

## Original Research Article

# Rainfall vs. Water Balance Components using R Software: A Case Study on a Micro-watershed in the Mid-lands of Kerala

### ABSTRACT

The conversion of rainfall to other water balance components is a complex hydrologic process influenced by various storm and drainage characteristics. In the ungauged watershed, measuring the water balance components for planning the water management activities takes much work. Thus, it is essential to understand their relationship in any watershed, which engineers can use for planning various water resources projects. In this study, R software was used to determine these relationships. The Pearson's correlation coefficient ( $r$ ) between rainfall - runoff was 0.83, rainfall - soil moisture was 0.80, rainfall - depth to GW table was 0.72, and rainfall - evapotranspiration was -0.64. The relationship between rainfall vs. runoff, rainfall vs. soil moisture, rainfall vs. depth to GW table, and rainfall vs. evapotranspiration was a polynomial equation with degrees 4, 3, 5, and 3, respectively. The study concludes that by measuring the rainfall, it is possible to estimate most of the other water balance components using the regression estimates.

*Keywords: R software, Rainfall, Relationship, Ungauged watershed, Water balance*

### 1. INTRODUCTION

Rainfall and water balance components are closely interconnected and play a vital role in the overall hydrological cycle of an area. Water balance refers to the equilibrium between the inputs, outputs, and storage of water within a defined region, typically measured over a specific period. Rainfall is one of the most significant input factors in the water balance equation. It is the source of water that replenishes water bodies and contributes to various hydrological processes (Biddoccu *et al.*, 2013; Krishnan *et al.*, 2018; Zheng *et al.*, 2021).

Runoff is the portion of precipitation that flows over the land surface and eventually reaches rivers, streams, and other water bodies. The relationship between rainfall and runoff is directly linked. When rainfall intensity exceeds the soil's infiltration capacity or the land's ability to retain water, excess water becomes runoff. Runoff is an essential factor in assessing flooding risks and water availability.

Evapotranspiration is the combined process of water vapour being released into the atmosphere through evaporation from soil and water surfaces, as well as transpiration from plants. The interactive relation between rainfall and evapotranspiration is crucial for determining water availability and the water deficit in a region. If rainfall exceeds evapotranspiration, the surplus water can contribute to runoff and groundwater recharge. Conversely, if evapotranspiration exceeds rainfall, it can lead to a water deficit. Rainfall

affects soil moisture content, influencing various water balance components. Adequate soil moisture is necessary for plant growth and maintaining the water balance within the ecosystem. Excessive rainfall can saturate the soil, increasing runoff and reducing infiltration.

Groundwater recharge occurs when water from precipitation percolates through the soil and reaches the groundwater table. The relation between rainfall and groundwater recharge is evident in regions with permeable soils and suitable hydrogeological conditions. Higher rainfall usually leads to increased groundwater recharge, essential for sustaining groundwater levels. The change in storage of water bodies, such as lakes, reservoirs, and wetlands, is influenced by the difference between inflows (primarily from rainfall and runoff) and outflows (evaporation, groundwater discharge, and human withdrawals). Rainfall contributes directly to the inflow component of storage change.

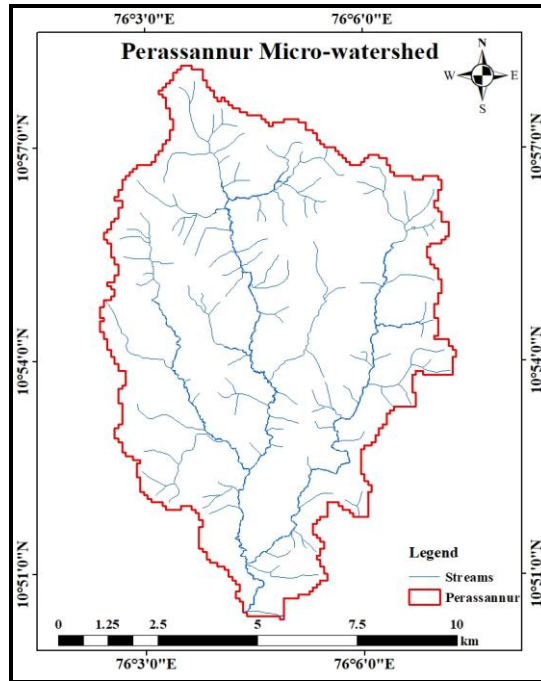
Understanding the relationships between rainfall and water balance components is crucial for water resource management, flood prediction, agricultural planning, and ecosystem sustainability. Changes in rainfall patterns due to climate change can significantly impact these relationships and a region's overall water balance (Verma *et al.*, 2020a, 2020b; Lian *et al.*, 2020; Kumar *et al.*, 2021).

