Evaluation of different loss models for runoff estimation

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ABSTRACT

For planning and management of land and water resources, watershed basin is a most suitable unit. The estimation of runoff volume of a watershed is an important aspect in environmental impact assessment, flood forecasting, engineering planning and water balance calculations. If runoff estimation is improper, then basins show trouble in maximum watershed resources management. So, exact estimation of runoff is an accurate solution. In the current study, different loss models like SCS-CN (soil conservation services-curve number) model and Green-Ampt model (GAM) have been employed for runoff simulation. Drainage map, elevation map, land use/land cover map, slope map and soil map of the watershed are prepared using remote sensing and GIS approaches as an input data to the SWAT hydrologic model. The main focus of the study is to compute the runoff with the help of hydrological model in Subarnarekha river basin (SRB). In my paper, water balance component runoff has been computed, after that validated the results also and lastly checks the performance of the model. Based on error indices parameter namely as mean square error (MSE), root mean square error (RMSE), nash sutcliff error (NSE), bias model (MB) and coefficient of determination (R^2)-outcome indicates that the SCS-CN method have low runoff estimation compared to GA infiltration method.

Keywords: GIS, SWAT, SCS-CN model, Green-Ampt model and error indices.

1. INTRODUCTION

Rainfall Runoff (RR) modelling using SWAT have found that extensive use in flood and floodplain management, hydraulic structure design and reservoirs and evaluation, flood warning, flood frequency analysis, river train planning and more recently in assessing impact of climate change, land use change along with runoff threshold on flood forecasting. Hydrological modelling system is a part of the hydrologic cycle. This conservation and circulation of rainwater as it rotates from the land to the sky and come back again is called the “water cycle” or “hydrological cycle”. The water cycle is never-ending cycle. Watershed hydrological modelling and in calibration and validation processes spatial and temporal data are required. The current paper describes the study of various literatures on development such a strategy by combining (different loss model) with SWAT (hydrologic engineering center’s hydrologic modelling system). Effective estimation of runoff values and groundwater recharges from a rainfall event helps in development of all water resources. Now-a-days, hydrologic response of catchment systems is changing due to rapid increase in urbanization and industrial growth including deforestation, land cover and land use pattern modifications. Along with climate modification, soil heterogeneity has also put great emphasis on the flow of many rivers all around the world. Therefore, to evaluate the impact of these modifications, Hydrological models have been developed across the world to study the hydrologic behavior of a catchment system.

Rainfall-Runoff model helps to compute – loss rate, Peak runoff rate, Runoff volume and Base flow. It is employed for - Flood protection, forecasting of real time flood, Water demand forecasting, Water resources management and to assess the modification in stream flow. Climatological parameters are also having great influence on the runoff process. Consider the evapotranspiration process it is influenced by the temperature, wind speed, vapour pressure and other parameters. Getting proper data for all these parameters is itself is the difficult task. The SCS is the most common method adopted to predict the runoff and doesn't consider rainfall duration and intensity, only consider total rainfall volume. GMA is a time-based model that can simulate rainfall intensity duration and infiltration process.

In this research paper, SCS Curve Number and GA investigations are used for rainfall-runoff modelling. The focus of this research is to match the results of GA and SCS-CN model to compute rainfall-runoff in Subarnarekha river basin. Mapping of watershed is done using Arc GIS and SWAT software also used for runoff simulation.

2. LITERATURE REVIEW

Durbude et al. (2001) Estimation of Surface Runoff Potential of a Watershed in Semi-Arid Environment. It is observed that SCS method, which is based on empirical relationships, is an efficiently for estimating the direct run-off of small-ungauged watershed. The run-off potential was estimated using SCS method based on the satellite data in conjunction with ground truth information collected during field visit. As per this study eight check dams and five lift irrigation schemes are proposed.

Pierluigi *et al.* (2003) represented the SWAT model application to predict the water budget for several Sardinian catchments and to predict future outcome. Parameters: land use, soil type, surface water systems, etc. whereas daily weather inputs, statistical analysis of the Sardinian climatic data has been executed.

