Performance Evaluation by using SWAT & GIUH to estimate surface runoff for ungauged basin

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Abstract

Runoff estimation is very important aspect in hydrological field and for reservoir analysis. To measure runoff various technique are available, but in case of ungauged basins synthetic unit hydrograph method has been used since last five decades. The outputs from these conventional methods are not efficient, so there is need for alternate methods. Soil and Water Assessment Tool (SWAT) and Geomorphological Instantaneous unit hydrograph (GIUH) are the advance tools have been developed and these tools are capable to measure the runoff for ungauged basins. So, the aim of this work is to measure runoff for ungauged basin in Kolhapur district with these tools. The methodology was used to achieve the said objective, SWAT and GIUH models were developed and performance of model was compared. To process the models, the meteorological data is used from (2000-2020). The Sequential Uncertainties Fittings-2 algorithm in SWAT-CUP was worn out to calibrate and validate the models. The result shows that, the statistical parameters NSE (0.80) and R2 (0.84) indicates the acceptance of model. The study concludes that, the SWAT model is helpful for continuous scale and GIUH tool for events based activities. The results obtained from GIUH are better than SWAT model.

Keywords- SWAT, GIUH, Ungauged basin, Runoff, Kolhapur.

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1. Introduction

The runoff estimation is an important process in hydrological study. There are two important categories of basins Viz, gauged basins and ungauged basins. It is easy to measure runoff for gauged basins; also there are many techniques available for gauged basins. Bernard, Clark, McCarthy and Snyderhave developed many methods for synthesizing hydrographs for ungauged areas[1]. The best known method to find runoff for ungauged basin is Snyder method (1938). Snyder (1938) developed a synthetic Unit Hydrograph;he studied the different watersheds which has the higher altitudes (Fig. 1). The area of basins was range from 10 mi^2 – 10,000 mi^2. The terms in Snyder's Synthetic unit hydrograph are defined as follows. The equations (1-3) explain the elements of synthetic unit hydrograph.

$$tp = Ct\,(LLC)0.3 \quad \text{..........[1]}$$

Where,

tp= basin lag.

Ct= Coefficient 1.8 to 2.2

L= length of the main channel

Lc = distance between centroid to outlet of catchment.

$$Qp = 640\,CpA/tp \quad \text{................[2]}$$

Where,

A = Catchment area

Qp = Peak Discharge of UH.

Cp = storage coefficient ranging from 0.4 to 0.8.

$$Tb = 3+tp/8 \quad \text{....................[3]}$$

Where,

Tb- Base time of UH.

2. Methodology used

2.1 Details of Study area

For current work, the ungauged basin from Kolhapur district was selected. The work compares the performance of SWAT and GIUH, the catchment area measuring 690 Sq.Km was selected for hydrological analysis [17, 18]. Kolhapur watershed is located at south region of Maharashtra, India with latitude and longitude 15058' & 73042' respectively. The average rainfall of area is 4000 mm per year. A major supply of water for the study region is the Panchganga river, which is a tributary of the Krishna river. Fig. (2) depicts the study area's location map, while Fig. (4) depicts the sub-basin details after outlining the Digital elevation model (DEM) in ArcMap 10.7.1, as well as the basin's boundary and longest path. The main crops seen in basin are, Paddy, Nagali, Cashewnut, Sugarcane and Groundnuts. The temperature observed in basin is ranges from 90C to 400C. The area receives its maximum portion of precipitation from Southwest monsoon during (June-September).

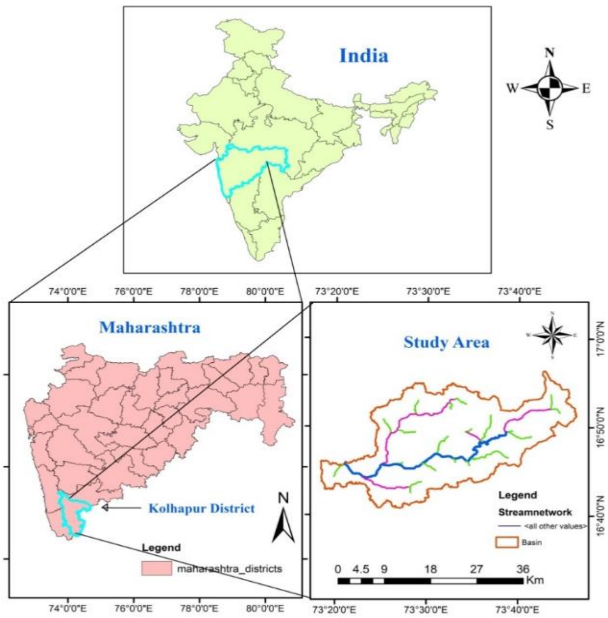


Fig.2 Location Map

2.2 Model Formulation-SWAT

The Soil and Water Assessment Tool (SWAT) is a Agro-hydrological, physical based and long term hydrologic model (Fig.3). SWAT is used to determine impacts of land management (Land use/Land cover) on runoff, sediment yields, chemical yields and it operates on daily time steps [2, 16]. The SWAT model is utilized to simulate high level spatial data and gives output in required format.

