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Utilizing the HEC-HMS Model for Hydrological Modelling of the Rambiara Watershed: Rainfall and Runoff Estimation

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Abstract: Hydrological modelling and flood prediction are essential components of the Rambiara watershed's water resource management. To improve disaster preparedness and reduce the danger of flooding in the area, the effectiveness of the HEC HMS model in flood forecasting must be assessed. In this study, various techniques for estimating rainfall are examined, and a customized hydrological model tailored to the hydrological complexities of the Rambiara watershed is developed. The goal of this project is to provide practical insights for better flood risk reduction and water resource management through the integration of cutting-edge modelling tools and rigorous analysis. This work advances our knowledge of watershed dynamics and provides guidance for sustainable water resource planning projects in the Rambiara watershed and beyond by thoroughly examining precipitation patterns and hydrological processes. In addition, the research takes into account a number of factors related to flood behaviour, such as determining places that are vulnerable to flooding, analysing the size of floods, and estimating how frequently they occur. By taking a holistic approach, it is possible to gain a thorough understanding of the dynamics of flooding in the Rambiara watershed, which paves the way for the development of efficient flood risk management techniques. This study looks into the temporal and spatial variability of rainfall in the Rambiara watershed in addition to research on floods. Through the comparison of several methods for estimating rainfall, including deterministic and geostatistical approaches, the study offers valuable insights into the precision and dependability of rainfall data, which are essential for hydrological modelling and flood forecasting. The hydrological processes of the Rambiara watershed can be more accurately represented by creating a bespoke hydrological model with the HEC HMS program. Informed decision-making and proactive flood risk reduction strategies are made possible by the study's model calibration and validation, which guarantee the model's dependability in simulating runoff and forecasting flood events. Overall, this study advances our knowledge of flood dynamics in the Rambiara watershed and advances hydrological modelling tools. The goal of this study is to promote sustainability and resilience in the face of hydrological hazards by offering practical insights for managing water resources and reducing the danger of flooding.

Keywords: Simulation, Calibration, DEM, GIS, HEC-HMS, Physical characteristics.

I. INTRODUCTION

Water is the foundation of life on Earth and is necessary for all living things to survive. Ecosystems could not survive without water. But there's a serious problem with the growing demand for water due to things like intensive farming, population growth, urbanization, and poor management of available water resources. Water shortages brought on by this rising demand have a negative impact on ecosystems and human populations alike. Societies are left exposed and unable to fully recover from the effects of water scarcity, endangering livelihoods. Effective management planning is necessary to meet this challenge and maximize the use of the natural resources that are already accessible. In terms of developmental activities, the management of water resources and economic expansion are particularly important to the agricultural sector. The basic idea of hydrology, which offers the necessary framework for comprehending hydrological parameters and processes, is fundamental to the assessment and development of water resources. Stakeholders can ensure the resilience and prosperity of communities and ecosystems by developing policies for the sustainable management of water resources by utilizing hydrological knowledge.

A watershed is home to a complex web of hydrological processes that operate on various temporal and spatial scales. These activities include precipitation, interception, surface runoff, infiltration, groundwater percolation, and evapotranspiration. The way these elements interact results in the watershed's response, which is usually shown on runoff hydrographs. This reaction depends on a number of variables, including land use patterns, soil properties, rainfall characteristics, and human interventions. Watershed topography includes shape, size, slope, and orientation.

For example, if the land surface is parched after a dry summer, then heavy precipitation in the fall may not result in large runoff. The same precipitation, however, can cause floods in the winter or spring because the soils are wetter or have a higher moisture content, which allows for more surface runoff. In a similar vein, poorly managed agricultural methods can worsen erosion by introducing an excessive amount of fertilizers and pesticides into bodies of water, lowering the quality of the water within the watershed. High levels of complexity, nonlinearity, and spatiotemporal variability are seen in hydrological events. The mathematical depictions of catchment systems' reactions to hydrological events over predetermined time intervals are known as hydrological models. Not only do these models serve industrial demands but also human needs by analysing and forecasting streamflow, they are invaluable tools. To make the investigation easier, a popular model that works well in a variety of geographic contexts has been chosen for this study.

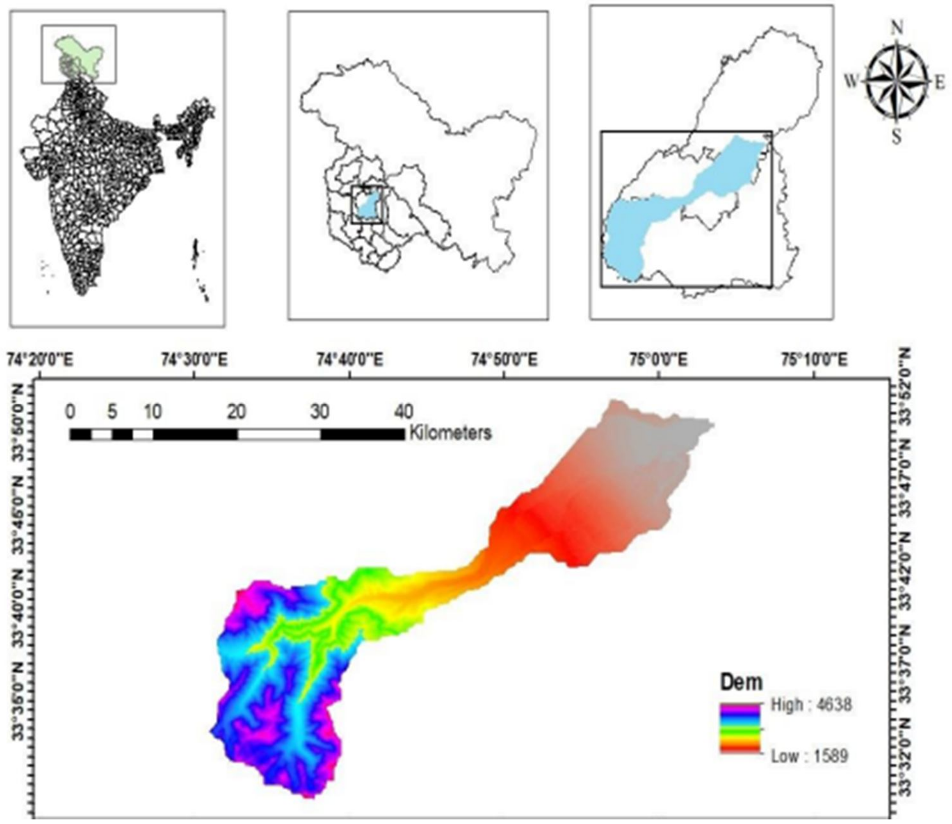
II. MATERIALS AND METHODS

This chapter outlines the selected study area, describes the data that was gathered and used for rainfall-runoff modelling, and provides an analysis of the models that were used. It focuses in particular on the calibration and procedure of the HEC-HMS model that is used to predict discharge at the Rambiara outlet within the watershed. Effective flood forecasting is the main goal. The following sections offer a thorough representation of the several datasets that were obtained throughout the study in order to successfully accomplish the goals of the research.

