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APPLICABILITY OF HEC-HMS TOOL TO WESTERN GHATS - NETHRAVATHI RIVER BASIN

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Abstract: Hydrologic simulation employing computer models has advanced, and computerized models that have become essential tool for understanding human influences on river flows and designing ecologically sustainable water management approaches. The HEC-HMS is a reliable model developed by the US Army Corps of Engineers (1998) that could be used for many hydrological simulations. The model parameter estimation on a regional scale is possible and this enables the hydrology community to switch over to watershed models like HEC-HMS (the Snyder unit hydrograph method and the Clark unit hydrograph method) and take advantage of such high speed computer programs instead of sticking to the traditional spreadsheet exercises. With this in view, this study has been undertaken to make a comparative study of hydrological models available for Western Ghats and the solution generated by HEC-HMS.HEC-HMS model is able to simulate precipitation-runoff and routing processes in both natural and controlled environment. HEC-HMS is a relatively simple conceptual model and has successfully been implemented worldwide by many researchers. It is good for simulation of peak flow as compared to Revitalised Flood Hydrograph (REFH) model because of semi-distributed modelling concept.
Keywords: HEC-HMS, Peak flow, REFH, Hydrograph, GUI, WMO (WORLD METEOROLOGICAL ORGANISATION) ETC.

1. Introduction

The rainfall - runoff model is one of the most frequently used events in hydrology. It determines the runoff signal which leaves the watershed from the rainfall signal received by the basin. Numerous methods have been developed by different researches to simulate the rainfall runoff process. Although a variety of rainfall runoff models are available, selection of a suitable rainfall runoff model for a given watershed is essential to ensure efficient planning and management of watersheds. It is GUI-based user friendly model available in the public domain and has been a useful tool for the hydrologists across the globe. With this in view, this study has been undertaken to make a comparative study of hydrological models available for Western Ghats and the solution generated by HEC-HMS.

2. Hydro Meteorological Description of Western Ghats

The Western Ghats are a series of hill ranges bordering the west coast of India almost throughout its length. The Western Ghats mountains extend 8° 19' 8" - 21° 16' 24" N and 72° 56' 24" - 78° 19' 40" E and encompass an area of approximately 1,29,000 km^2, in the states of Kerala, Tamil Nadu, Karnataka, Goa, Maharashtra and Gujarat (WGEEP, 2011). They run almost parallel to the coast and have a 1600 km long north-south orientation, width ranging from 48km – 210km. The Western Ghats supports 245 million people with water for drinking, transport, irrigation and hydroelectric power, together with food and resources to sustain livelihoods (WGEEP,2011).

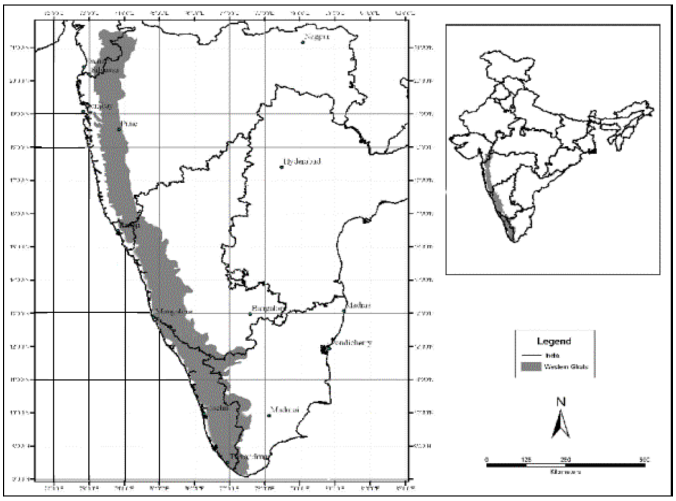

Figure-2.0: Location of Western Ghats in India Map

2.1 Physical Settings: Physiography, Geology and the Soils

Sahyadri ranges forms the most important topographic feature of South India. They consist of mountain ranges with an average elevation of 1000m. The Palakkad gap is a major discontinuity in the Sahyadri ranges extending about 30 km with an average elevation of 200m. The hills do not raise much beyond 1500 m in the northern tract, while in the south they tend to be rounded and rise even beyond 2000 m.