Arnold *et al*. (2012) Used SWAT model to calibrate and validate. In SWAT-CUP calibration forces to obtain a better understanding of the overall hydrologic processes (e.g., baseflow ratios, ET, sediment sources and sinks, crop yields, and nutrient balances) and of parameter sensitivity. When calibrating a physically based model like SWAT, it is important to remember that all model input parameters must be kept within a realistic uncertainty range.

Lin Jing *et al.* (2012) checked the suitability of SWAT for simulation of runoff and sediment load of Zhifanggou catchment (China). The results of this model for daily runoff simulation are acceptable, but for high -flow events runoff is miscalculated for the model.

Majidi and Shahedi. (2012) used the HEC-HMS 3.4 to calculate rainfall-runoff process in Abnama watershed (Iran). To calculate rainfall excess, infiltration and flow routing using SCS Unit hydrograph, Green-Ampt and Muskingum routing respectively. Hence calibration of this model has been checked with optimization and sensitivity analysis where validation of model has been done with the help of lag time value and that shows clear difference in peak flow.

Tesfahunegn *et al.* (2012) using the SWAT model application, identify hotspot soil degradation sub- catchments. Based on estimated runoff, sediment yield and nutrient losses in the Mai-Negus catchment, northern Ethiopia. Parameters: digital elevation model (DEM), land use-cover, soils and daily observed weather data.

Kabir *et al.* (2013) he compared the parameters using two loss models in Unit hydrograph method by HEC-HMS. SCS Curve Number and Green-Ampt methods by developing loss model as a major component in runoff and flood modeling. The study is conducted in the Kuala Lumpur watershed with 674 km2 area located in Klang basin in Malaysia. Then all the necessary parameters are assigned to the models applied in this study to run the runoff and flood model. The selection of best method is on the base of considering least difference between the results of simulation to observed events in hydrographs so that it can address which model is suit for runoff-flood simulation.

Shrestha *et al*. (2015) describes analyse the impact of LU changes on runoff and sediment yield in Da River basin of Hoah Binh province (Northwest Vietnam) using SWAT model. The results showed that runoff evaluation and sediment yield as interact from Nash-Sutcliffe Efficiency, BIAS % and Standard Deviation Ratio (Field (actual)) values. Vegetation serious impact on surface overflow and sediment yield of the research field.

Kangsabanik and Murmu. (2017) present study is based on SWAT Model which integrates the GIS information with attribute database to estimate the runoff of Ajay River catchment. In the present study the catchment area has been delineated using the DEM. For preparation of land use map the IRS-P6 LISS-III image has been used and the soil map is extracted from HWSD (Harmonized World Soil Database). They used 30 years of daily rainfall data and daily maximum and minimum temperature data SWAT simulation is done for daily, monthly and yearly basis to find out Runoff for corresponding Rainfall.

Patel *et al.* (2017) Accurate runoff estimation is carried out for effective management and development of water resources. He used SCS-CN method. In present study, Gonadal, Upper Bhadra, and Vasavdi sub watersheds of Bhadra watershed located in Gujarat, India is taken as study area. The thematic layers like soil map, land use map, DEM map and land cover map were created in Arc GIS.

3. CRITICAL APPRAISAL

Subarnarekha is a large basin, but all the previous works had been done only for the part of basin that is present inside Jharkhand and West Bengal.

SWAT simulation for discharge gives better result as well as basin parameters can be done through calibration. But this model had never been used for entire Subarnarekha sub-basin.

4. OBJECTIVE

The main objective of the study is-

Application of suitable models for flow estimation in Subarnarekha river basin,

Evaluation of different loss model to compute the runoff and

To perform the sensitivity analysis of flow parameters.

5. SOFTWARE USED

I have used two software for watershed mapping and simulation of runoff-

Arc MAP 10.3 and Arc SWAT.