The Rambiara watershed, nestled within the picturesque locales of Shopian and Pulwama districts in Jammu and Kashmir, covers an area of 471 km². Originating from the lofty Rupri ridge of the Pir Panjal Range, the Rambiara River is nourished by the cascading waters from Rupri peak and the serene Bug Sar Lake on one side, and the mountain passes of Pir Panjal and Naba Pir on the other. Across its course, the river descends an impressive 2466 meters

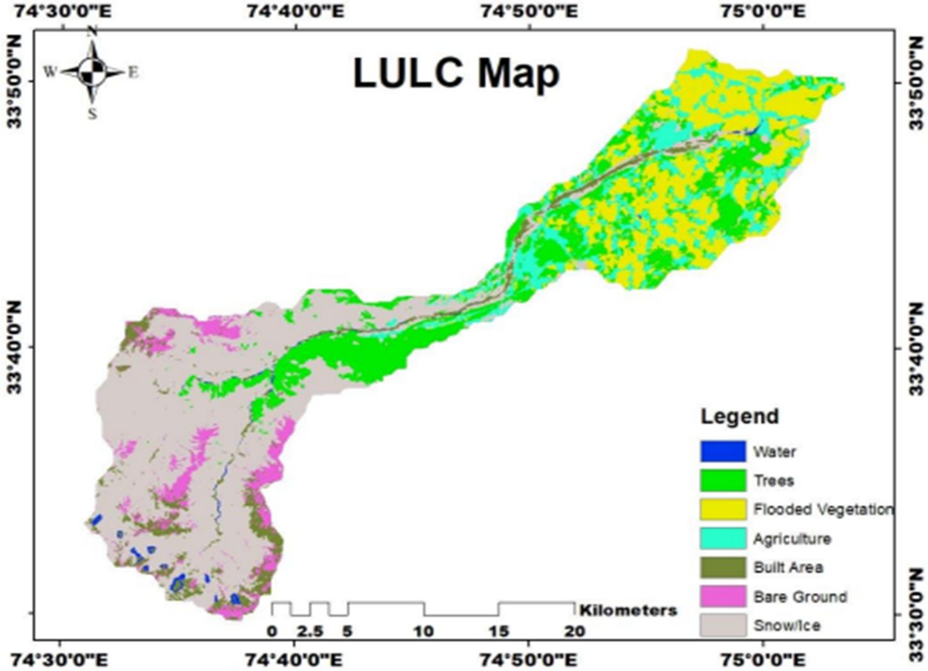
The catchment area of the Rambiara spans approximately 75100 hectares, contributing significantly to the hydrology of the region. Its journey converges with the Vishu River before they both merge into the mighty Jhelum at Sangam, located at latitude 33°83 and longitude 75°07'. This confluence serves as a vital source of irrigation for the valley, sustaining agriculture and livelihoods

Situated amidst the left bank mountainous terrain of the Jhelum River in the western Himalayas, the Rambiara river basin occupies a strategic position between latitudes 33°33' and 33°54'N, and longitudes 74°30' and 75°00'E, enriching the southern region of Kashmir valley with its abundant natural resources.



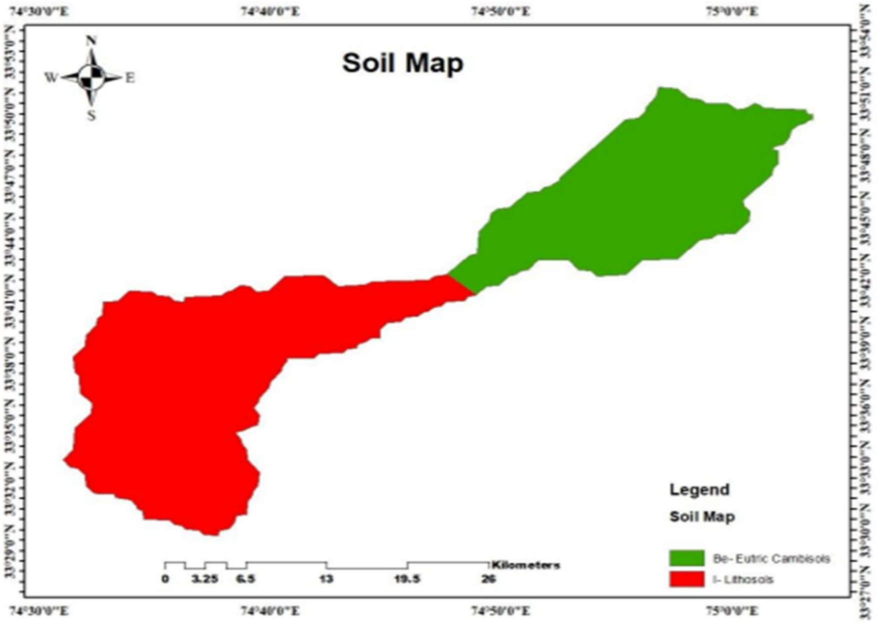
Location map of the study area.

The Climate Change and Mountain Agriculture (CCMA) Lab, Division of Soil Science, SKUAST-K provided the land use data used in this study. This shapefile-formatted information, which is intended for Geographic Information System (GIS) study, includes soil textural and land use categories unique to the defined Rambiara watershed. The estimation of the weighted Curve Number (CN) for the defined subbasins depended heavily on these datasets. The Land Use/Land Cover (LULC) map was subjected to the "union" command in ArcGIS 10.8 to enable CN computation for different sub-basins. This produced an extensive background database.



2 LU/LC Map of Rambiara Watershed

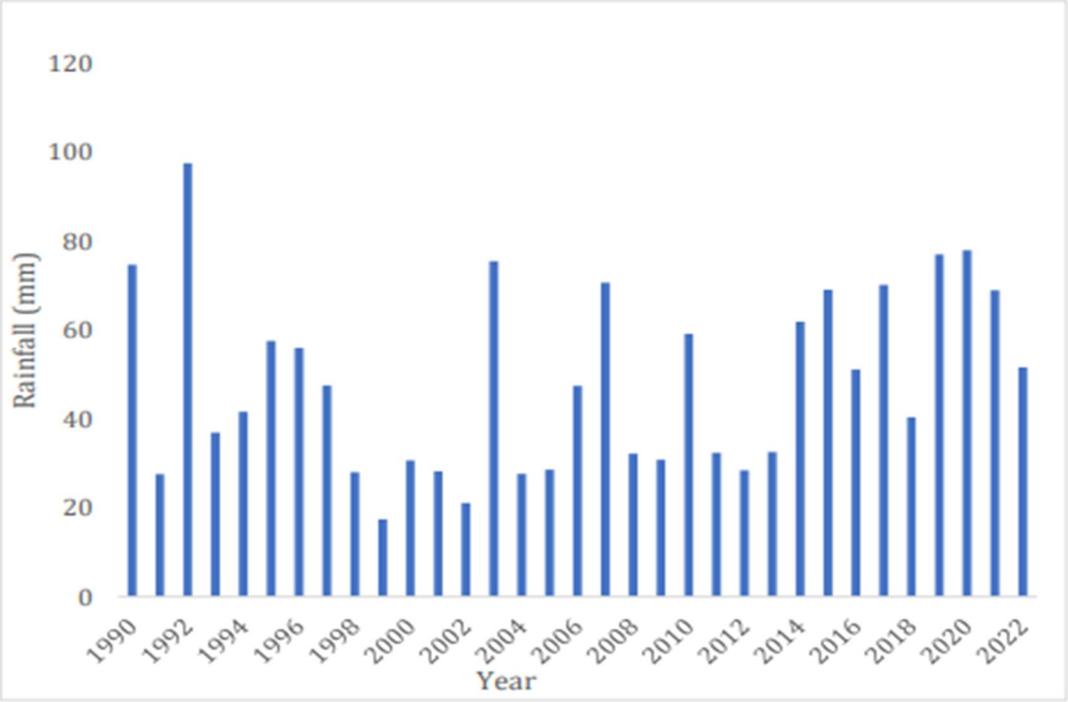
The topography of the catchment region varies greatly. The research area's primary soil types for altitudes > 3200 m.s.l. include mountain soils and brown forest soils; for altitude ranges (1600-3200 m.s.l.), the types of soils include Karewa; alluvial soils predominate in areas with altitudes



