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APPLICATION OF HEC-HMS MODEL FOR RUNOFF SIMULATION: A CASE STUDY OF KANKAI RIVER BASIN IN NEPAL

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ABSTRACT

Nepal is the world's second-richest country in water resources after Brazil. Most of Nepal's rivers area unit either ungauged or poorly gauged due to extreme terrains and climatical condition, and lack of technical and support. Hence, the hydrological model's role is beneficial for adequately managing water resources to gain the optimum benefits. The present study concerns simulating the Kankai River Basin (KRB) flow and validating the flow at the gauge station at Mainachuli. Furthermore, estimation and analysis of discharges for each sub-basins of the KRBhave been performed in this study. The HEC-HMS hydrologic model is used to calibrate (from 1992-1999) and validate (from 2000-2008) the KRB. The primary data required as input includes precipitation, Digital elevation model, soil data, land-use land cover data as spatial data for basin model preparation in HMS. Furthermore, various temporal data like time series of daily rainfall and daily discharge, Evapo-transpiration data has been used to develop the metrological model. The model performance was tested for the geographic area throughout the standardization and validation using the parameters like Nash Sutcliffe Efficiency(NSE) and co-efficient of determination(R^2). The results obtained were found to be satisfactory and accepted for simulation of runoff. Thus, this study shows that the HEC-HMS hydrological model can be a suitable modelfor the KRBfor further assessment and prediction of simulation of the hydrological responses. So it will be fruitful to carry on more studies that incorporate the land-use amendment of the basin within the model.

Keywords: *HEC-HMS, Kankai River Basin (KRB), Runoff Simulation, Model Performance*

INTRODUCTION

Hydrological modeling is the process to assess the basin's hydrological reaction to the rainfall. It is often used as an effective tool to estimate the basin response to precipitation and speculate the hydrologic response to various watershed management practices. Because of the temporal and spatial variability of precipitation,extreme hydrological events such as floods or droughts areinexorable. After the initial losses like evaporation from interception by plants & vegetation, in soil moisture storage, in depressions and in agriculture fields and through infiltration into the ground, the rainwater is transformed to excess runoff flowing down as streamflow. Hence, the hydrologic study starting from rainfall to runoff which is also referred to as rainfall-runoff modeling or hydrological modeling of the watershed, is of prime importance. During recent decades great numbers of runoff generation models have been developed by hydrologists, teams of hydrologists and collaborating hydrological institutes. The history of rainfall-runoff modeling is very old, considering various hydrological purposes. Irish engineer Thomas James Mulvaney was the one who published the first equation for the modeling of the flood peak, i.e. Q_p = CAR. The peak discharge Q_p is the function of the catchment area A, a maximum rainfall areal average R, and an empirical parameter C.

There are varieties of the model which has been used to evaluate the rainfall-runoff response within the basin.Some of the models popularly used for modeling are namely, Empirical model, Stochastic model, Deterministic model, Lumped model, Semi-distributed, Distributed model.

An empirical model is mainly based on the observations of the input and output parameter and a non-linear statistical relationship is then established afterwards to evaluate the model.It is also known as a data-driven model. Moreover, if a model generates different sets of output for given inputs then such types of model is known as a stochastic model. Contrary to this, the deterministic model generates a single output for a given input parameter.

On the basis of spatial representation, the model can be classified into three types, namely Lumped model, Semi-distributed and Distributed model. In the case of Lumped model, the whole basin is considered to be a single unit, and it gives the single runoff output value at the outlet point of the basin. In the semi-distributed model, the basin is dived into a number of sub-basins, and different sub-basins are assigned with different lumped parameters. Models are divided into different grids in distributed models. In this model, all input data are distributed spatially and temporally. They are more often data-intensive. The model can be classified into a single event and a Continuous model based on temporal representation. The event-based model runs for a small-time interval, whereas the continuous model lasts for a long-time period or several years.

Our study makes use of HEC-HMS, a hydrological modeling toolof version4.6 and HEC-GeO-HMS, an extension in Arc-GIS, has been used for terrain processing and preparing catchment boundary. The analysis was performed for the whole KRB by dividing it into ten sub-catchments.

