्यिकीय प्राचलों के मान अंशांकन अवधि में क्रमशः 0.62, 0.63, -8.64, और 0.6 पाए गए। और मान्यता की अवधि में 0.67, 0.66, -2.25 और 0.6 पाए गए अध्ययन से संकेत मिला कि HEC-HMS का उपयोग करके अपवाह के अनुकरण में संयुक्त CN उपगमन की अपेक्षा वितरित CN उपगमन अधिक सटीक है।

ABSTRACT. The present study was conducted in Baitarani basin up to Anandapur gauging station of Odisha covering an area of 8603.7 km². Pre-processing of basin from digital elevation model (DEM) was done using HEC-Geo-HMS extension and spatial analyst tool in ArcGIS. These pre-processed files were then imported to HEC-HMS for simulating runoff. In this study, runoff simulation was done using two methods, viz., composite and distributed curve number (CN) approaches. SCS curve number method was used for computation of runoff volume, SCS UH method for direct runoff, constant- monthly varying base flow method for base flow and Muskingum method for flow routing. The model was calibrated and validated using both composite and distributed CN approaches. Data from 1st January, 2007 to 31st December, 2013 were used for calibration and 1st January, 2014 to 31st December, 2016 were used for validation. During the calibration period of composite CN approach, the statistical parameters like Nash-Sutcliffe efficiency (NSE), Coefficient of determination (R^2), Percent bias (PBIAS) and RMSE-observations standard deviation ratio (RSR) were found to be 0.51, 0.63, 12.82 and 0.7, respectively and during the validation period they were found to be 0.53, 0.54, -19.73 and 0.7, respectively. In case of distributed CN approach, the statistical parameters like NSE, R^2 , PBIAS and RSR were found to be 0.62, 0.63, -8.64 and 0.6, respectively during the calibration period and 0.67, 0.66, -2.25 and 0.6, respectively during the validation period. The study indicated that distributed CN approach is more accurate than composite CN approach in simulation of runoff using HEC-HMS model.

Key words – Runoff, Composite CN, Distributed CN, HEC-HMS.

1. Introduction

Water is now a global concern and suitable water availability has become a challenge before the world

community. Knowledge on water availability is extremely important for water resource management. Failure in effective management of water sources will greatly affect the society and the economic growth of the country

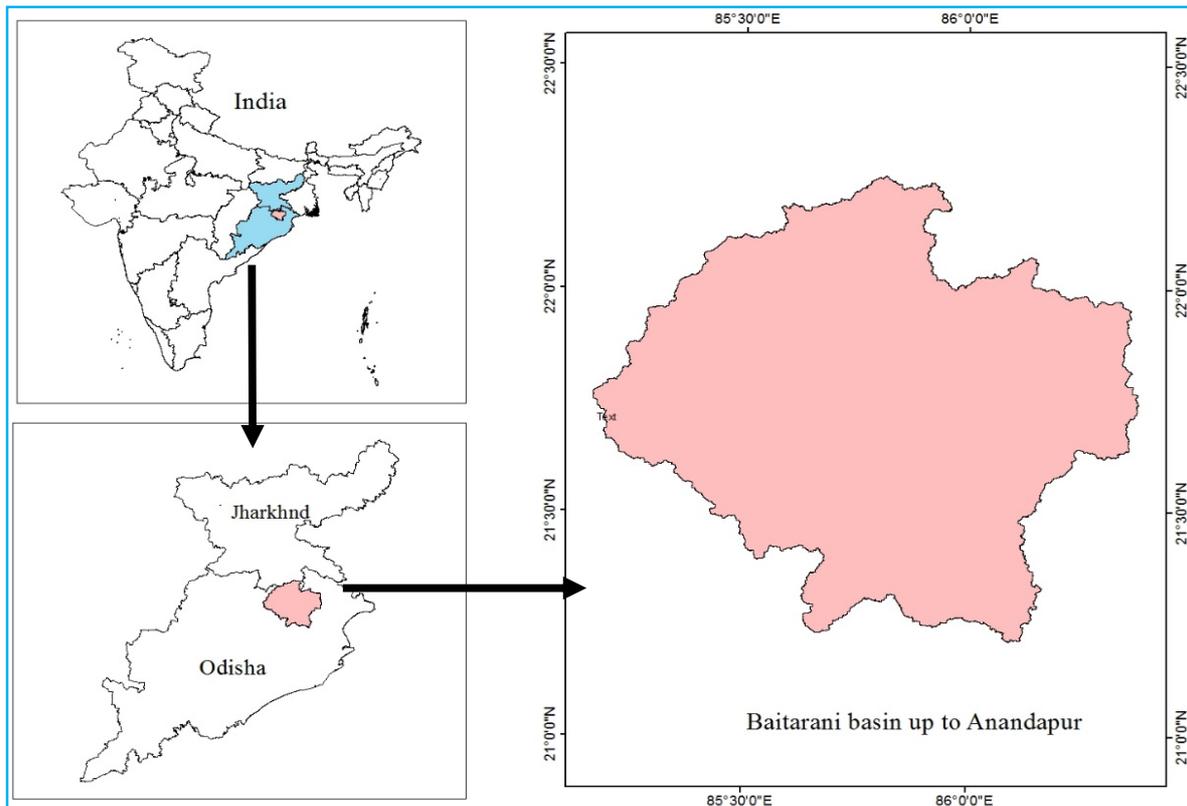


Fig. 1. Location map of study area

(Cosgrove and Loucks, 2015; Panigrahi *et al.*, 1992). A complete understanding of hydrologic response of a particular watershed should be known for sustainable and better management of water resources. Management of water resources in a basin requires understanding of dynamics of basin water which leads to an accurate representation of the rainfall-runoff relation at various spatial and temporal scales.