Soil Map of Rambiara Watershed

III. METEOROLOGICAL DATA

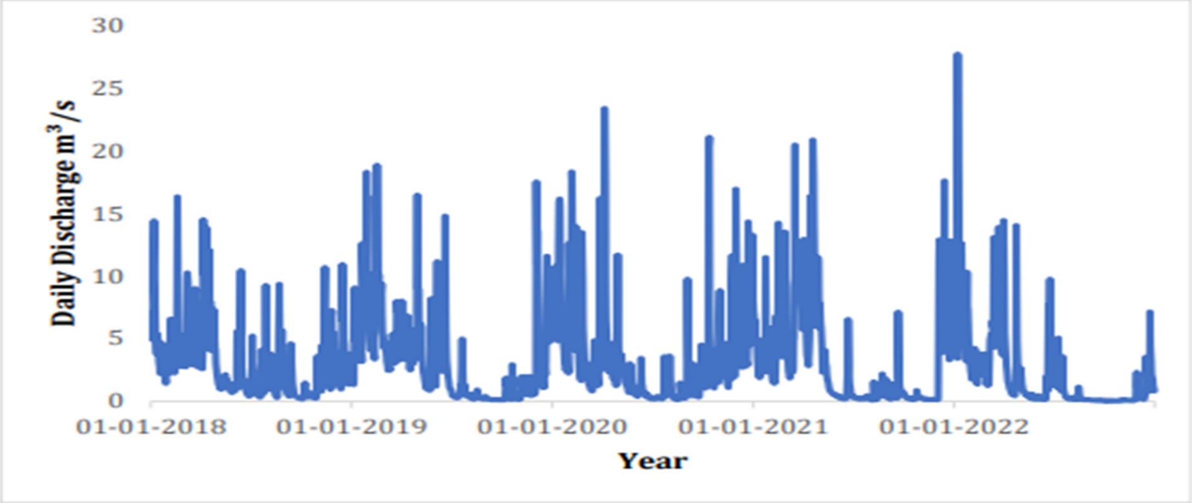
Data on daily rainfall was collected from the Indian Meteorological Department in Srinagar, covering a 33-year period from 1990 to 2022. In the study area, storm hydrograph rainfall-runoff simulations were carried out using this dataset. Figure below shows the annual rainfall records from the Shopian gauging station for the same 33- year period (1990–2022)



Annual rainfall data of Shopian station (1990-2022)

A. Hydrological Data

The study obtained daily stage data from the watershed outflow for the period of 2018 to 2022 from the Executive Engineer's Office of the Irrigation and Flood Control Department (I&FC) in Srinagar. This 0 20 40 60 80 100 120 Rainfall (mm) Year dataset, which is shown in Figure below, offers important information on the water discharge at the watershed's outlet over the given time frame.



Daily Discharge data at Rambiara Nallah At Nayina (Wachi) (2018-2022).

B. Estimation Of Mean Rainfall By Spatial Interpolation

As noted by Faure’s et al. (1995) and Chaubey et al. (1999), the use of point rain gauges for precipitation input causes substantial uncertainty in runoff estimation. Because of this uncertainty, it is difficult to anticipate discharge accurately, especially when rain gauges are located outside of the basin (Schuurmans and Bierkens, 2007). Hydrological modelling utilities require spatially continuous rainfall data in order to overcome these restrictions, as noted by Syed et al. (2003), Kobold and Sušelj (2005), Gabellani et al. (2007), Cole and Moore (2008), Collischonn et al. (2008), Ruelland et al. (2008), and Moulin et al. (2009). Singh (1997), Andréassian et al. (2001), Kobold and Sušelj (2005), Leander et al. (2008), and Moulin et al. (2009) have all 0 5 10 15 20 25 30 01-01-2018 01-01-2019 01-01-2020 01-01-2021 01-01-2022 Daily Discharge m³/s Year highlighted how much the quality of results depends on the spatial consistency of rainfall data.

Using known values from sampled points as a basis, spatial interpolation is a technique that predicts variable values at unsampled places. In order to estimate values at unknown places, a weighted average of the surrounding point values must be calculated. This process turns a discrete set of points into a continuous surface. The interpolated surface that is obtained is often known as a statistical surface, and it can be utilized for a variety of data types, including measurements of the groundwater table, elevation, temperature, precipitation, and snow accumulation. Waldo Tobler (1970) claimed that "Everything is related to everything else, but near things are more related than distant things" as the core tenet of interpolation. As a result, interpolation gives closer points a larger weight than farther points. Using GPS-measured elevation points to create a continuous map, such as a digital elevation map, requires the use of an appropriate interpolation technique to reliably predict values at places where samples or measurements are unavailable. Subsequently, the outcomes of interpolation analysis can be applied to more extensive area analyses and modelling. It's important to remember, though, that the variable should only be interpolated when it has a significant value at each location in the region of interest. Interpolation is not useful when points only show the existence of events without any associated values.

There are a number of difficulties in creating continuous surfaces from data that is unevenly distributed, especially when deciding which approach will best capture the true surface (Caruso and Quarta, 1998). Since the 1960s, there have been indirect methods for producing continuous surfaces from rainfall data by utilizing satellite platforms and ground-based meteorological RADARs. But more assessment is needed to determine the confidence and reliability of these indirect approaches for hydrological applications, which means historical data will need to be used for calibration and validation (Lanza et al., 2001). Many interpolation methods have been put forth in the literature to reproduce the spatial continuity of rainfall fields using rain gauge measurements. Deterministic approaches and geostatistical methods are the two primary divisions into which these techniques can be broadly divided. Deterministic approaches like Thiessen polygons and Inverse Distance Weighting (IDW) as well as geostatistical approaches like kriging are a few often employed strategies. The general formula for spatial interpolation is based on the idea that spatial interpolation usually entails estimating a regionalized value at unsampled places by giving weights to observed regionalized values.

$$z_g = \sum_{n=1}^{ns} \lambda_i \, zs_i$$

Where:
Zg is the interpolated value at the required points;
Zsi is the observed value at point I;
ns is the total number of observed points and λ =
(λi) is the weight contributing to the interpolation.

The computation of the weights, λ, that will be applied to the interpolation presents a challenge. The next sections provide the various approaches used to calculate the weights and their results for the research area

IV. GEOSTATISTICAL METHODS

A. Kriging Method

The field of geo-statistics, which links mathematics and earth sciences, includes the first group of spatial interpolation methods for measuring rainfall. One such method is the Kriging method, which was named and formalized by Matheron (1971) in honor of Daniel G. Krige, a South African mining engineer who pioneered the field of geostatistics. Based on statistical models involving autocorrelation—that is, the statistical relationships between measured points—these methods can generate a prediction surface and provide measures of certainty and accuracy.

Using a weighted sum of the available point observations— selected to guarantee unbiased interpolation and minimize variance—Kriging estimates the value of the variable at a given point. Linear, Authorized, Unbiased, and Optimal (LAUO) systems are required for kriging. Kriging comes in various forms: Simple Kriging (SK), Ordinary Kriging (ORK), and Universal Kriging (UNK).

These variations are attributed to the form that is applied to the mean of the variable of interest. UNK is not stationary with respect to the mean, in contrast to the other methods, because it makes the assumption that the mean is a polynomial function of spatial coordinates

V. DETERMINISTIC METHODS

A. Nearest Neighbourhood method

The nearest neighbour (NN) approach, sometimes called the Thiessen polygon method, makes the assumption that calculated values can adopt the observed values of the closest station. Even though it is straightforward, the NN approach is regarded as sturdy and versatile, and it continues to be widely used even as more complex options emerge. This method involves selecting a predetermined number of data vectors that are comparable to the vector of interest, then randomly resampling one of those vectors to represent the vector for the current time step in the simulation period.

This entails simultaneously sampling and replacing weather variables from observed data, such as temperature and precipitation, in weather data simulation. Days having features akin to those simulated for the previous day are first chosen, and one of these nearest neighbour is then selected based on a specified probability distribution or kernel in order to create meteorological variables for a new day.

The next day's simulated values are based on the observed values for the day after that closest neighbour. While maintaining temporal and spatial connections, models built using the NN technique can be expanded to simulate meteorological data across multiple sites.

