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Hydrological Modeling of Extreme Rainfall Events in the Gandaki River Basin Using HEC-HMS

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Abstract

Hydrological modeling is categorized into lumped, semi-distributed, and distributed models, and with the semi-distributed model dividing a basin into sub-basins to estimate runoff and compute stream flow at the outlet. This study applies the semi-distributed HEC-HMS model to assess the impact of channel geometry on hydrological modeling in the Narayani River Basin, Nepal. Different channel geometries were simulated to analyze their effects on stream flow. Results indicate that the trapezoidal channel section provides the most accurate representation, closely matching observed discharge. The model was calibrated using 2004-2005 rainfall-runoff data and validated with 2006 data. The findings suggest that trapezoidal channels are the most effective for flood forecasting and continuous simulation. Future research should incorporate high-resolution data sets to enhance accuracy and improve model performance.

Keywords: *simulation, modeling, distributed, geometry, Narayani basin, routing*

Introduction

Hydrological models are essential tools for simulating river basin behavior, predicting runoff, and managing water resources. These models can be broadly categorized into lumped, semi-distributed, and distributed models (Singh & Woolhiser, 2002). Semi-distributed models, which divide the basin into sub-basins and use conceptual relationships to simulate hydrological processes, are widely used due to their balance between computational efficiency and accuracy (Beven & Kirkby, 1997). However, the performance of these models is highly dependent on the spatial discretization of the watershed and the representation of physical processes, including channel geometry (Chow *et al.,* 1988; Singh & Woolhiser, 2002).

Channel geometry, defined by its cross-sectional shape, slope, and roughness, is a critical factor in hydrological modeling. The shape of the channel (e.g., trapezoidal, rectangular, or triangular) influences the flow velocity, water depth, and discharge, which in turn affect the timing and magnitude of the hydrograph at the basin outlet (Gautam, 2009; HEC, 2001). Despite its significance, the role of channel geometry in semi-distributed hydrological models has not been thoroughly investigated. Most studies focus on lumped or distributed models, leaving a gap in understanding how different channel geometries impact the accuracy of semi-distributed models (Jha *et al,* 2004; Mamillapalli *et al.,* 2000).

Objectives

While previous studies have explored the effects of watershed subdivision and spatial discretization on hydrological models (Karamouz *et al.,* 2012), there is limited research on the specific impact of channel geometry on the performance of semi-distributed models (Jha *et al.,* 2006; Lu & Jhao, 1980). Existing literature often assumes simplified channel shapes or overlooks the variability in channel geometry across different sub-basins. This study addresses this gap by evaluating the influence of alternative channel geometries (trapezoidal, rectangular, and triangular) on the hydrological response of a watershed using the HEC-HMS semi-distributed model. The specific objectives of this study are:

- To simulate the hydrological response of a watershed using a semi-distributed model with different channel geometries (trapezoidal, rectangular, and triangular).
- To evaluate the impact of channel geometry on the accuracy of the simulated hydrograph at the basin outlet.
- To identify the optimal channel geometry for accurate runoff simulation in semi-distributed hydrological models.

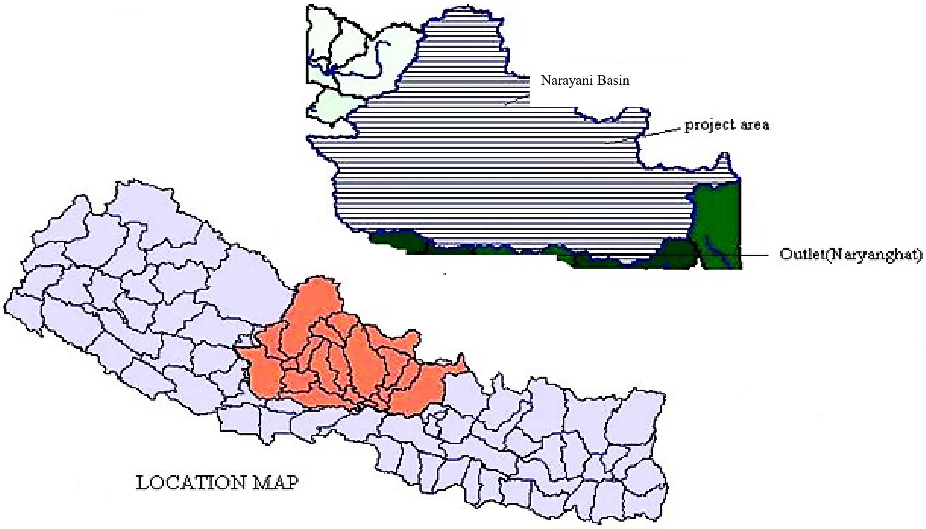
Methodology

Study Area

The Narayani River Basin, spanning the Gandaki and Bagmati provinces of Nepal, extends from the Himalayas to the Indo-Nepal border, covering 40,752 km² (30,162 km² in Nepal, 10,590 km² in China). It features elevations from 73 m to 7,163 m and includes major tributaries like the Kaligandaki, Seti, Modi, Madi, Budhi Gandaki, Marshyangdi, and Trisuli (Figure 1). The basin supports diverse ecosystems, from glaciers to subtropical forests, and is vital for agriculture, hydropower, and tourism. However, it faces challenges from climate change and anthropogenic activities (Acharya & Oli, 2004; Thapa, 2008; Thapa, 2003). This study examines the impact of channel geometry on hydrological processes, essential for water resource management, flood forecasting, and infrastructure planning.