Surface runoff is an important component of water cycle which is used for various purposes including design of hydraulic structures, planning and management of watersheds, planning of irrigation systems, design of storage reservoirs, flood protection structures, hydropower and irrigation projects. Efficient estimation of runoff is always a challenge before scientists and planners.

Measurement of stream discharge is a way to find runoff from a catchment. However, measurement of discharge in a catchment is expensive and labour intensive (Emdad, 2004). In most of cases proper facilities are not available for measurement of discharge and recording of data. On the other hand, estimation of runoff by simulated hydrological model is an efficient technique used now a day's which is less time consuming and cost effective.

Hydrological model is a simplified representation of natural water cycle (Sorooshian and Moradkhani, 2008). It helps in understanding, predicting and managing water resources. Using hydrologic models, one can study both quantitative and qualitative aspects of water resources. HEC-HMS is a hydrological model which is now increasingly used in simulation of runoff. It is designed to be applicable in a wide range of geographic area for solving the widest possible range of problems. This range includes small to large river basin water supply and flood hydrology and urban or natural watershed runoff simulation. Hydrographs produced by the model are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, flood loss reduction studies, environmental studies, reservoir design studies and systems operation (Charley *et al.*, 1995; Halwatura and Najim, 2013; Darji *et al.*, 2019).

For successful management of natural systems, one should have a thorough understanding of numerous physical, biological and chemical variables in regards to their characteristic in temporal and spatial

TABLE 1
Various data used in the study

Data type	Source
Rainfall	Special Relief Commission, website (www.srcodisha.nic.in)
Discharge	CWC office, Bhubaneswar (2007 to 2016)
Maximum and minimum temperature	CWC office, Bhubaneswar (2007 to 2016)
ASTER Digital elevation model (DEM)	United States Geological Survey (USGS) Earth Explorer
Soil map	FAO world soil map
LULC map	NRSC, Hydrabad

scales. Therefore, in present days there is numerous application of hydrological models coupled with GIS.

The Geospatial Hydrologic Modelling Extension (HEC-Geo-HMS) is a public-domain software package designed for use with the ArcView Geographic Information System available from the Environmental Systems Research Institute (ESRI). It uses spatial analyst tool of ArcGIS to develop a number of hydrologic modeling inputs. The software analyses the digital terrain information and transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation. It allows the user to construct a hydrologic schematic of the watershed at stream gages, hydraulic structures and other control points. The hydrologic results of the HEC-Geo-HMS can be imported to the Hydrologic Modeling System HEC-HMS, where simulation process is performed (Choudhari *et al.*, 2014).

The Soil Conservation Service Curve Number (SCS-CN) method is empirical equation that has been widely used in different scientific studies (Gitika and Ranjan, 2014). SCS-CN gives an empirical relationship for the estimation of initial abstraction and runoff which is a function of soil type and land-use (Hawkins, 1993). Surface runoff from a watershed can be simulated using composite and distributed CN approaches. Composite CN approach considers the entire watershed as a single unit which requires lumped spatial data to model runoff. However, distributed CN needs data at sub basin scale.

In this study, an attempt has been made to simulate the surface runoff by SCS-CN method using composite and distributed curve number approach in HEC-HMS

model and find the best simulation technique to predict surface runoff by comparing with observed surface runoff.

2. Materials and method

2.1. Study area

The present study has been conducted in Baitarani basin upto Anandapur gauging station of Odisha and it covers an area of 8603.7 km². The Baitarani river is one of the major rivers of Odisha. It originates from Guptaganga hills near Gonasika village in Keonjhar district of Odisha. The basin spreads over 20° 35' to 22° 15' N latitudes and of 85° 10' to 87° 03' E longitudes (Fig. 1). Anadapur is situated at the lower reach of Baitarani basin having 21° 12' 34" N latitude and 86° 07' 23" E longitude. The major portion of the river basin lies in the state of Odisha (94.8%), while a smaller part of the upper reach lies in Jharkhand state (5.2%) (Nath *et al.*, 2018).

The Baitarani river basin mainly falls within the sub-tropical and sub humid monsoon climate zone. The annual rainfall varies from 1250 to 1500 mm over the basin. About 80% of the annual rainfall occurs during south-west monsoon (June to September). The coefficient of variation of annual rainfall is 20% indicating the region is fairly dependable (HP, 1998).

Maximum temperature of 47 °C and minimum temperature of 9 °C has been recorded in the study area during summer and winter. The maximum and minimum relative humidity of 83% and 39% are observed in the month of August and April, respectively. The maximum wind speed is observed to be 70 km/h and minimum wind speed is 7 km/h (Anonymous, 2011). The drainage pattern is dendrite type and flash flood is a natural character of such type of drainage pattern. The major part of the basin is covered with agricultural land accounting to 52% of the total basin area and 3% of the basin is covered by water bodies. The upper catchment of Baitarani is full of hillocks (Anonymous, 2011).

2.2. Data collection

Various data as used in the present study were collected from different sources. Table 1 summarizes the various data used in the study.