The ungauged watershed needs measurement devices to collect hydrological data, such as rainfall, runoff, soil moisture, and groundwater table. Thus, there are limitations for hydrologists and environmental scientists to study such watersheds to understand the movement of water through a landscape and manage water resources effectively. However, by carefully considering available information and modelling techniques, it is possible to gain insights into the water dynamics of such areas and make informed decisions regarding water resource management (Abdulla and Al-Shurafat, 2020). R software is a versatile computerised statistical package that supports different regression techniques using the R programming language. The integrated features in R software can be used to write, execute, and visualise regression models efficiently. This study focuses on developing relationships between rainfall and other water balance components of a micro watershed.

## **2. MATERIALS AND METHODS**

### **2.1 Study Area**

The Perassannur micro-watershed is located in the Malappuram district of Kerala, between 10°50' and 10°58' N latitude and 76°2' and 76°7' E longitude, as shown in Fig. 1. The area and perimeter of the basin were 79.66 km<sup>2</sup> and 56.60 km, respectively. The average annual rainfall in this area was 2582.16 mm. The average temperature in this region was 27.38°C, with a mean yearly humidity of 77%. Also, the mean annual wind velocity was 2.16 km.hr<sup>-1</sup>. The region's climate is humid tropical, and it experiences high humidity during the monsoon months from June to October. The main streams play an essential role in the socio-economic development of society by providing water for domestic agriculture and other activities.



**Fig..1. Perassannur Micro-watershed with Drainage Network**

## 2.2 Data Acquisition

The study watershed was ungauged, and hence, the water balance components were determined by installing various instruments for measuring rainfall, runoff, soil moisture storage, and groundwater storage for 17 months from August 2021 to December 2022. There were four rain gauges for recording rainfall, a gauging station for recording runoff, soil moisture sensors for recording soil moisture, and a water table sensor for recording groundwater table.

## 2.3 R Software

R software is an Integrated Development Environment (IDE) for the R programming language, which is widely used for statistical computing, data analysis, and data visualisation. It provides a user-friendly interface that helps researchers, data scientists, and analysts work efficiently with R. It is an efficient statistical tool for conducting regression analysis in the R programming language. It provides an interactive and flexible environment for each step of the regression analysis process, from data import to model evaluation. Regression analysis can be efficiently performed by combining R's statistical capabilities with R software's user-friendly interface.

## 2.4 Steps Followed for Regression Analysis in R Software

The following are the steps followed for performing regression analysis:

1. Loading of Data: Import your data into R Software. You can read data from various file formats such as CSV, Excel, or databases. The read.csv() function is commonly used to read CSV files.

2. Exploring of Data: Exploring and understanding your data is essential before performing regression analysis. R Software provides various tools for data visualisation and summary statistics to help you understand the distribution and relationships among variables.
3. Preprocessing of Data: Clean and preprocess your data as needed. This might involve handling missing values, transforming variables, or dealing with outliers.
4. Choosing Regression Model: Decide on the type of regression model you want. Common types include:
  - a. Linear Regression: Modeling a linear relationship between the dependent and independent variables.
  - b. Multiple Regression: Extending linear regression to include multiple independent variables.
  - c. Logistic Regression: Used for binary or categorical dependent variables.
  - d. Polynomial Regression: Modeling non-linear relationships using polynomial terms.
5. Fitting Regression Model: Use R's regression functions to fit the chosen model to your data. For linear regression, the `lm()` function is typically used. For logistic regression, you might use functions like `glm()`.
6. Assessing the Fitted Model: Evaluate the goodness-of-fit of your regression model using various statistics, such as R-squared for linear regression, deviance for logistic regression, and more.
7. Interpretations of Results: Interpret the regression model coefficients to understand the relationships between the independent and dependent variables. The statistical significance of coefficients can be assessed using p-values.
8. Checking of Assumptions: Ensure that the assumptions of regression are met. These include assumptions about linearity, independence of errors, constant variance, and normality of residuals.
9. Making Predictions: Use the fitted regression model to predict new or unseen data.
10. Visualisation of Results: R Software offers various packages for creating plots and visualisations to help you visualise the relationships between variables, the model fit, and the residuals.
11. Reporting and Documentation: R Markdown in R Software can create a document that includes your code, explanations, visualisations, and results in a single file.

## **2.5 Development of Relationships between Rainfall and Water Balance Components**

The following are the statistical parameters for determining the relations between various water balance components.

