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Research Article

HYDROLOGICAL MODELING WITH HEC-HMS FOR WAN RESERVOIR CATCHMENT

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Abstract-Hydrological modelling is a mostly used appliance to estimate the basin's hydrological response to precipitation. HEC-HMS model is used to simulate rainfall-runoff modelling for catchment of Wan reservoir, Akola, Maharashtra. To compute runoff, Peak runoff rate, base flow and flow routing methods SCS curve number, Clark unit hydrograph, Recession and Muskingum-Cunge routing methods were chosen, respectively. Rainfall runoff simulation is conducted using 33 rainfall event data. Out of these, 12 events were selected for model calibration, 09 for model validation and remaining 12 for prediction. To judge the performance of model, statistical tests of error functions like Root mean square error (RMSE), Nash Sutcliffe coefficient (R^2_{NS}) and coefficient of residual mass (CRM) were selected. Curve number (CN), Initial abstraction (I_a), Time of concentration (T_c), Initial base flow (Q_o), Recession constant (R_c), and Threshold flow (Q_t) were the model parameters which were fixed as 61.47, 32.20, 10.50, 5.07, 6.38, 1.0 and 0.25, respectively, for catchment of Wan reservoir. The model performed well in terms of RMSE, R^2_{NS}, CRM (1.40 mm day^{-1}, 0.89 and - 0.11). Considering the performance of model in simulating the runoff, it is suggested that the calibrated HEC-HMS model could be used to predict runoff for the rainfall events over catchment of Wan reservoir.

Keywords- DEM, HEC-GeoHMS, HEC-HMS, Hydrologic Modeling, Wan reservoir

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Introduction

"Water is the elixir of life. Without it life is not possible"[1]. An increasing urbanization and per-capita demand, the water demands of domestic, industrial and other sectors are expected to increase and the country will face water scarcity if adequate and sustainable water management initiatives are not implemented. One of the most widely used techniques for estimating direct runoff depths from storm rainfall is the United States Department of Agriculture (USDA) Soil Conservation Service's (SCS) curve number (CN) method. However, it requires a detailed knowledge of several important properties of the watershed which may not be readily available. HEC-HMS is designed to simulate the precipitation runoff processes of watershed systems in a wide range of geographic areas such as large river basins and small urban or natural watersheds. HEC-HMS uses separate models to represent each component of the runoff process including models that compute runoff volume, direct runoff and base flow. Several studies proved the capability of HEC-HMS model in accurately simulating rainfall runoff process in different regions under different soil and climatic conditions. Wan reservoir project is located at village Wan, Taluka Telhara, Distt. Akola on river Wan, a tributary of Purnariver [1-4]. It is multipurpose major project with objective of irrigation, hydroelectricity and drinking water supply. The total length of dam, including spillway is 500 m and height of dam above lowest foundation is 67.65 m. Catchment area of Wan Reservoir is spread over 278.94 km^2. Maximum/Gross storage capacity of Wan Reservoir is 83.465 MCM, while live storage capacity is 81.955 MCM [5-8]. Region to region climate, geography and physical properties of watershed changes and because of it, basin response to the rainfall event accordingly changes. Thus, it has become inevitable to determine rainfall-runoff model and the model parameters for a particular watershed [9,10].

MaterialsandMethods

Wan river, a tributary of Purna River, after entering from Amravati district forms the part of northwest boundary of Akola district of Maharashtra State (India). The basin of wan river is spread over 173.65 km2 in Melghat Tiger Reserve Project in Satpura ranges, Amravati district of Maharashtra State.

Data Collection

R-R model using HEC HMS

The data required to build a HEC-HMS model are elevation, land cover, percent impervious area, soil and hydrography information. These datasets were used to determine stream/subbasin characteristics and hydrologic parameter estimations.

R-R data for basin

Rainfall is recorded at four stations in the basin viz. Wari Bhairavgarh, Wan Road Station, Kelpani and Khatkali.

