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Comparison of Runoff Estimation Using ArcSWAT and Conventional Method for Different Catchment Scales

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Abstract: In India, water availability and usage completely depend on rainfall pattern and its distribution. Monsoon regions are characterized by varying seasonality of water which has strong impact on environment. In order to overcome issues related to water availability and its supply, there should be an assessment of water resources using standard methods. However there is no single approach to give concrete idea of water availability due to issues like climate change, land use characteristics and catchment modifications due to ongoing urbanization and industrialization. To overcome these issues, comparison of runoff estimation is done using GIS based software named Soil and Water Assessment Tool (SWAT) and conventional empirical formula for Ghataprabha sub-basin by considering total area in different scales and suitability of method is concluded.
Keywords: Runoff, ArcSWAT, Ghataprabha sub-basin.

I. INTRODUCTION

The progress and prosperity of any country solely depends on its water resource availability and its effective management. In recent years, scarcity of water is widely observed due to increasing population, increasing urbanization and industrialization, energy use desertification and change in agricultural patterns. Hence water management has become the most concerned matter among the water resource engineers and hydrologists. To connect the natural hydrological cycle with the real time problem solutions various models have been developed to study various hydrological parameters. Hydrological models are widely used for flood forecasting, water supply, water demand analysis and water quality evaluation. These modelling approaches vary in conception and complexity. In monsoon regions model application is restricted by limited data availability or outdated data. Among others the recent Soil and Water Assessment Tool (SWAT; Arnold et al., 1998) has proven its capability to model water fluxes in regions with limited data availability (Ndomba et al., 2008; Stehr et al., 2008) Considering the limitations of both numerical approach and conventional method, in the present study an attempt is made to simulate the runoff in Ghataprabha river, a major tributary of river Krishna. The runoff estimation was made by using SWAT model at different scales and compared with conventional empirical formulas.

II. STUDY AREA

Ghataprabha River is one of the southern tributaries of River Krishna in its upper reaches. The catchment of the sub basin lies approximately between northern latitudes 15^0 45’ and 16^0 25’ and eastern longitude 74^0 00’ and 75^0 55’. April is generally the hottest December is generally the coldest month with the mean daily maximum and minimum temperatures being 29.3^0 C and 13.9^0 C respectively. The sub basin experiences only the southwest monsoon and the period is from 1st June to 31st October is the lowest. The relative humidity is high during the south west monsoon and low during the non-monsoon period. In summer the weather is dry and the humidity is low.

III. METHODOLOGY

The Ghataprabha catchment up to Kudalsangam has been selected and the model was applied three different stages. The first phase includes a catchment up to Daddi (Karnataka) with a catchment area of about 1000 sq. km has been selected. The second phase of the study was taken up for a catchment with an area of 2600 sq. km and in the final phase, the entire catchment up to Kudalsangam was considered for the modelling. The SWAT model was provided with sets of input data for three different scales as mentioned. The input data consisted of DEM file, LULC map, soil map and slope map of the basin. Also the runoff is estimated using following empirical formulas:

Inglis formula for ghat area:

$$R = 0.85P - 30.5$$

Inglis formula for non-ghat areas:

$$R = \frac{(P - 17.8)}{254} * P$$

Lacey's formula:

$$R = \frac{P}{1 + 304.8 f / PS}$$

Khosla's formula:

$$R = P - \frac{T - 32}{3.74}$$

Where R=runoff in cm
P=rainfall in cm
F=monsoon duration factor:
S = a value dependent on catchment class characteristics:
0.25---flat, cultivated B.C. soil(A)
0.60---flat, partly cultivated soils(B)
1.00---average(C)
1.70---hills and plains, little cultivation (D)
3.45---very hilly and steep with hardly any cultivation (E)
T= mean temperature in ^{0}F on the entire catchment.

IV. RESULT AND DISCUSSION

The SWAT model was run for 16 years data (1990-2005) drawn from SWAT India data base. Initially, the model was run on monthly basis. The average monthly rainfall varied between 0.01 mm during January month to a maximum of 411.2 mm in the month of July. ET shows variation between 7 mm to 66.7 mm. In the small basin average rainfall ranges from 0.01 mm to 411.20 mm. Runoff ranges from 0.09 mm to 241.51 mm. In the medium sub-basin, it showed slightly reduced runoff as compared to the smaller sub-basin. This is quite expected as the rainfall is quite higher than the medium and larger basin. Table 1 shows the output (annual average) of SWAT model.