Figure 1

Research Study Site



Data and Methods

Data Sources and Characteristics

The study utilizes a combination of spatial, hydrological, and meteorological data to achieve its objectives. The primary data sources and their characteristics are as follows:

i. **Digital Elevation Model (DEM):** High-resolution DEM data from the Copernicus and ASTER Global DEM (30m resolution) were used to accurately represent the basin's topography (Rao *et al.,* 2009). These data sets were chosen over coarser alternatives (e.g., 100m resolution) to minimize overestimation errors and improve the precision of hydrological simulations (Figure 2 and Figure 3).

ii. **Hydrometeorological Data:**Daily precipitation, temperature, and relative humidity data were obtained from the Department of Hydrology and Meteorology (DHM), Nepal. These data sets were processed using the Thiessen polygon method to account for spatial variability in rainfall distribution (Soliman, 2010).

iii. **Soil and Land Use Data:** Soil maps and land use data were acquired from the Ministry of Agriculture and Livestock Development, Nepal. These data sets were used to extract key parameters such as hydraulic conductivity, suction head, initial moisture deficit, and Manning's roughness coefficient (Assouline, 2013).

iv. **Streamflow Data:** Observed discharge data at the basin outlet were collected from DHM for model calibration and validation (Bhattarai, 2007).

Figure 2

Research Study Site

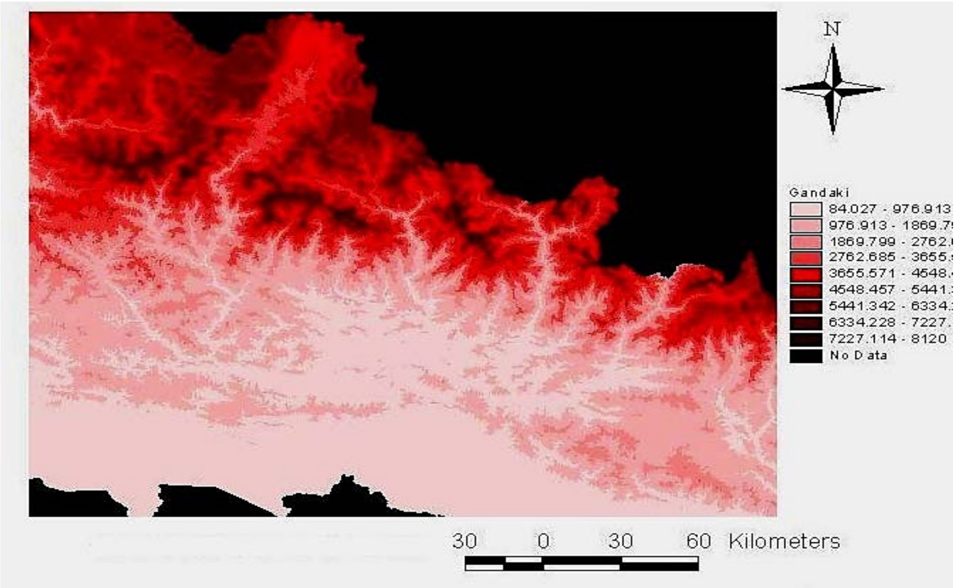


Figure 3

Direction Grid of Narayani basin

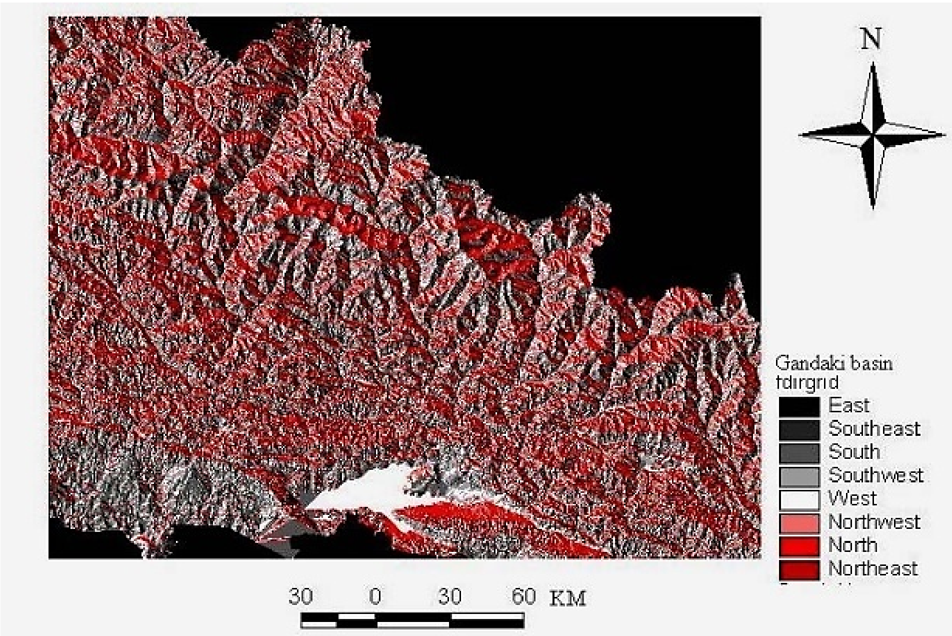
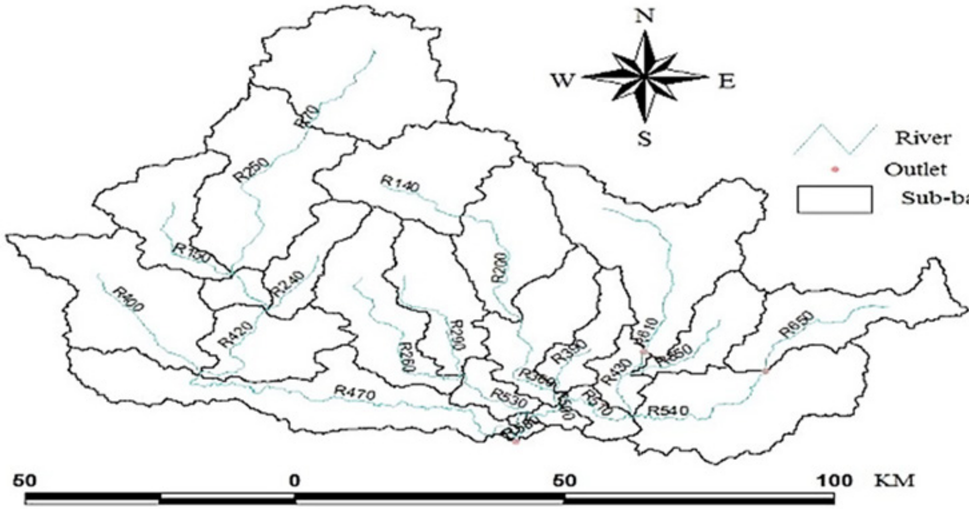


