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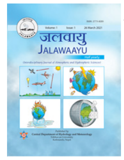

Research Article

Rainfall-runoff simulation of Bagmati River Basin, Nepal

Yam Prasad Dhital [1, 2*], Binod Dawadi [3, 4], Dambaru Ballab Kattel [5], and Krishna Chandra Devkota [6]

[1] Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[2] Institute of Eco-Chongming, Faculty of Earth Sciences, East China Normal University, Chongming, Shanghai, China
[3] Central Department of Hydrology and Meteorology, Tribhuvan University, Kathmandu, Nepal
[4.] Kathmandu Center for Research and Education, Chinese Academy of Sciences, Tribhuvan University 44613 Kathmandu
[5] Key Laboratory of Tibetan Plateau Environment and Land Surface Processes, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100101, China
[6] Global Institute for Interdisciplinary Studies (GIIS), Kathmandu, Nepal

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**Correspondence*

Yam Prasad Dhital
ypdhital@gmail.com

Abstract: Runoff simulation is a complex problem in mountain catchments due to high rainfall variability and rugged topography. In the lower parts of Nepal, river flooding is a serious disaster problem in July and August; sometimes it also occurs in September. In this context, Hydro-Informatic Modeling System (HIMS) was used for daily and monthly runoff simulation from the set of daily hydro-meteorological data (Maximum and minimum temperature, rainfall, and discharge) in the time series 1980 to 1989, 1990 to 1999, and 2000 to 2009, respectively. The model performed well for the monthly runoff simulation, whereas the efficiency coefficient and relative coefficient both were found a very good correlation between observed and simulated hydrographs,

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which varied between 0.883 to 0.940 and 0.889 to 0.945, respectively. However, the efficiency coefficient and relative coefficient both were found a very poor correlation between observed and simulated hydrographs for the daily runoff simulation, which averaged 0.342 and 0.348, respectively. The daily simulation result also might have been improved, if more number of uniformly distributed meteorological station data is available.

1. Introduction

Water resource management is essential for the sustainable development of the society under climate change, especially in densely populated and flood-sensitive areas. The hydrological model serves as a valuable tool in water resource management at the catchment scale, and its ultimate goal is to estimate the runoff from a catchment corresponding to rainfall and route the runoff downstream through a river network (Bhadra et al. 2010). Both stochastic and process-based hydrological models can be utilized for runoff simulation. Stochastic hydrological models are data-driven models and generally treat the catchment as a black-box system while the process-based hydrological model is a simplified and conceptual representation of the multi-scale and complex hydrological cycle in reality.

Over the past several decades, process-based hydrological modeling has made a great success and a series of lumped, semi-distributed, and fully distributed process-based hydrological models have been developed and applied in water resource management. Despite the remarkable success, uncertainties still exist in hydrological modeling results that can be mainly categorized into 3 sources: uncertainty in model structure, uncertainty in model inputs (forcing), and uncertainty in model parameter values (Wagener and Gupta 2005). Uncertainties from the model structure are fundamentally from the conceptual simplification of the real natural world. Uncertainties in model inputs in most of the river catchments are due to both (i) measurement errors and (ii) the poor spatial representativeness of operational station networks (Hwang et al. 2011). Moreover, uncertainties in model parameters can vary among catchments with different physical characteristics and climate conditions. Usually, the model parameter uncertainties are mitigated through parameter calibration. To calibrate a rainfall–runoff model by optimizing river flows statistics, one needs the long series of input data for the model itself (typically rainfall data). Then, the model is run by using trial values for its parameters and river flows are simulated. These simulated data allow one to estimate river flow statistics that are then compared with those obtained from the observed streamflow data or through regionalization (Lombardi et al. 2011), though it is not necessarily over the same period in which the input data are available. However, the complexity of the model varies according to the scale of operation, required accuracy, computer facilities, and type of hydrologic quantity to be modeled (Abulohom et al. 2001).