Geologically, the Sahyadris are a stable mark of Archaean and Pre-Cambrian formations, where the mountain building has ceased in the Pre-Cambrian times. Most of the exposed Gneisses of the Sahyadris are 2,500 million years old. The non-metamorphic sedimentary formations are very rare and found only along the coastal belt (WGEEP, 2011) in north.

An astonishing feature of the Sahyadris is their soil mantle, which is very thick, highly well drained and very stable. There are seven main soil groups found in the region, viz. laterites (high and low), red loam, medium black soils, hill soils, red gravelly soils and alluvial soils including coastal alluvium, mixed red and black soils. Experimental studies in the heavy rainfall zones of the district of Kodagu have revealed (Putty and Prasad, 2000b) that subsurface flow in the region is essentially through pipes. Even though preliminary investigations (Putty and Prasad, 2000b) have revealed that pipe flow response is slow and is of great significance during long duration low intensity rain.

2.2 Land Use and Land Cover

The Western Ghats have a natural cover of evergreen forests, which changes to moist and then dry deciduous types as one comes to the eastern slopes. The forests cover approximately 20 percent of the total area of the Sahyadris. The majority of the area under moist forest types falls within the southern states of Kerala and Karnataka. Together they account for 80 percent of the evergreen forest and 66 percent of the moist deciduous forests in the Western Ghats (IIRS, 2002). The entire Western Ghats has now been declared as an Ecologically Sensitive Area. It is estimated that not more than about 7% of the area of the Western Ghats is presently under primary vegetation cover, though a much larger area is under secondary forest or some form of tree cover (WGEEP, 2011) A number of horticultural and tuber crops such as tea, coffee, rubber, cashew, tapioca and potato were introduced to this region through European influence. Pepper and cardamom, which are native to the evergreen forests of the Sahyadris, were also taken up as plantation crops on a more extensive scale in the modern times.

2.3 Rainfall and the Climate

Western Ghats lies in the tropical South Asian monsoon tract characterised by wet summers and dry winters. The climate in general is hot and humid tropical. Mean temperature ranges between 20 and 240 C. The rainfall in the region is due to orographic lifting of S.W. Monsoon winds, than due to convective activities. Since the Sahyadri ranges are close to the coast and run nearly normal to the direction of the motion of moisture ladden air from the vast Indian Ocean, rainfall in the region is very heavy, and a major portion of the Ghats falls under the 'wet' category of climate classification (Strahler and Strahler, 1992). According to WMO (1984), the complete region comes under the meteorological division 'humid tropics, with no cyclonic activity'. July is the rainiest month, the second fortnight of June and the first of August together accounting for an equal amount. Throughout the length of the Ghats and the coast, daily intensities are very high, with rainfall exceeding 25 cm a day being quite a common feature in areas with NARF above 500 cm. Even in areas with NARF less than 200 cm, falls exceeding 10 cm contribute about 25 % of the annual value.

2.4 Stream flow and Catchment Response

Studies concerning the response of the catchments to rainfall have been carried out in experimental watersheds near Talakaveri and the results has been found that steep rising limbs, multiple peaks and insignificant base flow characterize the hydrographs of upland lower order streams draining predominantly grassed catchments (Putty and Prasad 2000b).

2.5 Catchment Geomorphology

The Geomorphologic parameters of the channel network in eight basins in the region and in many smaller catchments within these are measured by Reddy (1997) and Nirmala (1999) and their studies have established that the Stream Frequencies (Fs) and the Drainage Densities (Dd) in the region are low. Values of Dd measured in the Sahyadris are only characteristic of flat humid regions with rainfall around 1200 mm (Sclby, 1968). Also it is observed that Dd for areas in Meghalaya, with rainfall amounts similar to those in Sahyadris, range between 6 and 18, whereas Dd for Sahyadris range between 3 and 6.

3. Study of Models Available / Used for Western Ghats

A model is a representation of the reality, built in order to study and understand the behaviour of the prototype. Figure 3.0 represents the different classification of model