Topography of basin

The SRTM DEM obtained have a resolution of 1/3 arc-second (approximately 10 m). The DEM clears that there is 544 m elevation difference between the highest and lowest point of basin.

Soils of basin

Spatial soil map (shape file) for basin was obtained from MRSAC, Nagpur.

Land use land cover pattern of basin

The detail spatial 'land use land cover (LULC)' map for basin was also obtained

from MRSAC, Nagpur. LULC map divides the area of basin as dense forest, agriculture, water bodies, built up, wastelands and forest.

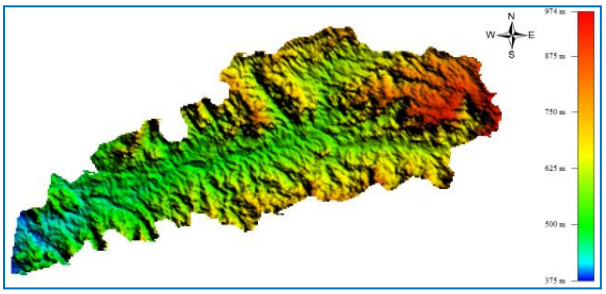

Fig-1 Topography (DEM) of catchment of Wan reservoir.

Pre-processing of Data

'Terrain Processing' menu in HEC-GeoHMS was used to process raw DEM. The steps or processes in terrain processing and watershed delineation are described briefly in following sections.

DEM Reconditioning

To ensure that the true channel is represented and flow is conveyed along the channel, the elevations of cells in the raw DEM that coincide with flow lines contained in the hydrography shape file were artificially lowered. This was done using the 'DEM Reconditioning tool'.

Fill Sink

'Fill Sink' tool was used to fill any potential sinks contained with the raw DEM or created during the reconditioning process. The resulting DEM [Fig-2] is hereafter referred as hydro DEM.

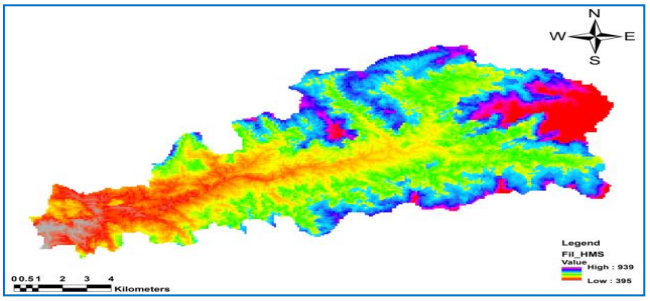

Fig-2 Hydro DEM for catchment of Wan reservoir

Flow Direction

The hydro DEM was used to determine the flow direction within each cell using 'Flow Direction' tool. This tool determines the steepest descent within each cell within the hydro DEM and create a new raster which assigns a flow direction ID for each cell as 1 (east), 2 (southeast), 4 (south), 8 (southwest), 16 (west), 32 (northwest), 64 (north) and 128 (northeast).

Flow Accumulation

A flow accumulation grid was created using 'Flow Accumulation' tool and flow direction grid. The number associated with a cell in the flow accumulation grid represents the total number of cells draining to that specific cell.

Stream Definition

A stream network grid was defined using flow accumulation grid and a user-specified threshold. The threshold defines the flow accumulation needed before a stream is initiated. The 1% default for threshold was used in the 'Stream Definition' tool to create the stream network grid.

Stream Segmentation

A segmented version of the stream network grid was created using the 'Stream Segmentation' tool. This segmented stream network grid creates the initial reaches for the HEC-HMS hydrologic model.

Catchment Grid Delineation

A sub-basin (catchment) grid was created from the flow accumulation grid and segmented stream network grid using 'Catchment Grid Delineation' tool. This creates an initial gridded form of sub-basins for HEC-HMS hydrologic model. Fifty-three sub-basins were created within basin of Wan river basin.