In Nepal, there are four major river basins of Koshi, Narayani, Karnali, and Mahakali River systems. The Karnali, the Narayani, and the Koshi are major snow and glacier-fed rivers, besides the Mahakali, which borders Nepal and India in the west. In general, discharge in these rivers increase from the pre-monsoon period to the monsoon period and remains high up to the post-monsoon period. However, high inter-annual variability in flow regimes was observed in most rivers (Hannah et al. 2005). So, runoff simulation is a complex task and requires great effort for calibrating model parameters (Nepal et al. 2014). In the Bagmati River Basin, Shrestha et al. (2008) simulated river flows based on a Geospatial Stream Flow Model (GeoSFM). Their results showed that the model performed well for simulating the flows of the river with observed rainfall data for a short period. In this study, Hydro-Informatic Modeling System (HIMS) has been used for rainfall-runoff simulation. HIMS has been already used in the case studies of the Yellow River Basin in China and Murray Darling Basin in Australia, and the results showed that HIMS was able to simulate runoff well for these selected catchments (Liu et al., 2008). This study aims to test the applicability of HIMS in the mountainous river basins of Nepal, whereas the Bagmati River Basin is selected for a representative study.

2. Study Area

Bagmati River Basin lies in the middle mountainous region of Nepal covering an area of about 3750 sq. km (Figure 1). It extends from 26° 42′ N to 27° 50′ N and from 85° 02′ E to 85° 58′E. The Bagmati watershed lies in Bagmati Province and Province number 2 and cover parts of eight different administrative districts: Kathmandu, Lalitpur, Bhaktapur, Makwanpur, Kavre, Sindhuli, Rautahat, and Sarlahi. The Bagmati River originates from the north of Kathmandu district at Shivapuri (Bagdwar) at an altitude of 2690 m inside the Mahabharat Range and ends in Sarlahi district and then enters into the Indian State of Bihar feeding into the Ganges River. The major tributaries of the Bagmati River are Nakkhu, Durlung, Kokhajor, Marin, and Chandi rivers. The watershed area above Pandhera Dobhan, called the upper watershed, covers 2720 sq. km and includes the mountainous area including Kathmandu valley. The region below Pandhera Dobhan is the flat alluvial plain of the Terai and called the lower watershed. The total length of the river from its origin to the Nepal- India border is 170 km.

The river basin has a subtropical climate in the lower regions (<1000 m asl) that characterizes the Terai and the Chure Range, warm temperate climate in the mid regions (1000-2000 m asl) that includes the lower hills of the Mahabharat Range, and a cool temperate climate in the upper regions (>2000 m asl) which represents the higher hills of the Mahabharat Range (Karki et al. 2016). The higher hills receive snowfall occasionally during the winter months (Khadka et al. 2020). The annual and monsoon (June, July, and August) average rainfall amounts of the catchment area are 2100 mm and 1700 mm, respectively, and the mean annual temperature varies between 12- 23 °C based on the data from 1980 to 2009 (Dhital et al. 2011, Dhital et al. 2013). High rainfall variability was observed in the river basin. The lower part of the river basin is heavily impacted by flooding during the main monsoon months (July and August). Both flash floods and riverine floods frequently occur in the river basin (Dhital and Kayastha, 2013). However, flash flood frequently occurs in pre-monsoon, and riverine flood frequently occurs in monsoon and post-monsoon. Further, flooding with inundation is a common problem in the lower parts of the river basin (Dhital and Tang, 2015).

