Proceedings of IOE Graduate Conference, 2019-Winter
Peer Reviewed
Year: 2019 Month: December Volume: 7
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Application of HEC-HMS Model for Runoff Simulation: A Case Study of Marshyangdi River Basin in Nepal

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Abstract
Many rivers in Nepal are either ungauged or poorly gauged due to extreme complex terrains, monsoon climate and lack of technical and financial supports. In this context the role of hydrological model is extremely useful. In practical applications, hydrological models are relatively simple to implement and reasonably accurate. The present study concerns about simulating the flow of the Marshyangdi river basin and validate with the gauge station within the studied basin area. Furthermore, estimation and analysis of discharges for each subbasins of Marshyangdi river basin has be performed in this study. The HEC-HMS 4.3 hydrologic model (Developed by US Hydrologic Engineering Center was used to calibrate (from 2003-2007) and validate (from 2008-2012) the Marshyangdi river basin. The main data required as input includes rainfall, DEM (digital elevation model) soil, land use and metrological for model. After having data, HEC-HMS model are operated. The main output from model is discharge at the outlet of the catchment. Finally, the output is compared with the observed discharge at selected gauging of the basin. It is crucial to properly calibrate and validate models to give confidence to model users in prediction of stream flow. The SCS curve number method, SCS unit hydrograph method, constant monthly method and Muskingum methods are the best fit performed methods of the hydrological processes of infiltration loss, direct runoff transformation, base flow and routing part respectively. The model performance was tested for the river basin during calibration and validation period, The Nash-Sutcliff (E_{NS}) and Coefficient of determination (R^2) used to evaluate the performance of the model. The results obtained are satisfactory and accepted for simulation of runoff. The SCS curve number method, SCS unit hydrograph method, constant monthly method and Muskingum methods are the best fit performed methods of the hydrological processes of infiltration loss, direct runoff transformation, base flow and routing part respectively. Thus, this study shows that HEC-HMS hydrological model can be used to model the upper Marshyangdi river basin for better assessment and prediction of simulation of the hydrological responses. The study recommends further studies which incorporate the land use change of the basin in the model.

Keywords
Hydrologic modeling, River discharge, Hydropower, Flow simulation

1. Introduction

1.1 Background

Hydrological studies are important and necessary for water and environmental resources planning and management [1]. It is well-known that diverse water-related challenges are expected to increase in the future. Current and future water-related challenges are location and time specific, and can vary from impact of glacier dynamics, floods or extended and more prolonged droughts, amongst others [2, 3, 4, 5]. So, to cope with these challenges, different hydrological models have been developed to analyze, understand, and explore solutions for sustainable water management, and to support decision makers and operational water managers. Climate change is threatening the normal hydrological cycle of river basins, due to rising temperature because of the global warming effect, which is associated in disturbing the frequency and intensity of precipitation in a given climatic condition. This has an implication on the hydrologic events and the water resources availability.

The Marshyangdi river basin is the main sources for economic and social welfare of the people living on the River basin. This is so because the majority of the people rely on climate sensitive sectors like agricultural productivity, fishery, and hydropower power sources. Also, the Marsyangdi river basin is an important river basin in Nepal from Hydropower perspective. At present, two hydropower projects namely Marsyangdi Hydropower Project (69 MW) and Middle Marsyangdi Hydroelectric Project (70 MW) are operating in the basin. Further, Upper Marsyangdi Hydroelectric Project (600 MW), Lower Manang Marsyangdi Hydroelectric Project (100 MW) and Nyadi Hydropower Project (30 MW) are under different stages of development.

In order to clearly understand the reality and predict the future water availability of different catchments, it is a must to use a mathematical hydrological modelling. According to Lastoria [6] and Xu [7], on the basis of process description, the hydrological models can be classified in to three main categories. Lumped, distributed and semi distributed models. Lumped models; parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins [6]. Most of the time these models are not good for event scale hydrological processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models [8]. The other one is Distributed models; parameters can easily vary in space at the desired resolution based on the preference of the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amount of (often unavailable) data [8]. However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy [9]. The last one is semi-distributed models. Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin in to a number of smaller sub-basins. The main advantage of these models is that their structure is more physically-based than the structure of lumped models, and they are less demanding on input data than fully distributed models [10]. HEC-HMS, SWAT, HBV, are some examples of semi-distributed models.

In this study, a semi distributed hydrologic model of HEC-HMS. HEC-HMS 4.3 (developed by USA Hydraulic Engineering Center-Hydrologic Modelling System) is used to model seven catchments in the Marshyangdi river basin. The basin has divided into seven catchments on the basis of its major tributaries and diving the Marshyangdi river stretch into three reaches.

HEC-HMS model is capable of simulating rainfall runoff relation for dendritic watershed in space and time. The HEC-HMS model has been used successfully in different parts of the world's river basins for catchment modeling. Hence a proper understanding of the rainfall-runoff relation at different catchments of the Marshyangdi river basin help to study water balance, water resources management. and flooding control of the basin. In this study in order to clearly understands the hydrologic characteristics of river basin, calibration of rainfall-runoff relation of the basin using HEC-HMS 4.3 model from 2003- 2007 was done. After calibration the model was validated from 2008-2012. Moreover, the basic sensitive parameters and the good modeling methods for each process part will be identified for assessment of runoff simulation on of seven catchments of the Marshyangdi river basin.

Marshyangdi river basin has only one working stream gauging station at its outlet called Bimalnagar station at present, which is established by Department of Hydrology and Meteorology (DHM). Having no established stream gauging stations in tributaries of Marshyangdi river and its sub-catchments, infrastructure projects like hydropower, dam and irrigation projects facing problems and challenges in its planning phase. So, the role of hydrological model is extremely useful in this context.

It is well known that one of the major functions of hydrological model is runoff simulation, which produces the surface runoff in-response to rainfall event. The simulation of runoff can be extremely helpful for watersheds with ungauged stream for planning of hydropower, irrigation and other water related infrastructure projects.

Marshyangdi river basin, having higher potential of water related projects, can definitely take advantages of the hydrological analysis for future planning.

The main objective of this study is to estimate/simulate the outflow of seven catchments of Marshyangdi river basin using HEC-HMS hydrological model.

Specifically, the study intends to achieve the following objectives.

a) Setting up a semi-distributed hydrological model using HEC-HMS for Marshyangdi river basin.

b) Calibrate the hydrological model for outlet station (basin pour point) from 2003 to 2007 using time series precipitation and stream flow data.

c) Validate the hydrological model for outlet station (basin pour point) from 2008 to 2012.

d) Simulate the outflow at outlet of each sub-basins of the Marshyangdi river basin.

1.2 Study Area

The study was conducted in the Marshyangdi river basin of Nepal (Figure 1.1). It is located between 27°56'13"N to 28°54'03"N latitudes and 83°47'23"E to 84°41'51"E longitudes. The basin has a total area of 4,058.59 sq. km. The elevation of the basin varies between 357m. a.s.l. to 8,055m. a.s.l. The mean slope of this basin is about 29°. Physiographically, the basin extends from high Himalayan in the north to lesser Himalayan region in the south. Administratively, the study area lies in four districts namely, Manang, Lamjung, Gorkha and Tanahu. The Marshyangdi river begins at the confluence of two mountain rivers, the Khangsar khola and Jharsang khola, northwest of the Annapurna massif at an altitude of 3600 m. a.s.l. near Manang village. Nar khola, Dudh khola, Dordi khola and Chepe khola are the major tributaries of Marshyangdi river. The Marshyangdi river flows east-ward through Manang district and then south-ward through Lamjung district. The Marsyangdi river originating from this basin is a tributary of the Narayani River system which ultimately confluence with the Ganges river. Hence, to explore the feasibility of development of hydropower, irrigation and other water related infrastructure projects, hydrological analysis can play a vital role in different phases.