2.2.1. Soil map

Fig. 2 shows the soil map of the study area. The major soil type of the study area is sandy loam. It is mainly classified under hydrologic soil group C. Other

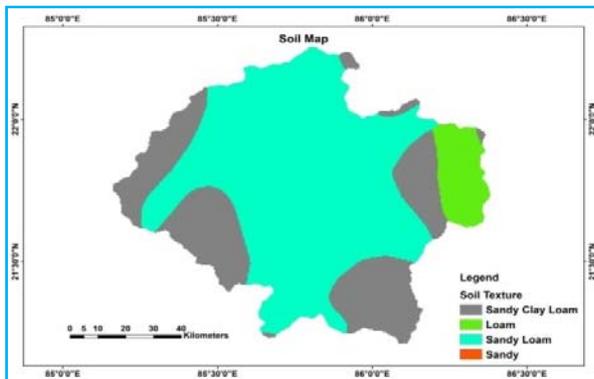


Fig. 2. Soil map of the study area

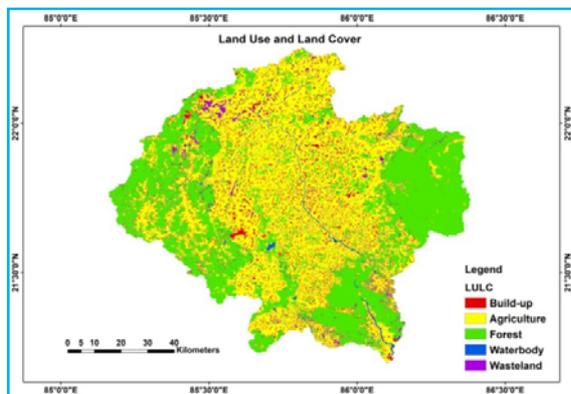


Fig. 3. LULC map of the study area

soil types present in the basin are sandy clay loam, loam and sandy soil.

2.2.2. LULC map

The land use and land cover (LULC) map is shown in Fig. 3. It is mainly classified into five major classes. Build up area, agriculture area, forest area, water body and wasteland of the study area are 5.3, 49.3, 40.1, 1.2 and 4.1%, respectively. The major land use of study area is agriculture followed by forest area.

2.3. HEC-HMS

In this study, the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) was used for runoff simulation. HEC-HMS, developed by US Army Corps of Engineers Hydrologic Engineering Center, is designed for both continuous and event-based hydrologic modelling system (USACE-HEC., 2010). It provides several options to the users for modelling various components of hydrologic cycle. Initially, it was developed to simulate the rainfall-runoff processes of dendritic watershed systems but later it was improved to

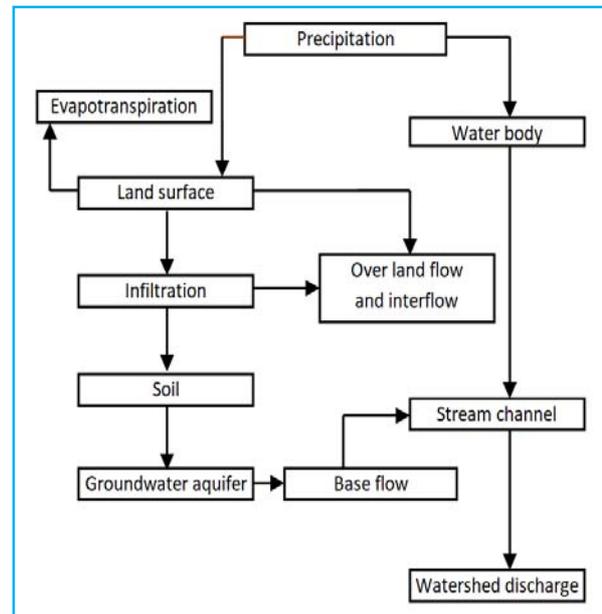


Fig. 4. Hydrological representation of watershed runoff

solve widest possible range of problems includes necessary procedures for continuous simulation including evapo-transpiration, snowmelt and soil moisture content. The advanced capabilities of gridded runoff simulation using the linear quasi-distributed runoff transform (ModClark) are also provided in the model. The model has supplemental analysis tools for model optimization, forecasting stream flow, depth-area reduction, assessing model uncertainty, erosion and sediment transport and water quality. The software HEC-HMS (v4.3) used in the study was downloaded from <https://www.hec.usace.army.mil/software/hec-hms> website.

2.3.1. Methods used for runoff simulation in HEC-HMS

HEC-HMS uses separate models to represent each component of the hydrological process that are represented in Fig. 4. It includes models for computation of runoff volume, models for direct runoff, including overland flow and interflow, models for base flow and models of channel flow.

There are different methods for each process in HEC-HMS model. User can select any method according to data availability and flexibility in use. In this study SCS CN method, SCS unit hydrograph (SCH UH) method, constant monthly varying base flow method and Muskingum routing methods are used for computation of runoff volume, computation of direct runoff, computation of base flow and channel flow (flow routing), respectively.

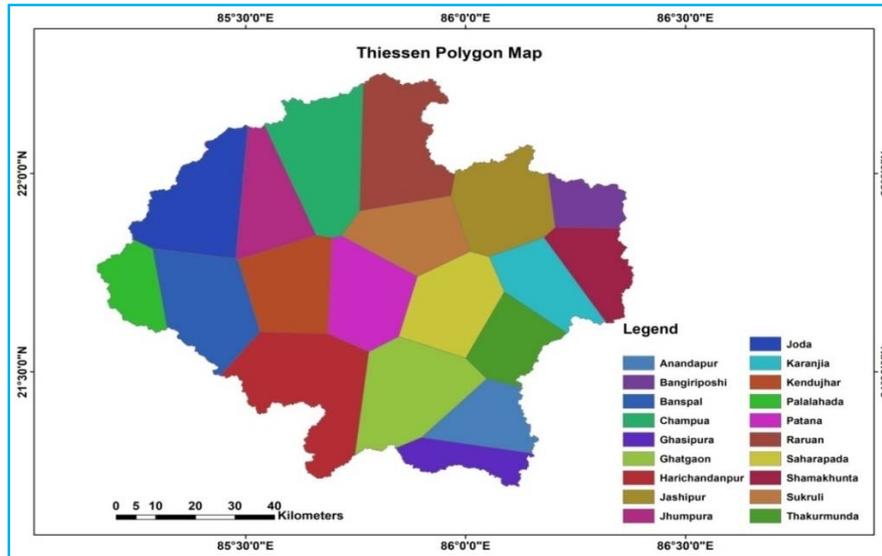


Fig. 5. Thiessen polygon map of the study area

2.3.2. SCS curve number method

SCS curve number method estimates rainfall excess as a function of cumulative precipitation, soil cover, land use and antecedent moisture, using the following equation:

$$P_e = \frac{(P - I_a)}{(P - I_a + S)} \quad (1)$$

where, P_e = accumulated rainfall excess (runoff) time t ; P = accumulated precipitation depth at time t ; I_a = the initial abstraction (initial loss); and S = potential maximum retention (watershed storage) which is a measure of the ability of a watershed to abstract and retain precipitation.

From analysis of results from many small experimental watersheds, the SCS developed an empirical relationship between I_a and S as:

$$I_a = 0.2S \quad (2)$$

Hence, the cumulative rainfall excess at time t is represented as:

$$P_e = \frac{(P - 0.2S)^2}{(P + 0.8S)}, P \geq 0.2S \quad (3)$$

Incremental excess for a time interval is computed as the difference between the accumulated excess at the end and beginning of the period. Watershed characteristics and

the maximum retention, (S) are related through an intermediate parameter called as curve number (commonly abbreviated as CN)

$$S = \frac{(25400 - 254CN)}{CN} \quad (4)$$

CN value ranges from 0 to 100. CN value is 100 for water bodies and approximately equals to 30 for permeable soils with high infiltration rates. In Eqns. (1) to (4), the units of P_e , P and S are in mm.

2.4. Estimating CN

The CN value for a watershed can be estimated as a function of land use, soil type and antecedent moisture condition, using tables published by the SCS. With these tables and knowledge of the soil type and land use, a single-value of CN can be found out.

2.4.1. Composite CN approach

In this method each grid in the hydrologic soil cover complex map is assigned curve number and weighted average of all CN values is calculated to determine the composite curve number of the basin. Runoff of the entire basin is calculated considering the weighted curve number of the whole area. This method represents the watershed as well as the hydrologic components as a single homogeneous unit. This is a lumping approach of watershed parameters which makes modelling approach simple and less complicated (Mohanty *et al.*, 2015; Panigrahi, 2011).

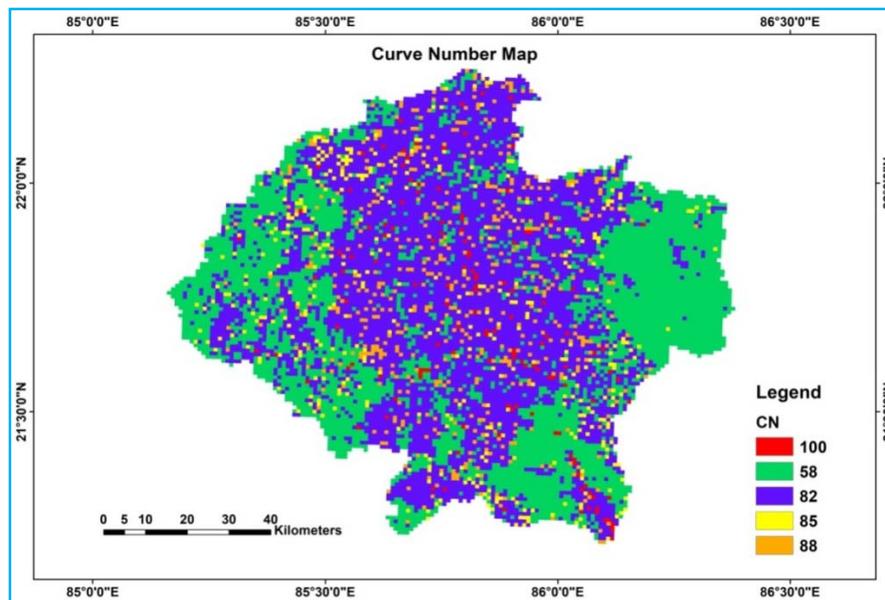


Fig. 6. CN grid map of the study area

2.4.2. Distributed CN approach

In this method, runoff depth is estimated for each individual grid cell or polygon in the watershed, based on hydrologic soil cover and land use of the grid (Mohanty *et al.*, 2015). Separate curve number values are assigned for each cell or polygon and separate runoff values are calculated for each of them. These runoff values are then added to find out total runoff depth of whole basin. This is called distributed modeling approach. This makes the modelling process more data intensive and time consuming.

2.5. Preparation of Thiessen polygon

Thiessen polygon map was prepared in ArcGIS by considering 19 rain gauge stations inside the study area (Fig. 5). These are Palalahada, Keonjhar, Banspal, Patana, Saharpada, Ghatgaon, Harichandanpur, Anandapur, Ghasipura, Champua, Joda, Jhumpura, Shamakhunta, Bangriposi, Jashipur, Karanjia, Thakurmunda, Sukruli, Raruana. As shown in Fig. 5 weighted area factor for raingauge stations were calculated for the whole basin designated as B1 by extracting them from thiessen polygon map for composite CN approach. For distributed CN approach, the whole basin B1 is divided into 3 small sub-basins designated as S1, S2 and S3, respectively. Weighted area factor for these 3 sub-basins were calculated by extracting them from thiessen polygon map. Then the weighted factor was multiplied with the rainfall values of corresponding rain gauge

stations. Then these rainfall values were added to get total rainfall over the area.