Figure 4

River Delineation of Study Area



Model Selection and Justification

The Hydrologic Engineering Centre Hydrologic Modeling System (HEC-HMS) was selected for this study due to its suitability for semi-distributed hydrological modeling and its ability to incorporate channel geometry variations (Hydrologic Engineering Centre, 2001). HEC-HMS is widely used for rainfall-runoff simulations, flood forecasting, and water resource management. Its advantages include:

i. **Flexibility:** HEC-HMS allows for the integration of various hydrological processes, including infiltration, surface runoff, and channel routing (Fleming, 2002).

ii. **User-Friendly Interface:** The model is supported by GIS extensions (HEC-GeoHMS and HEC-GeoRAS), which facilitate the extraction of basin characteristics and streamline the modeling process (Olivera, 2001).

iii. **Proven Applicability:** HEC-HMS has been successfully applied in similar studies in the Himalayan region, making it a reliable choice for the Narayani River Basin (Sagar, 2007).

While other models such as Spatial Processes in HYdrology (SPHY) and Hydrologiska Byrans Vattnbalansavdelning (HBV) are also prevalent, HEC-HMS was chosen for its ability to explicitly incorporate channel geometry and its compatibility with high-resolution DEM data.

Technical Methodology

The methodology for this study follows the following steps:

Data Preprocessing:

- The DEM was processed to remove sinks and generate flow direction, flow accumulation, and stream networks using the 8-Direction Pour Point Model in HEC-GeoHMS (Maidment & Snead, 2000).
- Sub-basins were delineated based on the stream network, and their physical characteristics (e.g., slope, area, longest flow path) were extracted (Di Luzio *et al.,* 2001) (Figure 4).

Infiltration Process:

- The Green-Ampt infiltration model was selected to simulate the vertical movement of water through the soil profile (Assouline, 2013). This model was chosen for its physical basis and ability to account for soil properties such as hydraulic conductivity and moisture content.

Routing Process:

- The Kinematic Wave method was used for both overland flow and channel routing (HEC, 1979). This method is suitable for simulating flow in steep terrains like the Narayani Basin, where inertial and pressure forces are negligible compared to gravitational and frictional forces.
- Channel geometry parameters (e.g., cross-sectional shape, slope, and roughness) were extracted using HEC-GeoRAS and incorporated into the model (Maidment & Snead, 2000).

Model Execution:

- The HEC-HMS model was calibrated using observed discharge data at the basin outlet (Fleming, 2002). Key parameters such as Manning's roughness coefficient and infiltration rates were adjusted to minimize discrepancies between simulated and observed hydrographs.
- The model was validated using an independent data set to ensure its reliability and accuracy.

Impact of Channel Geometry:

- Three alternative channel geometries (trapezoidal, rectangular, and triangular) were simulated to evaluate their impact on the hydrological response at the basin outlet (Gautam, 2009).

- The performance of each geometry was assessed based on metrics such as peak flow, time to peak, and total runoff volume.

Validation of Results:

- The simulated hydrographs were compared with observed discharge data using statistical metrics such as Nash-Sutcliffe Efficiency (NSE), Root Mean Square Error (RMSE), and Percent Bias (PBIAS) (Choudhury *et al.,* 2002; Singh & Woolhiser, 2002).
- Sensitivity analysis was conducted to identify the most influential parameters affecting model performance.

Validation and Sensitivity Analysis

To ensure the reliability of the results, the model was validated using an independent data set of observed discharge. Statistical metrics such as NSE, RMSE, and PBIAS were used to quantify the agreement between simulated and observed hydrographs (Piman & Babel, 2013). Sensitivity analysis was performed to identify the parameters (e.g., Manning's roughness coefficient, infiltration rate) that have the greatest impact on model output (Jha *et al.,* 2006). This step is crucial for understanding the uncertainties associated with the model and improving its accuracy.

Results and Discussion

The primary objective of this study was to evaluate the impact of different channel geometries (trapezoidal, triangular, and rectangular) on the hydrological response of the Narayani River Basin at its outlet near Narayanghat Bazar. This was achieved by simulating the temporal variation of flow using three distinct years of precipitation data (2004, 2005, and 2006). The results are presented in terms of model calibration, validation, and performance analysis, focusing on annual stream flow volume, mean flow, peak flow, and model efficiency.