STUDY AREA

The Kankai River Basin (KRB) in Nepal (Fig. 1) was selected to conduct the study It is located between 26˚

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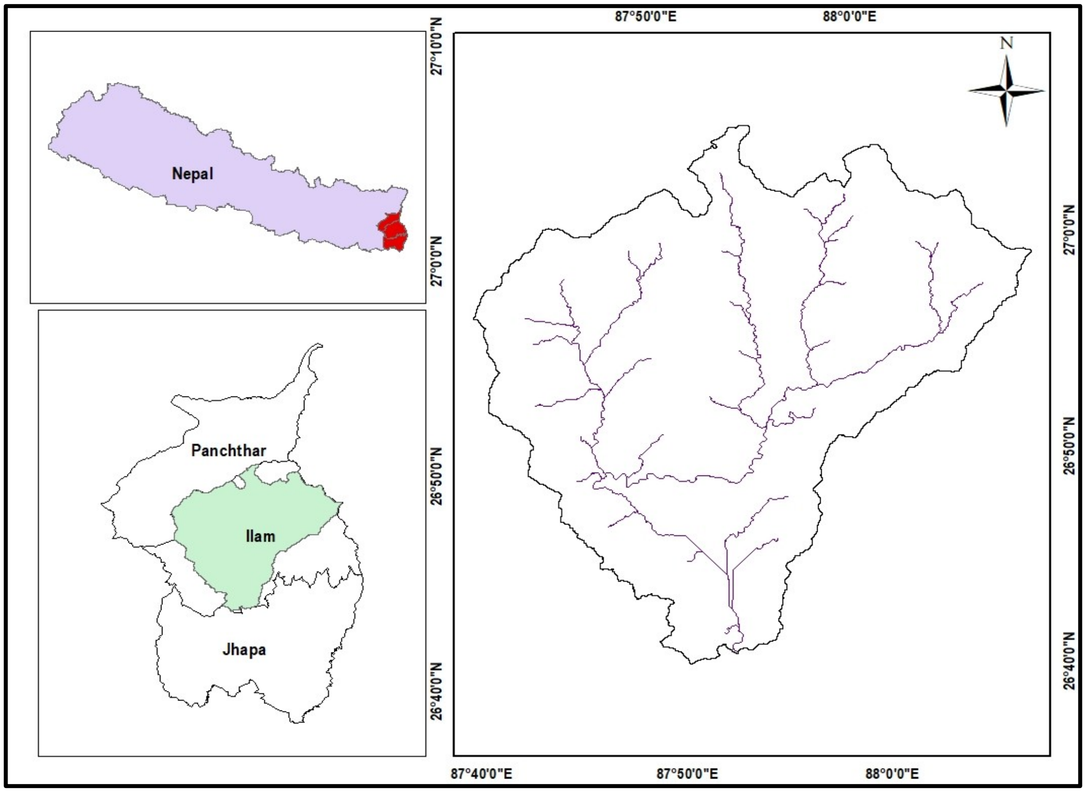


Fig. 1:Location of Kankai River Basin (KRB) in Nepal

40’0”N to 27˚05’0”N latitude and 87˚40’0” E to 88˚10’0”E longitude. The total catchment area of the basin is 1106.41 km^2.The basin area lies in the three districts, namely Jhapa, Ilam and Panchthar of Province-1 of Nepal. Downstream of the study area is a plain area, lies in the Jhapa district, which is rich in fertile agricultural land. Moreover, the lower catchment of the KRB has become the centre of attraction for the settling purpose. Large numbers of people from the hill region are migrating to settle here. Besides this, development in various sectors like agricultural development and infrastructural development is undergoing rapidly in this district. Also, it is one of the densely populated districts of Nepal. The elevation of the KRB varies from121m to 3286m above msl (Fig 2.). The basin extends from the Mahabharat range in the north to the Lesser Terai region in the south.

MATERIALS & METHODOLOGY

Material and Data

Meteorological Data

The study uses daily rainfall data of nearby six meteorological stationfrom 1972 to 2009 borrowed from the Department of Hydrology and Meteorology(DHM), Nepal. After then, the daily rainfall of each sub-basin was computed using the Theissen Polygon method.There were some missing rainfall data in different rainfall station. So Inverse distance square method is used to calculate these missing data. Potential evapotranspiration (PET) is a crucial component in hydrological modeling, which is a measure of the demand side. The PET of KRB computed using CLIMWAT 2.0 and CROPWAT 8.0 software, which came out to be 1377mm annually.