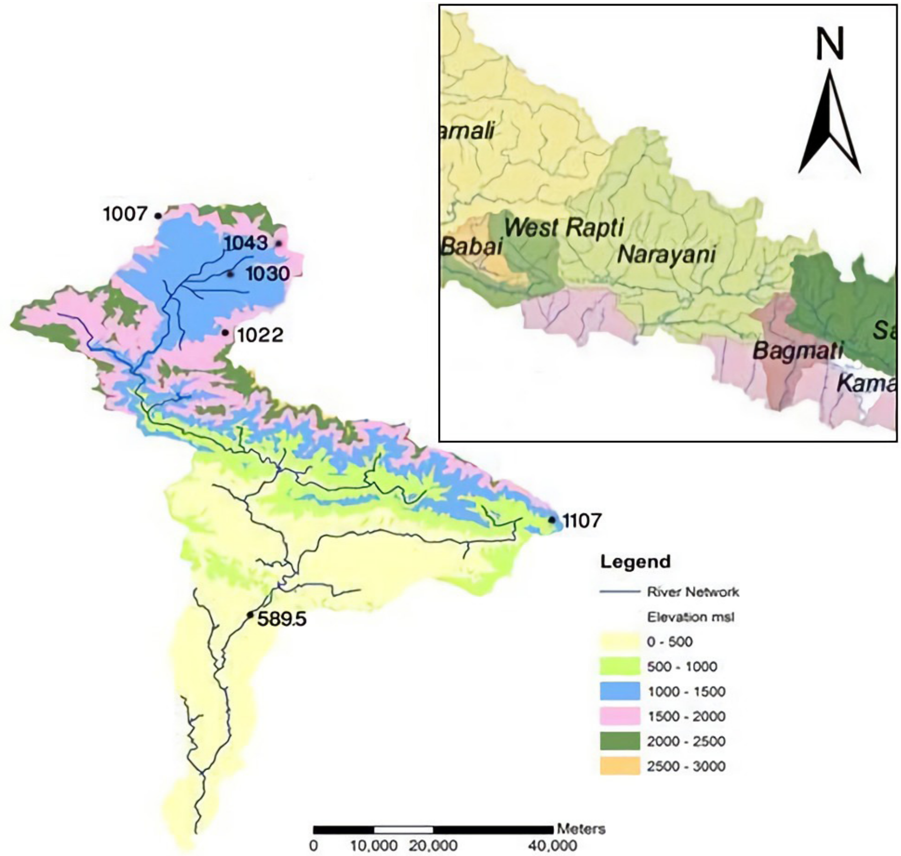

Figure 1. Location of climatological and discharge gauging stations in the Bagmati River Basin

3. Data and Methods

In this study, HIMS was used to simulate the flow of the river. HIMS is a modular-based open framework, which is very useful for customizing hydrological models. It enables the rapid assembling of hydrologic models to meet requirements for different spatial and temporal scales applications in various river catchments. It includes a hydrologic information system (HIS) and a hydrologic model library (HML). Integrated with geographic information system and remote sensing, the hydrologic information system of HIMS was well organized to provide functions to deal data with different sources and obtain geographical characters from the digital elevation model (DEM). Considering multiple parameters such as catchment heterogeneity, scaling issues, and the hydrological impacts of human activities, HIMS was designed to provide the functioning for multi-source data analysis and digital catchment analysis. Based on spatial topological relationships among the channel network, HIMS divides a catchment into different grids with different soil, vegetation, and land-use properties. Each grid can include a channel, and grids are linked through a stream network. The development and application of HIMS have been explained in detail by Liu et al. (2008).

In this study, daily precipitation, temperature (daily maximum and minimum), and daily discharge data from 1980 to 2009 (30 years) are used for rainfall-runoff simulation. The observed data from five climatological stations (Figure 1): Kakani (Station No. 1007), Nagarkot (Station No. 1043), Kathmandu Airport (Station No. 1030), Godavari (Station No.1022), and Sindhuli Gadhi (Station No.1107), and only one discharge station; Pandhera Dobhan (Station No. 589.5) were considered for runoff simulation. The observed data were used in the three-time series: 1980 to 1989, 1990 to 1999, and 2000 to 2009, respectively, and the other model input parameters are shown in Table 1.

Table 1. Input parameters for rainfall-runoff simulation

Parameter		1980-1989	1990-1999	2000-2009
Runoff parameter	SMSC(mm)	1000	1000	1000
	R	2.30	4.78	1.23
	r	0.90	0.99	0.99
	interflow	0.10	0.10	0.10
	infiltration	1.00	1.00	1.00
	evaporation	0.10	2.15	3.19
	base flow	0.05	0.17	0.29
Flow parameter	C1	0.18	0.18	0.18
	C2	0.66	0.66	0.66

(SMSC: Soil moisture storage capacity, R and r: Infiltration parameters)