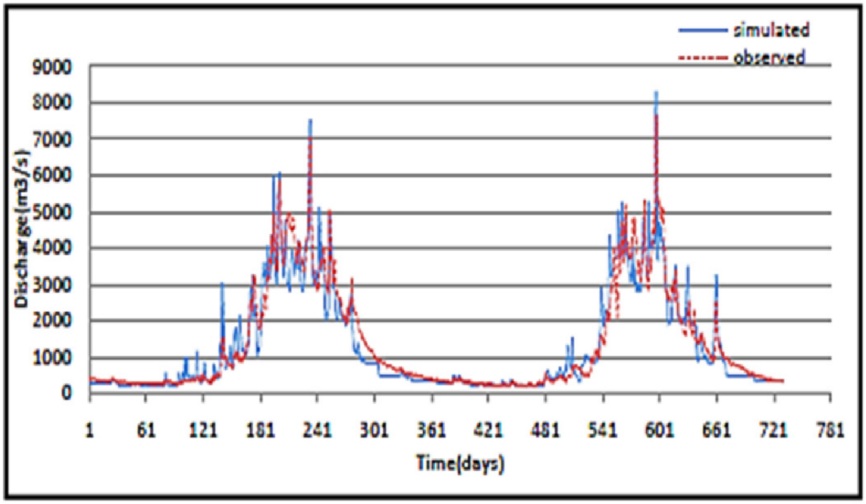
Model Calibration

The model was calibrated using daily rainfall-runoff data from 2004 and 2005. Both manual and automated calibration techniques were employed to estimate the optimal parameter values (Fleming, 2002). The simulated hydrographs for the calibration period are shown in Figure 5, Figure 6 and Figure 7.

- **Trapezoidal Channel Section (Figure 5):** The simulated hydrograph closely matches the observed hydrograph, with minor deviations during peak flow events. The Nash-Sutcliffe Efficiency (NSE) for this section was 0.89, indicating a high level of agreement between observed and simulated flows.

Figure 5

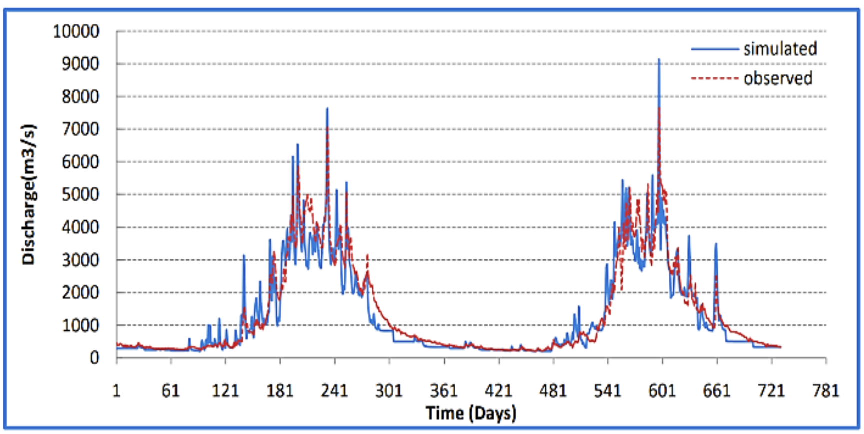
Observed and Simulated Hydrograph of Trapezoidal Channel Section for Calibration Period 2004-2005



- **Triangular Channel Section (Figure 6):** The triangular section showed a slightly higher peak flow compared to the observed data, with an NSE of 0.85. The overall shape of the hydrograph was well-captured, but the model overestimated flow during high-intensity rainfall events.

Figure 6

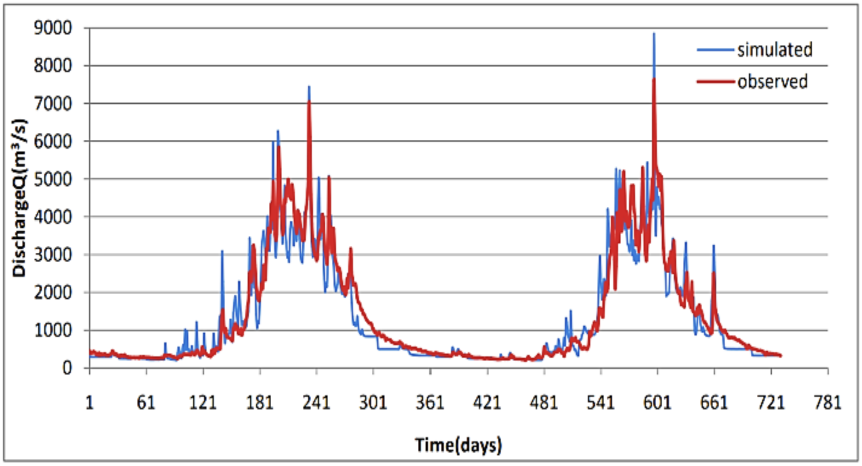
Observed and Simulated Hydrograph of Triangular Section for Calibration Period 2004-2005



- **Rectangular Channel Section (Figure 7):** The rectangular section exhibited the largest deviations from the observed data, particularly during peak flow periods. The NSE for this section was 0.82, reflecting lower accuracy compared to the trapezoidal and triangular sections.

Figure 7

Observed and Simulated Hydrograph of Rectangular Section for Calibration Period 2004-2005



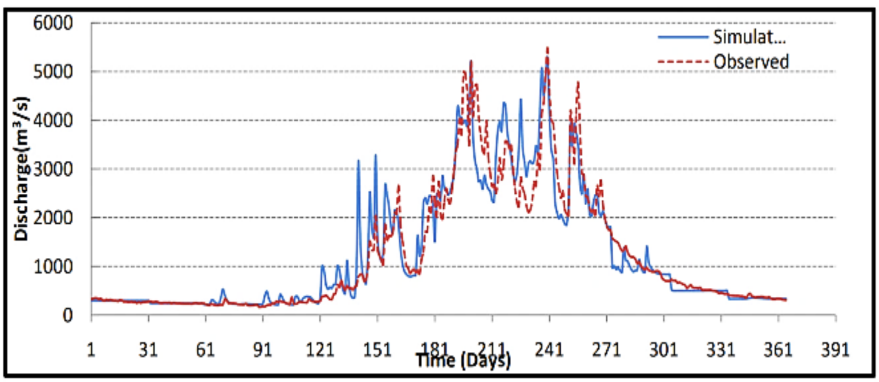
Model Validation

The model was validated using daily rainfall-runoff data from 2006. The calibrated parameters were used to simulate the runoff, and the results are presented in Figure 8, Figure 9 and Figure 10.