### **2.5.1 Pearson's Correlation Coefficient**

Pearson's correlation measures the strength of the linear relationship between two variables. It has a value between -1 and +1, with a value of -1 meaning a total negative linear correlation, 0 being no correlation, and +1 indicating an absolute positive correlation. The Pearson's correlation coefficient is given by Eq. 1.

$$r = \frac{\sum_{i=1}^n [(O_i - \bar{O}) * (P_i - \bar{P})]}{\sqrt{\left[ \sum_{i=1}^n (O_i - \bar{O})^2 * \sum_{i=1}^n (P_i - \bar{P})^2 \right]}} \dots(\text{Eq.1})$$

Where,

i is the counter for individual observed and predicted values

n is the number of observations

O<sub>i</sub> is the observed values

$\bar{O}$  is the mean of observed values

P<sub>i</sub> is the predicted values

$\bar{P}$  is the mean of predicted values

R software determined the Pearson's correlation coefficient between all the measured water balance components for monthly and weekly time scales.

### **2.5.2 Regression Model**

Regression analysis is a powerful technique for uncovering the associations between variables observed in data, but it cannot easily indicate causation. In statistical modelling, regression analysis is a set of statistical processes for estimating the relationships between a dependent variable and one or more independent variables.

This study developed a regression model after testing the relationship for linear, polynomial, exponential, logarithmic, and power functions in the R-Software software. The model was selected based on the coefficient of determination ( $R^2$ ), shown in Eq. 2, and the p-value obtained from R software.

$$R^2 = \left\{ \frac{\sum_{i=1}^n [(O_i - \bar{O}) * (P_i - \bar{P})]}{\sqrt{\left[ \sum_{i=1}^n (O_i - \bar{O})^2 * \sum_{i=1}^n (P_i - \bar{P})^2 \right]}} \right\}^2 \dots(\text{Eq.2})$$

The polynomial regression analysis appeared better and represents a non-linear relationship between rainfall and other water balance components, meaning a curved best-fit line. The regression plot was made with a 95% confidence interval, and the mathematical equation was determined.

### **2.5.3 Residual vs. Fitted Plot**

A residual plot has the residual values on the vertical axis and the independent variable on the horizontal axis. A "residuals versus fitted plot" is frequently created when conducting a residual analysis. It is a scatter plot of residuals on the y-axis and fitted values

(estimated responses) on the x-axis. The plot is used to detect non-linearity, unequal error variances, and outliers. The residuals are calculated from Eq. 3.

$$e_i = y_i - \bar{y}_i \quad \dots(\text{Eq. 3})$$

Where,

$i$  is the counter for individual observed and predicted values

$e_i$  is the residual

$y_i$  is the predicted value

$\bar{y}_i$  is the observed value

### **2.5.4 Normal Q-Q (Quantile-Quantile) Plot**

The Normal Q-Q plot is handy in graphically analysing and comparing two probability distributions by plotting their quantiles against each other. If the two distributions are exactly equal, then the points on the Q-Q plot will perfectly lie in a straight line.

The Normal Q-Q plot allows the selection of the points that do not fall close to the reference line. The points on the Normal Q-Q plot indicate the univariate normality of the dataset. If the data is normally distributed, the points will fall on the 45-degree reference line. On the other hand, the points will deviate from the reference line if the data is non-normally distributed.

## **3. RESULTS AND DISCUSSION**

### **3.1 Water Balance Components**

The results of monthly water balance components for 17 months from August 2021 to December 2022 for the Perassannur watershed are shown in Table 1.

**Table 1. Water Balance Components of the Perassannur Watershed**

<b>Month</b>	<b>Rainfall (mm)</b>	<b>Runoff (mm)</b>	<b>Soil Moisture (%)</b>	<b>Height of Ground Water Table from MSL (m)</b>	<b>Evapotranspiration (mm)</b>
Aug-21	356.63	220.47	29.98	44.99	65.36
Sep-21	309.62	233.27	29.78	44.98	71.90
Oct-21	529.08	412.22	31.21	45.63	69.95
Nov-21	279.18	230.00	30.52	45.18	58.51
Dec-21	12.05	129.18	25.74	44.58	85.32
Jan-22	0.00	70.28	19.95	44.39	102.55
Feb-22	0.00	25.27	17.63	44.26	101.99
Mar-22	35.96	4.70	19.36	43.88	127.17
Apr-22	68.67	1.57	22.84	43.48	113.74
May-22	342.89	77.29	26.90	44.18	97.23
Jun-22	392.19	141.76	28.55	44.81	76.11
Jul-22	502.62	391.95	29.85	45.95	60.38
Aug-22	351.32	352.78	28.31	45.11	54.68