4. Results and Discussion

The simulation results are shown in Figures 2 to 7 and the results are based on daily and monthly runoff simulations. Monthly simulated runoff values were quite closer to the observed runoff values in almost years, but daily simulated runoff values were smaller than the observed values with high differences. The highest observed runoff values in 1984, 1987, 1988, and 2009 were found quite larger than the simulated runoff values, whereas, simulated runoff values in 1995, 2005, and 2007 were quite larger than the highest observed runoff values in monthly simulation. However, both observed and simulated runoff values were found almost equal in 1980, 1983, 1985, 1993, 2002, and 2008. In the river basin, the 1993 flood is regarded as an extreme flood event to date, which corroborated with our result from the monthly simulation; both observed and simulated runoff was found to be 820 m^3/s in July 1993.

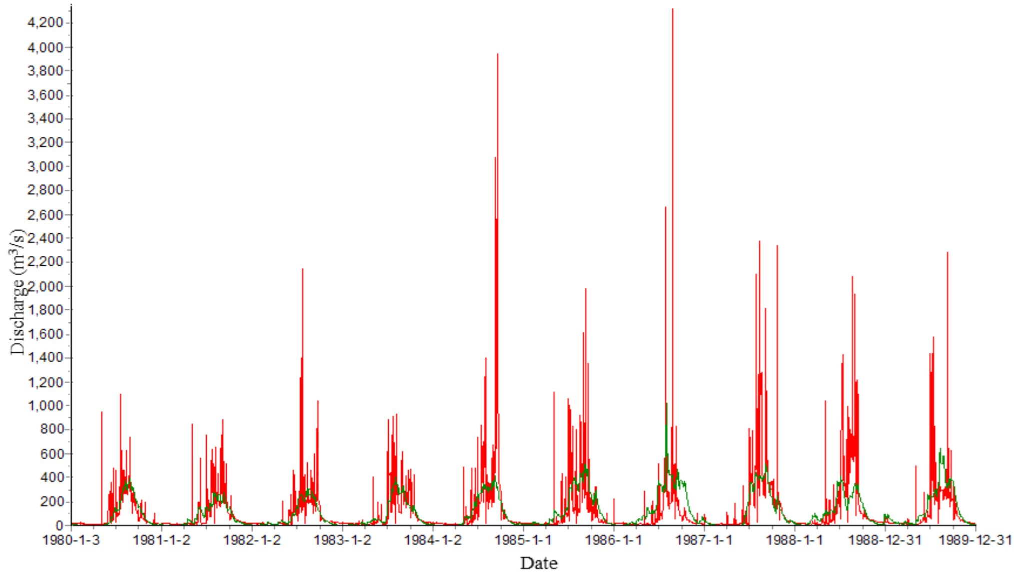

Figure 2. Daily runoff simulation from 1980-1989 (red line-observed runoff, green line-simulated runoff)

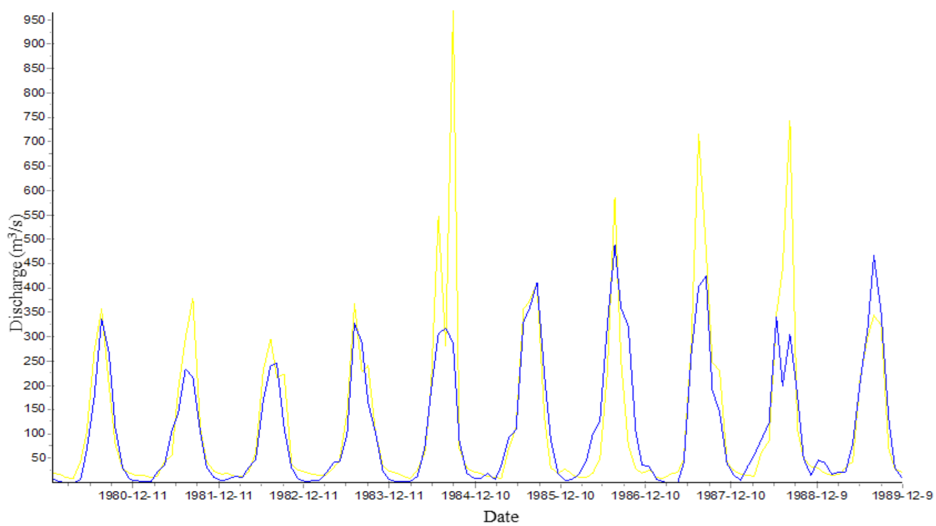

Figure 3. Monthly runoff simulation from 1980-1989 (yellow line-observed runoff, blue line-simulated runoff)