BASIN VALUES	Large basin (CA = >8000 sq. km)	Medium basin (CA = > 2500 sq. km)	Small basin (CA = > 1000 sq. km)
Precipitation (mm)	930.5	964.7	1343.5
Surface runoff(mm)	296.95 (31.93%)	306.88 (31.81%)	641.84 (47.7%)
Lateral soil flow (mm)	0.97 (0.001%)	2.14 (0.022%)	3.68 (0.027%)
ET (mm)	519.2 (55.79%)	533.6 (55.35%)	461.3 (34.33%)
PET (mm)	1829.9	1919.8	1920.2
Area of basin (Sq.km)	8615.23	2626.78	1005.18

Table 1. Comparison of SWAT output of Ghataprabha sub-basin with varying catchment areas

Figure 1 shows the variation of runoff in 3 sub-basins varying in size. It is observed that the highest runoff (47.7%) is in the smaller basin which is having highest rainfall. However, in the medium and larger catchments, runoff is found to be almost identical.

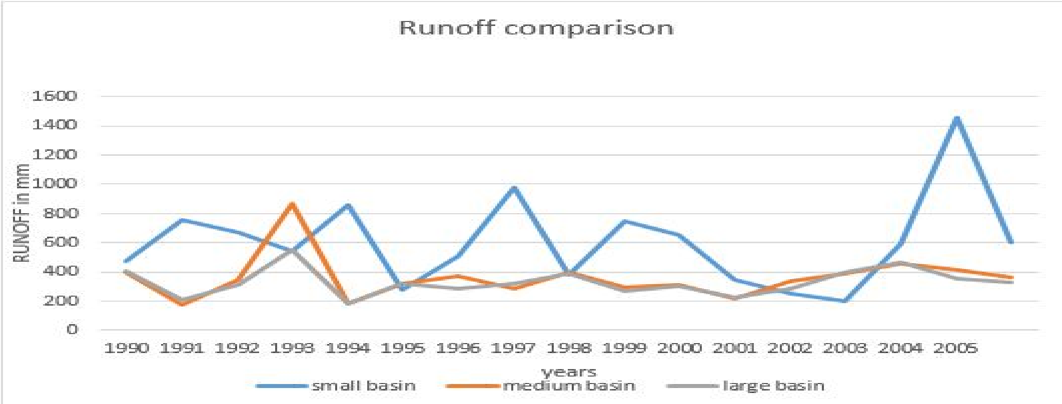

Fig.1 Comparison of estimated runoff in three sub basins

Table 2 shows the annual variation of runoff in three catchments. It is noticed that both rainfall and runoff significantly high during 1997 and 2005. Maximum rainfall of 2347.91 mm and the estimated runoff was 1455.56 mm during 2005. However, in the medium and larger basin there was no significant increase in the rainfall or runoff. This clearly indicates the role of catchment area and characteristics on runoff. Table 3 shows the runoff estimated by empirical methods such as Inglis, Lacey and Khosla methods for the Ghataprabha sub-basin up to Daddi (small basin). The results obtained by these methods are compared with the SWAT output. The runoff value estimated by SWAT model varies between 31.17% and 61.99% with an average of 45.91%. According to Inglis formula, the surface runoff vary from 36.46% to 72% with an average runoff of 57.57%. Lacey's methods showed variation between 26% and 56.7% and average is 39.92%. However, the runoff estimated by Khosla's method deviated far off from the predicted runoff using SWAT. Both Inglis and Lacey's method predicted relatively closer values as compared to Khosla's method.

Year	Rainfall (mm)	Small basin Runoff (mm)	Rainfall (mm)	Medium basin Runoff (mm)	Rainfall (mm)	Large basin runoff (mm)
1990	1129.15	473.38	1138.52	399.73	1116.54	402.93
1991	1499.19	759.49	648.28	177.17	722.05	211.88
1992	1303.54	671.02	1129.45	345.72	1052.02	312.02
1993	1174.73	544.22	1563.25	868.65	1224.74	549.76
1994	1585.45	856.4	713.28	179.79	712	185.34
1995	697.38	272.93	942.29	317.9	925.96	315.98
1996	1123.74	509.64	972.26	373.67	851.69	288.84
1997	1725.81	976.31	946.51	281.89	998.49	322.16
1998	1007.12	377.72	1089.68	397.84	1029.92	384.49
1999	1381.47	750.75	922.14	290.07	874.58	269.41
2000	1327.22	651.95	1031.81	308.92	984.03	299.77
2001	937.76	346.11	876.12	215.34	887.11	224.5
2002	729	247.9	1020.85	335.66	908.78	288.63
2003	628.37	195.87	1092.54	389.66	1088.24	399.8
2004	1331.3	589.27	1204.52	455.37	1214.19	461.48
2005	2347.91	1455.56	1129.42	409.98	1024.82	354.81
Average	**1245.57**	**604.90**	**1026.30**	**359.21**	**975.94**	**329.48**
Percentage		**48.56**		**35**		**33.76**