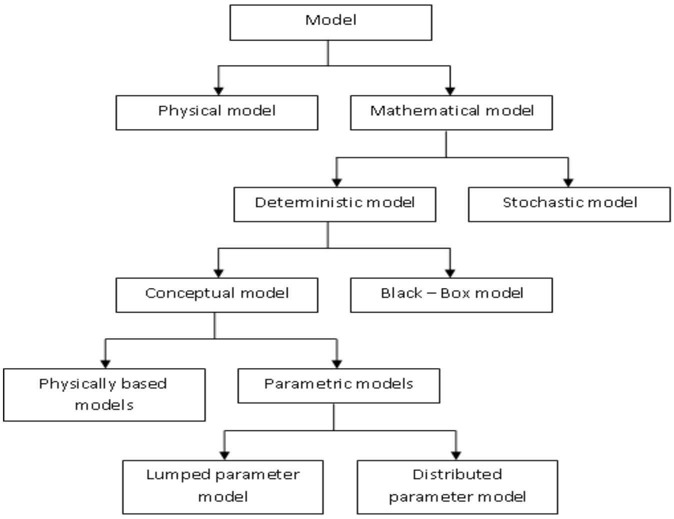

Figure – 3.0: Classification of model

3.1 Salient features of selected models

3.1.1 Model Name – SAHYADRI

- Type - Lumped Parameter Conceptual model.
- Basin - Nethravathi Basin
- Area (sq km) - 3000
- Type of soil - Sandy loams characterised by very high infiltration rates
- Input – Rainfall
- Output –Runoff
- Number of Parameters -11
- Method of Optimisation - Trial & Error

- Temporal extent of modelling -1981 to 1985
- Developed By - Putty and Prasad, 2000

3.1.2 Model Name - MODCUR-PQR
- Type – Lumped Parameter Conceptual model
- Basin – Nethravathi Basin
- Area (sq km) –3000
- Type of soil – Sandy loam
- Input **–**Rainfall
- Output –Runoff
- Number of Parameters –6
- Method of Optimisation - Trial & Error
- Temporal extent of modelling – 1981 to 1985
- Developed By - Harish et. al., 1996

3.1.3 Model Name - NITK MODEL
- Type – Conceptual model
- Basin – YenneHole Basin
- Area (sq km) –327
- Type of soil –Laterites towards coast and red loamy soils on hill slopes.
- Input **–**Rainfall
- Output –Runoff
- Number of Parameters –6
- Method of Optimisation –GIS Tools
- Temporal extent of modelling –1993 to 1998
- Developed By - Nandagiri et. al., 2004

4.0 HEC-HMS Tool and Its Salient Features

HEC-HMS is the US Army Corps of Engineers' Hydrologic Modelling System computer of HEC-1. Program developed by the Hydrologic Engineering Centre (HEC). The program simulates precipitation-runoff and routing processes, both natural and controlled. HEC-HMS is the successor to and replacement for HEC's HEC-1 program (USACE, 1998) and for various specialized versions. It is designed to be applicable in a wide range of geographic area for solving the widest possible range of problems; the range includes large river basin water supply 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 urbanisation impact, reservoir spillway design, flood damage reduction, flood plain regulation, flood-loss reduction studies, environmental studies, reservoir design studies and systems operation (Charley et al. 1995).

4.1 HEC-HMS Features

HEC-HMS project requires three input data components: a Basin Model, a Meteorological Model, and Control Specifications. Data entry can be performed for individual basin elements such as sub-basins and stream reaches or simultaneously for entire classes of similar elements. Parameter Optimisation is an optional component and can be performed to meet the necessity of the project. Output of the project will be in the form of Summary Tables, Graph and Time Series.

4.1.1 Control Specifications

The control specification defines time-related information for simulation. It includes starting and ending dates and the time interval for computations.

4.1.2 Parameter Optimisation

Optimisation is the selection of a best element from some set of available alternatives. Calibration uses observed hydro meteorological data in a systematic search for parameters that yield the best fit of the computed results to the observed runoff.

Four types of objective function offered by HEC-HMS are as follows:

1. Sum of absolute errors
2. Sum of squared residuals
3. Percent error in peak
4. Peak-weighted root mean square error

Trial parameters are selected, the models are exercised, and the error is computed. If the error is unacceptable, HEC-HMS changes the trial parameters and reiterates.

4.2 Limitations

A few limitations of HEC – HMS program are listed below:

1) The program is not stochastic i.e., all methods included in the program use deterministic techniques where the parameter values are fixed and is the same for every simulation.

2) The program assumes that evaporation and infiltration processes are not coupled. But in the real world, evaporation depends on the amount of water in the soil and amount of infiltration depends upon moisture content of soil which is related to the amount of water removed by evaporation. Hence we can say that evaporation and infiltration are coupled.