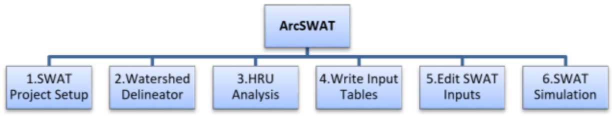


Fig. 3 SWAT model

The first step in model, entire catchment is divided into sub-basin and again sub-basin to Hydrologic response units (HRU). HRU is a small portion of sub-basins that have unique land use land cover management and soil attributes. As a common practice a sub-basin should contain optimum HRUs in between 1 to 10 in numbers. For the HRU in basin the hydrologic attributes are represented by 4 storage volumes namely: Deep aquifer (more than 20 m), Shallow aquifer (2-20 m), Soil profile (0-2 m) and rainfall (mm). The ground profile is divided into number of layers. The soil and water process includes evaporation, infiltration, lateral flow, plants uptake and deep percolation [19]. The details from each HRU like flow, nutrients, and sediments are summed together and resulting information are used for further process.

The SWAT model has eight major and important modules namely; Climate, hydrology, sediment, Agriculture, water quality & quantity, land cover, main channel and water bodies. Modified CN technique was used to simulate runoff daily basis (USDA-NRCS 2004). The model has three options for estimation of potential evapotranspiration (PET) such as Hargreaves, Penman-Monteith (PM) and Priestley- Taylor (PT). The Manning's formula has been worn to determine watershed time of concentration. A detail description and guidelines for SWAT is available on SWAT website (J.G.Arnold et al. Version 2012) [3].

2.3 GIUH

Rodriguze Iturbe and Valdes (1979) [4] introduced the concept of GIUH which facilitates the linkage of hydrological characteristics of basin to geomorphological parameters [5,6]. In present work the catchment area has 3rd order stream network, the formula given by Rodriguze Iturbe and Valdes (1979) was used to find geomorphological parameters. The GIUH can be used to draw unit hydrograph for river basin, further it facilitates and afford the hydrologic response of river basin on the basis of its physical characters derived by Horton's formula [7]. The GIUH presents the probability function of rainfall drops which is fallen on catchment and collected at outlet [8]. The travel time of rain drops along undulated topography is assumed to follows exponential distribution and Horton's equation is used to calculate initial and transitional probabilities and morphological parameters. The parameters in GIUH are Length ratio,area ratio, and Bifurcation ratio [9].

The general equation of GIUH by the Rodriguze Iturbe and Valdes (1979) is given by the following formula and it can be used for Nth order stream (Eq. 4).

$$\frac{d\theta_N + 2^{(t)}}{dt} = \sum_{i=1}^{N} \Theta_i(0)\, t\, \frac{d\phi_{i\,(N+2)}}{dt} \quad \ldots\ldots\ldots[4]$$

Where,

$\phi_i(N+2)(t)$- Interval transition probability from state 'i' to state (N+2).

$\theta N(t)$-State probability,

$\theta i(0)$- Initial state probability.

The above equation is based on the Semi Markov process, which assumes that the mean waiting time follows an exponential distribution. However, because the origin of the exponential distribution shifts from zero, it does not work well in practice. [10].

Bifurcation Ratio

$$RB= \frac{N_i}{N_{i+1}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[5]$$

Where,

Ni and Ni+1are the numbers of streams in order i and i+1. Let Ω represent the highest stream order in watershed i.e. i = 1, 2, 3………Ω. In present work highest stream order is three (Eq. 5).

Length Ratio

$$RL = \frac{L_{i+1}}{L_i} \quad \ldots\ldots\ldots\ldots[6]$$

Where, Li = average length of channel of order i (Eq. 6).

Area Ratio

$$RA = \frac{A_{i+1}}{A_i} \quad \ldots\ldots\ldots[7]$$

Where,

Ai = Area contributed by stream of order i (Eq. 7).

Initial State Probabilities

The catchment basins may have one or more reservoir or temporary storages. The topography of basin affects the storage properties of catchment. The initial state probabilities take an account of the time or area of raindrops which is fallen on ground and neglects the raindrops which are fallen on channel networks [11, 20]. The transition probability and initial probability are the function of geometric and geomorphological parameters of basins. The initial probability of any rain drop of order i means the area contributing to that stream for given order [12].