In sub-basin S₁, the weighted area factor for raingauge stations Harichandanpur, Joda, Palalahada, Banspal, Raruan, Champua, Kendujhar and Jhumpura were calculated to be 0.17, 0.14, 0.06, 0.13, 0.14, 0.15, 0.11 and 0.09, respectively. In sub-basin S₂, the weighted area factor for raingauge stations Bangiriposhi, Sukruli, Saharapada, Shamakhunta, Karanjia, Patana, Jashipur, Raruan, Champua and Kendujhar were calculated to be 0.047, 0.094, 0.104, 0.072, 0.077, 0.104, 0.117, 0.137, 0.142 and 0.104, respectively. In sub-basin S₃, the weighted area factor for raingauge stations Harichandanpur, Ghatgaon, Sukruli, Anandapur, Ghasipura, Saharapada, Thakurmunda, Karanjia, Patana and Kendujhar were calculated to be 0.173, 0.139, 0.095, 0.072, 0.052, 0.106, 0.073, 0.079, 0.106 and 0.106, respectively. In basin B₁, the weighted area factor for raingauge stations Harichandanpur, Ghatgao, Bangiriposhi, Sukruli, Joda, Palalahada, Banspal, Anandapur, Ghasipura, Saharapada, Thakurmunda, Shamakhunta, Karanjia, Patana, Jashipur, Raruan, Champua, Kendujhar and Jhumpura were calculated to be 0.089, 0.072, 0.025, 0.049, 0.070, 0.030, 0.066, 0.037, 0.027, 0.055, 0.038, 0.037, 0.041, 0.054, 0.061, 0.071, 0.074, 0.054 and 0.046, respectively.

2.6. CN map preparation

Considering LULC and hydrologic soil group (HSG), CN grid map (900 m × 900 m size) was prepared



Fig. 7. Schematic map of study area for composite CN approach

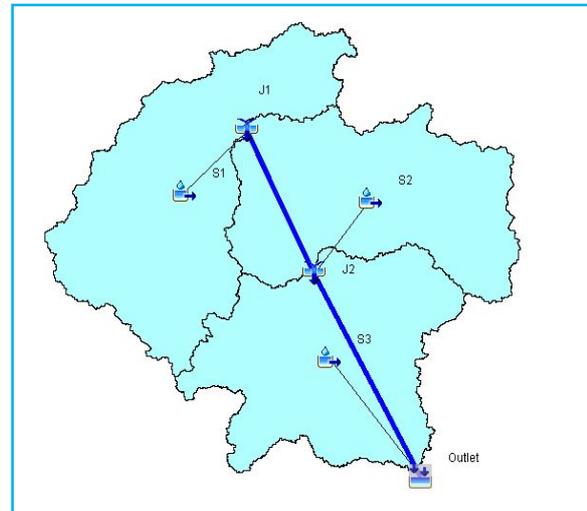


Fig. 8. Schematic map of study area for distributed CN approach

with the help of HEC-Geo-HMS utility tool in ArcGIS. For LULC map, classified image LISS III sensor was used. For knowing soil type, FAO World soil map was used. Then the weighted CN value for each sub basin and the whole study area were calculated.

The CN grid map is shown in Fig. 6. From the CN grid map, the CN values are obtained as 100, 58, 82, 85, 88 which are 1.27, 39.70, 49.77, 3.92 and 5.33% of the study area, respectively. The weighted CN value for basin B_1 is calculated to be 74.4 and for sub-basin S_1 , S_2 and S_3 , these values are 76.28, 66.03 and 70.48, respectively.

2.7. Data pre-processing with HEC-Geo-HMS

The Geospatial Hydrologic Modeling Extension (HEC-Geo-HMS) has been developed as a geospatial hydrology tool kit for engineers and hydrologists with limited GIS experience. HEC-Geo-HMS uses ArcGIS and the Spatial Analyst extension to develop a number of hydrologic modeling inputs for HEC-HMS.

Digital Elevation Model (DEM) of the study area is the input for basin pre-processing with HEC-Geo-HMS. The main aim of basin pre-processing is to conduct the initial analysis of the terrain and prepare the data set for later processing. Terrain pre-processing is done in step by step or by full pre-processing set up including filling the sinks, flow direction, flow accumulation, stream definition, stream segmentation, watershed delineation, watershed polygon processing, stream segment processing and watershed aggregation. Basin characteristic is done to extract river length, slope calculations, centroid determination, longest flow path and centroid flow path calculations. Some steps from the menu of HMS can also

be done before importing files to HEC-HMS, such as reach auto name, basin auto name, map to HMS units, HMS check data, HMS schematic, HMS legend, background map file etc. After the completion of pre-processing, map files and HMS files are imported to HEC-HMS and then generation of basin model, meteorological model and control specifications was carried out. Figs. 7&8 show the schematic map of study area which is prepared by HEC-Geo-HMS extension tool in ArcGIS and exported to HEC-HMS.

Fig. 7 shows the map of study area for composite CN method (approach) and Fig. 8 shows the map of study area for distributed CN approach in HEC-HMS model. In composite CN approach, the whole basin is considered as single unit and named as B_1 . In distributed CN approach, the basin is divided into 3 sub-basins named as S_1 , S_2 and S_3 . A reach R_1 joined from junction J_1 to junction J_2 and another reach R_2 joined from J_2 to the final outlet.