Flow Data

The daily observed hydrological data borrowed from the Department of Hydrology and Meteorology (DHM), Nepal, were used in the study. DHM is the responsible agency for establishing and maintaining a network of hydrological stations across the country. Daily discharge data of the Kankai river at Mainachuli station has been collected from DHM from 2003 to 2012.

Land use and Soil Map of Kankai River Basin

In a basin, runoff, evapo-transpiration, and soil erosion characteristics are mainly governed by the land cover scenario of the basin. Figure 2.6 shows the landuse landcover map of the Kankai river basin. The basin is dominated by green forestand agricultural land, which means the initial loss,infiltration and canopy is maximum.

Model Setup

For the prediction of runoff, the HEC-HMS Model was used, which is a semi-distributed model. The model has four main components, namely Basin model manager, Meteorological model manager, Control specification manager and time-series data manager. A basin was created in basin model manager with ten sub-basins. With time-series data of rainfall and average monthly

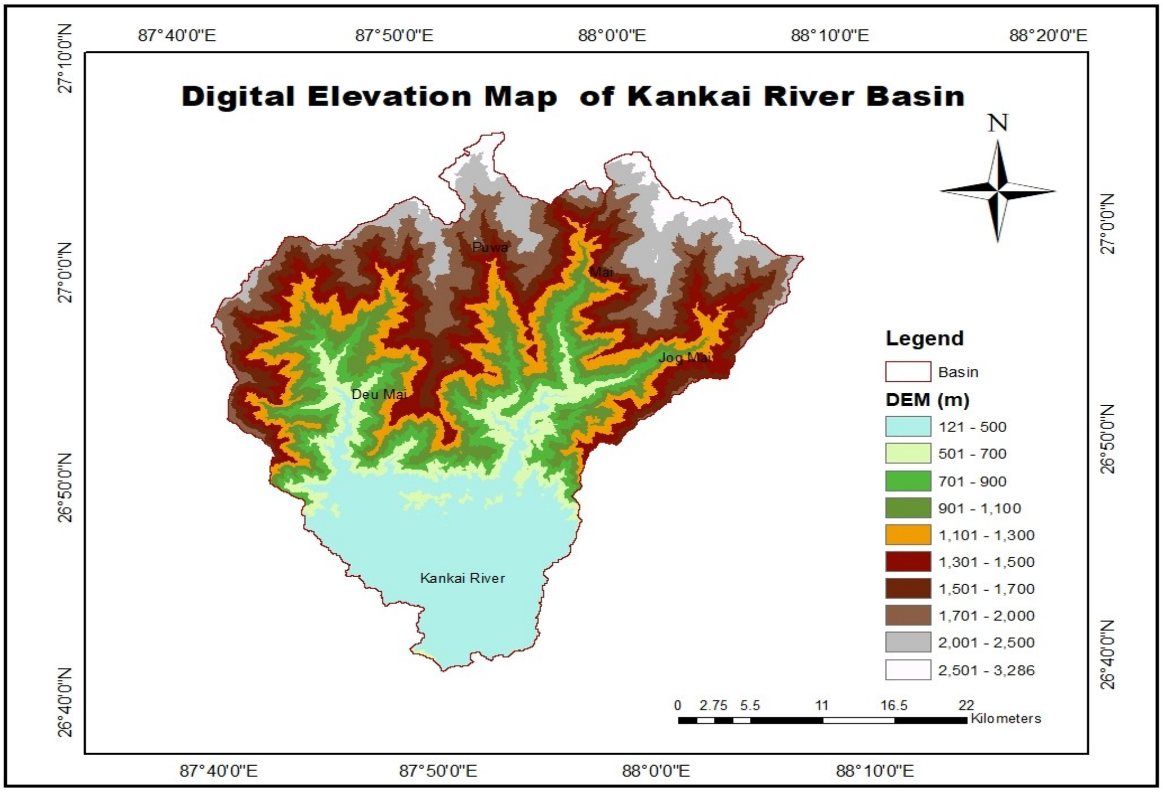


Fig.2: Elevation Map of Kankai River Basin

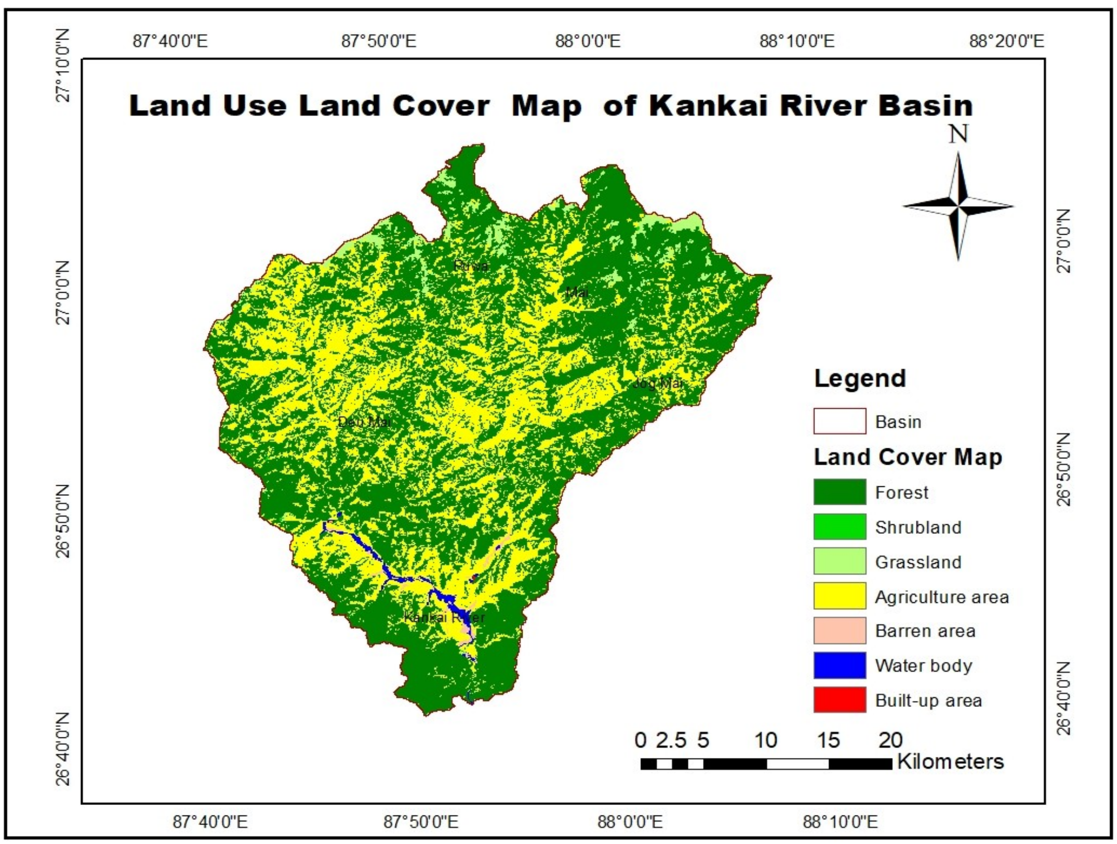


Fig. 3: Landuse LandCover Map of KRB

evapotranspiration, a meteorological model was prepared. Similarly, time-series discharge data was filled in the time-series data manager. Moreover, the calibration and validation period was specified using the control specification manager. The Basin model, for instance, contains the hydrologic element and their connectivity that represent the movement of water through the drainage system. A flowchart of various steps involved in the modeling approach is shown in Fig. 4.

The details of the processing steps are as below.

