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Modelling the Hydrology of Watershed by using HEC-HMS

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Abstract:
Hydrological modelling is a commonly used tool to estimate the basin's hydrological response to precipitation. It also allows to predict the hydrologic response to different watershed management practices and to have a better understanding of the impacts of these practices. HEC-HMS is hydrologic modelling software developed by the US Army Corps of Engineers-Hydrologic Engineering Centre (HEC). It is a physically based semi-distributed model designed to simulate the rainfall-runoff processes in a wide range of geographic areas for scenarios such as large river basin water supply and flood hydrology to small urban and natural watershed runoff. The system encompasses losses, runoff transformation, open channel routing, analysis of meteorological data, rainfall-runoff simulation and parameter estimation. HEC-HMS uses separate models to represent each component of the runoff process, like models that compute runoff volume, models of direct runoff, and models of base flow. Every model run combines a basin model, meteorological model and control specifications with run options to obtain results. The Nash Sutcliffe - model efficiency criterion, percentage error in volume (PEV), the percentage error in peak (PEP) and Net difference of observed and simulated time to peak were usually used for evaluating the model performance. When the model has to be applied to a watershed, the model parameters corresponding to that watershed should be estimated and calibrated. The sensitivity of the model parameters are also determined. Finally, the model validation with a known input-output time series is carried out before testing the model in a particular watershed. A model, calibrated and validated for a watershed, can be used for several design estimation purposes and planning and management functions with regard to the water resources utilization in that watershed.

Keywords: HEC-HMS, Hydrological Model, Watershed, SCS-CN, Parameters, Simulation

1. INTRODUCTION

Water management assumes great significance all over the world in the present time as modern life has put tremend ous pressure on the sustainability of this life supporting and precious resources. Water has undergone severe deterioration in both quantity and quality in the recent past due to unplanned and unscientific human interventions under the guise of development and modernization. Scientific water conservation and its judicious utilization are the need of the hour to protect these lifeline natural resources. Water conservation measures have to be planned on a watershed basis as hydrologic processes can only be analysed and quantified within the watershed boundaries. A thorough understanding of hydrologic processes is an important prerequisite for the planning and management of water resources. As the hydrologic processes are highly complex and heterogeneous, mathematical modeling is a necessity for its abstraction One of the component consists of a hydrologic cycle is the Stream flow. And it is useful for the water resources to sustain not only for human life but also to furnish the needs of industries. To satisfy all these needs from stream flow, analysis and forecast of stream flow is essential. Similarly for to make stable water use and flood control. Hydrological models are the paradigms used for this purposes (Narasayya 2015). The assement of the water resources are necessary in order to frame long term sustainable management strategy for water to comflict this situation. Hydrologic models which comprise integration of key hydrologic processes, those are appropriate tools for such studies however hydrologic modelling which is a simplified representation of the real situation. This is a challenging task particularly for the regions with limited data and hydrologic models should be well calibrated and its performance be evaluated to present reliable result for any study.

Thuthapuzha Sub- Basin is a sixth order basin covering an area of 1018 km^2 and located within the Palakkad and Malappuram districts of Kerala. Thuthapuzha is nearly 63 km in length with an average annual discharge of 1750 MCM. There are four tributaries draining to Thuthapuzha namely Kuntipuzha, Nellipuzha, Kanhirapuzha and Thuppanadpuzha. Apart from the reservoir which is built across Kanhirapuzha that serves as a resource of water for irrigation, there are no other major structures built in the river course. In this background as study on the calibration and evaluation of the watershed simulation model, hydrological modeling system viz, developed by the hydrologic engineering system, US (HEC-HMS) with SCS CN method. It has been carried out for the assement of the rainfall-runoff modelling for the toothapuzha basin. It is also significance mentioning that the HEC-HMS model has been used successfully worldwide by researchers (Choudari et.al (2014), Roy et. al (2013), Rafi et.al (2012), Asadi & Boostani (2013).

