Journal of
Water Resource Engineering and Management

ISSN: 2349-4336
Volume 13, Issue 1, 2026
January–April
DOI (Journal): 10.37591/JoWREM

https://journals.stmjournals.com/jowrem

Review JoWREM

Hydrological Modeling and Classification of Various Models: A Review

Shreya Kayal[1,*], Susmita Ghosh[2], Swapan Kumar Ghosh[3], Sandip Sarkar[4], Subhojit Chattaraj[5]

Abstract

Hydrology is the science that deals with the existence, movement, and distribution of water on the earth, below the earth, and in the earth's atmosphere. As one of the branches of earth science, hydrology deals with the water in waterways and lakes, precipitation and snow, snow on the terrestrial and water underneath the earth, and rocks. Hydrology has links with meteorology, geography, measurements, science, material science, and fluid mechanics. Engineers and hydrologists are highly concerned about the amount of runoff generated from a given rainfall amount. The surface excess water is the most basic and vital parameter for the appraisal of watershed water yield. Watershed management has made use of hydrological models since they are crucial instruments for comprehending the hydrological behavior of the watersheds. The hydrological models can replicate the effects of various soil and water conservation structures. This aids decision-makers in implementing appropriate conservation strategies in regions that are vulnerable to erosion. A summary of various hydrological models and their uses in watershed management is provided in this article.

Keywords: Artificial neural network, hydrological modeling, SCS-CN, SWAT

INTRODUCTION

A watershed hydrology model is a collection of mathematical descriptions of the components of the hydrologic cycle. Recently, mathematical models have taken over the most important tasks in problem-solving in hydrology. Rainfall-runoff models originated in the mid-19th century, mainly to estimate the maximum flow to solve problems such as the design of drainage systems, flood flow outlets, and sewage systems. In the 1960s, many other approaches in search of a more physical interpretation of the rainfall-runoff process were considered, and a large number of conceptual lumped rainfall-runoff models were introduced. Most hydrological models are deterministic in nature. Hydrological models can be categorized as physically based, conceptual, and black box. A comprehensive examination of various hydrologic phenomena and the hydrologic cycle is essential to understand these variations. In contemporary times, numerous hydrological models have been created globally to assess the effects of climate and soil properties on hydrology and water resources. Each model has distinct characteristics. The inputs utilized by these diverse models include rainfall, air temperature, soil characteristics, topography, vegetation, hydrogeology, and other physical parameters. These models are applicable in highly complex and expansive watersheds [1–5].

HYDROLOGICAL MODELS FOR PROPERLY MANAGING WATERSHEDS

Hydrological modeling has become increasingly important for the sustainable management of water

***Author for Correspondence**
Shreya Kayal
E-mail: kayalshreya03@gmail.com

[1–3]Undergraduate Student, Department of Civil Engineering, Greater Kolkata College of Engineering and Management, JIS Group, Baruipur, West Bengal, India
[4,5]Assistant Professor, Department of Civil Engineering, Greater Kolkata College of Engineering and Management, JIS Group, Baruipur, West Bengal, India

Received Date: December 06, 2025
Accepted Date: January 21, 2026
Published Date: January 24, 2026

Citation: Shreya Kayal, Susmita Ghosh, Swapan Kumar Ghosh, Sandip Sarkar, Subhojit Chattaraj. Hydrological Modeling and Classification of Various Models: A Review. Journal of Water Resource Engineering and Management. 2026; 13(1): 1–5p.

at the watershed scale. Hydrological models are generally divided into three groups: empirical, conceptual, and physical. Observation-aligned models, which are based on information from existing records and do not consider the characteristics and processes of the hydrological system, are called empirical models. Conceptual models represent the catchment as a series of internal storages with parameters having limited physical interpretability. They include only a general description of catchment processes; particular features of process interactions and detailed facts of the catchment are unavailable. Physical models represent water flow using equations of conservation of mass and momentum [6–15].

Stuebe and Johnston (1990) conducted a side-by-side analysis of the presentation of results derived from GIS with surface runoff calculations using the SCS curve number, obtained through manual methodology. The study area was located in Lawrence County, South Dakota, USA. The final observation showed the superiority of the GIS method, as it had a simple processing procedure [13].