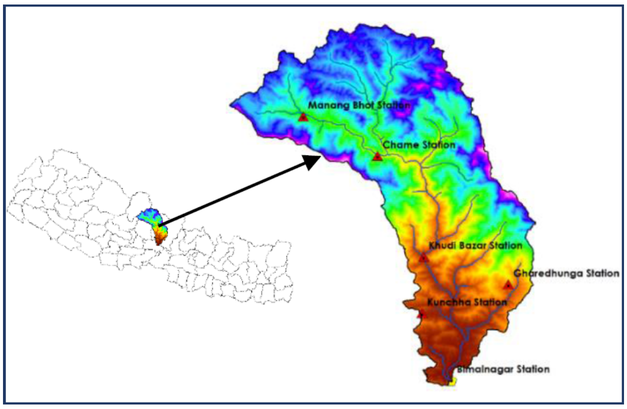

Figure 1.1: Location of Marshyangdi river basin

2. Material and Methods

2.1 Meteorological Data

The study makes use of observed meteorological data acquired from Department of Hydrology and Meteorology (DHM), Nepal. DHM is the sole organization responsible for collection and dissemination of meteorological and hydrological information in the country. It has established and maintained network of hydro-meteorological stations across the country. Daily meteorological data of Marsyangdi river basin has been collected from DHM for available period.

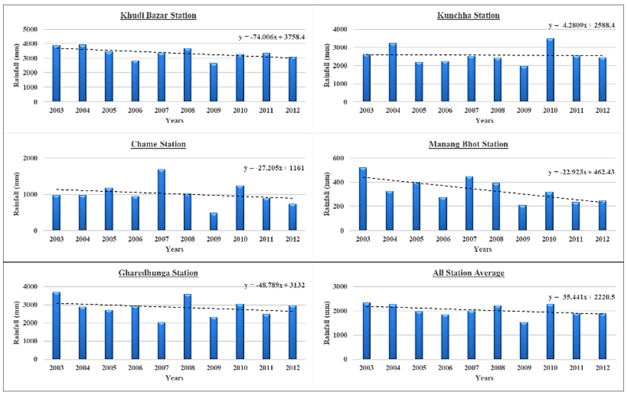

Figure 2.1: Annual total rainfall within the Marshyangdi river basin (Source: DHM)

There are five rainfall stations available within study having different type of climate, within which the station located at Manang district i.e. Chame and Manang Bhot station which receives significantly less rainfall compared to station located at Lamjung station i.e. Khudibazar, Kunchha station and Gharedhunga station (Figure 2.1). The projection suggests the decrease in rainfall within Nepal but the linear trend (2003-2012) suggests the decrease in rainfall for all station average rainfall 31.897 mm/year. The rainfall pattern is different in all five stations within the study area. In some stations there is increasing linear trend while in some there is decline in rainfall amount. The rainfall is the dominant source for water discharge in the basin and fluctuation in rainfall creates the fluctuation in river discharge.

2.2 Temperature Data

The study makes use of observed average temperature data acquired from Department of Hydrology and Meteorology (DHM).

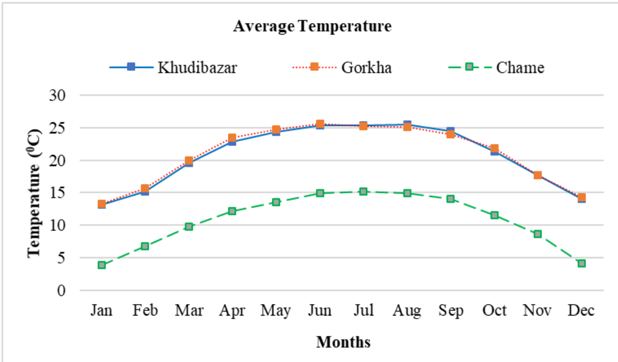

Figure 2.2: Monthly distribution of average temperature (Source: DHM)

Figure 2.2 shows the average temperature of Khudibazar, Gorkha and Chame temperature stations, which are in the Marshyangdi river basin. Thiessen polygon method was applied to calculate the average temperature of the basin. From the graph, the maximum observed average temperature is 25.7°for Gorkha station in July. The average temperature of Chame station is comparatively lesser as compared to other two stations because it is located in the higher Himalayan region where the weather is cold throughout the year. The maximum average temperature was 15.25 in July. This average basin temperature is used to calculate potential evapotranspiration by using Thornthwaite method. Which is illustrated in next section.

2.3 Potential Evapotranspiration

Potential evapotranspiration (PET) is defined as the amount of evaporation that would occur if a sufficient water source were available. If the actual evapotranspiration is considered the net result of atmospheric demand for moisture from a surface and the ability of the surface to supply moisture, then PET is a measure of the demand side. Surface and air temperatures, insolation, and wind all affect this. A dryland is a place where annual potential evaporation exceeds annual precipitation.

Thornthwaite Equation (1948)

$$PET = 16\left(\frac{L}{12}\right)\left(\frac{N}{30}\right)\left(\frac{10T_d}{I}\right)^{\alpha} \tag{2.1}$$

Where,

PET is the estimated potential evapotranspiration (mm/month)

T_d is the average daily temperature (degrees Celsius; if this is negative, use 0) of the month being calculated

N is the number of days in the month being calculated

L is the average day length (hours) of the month being calculated

$$\alpha = (6.75\times10^{-7})I^3 - (7.71\times10^{-5})I^2 + (1.792\times10^{-2})I + 0.49239$$

$$I = \sum_{i=1}^{12}\left(\frac{T_{m_i}}{5}\right)^{1.514}$$

is a heat index which depends on the 12 monthly mean temperatures T_{m_i}

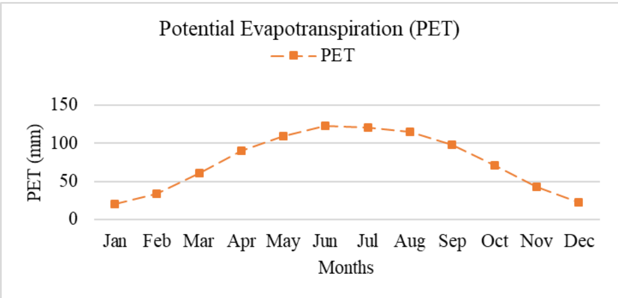

Figure 2.3: Monthly average potential evapotranspiration of Marshyangdi river basin

Figure 2.3 shows the line chart of average potential evapotranspiration (PET) of the Marshyangdi river basin based on the temperature by using Thornthwaite Method. In figure, the trend shows average PET of the basin is in increases as the temperature of the basin increase and vice versa. The maximum PET has observed 123.41 mm in June and minimum of 20.18 mm in January.

