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Rainfall-Runoff Modelling: An Overview

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Abstract—This is a review paper in which short-term memory (LSTM) networks, the Non-stationary Rainfall-Runoff Toolbox (NRRT), nonlinear autoregressive model with exogenous inputs lumped (LNARX), nonlinear autoregressive model with exogenous geomorphometrically processed inputs (GNARX), wavelet nonlinear autoregressive model with exogenous inputs (WLNARX), and nonlinear autoregressive model with exogenous geomorphometrically processed inputs (WGNARX), three neural network methods, Feed Forward Back Propagation (FFBP), Radial Basis Function (RBF) and Generalized Regression Neural Network (GRNN) were employed for rainfall-runoff modelling along with two numerical models including ANN and ANFIS used to model the rainfall runoff process and the best model was chosen. The rainfall-runoff correlograms proved to be effective in determining the appropriate number of nodes for the input layer. Also the whole R-R was calibrated using different mentioned tools with different correlations and whose who gave the best correlation was chosen for R-R model for respective catchments. The coefficient of correlation, RMSE and NSE were calculated for better correlation.

Index Terms—R-R model, LSTM, ANN, ANFIS, GRNN, RBF, RMSE, NSE.

I. INTRODUCTION

Water resources development plays a crucial role in achieving comprehensive economic and social progress within a nation. India, with 16% of the world's population, faces significant pressure in meeting its water demands. The Indian River systems, spanning approximately 1800 km2, contribute 4% of the global annual flows according to the latest estimates from the Central Water Commission. While there have been substantial advancements in water resource development and management over the past few decades, it has also led to the improper utilization of surface water and overexploitation of groundwater. To facilitate any developmental activities, efficient water resource planning becomes imperative. [1]

The generation of runoff from rainfall events is dependent on various factors, such as the duration and intensity of rainfall, as well as basin characteristics including length, soil type, slope, land use, and shape. Hydrological modeling, particularly Rainfall-Runoff modeling, serves as a valuable tool in determining the amount of runoff leaving a basin or catchment area based on the received rainfall. Numerous methods are available for rainfall-runoff modeling, including deterministic and stochastic models. These models aid in understanding and managing water resources effectively.

For the Rainfall-Runoff (R-R) model, it is essential to have specific rainfall data for the study area. Additionally, runoff data is required for simulating the R-R model effectively. During the simulation, the catchment area of the study is taken into account, and factors like infiltration, evaporation, evapotranspiration, moisture content, and snow also play a crucial role and need to be considered in the model. These types of models are particularly important for water-scarce regions in India. Rainfall-Runoff models, as well as other hydrologic models, are simplified representations of real-world systems. Researchers and practitioners use a variety of R-R models, each tailored to specific purposes and applications. Some models are employed for research to gain a better understanding of hydrological processes in real-world systems. On the other hand, other models are developed as tools for simulation and prediction, with the aim of aiding decision-makers in effective planning and operations while considering various aspects such as physical, ecological, economic, and social elements of the system. The applications of the latter type of R-R models are diverse and include real-time flood forecasting and warning, estimation of flood frequencies, flood routing and inundation prediction, impact assessment of climate and land use changes, and integrated watershed management. Developing R-R models requires reliable data for calibrating the nonlinear behavior of these models [2]. This data serves as prior knowledge in the model, enabling it to extrapolate the

R-R process into the future. Traditionally, batch model calibration, using a set of data for calibration, has been common. However, there is a different approach that suggests continuous updates (corrections) to the model components (state variables and parameters) based on the availability of ongoing observations. This approach takes advantage of the temporal organization and structure of information, leading to better compliance of the model output with observed system responses. [3]