2. MATERIALS AND METHODS

Thutha River is one of the main stream of the Bharatha puzha (Nila River), the second longest river on the south west coast of India. Bharathapuzha originates from the Western Ghats and has a total catchment area of 6400 km2 of which about 70% spread in Kerala and the remaining in Tamilndu. Thuthapuzha water shed lies between 10^0 50'to $11^0$15' ' north latitude and 70^0 14'to 76^0 0'East longitude. The watershed has a total area of 1018 sq kms and covers 27 panchayats 6 blocks and two districts.

Thutha River is the main stream which supplies water to Nila River especially during summer. Catchment area at Pulamanthole river gauging station (10^0 53' 50'' N, 76011’50’’E) manned by Central Water Commission, India is 822 km2.

DATA ACQUISITION:

The daily rainfall data and maximum and minimum temperature of the pattambi from 2000-2008 has taken from the RARS pattambi. And also other meteorological data such as wind speed, solar radiation, relative humidity and evaporation for the pattambi has taken from the RARS (Pattambi).The daily discharge data from 1999-2008 for the pulamanthole has collected from the central water commission, Land use data of the study area has procured from the kerala land use board, Trivandrum. Soil resource map has collected from the kerala land use board, thrivandrum.

3. METHODOLOGY:

3.1HEC-HMS model:

The Hydrological modelling system (hec-hms) is designed to simulate the precipitation-runoff processes. It is designed to be applicable in a wide range geographical areas for solving the widest possible range of problems. This includes the large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in shaped with other soft-ware for the studies of water availability, urban drainage flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, flood plain regulation system approach. A model of the watershed constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed outlet.

3.2 PREPARATION OF THE MODEL INPUTS:

For the distributed model average rainfall was calculated using WMS. The SRTM digital elevation data is used to delineate the catchment watershed and generation of stream network. Figure shows the DEM of study area and water flow direction, which is calculated using TOPAZ. Basin processing module of WMS was used for the generation of background map file of the study area which in turn was used as an input to the HEC-HMS model. The other model input like CN of watershed is assumed for calibration purpose. Table 1shows the basic model input which is described earlier.

Table.1. Basic Model Input

Input data	Source of data	Software used
Mean areal rainfall	Field data	WMS
Curve number	assumed	HEC-HMS
Boundary map and drainage network of the study area.	SRTM DEM (Remote sensing)	WMS and HEC-HMS

Intial and optimized parameters of the model:

For simulating the stream flow by the HEC-HMS model SCS transform method was used to compute the direct surface runoff hydrograph, SCS CN number loss method to compute the runoff volumes. Intial abstraction and CN as calibration parameters. These model parameters were estimated using the optimization algorithm available in HEC-HMS. After each parameter correction and corresponding simulation run, the simulated and observed stream flow hydrographs were visually compared.

Model Evaluation: The model evaluation procedure included sensitivity analysis, calibration and validation. The sensitivity analysis of the model was performed to determine the important parameters which are needed to be precisely estimated to make accurate prediction of the basin yield. Thus the model was run with the model input values. The model was calibrated for the identified sensitive parameters for the years 2003 and 2004.the datasets for the 2003 and 2004 were chosen for the calibration. Because these weather conditions in these years were less extreme than in others. The criteria for model evaluation adopted for this involves the following: percentage error in simulated volume (PEV), percentage error in simulated peak (PEP) and net difference of observed and simulated information system. The hydrological modeling time to peak (NDTP) as given below.

$$PEP\text{-} \frac{Q_{po} - Q_{pc}}{Q_{po}} \times 100$$

$$PEV= \frac{Vol_o - vol_c}{vol_o} \times 100$$

$$NDTP= T_{po} - T_{pc}$$

The prediction of overall performance of the model obtained from a study by using Nash-Sutcliffe model efficiency (EFF) criteria:

$$EFF= 1\text{-} \frac{\sum_{i==1}^{n} (Q_{oi} - Q_{ci})^2}{\sum_{i=1}^{n} \left(Q_{oi} - \overline{Q}_o\right)^2} \times 100$$

where Vol_o and Vol_c are the observed and computed runoffvolume, respectively, in cumec, Q_{po} and Q_{pc} are the observed and computed peak discharge, respectively, in cumec; T_{po} and T_{pc} are the time to peak of observed and computed discharge respectively in hours. Q_{oi} and Q_{ci} are the i^{th} ordinate of the observed and computed discharge, respectively, in cumec, and $\overline{Q_O}$ is the mean of the ordinates of observed discharge in cumec. The PEV value measures the deviation between the simulated and the observed volume of stream flow. The NDTP and the PEP values measure the average absolute time lag and the percent deviation between the for estimation of soil simulated and observed peak flows, respectively. The EFF vary from 0-1, which one indicating a perfect fit of the data. According to common practice, simulation results are considered to be good for values of EFF between 0.75&0.36. The simulation results are considered to be satisfactory.