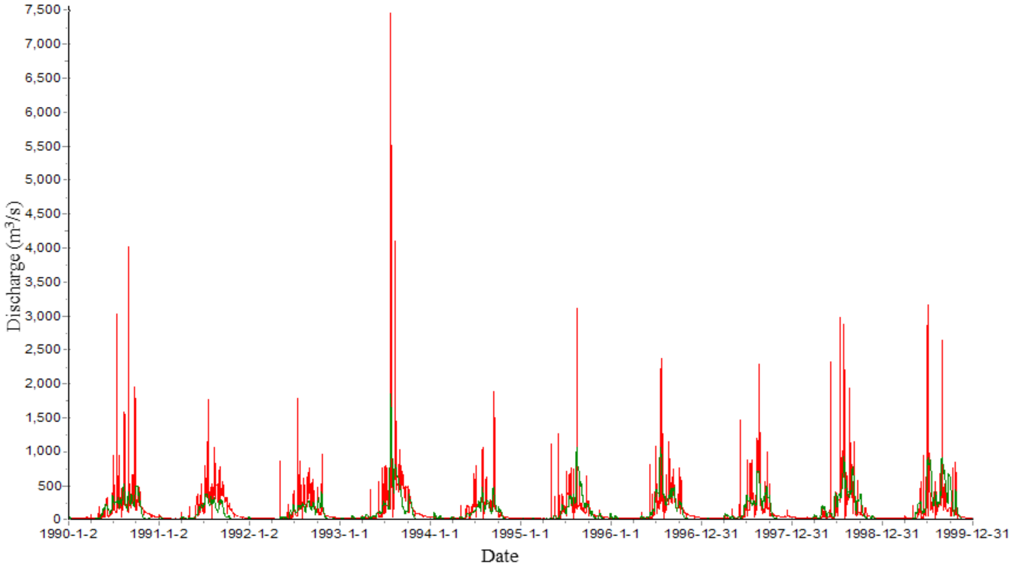

Figure 4. Daily runoff simulation from 1990-1999 (red line- observed runoff, green line- simulated runoff)

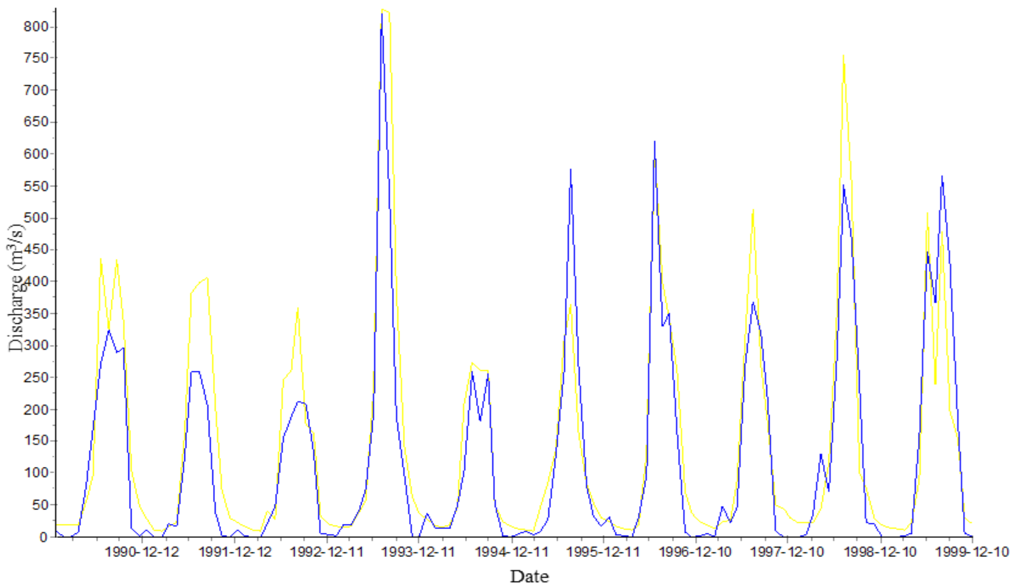

Figure 5. Monthly runoff simulation from 1990-1999 (yellow line- observed runoff, blue line- simulated runoff)