2.4 Stream Flow Data

The study makes use of observed hydrological data acquired from Department of Hydrology and Meteorology (DHM), Nepal. DHM is the sole organization responsible for collection and dissemination of hydrological information in the country. It has established and maintained network of hydrological stations across the country. Daily discharge data of Marsyangdi river at Bimalnagar station (station no.439.7) has been collected from DHM for 2003 to 2012 and plotted in Figure 2.4.

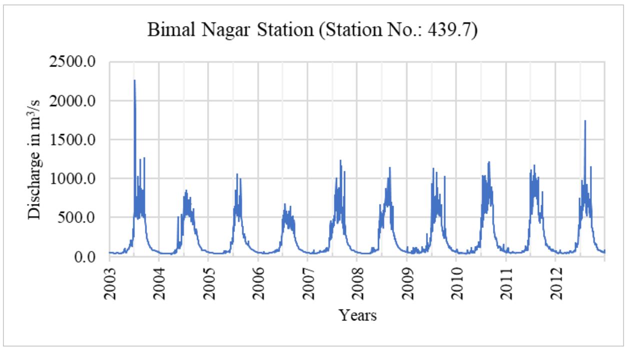

Figure 2.4: Time series of discharge at Bimalnagar station (Source: DHM)

The time series discharge data of Bimalnagar station shows similar trend in every year. The maximum flow at river occur at monsoon season (between June to August) due to heavy rainfall, and the discharge significantly decreases during winter season (between November to February). The peak observed flow of 2270.0 m^3/s has been recorded in 9th July, 2003.

2.5 Topography of Marshyangdi River Basin

The elevation of the Marshyangdi river basin varies between 357m. a.s.l. to 8,055m. a.s.l. with most of the area between 4,000-6,000m. a.s.l. Physiographically, the basin extends from High Himalaya in the north to Lesser Himalayan region in the south.

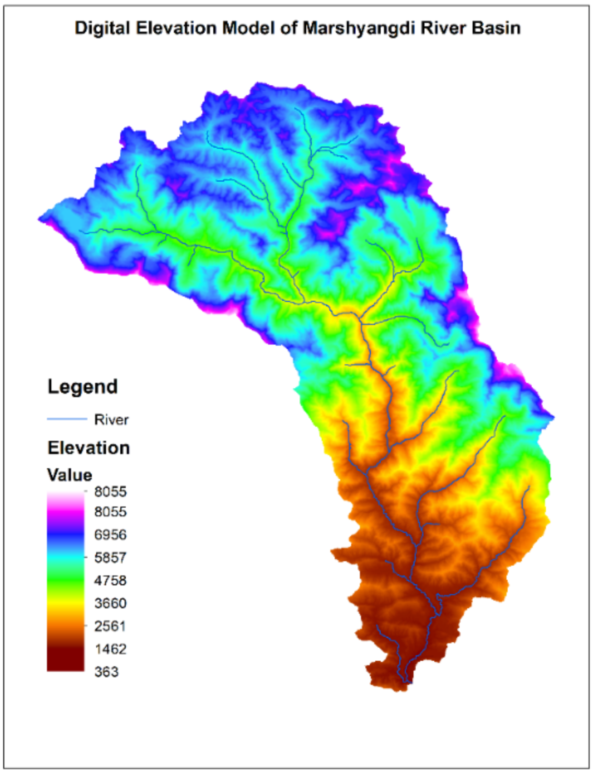

Figure 2.5: Digital Elevation Model of Marshyangdi river basin

The climate of this area ranges from cold high alpine type to hot and humid tropical type. The mean slope of this basin is about 29°, which reflects the high potential relief energy of the catchment.

2.6 Landuse of Marshyangdi River Basin

Landcover is the major factor that affect runoff, evapotranspiration, and soil erosion characteristics of the basin. Figure 2.6 shows the landuse landcover map of the Marshyangdi river basin. The basin is dominated by glacier land which means the percentage impervious area is greater so there is possibility of direct runoff during rainfall in those area.

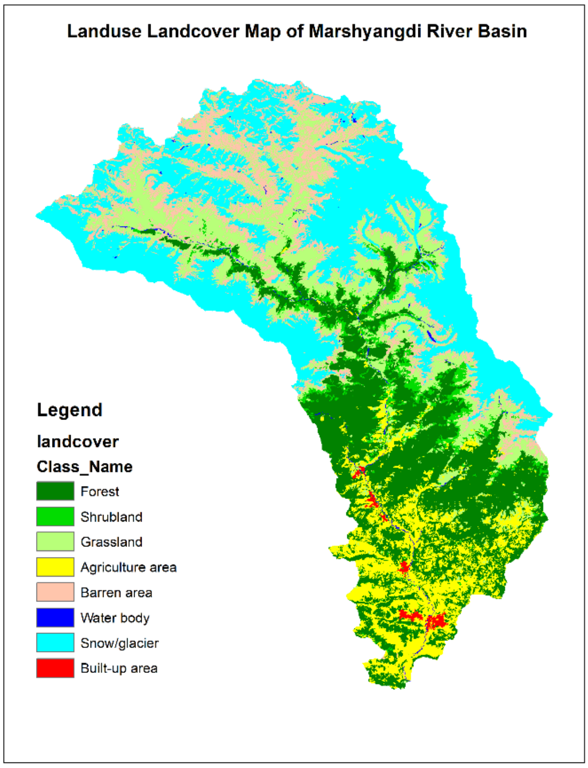

Figure 2.6: Landuse landcover map of Marshyangdi river basin

Table 2.1: Landuse coverage in percentage of Marshyangdi river basin

Class Name	Percentage Coverage
Forest	23.5 %
Shrub Land	3.9 %
Grass Land	19.0 %
Agricultural Area	10.3 %
Barren Area	12.7 %
Water Body	0.4 %
Snow/Glacier	29.6 %
Built-Up Area	0.4 %

Majority of the basin area is covered by snow-cover area and forest. Agricultural land and grassland cover moderate area where, the build-up area is significantly lesser as compared to other classes. Table 2.1 shows the percentage coverage of different landcover classes

2.7 HEC-HMS Model Setup

The model that will be used in this study is, HEC-HMS 4.3, which is developed by the United States Army Corps of Engineers, and is designed to simulate the precipitation–runoff processes of dendritic watershed systems. HEC-HMS is a semi -distributed conceptual hydrological model which simulates run off. It requires daily precipitation, long term average monthly potential evapotranspiration, runoff flow of the basin (for calibration and validation), and geographical information of the basin to get the simulated runoff as output. HEC-HMS model setup consists of four main model components: basin model, meteorological model, control specifications, and input data (time series, paired data, and gridded data). The Basin model for instance, contains the hydrologic element and their connectivity that represent the movement of water through the drainage system.

The meteorological component is also the first computational element by means of which precipitation input is spatially and temporally distributed over the river basin. The spatio-temporal precipitation distribution was accomplished by the gauge weight method.