Table 2. Annual variation of runoff in three catchments

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year	Rainfall in mm	Swat Runoff in mm	% Runoff	Inglis Runoff in mm	% Runoff	Lacey's Runoff in mm	% Runoff	Khosla's Runoff in mm	% Runoff
1990	1129.15	473.38	41.92	654.77	57.98	436.32	38.64	1013.90	89.79
1991	1499.19	759.49	50.66	969.31	64.65	682.70	45.53	1383.94	92.31
1992	1303.54	671.02	51.47	803.00	61.60	548.75	42.09	1188.29	91.15
1993	1174.73	544.22	46.32	693.52	59.03	465.00	39.58	1059.48	90.19
1994	1585.45	856.4	54.01	1042.63	65.76	744.03	46.92	1470.20	92.73
1995	697.38	272.93	39.13	287.77	41.26	195.29	28.00	582.13	83.47
1996	1123.74	509.64	45.35	650.17	57.85	432.95	38.52	1008.49	89.74
1997	1725.81	976.31	56.57	1161.93	67.32	846.44	49.04	1610.56	93.32
1998	1007.12	377.72	37.50	551.05	54.71	362.23	35.96	891.87	88.55
1999	1381.47	750.75	54.34	869.24	62.92	601.20	43.51	1266.22	91.65
2000	1327.22	651.95	49.12	823.13	62.01	564.55	42.53	1211.97	91.31
2001	937.76	346.11	36.90	492.09	52.47	322.03	34.34	822.51	87.71
2002	729	247.9	34.00	314.65	43.16	210.72	28.90	613.75	84.19
2003	628.37	195.87	31.17	229.11	36.46	163.07	25.95	513.12	81.66
2004	1331.3	589.27	44.26	826.60	62.09	567.29	42.61	1216.05	91.34
2005	2347.91	1455.56	61.99	1690.72	72.00	1331.29	56.70	2232.66	95.09
Avg	**1245.57**	**604.90**	**45.91**	**753.73**	**57.57**	**529.61**	**39.92**	**1130.32**	**89.63**

Table 3. Estimated runoff by SWAT model and Conventional methods.

The comparison of runoff estimated by different methods are shown in fig. 2.

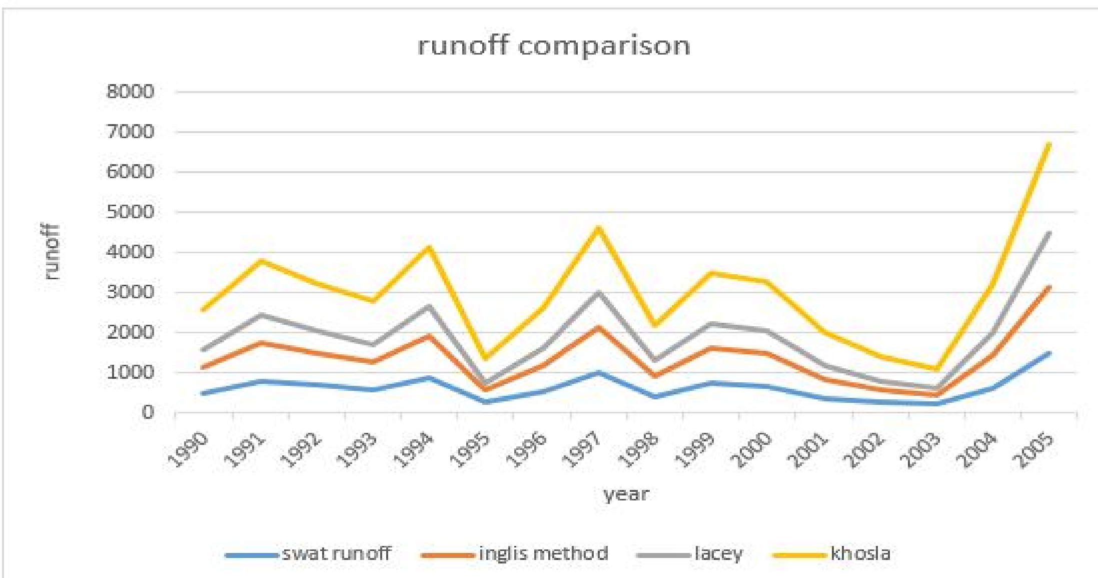

Fig.2. Comparison of Runoff estimated by different methods.

V. CONCLUSION

The present study has been carried out to assess the surface runoff in Ghataprabha sub-basin. It is observed that the variations in surface runoff are attributed to variation in rainfall, land use/land cover changes and soil characteristics. The study substantiated that there is a significant influence of catchment size on estimating runoff.Further, the study demonstrated the impact of land use/land cover changes and soil type on runoff. Conventional methods also provided quite encouraging results. This indicated that the development of regional based empirical formulae may be quite useful in estimation of runoff in data limited environment. Some of the important observations of the study are the following:

A. Average annual runoff estimated of small basin from ArcSWAT is 604.90 mm i.e. (45.91%) of rainfall. Minimum and Maximum Runoff values are 247.9 mm and 1455.56 mm respectively.