Catchment Polygon Processing

The sub-basin grid was converted to a polygon shape file through the Catchment Polygon Processing tool.

Drainage Line Processing

The drainage line shape file was created within a geo database to comply with ArcGIS structuring and avoid errors.

Watershed Aggregation

The last step before creating a HEC-HMS project within ArcGIS was to combine the upstream subbasins at every stream confluence using the 'Watershed Aggregation' tool

HEC-HMS project setup in HEC-GeoHMS

Basin Processing

This created 53 subbasins within the Wan river basin for use in the final HEC-HMS hydrologic model. The area for all subbasins was recalculated and stored in the subbasin attribute [Fig-2].

Stream and Watershed Characteristics

i) The length of each reach was determined by the 'River Length' tool. The units are taken to be the units of the DEM, which is 'meter' for this study.
ii) 'River Slope' tool calculated river slope by using the upstream and downstream elevation and length of each reach.
iii) The 'Slope' tool finds the slope at each cell, while the 'Basin Slope' tool finds the average slope across a subbasin. The basin slope was used to determine the CN lag time parameter if used in the hydrologic model.
iv) the longest flow paths were created using the 'Interactive Longest Flow Path' tool. Using interactive tool, the approximate upstream location of the longest flow path was selected.

Hydrologic Parameter Estimation

This program assisted in estimating a number of parameters for the loss methods, Muskingun-Cunge and kinematic wave routing parameters, sub-basin time of concentration, and sub-basin lag time.

HEC-HMS Model Setup

HEC-GeoHMS has the ability to set up the model files needed for HEC-HMS.

Basin Model

A basin model in HEC-HMS describes the physical representation of watersheds and river channels [Fig-3].

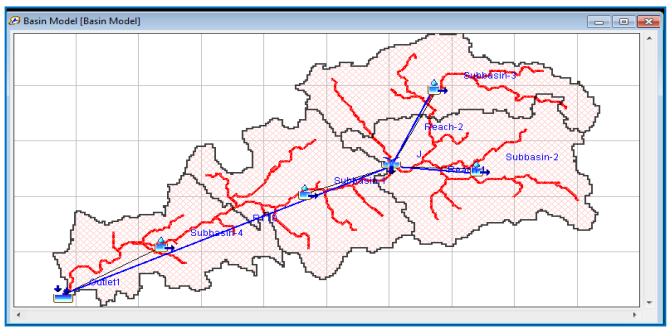

Fig-3 HEC-HMS schematic of Wan river basin

Model calibration and validation

Runoff depths for events *i.e.* 29th June 2013 to 10th July 2013 were used for calibration of HEC-HMS model for entire catchment of Wan reservoir. During calibration the following parameters were adjusted.

i. Curve number (CN),
ii. Initial abstraction (I_a),
iii. Time of concentration (T_c),
iv. Initial base flow (Q_o),
v. Recession constant (R_c), and
vi. Threshold flow (Q_t)

The calibrated model was finally validated using data of two years *i.e.* 02nd August 2013 to 10th August 2013. Here also, the model performance was evaluated by comparing observed and simulated runoff depths.

Performance criteria

To evaluate the performance of model, the simulated data was compared with observed ones. As suggested by ASCE Task Committee [11] on hydrological modelling, Root Mean Square Error (RMSE), Nash-Sutcliffe coefficient and Coefficient of Residual Mass (CRM).

Prediction of runoff

Using validated HEC-HMS model, runoff for catchment of Wan reservoir was predicted for the event 28th August 2013 to 04st September 2013.

Results and Discussion

Calibration and validation of HEC-HMS model for catchment of Wan reservoir

Calibration of HEC- HMS model

To judge the performance of model, observed runoff was compared with simulated output. Temporal variation of observed and simulated runoff is depicted in [Fig-4], while [Fig-5] depicts comparison of observed and simulated runoff over calibration period.