Sep-22	180.54	182.20	27.25	44.93	83.57
Oct-22	114.69	108.94	26.12	44.91	82.19
Nov-22	59.58	60.83	26.81	44.74	69.73
Dec-22	135.40	77.04	26.93	44.72	72.40

### 3.2 Relationships between Rainfall and Water Balance Components

#### 3.2.1 Pearson's Correlation Coefficient (r)

Fig. 2 shows the Pearson's correlation coefficient (r) between the monthly water balance components for the Perassannur watershed. It was observed that 'r' between rainfall and runoff was 0.83, rainfall and soil moisture was 0.80, rainfall and depth to GW table was 0.72, and rainfall and evapotranspiration was -0.64. Pearson's correlation coefficient was also observed as 0.76 between runoff and soil moisture, 0.89 between runoff and depth to GW table, and -0.76 between runoff and ET. The 'r' value between soil moisture and depth to the GW table was 0.76, and between soil moisture and ET was -0.85. Also, the 'r' value between depth to GW table and ET was -0.86. This indicates that evapotranspiration negatively correlates with other water balance components. The values of 'r' between monthly rainfall vs. runoff and rainfall vs. soil moisture indicate an excellent correlation; rainfall vs. depth to GW table indicates good. In contrast, rainfall vs. ET shows a weak correlation.

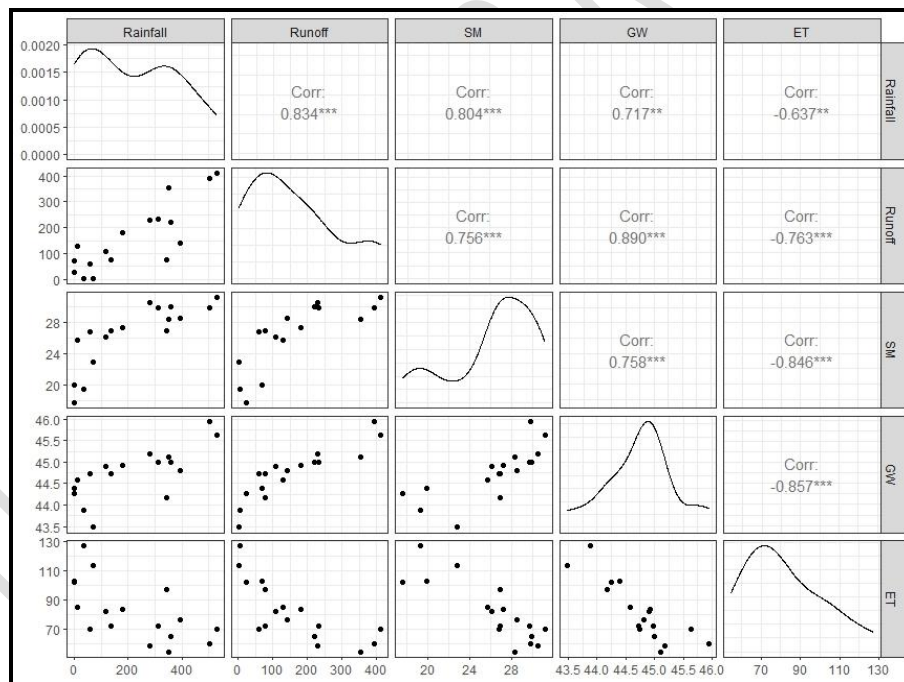


Fig. 2. Pearson's Correlation Coefficient for Perassannur Watershed

#### 3.2.2 Regression Model

The polynomial non-linear regression model was developed between monthly rainfall vs. runoff, rainfall vs. soil moisture, rainfall vs. depth to GW table, and rainfall vs. ET with a 95% confidence interval for the Perassannur watershed as shown in Fig. 3, Fig. 4, Fig. 5, and Fig. 6, respectively.

The monthly rainfall and runoff relationship for the Perassannur watershed is given by Eq. 4, with  $R^2$  of 0.78 and a p-value of 0.0006, having an F-statistic of 10.64 on 4 and 12 degrees of freedom.

$$121.55x^4 + 34.01x^3 + 85.13x^2 + 434.60x + 159.99 = 0 \quad \dots (\text{Eq. 4})$$

The monthly relationship between rainfall and soil moisture for the Perassannur watershed is given by Eq. 5, with  $R^2$  of 0.77 and a p-value of 0.0001, having an F-statistic of 14.99 on 3 and 13 degrees of freedom.