6. STUDY

6.1 Study area

Based on discharge data (12.37 billionm3/annum) Subarnarekha river basin is getting rank eighth(India). The whole catchment area of this basin is 13,354 sq. km. The river originating from chhotanagpur plain, Ranchi (Jharkhand) having height 610m(lat. 23°18'N and long. 85°11'E) and joining in Bay of Bengal (latitude 21°33′18″N and longitude 87°23′31″E). Full range (length) of Subarnarekha river basin is 391 km. Its influential tributaries are the Kanchi, Karkari and Kharkai. The Subarnarekha river basin extends over States of Jharkhand, Odisha and lesser part in West Bengal. The Subarnarekha river basin's bottom part comes under flood hazard zone, mainly the coastal areas (Odisha and West Bengal). Annual rainfall(Avg.) of study area is 1,100-1,400 mm also rainfall(max.) occurs during June to September months. During storm period 80% total rainfall (annual) is collected. The altitude of the basin 590-760 m from mean sea level (MSL).

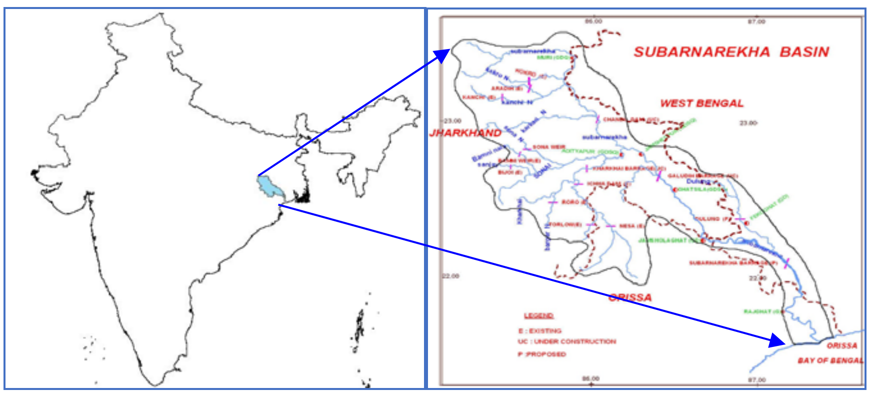


Figure 1: Map study of Subarnarekha river basin (Adapted from CWC, Bhubaneswar site)

6.2 Data set

Table 2: Data Source

Data type	Source	Scale/ Periods	Data description
Terrain data	Bhuvan, ISRO	30m x 30m	Digital elevation model
Soil data	NBSS & LUP	1:25000	Soil distribution and physical properties
Land use/Land cover	NSRC, ISRO	2015	Land use classification (Satellite imageries)
Climate data	NOAA	2000-2014	Daily precipitation, minimum and maximum temperature, Relative humidity, Wind speed,
Discharge data	WRIS, CWC	2009-2014	Daily discharge data at gauging station

For the present study seven rain gauges station and seven discharge gauging station have been considered. Physiographic components of sub basin have been calculated using Digital Elevation Model (DEM). The values of CN and hydraulic conductivity (*K*) are taken from soil hydrologic group, land use and soil texture maps which lead to CN map.

Table 3: Classification of catchment area

Sl. No.	State name	Catchment area (Sq. km)	Total area
1	Jharkhand	8,743	65.47%
2	Orissa	2,466	18.47%
3	West Bengal	2,145	16.06%
	Total:	**13,354**	**100%**

Soil found in Subarnarekha river basin have red soil, reddish-yellow soils, red-sandy and sandy-loams soils, mixed red and black soils and alluvium. Soil in coastal plains are laterite, red, alluvial and fertile area which is good for cultivation. LULC Image of this study area is classified into to five classes i.e. agricultural land, forest, built up area, open land and water body (shown in table 4).

Table 4: Lookup Table Prepared

Object ID	LU value	Description	A	B	C	D
1	82	Agricultural Land	51	67	81	85
2	47	Forest	37	64	77	86
3	36	Open land	71	67	82	85
4	23	Built up area	53	73	77	88
5	13	Water body	0	0	0	0