- **Trapezoidal Channel Section (Figure 8):** The trapezoidal section continued to perform well during the validation period, with an NSE of 0.88. The simulated hydrograph accurately captured the timing and magnitude of peak flows.

Figure 8

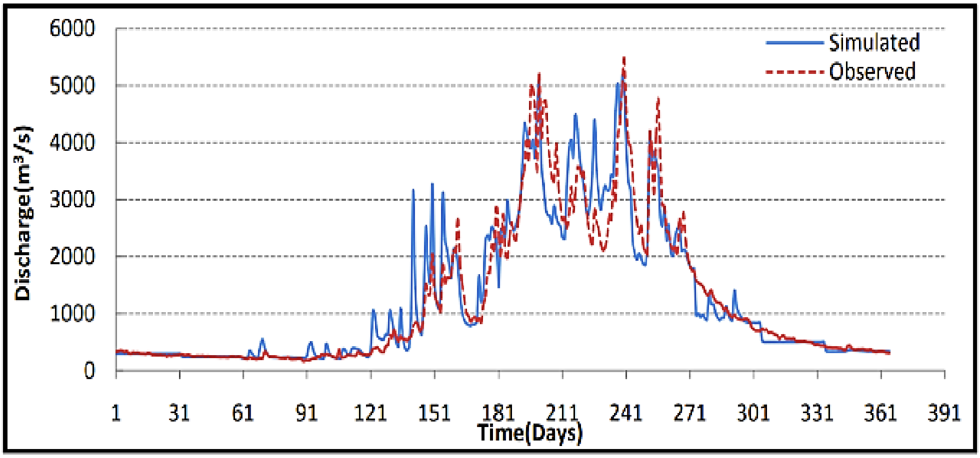
Observed and Simulated Hydrograph of Trapezoidal Channel Section for Validation - 2006



- **Triangular Channel Section (Figure 9):** The triangular section showed a slight overestimation of peak flows, with an NSE of 0.84. The model performed well during low-flow periods but struggled to accurately simulate high-flow events.

Figure 9

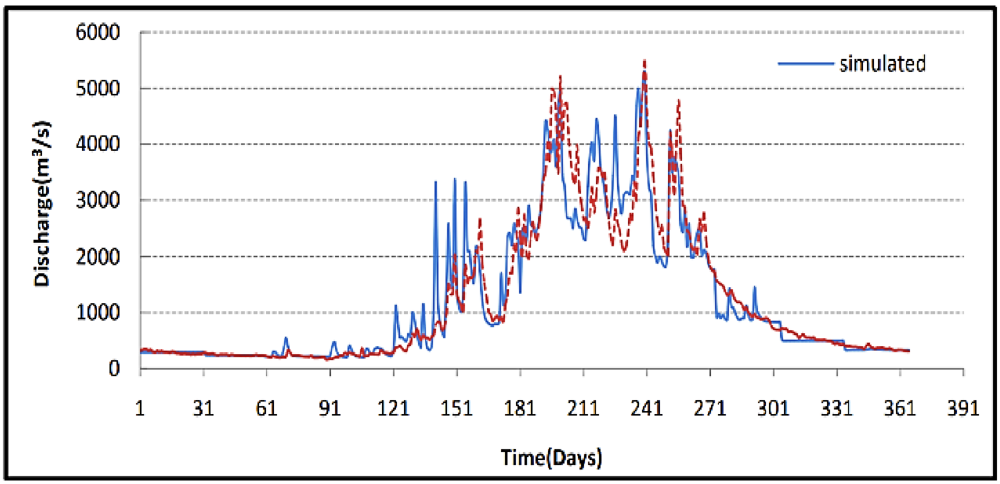
Observed and Simulated Hydrograph of Triangular Channel for Validation - 2006



- **Rectangular Channel Section (Figure 10):** The rectangular section had the lowest performance during validation, with an NSE of 0.81. The model consistently overestimated peak flows and underestimated base flows.

Figure 10

Observed and Simulated Hydrograph of Rectangular Channel for Validation - 2006



Performance Analysis

The performance of the model was evaluated based on annual stream flow volume, mean flow, peak flow, and model efficiency for each channel section.

Volume Deviation for Three Channel Sections

Table 1 and Figure 11 present the annual stream flow volume at the basin outlet for the calibration and validation periods. The trapezoidal and triangular sections showed minimal volume deviation, while the rectangular section exhibited the highest deviation.

Table 1

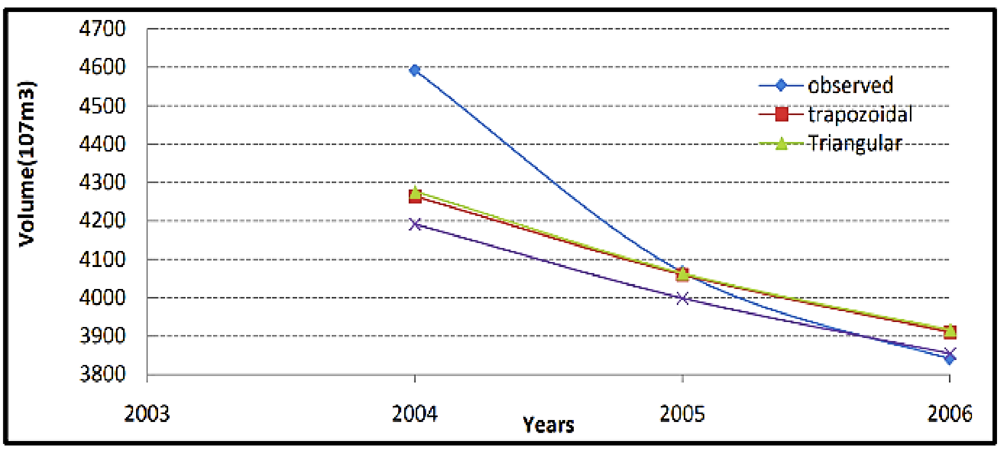
Annual Outlet Stream Flow Volume

Channel section	2004		2005		2006	
	Observed volume (10^7m^3)	Simulated volume (10^7m^3)	Observed volume $(10^7$m3)	Simulated volume (10^7m^3)	Observed volume (10^7m^3)	Simulated volume (10^7m^3)
Trapezoidal		4264.458		4060.03		3909.9
Triangular	4591.8	4276.44	4066.3	4063.27	3840.46	3916.41
Rectangular		4191.34		3998.9		3854.42