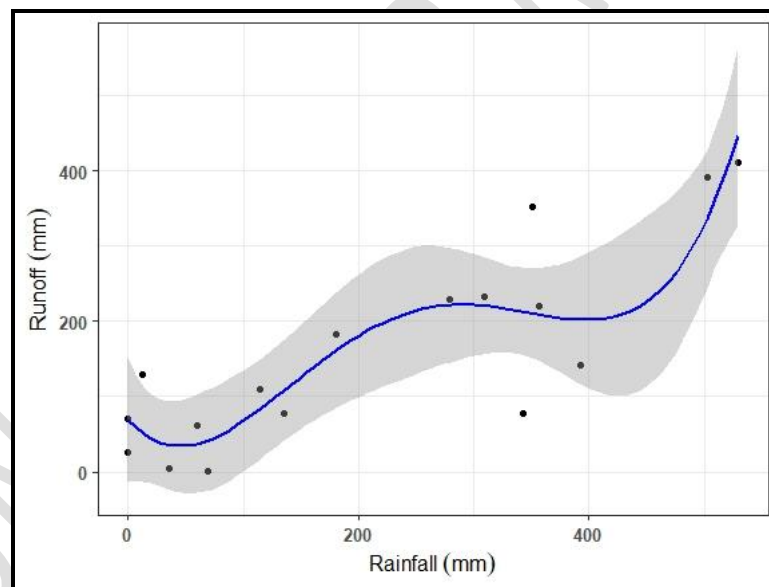
$$3.49x^3 - 4.72x^2 + 13.14x + 26.34 = 0 \quad \dots (\text{Eq. 5})$$

The monthly relationship between rainfall and depth to GW table for the Perassannur watershed is given by Eq. 6, with  $R^2$  of 0.69 and p-value of 0.01, having an F-statistic of 4.84 on 5 and 11 degrees of freedom.

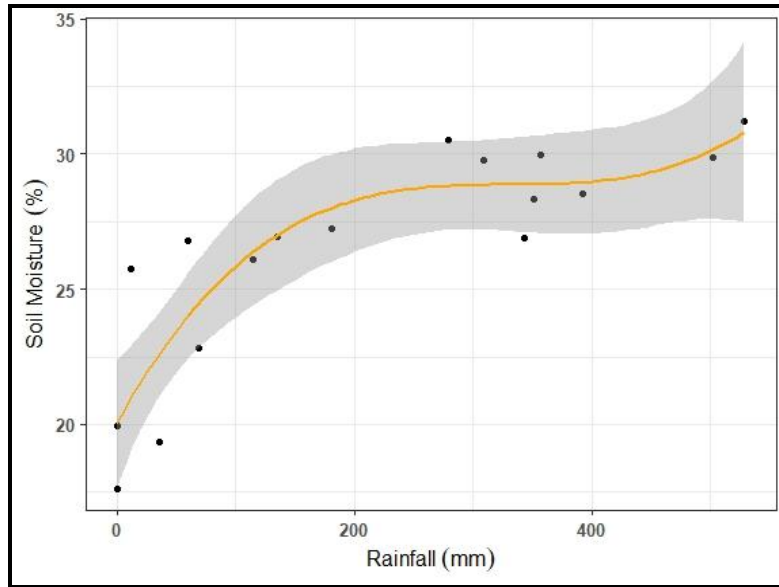
$$-0.69x^5 + 0.52x^4 + 0.40x^3 + 0.32x^2 + 1.73x + 44.75 = 0 \quad \dots (\text{Eq. 6})$$

The relation between monthly rainfall and evapotranspiration for the Perassannur watershed is given by Eq. 7, with  $R^2$  of 0.45 and a p-value of 0.04, having an F-statistic of 3.62 on 3, and 13 degrees of freedom.