- Acquisition and processing of Spatial, Meteorological, and Hydrological data.
- Creation of basin catchment and stream network model using HEC-GeoHMS extension in Arc-GIS.
- Preparation of Thiessen Polygon map and weight computation.
- Preparation of Land-use land covers map, slope map, drainage network and soil map.
- Development of hydrologic parameters based on stream and sub-basin characteristics in HEC-Geo HMS.
- Development of Hydrological Model by calibration and validation of hydrological parameters with past recorded long-term observed discharge data.
- Performance evaluation of different basin model for the basin using performance criterion.

by adjusting different parameters like initial storage, maximum storage, initial loss, maximum loss, impervious percentage, manning's roughness etc. The method used for simulation are SCS curve number loss, SCS unit hydrograph transform, constant monthly base flow, and Muskingum-Cunge routing methods. Two commonly used statistical hydrological model performance indices, i.e. the NSE (Nash Sutcliffe Efficiency) and R^2 (Coefficient of Determination) were used to assess the model predictability and to represent the hydrological simulation of the basin,

Model Calibration

The HEC-HMS model for KRB was calibrated from1/1/1992 to 31/12/1999 using daily rainfall-runoff data as input and comparing simulated outflow with observed outflow at the outlet mentioned above point. Initially, the parameters were manually adjusted to get simulated flow closer to the observed flow. Afterwards, optimized parameters were obtained by using auto-calibration tools.

The time series of predicted and observed flow and scatter plot at the calibration period 1992 to 1999 is shown in Fig. 5. It can be seen that the daily hydrograph of the predicted runoff caught the observed flow during the calibration period with a very good value of NSE (0.805) and R^2 (0.816). The PBIAS during the calibration period was found to be 11.08%, which also signals a good fitness of the model.

Model Validation

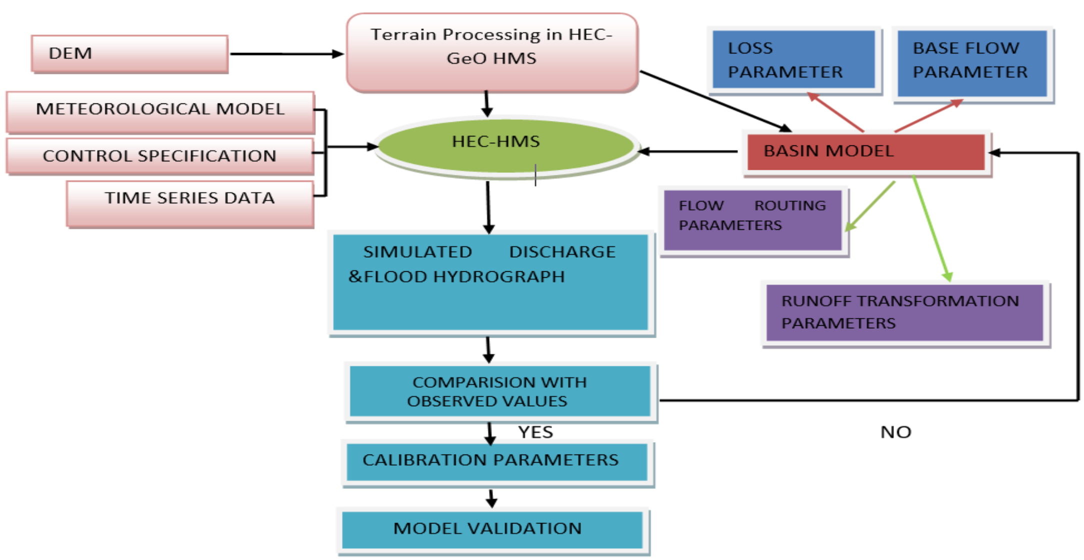


Fig. 4: Flow Chart of HEC-HMS Model

RESULTS & DISCUSSIONS

Hydrological Modeling

A computer-based hydrological model for KRB is calibrated manually and by automatic trial and error method and validated the model using HEC-HMS 4.6. The calibration and validation were carried out by checking the closeness of predicted and available flow data at the outlet

Using optimized parameters corresponding to the calibration, the model was validated for eight years(1/1/2000 -31/12/2008), and the performance was found to be a little bit improved. The daily hydrograph well simulated with observed stream flow. From the statistical analysis, the model's NSE has calculated as 0.856, and the R^2 has calculated as 0.868. This shows the developed hydrological model for the Kanaki river basin is well-performing for the validation period.