Hydrological modeling involves creating a simplified representation of the hydrological cycle to mimic natural systems. Within this framework, a rainfall-runoff model serves as a mathematical representation, describing the relationship between rainfall and runoff in a catchment area, drainage basin, or watershed. Specifically, it generates a surface runoff hydrograph as a response to a given rainfall input. These rainfall-runoff models can be categorized based on various characteristics, such as being deterministic, stochastic, conceptual, theoretical, black box, continuous, event-based, complete, routing-focused, or simplified in nature (Linsley, 1982)[4]. Hydrologic models, particularly simple rainfall-runoff models, play a significant role in comprehending and quantifying the effects of land use changes. They also offer valuable information that aids in making informed decisions regarding land use. These hydrologic models come in various types, differing in their characteristics, complexity, and intended purposes. (Shoemaker et al., 1997)[5]. One of the well-known rainfall-runoff models is the Rational Method. (Mcpherson, 1969)[6], Soil Conservation Services (SCS) Curve Number method (Maidment, 1993) [7], and Green-Ampt method (Green and Ampt, 1911) [8]. The hydrological response of a catchment to rainfall, along with estimates of catchment yield and runoff data, holds immense significance in hydrological analysis. These parameters are crucial for various applications such as water resources planning, flood forecasting, pollution control, and other related purposes. (Shamsudin and Hashim 2002)[9].

In India, a significant number of river catchments remain ungauged, and typically, only limited discharge data are available from state and central agencies. In such situations, a rainfall-runoff model becomes essential for simulating natural hydrological processes and estimating runoff in these catchments. Proper water resources development and management within a river basin can be achieved by employing suitable hydrological models. The rainfall-runoff process is intricate, influenced by various implicit and explicit factors, including precipitation distribution, evaporation, transpiration, abstraction, topography, and soil types. Numerous researchers have conducted various rainfall-runoff modeling studies, using different models and techniques to better understand this complex process. Nash (1958) taken an approach involved conceptualizing the watershed as a sequence of identical reservoirs and developing a rainfall-runoff model [10]. The model was developed by sequentially routing a unit in flow through these reservoirs. Kumbhare and Rastogi (1984) calibrated the Nash conceptual model (1958) then runoff was validated in better values with actual runoff hydrograph observed [11]. Pathak et al. (1984) created a model to accurately predict the runoff volume from a small watershed, enabling simulation of daily, monthly, and annual runoff volumes with high precision [12].

II. LITERATURE REVIEW

As a part of literature survey, we investigated some Rainfall-Runoff models using different tools.

F. Kratzert et al., (2018) describes about rainfall-runoff modeling using long short-term memory (LSTM) networks. In this they have proposed a novel data-driven approach. They have used 241 catchments of the freely available CAMELS data set to test our approach and also compare the results to the well-known Sacramento Soil Moisture Accounting Model (SAC-SMA) coupled with the Snow-17 snow routine. The LSTM (Long Short-Term Memory) has demonstrated promising potential as a regional hydrological model, where a single model can predict the discharge for multiple catchments. Using this approach, we were able to achieve better model performance as the SAC-SMA + Snow-17, which underlines the potential of the LSTM for hydrological modelling applications. [14]

M. Sadegh et al., (2019) presents the Non-stationary Rainfall-Runoff Toolbox, (NRRT), for multi-model (one at a time) non-stationary modeling of rainfall runoff (RR) processes. The conceptual rainfall-runoff models available in the NRRT toolbox, such as GR4J, GR5J, GR6J, HyMod, and HBV, have been designed with a time-varying nature. This design feature enables these models to simulate processes that are inherently non-stationary. NRRT translates the potentially time-varying changes in parameters into model simulations in order to imitate the non-stationary nature of the watershed processes. They have shown that a time-varying parameterization of conceptual RR models, if corresponds to the physical changes of a watershed, is indeed capable of modeling the response of a non-stationary watershed to climate forcing. In their case study, the weights catchment, loss of near surface storage due to deforestation is adequately represented by a decrease in the maximum capacity of the production store (S1max) of the GR4J model. [15]

