Rainfall-Runoff Estimation and Comparative Analysis Using Advanced Geospatial Digital Hydrological Modelling Tools, ArcCN-Runoff & ArcSWAT

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Abstract: *Runoff is one of most important hydrological parameter that are used in many civil works, planning for optimal use of reservoirs, organizing rivers and warning flood. Hydrological models are proved elements involved in rainfall-runoff estimation. The most prominent method and most widely used approach for accurate estimation of surface runoff is Soil Conservation Services-Curve Number (SCS-CN). This work uses a methodology of determining surface runoff having its advantages, if integrated with advance tools such as remote sensing and geographical information system to enhance the accuracy and precision of runoff prediction. Using modern tools of geospatial technology it is possible to built Digital Hydrological models by implementing some well known hydrologic methods in GIS. This paper discusses utilization of these Digital Rainfall Runoff Modelling tools like, ArcCN-Runoff, ArcSWAT for estimation of spatial Rainfall-Runoff for the storm event with more accurate assessment for Gumani watershed. A comparative analysis reveals that ArcCN Runoff Model gives 90% of rainfall in the form of runoff and 75% of rainfall becomes surface runoff from ArcSWAT Model. The digital runoff thus obtained show the use of Geoinformatic tools in addition to accelerate.*

Key words: *Hydrological Models, DEM, ArcCN, Watershed, ArcSWAT, SCS-CN*

I. INTRODUCTION

Geo-informatics becomes a valuable tool for analysing environment and water resources management. It has provided a consistent method for watershed delineation and dealing with many issues related to watershed management (R.N.Shanhua, 2012). There are various methods for estimating runoff in the basins that they have not enough data. However, for effective application of SCS-CN method that needs the necessary parameters such as physiographic characteristic of the basin such as DEM, land use map, hydrologic soil groups, and rainfall data. The SCS-CN hydrological model consists in a methodology for transforming a certain amount of rainfall for a certain period of time into surface runoff, taking into consideration the land-use and the hydrological soil classes (Mahmoud S. et al, 2014). The curve number is a function of land use, hydrologic soil group (HSG) and it is a method that can incorporate the land use for computation of runoff from rainfall (Shadeed S, et al,2010). SCS method based on GIS was used in many studies for estimating runoff identify potential water harvesting areas by the SCS-CN and GIS in the Kali watershed, Mahi River basin of India (Ramakrishnan D, et al 2009). (Xiao et al, 2011) predicted runoff of small basin in China using SCS-CN method and spatial information technologies (GIS and RS). Apart from this method, there are also other models used in different studies, such as: KINEROS (Hernandez M, et al,2000), TOPMODEL (Domnita M ,2012), NAM rainfall-runoff model (Billa L, et al,2011), Mike 11 (Alfugura A, et al,2011) WMS, SWAT, HEC-GeoHMS etc. in the water and environmental research that have combined well with GIS and in these models the SCS-CN method is used to determine hydrological parameters (Zhan X, et al,2004), (Kopp, S et al, 2011). In another case study (N.Omani et al, 2007) a GIS tool SWAT is used for hydrologic modeling, development of management scenario and the simulation of the effect of management practices on water and sediment yielding in a watershed. In order to estimate runoff from rainfall events loss rate or infiltration parameters for the basin have to be calculated. The infiltration capacity of the basin depends on landuse and soil property. Horton's and Green & Ampt equations are most commonly used equations for estimation of infiltration of a basin (Green W.H, et al, 1911)

II. STUDY AREA

River Gumani rises near Singarsi village at an elevation of RL 520 m from the southern part of Rajmahal hills in Godda district. River Gumani traverses 120.9 km in Jharkhand, 4.5 km along Jharkhand – West Bengal border, and 1 km in the state of West Bengal before it joins with the Ganga. Its main tributaries are Darmonala, Morang or Mural river. Gumani river basin is situated between latitudes 24° 40' N and 25° 28' N and longitudes 87° 31'E and 88° 10' E. The total catchment area of Gumai basin upto its confluence with river Ganga is about 2271.9 sq. km of which 2000 sq. km is in Sahebganj district and the remaining 271.9 sq. km in Godda district as shown in Fig:1