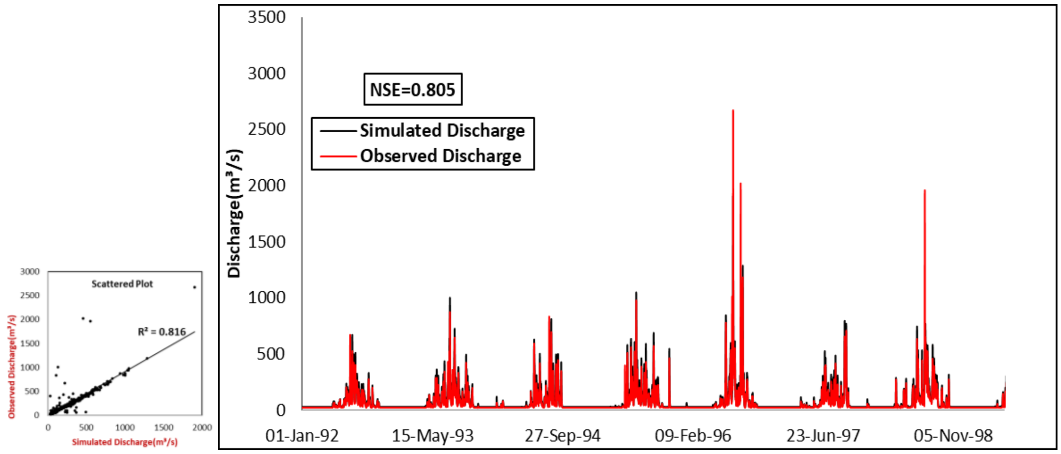


Fig.5: Calibration (1992-1999) of HEC-HMS Model for KRB

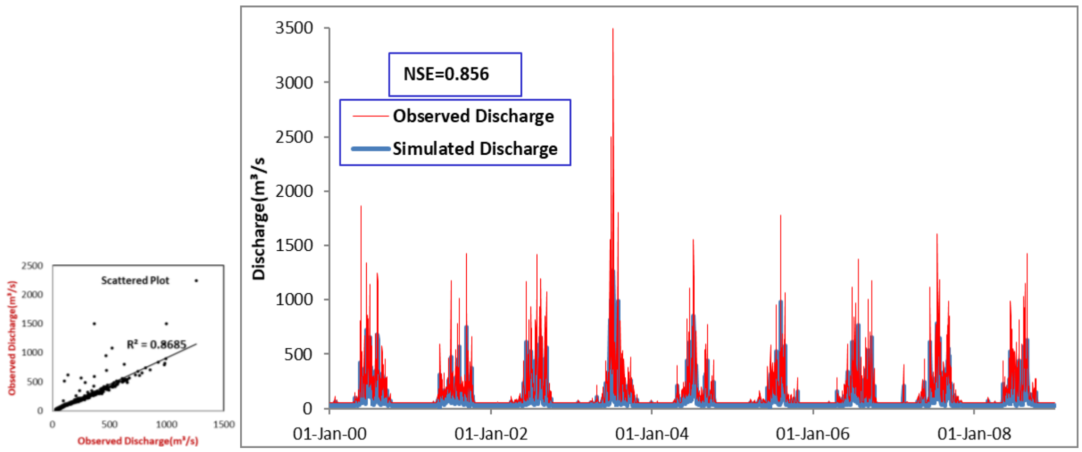


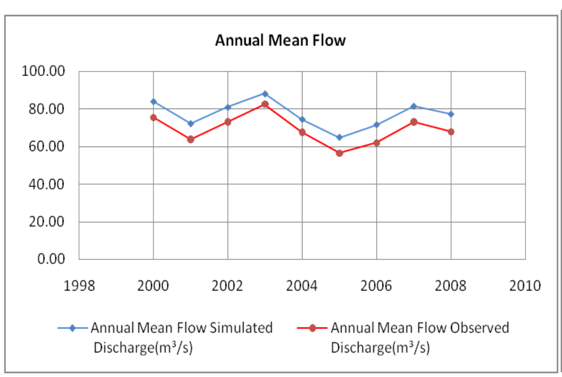
Fig. 6: Validation (2000-2008) of HEC-HMS Model for KRB

Analysis of Model

Performance Analysis on Annual Mean Flow and Annual Peak Flow

The annual mean flow and peak flow of each year have been calculated from the simulated outflow discharge.The same has been done with the observed data. After then, both simulated and observed data are compared for the validation period, as shown in Fig.7 and Fig.8.