Setting up of HEC-HMS Model

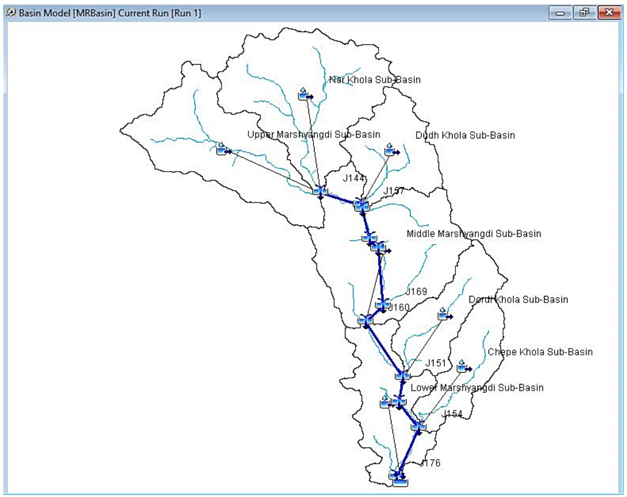

Figure 2.7: HEC-HMS 4.3 Model for Marshyangdi river basin

Thiessen polygon technique was used to determine the gauge weights and the following input data like daily precipitation, monthly average temperature, elevation, and long term mean monthly actual potential evapotranspiration. In order to increase the performance of modelling, the catchment is sub divided into seven (7) sub basins: Nar Khola sub-basin, Upper Marshyangdi sub-basin, Dudh Khola sub-basin, Middle Marshyangdi sub-basin, Dordi Khola sub-basin, Chepe Khola sub-basin and Lower Marshyangdi sub-basin, to use the model as semi-distributed.

2.8 Flow Diagram of the Methodology

A conceptual framework serves to describe the overall study steps. The main data types required as input includes rainfall, DEM (digital elevation model) soil, land use and metrological for model. After having data, HEC-HMS model are operated. The main output from model is discharge at the outlet of the catchment. Finally, the output is compared with the real discharge at selected gauging of the basin.

The semi-distributed hydrological model to simulate the river flow on the Marshyangdi river basin was used for rainfall-runoff simulation. The study deals with pre-processing and spatial analysis of the Digital elevation model (DEM) for the automated delineation of sub basins and river. GIS tools were used for the extraction of physical characteristics of sub basin and rivers. Required other model parameters such as daily precipitation, temperature and evapotranspiration was collected from DHM and analyzed by thiessen polygon method. SCS curve number, percentage impervious were extracted on the basis of soil and land use map of the study area. These models' parameters were used in HEC-HMS model simulation.

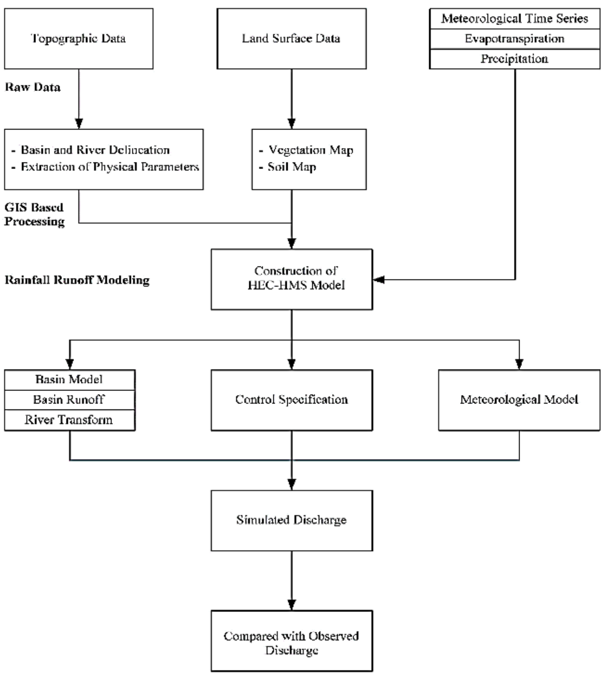

Figure 2.8: Flow diagram of the methodology

A new project file in HEC-HMS was generated, for a new project, an area and outlet of the basin was defined, after that the result was computed by giving input of all the parameters for river basins.

Simulated flow was compared with the observed flow at the outlet of the basin and analyzes the performance of the result to achieve the objective of the study. For routing process, collection of the relevant metrological, hydrological and topographical data is essential for the study. Metrological and hydrological data such as precipitation and discharge respectively were acquired from the Department of hydrology and meteorology (DHM) whereas topographical data of 90m x 90m resolution Digital map (DEM) is available easily from USGS earth explorer website.

3. Results and Discussions

3.1 Hydrological Modeling of Marshyangdi River Basin Using HEC-HMS

A computer-based hydrological model for Marshyangdi river basin was calibrated manually and also by automatic trial and error method, and validated the model using HEC-HMS 4.3. To obtain the best possible fit, SCS curve number loss, SCS unit hydrograph transform, constant monthly base flow, and Muskingum routing methods were used. The calibration and validation performance of the HEC-HMS 4.3 was carried out by comparing the daily simulated runoff with observed stream flow at the outlet of the river basin. To assess the performance of the model predictability of representing the hydrological simulation of the reality of the basin, two basic statistical hydrological model performance check was used: The E_{NS} (Nash Sutcliffe efficiency), and R^2 (Coefficient of Determination).

A semi-distributed hydrological modelling technique was applied in order to increase the performance of the model. Each sub basin parameters were manually adjusted by trial and error method and by using automatic optimization to get the best fit.

The daily hydrograph of the simulated runoff caught the observed flow during calibration period (1/1/2003-1/12/2007), it is well simulated, but the peak flow is under predicted in the model. Based on the calibrated parameters and values the model is validated from (1//1/2008-31/12/2012), and the performance a little bit improved. The daily hydrograph well simulated with observed stream flow, however as like calibration period, there is also under prediction in the peak flow. The model performance was checked using E_{NS} and R^2, the result obtained are satisfactory and acceptable to simulate the basin runoff for future projection (Table 2.2). The SCS curve number loss method, SCS unit hydrograph method, constant monthly baseflow method, and Muskingum routing method are the best fit performed methods of the hydrological processes of infiltration loss, direct runoff transformation and base flow part of the model.

3.2 Model Calibration

The model for Marshyangdi river basin is calibrated using 1/1/2003 to 1/12/2007 daily rainfall runoff data. Manual and automatic calibration techniques are applied to estimate values of parameters.

The whole study area is divided into seven sub basins. The sub basins are assumed to be homogenous and the model parameters are assigned according to the type of soil and land use pattern within sub-basin. The optimal values of the model parameters are obtained using the criterion of maximizing the efficiency by comparing the observed and simulated flows. The accuracy of the model is verified by qualitative and quantitative analysis.

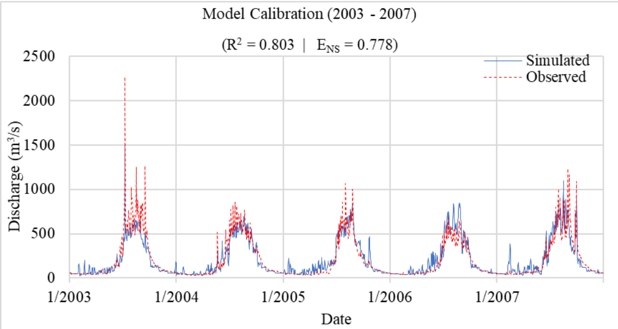

Figure 3.1: Calibration of time series of observed and simulated discharge using HEC-HMS model for Marshyangdi river basin

3.2.1 Comparison of Simulated and Observed Hydrograph

The simulated and observed hydrograph and scatter plot at calibration period 2003 to 2007 is shown in Figure 3.2. It is seen that the daily hydrograph of the simulated runoff caught the observed flow during calibration period (1/1/2003-1/12/2007).