D. Tiwari et al., (2021) uses r-r model using various parameters such as land use land cover, soil type classification, rainfall, and atmospheric data such as temperature, evapotranspiration, solar radiation, and wind speed. But these data may not be available for developing countries and data scares semiarid watershed. Furthermore, the issue becomes even more critical in the case of ungauged catchments and areas where manual records of water level and rainfall data are maintained. To address this issue, trend analysis is performed using Mann-Kendall test and Sen's slope test, which shows significant trend change stressing the need for new method for runoff prediction for better water resource management. The study involved the use of four distinct models: the nonlinear autoregressive model with exogenous inputs lumped (LNARX), the nonlinear autoregressive model with exogenous geomorphometrically processed inputs (GNARX), the wavelet nonlinear autoregressive model with exogenous inputs (WLNARX), and the nonlinear autoregressive model with exogenous geomorphometrically processed inputs (WGNARX). Ten models with different input combinations were selected based on their performance and analyzed for all the four networks. The best performing model for these networks is model no. 6 with WGNARX network with NSE 0.97 and RMSE 0.97 and with least value of RMSE. This method can be applied to data scarce region, where data available are available for shorter duration and helpful for ungauged catchments also. [16]

J. Joshi and V. Patel (2011) used neural network tool in which three neural network methods, Feed Forward Back Propagation (FFBP), Radial Basis Function (RBF) and Generalized Regression Neural Network (GRNN) were employed for rainfall-runoff modelling of Maleshri hydrometeorologic data. It was seen that all three different ANN algorithms compared well with conventional Multi Linear Regression (MLR) technique. The observation revealed that the GRNN technique was the only one that did not yield negative flow estimations for certain data points. Additionally, the rainfall-runoff correlograms proved effective in determining the appropriate number of nodes for the input layer. [17]

Behmanesh J. and Aysham S. (2015) used numerical and regression model for finding out rainfall-runoff model. In this research work, two numerical models including ANN and ANFIS used to model the rainfall runoff process and the best model was chosen. Also, by using SPSS software, the regression equations were developed and then the best equation was selected from regression analysis. The obtained results from the numerical and regression modeling were compared with each other. The analysis revealed that the ANFIS (Adaptive Neuro-Fuzzy Inference System) model outperformed the regression model. According to the results, there is a clear and logical relationship between the Turkey river flow rate and the flow rates from one and two days ago, as well as the rainfall values from one, two, and three days ago. [18]

CONCLUSION

This paper describes the presented research studies focus on the application of various methods and models for rainfall-runoff modeling and hydrological analysis. A data-driven approach using Long Short-Term Memory (LSTM) networks, demonstrating its potential as a regional hydrological model with better performance than the Sacramento Soil Moisture Accounting Model (SAC-SMA) coupled with the Snow-17 snow routine. The Non-stationary Rainfall-Runoff Toolbox (NRRT) for non-stationary modeling of rainfall-runoff processes. The time-varying nature of conceptual rainfall-runoff models in NRRT proved effective in simulating non-stationary watershed responses to climate forcing. The challenges of data scarcity in developing countries and ungauged catchments, using trend analysis and four different models to predict runoff. The Wavelet Nonlinear Autoregressive Model with Exogenous Geomorphometrically Processed Inputs (WGNARX) showed promising results with potential applicability to data-scarce regions. ANFIS modeling was found to be superior to regression modeling in capturing the Turkey river flow rate's logical relationships with past flow rates and rainfall values.

Overall, these studies offer valuable insights into different approaches for rainfall-runoff modeling, providing researchers and decision-makers with valuable tools for water resources planning, flood forecasting, and other hydrological applications.

REFERENCES

[1] Rekha Verma, Azhar Husain, Mohammed Sharif, "Rainfall-Runoff Modeling Using NRCS-CN method and GIS" Authorea, December 01, 2020.

[2] Hamid Moradkhani and Soroosh Sorooshian, "General Review of Rainfall-Runoff Modeling: Model Calibration, Data Assimilation and Uncertainty Analysis", Hydrological Modelling and the Water Cycle, 1–24.