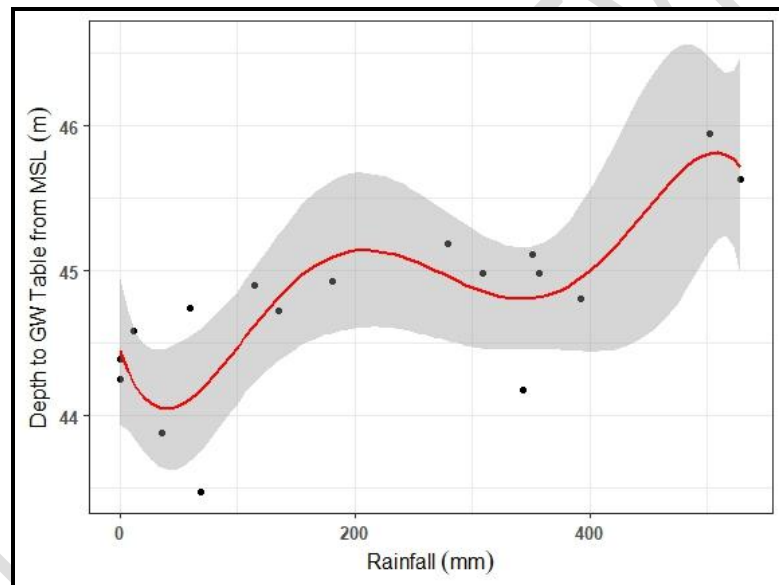
$$-4.93x^3 + 17.57x^2 - 52.06x + 81.93 = 0 \quad \dots (\text{Eq. 7})$$



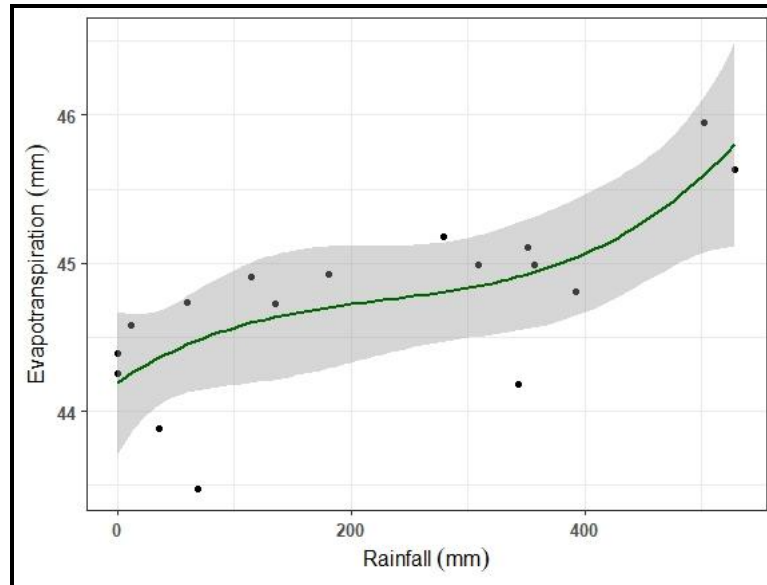
**Fig. 3. Relation between Monthly Rainfall and Runoff**



**Fig. 4. Relation between Monthly Rainfall and Soil Moisture**



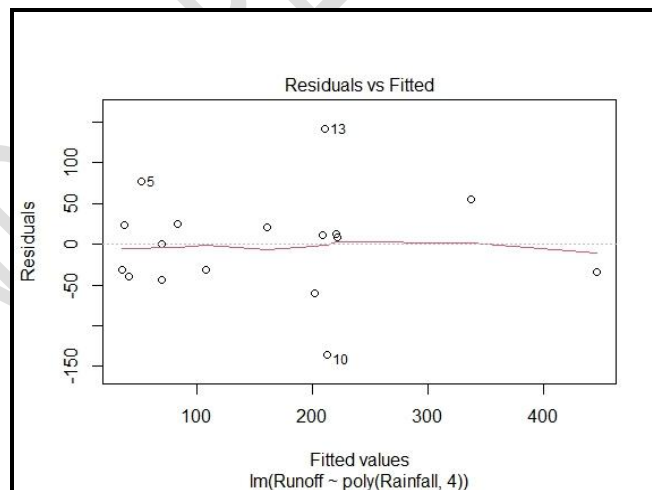
**Fig. 5. Relation between Monthly Rainfall and Depth to GW Table**



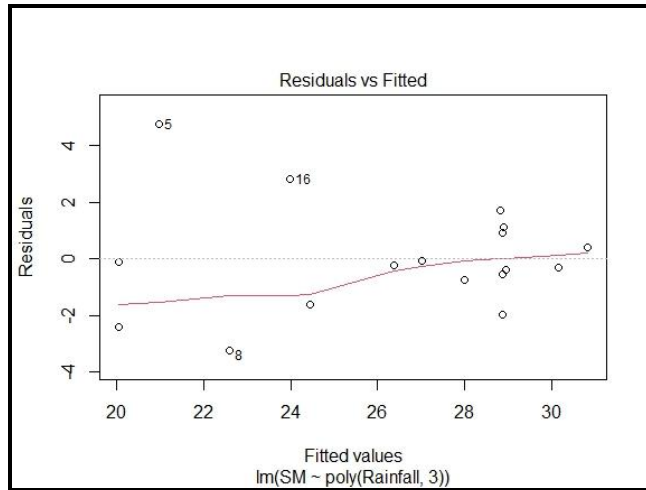
**Fig. 6. Relation between Monthly Rainfall and Evapotranspiration**

