



A Review on Sensitivity Analysis of Rainfall-Runoff Models

*Adithya Sabu

Under Graduate Student
Dept. of Civil Engineering
Government Engineering College
Barton Hill
Thiruvananthapuram, Kerala, India
adithya.trv20ce004@gecbh.ac.in

Parvathy G.R

Under Graduate Student
Dept. of Civil Engineering
Government Engineering College
Barton Hill
Thiruvananthapuram, Kerala, India
parvathy.ltrv20ce9313@gecbh.ac.in

Athira S

Under Graduate Student
Dept. of Civil Engineering
Government Engineering College
Barton Hill
Thiruvananthapuram, Kerala, India
athira.trv20ce025@gecbh.ac.in

Sony C.R

Under Graduate Student
Dept. of Civil Engineering
Government Engineering College
Barton Hill
Thiruvananthapuram, Kerala, India
sony.ltrv20ce9312@gecbh.ac.in

Prof. Lini R Chandran

Dept. of Civil Engineering
Government Engineering College
Barton Hill
Thiruvananthapuram, Kerala, India
lini.sam@gecbh.ac.in

Abstract— A runoff model, also known as a rainfall-runoff model, explains how precipitation in a drainage basin is transformed into runoff. A rainfall-runoff model may be used to understand, regulate, and monitor the quantity and quality of water resources. Various factors of the watershed directly or indirectly impact runoff, thereby influencing the runoff model, including terrain features, soil composition, vegetation variety and distribution, land use landcover (LULC), and slope characteristics. Through the utilization of a rainfall-runoff model, both the quantity and quality of water resources can be comprehensively analysed, managed, and monitored. A sensitivity analysis is usually done to comprehend the impact of each parameter in a mathematical model and study about the uncertainty in their output. In case of watershed hydrological modelling, sensitivity analysis is used to assess the hydrological influences of specific hydrological parameters on simulation outcomes of the models. It assesses the model's responsiveness to changes in input parameters and helps to understand how those parameters affect model outputs. This paper examines various

sensitivity analysis conducted on rainfall-runoff models to assess their response to different parameters.

Keywords— *Rainfall-runoff model, Sensitivity analysis, Land use Landcover (LULC)*

1. INTRODUCTION

Water travels down the ground's natural slope in little, concentrated rivulets, where it falls in separate streams. To assess the peaks of floods to determine the amount of water needed for municipal needs to plan irrigation operations for agriculture or other industrial uses to design multipurpose storage facilities, protect wildlife, estimate future reliable water supplies for power generation, and other related tasks, it is necessary to estimate runoff from a catchment. Additionally, the main input to the hydrological cycle that is simply and reasonably accessible monitored is rainfall; on the other hand, stream flow is a dependent variable that has to be anticipated in relation to matching rainfall. Measurement of rainfall is more accessible than runoff and has

been done for a long time. Catchment size, and shape, precipitation characteristics, soil types, terrain and land use are the main factors determining catchment runoff. The process by which rainfall in a drainage basin (catchment area or watershed) is converted into runoff is described by a runoff model, sometimes referred to as a rainfall runoff model. In reaction to a rainfall event, it produces a surface runoff hydrograph, which is entered as a hyetograph. Hazardous hydrological forecasting, in particular, might involve flood forecasting and rainfall-runoff modelling to reduce risks and minimize hazards. The river basin system's rainfall-runoff processes are simulated by several models.

A few of the subjects that can be researched using the different models include water availability, flow forecasting, urban drainage, flood occurrence modelling, the impact of future urbanization, flood damage reduction, wetland hydrology, reservoir spillway design, flood plain control, and system operation. Sensitivity analysis assesses the impact of shifting values of an independent variable on a certain dependent variable, given a set of presumptions. Every stage of the modelling process, from model construction to calibration and verification, may benefit from the application of sensitivity analysis. The sensitivity of model parameters is a subset of the general idea presented above. A significant factor in the majority of optimization techniques is metric sensitivity. Sensitivity analysis of the rainfall-runoff model that results from this will help determine the regulating parameter needed for accurate output estimation.