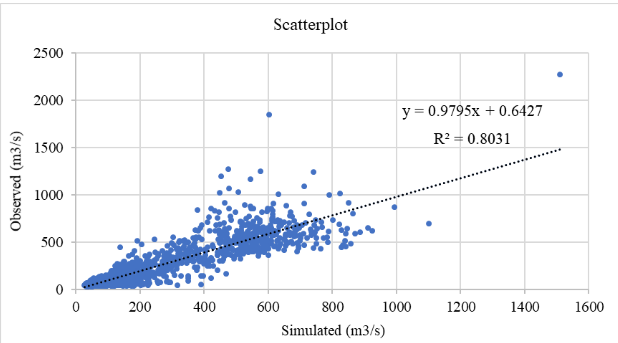

Figure 3.2: Comparison of simulated and observed discharge for calibration period

This result show that base flow is matched with the observed flow. However, the peak value of the simulated discharge is under predicted in the model as compared to the observed discharge of the outlet station.

From the statistical analysis the Nash-Sutcliff efficiency (E_{NS}) of the model has calculated as 0.778 and the coefficient of determination (R^2) has calculate as 0.803. Which shows the developed hydrological model for the Marshyangdi river basin is well performing for calibration period. Manual and automatic method was applied for the optimization of model parameter during calibration and validation period.

3.3 Model Validation

The validated result of the HEC-HMS Model for Marshyangdi river basin can be seen in the Figure 3.3. Based on the calibrated parameters and values the model is validated from (1/1/2008 – 31/12/2012), and the performance a little bit improved. The daily hydrograph well simulated with observed stream flow. From the statistical analysis the Nash-Sutcliff efficiency (E_{NS}) of the model has calculated as 0.842 and the coefficient of determination (R^2) has calculate as 0.846. Which shows the developed hydrological model for the Marshyangdi river basin is well performing for calibration period. However as like calibration period, there is also under prediction in the peak flow.

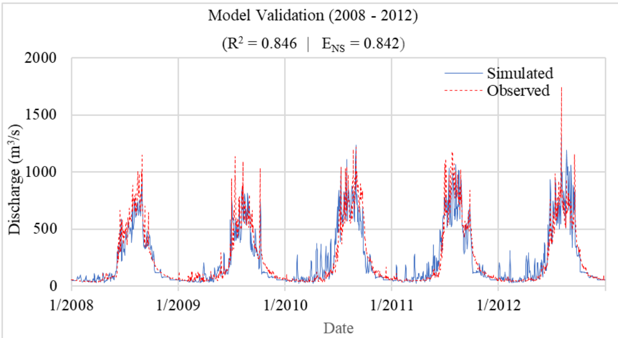

Figure 3.3: Validation of time series of observed and simulated discharge using HEC-HMS model for Marshyangdi river basin

3.4 Analysis of Modeling

3.4.1 Performance Analysis on Volume Deviation

The simulated annual stream flow volume that occurred at the outlet of the basin in response to the modeling during calibration and validation period is shown in Figure 3.4.

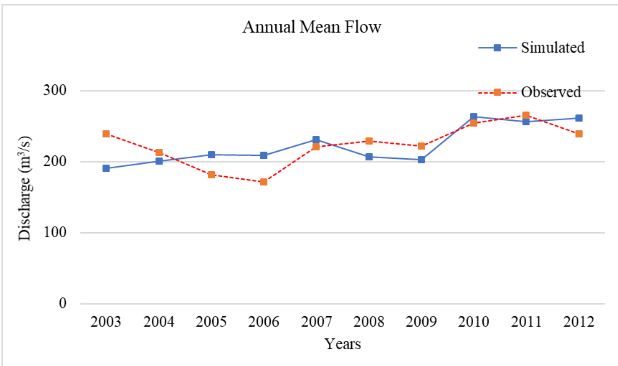

Figure 3.4: Annual stream flow volume at outlet

The volume deviation obtained almost similar. The maximum volume deviation of 1502.95×106 m^3 is observed in year 2003 and the minimum volume deviation of 269.5×106 m^3 in year 2011. It is seen the deviation is lesser in validation period as compared to calibration period, which also shows the model is working well in validation period as compared to calibration period.

The observed vs simulated volume that occurred at the outlet of the basin is presented in Table 3.1.

Table 3.1: Annual stream flow volume at outlet

Year	Volume (10^6 m^3)	
	Observed	**Simulated**
	Observed	Simulated
2003	7522.68	6019.73
2004	6714.46	6350.46
2005	5727.92	6600.98
2006	5406.35	6572.34
2007	6974.00	7290.22
2008	7248.93	6541.57
2009	6987.03	6374.30
2010	8008.47	8293.26
2011	8395.22	8122.72
2012	7542.90	8258.73

3.4.2 Performance Analysis on Annual Mean Flow

The simulated annual mean stream flow that occurred at the outlet of the basin in response to the modeling during calibration and validation period is shown in Figure 3.5. The annual mean flow obtained almost similar.

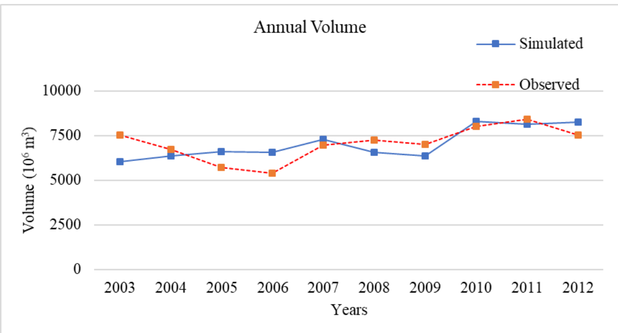

Figure 3.5: Annual mean flows at outlet

The maximum annual mean flow deviation of 74.74 m^3 is observed in year 2003 and the minimum annual mean flow deviation of 8.59 m^3 in year 2011. It is seen the deviation is lesser in validation period as compared to calibration period, which also shows the model is working well in validation period as compared to calibration period. The observed vs simulated annual mean flow that occurred at the outlet of the basin is presented in Table 3.2.

Table 3.2: Annual mean flows at outlet

Year	Annual mean flow (m^3/s)	
	Observed	**Simulated**
2003	238.54	190.88
2004	212.33	200.82
2005	181.63	209.32
2006	171.43	208.41
2007	221.14	231.17
2008	229.23	206.87
2009	221.56	202.13
2010	253.95	262.98
2011	264.76	256.17
2012	238.53	261.17

3.4.3 Performance Analysis on Peak Flow

The simulated peak stream flow that occurred at the outlet of the basin in response to the modeling during calibration and validation period is shown in Figure 3.6. The time of peak in simulation is same to the observed time of peak in calibration and validation period. However, it is observed that the peak value of the simulated discharge is under predicted in the model as compared to the observed discharge of the outlet station.