Djokic and Maidment (1991) identified four main hydrological applications of GIS: evaluation of hydrological characteristics, determination of hydrological parameters, hydrological setup of models utilizing GIS, and GIS-based modeling of hydrological processes. During evaluation, related hydrologic factors were mapped using GIS. The study area was located in Asheville, North Carolina, USA. The authors suggested that, as the time–space structures of data are in a continuous development phase in GIS, the next step would be to develop an unsteady numerical model in geoinformatics to visualize performance [4].

Bingner (1996) used the Soil and Water Assessment Tool (SWAT) model to simulate surface runoff for a period of ten years. The study area was a watershed in northern Mississippi, USA. The results obtained through the SWAT model for runoff were satisfactory for the daily and annual timeframes. The results were based on outputs obtained from multiple subcatchments; however, in the case of wooded subcatchments, the results were unsatisfactory during the simulation [2].

Van Liew and Garbrecht (2003) examined the capability of the SWAT model to estimate discharge under varying climate conditions for three sub-watersheds in the 610 km^2 Little Washita River Experimental Watershed, located in south-western Oklahoma, USA. The researchers observed that the SWAT model could sufficiently produce discharge for dry, average, and wet climate conditions in one of the sub-watersheds, after calibration for wet years in the other two sub-watersheds was performed [16].

Akbarpour (2004) simulated the rainfall-runoff process using artificial neural networks (ANNs) and the HEC-HMS model application on the Zard River Basin in the Khuzestan province, Iran. The use of multilayer perceptron (MLP) ANN models with twin structures of hidden layers and radial basis functions (RBFs) was simulated for this process. The fourteen flood events that occurred during the time frame of 1991–2000 were used for simulation purposes for the HEC-HMS model. The comparison of the results showed that the RBF model was more powerful than the MLP and the calibrated HEC-HMS model for the basin could be utilized for computing flood flows in other ungauged basins with similar characteristics.

Nayak et al. (2004) used an adaptive neuro–fuzzy inference system (ANFIS) for time series river flow modeling of the Baitarani River, located in Orissa, India. The ANFIS model exhibited satisfactory performance based on numerous statistical criteria. The output showed that ANFIS outperformed the ANN and other conventional time series models in terms of peak flow estimation, forecasting errors, computational speed, and efficiency. It was noticed that the ANFIS model could save considerable time while modeling compared to the ANN model [10].

Xu et al. (2009) conducted a SWAT model to estimate the discharge volume and sediment yield in the Miyun River catchment in China. The catchment has steep slopes as well as deep valleys with mountain ranges. The simulation of the model for daily and monthly discharge and sediment was good, with an NSE value greater than 0.6. During sensitivity analysis, it was found that discharge was highly sensitive to the curve number (CN) and base flow alpha factor (ALPHA_BF), whereas sediment yield was also highly sensitive to CN and the linear parameter that could be re-entrained during channel routing (SPCON) [17].

HEC-HMS and Watershed Erosion Prediction Project (WEPP) models were used for rainfall-runoff modeling using data prepared with modeling using data prepared (RS) and GIS techniques for the Upper Baitarani River Basin in India. Data on daily rainfall during the monsoon and stream flow from 1999 to 2005 were used in conjunction with images of the Digital Elevation Model (DEM), soil, topography, and Landsat satellite. The outputs disclosed that both models underpredicted stream flow for the years 1999, 2002, 2004, and 2005 and overpredicted it for 2001 and 2003. Moreover, after statistical analysis of the results, HEC-HMS showed better reliability than WEPP [18].

Application of the SWAT model to a Himalayan watershed to simulate runoff and sediment yield. The model was calibrated for 1993–1994 and validated for 1995–1997 with daily and monthly timeframes. The simulation performance of the model was evaluated using statistical methods. The R2 values for daily and monthly runoff were 0.53 and 0.90 for the calibration period and 0.33 and 0.62 for the validation period. For sediment yield, the R2 values for the daily and monthly periods during calibration were 0.33 and 0.38, and during validation were 0.26 and 0.47. In a remote area with scarce data, these values could be deemed satisfactory [7].