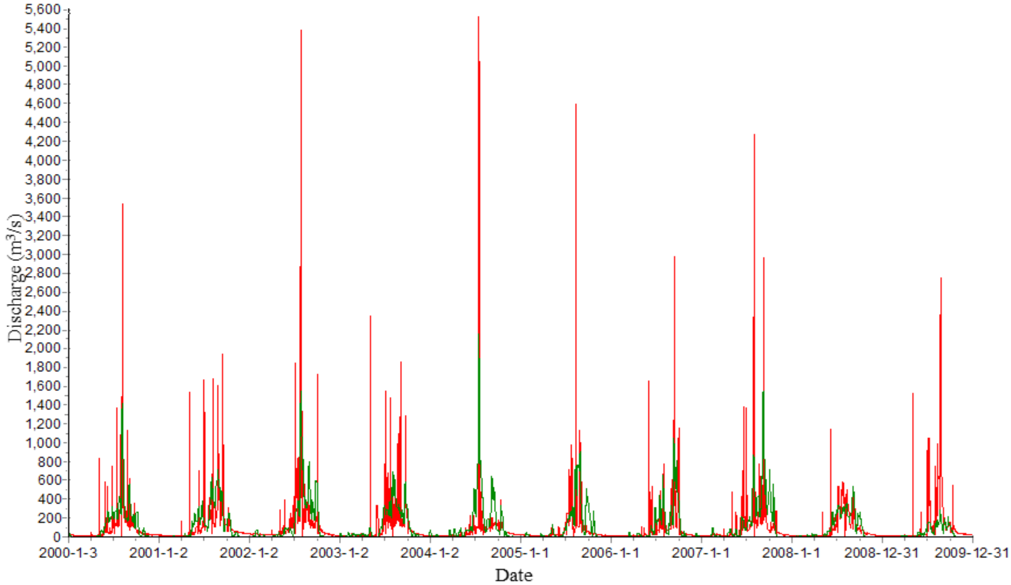

Figure 6. Daily runoff simulation from 2000-2009 (red line-observed runoff, green line- simulated runoff)