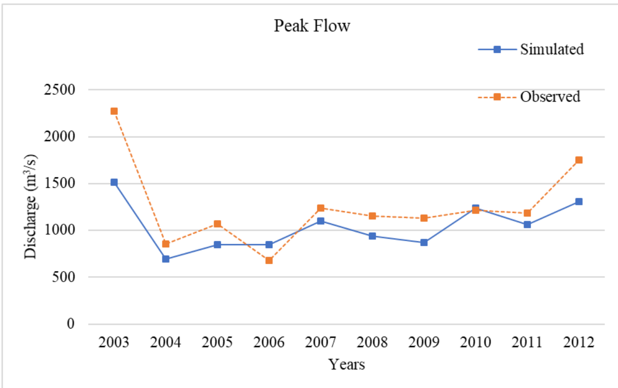

Figure 3.6: Peak flow at outlet

The observed vs simulated peak flow that occurred at the outlet of the basin is presented in Table 3.3.

Table 3.3: Peak flows at outlet

Calib. (2003 -2007)		Valid. (2008 – 2012)	
Time of observed peak flow	Time of simulated peak flow	Time of observed peak flow	Time of simulated peak flow
09 July, 2003	09 July, 2003	03 Aug, 2012	03 Aug, 2012

Table 3.4: Time of peak flow at outlet

Year	Peak flow (m^3/s)	
	Observed	Simulated
2003	2270.00	1510.50
2004	855.00	693.80
2005	1070.00	850.40
2006	679.00	845.70
2007	1240.00	1101.70
2008	1151.00	937.90
2009	1134.00	871.70
2010	1217.00	1238.10
2011	1181.00	1065.70
2012	1749.00	1310.40

3.4.4 Performance Analysis on Efficiency

The calibration and validation performance of HEC-HMS model for Marshyangdi river basin in Figure 3.7. The performance value is based on the simulated and observed time series discharge data of the outlet station (i.e., Bimalnagar station). validation period.

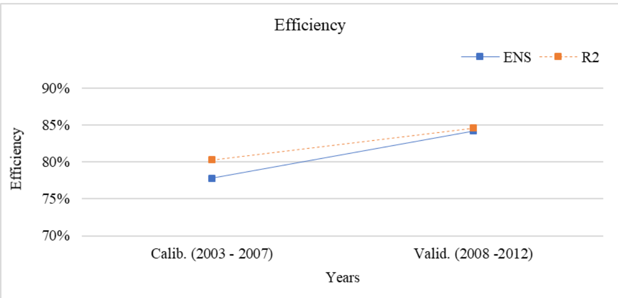

Figure 3.7: Calibration and validation performance of HEC-HMS model for MRB

Table 3.5 shows the performance of the HEC-HMS model for Marshyangdi river basin during calibration and validation period. It is seen that the performance of the model is a bit improved during validation period as compared to calibration period.

Table 3.5: Calibration and validation performance value of HEC-HMS model for Marshyangdi River Basin (MRB)

Performance Factor	Calib. Period (2003 – 2007)	Valid. Period (2008 – 2012)
E_{NS} (Nash Sutcliff Efficiency)	0.778	0.842
R^2 (Coeff. of Determination)	0.803	0.846

3.5 Flow Simulation of Sub-Basins

The outlet of catchments usually is the point of interest where the river runoff is required for proposing infrastructure project like hydropower, dam, bridge etc. Based on the calibration and validation of hydrological model of Marshyangdi river basin using HEC-HMS, the estimated river runoff of each of the seven sub-basins has represented in the graphs in following subsections.

3.5.1 Flow Simulation of Nar Khola Sub-Basin

Nar Khola sub-basin having catchment area of 889.59 km^2 lies in north west part of the Marshyangdi river basin. Most of the part of this sub-basin is covered with glacier and barren land. The simulated runoff of the Nar Khola sub-basin is shown in Figure 3.8. It is observed that the peak simulated discharge for Nar Khola Sub-Basin is 249.9 m^3/s in 28th September 2007 while annual mean flow is 34.28 m^3/s and annual flow volume is 1081.03×106 m^3.

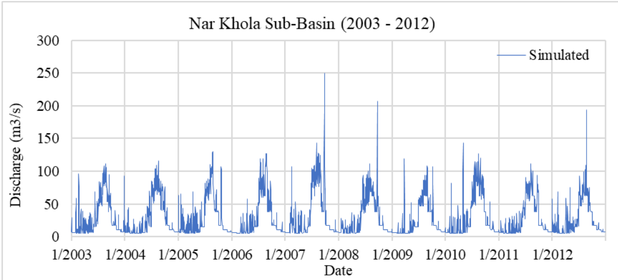

Figure 3.8: Estimation of time series discharge for Nar Khola sub-basin

The annual flow volume, annual mean flow and annual peak flow of the Nar Khola sub-basin is shown in Table 3.6.

Table 3.6: Simulated annual mean, peak and flow volume of Nar Khola sub-basin

Nar Khola sub-basin			
Year	Volume ($\times 10^6$ m^3)	Mean Flow (m^3/s)	Peak Flow (m^3/s)
2003	921.12	29.21	111.30
2004	881.50	27.88	115.90
2005	946.01	30.00	130.00
2006	870.01	27.59	126.90
2007	1081.03	34.28	249.90
2008	920.81	29.12	207.30
2009	733.60	25.42	119.30
2010	980.73	28.66	143.10
2011	860.85	27.30	112.00
2012	828.48	26.20	193.5

3.5.2 Flow Simulation of Upper Marshyangdi Sub-Basin

Upper Marshyangdi sub-basin having catchment area of 745.51 km^2 lies in north east part of the Marshyangdi river basin. Most of the part of this sub-basin is covered with glacier and impervious rocks. The estimated runoff of the Upper Marshyangdi sub-basin is shown in Figure 3.9. It is observed that the peak simulated discharge for Upper Marshyangdi Sub-Basin is 195.9 m^3/s in 29th September, 2007 while annual mean flow is 30.16 m^3/s and annual flow volume is 950.98×106 m^3.

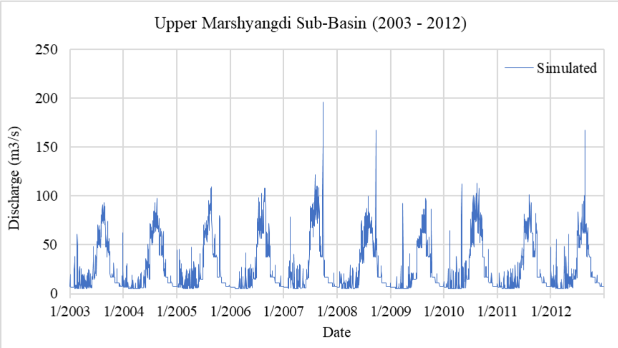

Figure 3.9: Estimation of time series discharge for Upper Marshyangdi sub-basin

The annual flow volume, annual mean flow and annual peak flow of the Upper Marshyangdi sub-basin is shown in Table 3.7.

Table 3.7: Simulated annual mean, peak and flow volume of Upper Marshyangdi sub-basin

Upper Marshyangdi sub-basin			
Year	Volume ($\times 10^6$ m^3)	Mean Flow (m^3/s)	Peak Flow (m^3/s)
2003	798.41	25.32	93.20
2004	782.72	24.75	97.60
2005	834.81	26.47	109.10
2006	789.37	25.03	108.20
2007	950.98	30.16	195.90
2008	841.10	26.60	167.10
2009	717.33	22.75	97.30
2010	878.74	27.86	112.90
2011	805.13	25.53	101.60
2012	781.44	24.71	167.50

3.5.3 Flow Simulation of Dudh Khola Sub-Basin

Dudh Khola sub-basin having catchment area of 382.76 km^2 lies in mid north east part of the Marshyangdi river basin. Most of the part of this sub-basin is covered with glacier and forest.