- The trapezoidal section had the closest match to the observed volume, with deviations of 7.1% (2004), 0.15% (2005), and 1.8% (2006).
- The rectangular section showed the highest deviations, with differences of 8.7% (2004), 1.7% (2005), and 0.4% (2006).

Figure 11

Annual Outlet Stream Flow Volume for Different Channel Section



Annual Mean Flow for Different Channel Sections

Table 2 and Figure 12 summarize the annual mean flow at the basin outlet. The trapezoidal and triangular sections performed similarly, while the rectangular section showed higher deviations.

Table 2

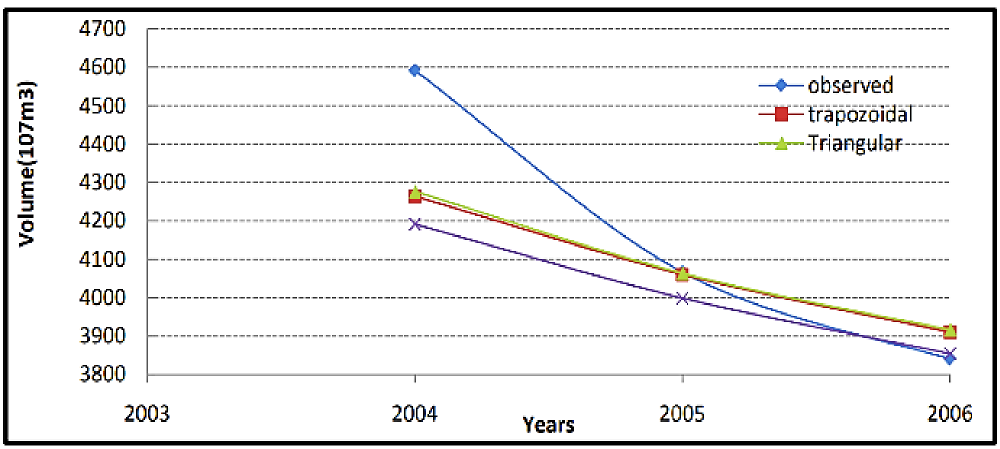
Annual Outlet Mean Flow for Different Channel Section

Channel section	2004		2005		2006	
	Observed mean flow (m^3/s)	Simulated mean flow(m^3/s)	Observed mean flow (m^3/s)	Simulated mean flow(m^3/s)	Observed mean flow (m^3/s)	Simulated mean flow(m^3/s)
Trapezoidal		1350		1282		1240.5
Triangular	1455	1352	1285	1280.5	1218	1242.2
Rectangular		1325		1265.5		1220.2

- The trapezoidal section had mean flow deviations of 7.2% (2004), 0.2% (2005), and 1.8% (2006).
- The rectangular section showed deviations of 8.9% (2004), 1.5% (2005), and 0.2% (2006).

Figure 12

Annual Outlet Mean Stream Flow for Different Channel



Peak Flow in Different Channel Sections

Table 3 and Figure 13 illustrate the simulated peak flows for each channel section. The trapezoidal section closely matched the observed peak flows, while the triangular and rectangular sections overestimated peak flows.

Table 3

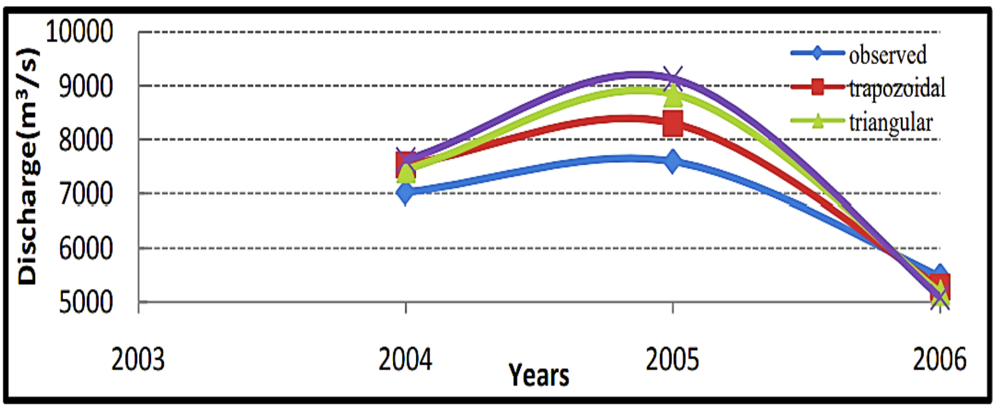
Annual Outlet Peak Flow for Different Channel Section

Channel section	2004		2005		2006	
	Observed peak flow (m^3/s)	Simulated peak flow (m^3/s)	Observed peak flow (m^3/s)	Simulated peak flow (m^3/s)	Observed peak flow (m^3/s)	Simulated peak flow (m^3/s)
Trapezoidal	7020	7531.3	7590	8302.1	5480	5277.8
Triangular		7445.1		8850.5		5184.2
Rectangular		7621.7		9131.5		5093.3

- The trapezoidal section had peak flow deviations of 7.3% (2004), 9.4% (2005), and 3.7% (2006).
- The rectangular section showed deviations of 8.6% (2004), 20.3% (2005), and 7.1% (2006).