Kuruki nala is a minor tributary of river Gumani, originating near Paharpur village. Kewari nala

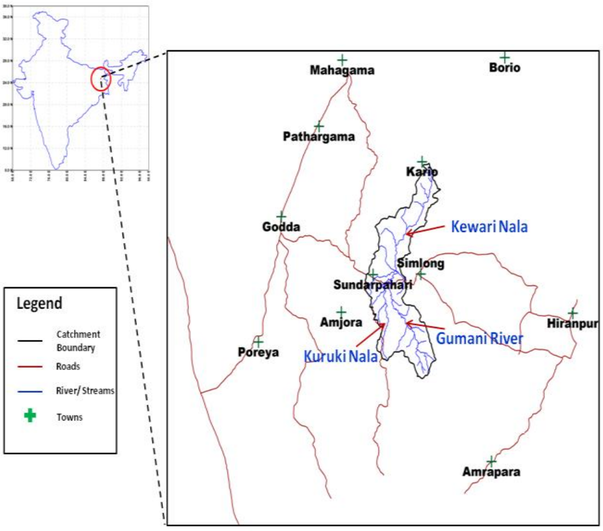


Fig. 1 Location map of the Gumani Watershed

another perennial tributary of Gumani originating near Udali village. Further Gumani flows towards north-east and meets river Mural at Berhait valley and finally it meets with river Ganga.

III. DATA USED

In order to understand the land-use/land-cover practices in the study area, Landsat image of year 2009 down loaded from Global Land Cover Facility (GLCF), NASA Landsat Program(www.landcover.org) and it is classified under supervised classification. Five major categories of area classified in the Gumani river basin using satellite imagery undr supervised classification as shown in Fig: 2.

The classified map shows that 73.85% of the river basin, admeasuring an area of 121.54 sq. km, falls under the Forest category, 22.94% of the river basin under agricultural Fallow-land category, and the remaining area is divided among other two categories namely Urban and Water bodies. The most of the Gumani basin area is weak pasture that this kind of land use has poor hydrological condition and low infiltration.

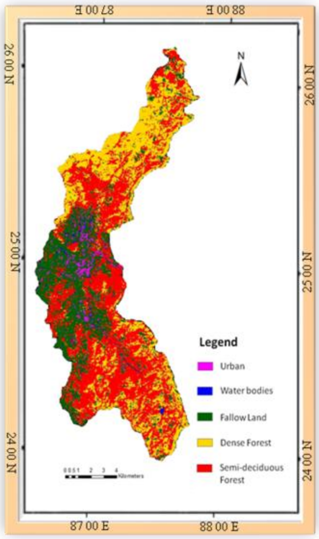


Fig. 2 Land Use-Land Cover map of the Gumani Watershed

The soil map of Gumani river basin is extracted from the Soil Map of South Asia, which was prepared by Food and Agricultural Organization (FAO) based on the 1: 5,000,000 topographic map series of the American Geographical Society of New York. Finally, the hydrological soil groups map was prepared based on soil map that has information about soil depth and texture characteristics. Fig. 3 shows a hydrological soil groups map of Gumani basin and each of these groups that indicates high percent (129.49 Km2) of Gumani basin area is under C type with low permeability.

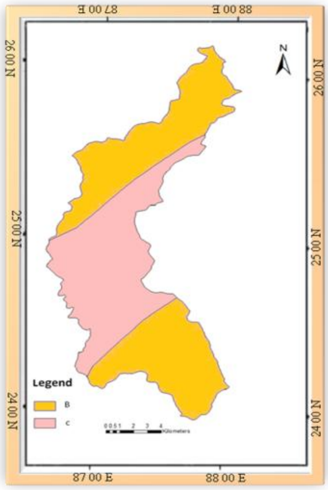


Fig. 3 HSG map of the Gumani Watershed

The first and foremost input layer to ArcSWAT model is digital elevation model (DEM). The DEM used in the ‘Watershed delineation’ together with the river layer. It is used to segment the watershed into several hydrologically connected subwatershed and also used to predict the location of the streams. The DEM of the study area is downloaded from ASTER web site and clipped to the area of interest of the Gumani watershed as shown in Fig: 4