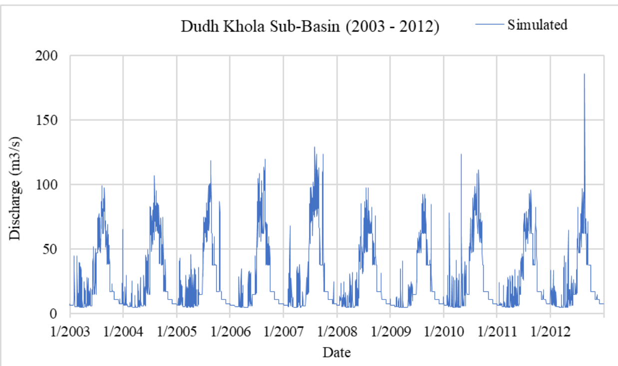

Figure 3.10: Estimation of time series discharge for Dudh Khola sub-basin

The estimated runoff of the Dudh Khola sub-basin is shown in Figure 3.10. It is observed that the peak simulated discharge for Dudh Khola Sub-Basin is 185.8 m^3/s in 22nd August, 2012 while annual mean flow is 24.04 m^3/s and annual flow volume is 760.09×106 m^3.

The annual flow volume, annual mean flow and annual peak flow of the Dudh Khola sub-basin is shown in Table 3.8.

Table 3.8: Simulated annual mean, peak and flow volume of Dudh Khola sub-basin

Dudh Khola sub-basin			
Year	Volume ($\times 10^6$ m^3)	Mean Flow (m^3/s)	Peak Flow (m^3/s)
2003	795.99	25.24	99.10
2004	798.15	25.24	107.00
2005	842.36	26.71	118.40
2006	796.26	25.25	119.70
2007	957.97	30.38	128.90
2008	816.75	25.83	97.60
2009	699.89	22.19	92.40
2010	868.27	27.53	123.30
2011	793.51	25.16	95.60
2012	760.09	24.04	185.80

3.5.4 Flow Simulation of Middle Marshyangdi Sub-Basin

Middle Marshyangdi sub-basin having catchment area of 903.25 km^2, lies in middle part of the Marshyangdi river basin. The major river of the sub-basin is Marshyangdi river. Most of the part of this sub-basin is covered with forest and grassland. The estimated runoff of the Middle Marshyangdi sub-basin is shown in Figure 3.11. It is observed that the peak simulated discharge for Middle Marshyangdi sub-basin is 328.90 m^3/s in 18th June, 2008 while annual mean flow is 49.05 m^3/s and annual flow volume is 1546.76×106 m^3.

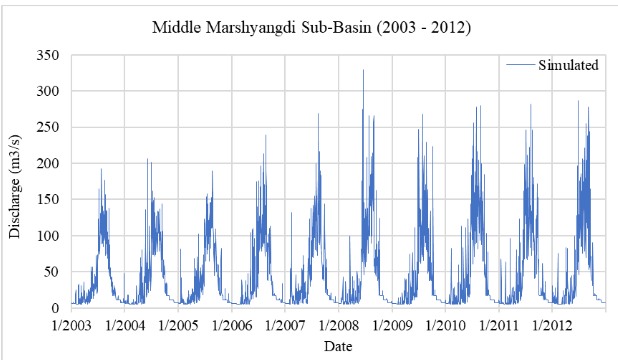

Figure 3.11: Estimation of time series discharge for Middle Marshyangdi sub-basin

The annual flow volume, annual mean flow and annual peak flow of the Middle Marshyangdi sub-basin is shown in Table 3.9.

Table 3.9: Simulated annual mean, peak and flow volume of Middle Marshyangdi sub-basin

Middle Marshyangdi sub-basin			
Year	Volume ($\times 10^6$ m^3)	Mean Flow (m^3/s)	Peak Flow (m^3/s)
2003	1183.54	37.53	192.10
2004	1216.05	38.46	206.80
2005	1249.49	39.62	190.00
2006	1251.00	39.67	238.90
2007	1339.91	42.49	269.20
2008	1532.76	48.47	328.90
2009	1249.30	39.62	267.80
2010	1546.76	49.05	279.70
2011	1482.52	47.01	281.70
2012	1532.20	48.45	286.80

3.5.5 Flow Simulation of Dordi Khola Sub-Basin

Dordi Khola sub-basin having catchment area of 354.44 km^2, lies in upper south east of the Marshyangdi river basin. The major river of the sub-basin is Dori khola. Most of the part of this sub-basin is covered with forest and shrubland and agricultural land. The estimated runoff of the Dordi khola sub-basin is shown in Figure 3.12. It is observed that the peak simulated discharge for Dordi Khola sub-basin is 279.50 m^3/s in 30th July, 2010 while annual mean flow is 46.25 m^3/s and annual flow volume is 1458.51×106 m^3.

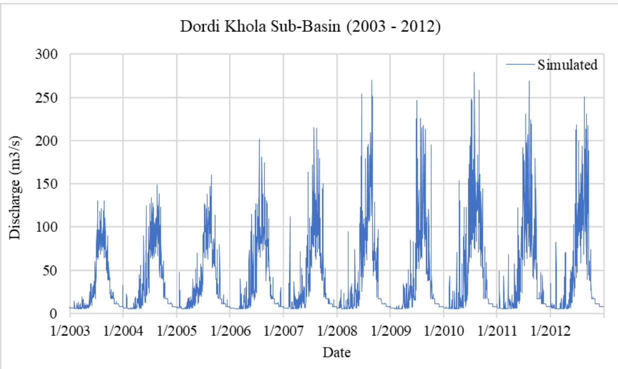

Figure 3.12: Estimation of time series discharge for Dordi Khola sub-basin

The annual flow volume, annual mean flow and annual peak flow of the Dordi Khola sub-basin is shown in Table 3.10.

Table 3.10: Simulated annual mean, peak and flow volume of Dordi Khola sub-basin

Dordi Khola sub-basin			
Year	Volume ($\times 10^6$ m^3)	Mean Flow (m^3/s)	Peak Flow (m^3/s)
2003	917.84	29.10	130.90
2004	1082.32	34.23	148.50
2005	1093.82	34.68	160.20
2006	1139.37	36.13	202.30
2007	1182.15	37.49	215.10
2008	1367.85	43.26	269.80
2009	1180.43	37.43	246.60
2010	1458.51	46.25	279.50
2011	1360.40	43.14	268.80
2012	1395.67	44.14	251.10

3.5.6 Flow Simulation of Chepe Khola Sub-Basin

Chepe Khola sub-basin having catchment area of 311.85 km^2, lies in south east part of the Marshyangdi river basin. The major river of the sub-basin is Chepe khola. Most of the part of this sub-basin is covered with forest and agricultural land. The estimated runoff of the Dordi khola sub-basin is shown in Figure 3.13. It is observed that the peak simulated discharge for Chepe Khola sub-basin is 167.0 m^3/s in 20th August, 2012 while annual mean flow is 29.49 m^3/s and annual flow volume is 932.64×106 m^3.