The weather of the same day is used for all stations, maintaining spatial dependencies, while each day's simulated values are predicated on the values from the day before, maintaining temporal reliance. Furthermore, when a block of variables rather than a single variable is resampled from observed data, cross-correlation among variables at any particular site is automatically retained. The research area's monthly rainfall interpolation map from January to December, produced using the nearest neighbour method

B. Performance Evaluation

Using a strict cross-validation framework, we carefully assess and compare the performance of two well-known interpolators in this work: the Ordinary Kriging (OK) and Nearest Neighbour approaches. Our method consists of temporarily removing a rainfall observation that was chosen at random from the dataset, and then "re-estimating" the value of that observation using both interpolation techniques. We carefully check the estimated mean rainfall calculated using these techniques with the measured values. We use well-established measures, such as mean error and root mean square error (RMSE), to assess the quality of our estimations. A series of governing equations that have been carefully adapted to our study aims serve as the basis for these assessments. They are as follows:

$$\text{Mean Error} = \sum_{i=1}^{n} \frac{P_i - O_i}{N}$$

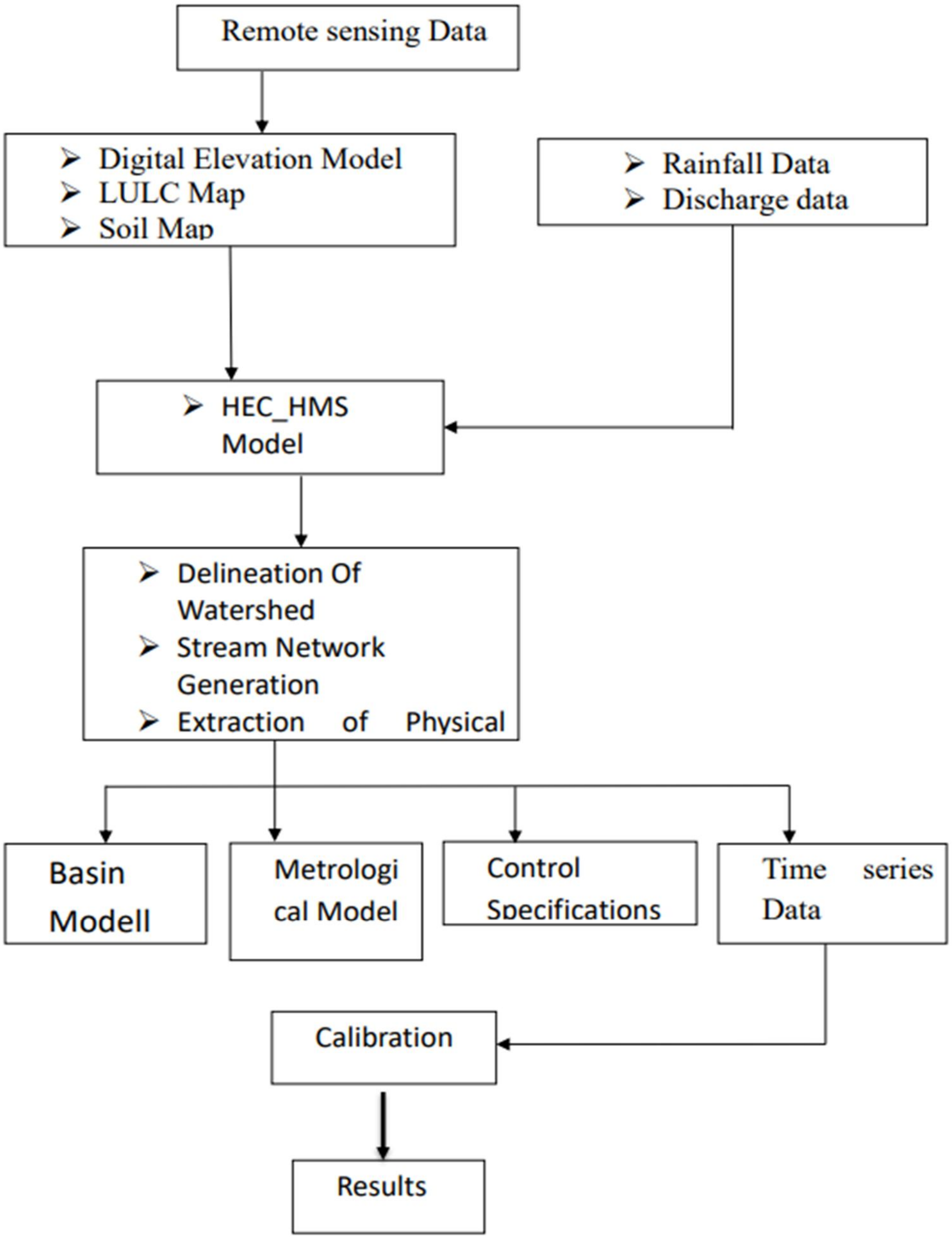
$$\text{Root Mean Square Error} = \sum_{i=1}^{n} \sqrt{\frac{(Pi-Oi)^2}{n}}$$

Where, Pi =Predicted values.

Oi=Observed Values

C. Utilization of HEC-HMS in Model Development

HEC-HMS Methods and Parameters



Processes, Methods and data Requirements For HEC_HMS

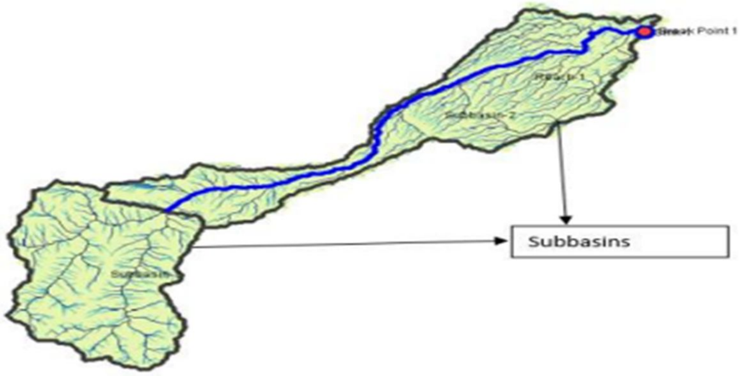
HEC-HMS is used to simulate precipitation-runoff processes, route flows across river networks, and assess hydrological responses in a simple way when developing models for watershed hydrology. In order to inform decisions about the management of water resources, this entails establishing the watershed, specifying hydrological parameters, choosing suitable models, executing simulations, and analysing the outcomes.

The hydrologic response of a watershed is simulated using the HEC-HMS model components. The primary elements are

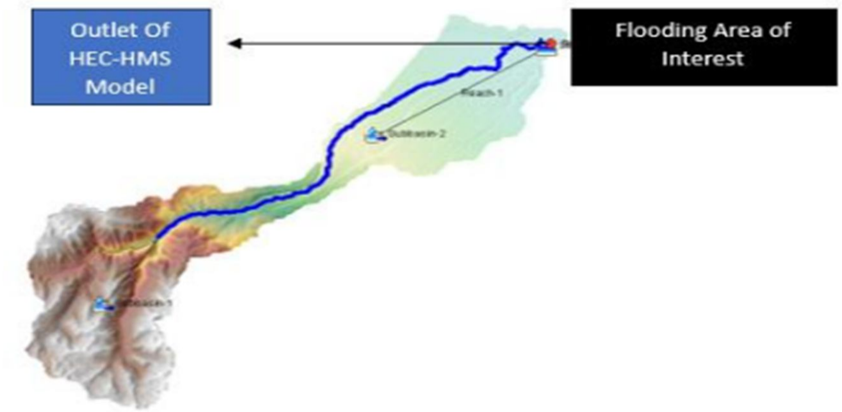
- Basin model
- Meteorological model
- Control specifications and
- Time-Series Manager.

1) *Basin Model:* Determining the boundaries, topography, soil types, land use/cover, and hydrologic features (such as streams and reservoirs) of the watershed are all part of this component. The spatial distribution of hydrological parameters within the watershed is primarily represented by the basin model.
2) *Meteorological Model:* The hydrological model's incorporation of meteorological data is handled by the meteorological model component. This contains information on sun radiation, wind speed, temperature, humidity, and precipitation. The meteorological model provides inputs like rainfall and possible evapotranspiration, which assist drive the hydrological processes within the watershed.
3) *Control Specification:* Determining the simulation's characteristics and settings, including its duration, time step intervals, and other control options, is known as control specification. This part makes that the simulation performs in accordance with the intended goals and standards.
4) *Time Series Data:* The historical or observable data used for model analysis, validation, and calibration is referred to as time series data. Measurements of streamflow, rainfall, and other pertinent hydrological observations gathered over time are usually included in this data. Time series data are necessary to verify the hydrological model's outputs against observed hydrological responses and assess the model's performance.