Figure 13

Annual Outlet Peak Flow Volume for Different Channel Section

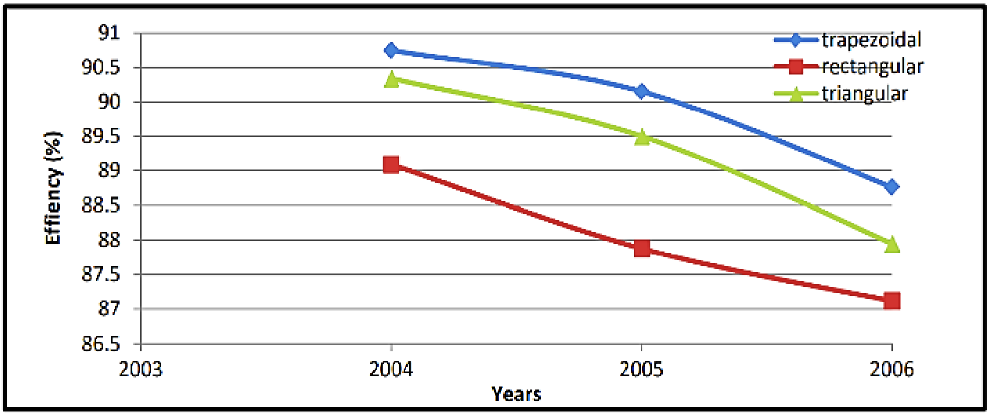


Efficiency in Different Channel Geometries

Figure 14 presents the Nash-Sutcliffe Efficiency (NSE) for each channel section during the calibration and validation periods. The trapezoidal section consistently outperformed the other sections, with NSE values of 0.89 (calibration) and 0.88 (validation). The triangular and rectangular sections had lower NSE values, indicating reduced accuracy.

Figure 14

Efficiency Using Different Channel Geometry



Discussion

The results demonstrate that channel geometry significantly influences the hydrological response of the Narayani River Basin. The trapezoidal channel section consistently provided the most accurate simulations, with minimal deviations in annual stream flow volume, mean flow, and peak flow. This can be attributed to the trapezoidal shape's ability to better represent natural river channels, which often have sloping sides and a flat bottom (Gautam, 2009).

The triangular and rectangular sections, while performing reasonably well, exhibited higher deviations, particularly during peak flow events. This suggests that these geometries may not adequately capture the complex flow dynamics of the Narayani River, especially during high-intensity rainfall events (Choudhury *et al.,* 2002).

The study also highlights the importance of accurate input data and parameter estimation in hydrological modeling. Discrepancies between observed and simulated hydrographs can be attributed to factors such as:

- **Precipitation Data:** Inaccurate or spatially uneven rainfall distribution can lead to errors in simulated runoff (Soliman, 2010).

- **Infiltration Parameters:** Variations in soil properties and land use across the basin can affect infiltration rates and, consequently, runoff generation (Assouline, 2013).
- **Routing Methods:** The choice of routing method (e.g., Kinematic Wave) and channel geometry parameters (e.g., Manning's roughness coefficient) can significantly impact model performance (Tseng, 2010).

These findings underscore the need for high-quality input data and careful parameter calibration to improve the accuracy of hydrological models. Future studies could explore the use of higher-resolution DEMs and more advanced routing methods to further enhance model performance (Rijal, 2001).

Conclusion and Recommendations

Conclusion

The primary objective of this study was to evaluate the effectiveness of different channel geometries (trapezoidal, triangular, and rectangular) in simulating rainfall-runoff processes for the Narayani River Basin using the HEC-HMS semi-distributed hydrological model. The study utilized GIS-based tools (HEC-GeoHMS and HEC-GeoRAS) to prepare input data, including DEM, land use, and soil characteristics. The key findings are summarized below:

1. **Trapezoidal Channel Section:** The trapezoidal channel section demonstrated the highest efficiency, with Nash-Sutcliffe Efficiency (NSE) values ranging from 88.51% to 90.47% during calibration and 87.12% to 88.76% during validation. This section closely matched the observed peak flow and time to peak, making it the most effective for flood forecasting and continuous simulation.
2. **Triangular and Rectangular Sections:** While the triangular section performed reasonably well, the rectangular section showed higher deviations in peak flow and total annual runoff volume. Both sections were less accurate than the trapezoidal section in simulating flood events.
3. **Model Performance:** The semi-distributed HEC-HMS model provided reliable results across all channel sections, with the trapezoidal section being the most suitable for flood prediction and hydrological analysis.

4. **Data and Parameters:** The study highlighted the importance of high-quality input data, including DEM, precipitation, and stream flow records, for accurate parameter estimation and model calibration.

Recommendations

Based on the study's findings, the following recommendations are proposed for the future lines of research and model improvement:

1. **High-Resolution DEM:** To enhance model accuracy, high-resolution DEM data sets (e.g., 30m or finer) should be used to better represent the basin's topography and channel geometry.
2. **Field Surveys:** Field measurements of channel geometry, roughness coefficients, and soil properties should be conducted to validate and refine model parameters.
3. **Advanced Routing Methods:** Future studies should explore advanced routing techniques and incorporate additional hydrological processes (e.g., groundwater interactions) to improve model performance.
4. **Long-Term Data:** The use of long-term hydrometeorological data is recommended to account for variability in climate and land use changes, ensuring the model's applicability under different scenarios.
5. **Comparative Studies:** Comparative studies using other hydrological models (e.g., SPHY, HBV) could provide further insights into the effectiveness of different modeling approaches in the Narayani River Basin.