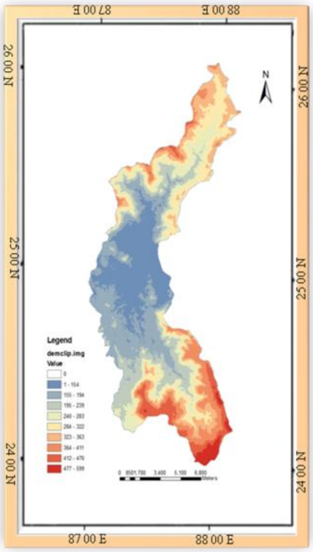


Fig. 4 Digital Elevation Model (DEM) of the Gumani Watershed

Rainfall data of the watershed for the period from 1975 to 2004 was collected from IMD-Pune to utilizing in this study. There is one hydrometric station 'Sundarpahar' which is located within the basin. Since the precipitation data has been collected from single available station, the variations in antecedent moisture conditions could not be accounted. Hence, antecedent moisture conditions II is considered for the entire watershed for the given storm event. In this study spatial analyst and other collateral tools are utilized from ERDAS Imagine, ArcGIS softwares for preparing all the required data. Finally, with the prepared spatial information and other ancillary data, Digital Hydrological Models of ArcCN-Runoff, ArcSWAT were used for estimation of runoff.

IV METHODOLOGY UTILISED

1) For ArcCN-Runoff Model: In recent decades, with the development and utilization of GIS in hydrological models, there are different tools. One of the tools introduced by Zhang et al. 2004 in ArcGIS is ArcCN-Runoff. Curve number and runoff maps of an area can be easily generated using ArcCN–Runoff. The tool is an excellent visualization method for analyzing the runoff occurring in a specific area. This helps in easy interpretation of areas with different runoff values.

The tool makes use of the popularly used SCS-CN method for calculating runoff. The steps involved in ArcCN–Runoff tool is simple, because it requires only 3 inputs in the form of soil, land use/land cover and rainfall data. In this study, ArcCN-Runoff model used as interface to ArcGIS 9.3. The Flowchart in Fig: 5 depict the overall methodology utilized in this study.

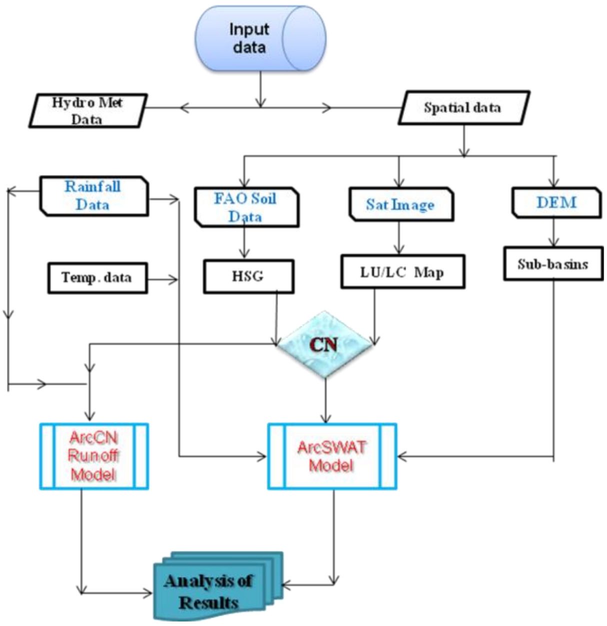


Fig. 5 Flow chart of Methodology

2) For ArcSWAT Model: SWAT is the acronym for Soil And Water Assessment Tool, a physically based continuous time model to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, landuse and management conditions over a large period of time. SWAT sometimes called as ArcSWAT, because it is interface to ArcGIS, otherwise there is no specific difference of both terms. SWAT allows a number of different physical processes to be simulated in a watershed. No matter what type of problem studied with SWAT, water balance is the driving force behind everything that happens in the watershed (Arnold J .G, t al,1998). To accurately predict the movement of water the hydrological cycle as simulated by the model must confirm to what is happening in the watershed. The hydrological cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_o + \text{sum}\,(R_{day} - Q_{surf} - ET_a - W_{seep} - Q_{gw})$$

SW_t = Final soil water content,
SW_o = Initial soil water content on day i,
T = time (day),
R_{day} = Amount of precipitation on day i,
Q_{surf} =Amount of surface runoff on day i,
ET_a =Amount of Evapotranspiration on day i,
W_{seep}=Amount of water entering the vadose zone from the soil profile on day i,
Q_{gw} = Amount of return flow on day i.