3) All the ground water interactions in the program should be considered as “shallow subsurface” or “interflow” processes and are usually confined to the top 2 – 3 meters of the soil column.

4) All parameter values are taken as constant in time, even for long simulations.

5) The program is not designed to work with looped or braided systems.

6) All computations are carried out from the headwaters to the outlet. It is not possible for upstream calculations to have any knowledge of downstream conditions so the effects of backwater cannot generally be included.

4.3 Applicability of HEC-HMS software to Western Ghats

The software is very adaptable because it includes a variety of model choices for each segment of the hydrologic cycle. It has been used in many studies for achieving goals in flood damage reduction, reservoir and system operation, floodplain regulation, environmental restoration, water supply planning etc., In the un-gauged case like Western Ghats, it is generally accepted that physically based Models are a better choice. Several physically-based simulation components have been included in the software. The design of this software system has been done is such a way that appropriate process models can be selected, including the possibility that certain processes would not be included at all.

It was recognized that only minimal effort can be invested in collecting data and constructing simulation models at the early phase, due to the large number of options under consideration. In the later phase more detailed models should be used in order to develop accurate estimates of economic and environmental variables. The final phase usually includes detailed study in order to have sufficient information to complete a good design. In this view, HEC-HMS software provides process models that range from simple to detailed. While the simple models would be quick and easy to implement in a screening study, more detailed models can be included for use in design studies. By observing the data available for Western Ghats and the methods present in the HEC-HMS software, it may be applicable for Western Ghats region.

5.0 Case Study of Nethravathi River Basin

The Nethravathi River originates at Gangamoola near the village Samse in the Chikamagaluru district of the state of Karnataka. It has latitude of 75°33’ and longitude of 76°38’ peaks with elevation of about 2000m high. The total area of the river is about 3184 km2 and area up to Buntwala, where the gauging station is located is about 3000 km2. Total length of the river is about 103 km and breadth about 200m. The river basin consists of 11 sub-basins viz., Kumaradhara, Gundya, Mundaja, Yettinahole, Kallajehole, and Gowrihole, Kadumane hole, Belthangadi hole, Charmadi hole, Aniyur hole and Shisla hole. The Nethravathi river basin is shown in figure 5.0.

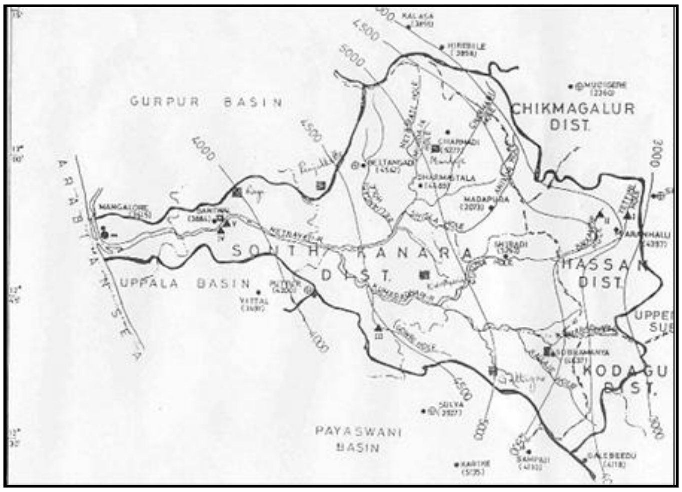

Figure – 5.0: Map of Nethravathi river basin

5.1 Data Availability

- Daily Rainfall data of five years (1981-1985),
- Daily Runoff (observed) data of five years (1981-1985),
- DEM of Nethravathi catchment and
- LULC of Nethravathi catchment**.**

5.2 Description of methods used in HEC-HMS software

Entire catchment of Nethravathi basin is sub-divided into four sub-basins shown in figure 5.1 using Arc-GIS software tools for analysis of rainfall-runoff simulation. Based on the data availability, methods have been chosen for loss method; transform method and routing analysis of simulation process

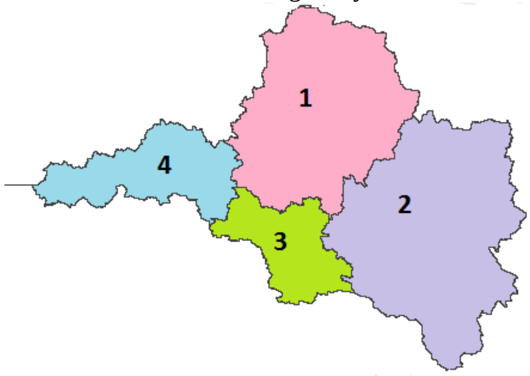

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Figure - 5.1: Map of sub-catchments of Nethravathi basin

