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Estimation of Infiltration Parameter for Tehri Garhwal Catchment

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Abstract

The rate of infiltration is the maximum velocity at which water enters the soil surface. When the soil is in good condition or has good soil health, it has stable structure and continuous pores to the surface. This allows water from rainfall to enter unimpeded throughout a rainfall event. Soils that have reduced infiltration can become saturated at the surface during rainfall. Saturation decreases soil strength, increases detachment of particles, and enhances the erosion potential. Proper management of the soil can help maximize infiltration and capture as much water as allowed by a specific soil type.

There are numerous techniques available for the estimation of water infiltration rate. In this project we have used SCS Curve number method as it requires only one parameter for the estimation infiltration characteristics of the watershed, based on the land use property and soil property. An inverse model is formulated using HEC-HMS for obtaining the infiltration parameters from the historically recorded rainfall and runoff data. Optimization of different parameters is also done to find out the best value which shows minimum variation between observed and simulated runoff at outlet. In this study, rainfall-runoff modelling was carried out using HEC-HMS and GIS (geographical information system) techniques. A map was obtained from the SRTM (Shuttle Radar Topography Mission) site perform the Digital Elevation Model (DEM). Topographic ParameteriZation (TOPAZ) computer program was run to create the flow directions and flow accumulation files which were used later to delineate the basin boundary and the stream networks. Daily rainfall data was analyzed for the years 1992 to 2009 in addition to daily runoff data from the outlet point (Tehri Dam) for the same years. The daily flow data from the outlet point were used to create the runoff hydrographs for the calibration and validation purposes. HEC-HMS model was used to simulate the rainfall-runoff process. Bhagirathi watershed was chosen as a study area in this study. The present study is first of its kind in the Bhagirathi watershed.

Keywords: Model, HEC-HMS, rainfall, runoff, catchment.

Introduction

The curve number method of the Natural Resources Conservation Service (formerly Soil Conservation Service) has been the foundation of the hydrology

algorithms in most simulation models developed by the U.S. Department of Agriculture for hydrology, soil erosion, and nonpoint source water quality. The use of curve number in this manner, however, is beset with a number of problems, issues, and misinterpretations that undermine its utility in providing a realistic and accurate representation of the water flow amounts, paths, and source areas upon which erosion and water quality predictions depend. Curve Number model containing two parameters – the curve number and the initial abstraction. As typically used, however, the initial abstraction is made to be a function of the curve number, so in reality, it is a one parameter model. The reasons for the use of curve number include its simplicity, ease of use, widespread acceptance, and the significant infrastructure and institutional momentum.

Curve Number (CN) method is also a widely used method for estimating infiltration characteristics of the watershed, based on the land use property and soil property. Cowan (1975) stated that the SCS CN method is comfortably used for estimation of runoff in a watershed where soils, vegetation and other characteristics affecting runoff have not been evaluated experimentally. Proper estimation of CN or infiltration parameters is necessary for estimation of runoff from rainfall data. Therefore, one of the objectives of the study is the estimation of infiltration parameters or curve number of the basin. An inverse model is formulated using WMS (Watershed Modelling System) and HEC-HMS for obtaining the infiltration parameters or curve number from the historically recorded rainfall and runoff data. Optimization of different parameters is also done to find out the best value which shows minimum variation between observed and simulated runoff at outlet. In this study, rainfall-runoff modelling was carried out using HEC-HMS and GIS (Geographical Information System) techniques.

The Bhagirathi watershed was chosen as a study area in this study because it is first of its kind study in the Bhagirathi watershed. The HEC-HMS and WMS hydrologic models, used in the study are physically based. The HEC-HMS model is designed to simulate rainfall-runoff processes of networked watershed systems which include sub-basins, reaches, junctions, reservoirs, diversions, sources, and sinks.

So, the prime objectives of our study are:-

(i) Estimation of infiltration parameters or curve number of the Tehri Garhwal catchment.

(ii) An inverse model is formulated using WMS (Watershed Modelling System) and HEC-HMS for obtaining the infiltration parameters or curve number from the historically recorded rainfall and runoff data.

(iii) Optimization of different parameters is also done to find out the best value which shows minimum variation between observed and simulated runoff at outlet.