As a matter of fact, SWAT (Arc SWAT) is a physically based distributed hydrologic model, for modelling purpose, a watershed may be partitioned into a number of sub-watersheds or sub-basins. Since HRU is the primary modelling unit for the model, it often consists of areas with the same hydrology, soil type and land use characteristics**.** Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. Each HRU for each sub-basin/watershed compute runoff from the Soil Conservation Services (SCS) Curve Number (CN) procedure. The SCS method that is also well known as curve number method is based on water balance.

3) SCS-CN method: The Soil Conservation Services (SCS) empirical method proposed by the U.S. Soil Conservation Service is widely used for estimating direct runoff. SCS-CN method is very sensitive to curve number values, necessitating accurate determination of this parameter. SCS method estimates the runoff according to rainfall and characteristics of basins. So it is appropriate for estimating runoff where there isn't any station for the flow measurement in the basin. The model was developed to provide a consistent basis for estimating the amounts of runoff under varying land use and soil types (Neitsch.S.L, et al, 2002)

$$P = Ia + F + Q \qquad \text{eqn. (1)}$$

Where P is rainfall (mm), Ia is Initial abstraction (mm), F is cumulative infiltration other than Ia (mm), Q is direct runoff (mm). Initial abstraction (Ia) is function of the maximum potential abstraction (S). The following equation is using for estimating Runoff:

$$Q_{surf} = \frac{(P - I_a)}{(P - I_a + S)^2} \qquad \text{eqn. (2)}$$

Equation (2) is true for P> Ia, otherwise the estimated runoff to be zero. Initial retention (Ia) is in fact part of the precipitation that does not participate in the runoff and is considered equal to Ia = 0.2S in SCS:

$$Q_{surf} = \frac{(P - 0.2S)}{(P - 0.8S)^2} \qquad \text{eqn. (3)}$$

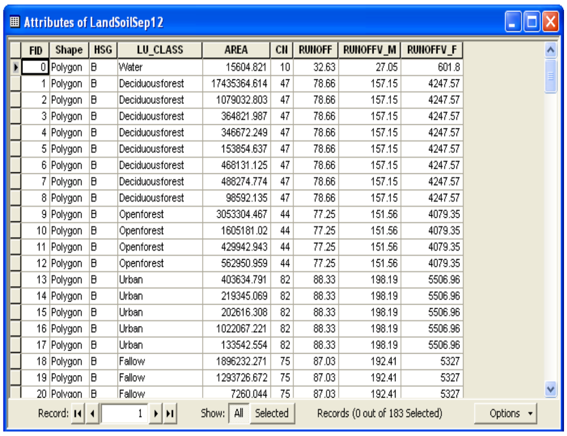
The potential maximum retention(S) is determined based on curve number (CN) from the following equation:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \qquad \text{eqn. (4)}$$

In this case CN is the curve number that depends on some factors such as hydrologic soil groups, vegetation,watershed land use,and antecedent moisture condition (Chow V.T, et al,1998).

V APPLICATION OF MODELS AND DISCUSSIONS

1) Application of ArcCN-Runoff Model: After preparation of soil map, attribute table of soil data should be added as a table area under consideration the hydrologic soil group (HSG). Land use data includes various land use classes as an attribute table, since calculating curve number will be difficult without using GIS techniques. Therefore in ArcCN-Runoff model, the curve number map for each polygon is created by combining land use (Fig:2) and hydrologic soil group map (Fig:3) and utilizing curve number database can be added by the user in .dbf format based on field data. The average annual precipitation value of the desired year is also given as input.



