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RAINFALL RUNOFF MODELLING USING ArcSWAT

[1]Premkumara*, [1]Praveen P and [2]Basavareddy

Email

premkumar4032123@gmail.com

[1]College of Agriculture, University of Agricultural Sciences, Mandya, Karnataka- 571401, India

[2]College of Agricultural Engineering, University of Agricultural Sciences, Raichur, Karnataka- 584104, India

Water is a very precious natural resource and at the same time very complex to manage. Therefore, this one-line objective is a mammoth task if this very precious resource has to be managed judiciously. A watershed is a hydrologic unit which produces water as an end product by interaction of precipitation and the land surface. The quantity and quality of water produced by the watershed are an index of amount and intensity of precipitation and the nature of watershed management. As fresh water resources are increasingly strained by agricultural and industrial usage, water conservation has become more and more important. As water demand increases, issues on water availability and demand become critical. This makes the management of water resources (assessing, managing and planning of water resources for sustainable use) a complex task. It has become more critical in places where rainfall is very low and erratic (Sowmiya & Arul, 2017). Land and Water are two important natural resources, as the entire life system depends on it. Effective management of these natural is very much important. The natural resources are mostly managed on the basis of watershed as natural unit. Watershed is a natural hydro geological entity bounded by a ridge line having single outlet. (Gavit et al., 2017)

The hydrological cycle has many interconnected components, with runoff connecting precipitation to bodies of water. Surface runoff is precipitation that does not infiltrate into the soil and runs across the land surface into surface waters (streams, rivers, lakes or other reservoirs). Surface runoff varies by time and location, with about one-third of the precipitation that falls on land turning into runoff; the other two-thirds is evaporated, transpired, or infiltrated into the soil. By returning excess precipitation to the oceans and controlling how much water flows into stream systems, runoff is important in balancing the hydrological cycle. The water balance equation governs the hydrological cycle by describing the flow of water into and out of a system for a specific period of time.(Knightes, 2017)

$$Q_S = P - ET - \Delta SM - \Delta GW$$

Where,

Q_S=surface runoff, P=precipitation, ET=evapotranspiration, ΔSM=change in soil moisture ΔGW=change in groundwater storage

Over the last few decades, a great stride is made on developing physically-based and distributed-parameter hydrological models (e.g., SWAT, SHE, AGNPS, etc.), which are capable of generating area-wise and hydrologic process-wise outputs over a watershed.

ArcSWAT 2012, a physical-based semi-distributed hydrological model having an interface with ArcView GIS software, Among the different kinds of models, semi-distributed models are the most efficient model for hydrological simulation as it exceeds the difficulties normally faced with fully distributed model and lumped model

Out of these models, the Soil and Water Assessment Tool (SWAT) is a continuous daily step, long period, physically based parameter, and distributed hydrologic model has been used widely to simulate agricultural watersheds management practices.

Model Input

ArcSWAT version 1.0.7 was used to prepare the input database for SWAT run.

Inputs:

1) Digital elevation model (DEM)
2) soils
3) land use land cover (LULC)
4) weather data of the study area (precipitation in daily details, solar radiation, maxi-mum and minimum air temperature, wind speed, and relative humidity).

Sensitivity analysis of model: (Khayyun et al., 2019)

For Sensitivity analysis of model 7 to 8 parameters are considered for runoff estimation. They are given below:

i) ALPHA_BF: Base flow alpha factor (days),

ii) CH_K2: Effective hydraulic conductivity in main channel alluvium

iii) CH_N: Manning's roughness coefficient for the main channel,

iv) CN2: Initial SCS runoff curve number for moisture condition II,

v) ESCO: Soil evaporation compensation factor,

vi) GW_DELAY: Groundwater delay time (days).

vii) GWQMN: Threshold depth of water in the shallow aquifer required for return flow to occur (mm H_2O),

Performance Evaluation of The Model

Following is used to evaluate the performance of the SWAT model simulation

1) Nash–Sutcliffe efficiency (ENS)
2) ratio of root-mean-square error (RMSE) to the standard deviation of observed data (STDEVobs), (RSR)
3) percent bias (Pbias)
4) coefficient of determination (R^2) was used for performance evaluation of the model

Nash-Sutcliffe Efficiency (N-S)