2.8. Calibration and validation of HEC-HMS model

Calibration of the model depends on the technical capability of model and quality of input data. In this research work, HEC-HMS model was calibrated on daily time step for simulating the runoff in outlet. SCS curve number method was used for computation of runoff volume, SCS UH for direct runoff, constant- monthly varying base flow for base flow and Muskingum method for flow routing. Model parameters were calibrated until a reasonable match between observed and simulated runoff was obtained. Calibration was done with the data from 1st January, 2007 to 31st December, 2013. Using the calibrated parameters the model was validated for 3 years

TABLE 2
Maximum and minimum values of parameters used in different models

Model	Parameter	Minimum	Maximum
SCS CN	Initial abstraction	0 mm	500 mm
	Curve number	1	100
SCS UH	Lag time	0.1 min	3000 min
Muskingum Routing	K	0.1 hr	150 hr
	X	0	0.5
	Number of steps	1	100

(1st January, 2014 to 31st December, 2016) for simulating runoff at daily time step.

2.8.1. The minimum and maximum parameter values

In simulation process of rainfall runoff models, a reference range of parameters are generally fixed. The assumed maximum and minimum range of parameters values in the study are presented in Table 2.

2.9. Model evaluation statistics

The statistical parameters used for comparison of simulated and observed runoff during both the calibration and validation process are described below.

Coefficient of determination (R^2) given by (Moriassi *et al.*, 2015) is:

$$R^2 = \left[\frac{\sum_{i=1}^n (Y_i^{obs} - Y_i^{obs\ mean}) - \sum_{i=1}^n (Y_i^{sim} - Y_i^{sim\ mean})}{\sqrt{\sum_{i=1}^n (Y_i^{obs} - Y_i^{obs\ mean})^2} \sqrt{\sum_{i=1}^n (Y_i^{sim} - Y_i^{sim\ mean})^2}} \right]^2 \quad (5)$$

where,

Y_i^{obs} = observed value of runoff of day, i

$Y_i^{obs\ mean}$ = mean of observed values of runoff of days, i

Y_i^{sim} = simulated values of runoff of day, i

$Y_i^{sim\ mean}$ = mean of simulated values of runoff of days, i

R^2 ranges from 0 to 1. Higher values indicate less error variance and R^2 values greater than 0.5 are considered acceptable (Moriassi *et al.*, 2015).

Nash-Sutcliffe efficiency (NSE) is given as (Moriassi *et al.*, 2015):

$$NSE = 1 - \left[\frac{\sum_{i=1}^n (Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^n (Y_i^{obs} - Y_i^{mean})^2} \right] \quad (6)$$

NSE = 1 is the optimal value and it varies from 0 to 1. Values of NSE greater than 0.5 are generally regarded as acceptable levels of performance (Servat and Dezetter, 1991).

Percent bias (PBIAS) is given as (Moriassi *et al.*, 2015):

$$PBIAS = \left[\frac{\sum_{i=1}^n (Y_i^{obs} - Y_i^{sim}) \times 100}{\sum_{i=1}^n (Y_i^{obs})} \right] \quad (7)$$

The optimal value for PBIAS is 0 and its low-magnitude values indicate accurate model simulation. Positive values indicate model underestimation bias while negative values indicate model overestimation (Gupta *et al.*, 1999).

RMSE-observations standard deviation ratio (RSR) is given as (Moriassi *et al.*, 2015).

$$RSR = \frac{RMSE}{STDEV_{obs}} = \left[\frac{\sqrt{\sum_{i=1}^n (Y_i^{obs} - Y_i^{sim})^2}}{\sqrt{\sum_{i=1}^n (Y_i^{obs} - Y_i^{mean})^2}} \right] \quad (8)$$

RSR has optimum value of 0 that indicates zero RMSE or residual variation, that is a perfect model simulation. The lower value RSR indicate the lower RMSE and the better the model simulation performance (Moriassi *et al.*, 2015). The various parameters of Eqns. (6) to (8) are as defined in Eqn. (5). However, in Eqns. (6) to (8), the parameter Y_i^{mean} , refers to mean of the observed values of runoff of days, i .

3. Results and discussion

3.1. Calibration and validation of HEC-HMS model

The model was calibrated in a daily time step using daily data for seven years *i.e.*, from 1st January, 2007 to

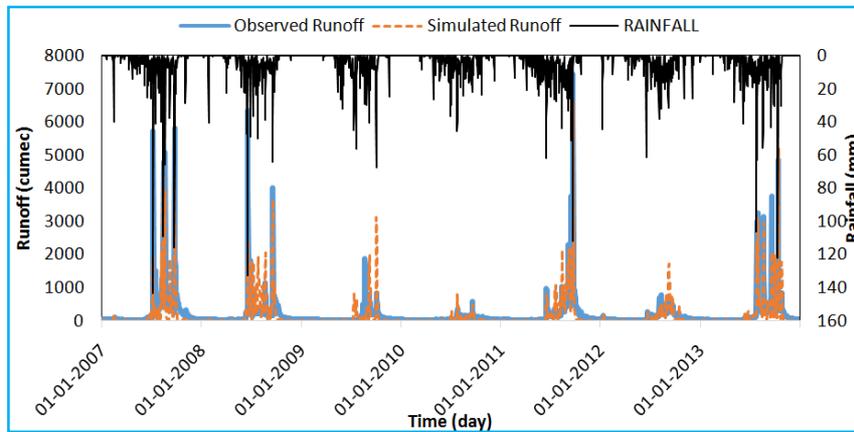


Fig. 9. Comparison of simulated and observed runoff for calibration period in composite CN approach