Table 5: Characteristic of Subarnarekha river basin

Sl No.	Outlet ID of watershed	Area in Km^2	Mean elevation in m	Max. elevation in m	Min. elevation in m	Latitude	Longitude
1	100015	592.0	188.16	699	10	22.92	86.06
2	100005	482.5	290.3	866	91	22.85	85.78
3	100004	101.7	113.84	260	77	22.78	86.01
4	100002	155.2	105.37	386	63	22.76	86.14
5	100007	321.2	346.17	834	152	22.73	85.51
6	100006	664.3	195.44	836	91	22.71	85.73
7	100009	663.8	142.94	868	28	22.79	86.36
8	100003	462.3	137	412	75	22.65	86
9	100010	721.1	150.12	665	31	22.59	86.23
10	100008	577.2	314.85	805	151	22.58	85.48
11	100011	504.4	246.41	600	125	22.49	85.72
12	100012	107.6	162.09	401	122	22.56	85.9
13	100001	310.2	251.04	868	63	22.39	85.81
14	100016	570.8	109.42	502	5	22.61	86.52
15	100027	384.0	183.64	-29	-67	22.43	86.39
16	100013	986.6	228.49	559	141	22.38	86
17	100018	272.3	285.51	847	172	22.349	86.23
18	100017	89.0	282.24	526	173	22.23	86.04
19	100019	658.0	316.96	875	170	22.16	86.27
20	100022	1463.5	39.93	529	-37	22.29	86.7
21	100021	1199.1	31.89	371	-35	22.41	86.87
22	100020	533.3	290.3	781	175	22.12	86.05
23	100023	760.7	-21.58	45	-64	22.01	87.16
24	100024	348.7	-46.14	-22	-65	21.79	87.29
25	100025	68.1	-52.42	-26	-91	21.6	87.31
26	100026	304.1	-48.67	-22	-72	21.73	87.41
27	100014	51.8	-50.61	460	145	21.62	87.43

7. METHODOLOGY

7.1 Hydrologic model description

SWAT is based on physical-theoretical model perform to predict water, chemical values, sediments at different section of channel. SWAT is designed previously continuous time step model named Simulator for Water Resources in Rural Basins (SWRRB) (Williams *et al.,*1985, Arnold *et al.,* 1990). This model has vast utilization to design watershed and for forecasting the effect of soil and water management process with distinct land use land cover status and soil type over long periods of time. In SWAT, the sub-basins are breaks into watershed, then these are applying into hydrologic response units (HRUs). The HRUs conserve physical parameter of the watershed and designed by superimposed topography, soil data, and land use maps in GIS. Due to sub-division model presents good results for each watershed that may have a serious outcome in this model.

7.2 Run-off estimation

The catchment delineation for the basin by using SWAT model. In urban areas, surface runoff is responsible for urban flooding, damage to property. Surface runoff is also responsible for pollution and soil erosion. Surface over flow is the portion of precipitation i.e. not lost by interception, infiltration and evaporation. Over flow arise whenever rainfall rate beats infiltration rate. SWAT have two methods for estimating the overflow runoff these are Soil Conservation Service (SCS) curve number method and second is the Green-Ampt infiltration method. Let's have a close look on these loss model-

7.2.1 SCS-Curve Number method

CN amount for different type land use (LU) and soil type of SUBARNAREKHA RIVER BASINtaken from Technical Release 55. The hydrologic soil groups (HSGs) have splits into four group A, B, C and D, out of which infiltration indicates high, moderate, less, and very less rate of infiltration appropriately. The assumes that surface runoff will be obtained once initial losses are fulfilled. Calculation of accumulated runoff (Q in mm) by SCS-CN equation (SCS,1972) is shown in equation 1.

$$Q = \frac{(P-Ia)^2}{(P-Ia+S)} \quad (1) \qquad\qquad S = \frac{25400}{CN} - 254 \quad (2)$$

If $P > I_a$, then runoff will exit. Where P = full precipitation depth (mm), I_a =Initial abstractions (mm)=0.2*S, and S= potential recharge capacity(maximum) in mm.

The initial abstraction is linked with S by this equation: $I_a = \lambda * S$.

Here, λ initial abstraction ratio (λ=0.2) and S is potential retention (maximum) represented in Equation 2. CN is Curve Number of the day; its values lies between 0-100. The CN can be obtained from tables that depends on soil moisture, land cover, soil type. Runoff curve numbers has been taken for each watershed from National Engineering Handbook (SCS 1972,1986).