Deriving Physical Watershed Parameters



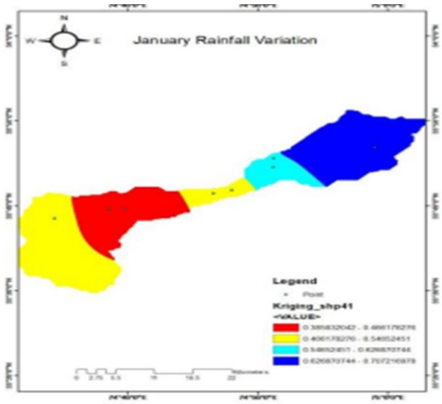
There are multiple sequential phases involved in determining the physical parameters in HEC-HMS. Sinks must be preprocessed first, followed by drainage preprocessing, stream identification, breakpoint management, and finally, element delineation within the watershed.

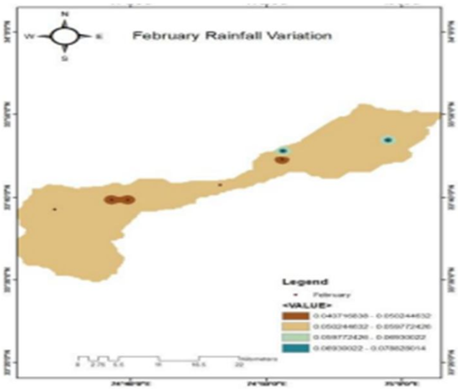


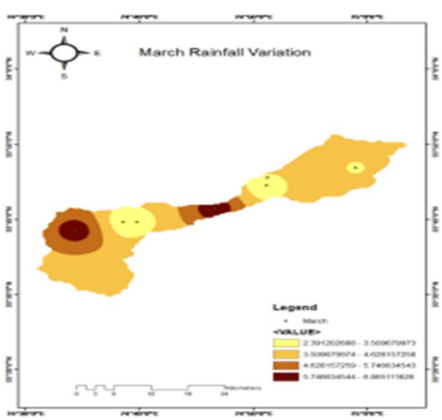
This section summarizes the findings of our study, which employed the HEC-HMS software to hydrologically model the Rambiara watershed, with a focus on rainfall estimation and flood forecasting. The study had three main goals: first, it estimated mean rainfall throughout the Rambiara watershed using a variety of deterministic and geostatistical techniques, such as nearest neighbourhood and Kriging techniques; second, it developed a hydrological model using the HECHMS software that was customized to the study area's features; and finally, it assessed the effectiveness of the HEC-HMS model in flood forecasting within the Rambiara watershed and improved the accuracy of flood predictions. In this section, we discuss the performance of several techniques for estimating rainfall, the creation and adjustment of the HEC-HMS model, and the evaluation of its efficacy in flood forecasting. The findings reported here help to enhance the region's capacity for flood prediction while providing insightful information on the hydrological dynamics of the Rambiara watershed.

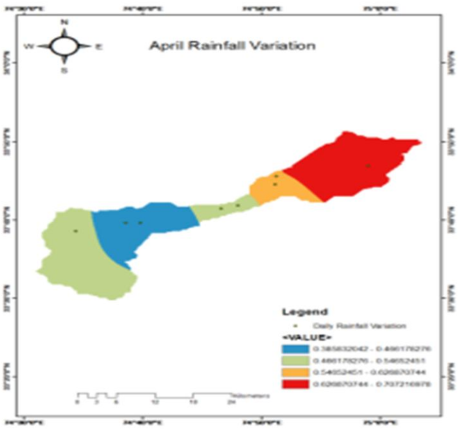
A. *Estimation of Mean Rainfall over the Rambiara Watershed Using Deterministic and Geostatistical Methods*

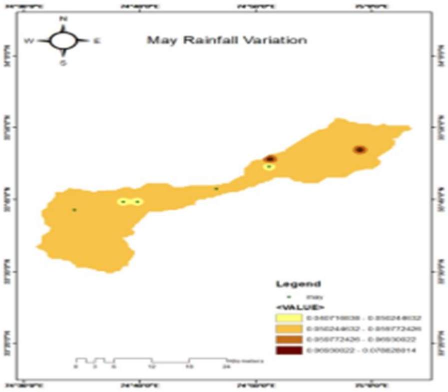
The following figures display the monthly rainfall interpolation map of the research area from January to December produced by the nearest

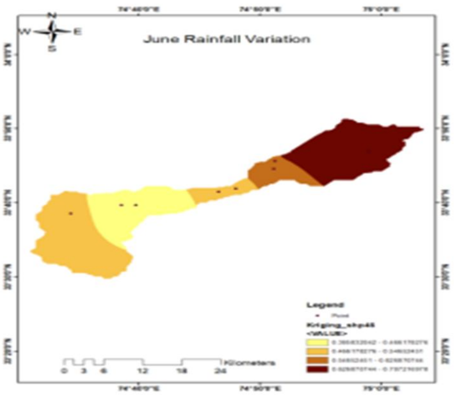


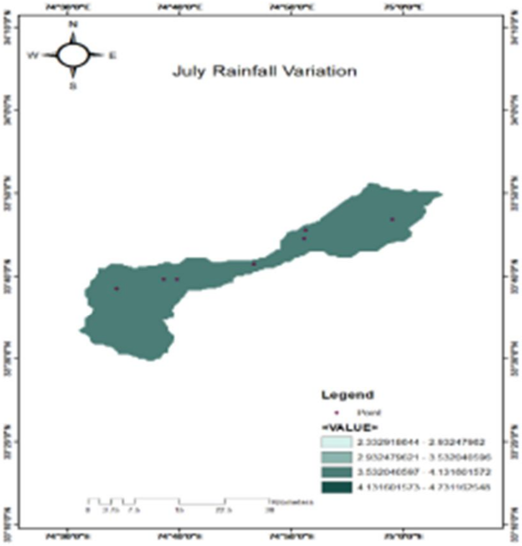


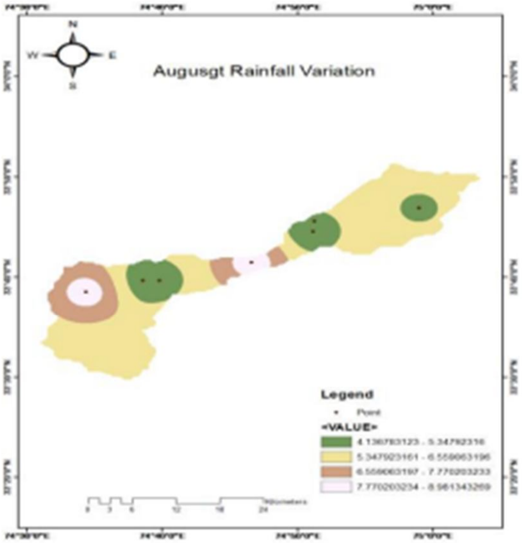


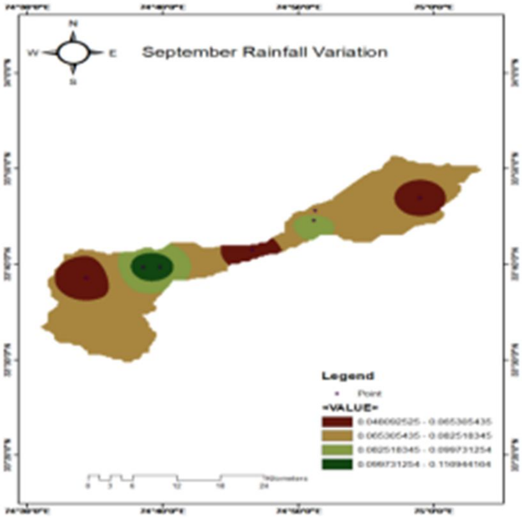







N
W
E
S
July Rainfall Variation
Legend
Point
<VALUE>
2.332918644 - 2.93247962
2.932479621 - 3.532040596
3.532040597 - 4.131601572
4.131601573 - 4.731162548
0 3.75 7.5 15 22.5 30
Kilometers


N
W
E
S
Augusgt Rainfall Variation
Legend
Point
<VALUE>
4.136783123 - 5.34792316
5.347923161 - 6.559063196
6.559063197 - 7.770203233
7.770203234 - 8.981343269
0 3 6 12 18 24
Kilometers


