

Chapter 1

INTRODUCTION

1.1 Background

Rainfall runoff modeling is the study of how precipitation is transformed into surface water runoff or base flow (groundwater discharge) in a watershed. The process is important in understanding and managing water resources, predicting floods, and designing water infrastructure. Rainfall runoff modeling has been studied for many years, with early models developed in the mid-19th century. The development of computers in the mid-20th century spurred the creation of more sophisticated models that could simulate complicated hydrological processes such as evapotranspiration, infiltration, and groundwater flow. Over the years, rainfall runoff modeling has become an increasingly important tool for water resources management. It has been used to analyze the impacts of land use changes, climate change, and other factors on water availability and quality in watersheds. It has also been used to design and optimize water infrastructure systems, such as dams, reservoirs, and levees.

The unit hydrograph concept is developing to conceptualize the reaction of a catchment to a storm event based on the theory of superposition. The unit hydrograph helps to isolate the runoff of the base flow and storm events from the streamflow [Fowler, Peel, et al., (2016)]. Runoff models have become more complex with increased computational capacity and a deeper understanding of hydrological processes [Guo, Westra, et al., (2017)]. Modeling runoff helps to understand hydrological processes better and how changes impact the hydrological process. [Dakhlaoui, Ruelland, et al., (2017)]. A runoff model is represented as a sequence of equations that help to estimate how much rainfall functions runoff of the different parameters used to characterize the watershed. It can be difficult to model the surface runoff since the measurement is complex and includes several interconnected variables [Sitterson, Knightes, et al., (2018)].

A model's overall modules include inputs, control equations, boundary or parameter conditions, model processes, and outputs [Garcia, Folton, et al., (2017)]. It requires surface runoff simulation to consider yields of floodplain and reactions, predict water quality, change over time, and forecast. Hydrological Simulation Program-Fortran (HSPF1) is a hydrological model which as part of its management, utilizes runoff functions for the prediction of sediment

charges, nutrients, pollutants, harmful chemicals and other concentrations of water quality [Fraga, Cea, et al., (2019)]. Whilst there are many ways to classify models, not all models fall into one category as they are designed for a variety of purposes. The water demand has increased as a result of fast population growth, industrialization, and urbanization [Kratzert, Klotz, et al., (2018)]. It is also one of the prime criteria for farming, domestic, and industrial activities. Nevertheless, the careful preparation and control of water supplies to mitigate property damage and lifelessness due to flooding is becoming very important [Nourani, (2017)].

In essence, rainfall runoff modeling has evolved from rudimentary beginnings into a powerful tool that empowers experts to better understand, manage, and protect our water resources. Its contributions extend far beyond academia, enabling us to make more sustainable and resilient decisions in the face of evolving environmental challenges. This discipline continues to evolve alongside advancements in technology and our growing awareness of the importance of water in our lives.

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According to the Asian Development Bank (ADB), from 1950 to 2011 Pakistan witnessed 21 floods which are mostly attributed to rainfall. Unexpected and strong rainfall contributes to overflowing dams, which are the leading cause of severe flooding (Ledesma and Futter, 2017). Streamflow forecasting for a catchment area is one of the well-known and main

hydrological variables since hydrological engineering, design, and actions for development and evaluation such as water supply, irrigation, flood control, and hydropower production require information on hydrological catchment stream flows (Song et al., 2019). The modeling of the rainfall-streamflow is considered to be complicated, nonlinear, and time-variable because the streamflow produced from a watershed depends not only on the hydro-meteorological parameters but also on the spatiotemporal irregularities in the features of the watershed and the patterns of rainfall (Xiang et al., 2020). Precisely forecasting streamflow helps to manage different water uses such as irrigation, hydropower development, preparing water delivery policies, and flood risk management (Jaiswal et al., 2020). Hydrologists have developed and used various types of models for modeling hydrological processes such as streamflow forecasting, prediction of rainfall, flood forecasting, and modeling of rainfall-runoffs, etc (Nourani et al., 2019)

For the efficiency of the spatial-temporal resolution, the entire network state is removed after each example has been processed. When data points are naturally connected a conclusion is not needed. Besides, a typical Artificial Neural Networks (ANN) model (feed-forward) will allow a fixed-sized sliding window over the dataset to handle time-series data (Chlumecký et al., 2017). Tuning the scale of these sliding windows for the highest predictive precision adds additional work to the range of models. In finer time resolution flood assessments, the constraint is increasingly noticeable. Despite some examples of using a Recurrent Neural Network (RNN) for hydrological modelling (Reshma et al., 2018), there is no Long Short-Term Memory (LSTM) model that forecasts future river flow solely based on precipitation inputs to address the issue of accumulative uncertainty in the literature. Therefore, to overcome the model errors, the infiltration rate with the soil moisture and steep slopes in the hill is a vital part to calculate in the runoff model for the prediction of daily rainfall. Thus, the research work proposed a novel framework for better prediction of rainfall with a runoff model.