7.2.2 Green-Ampt method (GAM)

This GAM is an infiltration equation which is invented in 1911.Green-Ampt model is an empirical model that used to simulate precipitation loss in pervious platform for particular period. Initial content (volumetric moisture content at simulation time), suction head in mm, hydraulic conductivity in mm/hr, saturated content (how much moisture content that soil can hold) and imperviousness % are the factors of the GAM. All these factors are depending on soil type currently present in the catchment. Ideal equation for GAM presents in equation 5.

$$\int_0^{F(t)} \frac{1-\varphi\Delta\theta}{F+\varphi\Delta\theta} dF - \int_0^t K.dt \quad (3) \qquad f(t) = K\left[\frac{\varphi\Delta\theta}{F(t)} + 1\right] \quad (4)$$

Rate of infiltration can be represented as:

$$F(t) = Kt + \varphi\Delta\theta ln\left[\frac{F(t)}{\varphi\Delta\theta} + 1\right] \quad (5)$$

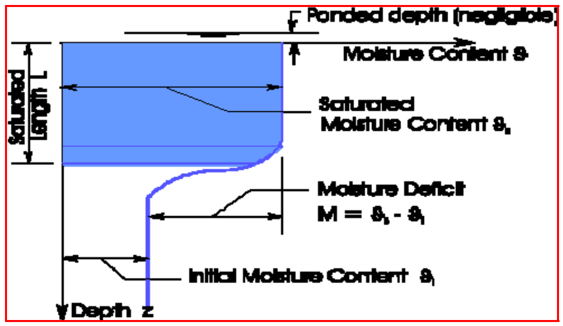


Fig2: Wetting front (Green & Ampt model) taken from MIDUSS version 2 - chapter 7(Alan A. Smith Inc)

Here, f (t) = infiltration rate in millimeter per hour, K= hydraulic conductivity in millimeter per hour, η is porosity, ψ = absorption of water in moisture area in mm, ϴ is slope gradient, Δθ = change in primary moisture % and the porosity degree and starting time of precipitation (t) is in hour. F(t) rate of infiltration(cumulative).

In Potential Evapotranspiration (PET), water is removed from the water bodies, soil and plants. Evaporation is a process in which water gets lost from catchment. Many applications are there to calculate PET. Here we are using Penman-Monteith (Monteith, 1965) in SWAT to evaluate PET. Basic variable requires in this method like net solar radiation, temperature of air, relative humidity and wind sped.

7.3 Model Setup

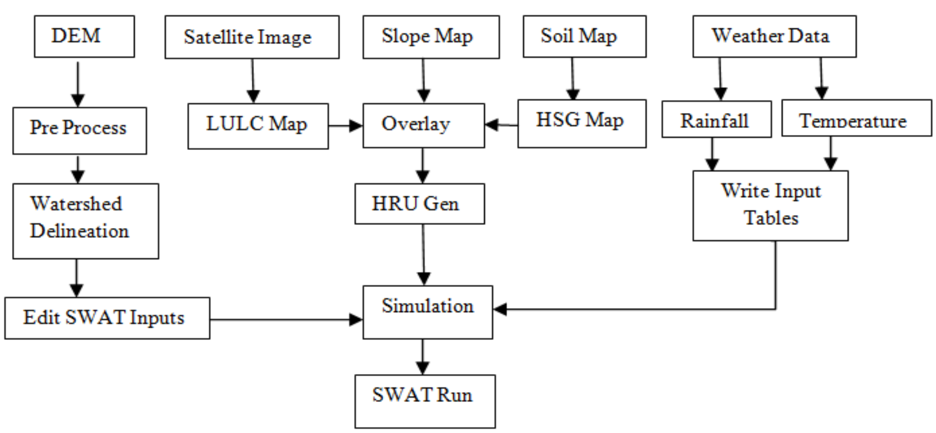


Fig 3: Flow chart for SWAT model setup

7.4 Simulation of model

Swat have only five steps are associated to run the model these are swat project setup, watershed delineation, HRU study, input tables and finally SWAT simulation.