Methodology

The study is conducted in a 3796 km^2 sub-tropical watershed located in northern part of India in Uttarakhand state,

between $30^0$30' to 30^0 53' North and 77^0 56' to 79^0 04' East. Tehri Garhwal is one of the mountainous districts of Uttarakhand State. The climate in Tehri Garhwal district varies

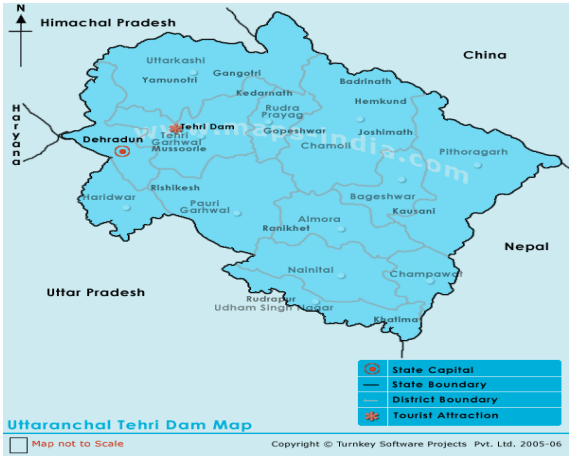


Fig 1 STUDY AREA (TEHRI GARHWAL)

from cold temperate, tropical to sub-tropical. The mean relative humidity is 60.5%, while the minimum and maximum temperatures are 14.8^0C and 29.3^0C respectively. The average annual rainfall is 1395mm. The average daily wind speed is 2.3 km/hr.

Data acquisition

The data used in this study are:-

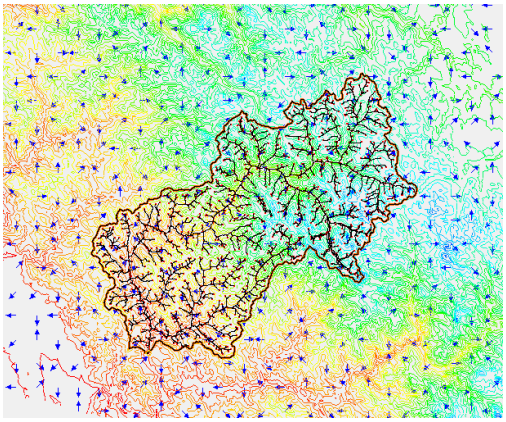
1. Daily rainfall data of Tehri Garhwal catchment for the 18-year period (1992–2009).
2. Daily discharge data of the watershed at main outlet (Tehri Dam) for the 18- year period (1992–2009).
3. Digital Elevation Model (DEM) of the Bhagirathi River basin was acquired from the SRTM Site.

Preparation of model inputs

The rainfall record for Tehri Garhwal Catchment was available. For the lumped 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 2.3 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 inturn was used as an input to the HEC-HMS model. The other model input like CN of watershed is assumed for calibration purpose. Table 2.2 shows 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 Networks Of Study Area	SRTM DEM (Remote Sensing)	WMS and HEC-HMS



HEC-HMS: An Introduction

The Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes 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 conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation and systems operation. The program is a generalized modeling system capable of representing many different watersheds. A model of the watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed of interest.

Calibration and Validation of the Models

HEC-HMS watershed model were calibrated using daily rainfall data (January to December) and stream flow data of 18 years (Jan.1992–Dec.2009). The objective of the model calibration was to match simulated volumes, peaks, and timing of

Table 2 Initial and optimized parameters of the lump approach.

hydrographs with the observed ones. For simulating stream flow by the HEC-HMS model, the SCS unit hydrograph transform method was used to compute direct surface runoff hydrographs, the SCS curve number loss method to compute runoff volumes. Initial abstraction (Ia) and Curve Number as HEC-HMS calibration parameter. These model parameters were estimated using the optimization algorithm available in HEC-HMS. After each parameter adjustment and corresponding simulation run, the simulated and observed stream flow hydrographs were visually compared

Calibration results of HEC-HMS

The rainfall runoff data recorded in the Bhagirathi catchment have been used to calibrate and validate the developed model. The geomorphologic information of the catchment has been extracted from the SRTM digital elevation data. Table 5.1 shows the initial and optimized parameters of the lump approach. It is clear from the table that the values of the calibrated parameters for the model vary. These parameters have been optimized using the optimization tools available in HEC-HMS, as discussed earlier. The variation in Ia values is attributed to the variation in antecedent moisture condition (AMC) over the years and the variation in SCS lag time

is attributed to the varying observed stream flow over the years.