4. RESULTS AND DISCUSSIONS:

4.1 parameter sensitivity:

The sensitivity analysis has carried out and the sensitive parameters have shown in Table1. Here sensitive parameters related to study are Intial abstraction, followed by CN, and followed by lag time and remaining parameters are given in sequence Intial discharge, recession constant, and Muskingum X and K values.

Table.1. Calculated initial and optimized parameters for the watersh

No	parameters			Initial value	Optimized value
1	Initial abstraction	Ia	mm	17.23	13.10
2	Curve number	CN		63.15	65.90
3	lagtime	Tlag	min	18.51	17.90
4	Initial discharge	Q	m^3/sec	0.0774	0.069
5	Recession constant			0.746	0.627
6	Threshold flow	Q	m^3/sec	0.0564	0.055
7	Muskingum	K	hr	0.378	0.292
8	Muskingum	X		0.287	0.301

4.2 Model Calibration And Validation

The goal of calibration is to identify parameter value adjustments so that the simulated results match the observed hydrographs. The mathematical search is a trial and error analysis (optimization trials) that iterates until the simulated measurements: runoff volume, peak flow, time of peak, and time of center of mass, is within an acceptable error range (less than 5%) of the observed hydrograph. By comparing measured discharge from a significant event to the model, the reliability of the model is improved. The calibration of the model has been carried out by suitably modifying the sensitive parameters, within the range suggested by the certainty analysis. It is emphasized here that the calibration effort was very much reduced when the optimum parameter search was limited to the parameters suggested by the sensitivity analysis. calibration was attempted to monthly time series bases. Time series of the observed and simulated based on monthly river flow is shown in fig 4.1, 4.2and their summary statistics in table 4.5. The Nash Sutcliff Efficiency and the coefficient of determination were respectively 0.77-0.83 and 0.88-0.86 for calibration period and validation. Before calibration. It is very much clear that the simulated values closely match with the observed counterparts as revealed by the time series The comparison of monthly average flow for validation period is shown in figures 4.3 to 4.4. Very high NSE of 0.82 and 0.91 and R2 of 0.91 and 0.93 have been obtained for both the calibration and validation period. However, the simulations under estimate the peak values and this under estimation has been reported by other researchers (Chatterjee et.al 2014, roy et.al 2013**)**