7.5 Error analysis

The physical surface overflow along with predicted surface overflow which are correlated based on these parameter of mean square error (MSE), root mean square error (RMSE), Nash Sutcliff error (NSE), performance model of bias (MB) and coefficient of determination (R^2). In below we are mentioned the formula of above parameter (equations 5-8):

$$MSE = \sum_{i=1}^{n} \frac{Qo - Qp}{n} \quad (6) \qquad RMSE = \sqrt{\sum_{i=1}^{n} \left(\frac{Qo - Qp}{n}\right)} \quad (7)$$

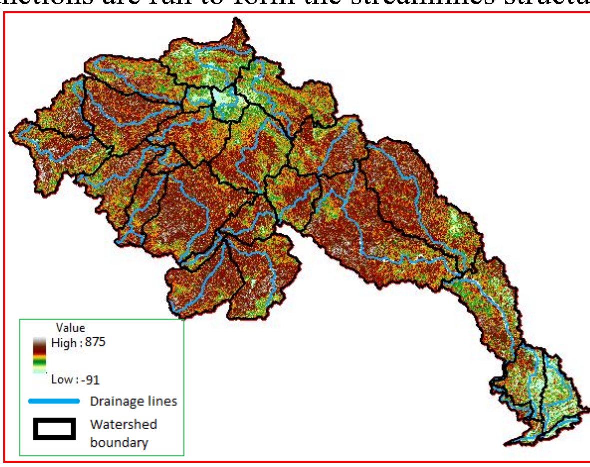
$$NSE = 1 - \frac{\sum_{i=1}^{n}(Qp - Qo)^2}{\sum_{i=1}^{n}(Qo - \overline{Qo})^2} \quad (8) \qquad MB = \frac{\sum_{i=1}^{n}(Qp - Qo)}{\sum_{i=1}^{n} Qo} \quad (9)$$

$$R^2 = \frac{\left(\sum_{i=1}^{n}(Qp - \overline{Qp})(Qo - \overline{Qo})\right)^2}{\sum_{i=1}^{n}(Qp - \overline{Qp})^2 \sum_{i=1}^{n}(Qo - \overline{Qo})^2} \quad (10)$$

Here, Q_o is field (actual) value, Q_p is predicted value, $\overline{Qo}$ is mean field (actual) value and $\overline{Qp}$ is mean predicted value in above equations.

8. RESULTS AND ANALYSIS

DEMs are downloaded from Bhuvan site (ISRO) and then design the sub-basin and hydrological characterization like fill, flow direction, flow accumulation and stream definition functions are run to form the streamlines structure with the help of Arc map platform.



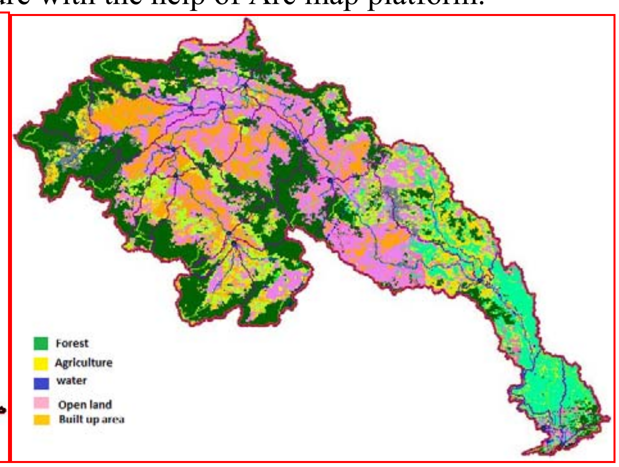


Figure 4: DEM with drainage map **Figure 5: Land use land cover map**

5.1 Generating Direct Runoff and Peak Discharge

At beginning set up the model parameters in SWAT, then run the model to pick up the peak discharge and direct runoff concern watershed. After run the system (rainfall events are taken) outcomes are coming represented in below table no. Final results show that Nash-Sutcliffe coefficient value and correlation coefficient value between field (actual) and predicted discharge is more than 0.9 in Subarnarekha river basin.