- Nash–Sutcliffe efficiency quantifies the variance of observed versus simulated data
- N-S values range between $-\infty$ and 1, where any ENS value greater or equal to zero indicated that the simulated value estimated the constituent of concern better than the mean observed value and an ENS value of one is a perfect simulation. The ENS values were calculated using the following equation:

$$E_{\mathrm{NS}} = 1 - \frac{\sum_{i=1}^{n} \left(O_i - S_i\right)^2}{\sum_{i=1}^{n} \left(O_i - \bar{O}\right)^2}$$

Ratio of Root-Mean-Square Error (RMSE) To the Standard Deviation (RSR)

The ratio of root-mean-square error to the standard deviation is an error index statistic. Where, a perfect simulation will get if the values of RSR equal to zero and any RSR value less than 0.50 indicated an acceptable simulation. The RSR values were calculated using the following equation:

$$\mathrm{RSR} = \frac{\mathrm{RMSE}}{\mathrm{STDEV_{obs}}} = \frac{\sqrt{\sum_{i=1}^{n}(O_i - S_i)^2}}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}}$$

Percent Bias Test

Percent bias test gives an indication about the average tendency of the simulated data to be greater than or less than the observed data.

Where any negative Pbias value indicates that the simulated data are greater than the observed data on average.

any positive Pbias value indicates that the simulated data is less than the observed data on average.

A perfect simulation will get if the Pbias is equal to zero. The Pbias values were calculated using the following equation:

$$P_{\mathrm{bias}} = \frac{\sum_{i=1}^{n}(O_i - S_i)}{\sum_{i=1}^{n} O_i} \times 100$$

Coefficient of Determination R^2

The R^2 describes the proportion of the variance between the measured data and that explained by the model.

Ranges of R^2 extend between 0 and 1, with higher values indicating an improved accuracy of the simulation, and typically values greater than 0.5 are considered acceptable.

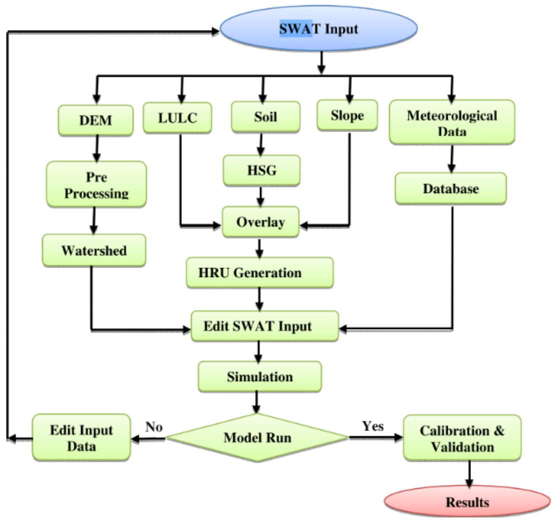
The R^2 values were calculated using the following equation:

$$R^2 = \frac{\left[\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})\right]^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2 \sum_{i=1}^{n}(S_i - \bar{S})^2}$$

General performance ratings for recommended statistics in arc swat (Khayyun et al., 2019)

Performance rating	E_{NS}	RSR	P_{bias} (%)
Very good	$0.75 < E_{NS} \leq 1.00$	$0.00 \leq \mathrm{RSR} \leq 0.50$	$P_{\mathrm{bias}} < \pm 10$
Good	$0.65 < E_{NS} \leq 0.75$	$0.50 < \mathrm{RSR} \leq 0.60$	$\pm 10 \leq P_{\mathrm{bias}} < \pm 15$
Satisfactory	$0.50 < E_{NS} \leq 0.65$	$0.60 < \mathrm{RSR} \leq 0.70$	$\pm 15 \leq P_{\mathrm{bias}} < \pm 25$
Unsatisfactory	$E_{NS} \leq 0.50$	$\mathrm{RSR} > 70$	$P_{\mathrm{bias}} \geq \pm 25$

Methodology flow chart (Gavit *et al.*, 2017)



Conclusion

ArcSWAT is a robust and scientifically sound tool for rainfall–runoff modelling and watershed-scale hydrological assessment. The model effectively represents key hydrological processes and demonstrates strong capability in simulating runoff responses under varying land use, soil, and climatic conditions. When appropriately parameterized, calibrated, and validated using standard statistical performance indicators, ArcSWAT can reliably support watershed management planning, evaluation of water conservation measures, and formulation of sustainable land and water resource management strategies. Its applicability is particularly significant in regions experiencing high rainfall variability and increasing stress on available water resources.

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