[3] Soroosh Sorooshian, Kuo-lin Hsu, Erika Coppola, Barbara Tomassetti, Marco Verdecchia, Guido Visconti, "Hydrological Modelling and the Water Cycle: Coupling the Atmospheric and Hydrological Models", Springer Science & Business Media, 18-Jul-2008.

[4] R. L. Linsley, "Rainfall-runoff models - An overview in rainfall-runoff relationship", Proceedings of the International Symposium on Rainfall-Runoff Modeling, May 18-21, pp. 3-22, 1982.

[5] L. Shoemaker, M. Lahlou, M. Bryer, D. Kumar and K. Kratt, "Compendium of tools for watershed assessment and TMDL development", U.S. Environmental Protection Agency, EPA841-B-97-006, 1997.

[6] M. B. McPherson, "Some notes on the rational method of storm drain design", Tech. Memo. No. 6 ASCE, Water Resources Research Program, Harvard University, Cambridge, MA, 1969.

[7] D. R. Maidment, "Handbook of Hydrology", 1st edn. McGraw Hill Publication, NewYork, 1993.

[8] W. H. Green and G. A. Ampt, "Studies on soil physics. The flow of air and water through soils", Journal of Agriculture Science, Vol. 4, pp. 1-24, 1911.

[9] S. Shamsudin, N. Hashim, "Rainfall-Runoff simulation using MIKE 11 NAM", Journal of Civil Engineering, vol. 15, no. 2, pp. 1-13, 2002.

[10] J. E. Nash, "Determination of runoff from rainfall", Institute of Civil Engineering, Proc., vol. 10, pp. 163-184, 1958.

[11] P. S. Kumbhare, R. A. Rastogi, "Determination of surface runoff from Himalayan watershed using two-parameter conceptual model", 21st Annual Convocation of ISAE, IARI, New Delhi, 1984.

[12] P. Pathak, S. A. Swaify, V. V. N. Murty and R. Sudi, "Runoff model for small semi-arid watersheds", 21st Annual Convocation of ISAE, IARI, New Delhi, 1984.

[13] Kumar and Rastogi, "Determination of direct runoff from a small agricultural watershed", Journal of Agricultural Engineering, vol. 26, pp. 223-228, 1989.

[14] Frederik Kratzert , Daniel Klotz , Claire Brenner, Karsten Schulz , and Mathew Herrnegger, 2018, Rainfall–runoff modelling using Long Short-Term Memory (LSTM) networks, Hydrology and Earth system sciences, 22, 6005–6022.

[15] Mojtaba Sadegh, Amir Agha Kouchak, Alejandro Flores, Iman Mallakpour, Mohammad Reza Nikoo, 2019, A Multi-Model Nonstationary Rainfall-Runoff Modeling Framework: Analysis and Toolbox, water resources management, 33, pages 3011–3024.

[16] Deepak Kumar Tiwari, H. L. Tiwari and Raman Nateriya, 2021, Geomorphology-wavelet based approach to rainfall runoff modeling for data scarce semiarid regions, Kolar River catchment, India, Journal of Engg. Research Vol.10 No. (1B) pp. 29-40.

[17] Jignesh Joshi, Vinod M. Patel, 2011, Rainfall-Runoff Modeling Using Artificial Neural Network (A Literature Review), National Conference on Recent Trends in Engineering & Technology, 13-14 May 2011.

[18] Behmanesh J., Ayashm S., (2015), Rainfall-runoff modelling in the Turkey river using

numerical and regression methods, J. Fundam Appl Sci. 7(1), 91-102.

[19] S. K. Mishra and V. P. Singh, “Another look at ‘SCS-CN’ method”, J. Hydrology Engg.,vol. 4, no. 3, ASCE, pp. 257-264, 1998.

[20] S. K. Mishra, “A modified SCS-CN based hydrologic model”, National Institute of Hydrology Report, TR(BR)-2, 2000.