B. Average annual Runoff for Small basin from Inglis method is 753.73 mm, it is around 57.57% of Rainfall. Minimum and maximum runoff values are 229.11 mm, and 1690.73 mm, respectively. Lacey's method estimated the runoff as 529.61 mm (39.92%) of rainfall. Minimum and Maximum Runoff values are 163.07 mm, and 1331.29 mm, respectively. However, the Khosla's method calculated very high runoff values (89.63%).

VI. ACKNOWLEDGEMENT

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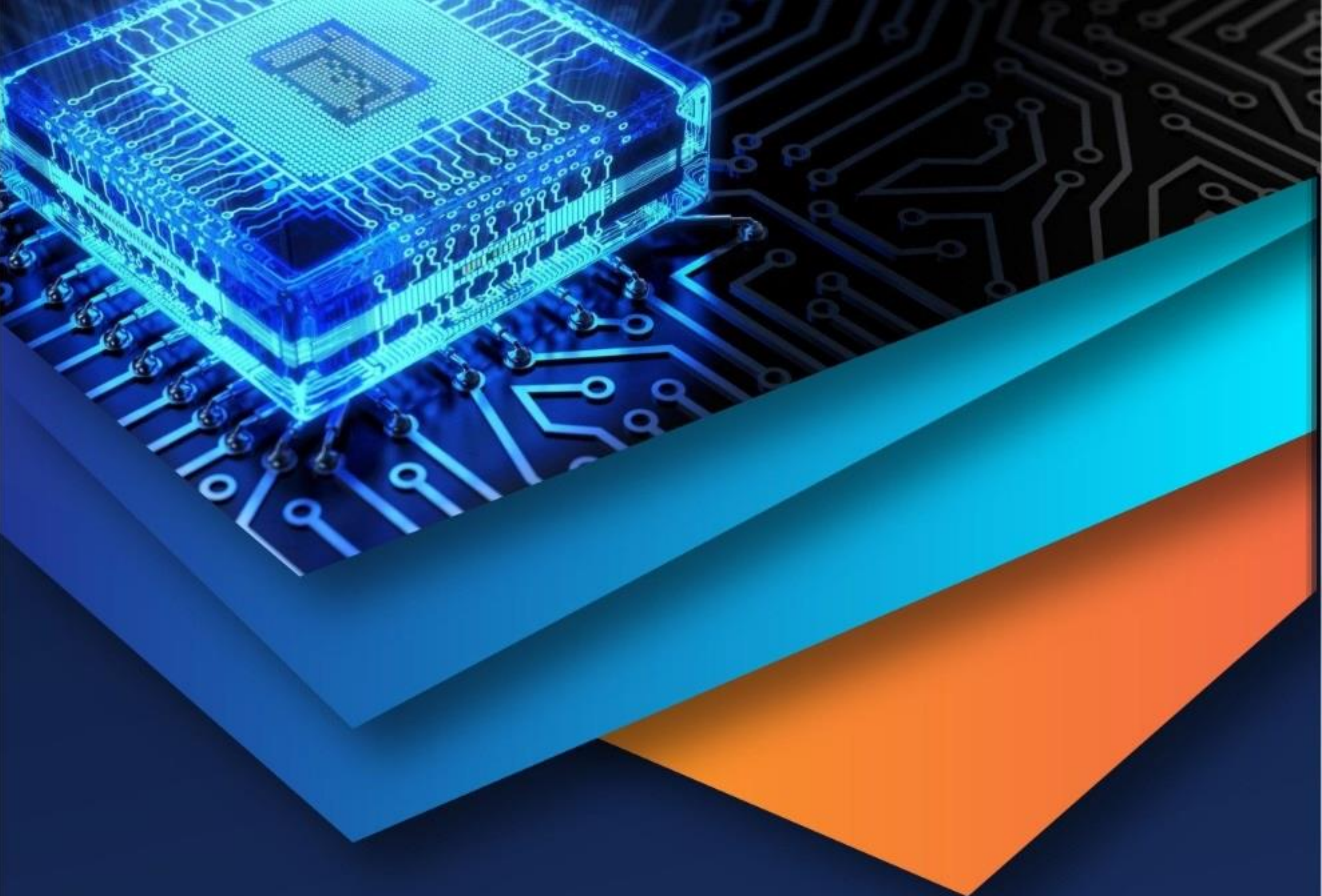

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