2. Effect of change in input parameters to runoff models:

The effect of variation in various input parameters on the generated runoff from the watershed runoff models are discussed in detail in the following sections.

2.1 Effect of slope:

In hydrological research, precise modelling and water flow prediction in watersheds depend on a knowledge of how topographical characteristics affect runoff production. Slope is one of these terrain characteristics that is most important for affecting runoff dynamics. Numerous hydrological processes, such as surface runoff, infiltration, erosion, channel flow, and

interactions with land use and cover, are impacted by the slope of the land surface. One of the most significant effects of slope on runoff models is its influence on surface runoff generation. Compared to gentler slopes, steeper slopes produce more concentrated and faster runoff. Higher slope gradients cause the gravitational force pushing on water to rise, which raises velocities and increases surface runoff. For runoff models to properly estimate the time and volume of surface runoff, especially during precipitation events, the slope gradient must be taken into account. In the work done by Yacoub et al. [1] spatial discretization of terrain slope was done on the Jequetepeque River Basin located in the northern part of Peru and having an area of 4,372.5 km². In their study it was found that when discretizations with fewer sub-basins (than the default discretization) were utilized, the addition of slope significantly improved the simulation outcome. In these situations, adding slope improved the simulation's output. In the research conducted by Osama Z. Al-Hamdan [2], the SCS approach was utilised in HEC-HMS hydrological model and it was found that the HEC-HMS model is more sensitive to the input slope parameter than the imperviousness. In conclusion, runoff models and hydrological processes in watersheds are significantly impacted by the slope of the ground surface. Accurate hydrological modeling and watershed management depend on an understanding of how slope gradient affects surface runoff, infiltration, erosion, channel flow, and land-atmosphere interactions.

2.2 Effect of Curve Number:

The Curve Number (CN) is a parameter that represents the soil's hydrological properties, including infiltration and runoff potential. It ranges from 0 to 100, with lower values indicating higher infiltration rates and greater water storage capacity in the soil. The study by Arash Asadi et al. [3] looked at the rainfall-runoff dynamics in the Kabkian basin and the minor sub-basin Delibajak in Kohgilouye and Boyerahmad. They utilized the SCS curve number method to estimate infiltration loss and the SCS unit hydrograph method to simulate the transformation of precipitation excess into direct surface runoff. The SCS-CN method considers factors such as soil cover, land use, and antecedent moisture to

estimate precipitation excess. Additionally, the constant monthly method was employed to model base flow. Parameters for the SCS curve number method, including curve number and initial abstraction, were calibrated, while the lag time parameter was calibrated for the SCS unit hydrograph method. The results demonstrated that the model accurately predicted peak discharge and flood volume timing based on historical flood data, indicating the suitability of HEC-HMS for the studied basin. The optimization of SCS hydrologic parameters, including curve number, initial abstraction, and lag time, further enhanced the model's performance. Curve number and initial abstraction were the main causes of the largest variances between the produced baseline peak hydrographs and the peak hydrographs, respectively. The optimization of SCS hydrologic parameters, including curve number, initial abstraction, and lag time, further enhanced the performance of model.

Another study by Kishor Choudhari et al. [4] used the HEC-HMS model to simulate rainfall-runoff processes in the Balijore Nala watershed, Odisha, India. The method utilized for this study area is the Soil Conservation System Curve Number (SCS-CN) method, known for its simplicity and efficiency in estimating runoff from rainfall events. In this study, a modified SCS-CN method is applied to determine the loss model for rainfall-runoff modeling in the Nasik region watershed using long-term daily rainfall data. The Curve Numbers (CN) are based on hydrologic soil groups, with Group A consisting of soils with low runoff potential and high infiltration rates, Group B with moderate infiltration rates, Group C with low infiltration rates, and Group D with the highest runoff potential. In the central Nasik region, Group B soils with a CN of 74 are prevalent, while in the surrounding areas, Group D soils with a CN of 86 dominate. These distinctions in soil types and CN values are crucial for accurately estimating runoff in the study area.