References

Acharya, K., & Oli, B. (2004). Impacts of community forestry on rural livelihoods: A case study from Bharkhore Community Forest, Parbat District. *Banko Janakari, 14*(1), 46–50. https://doi.org/10.3126/banko.v14i1.17059

Assouline, S. (2013). Infiltration into soils: Conceptual approaches and solutions. *Water Resources Research, 49*(4), 1755–1772. https://doi.org/10.1002/wrcr.20155

Beven, K. J., & Kirkby, M. J. (1979). A physically based, variable contributing area model of basin hydrology. *Hydrological Sciences Bulletin, 24*(1), 43–69. https://doi.org/10.1080/02626667909491834

Bhattarai, R. (2007). *Application of distributed hydrologic soil vegetation model (DHSVM) in plain region of Nepal.* (Unpublished Master's dissertation), Water Resource Engineering, IOE Pulchowk Campus.

Choudhury, P., Shrivastava, R. K., & Narulkar, S. M. (2002). Flood routing in river networks using equivalent Muskingum inflow. *Journal of Hydrologic Engineering, 7*(6), 413–419. https://doi.org/10.1061/(ASCE)1084-0699(2002)7:6(413)

Chow, V. T., Maidment, D. R., & Mays, L. W. (1988). *Applied hydrology*. McGraw-Hill.

Di Luzio, M., Srinivasan, R., & Arnold, J. G. (2001). *Soil and water assessment tool ArcView interface manual* (Version 2000).

Fleming, M. (2002). *Continuous hydrologic modeling with HMS: Parameter estimation and model calibration and validation.* (Unpublished Master's dissertation), Tennessee Technological University.

Gautam, N. P. (2009). *Effect of channel geometry on routing in the case of Gandaki River Basin.* (Unpublished Master's dissertation), Water Resource Engineering, IOE Pulchowk Campus.

HEC. (2001). *Hydrologic modeling system HEC-HMS: Technical reference manual* (Version 2.1). Hydrologic Engineering Center, U.S. Army Corps of Engineers.

HEC. (1979). *Introduction and application of kinematic wave routing techniques using HEC-1.* Hydrologic Engineering Center (Training Document No. 10). U.S. Army Corps of Engineers.

Jha, M., Gassman, P. W., Secchi, S., Gu, R., & Arnold, J. (2004). Effect of watershed subdivision on SWAT flow, sediment, and nutrient predictions. *Journal of the American Water Resources Association, 40*(3), 811–825. https://doi.org/10.1111/j.1752-1688.2004.tb04460.x

Jha, R., Singh, V. P., Ojha, C. S. P., & Bhatia, K. K. S. (2006). *Estimation of non-point source pollution in a typical river of India.* World Environmental and Water Resources Congress 2006. https://doi.org/10.1061/40856(200)247

Karamouz, M., Nazif, S., & Falahi M. (2012). *Hydrology and hydro-climatology: Principles and applications.* CRC Press, pp. 50-53. https://doi.org/10.1201/b13771

Lu, M., & Zhao, Q. (1980). *Semi-distributed daily runoff process modeling with the aid of GIS: A case study of Yanqi catchment in Beijing, northern China.* Cold and Arid Regions Environment and Engineering Research Institute, Chinese Academy of Sciences.

Maidment, D. R., & Snead, D. (2000). *Floodplain visualization using HEC-GeoRAS.* Center for Research in Water Resources, University of Texas at Austin.

Mamillapalli, S., Srinivasan, R., Arnold, J. G., & Engel, B. A. (1996). *Effect of spatial variability on basin scale modeling.* Proceedings of the Third International Conference/Workshop on Integrating GIS and Environmental Modeling.

Olivera, F. (2001). Extracting hydrological information from spatial data for HMS modeling. *Journal of Hydrologic Engineering, 6*(6), 524–530. https://doi.org/10.1061/(ASCE)1084-0699(2001)6:6(524)

Piman, T., & Babel, M. S. (2013). Prediction of rainfall-runoff in an ungauged basin: Case study in the mountainous region of northern Thailand. *Journal of Hydrologic Engineering, 18*(12), 1582–1594. https://doi.org/10.1061/(ASCE)HE.1943-5584.000057

Rao, K. H. V. D., Bhanumurthy, V., Roy, P. S. (2009). Application of satellite-based rainfall products and SRTM DEM in hydrological modelling of Brahmaputra basin. *Journal of the Indian Society of Remote Sensing, 37*(4), 587–600. https://doi.org/10.1007/s12524-009-0051-5

Rijal, S. P. (2001). *Optimization of catchment routing parameters of Jhikhu Catchment in Nepal.* (Unpublished Master's dissertation), Water Resources Engineering Program, Institute of Engineering, Pulchowk.

Sagar, A. (2007). *Application of Distributed Hydrologic Model (BTOPMC) in Narayani Basin.* (Unpublished Master's dissertation), Water Resource Engineering, IOE Pulchowk Campus.

Singh, V. P., & Woolhiser, D. A. (2002). Mathematical modeling of watershed hydrology. *Journal of Hydrologic Engineering, 7*(4), 270–292. https://doi.org/10.1061/(ASCE)1084-0699(2002)7:4(270)

Soliman, M. M. (2010). *Engineering hydrology of arid and semi-arid regions*. CRC Press.

Thapa, D. R. (2008). *Assessment of hydropower potential: A case study of Kaligandaki Basin*.

Thapa, D. R. (2003). *Application of computer-based tools in floodplain analysis incorporating hydrological impact of global climate change: A case study of Bagmati Basin in Terai.* (Unpublished Master's dissertation), Institute of Engineering.

Tseng, M.-H. (2010). Kinematic wave computation using an efficient implicit method. *Journal of Hydroinformatics, 12*(3), 329–338. https://doi.org/10.2166/hydro.2010.068