Attributes of LandSoilSep12

FID	Shape	HSG	LU_CLASS	AREA	CN	RUNOFF	RUNOFFV_M	RUNOFFV_F
0	Polygon	B	Water	15604.821	10	32.63	27.05	601.8
1	Polygon	B	Deciduousforest	17435364.614	47	78.66	157.15	4247.57
2	Polygon	B	Deciduousforest	1079032.803	47	78.66	157.15	4247.57
3	Polygon	B	Deciduousforest	364821.987	47	78.66	157.15	4247.57
4	Polygon	B	Deciduousforest	346672.249	47	78.66	157.15	4247.57
5	Polygon	B	Deciduousforest	153854.637	47	78.66	157.15	4247.57
6	Polygon	B	Deciduousforest	468131.125	47	78.66	157.15	4247.57
7	Polygon	B	Deciduousforest	488274.774	47	78.66	157.15	4247.57
8	Polygon	B	Deciduousforest	98592.135	47	78.66	157.15	4247.57
9	Polygon	B	Openforest	3053304.467	44	77.25	151.56	4079.35
10	Polygon	B	Openforest	1605181.02	44	77.25	151.56	4079.35
11	Polygon	B	Openforest	429942.943	44	77.25	151.56	4079.35
12	Polygon	B	Openforest	562950.959	44	77.25	151.56	4079.35
13	Polygon	B	Urban	403634.791	82	88.33	198.19	5506.96
14	Polygon	B	Urban	219345.069	82	88.33	198.19	5506.96
15	Polygon	B	Urban	202616.308	82	88.33	198.19	5506.96
16	Polygon	B	Urban	1022067.221	82	88.33	198.19	5506.96
17	Polygon	B	Urban	133542.554	82	88.33	198.19	5506.96
18	Polygon	B	Fallow	1896232.271	75	87.03	192.41	5327
19	Polygon	B	Fallow	1293726.672	75	87.03	192.41	5327
20	Polygon	B	Fallow	7260.044	75	87.03	192.41	5327

Record: 1 Show: All Selected Records (0 out of 183 Selected) Options

Fig. 6 Attribute table of ArcCN-unoff Model results

Soil and landuse/landcover data were intersected to generate new and smaller polygons associated with soil type and landuse class name. If all the GIS layers and attribute tables in proper format the ArcCN-Runoff tool makes use of for calculating runoff. The computed Runoff shown in attribute table of intersected layers named as land_soil map as shown in Fig: 6.

The results obtained from ArcCN-Runoff model shown in graphical form in Fig:7. The results depicts a smooth trend line of runoff along with rainfall. The average annual runoff depth obtained a maximum of 101.397 mm and minimum of 51 mm.

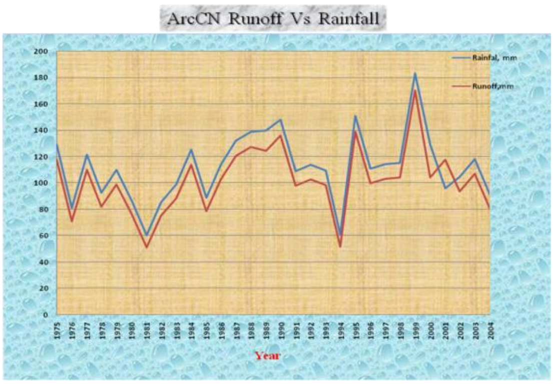


Fig. 7 Year wise graph for ArcCN Runoff with Rainfall of Gumani Watershed

The maximum runoff depth is 170.18 mm for a rainfall of 183.36 mm occur in the year 1999. The minimum runoff depth is 51 mm for a rainfall of 60.24 mm in the year 1981. The graph clearly shows that the runoff trend follows the similar trend of rainfall with only 10% of overall difference. The most exposed to surface runoff areas are built up areas and river valleys, where the Curve Number frequently exceeds the value of 90.

2) Application of ArcSWAT Model: After preparing the required data files and geospatial layers, the model was simulated for 30 years. The results reveals, that the maximum runoff obtained in the year 1999 is 168.74 mm. The least runoff depth obtained in the year 1975 is 19.63 mm. The graph between ArcSWAT model simulation results with rainfall is shown in Fig: 8. According to the simulation the graph plotted and, the trend line of runoff along with rainfall is quite aloof.