TABLE 3

Calibration parameters of composite CN approach

Description	Basin B1	
Curve Number	71	
Initial abstraction (mm)	50.9	
Impervious %	25	
Lag time (min)	2178	
Base flow (cumec)	January	14.2
	February	8.50
	March	7.80
	April	8.50
	May	5.70
	June	11.3
	July	17
	August	25.5
	September	28.37
	October	25.71
	November	17.29
	December	11.43

TABLE 4

Calibration parameters of distributed CN approach

Description	Sub basin S1	Sub basin S2	Sub basin S3
Curve Number	74	67	78
Initial abstraction (mm)	34	40.64	25.4
Impervious (%)	20	12	7
Lag time (min)	1210	2280	2000
Base flow (cumec)			
January	5.7	6.4	7.10
February	5.4	5.2	7.80
March	3.1	3.4	4.1
April	2.8	2.8	3.4
May	2.3	2.6	2.5
June	3.7	3.7	7.1
July	5.8	5.6	7.6
August	22.7	17	25.5
September	28.37	26	28.03
October	25.71	23.71	25
November	14.29	15.6	15.6
December	8.9	8.5	9.9
	From Junction J1 to J2		From Junction J2 to Outlet
Muskingum K (hr)	10		7
Muskingum X	0.17		0.3

31st December, 2013 using both composite CN and distributed CN approach. The calibration parameters in composite CN approach are presented in Table 3. The calibration parameters in distributed CN approach are presented in Table 4. Using the calibrated parameters, the model was validated by both the approaches with 3 years daily data *i.e.*, from 1st January, 2014 to 31st December, 2016.

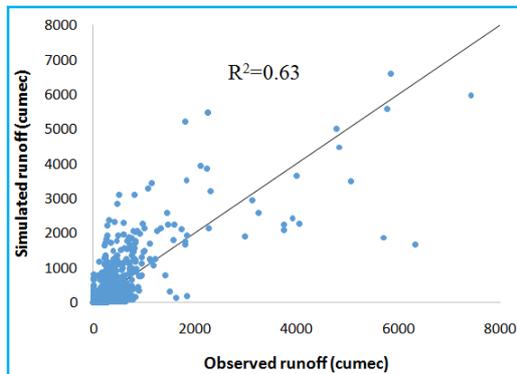


Fig. 10. Scatter diagram of simulated and observed runoff for calibration period in composite CN approach

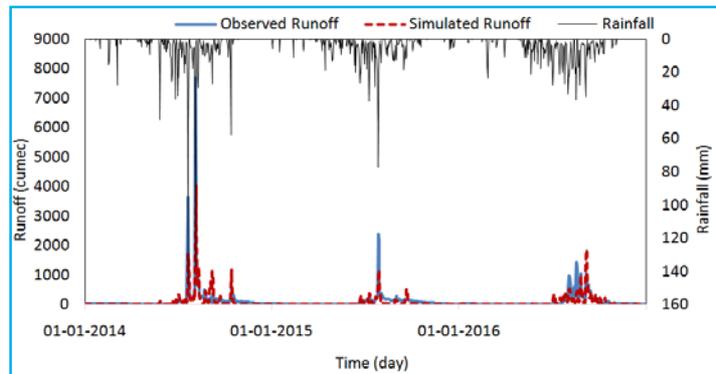


Fig. 11. Comparison of simulated and observed runoff for validation period in composite CN approach

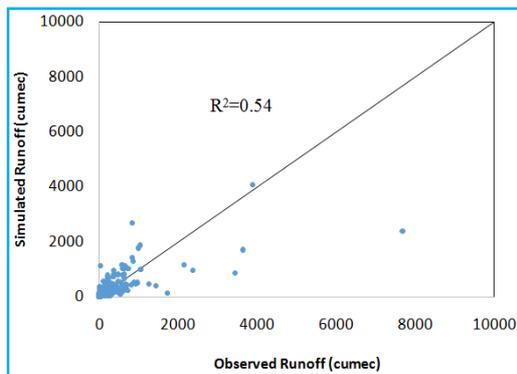


Fig. 12. Scatter diagram of simulated and observed runoff for validation period in composite CN approach

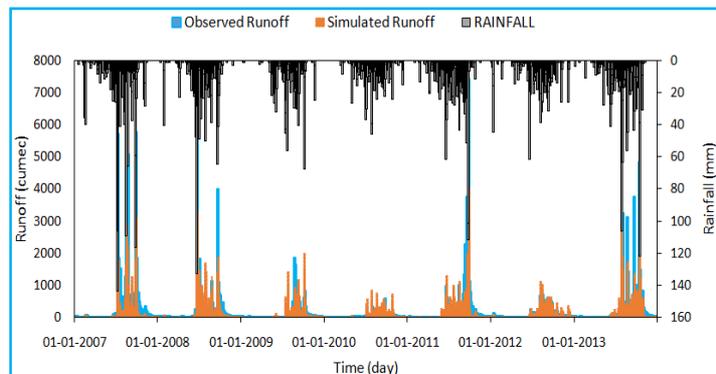


Fig. 13. Comparison of simulated and observed runoff for calibration period in distributed CN approach