### **3.2.3 Residual vs. Fitted Plot**

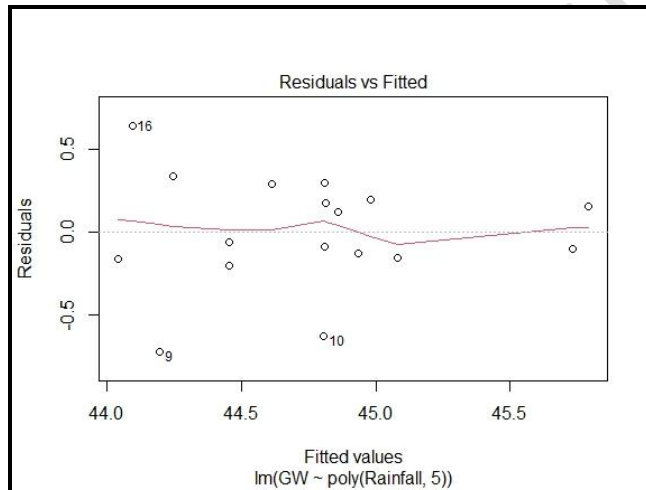
Fig. 7, Fig. 8, Fig. 9 and Fig. 10 show the residual vs. fitted plot between rainfall vs. runoff, rainfall vs. soil moisture, rainfall vs. depth to GW table, and rainfall vs. evapotranspiration for the Perassannur watershed. The x-axis indicates the water balance component's monthly value, and the y-axis indicates the residuals. All these figures show that the fitted line is not a straight line passing through zero residual, indicating non-linearity between the plotted variables.



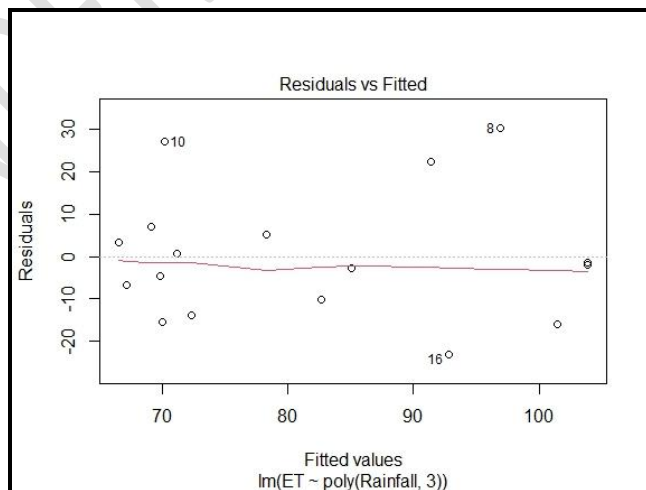
**Fig. 7. The Residual vs. Fitted Plot between Rainfall and Runoff**



**Fig. 8. The Residual vs. Fitted Plot between Rainfall and Soil Moisture**



**Fig. 9. The Residual vs. Fitted Plot between Rainfall and Depth to GW Table**



**Fig. 10. The Residual vs. Fitted Plot between Rainfall and Evapotranspiration**

### **3.2.4 Normal Q-Q Plot**

Fig. 11, 12, 13 and 14 show the Normal Q-Q plot between rainfall and runoff, rainfall and soil moisture, rainfall and depth to GW table, rainfall and evapotranspiration for the Perassannur watershed. The x-axis indicates the theoretical quantities of the water balance component, and the y-axis shows the standardised residuals.