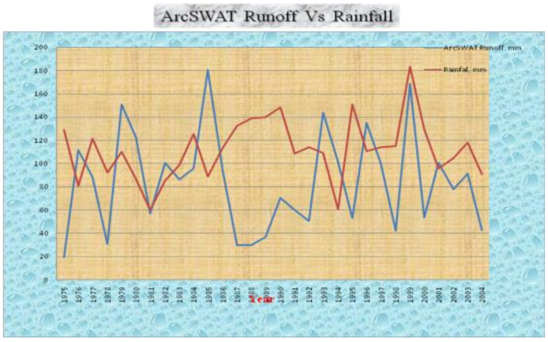


Fig. 8 Year wise graph for ArcSWAT Runoff with Rainfall of Gumani Watershed

3) Comparative Analysis: For 30 years rainfall event the mean annual rainfall is 111.97 mm/yr. The runoff results shows that ArcCN model gives 101.397 mm/yr, is equal to 90.55% of the given rainfall. Similarly ArcSWAT model gives runoff nearly about 84.34 mm/yr which is equal to 75.32% of the given rainfall. The trend lines of runoff for both the models at the given rainfall event is shown in Fig: 9**.** The variation of runoff values obtained from both the models causes due to consideration of losses in the models. In case of ArcCN model the higher runoff obtained due to non consideration of losses as in the case of ArcSWAT model. The highest rainfall in 1999 is 183.36 mm, the corresponding runoff obtained 170.18 mm, 168.74mm from ArcCN and ArcSWAT model respectively. Though the runoff trend lines are aloof for both ArcCN and ArcSWAT models, these are comparable, because the main tenet behind both the model is SCS-CN for simulation of models.

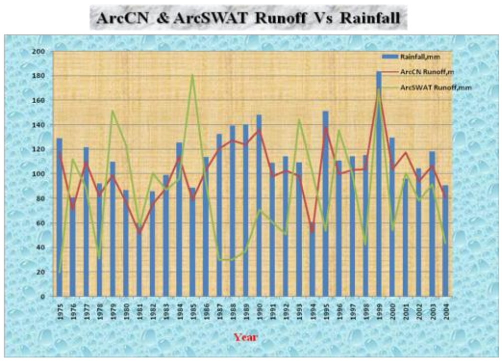


Fig. 9 Year wise graph for ArcCN Runoff with Rainfall of Gumani Watershed

The resultant graph demonstrated that the Runoff depth obtained from ArcCN model shows higher than ArcSWAT runoff. It reveals that in case of ArcSWAT model losses are more in the form of Evapotransipiration and infiltration. In case of ArcSWAT one of the input data taken into account in the form of temperature data. The accuracy of the model results is significantly improved by the use of measured temperature data (Dingman S.L, 1994). Evapotranspiration is the primary mechanism by which water is removed from a watershed roughly 62% of the precipitation that falls on the Continents is evapotranspired, evapotranspiration exceeds runoff in most river basins and on all Continents except Antarctica (Williams J.R, et al, 2000). Ultimately, both these Digital Hydrological Models are developed under a common platform of water balance.

VI. CONCLUSIONS

This work presented a GIS-based SCS-CN for estimation of rainfall-runoff using Digital Hydrological Models-ArcCN-runoff and ArcSWAT. As such, the present study highlighted the efficiency of the CN method in analysing dynamic processes efficiently. Regarding ArcCN–Runoff model has high accuracy of Geospatial technique so that determining the exact CN by GIS is cause of high accuracy method. Also the main advantage of this ArcCN model is determining of Runoff at each point of the catchment which is the basic parameters in the design of the hydraulic structures and flash floods. An ArcSWAT runoff result reveals much variation with ArcCN results because of higher losses are do considered. Though the simulation procedures are aloof, the author has made an attempt to estimate and comparison of runoff results, because of the main tenet of both the models are similar. It can be concluded that the results obtained using Digital Hydrological Models can be very much used for runoff estimation with more accuracy and very short processing time with the help of geospatial tools and technology

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