The mean annual discharge deviation obtained almost similar. The maximum mean discharge deviation of 9.6 m³/s is observed in the year 2006, and the minimum means discharge deviation of 5.6 m³/s in the year 2003. Moreover, The peak discharge deviation obtained is also almost similar. The maximum peak discharge deviation of 980 m³/s is observed in the year 2003, and the minimum peak discharge deviation of 49.5 m³/s in the year 2001. The mean annual and peak flow values for both observed vs simulated discharge time series are compared at the basin's outlet and given in Table 1.



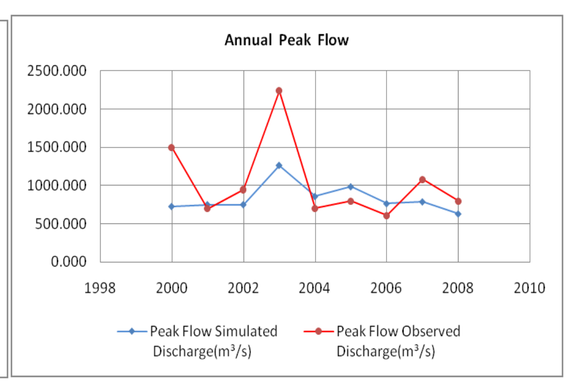


Fig. 7: Annual streamflow at the KRB outlet

Fig. 8: Peak flow at the KRB outlet

Table 1: Year-wise summary of annual mean and peak flows for observed and simulated

Year	Annual Mean Flow (m³/s)			Peak Flow (m³/s)		
	Simulated Discharge	Observed Discharge	Deviation	Simulated Discharge	Observed Discharge	Deviation
2000	84.0	75.5	8.5	726.2	1500.0	-773.8
2001	72.2	63.9	8.3	749.5	700.0	**49.5**
2002	80.9	73.1	7.8	749.5	950.0	-200.5
2003	88.1	82.5	**5.6**	1259.4	2240.0	**-980.6**
2004	74.5	67.6	6.8	855.3	703.0	152.3
2005	64.9	56.6	8.3	981.7	796.0	185.7
2006	71.6	61.9	**9.6**	762.1	611.0	151.1
2007	81.5	73.1	8.4	786.0	1081.0	-295.0
2008	77.3	67.9	9.4	629.3	800.0	-170.7

CONCLUSIONS

In this study, an attempt has been made to model the KRB using HEC-HMS. The model was setup with various models like Clark UH, Snyder UH, SCS UH. Among these, SCS-UH showed the best result, and hence this model accepted. Hydrological studies are essential and necessary for water and environmental resources management. The Hydrological Modeling of KRB is critical because downstream of the outlet point is undergoing rapid infrastructure development. The plain area is day per day becoming the centre of attraction for the settling purpose.

The HEC-HMS hydrological model was calibrated (1992-1999) and validated (2000-2008) at the KRB. The parameter percentage impervious in Initial constant loss and maximum storage are found to be highly sensitive for runoff prediction. To check the model performance during the simulation, NSE and R^2 were used. The calculated value of both NSE and R^2 has found 0.805, 0.816 for the calibration period and 0.856, and 0.868 for the validation period, which indicates the finer accuracy of simulated outflow. The drawbacks of the HEC-HMS Model is that peak predicted, and simulated flow rarely coincide. So It was also observed in our cases. Further, the runoff at the un-gauged outlet of each seven sub-catchments has been estimated using this model for 2000-2008. It has been found that the algebraic sum of runoff of each seven catchments is nearly equal to simulated discharge at the outlet of the KRB, which also proves the reliability of the model. In our study, land-use and land cover is assumed to be unchanged because the basin has very less settlement area, and the basin is dominated by forest and agricultural land.Landslides, soil erosion rarely occurs. Besides this, the population of the area is almost constant during the last decades. Hence there is no significant change in the land cover pattern, so it is ignored.

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