N
W
E
S
September Rainfall Variation
Legend
Point
<VALUE>
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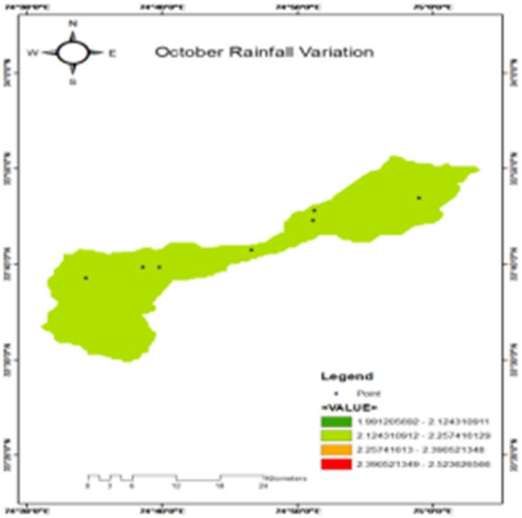
0.065305435 - 0.082518345
0.082518345 - 0.099731254
0.099731254 - 0.116944164
0 3 6 12 18 24
Kilometers


N
W
E
S
October Rainfall Variation
Legend
Point
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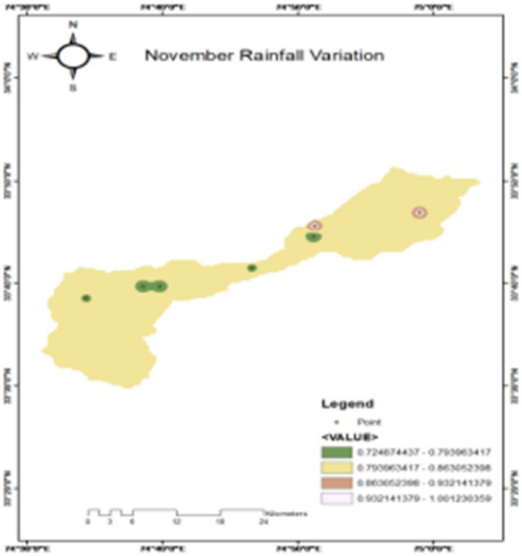
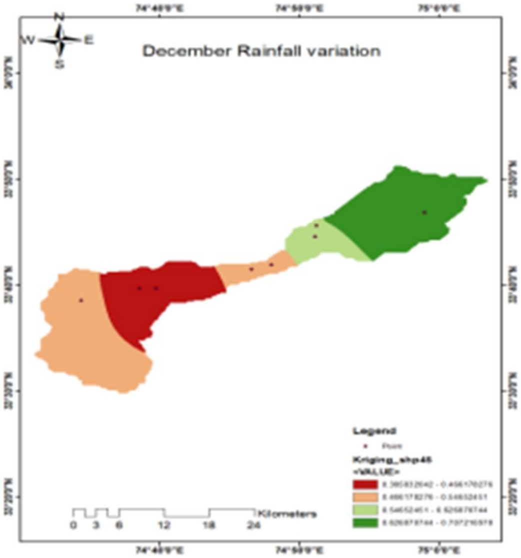
2.124310912 - 2.257416129
2.25741613 - 2.390521348
2.390521349 - 2.523626566
0 3 6 12 18 24
Kilometers


N
W
E
S
November Rainfall Variation
Legend
Point
<VALUE>
0.724674437 - 0.793963417
0.793963417 - 0.863052398
0.863052398 - 0.932141379
0.932141379 - 1.001230359
0 3 6 12 18 24
Kilometers


N
W
E
S
December Rainfall variation
74°40'0"E
74°50'0"E
75°0'0"E
Legend
Point
Kriging_shp45
<VALUE>
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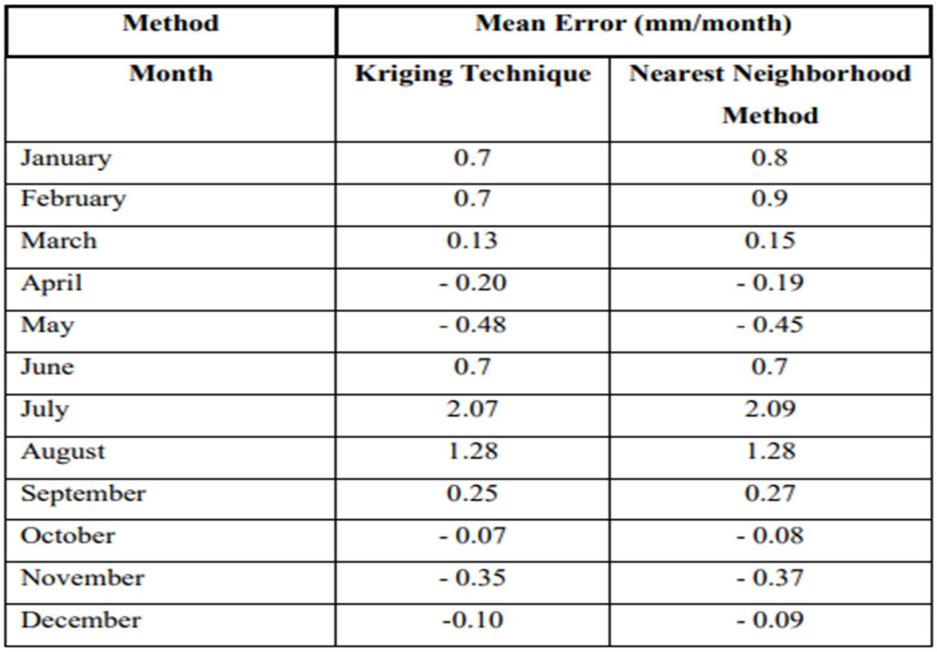
0.456178276 - 0.546524511
0.546524511 - 0.626878744
0.626878744 - 0.707216978
0 3 6 12 18 24
Kilometers

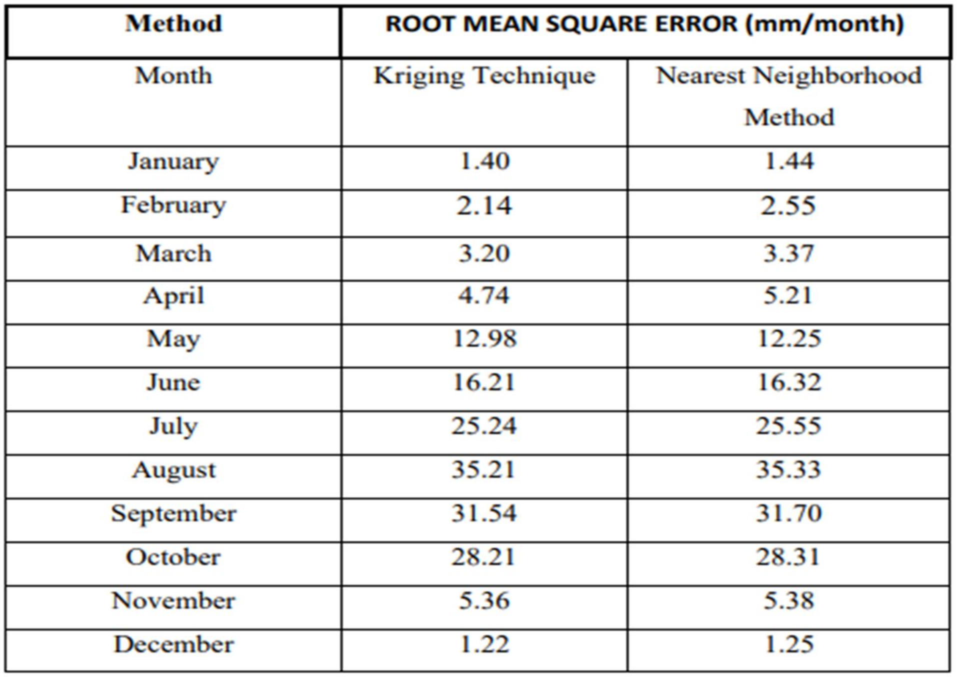
B. Performance Evaluation

Via cross-validation, the effectiveness of two interpolators, such as the Kriging and Nearest Neighbourhood approaches, is evaluated and contrasted. In order to "re-estimate" this number from the remaining data, the concept is to arbitrarily remove a rainfall measurement from the data set for a short period of time. When comparing the computed and observed mean rainfall estimates, the mean error and root mean square error (RMSE) criteria were used to estimate the inaccuracy in the observations. These formulas control the following