The observed and simulated runoff varied between 00.00 to 81.34 m over calibration period. Value of RMSE, Nash Sutcliffe coefficient (R^2_{NS}) and coefficient of residual mass (CRM) were observed as 1.40 mm day-1, 0.89 and - 0.11, respectively. Model overall slightly overestimated the runoff, as indicated by negative value of CRM. Value of R^2_{NS} close to 1 indicates that the model simulated runoff accurately.

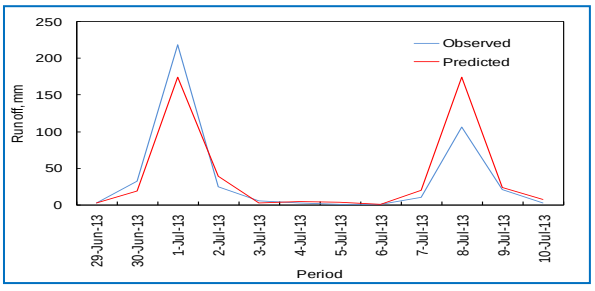

Fig-4 Temporal variation of observed and simulated runoff over calibration period

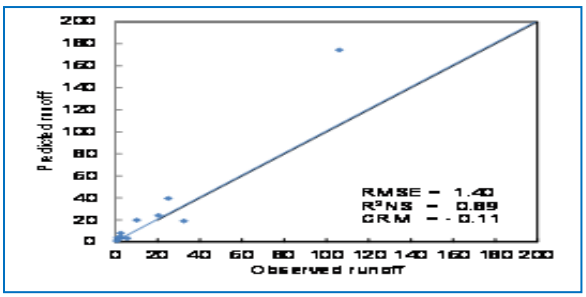

Fig-5 Comparison of observed and simulated runoff over calibration period

[Fig-4] clears that the observed and simulated runoff over calibration period are in close match at outlet of the command. It is seen from scattered plot *i.e.* [Fig-5], that the runoff lie on both sides of 1:1 line, which shows that there is no consistent over or under estimation.

Above results confirmed that the observed and simulated runoff matched well. RMSE, R^2_{NS} and CRM statistics were also acceptable. Hence, the model setup was considered as calibrated

Thus, the model parameters for sub-basin 1, sub-basin 2, sub-basin 3 and sub-basin 4 are presented in [Table-1].

Table-1 *Calibrated model parameters for Sub-basin 1, 2, 3 and 4*

Description	sub-basin 1	Sub-basin 2	sub-basin 3	sub-basin 4
Curve number (CN),	53.78	60.80	62.06	61.47
Initial abstraction (Ia),	19.80	37.00	40.70	32.20
Time of concentration (Tc),	10.54	13.74	18.94	10.50
Storage coefficient	05.28	07.54	08.12	05.07
Initial base flow (Qo),	06.88	04.97	10.81	06.38
Recession constant (Rc),	01.00	01.00	01.00	01.00
Threshold flow (Qt)	00.23	00.25	00.20	00.25

Validation of HEC-HMS model

The observed and simulated runoff varied between 00.00 to 81.34 m over validation period. Value of RMSE, R^2_{NS} and CRM were found as 0.64 mm day^{-1}, 0.91 and -0.44, respectively. As value of CRM are negative, indicating that the simulated runoff was overestimated by the model.