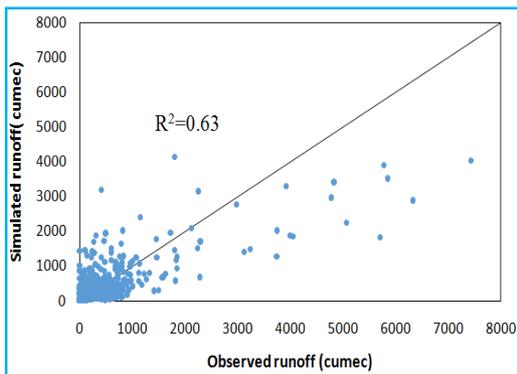


Fig. 14. Scatter diagram of simulated and observed runoff for calibration period in distributed CN approach

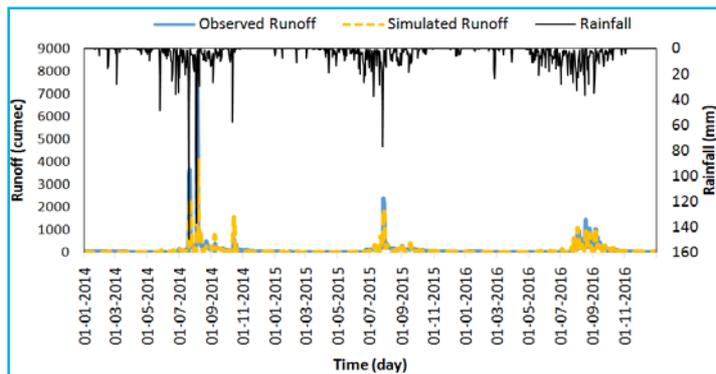


Fig. 15. Comparison of simulated and observed runoff for validation period in distributed CN approach

Variation between observed and simulated runoff during calibration period in composite CN approach is shown in Fig. 9 and the scatter diagram is shown in Fig. 10. From the scatter diagram, R^2 value is found as 0.63. Similarly, variation between observed and simulated

runoff during validation period in composite CN method is shown in Fig. 11 and the scatter diagram is shown in Fig. 12. From the scatter diagram, the value of R^2 between observed and simulated runoff during validation period is found to be 0.54.

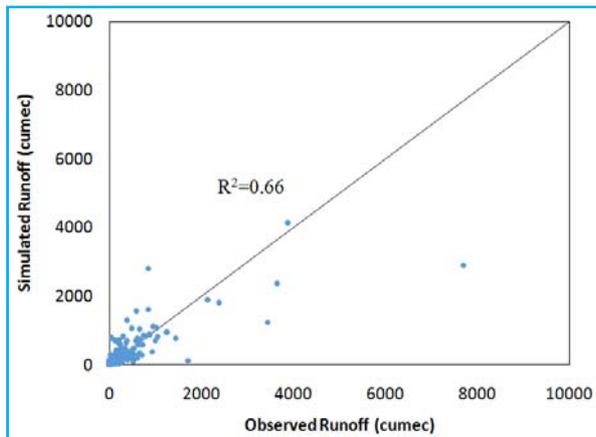


Fig. 16. Scatter diagram of simulated and observed runoff for validation period in distributed CN approach

Variation between observed and simulated runoff during calibration period in distributed CN method is shown in Fig. 13 and the scatter diagram is shown in Fig. 14. From the scatter diagram, R^2 value is found as 0.63. Similarly, variation between observed and simulated runoff during validation period in distributed CN method is shown in Fig. 15 and the scatter diagram is shown in Fig. 16. From the scatter diagram, the value of R^2 between observed and simulated runoff during validation period is found to be 0.66.

3.2. Statistical analysis

Statistical test between observed and simulated runoff by distributed CN approach and composite CN approach during calibration and validation period is presented in Table 5. In distributed CN approach, values of NSE and R^2 for calibration are found to be 0.62 and 0.63, respectively and during validation, they are 0.67 and 0.66, respectively. For both calibration and validation, RSR value is found to be 0.6 and PBIAS values are -8.64 and -2.25, respectively. In composite CN approach NSE and R^2 for calibration and validation are 0.51, 0.53, 0.63 and 0.5, respectively. For both calibration and validation, RSR value is 0.7 and PBIAS values are 12.82 and -19.73, respectively.

From the statistical analysis, it is seen that the NSE and R^2 are more in distributed CN approach than composite CN approach both for calibration and validation period. PBIAS and RSR are less in distributed CN approach than composite CN approach both for calibration and validation period. Thus, the study reveals that simulation of runoff by distributed CN approach in HEC-HMS model gives more accurate result than that by composite CN approach.

TABLE 5

Statistical test analysis

Parameters	NSE	R^2	PBIAS	RSR
Calibration for composite CN method	0.51	0.63	12.82	0.70
Validation for composite CN method	0.53	0.54	-19.73	0.70
Calibration for distributed CN method	0.62	0.63	-8.64	0.60
Validation for distributed CN method	0.67	0.66	-2.25	0.60

4. Conclusions

In the calibration of distributed CN approach, the statistical parameters of NSE, R^2 , PBIAS and RSR are found to be 0.62, 0.63, -8.64 and 0.6, respectively. In the validation for distributed CN approach, the statistical parameters of NSE, R^2 , PBIAS and RSR are found to be 0.67, 0.66, -2.25 and 0.6, respectively. In the calibration for composite CN approach, the statistical parameters of NSE, R^2 , PBIAS and RSR are found to be 0.51, 0.63, 12.82 and 0.7 respectively. In the validation for composite CN approach, the statistical parameters of NSE, R^2 , PBIAS and RSR are found to be 0.53, 0.54, -19.73 and 0.7 respectively. Since, the values of statistical parameters of NSE and R^2 are more and PBIAS and RSR are less in distributed CN approach than composite CN approach both during calibration and validation period, it is concluded that runoff simulation by distributed CN approach is better than composite CN approach.

Disclaimer

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

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