5.3 Analysis carried without routing

Analysis is carried out for five reference years (1981- 1985). Figure 5.2 represents the input basin model map. Required input data has been tabulated in table 5.3.0 according to the methods chosen. A rain gauge of depth 300mm along with the rainfall values has been given as input to the meteorological model. A gauge weight of 0.85 for rainfall, 0.15 for rain gauge and a time weight of 1 for rain gauge is adopted. Simulation run is carried for the given input data and optimisation trial is carried based on the simulation run. Peak weighted RMS error method is chosen in Univariate gradient search algorithm for optimising the values of CN and SCS lag. Three years data i.e. from 1981-1983 is used as calibration period and the data of monsoon months for the year 1984 and 1985 is used for validation.

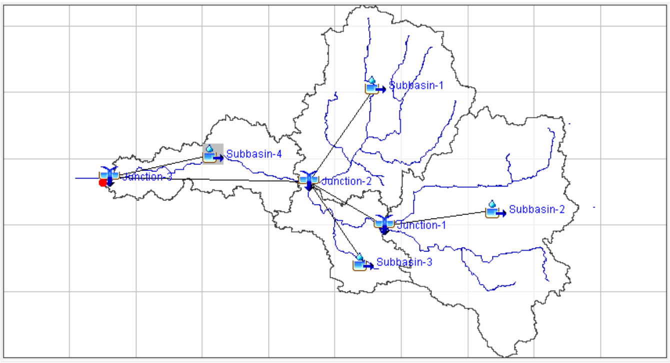

Figure – 5.2: Input Basin Model Map

Elements	**Drainage Area (km2)**	**Initial abstraction (mm)**	**Curve Number**	**Lag time (Min)**	**Downstream**
Sub-basin 1	1144.36	33.86	60	8300	Junction 2
Sub-basin 2	1425.36	33.86	60	8500	Junction 1
Sub-basin 3	375.18	33.86	60	7200	Junction 2
Sub-basin 4	494.73	33.86	60	6000	Junction 3
Junction 1	-	-	-	-	Junction 2
Junction 2	-	-	-	-	Junction 3
Junction 3	-	-	-	-	Outlet point

Table – 5.3.0: Input data given for various elements

5.3.1 Results of analysis carried without routing

Optimised values of CN and SCS lag time is tabulated in table-5.3.1. Summary and hydrographs of outlet point i.e. at junction-3 of validation period is shown in following figures. Result of validation is tabulated in table 5.0.

Elements	**Parameter**	**Unit**	**Initial value**	**Optimised value**	**Objective function sensitivity**
Subbasin-1	**Curve Number**	**-**	**60**	**61.42**	**0**
Subbasin-2	**Curve Number**	**-**	**60**	**59.628**	**0.02**

Subbasin-3	**Curve Number**	**-**	**60**	**61.158**	**0**
Subbasin-4	**Curve Number**	**-**	**60**	**61.149**	**0**
Subbasin-1	**SCS Lag**	**MIN**	**8300**	**1071.1**	**0.08**
Subbasin-2	**SCS Lag**	**MIN**	**8500**	**2468.1**	**0.07**
Subbasin-3	**SCS Lag**	**MIN**	**7200**	**929.19**	**0.02**
Subbasin-4	**SCS Lag**	**MIN**	**6000**	**526.75**	**0**