2.3 Effect Of Land Use Land Cover (LULC)

Economic development and population growth have triggered rapid changes to the earth's land cover over the last two centuries. Land cover, defined as the assemblage of biotic and abiotic

components on the earth's surface, is one of the most crucial properties of the earth system. Land cover and land use may seem similar, but they're actually different. Land cover refers to what's on the surface of the earth, while land use is about how people use the land. The change in land use and land cover due to human activities is a major cause of hydrological process changes in watersheds. The effects of land cover changes have impacted the stream flow of the watershed by changing the magnitude of surface runoff and groundwater flow.

Asmamaw Adamu Geremew et al. [5] studied how changes in land cover affect stream flow, and they looked at wet months (June, July, and August) and dry months (January, February, and March) using satellite images and GIS along with the SWAT model. ArcGIS was used to generate land use and cover maps from Landsat TM and ETM+, respectively. Using the generated land cover maps, SWAT models were run to evaluate the impacts of land use and cover changes on the stream flow of the study watershed. The performance of the SWAT model was evaluated through sensitivity analysis, calibration, and validation. Ten flow parameters were identified as sensitive for the stream flow of the study area, and they were used for model calibration. The results showed both the calibration and validation of the measured and simulated stream flow data, with a coefficient of determination (R^2) of 0.91 and a Nash Sutcliffe Efficiency (NSE) of 0.90 for the validation period. The analysis showed that, stream flow characteristics changed due to land cover changes during the study period.

The study conducted by N. Sajikumar et al. [6] have also examined the effects of land cover and usage on the runoff characteristics of two watersheds in Kerala and how these features have changed in the last several decades. Data on land use, land cover, soil, and other factors are required for the Soil and Water Assessment Tool (SWAT) to simulate watersheds. The study discovered that although the forest cover in the investigated region varied significantly, the impact of land use change on runoff characteristics was only marginally significant. In the Manali and Kurumali watersheds, the forest area changed by 60% and 32%, respectively, yet the discharge maxima rose by 15% and the flows throughout the dry seasons dropped. The dual impact of increased evapotranspiration from crops like

rubber and enhanced percolation from terracing contributed to the relatively moderate impact of land use change compared to the substantial forest area alterations. In Manali and Kurumali watersheds, the conversion of woodland into agricultural land was observed, particularly as plantations with qualities somewhat similar to forests, except for heightened evapotranspiration. The researchers have emphasized that in areas where high evapotranspiration species are planted, water collection techniques such as rain harvesting ditches may be necessary to improve groundwater penetration and mitigate the effects of increased evapotranspiration.

2.4 Influence Of Sediment Transport

Calibration and validation procedures are used to assess watershed models. However, it is sometimes costly and challenging to gather observable data for calibration purposes as well as sediment model parameters. Sensitivity analysis can be used to determine the model's most important parameters in situations where sediment data is few. For the construction and use of models, determining the sensitive input parameters is essential. Rainfall-runoff modelling took into account all relevant factors, including baseflow, reservoirs, diversions, canopy, soil, and surface runoff. For the subbasin, reach, and reservoir aspects of this sensitivity analysis, a broad range of input parameters can be used, including Enrichment Ratio, Sand, Silt, Clay, MUSLE (Cover Factor), Fraction of Gravel, Channel Width Active Layer Factor, Fall Velocity Method, etc. Usually, one chosen parameter was changed while the basic values of the other parameters remained constant. In the study about the sensitivity analysis of sediment transport, Jang Pak et al. [6] investigated elevations ranging from 299 m to 495 m (981 ft to 1624 ft) above sea level in the Upper North Bosque River in Central Texas. According to that study, the subbasin components' sensitive characteristics were the Sand Enrichment Ratio and the MUSLE cover factor. The outflow sediment yields were also somewhat impacted by the fall velocity approach for the reservoir components. River-based sediment movement from continents to seas is one of the most significant processes. An indication of the rate of erosion or soil loss is the volume of sediment removed from a watershed system. Rainfall and runoff that occur over a watershed

region affect the movement of sediment at the watershed's exit. An annual, seasonal, monthly, and diurnal fluctuation in the sediment production response behavior is evidently exhibited by a temporal and geographical change in the quantity of rainfall and runoff. There may be an increase in sediment flow production as a result of the larger concentration of rainfall depths with considerable variability.