Rainfall-runoff modeling is one of the most important hydrological processes, especially large-scaled processes (Chang, 2009). Also, nonlinearity and multidimensionality render the modeling of the transformation of rainfall into runoff very complex (Ishtiaq et al., 2010). Hydrological models have an extensive classification but in general, these models have been divided into three groups, which are the empirical or data-driven models, conceptual or gray box models, and physically-based or white box models (Willems, 2000).

a) **Conceptual or Gray Box Models:** Conceptual models strike a balance between empirical and physically-based models. They are constructed based on a conceptual understanding of

the hydrological system, capturing its essential behavior while simplifying or abstracting some of the intricate physical processes. Conceptual models are often favored when a moderate level of understanding of the system's behavior exists, allowing for a more interpretable representation of hydrological processes. Designers of these models draw upon their knowledge and intuition to create models that mimic observed system behavior effectively.

- b) **Physically-Based or White Box Models:** Physically-based models, also known as theoretical models, strive to represent all relevant physical processes within the hydrological system. These models aim to describe the system's behavior by explicitly incorporating physical principles, equations, and mathematical representations of processes such as infiltration, evapotranspiration, and flow through porous media. Physically-based models are highly accurate but can be computationally intensive and data-demanding. They are often employed in situations where a deep understanding of the system's mechanics is crucial (Moore et al., 1988).
- c) **Empirical or Data-Driven Models:** Empirical models do not explicitly incorporate the underlying physical laws and processes governing the hydrological system. Instead, they rely on statistical relationships and correlations to link input variables (such as rainfall) to output variables (like runoff). These models are particularly useful when a direct mechanistic understanding of the system is not a primary concern. They are often employed in situations where data availability is high, and quick predictions are required (Leavesley et al., 2002)

The choice of which type of hydrological model to use depends on various factors, including the availability of data, the level of understanding of the system, computational resources, and the specific goals of the modeling exercise. Each category of models has its strengths and limitations, and researchers and practitioners in hydrology must carefully consider these factors when selecting the most appropriate modeling approach for a given application.

The next section highlights the motivation for the study.

1.2 Motivation for the Study

Rainfall runoff modeling is an important process in hydrology that helps predict the amount of runoff that will result from a given rainfall event. This information is important for activities such as flood control, drought management, water resource management, and urban planning. In recent years, Soft computing technique such as Artificial Neural Networks (ANN) and

Genetic Algorithms (GA) have been used to model rainfall runoff. ANN is a machine learning technique that is used to model complex relationships between inputs and outputs. In the case of rainfall runoff, inputs may include rainfall data, architecture of the basin, soil and vegetation types, etc., while the output is the amount of runoff. GA is a heuristic optimization technique that is used to solve complex problems by mimicking natural selection and evolution. In the context of rainfall runoff modeling, GA can be used to optimize the input parameters of an ANN model to achieve the best possible performance.

The use of AI, ANN, and GA in rainfall runoff modeling has several advantages over traditional methods. For instance, AI techniques can learn from historical data to make more accurate predictions. They can also handle nonlinear relationships between inputs and outputs, making them more reliable and efficient. In conclusion, the application of AI, ANN, and GA in rainfall runoff modeling is an emerging field that offers a lot of promise in improving the accuracy of hydrological predictions. With the continuous advancement of technology, we can expect AI to continue to play an increasingly important role in hydrological modeling and other areas of water resource management. The next section details the objectives of this work.

1.3 Thesis Objectives

The objectives of this research are:

- To estimate model errors in the computational runoff by using posterior fire-breathing network,
- To estimate the infiltration rate by the prophetic multilayer network is directly considering the relationship between infiltration and soil moisture through a collection of parsimonious computational parameters
- To predict rainfall and calculates the velocity of runoff on steep slopes by utilizing well-ordered selective genetic algorithm
- To estimate discharge through the hydrological and data driven models.
- To compare hydrological and data driven models for discharge prediction (HEC-HMS and RF).

The novelty of such a comparison lies in the integration of traditional hydrological models and modern soft computing techniques. Here are some potential points of novelty:

- a) Soft computing models like Random Forest (RF) and M5P are known for their flexibility in capturing complex relationships in data. The novelty arises from leveraging this flexibility to improve the representation of hydrological processes.

- b) Soft computing models are particularly effective in capturing nonlinear relationships and patterns in data. The novelty here lies in exploring whether these data-driven models outperform traditional hydrological models in certain scenarios.
- c) Soft computing models are often more adept at handling uncertainty and variability in data. The novelty in the comparison may involve assessing how well these models adapt to changing conditions and uncertainties compared to more rigid hydrological models.

Comparing these models could provide novel insights into the strengths and weaknesses of each approach, offering valuable information for decision-making in water resources management. The next section details the thesis organization for this study.

1.4 Thesis Organisation

This thesis is organized in six chapters. Brief descriptions of the contents of each chapter are as follows:

Chapter 1 - Introduction: An illustration of several key concepts, importance of, aim and key contribution from this work are presented.

Chapter 2 - Literature Review: In this chapter an overview of the relevant literature review is discussed.

Chapter 3 - Research Methodology: The chapter details description of the methodologies adopted for the present work.

Chapter 4 – Data and Model setup: The chapter details the Rainfall data and Different Rainfall Runoff Model setup for prediction of Discharge.

Chapter 5 - Results and Discussion: The chapter contains the simulation results and discussions for four Rainfall Runoff prediction models.

Chapter 6 – Summary and Conclusion: This chapter provides summary, highlights and conclusions of the work.