Table 6: Results of direct runoff and peak discharge

Rainfall event	Direct runoff (mm)				Peak discharge (m^3/s)			
	SCS-CN method		GA method		SCS-CN method		GA method	
Date	Field	Predicted	Field	Predicted	Field	Predicted	Field	Predicted
06-July-09	11	9.7	11	10.7	281.6	280.3	281.64	279.83
01-Sep-09	6.5	7.8	6.5	7.1	703.3	702.41	703.3	702.49
11-Sep-11	31	30	31	32	992.64	993.7	993.64	994.74
08-Oct-13	27	25	27	24.4	828.8	829.2	828.78	831.84

In below table, we done the error analysis for both the models and calculate the parameter value of MSE, RMSE, MB, NSE, R^2 by taking runoff depth and peak discharge respectively. In swat, data will adjust (regulate) the data by comparing with observed data with the help of auto-calibration.

Table 7: Results of error indices

Methods	Parameter	MSE	RMSE	MB	NSE	R^2
SCS-CN method	Direct runoff (mm)	0.27	0.6	0.15	0.94	0.94
	Peak discharge (m3/s)	0.32	0.56	-0.001	0.96	0.98
GA method	Direct runoff (mm)	0.07	0.28	-0.06	0.95	0.95
	Peak discharge (m3/s)	0.27	0.52	0.002	0.97	0.97

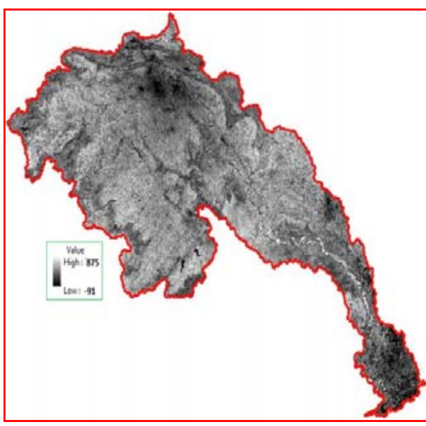


Fig 6: Elevation map

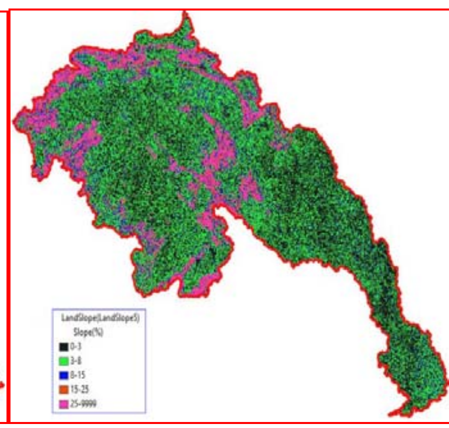


Fig 7: Slope map

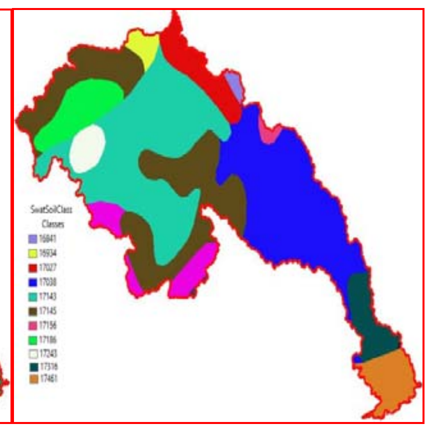


Fig 8: Soil map

(These maps are extracted from ArcGIS)

9. CONCLUSION

To check the performance and fitness of methods, there has been made a comparison on results based on error indices NS and R^2 is near to one and the MSE, RMSE and MB is near to zero. See in table no. 7, results are showing for respective model and established an observation depends on the outcome that calculated in table no. 5. Fifteen years of data have been looked at Subarnarekha river basin for study. Duration of simulation is taken from 2004 to 2013 (9 years) and for validation is taken from 2010-2014 (4 years). For evaluation of model, we need the help of Arc-SWAT and for model calibration and validation, we need SWAT CUP tools. From four rainfall events, comparison analysis is done and it shows that the estimate the error indices are less in GAM as compared to SCS-CN methods of rainfall-runoff studies in Subarnarekha river basin. Hence, the Green-Ampt model presents better performance than CN model.

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