Transition state probabilities-

P12, P13, and P23 describe the varying condition of a water drop from a lower order to a higher order stream in the transition probability (Eq.8). P23 denotes the likelihood of a rain drop moving from a second to a third order stream [13,14]. The formula for transition probabilities is given as below;

$$\text{Transition probabilities (Pij)} = \frac{No.of\ streams\ of\ order\ 1\ flowing\ into\ order\ i}{Total\ no\ of\ streams\ of\ order\ 1}; \quad \ldots\ldots\ldots[8]$$

Path Probabilities-

Path probabilities in GIUH is defined as, it is the probability of water drop that can travel in all possible direction or paths (Si) to drain at outlet (Eq.9). It is denoted by (Si) and it can be calculated by following formula, [15]

$$N = 2\,\Omega - 1 \quad \ldots\ldots\ldots\ldots[9]$$

Where,

Ω- Order of stream and N – number of possible paths.

3. Results and Discussions-

In the current work, the SWAT model was processed on daily data base and the results are compared with GIUH outcomes.

3.1 Estimation of Runoff- GIUH tool.

To estimate runoff the Python script is used in this work. The ArcGIS in ArcMap facilitates the hydrologic simulation and GIUH parameters can be estimated with the help of ArcMap. In this work, ArcMap 10.7.1 is used to simulate the GIUH parameters.

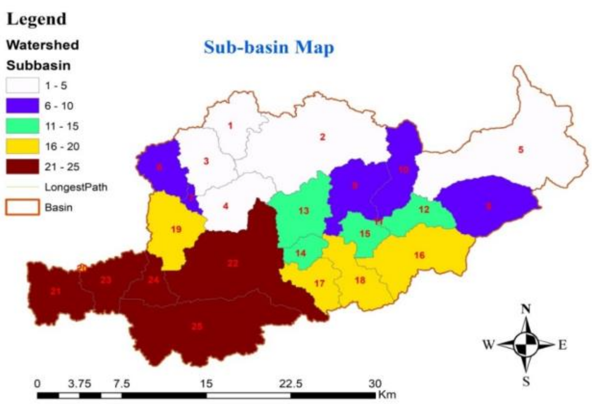


Fig.4 Sub-basins details

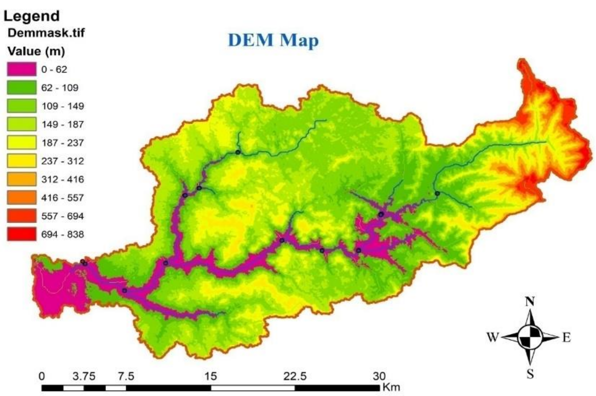


Fig.5 DEM Map

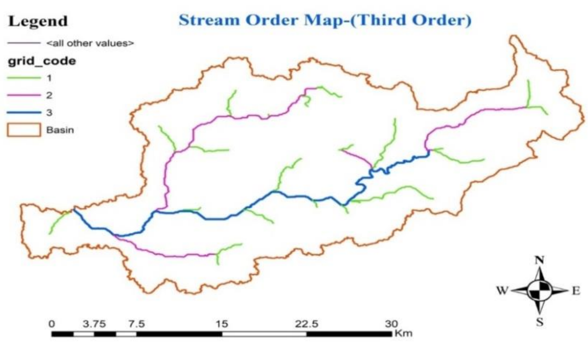


Fig.6 Details of Stream orders

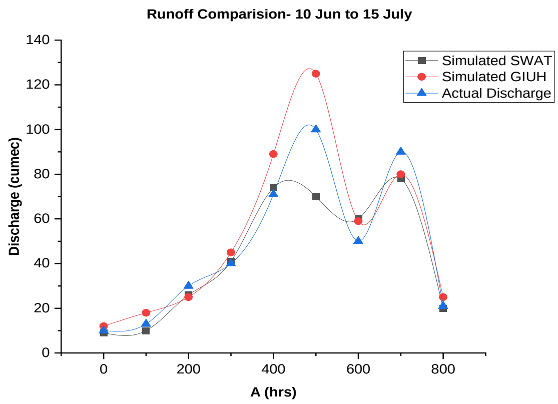
The digital elevation model (DEM) was delineated by ArcMap, the study basin is divided into 25 sub-basins, and the highest stream order of basin is 3. Fig. (6) shows the stream order map of basin. The IUH represent the response of catchment for 1 cm of rainfall. The numbers of hours was taken as input and IUH was plot from GIUH tool.