Method	**Mean Error (mm/month)**	
Month	**Kriging Technique**	**Nearest Neighborhood Method**
January	0.7	0.8
February	0.7	0.9
March	0.13	0.15
April	- 0.20	- 0.19
May	- 0.48	- 0.45
June	0.7	0.7
July	2.07	2.09
August	1.28	1.28
September	0.25	0.27
October	- 0.07	- 0.08
November	- 0.35	- 0.37
December	-0.10	- 0.09

Performance Evaluation of Kriging and Nearest Neighbourhood Methods



Method	**ROOT MEAN SQUARE ERROR (mm/month)**	
Month	Kriging Technique	Nearest Neighborhood Method
January	1.40	1.44
February	2.14	2.55
March	3.20	3.37
April	4.74	5.21
May	12.98	12.25
June	16.21	16.32
July	25.24	25.55
August	35.21	35.33
September	31.54	31.70
October	28.21	28.31
November	5.36	5.38
December	1.22	1.25

Performance Evaluation of Kriging and Nearest Neighbourhood Methods

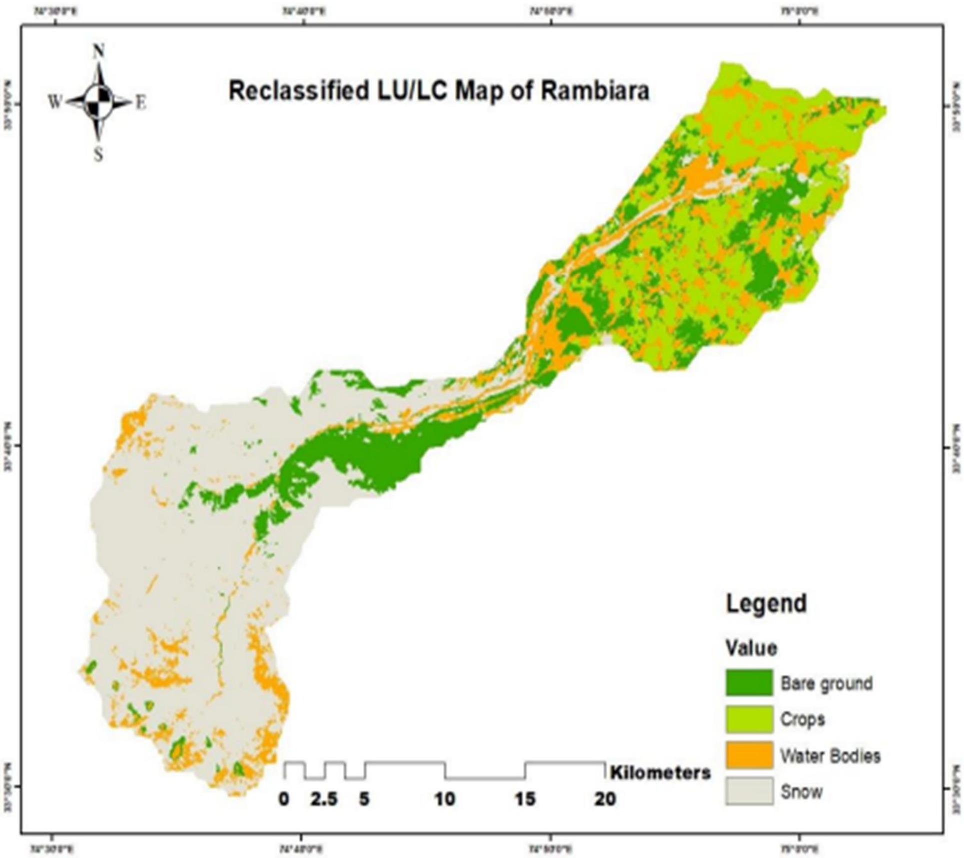
C. Evaluation of the HEC-HMS Hydrological Model.

Land use/ Land cover

The most important factor affecting the process of surface runoff generation is land use. The Rambiara watershed is split up into four major LULCs in order to combine the effects of land use. classifications viz., water bodies, trees, Crops, agriculture, built area, bare ground and snow. The reclassified land use categories for Rambiara watershed are presented in figure and the area covered under various land use classes is shown in Table

Land Use Class	**Area (Km)^2**	**Area %**
Water	3.1372	0.617174
Trees	88.2212	17.35556
Flooded Vegetation	91.3961	17.98015
Agriculture	53.9034	10.6043
Built Area	29.1945	5.743369
Bare Ground	26.8208	5.276397
Snow/Ice	215.6434	42.42305

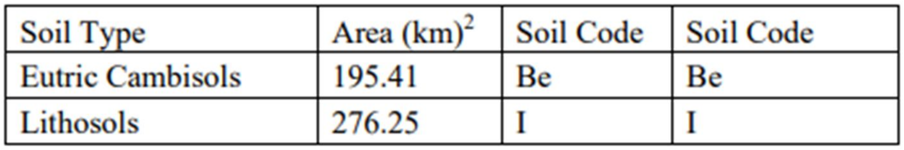
Area Covered under different Land use Classes



Reclassified LU/LC of Rambiara watershed

D. Soil Map

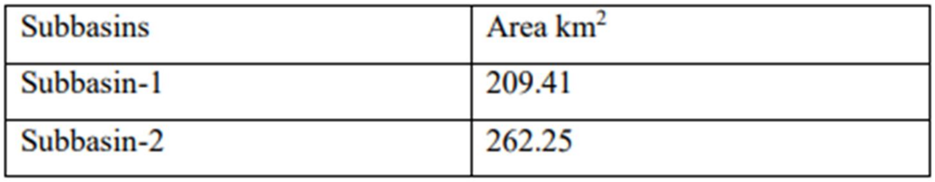
The soil types obtained for the study region are Eutric Cambisols and Lithosols, which cover an area of 195.41 km2 and 276.25 km2, respectively, after preprocessing the soil map using GIS. The area covered by each type of soil is displayed in Table



Soil Type	Area $(km)^2$	Soil Code	Soil Code
Eutric Cambisols	195.41	Be	Be
Lithosols	276.25	I	I

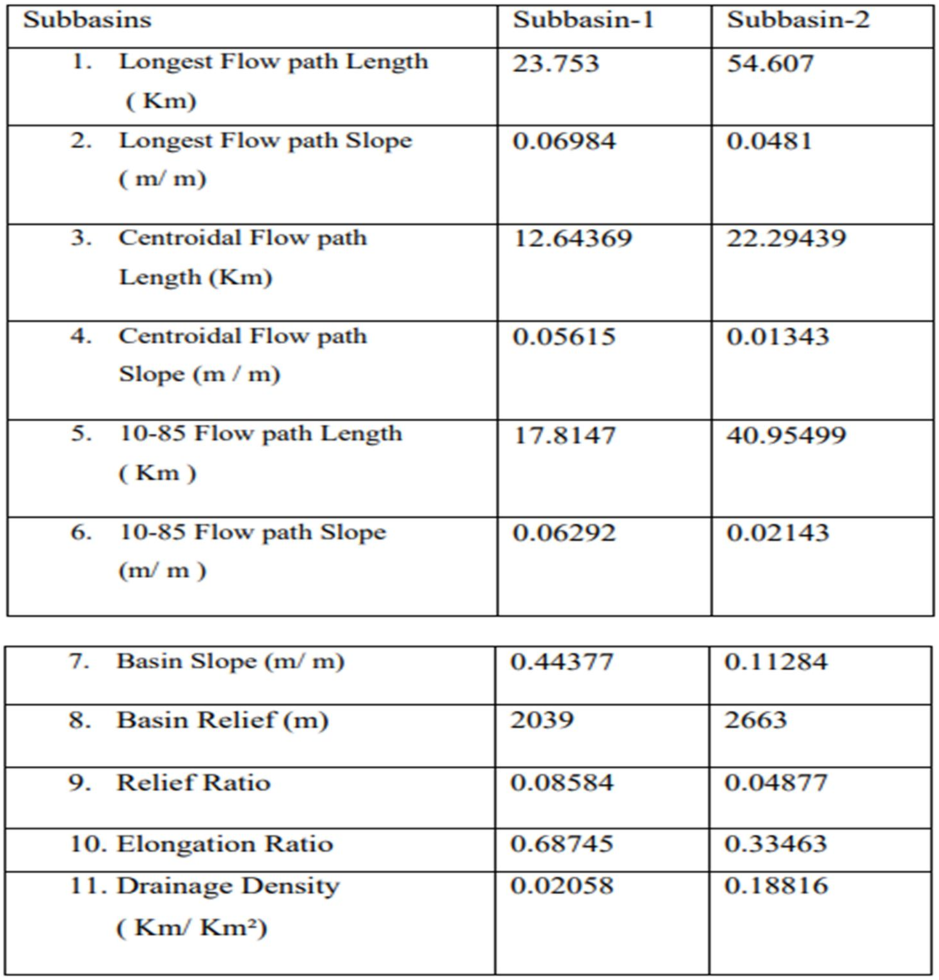
Area under different soil classes in Rambiara watershed