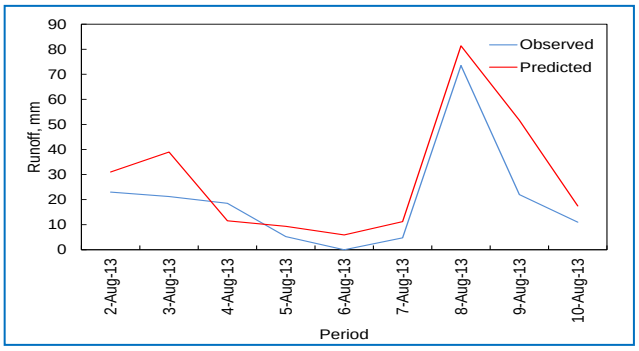

Fig-6 Temporal variation of observed and simulated runoff over validation period

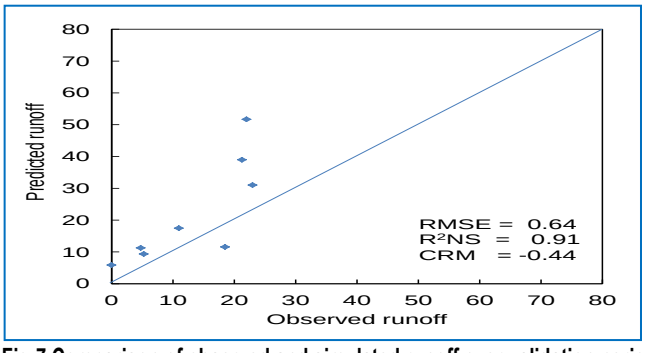

Fig-7 Comparison of observed and simulated runoff over validation period

[Fig-6] clears that the observed and simulated runoff for validation period are in close match. It is seen from [Fig-7] that the runoff lies on both sides of 1:1 line, which shows that there is no consistent over or under estimation over validation period. As RMSE, R^2_{NS} and CRM statistics were acceptable, the HEC-HMS model, as such, was accepted as validated.

Prediction of runoff using validated HEC-HMS model

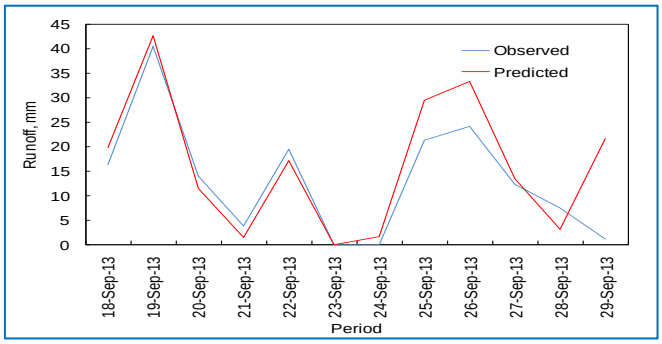

Fig-8 Temporal variation of observed and simulated runoff over prediction period

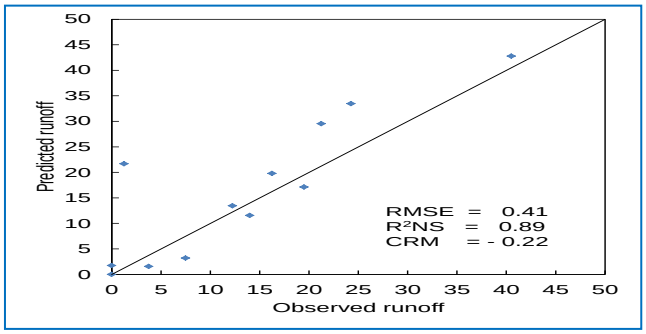

Fig-9 Comparison of observed and simulated runoff over prediction period

[Fig-8] clears that the observed and simulated runoff are in close match over prediction period. It is supported by statistical parameters i.e. RMSE, R^2_{NS} and CRM in acceptable limit.

Conclusions

HEC-HMS model proved its capability in simulating runoff for catchment of Wan reservoir. The calibrated model parameters i.e. Curve number (CN), Initial abstraction (Ia), Time of concentration (Tc), Initial base flow (Qo), Recession constant (Rc), and Threshold flow (Qt) were observed as 61.47, 32.20, 10.50, 05.07, 06.38, 01.00 and 00.25, respectively, for catchment of Wan reservoir.

Considering the performance of model in simulating the runoff, it is suggested that calibrated HEC-HMS model could be used to predict runoff for the rainfall events over catchment of Wan reservoir.

Conflict of Interest: None declared

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