3.2 Runoff estimation –SWAT.

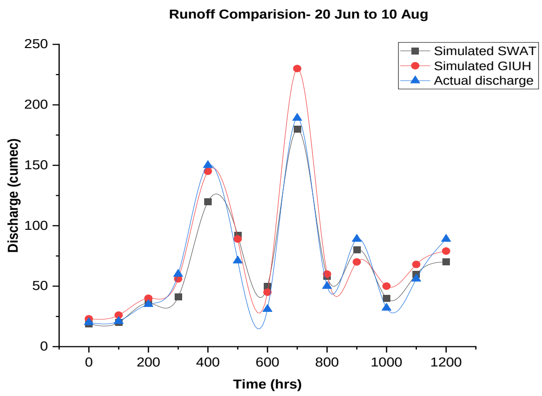
The SWAT model uses the daily meteorological data to estimate the runoff. Four storm events from Kolhapur watershed were taken for comparative study. The comparison of outputs from SWAT and GIUH in terms of runoff are shown in Fig. (7).

Fig. (7), (a) illustrate the work out hydrograph from SWAT and GIUH for time period (10 Jun to 15 July, 2010). The outcomes show that GIUH model is slightly improved than SWAT model. Similarly Fig. 7,(b)(c)(d) shows remaining storm events.

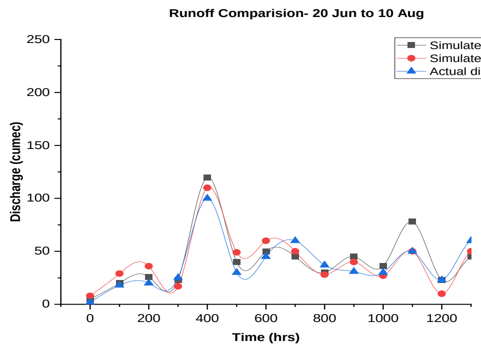
From simulation study it was observed that, the RMSE error in runoff estimation is better in GIUH (Table.1). To improve the results it is highly recommended that to use sub-daily and hourly meteorological data.



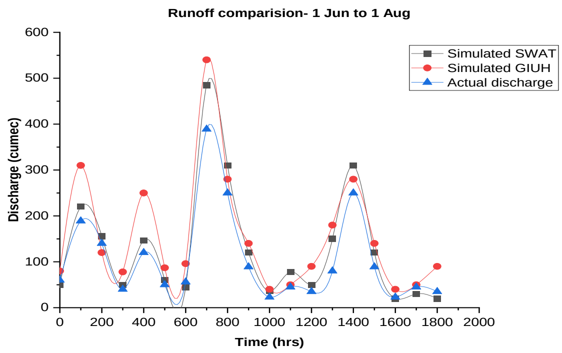
(a)



(b)



(c)



(d)

Fig.7 – a) Simulated Vs. Observed Runoff, 10 Jun-15 July b) Simulated Vs. Observed Runoff, 20 Jun-10 Aug c) Simulated Vs. Observed Runoff, 1 Aug-1 Oct d) Simulated Vs. Observed Runoff, 1 Jun-1 Aug.

Table.1 RMSE values for SWAT and GIUH

Parameter/Tool	Events			
	10 Jun-15 July 2010	**20 Jun-10 Aug 2012**	**1 Aug-1 Oct 2014**	**1 Jun-1 Aug 2016**
RMSE OF GIUH	42.40	72.10	35.30	120.30
RMSE OF SWAT	42.00	69.20	31.20	118.10
Av. Observed discharge	44.30	73.60	35	124.90

4. Conclusion-

This study was aimed at to measure up to the performance of GIUH and SWAT tools in runoff estimation. The ungauged watershed was selected for this study from Kolhapur district. The model uses daily meteorological data to simulate the flood events. The four storm events from Kolhapur watershed were selected to compare the performance of models. The study concludes with, the consistent good results were obtained from GIUH model. As the output from SWAT-CUP in calibration and validation shows large discrepancy in simulated data and observed data so large refinement and more data is required to overcome the errors. Mainly the hourly and sub-daily data is required and rain gauges shall be increased in the numbers to enhance the results.

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