Table – 5.3.1: Optimised values for the analysis carried without routing

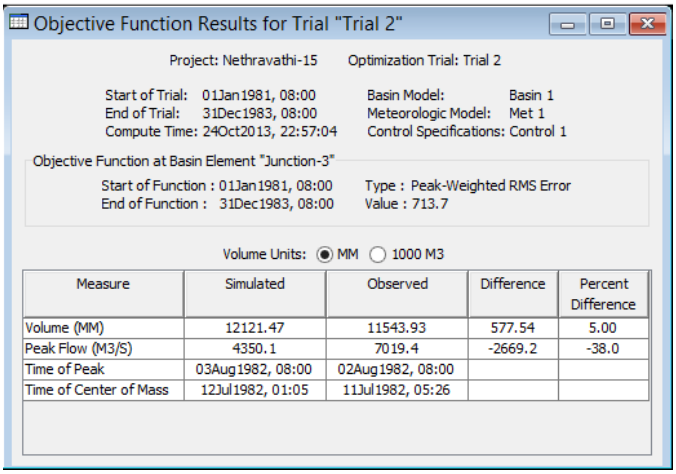

Figure – 5.3.2: Summary of results for the year 1985

Year	Simulated flow (mm)	Observed flow (mm)	Difference	Percent Difference
1984	**3117.68**	**3227.9**	**110.22**	**3.41**
1985	**2724.87**	**2806.9**	**82.03**	**2.92**

Table – 5.3.3: Validation results

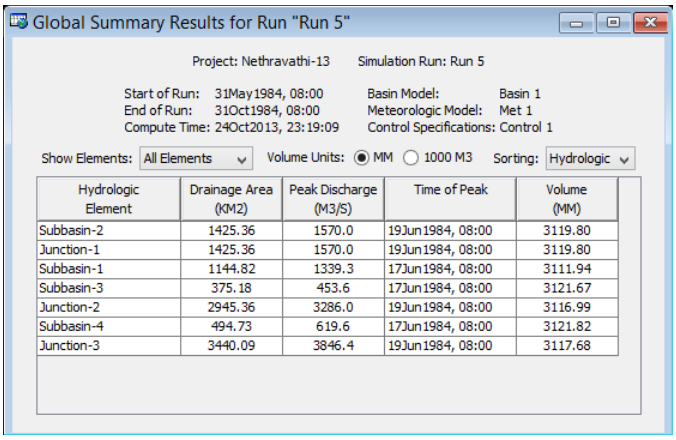

Figure – 5.3.4: Summary of results for the year 1984

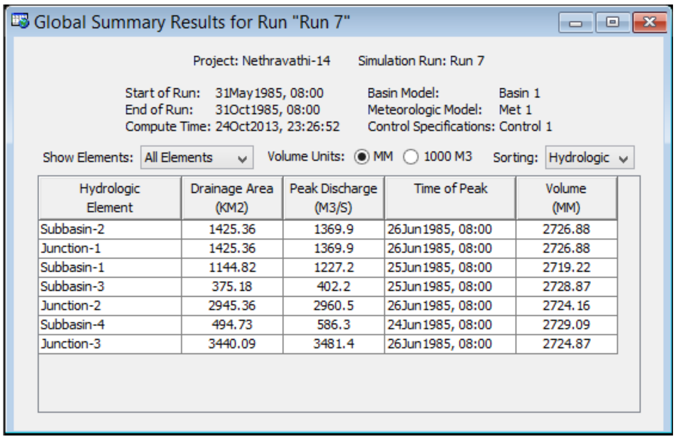

Figure – 5.3.5: Summary of results for the year 1985

6.0 Results

A comparison is made for the results obtained from the HEC-HMS software with the results of SAHYADRI model and MODCUR-PQR model for the same temporal extent by applying the optimised values**.**

Temporal Extent (years)	Observed Flow	HEC-HMS	Sahyadri model	MODCUR-PQR Model
	Flow(mm)			
1981	4452.7	4295.3 (3.53%)	4155.4 (6.67%)	4400.7 (0.92%)
1982	3224.3	3280.08 (1.7%)	2982.9 (7.49%)	3212.7 (0.35%)
1983	3322.7	3297.43 (0.76%)	3025.7 (6.26%)	3242.6 (2.41%)
1984	3227.9	3117.68 (3.41%)	2840.3 (12%)	3078.9 (4.62%)
1985	2806.9	2724.87 (2.92%)	2360 (15.92%)	2597.4 (0.92%)

Table-6.0: Comparison of estimated runoff with observed runoff The conclusions drawn from the results are:

1) Optimisation of CN value is carried out by varying the CN value between 35 and 95 and it is observed that there's a difference between observed flow and estimated flow by 5%.
2) Validation is done for two years and it is observed that observed flow and estimated flow differs by 3.41% and 2.92%.
3) Applying optimised values, results of reference years are compared with SAHYADRI model and MODCUR-PQR model. It is observed that values obtained using HEC-HMS tool are within 4% difference with observed flow.
4) It is observed that results are in acceptable limits for the condition of without routing.

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