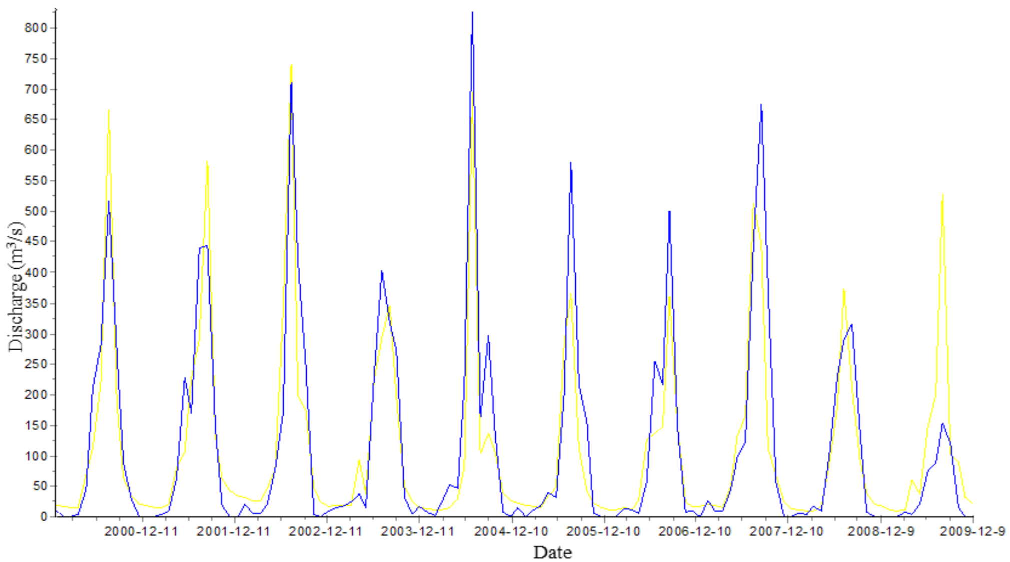

Figure 7. Monthly runoff simulation from 2000-2009 (yellow line-observed runoff, blue line-simulated runoff)

The efficiency coefficient and relative coefficient both were found a very poor correlation between observed and simulated hydrographs in the daily simulation, which averaged 0.342 and 0.348, respectively. Nevertheless, from the monthly simulation, the efficiency coefficient and relative coefficient both showed a very good correlation between observed and simulated hydrographs, which varied between 0.883 to 0.940 and 0.889 to 0.945, respectively. Furthermore, the standard error was also very high in daily simulation in comparison to the monthly simulation (Table 2).

Table 2. Correlation result between observed and simulated hydrographs

Index	Process	1980-1989	1990-1999	2000-2009
Efficiency Coefficient	Day	0.319	0.367	0.342
	Month	0.883	0.940	0.907
Relative Coefficient	Day	0.325	0.373	0.348
	Month	0.889	0.945	0.916
Volume Error	Day	-0.119	-0.167	0.031
	Month	0.005	0.009	-0.001
Standard Error	Day	211.007	250.642	245.864
	Month	17.689	13.505	14.274
Relative Error	Day	1.082	0.904	1.148
	Month	0.019	0.018	0.020

The results of the HIMS model in a daily simulation might have been improved, if more climatological station data are available. In the river basin, only the regular data from five climatological stations above the discharge measuring station were available where the catchment area is 2720 sq. km. These five climatological stations are also not uniformly distributed. On the other hand, landslides and debris flow frequently occur in the river basin (Dhital and Kayastha 2013), which intensifies the flash flood events more than the riverine flood. This also may be responsible for increasing the daily peak flow. Furthermore, anthropogenic factors such as deforestation, mining, and unurbanized planning in the valley side may affect daily simulation hydrographs.

During the analysis period, hydrograph results show higher runoff values after 2000, indicating the increasing flood events. A previous study (Dhital et al. 2013) also revealed that the intensity of peak discharge trend was increasing in the Bagmati River Basin. However, mean discharge trends in winter and monsoon have been decreasing but increasing in pre-monsoon. Sharma and Shakya (2006) focused on hydrological changes and concluded that the mean yearly flow in the Bagmati River was decreasing significantly, and the hydrograph was shifting in time. Based on the Hadley Centre Coupled Model (HadCM3), Babel et al. (2014) predicted that precipitation might increase during the wet season, but it may decrease during other seasons in the future. In sum, previous studies, including this study, have intensified the challenges for water resource management in the Bagmati River Basin.

5. Conclusions and Recommendations

Hydro-Informatic Modeling System (HIMS) can be used for the monthly runoff simulation of the Bagmati River. The efficiency coefficient and relative coefficient are both found to have a good correlation between observed and simulated hydrographs for the monthly runoff simulation, which vary between 0.883 to 0.940 and 0.889 to 0.945. In July 1993, both observed and simulated monthly runoff was found to be 820 m^3/s. However, the efficiency coefficient and relative coefficient both are found to have a very poor correlation between observed and simulated hydrographs for the daily runoff simulation, which averaged 0.342 and 0.348, respectively. More number of uniformly distributed climatological stations should be established for further improvement in the current results. Moreover, the installation of weather radars should be beneficial for the estimation of high runoff values and also for the prediction of extreme flood events. The application of the latest hydrological models can be helpful to provide a scientific basis for water resources management. It may provide future runoff scenarios, including flood forecasting, which will also be very important for policymakers to save the lives and property of the country.

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Conflicts of Interest: The authors declare no conflict of interest.

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