Performance evaluation using graphical indicator

A comparison of the observed stream flow hydrograph with the simulated one by

Element	Parameter	Units	Initial value	Optimized Value	Objective Function Sensitivity
1B	Curve Number		65	35.100	0.01
1B	Initial Abstraction	IN	10	15.150	0.00
1B	SCS Lag	MIN	400	400	0.00
All Sub-basins	Curve Number Scale Factor		1.00	0.19763	0.01
All Sub-basins	Initial Abstraction Scale Factor		1.00	3.3919	0.00

HEC-HMS as Lumped modelling approach is shown in Fig 1. It is apparent from these figures that although there is a similar trend between the observed and simulated stream flow hydrographs, the peaks of the two hydrographs do not match reasonably at lean period of rainfall and for high peak. As discussed earlier that an objective functions is a mathematical tool to measure the goodness of fit between the observed and generated hydrographs. To find the lowest objective function value and optimum parameter values are the main objectives behind our optimization trial. The Univariate gradient method computes and adjusts one parameter at a time while locking the other parameters. Alternatively, the Nelder and Mead method valuates all parameters simultaneously and determines which parameter to adjust. The search algorithms are also known as optimization methods.

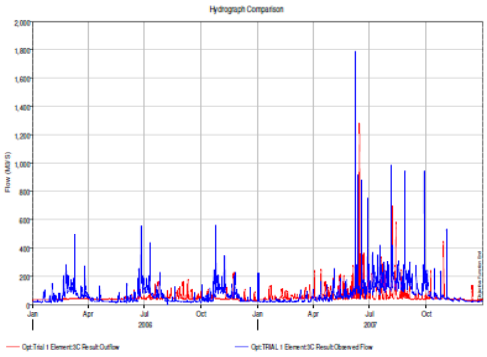


Fig 2 Hydrograph comparison between Outflow and Observed flow

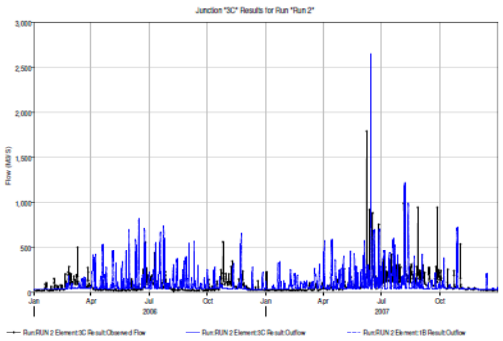


Fig 3 Observed vs Simulated Hydrograph of Tehri Garhwal catchment

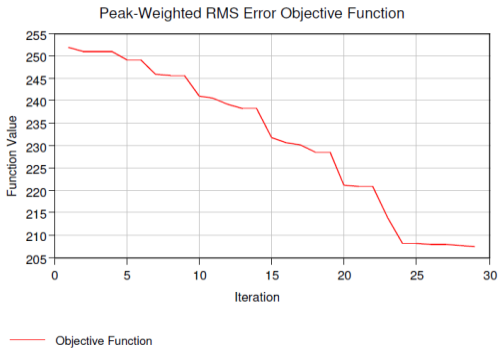


Fig 4 Peak-Weighted RMS Error Objective Function.

The required precipitation and stream flow data were collected for 18 years (1992–2009), together with the topographic maps,

and DEM images Of the study area. The input file for the proposed hydrologic models was prepared using Remote Sensing, GIS techniques and WMS (Watershed Modelling System).

For simulating stream flow by the HEC-HMS model, the SCS unit hydrograph transform method was used to compute direct surface runoff hydrographs, the SCS curve number loss method to compute runoff volumes. Lumped modelling was simulated and validated using the rainfall stream flow data of Jan 1992 to Dec 2009, and rainfall-stream flow data of 2008 respectively. Based on the analysis of the results obtained in this study, the following conclusions could be drawn:

1. Based on the graphical indicators used in this study, it was found that the HEC-HMS Lumped approach simulated daily stream flow is satisfactory method for simulation and optimization.

2. Although there is a reasonably good matching between observed and simulated stream flow hydrographs for HEC-HMS Lumped modelling approach, the hydrographs do not match well for lean period of rainfall season and for high peak. The main reason behind that was the present watershed has great influence of snowfall. In this study, since we are not considering the snowfall effect, so the peak hydrograph (observed) is not exactly matching with simulating one.

3. The main objective of our study is to estimate the infiltration parameter i.e. CN, was found to be **35.10** after optimization. As per Universal CN table (Appendix B), the present area is under good hydrological condition i.e. high plantation and mountains which is matched actual one.

4. Overall, it is concluded that the HEC-HMS model is reliable for estimating infiltration parameters and for simulating daily stream flow in the Bhagirathi River basin of North- India. Therefore, the use of HEC-HMS model may be used for future studies on hydrological modelling in this basin.

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