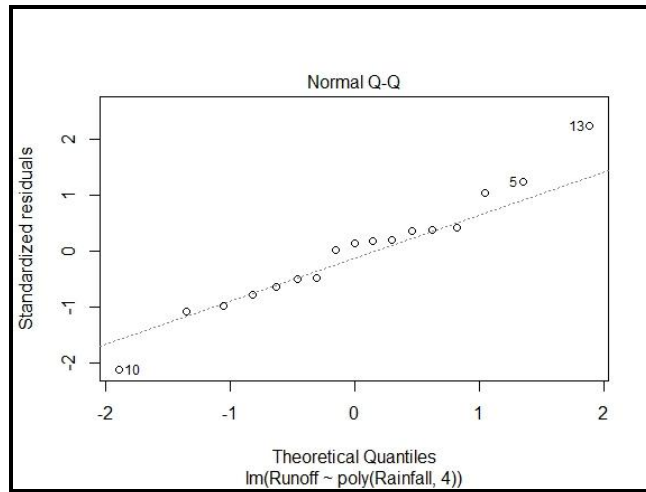


Fig. 11. The Normal Q-Q Plot between Rainfall and Runoff

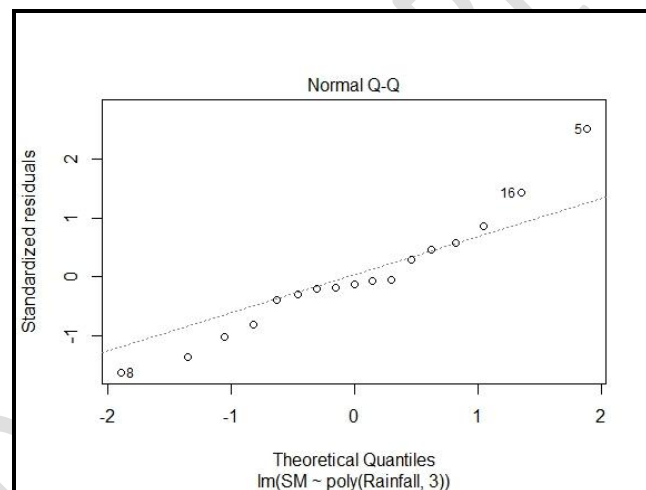
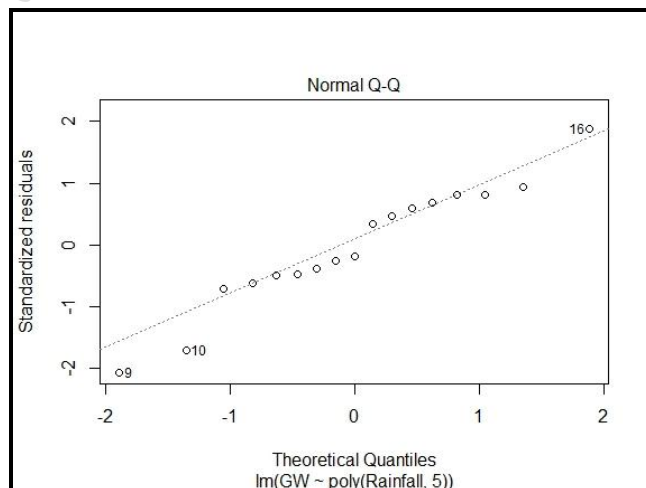
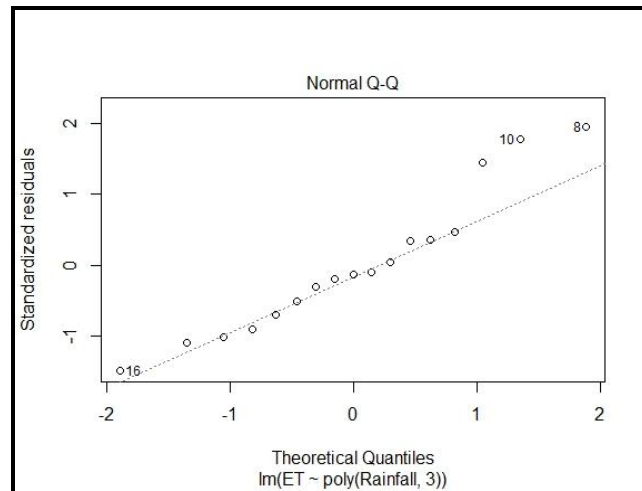


Fig. 12. The Normal Q-Q Plot between Rainfall and Soil Moisture



**Fig. 13. The Normal Q-Q Plot between Rainfall and Depth to GW Table**



**Fig. 14. The Normal Q-Q Plot between Rainfall and Evapotranspiration**

#### 4. CONCLUSION

The study could determine the water balance components of a micro watershed by directly measuring each hydrological process in the watershed, which otherwise was an ungauged basin. Relationships between rainfall and other water balance components were also developed with the help of R software. It was found that good correlations existed between rainfall and other water balance components, with the 'r' value ranging between 0.70 and 0.83. The maximum correlation was seen between rainfall and runoff, followed by rainfall and soil moisture. The importance of the study lies in the fact that by measuring the rainfall, it is possible to estimate most of the other water balance components using the regression estimates. The professionals and planners can utilise these relationships to conserve and develop water resources.

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