E. Derived Physical Parameters in HEC-HMS Model.



Subbasins	Area km^2
Subbasin-1	209.41
Subbasin-2	262.25

Area of Sub-basins

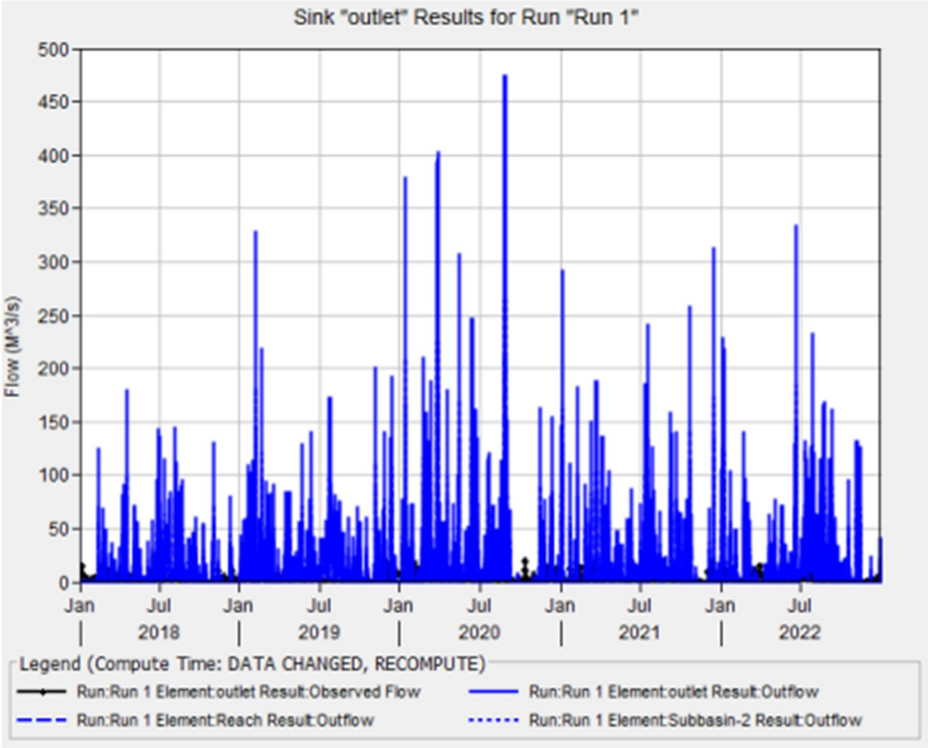


Subbasins	Subbasin-1	Subbasin-2
1. Longest Flow path Length (Km)	23.753	54.607
2. Longest Flow path Slope (m/ m)	0.06984	0.0481
3. Centroidal Flow path Length (Km)	12.64369	22.29439
4. Centroidal Flow path Slope (m / m)	0.05615	0.01343
5. 10-85 Flow path Length (Km)	17.8147	40.95499
6. 10-85 Flow path Slope (m/ m)	0.06292	0.02143
7. Basin Slope (m/ m)	0.44377	0.11284
8. Basin Relief (m)	2039	2663
9. Relief Ratio	0.08584	0.04877
10. Elongation Ratio	0.68745	0.33463
11. Drainage Density (Km/ Km^2)	0.02058	0.18816

Characteristics of Sub-basins

F. Simulation of Rainfall and Runoff

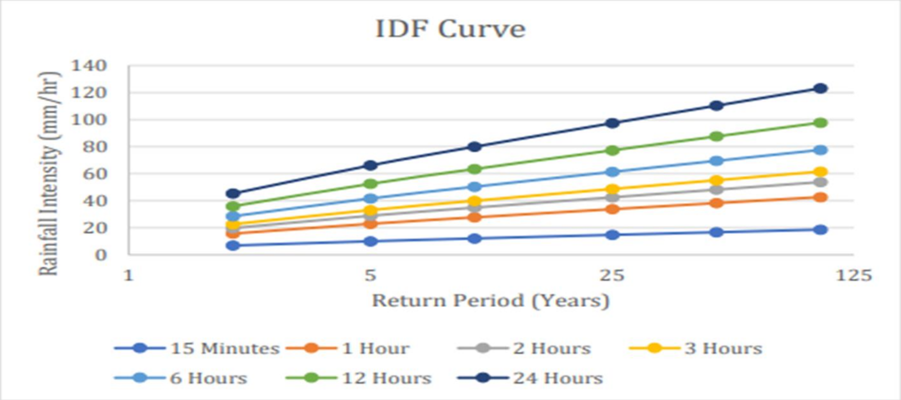
The parameters and procedures are followed when running the simulation. The simulated hydrograph at outlet is compared to the historically observed hydrograph data at the same location in order to determine the correctness of the model results. By comparing the results of the simulation to the real hydrological patterns observed data, this comparative analysis allows for an assessment of the model's efficacy and dependability. The two hydrographs can be seen in Figure below.



Hydrograph of simulated and observed values

G. Construction of IDF Curves

The construction of IDF (Intensity-Duration-Frequency) curves involves plotting rainfall intensity (measured in mm/hour) on the y-axis against duration (measured in hours) on the x-axis for various return periods. Each curve represents the relationship between rainfall intensity, duration, and the probability of occurrence for a specific return period. Common durations include 15 minutes, 1 hour, 2 hours, 3 hours, 6 hours, 12 hours, and 24 hours, among others. Return periods typically include 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year events, indicating the likelihood of a particular rainfall event occurring in any given year.



IDF Curve Graph.

VI. CONCLUSION

Flooding is a major natural danger, which emphasizes how important it is to have trustworthy forecasting tools and safety precautions. It results from the buildup of surface runoff over a certain area, underscoring the critical need of precisely calculating runoff in order to properly forecast and minimize flood occurrences. The management of water resources and the operation of reservoir dams can be severely hampered by inaccurate runoff estimations. Therefore, using hydrological models to simulate rainfall-runoff processes becomes a practical way to estimate runoff. Utilizing hydrological models also makes it easier to comprehend the hydrological dynamics in catchment areas, which improves flood event preparedness and response tactics.

The Rambiara watershed is located in the Indian Union Territory of Jammu and Kashmir. It is in a strategic location between latitudes 33°33' and 33°54'N and longitudes 74°30' and 75°00'E. This watershed, which is well-known for having an abundance of natural resources, is essential to improving the southern Kashmir valley. Using digital elevation models (DEM) and ArcGIS 10.8 and HEC-HMS 4.10, the Rambiara watershed was carefully mapped in this study. To achieve the study goals, a large dataset including daily discharge, rainfall, soil, and satellite data was gathered. The hydrological behaviour of the Rambiara watershed was investigated by a study that included HEC-HMS and previously published research. Then, in order to simulate streamflow dynamics, the HEC-HMS model was calibrated using rainfall and discharge data covering the years 2018 to 2022

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