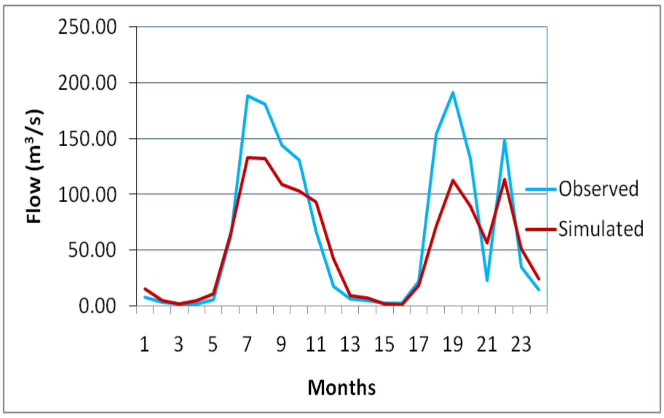

Figure.1. Observed and simulated Flow before Calibration

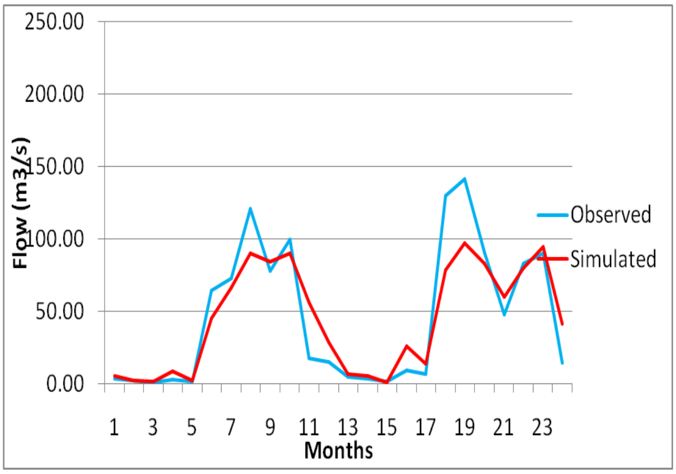

Figure.2. Observed and simulated Flow before Calibration

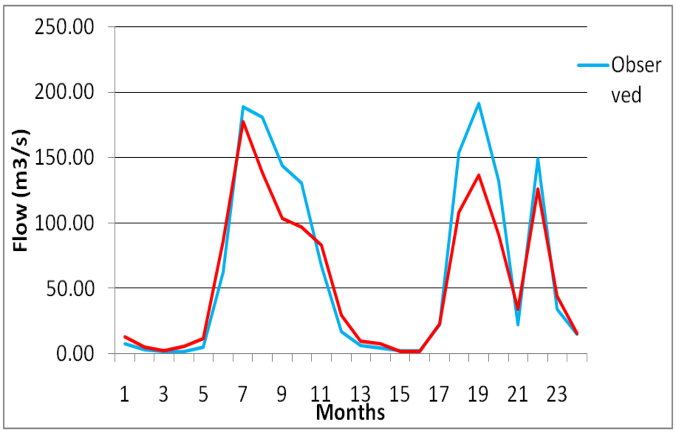

Figure.3. Observed and Simulated Flow after Calibration

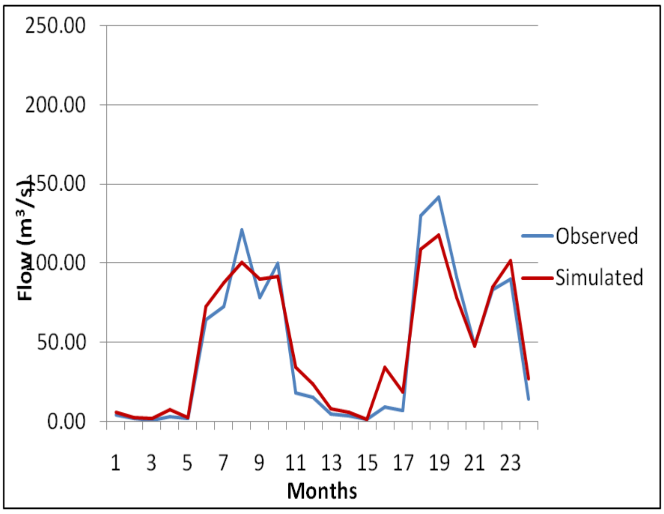

Figure.4. Observed And simulated Flow After Calibration

Table.3. Observed and Simulated Flow before Calibration

			period	
stastic	calibration		validation	
Flow(m^3/sec)	observed	simulated	observed	simulated
mean	64.46	53.16	46.05	44.63
Standard deviation(s)	71.50	46.97	47.84	36.42
Nash suctliff model efficiency(E)		0.77		0.83
Coefficient of determination(R^2)		0.88		0.86

Table.4. Observed and Simulated Flow after Calibration

			period	
static	calibration		validation	
Flow(m^3/sec)	observed	simulated	observed	simulated
mean	64.46	56.34	46.05	48.04
Standard deviation(s)	71.50	54.76	47.84	41.42
Nash sutcliff model efficiency(E)		0.82		0.91
Coefficient of determination(R^2)		0.91		0.93

5. CONCLUSIONS:

- The HEC-HMS model simulation has been calibrated and validated for Thuthapuzha watershed.
- The analysis showed that CN, lagtime are the most sensitive parameters for the simulation of stream flow.
- The Nash-Sutcliffe model efficiency (E) improved to 0.82-0.91from 0.77-0.83 and coefficient of determination (r2) to 0.91 – 0.93 from 0.88-0.86 after the calibration indicating the good performance of the model

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