Omvir Singh [7] has investigated about the relationship of rainfall, runoff and sediment transport in the outlet of Tirthan watershed, Himachal Pradesh, India. July and August have been determined to have the greatest sediment concentration and load, respectively, and to have transported about 67% of the total sediment load during these two months. The fact that the amount of sediment load peaks in July and August suggests that during this time, materials that have weathered throughout the dry season get mobilized. Elevated sediment concentrations are sometimes linked to increased runoff during monsoon seasons, but they can also result from topsoil erosion and the movement of loosened debris after a mild rainfall event. Due to insufficient rainfall, silt concentrations are often low throughout the post-monsoon and winter seasons. It is not essential for high yearly rainfall and runoff to cause high suspended sediment load in the watershed and vice versa; the growing suspended sediment load with runoff is just episodic. In the Tirthan watershed, there was a seasonal change in the flow of silt, especially during the monsoon (wet) season. Large, transitory sediment pulses are mostly linked to transient increases in stream flow brought on by downpours.

2.5 Influence of soil moisture accounting model

Basically, data from prior years were compared with data on observed stream flow to make additional forecasts. The Soil Moisture Accounting (SMA) model may be used to continually estimate stream flow. To evaluate the effectiveness of the model, plotted hydrographs were examined visually and computed statistical parameters were employed. Every model parameter was graded according to how sensitive it was to changes in the base flow index, peaks, Nash-Efficiency, seven-day low flow, and percent

change in the simulated runoff volume after a sensitivity assessment of the parameters was conducted. The runoff studies done by Wendso Awa et al. [7] on the Mkurumudzi River which flows through the coast of Kenya is a work related to the effect of SMA model. In light of these findings, the Mkurumudzi catchment's continuous daily streamflow may be predicted using the SMA model in the HEC-HMS model. Based on sensitivity analysis performed on the continuous model, the groundwater layer storage coefficients and the impervious area were shown to be the most important parameters. It was shown that the maximum infiltration rate was the least significant parameter.

2.6 Influence of Temperature

Temperature is one of the main determinants of runoff among other things. Temperature influences precipitation, snowmelt, evaporation, and soil moisture, all of which have an impact on runoff patterns. It is essential to comprehend how temperature affects runoff in order to manage water resources, forecast floods and droughts, and lessen the consequences of climate change. Temperature's impact on precipitation patterns is one of the main ways it influences runoff. Changes in the distribution, intensity, and frequency of precipitation episodes can be brought about by warmer temperatures. Elevated temperatures have the potential to accelerate evaporation, resulting in drier conditions in certain areas and more severe precipitation in other locations. In a research by Kazem Javan et al. [8], the impact of temperature was investigated in the Gharehsoo River basin in northwest Iran and came to the result that 1°C and 2°C rise in temperature leads to 8% and 15% drop in average monthly flow, respectively. Temperature has a significant impact on precipitation patterns, influencing both the kind and intensity of precipitation episodes. As global temperatures rise, atmospheric circulation patterns shift, altering regional precipitation regimes. Warmer temperatures can increase the intensity of convective rainfall, resulting in more surface runoff from greater rainfall rates and shorter-duration storms.

3. Conclusion

This paper investigates how varying values of an independent variable affects the rainfall-runoff model under specific assumptions. According to research undertaken by various experts, certain factors impact the rainfall-runoff model while others do not. Slope, LULC variations, and sediment movement were all shown to have a substantial impact on the model. Some elements, such as the number of drainage basins, have little effect on the model. The effectiveness of the model varies with the approach and software employed. As a result, sensitivity analysis of various parameters can aid in the development of a false proof model as well as the identification of both significant and irrelevant variables in runoff modeling.

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