The SWAT model to assess the runoff, sediment yield, and water balance for the Ken Basin, located in the middle part of India. Using the SWAT model, the whole basin was divided into ten sub-watersheds, which comprise 143 hydrological response units (HRUs) based on unique LU/LC, soil, and slope. Runoff simulated during the daily and monthly phases shows that in the case of calibration (1985–1995), R2 was 0.766 and 0.946, and in the case of validation (1996–2005), R2 was 0.780 and 0.959. For sediment, R2 values were 0.429 and 0.379 (daily and monthly) during calibration, and 0.748 and 0.721 (daily and monthly) during validation. From the water balance study, it was found that evapotranspiration was the most dominant factor, accounting for 44.6% of the mean annual rainfall occurring over the basin [6].

Simulated runoff for the Luvubhu River catchment in South Africa was utilized with the stands for QGIS Interface for the Soil and Water Assessment (QSWAT) model, an interface of Quantum Geographic Information System (QGIS) and Soil and Water Assessment Tool (SWAT). Four parameters of the model were found to be extremely sensitive to stream flow and were ALPHA_BF, CN, ground water delay (GW_DELAY), and saturated hydraulic conductivity (SOL_K) during analysis. Monthly outputs of calibration (1986–2005) yielded values of R2 = 0.63, NSE = 0.66, and standard deviation ratio (RSR) = 0.56, whereas outputs of validation (2006–2015) yielded values of R2 = 0.52, NSE = 0.48, and RSR = 0.72, which could be considered satisfactory [15].

The SWAT model was applied in the Upper Blue Nile River catchment in Ethiopia, which has many tributaries draining from the regions of the north and west. Multisite streamflow data were used during the calibration (2001–2009) and validation (2010–2014) periods. During calibration, it was observed that the values of R2 were in the range of 0.81 to 0.85, NSE were in the range of 0.68 to 0.83, and Percent bias (PBIAS) was in the range of -10.8% to -4.7% from multisite. Similarly, during validation, the values of R2, NSE, and PBIAS were in the ranges of 0.89–0.93, 0.88–0.89, and 8.3%–9.7%, respectively, for the multisite. An evaluation of the water balance components depicted that approximately 22.43% of the annual mean rainfall flows out as discharge, whereas approximately 49.5% of the annual mean rainfall is lost due to evapotranspiration [14].

There is a critical need for efficient and accurate artificial intelligence (AI) models to simulate river flows, particularly in data-scarce regions. A hybrid ANN model, combining the Hydrologic Engineering

Center Hydrological Modeling System (HEC-HMS) and a feed-forward neural network (FFNN), was developed using Python. This model was applied to simulate future stream flows in the River Mayanja catchment in Central Uganda. The hybrid HEC-HMS–ANN model demonstrated superior performance during both the calibration and validation phases (NSE and $R^2 > 0.99$) compared with individual HEC-HMS (NSE and $R^2 > 0.50$), MIKE HYDRO (NSE and $R^2 > 0.42$), and standalone ANN models (NSE and $R^2 > 0.56$) [9].

CONCLUSION

It is possible to successfully manage watershed resources using hydrological models, according to the current study. Generally, the most common instruments for examining hydrological processes are rainfall-runoff models. Numerous models have been constructed for a variety of applications, ranging from small catchments to global models. Every model has distinct qualities of its own and special uses. Some are extensive and dispersed throughout space and time, relying on the physics of the underlying hydrological processes. In addition to aiding in flood forecasting, appropriate management of water resources, and assessment of water quality, erosion, and sedimentation, nutrient and pesticide circulation, land use, and climate change, models are utilized for modeling both gauged and ungauged watersheds. Each model has several shortcomings, such as being difficult to use, requiring a large amount of data, and not clearly stating its limitations. Rapid advancements in risk analysis and remote sensing technology must be incorporated into models to overcome these flaws. New distributed models for modeling gauged and ungauged watersheds can be created using new technologies.

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