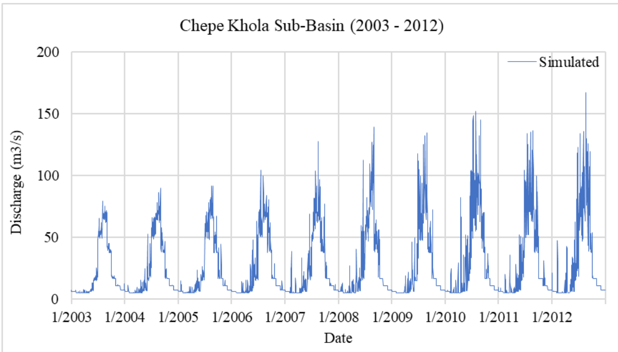

Figure 3.13: Estimation of time series discharge for Chepe Khola sub-basin

The annual flow volume, annual mean flow and annual peak flow of the Chepe Khola sub-basin is shown in Table 3.11.

Table 3.11: Simulated annual mean, peak and flow volume of Chepe Khola sub-basin

Chepe Khola sub-basin			
Year	Volume ($\times 10^6$ m^3)	Mean Flow (m^3/s)	Peak Flow (m^3/s)
2003	654.27	20.75	79.50
2004	707.44	22.37	89.80
2005	719.49	22.81	91.90
2006	759.05	24.07	104.50
2007	764.18	24.23	127.70
2008	852.31	26.95	139.50
2009	801.65	25.42	134.70
2010	942.04	29.87	151.90
2011	887.61	28.15	136.50
2012	932.64	29.49	167.00

3.5.7 Flow Simulation of Lower Marshyangdi Sub-Basin

Lower Marshyangdi sub-basin having catchment area of 471.20 km^2, lies in south west part of the Marshyangdi river basin. As described by its name the major river of the sub-basin is Marshyangdi river. Most of the part of this sub-basin is covered with agricultural land and settlements. The estimated runoff of the Middle Marshyangdi sub-basin is shown in Figure 3.14. It is observed that the peak simulated discharge for Lower Marshyangdi sub-basin is 273.4 m^3/s in 30th July, 2010 while annual mean flow is 45.47 m^3/s and annual flow volume is 1434.03×106 m^3.

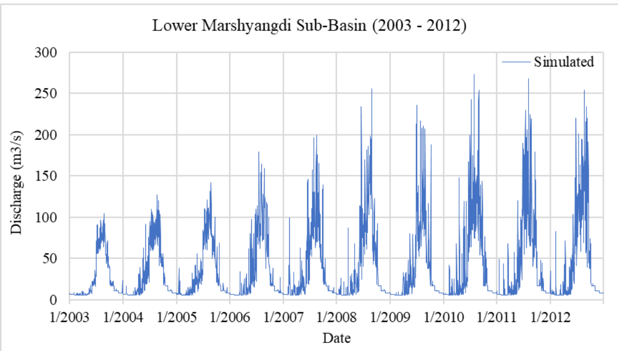

Figure 3.14: Estimation of time series discharge for Lower Marshyangdi sub-basin

The annual flow volume, annual mean flow and annual peak flow of the Lowe Marshyangdi sub-basin is shown in Table 3.12.

Table 3.12: Simulated annual mean, peak and flow volume of Lower Marshyangdi sub-basin

Lower Marshyangdi sub-basin			
Year	Volume ($\times 10^6$ m^3)	Mean Flow (m^3/s)	Peak Flow (m^3/s)
2003	771.77	24.47	104.40
2004	946.36	29.93	126.80
2005	994.59	31.54	142.20
2006	1058.22	33.56	179.30
2007	1116.66	35.41	198.90
2008	1307.92	41.36	255.80
2009	1150.50	36.48	235.70
2010	1434.03	45.47	273.40
2011	1354.92	42.96	268.00
2012	1403.97	44.40	253.70

3.5.8 Flow Simulation of Marshyangdi River Basin

It is observed that the simulated discharge at the outlet of the river basin is the algebraic sum of outflow of all the sub-catchments. The simulate discharge of the Marshyangdi river basin is shown in Figure 3.15. It is also observed that the peak simulated discharge for Marshyangdi river basin is 1510.50 m^3/s in 9th July, 2003.

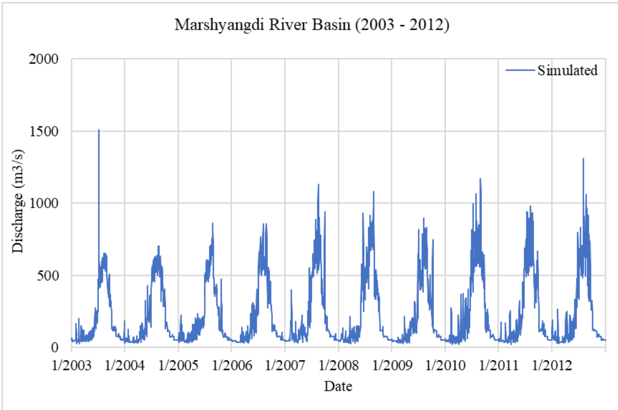

Figure 3.15: Estimation of time series discharge for Marshyangdi river basin

4. Conclusion and Recommendations

4.1 Conclusions

Hydrological studies are important and necessary for water and environmental resources management. Demands from society on the predictive capabilities of such study and analysis of hydrological parameters are becoming higher and higher, leading to the need of enhancing existing research theories and even on developing new theories. The study has been conducted in the Marshyangdi river basin of Nepal, which is an important river basin in Nepal from Hydropower perspective.

The HEC-HMS hydrological simulation catchment model has been calibrated (2003 – 2008) and validated (2008 – 2012) at outlet of Marshyangdi river basin. The soil moisture storage coefficient and the base flow coefficients are the most sensitive parameters for simulation of runoff. The Nash-Sutcliffe efficiency (E_{NS}) and coefficient of determination (R^2) of model performance criterion are used to evaluate the model applicability for Marshyangdi river basin. Where the calculated value of both E_{NS} and R^2 has found 0.778 for calibration period and 0.842 for validation period. Which shows the model has well simulated the daily stream flow at the outlet of the river basin, however there is a slight under and over prediction of the high flows; this is the common draw backs of hydrological models. The results obtained are satisfactory and acceptable. Further the runoff of each seven sub-catchments have been estimated using this model for 2003-2012. It has been found that the algebraic sum of runoff of each seven catchments is nearly equal to simulated discharge at outlet of the Marshyangdi river basin, which also proves the reliable of the model.

4.2 Recommendations

The HEC-HMS model can be used for modeling and projection of future impacts of climate changes on runoff for Marshyangdi river basin and can be applied to other catchments with similar hydro meteorological and land use characteristics. Since HEC-HMS hydrological model assumed that the land use has been unchanged during modeling period, in reality the land use may change. Also, the soil type is assumed based on land use map and visual inspection for the estimation of curve number. In the future, we recommend further studies which incorporate the land use change and use of soil map of the basin.

Acknowledgments

Authors are grateful to the Center of Research for Environment, Energy and Water, Kathmandu for 10th CREEW Research Grant, and Research Management Unit, Pashchimanchal Campus, Pokhara for Mini Research Grant for this research work.

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