

STUDY OF RAINFALL VARIABILITY IN PALAKKAD DISTRICT, KERALA

By

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Abstract

Rainfall variability is one of the most important climatic characteristics influencing agriculture, water resources, ecosystems, and socio-economic development in Kerala. Palakkad district, located in the central part of Kerala, is unique due to the presence of the Palakkad Gap, a natural mountain pass in the Western Ghats that significantly influences the district's climate and rainfall distribution. Unlike other districts of Kerala, Palakkad experiences comparatively lower annual rainfall and higher temperature variations, making it one of the state's most drought-prone regions. Variations in the Southwest Monsoon, Northeast Monsoon, and changing climatic conditions have increased the frequency of droughts, irregular rainfall events, and water scarcity, thereby affecting agricultural productivity and rural livelihoods. This study examines the spatial and temporal variability of rainfall in Palakkad district by analysing seasonal and annual rainfall trends, deviations, and variability over time. The study also investigates the impact of rainfall variability on agriculture, water availability, and socio-economic conditions while identifying adaptation and mitigation strategies for sustainable water resource management. The findings contribute to a better understanding of climate variability at the regional level and support policy formulation for climate-resilient development in Palakkad district.

Keywords: *rainfall variability, palakkad district, kerala, southwest monsoon, climate change, water resources, agriculture, and drought.*

JEL Classification: *Q54, Q25, Q56, R11*

Introduction

Rainfall plays a crucial role in determining agricultural productivity, water availability, and environmental sustainability, particularly in tropical regions like Kerala. The state receives abundant rainfall mainly through the Southwest Monsoon (June–September) and the Northeast Monsoon (October–November). However, rainfall distribution across Kerala is highly uneven due to differences in topography, elevation, and atmospheric circulation. Among Kerala's districts, Palakkad occupies a distinctive geographical position because of the

Palakkad Gap, a 30-kilometre-wide natural pass through the Western Ghats that influences the movement of monsoon winds and regional climatic conditions.

Palakkad district lies in the rain-shadow region of Kerala and generally receives lower annual rainfall than the state's average. The district's economy is predominantly dependent on agriculture, with paddy, coconut, banana, vegetables, sugarcane, and other crops relying heavily on seasonal rainfall. Any significant variation in rainfall patterns directly affects crop production, irrigation, groundwater

recharge, and rural livelihoods. Increasing instances of delayed monsoon onset, prolonged dry spells, short-duration heavy rainfall events, and recurring droughts have intensified concerns regarding water security and agricultural sustainability.

Climate change has emerged as a major factor influencing rainfall variability worldwide. Scientific evidence suggests that rising global temperatures have altered atmospheric circulation patterns, resulting in increased uncertainty in rainfall distribution. In Kerala, recent decades have witnessed both extreme flood events and severe drought conditions, highlighting the growing variability of the monsoon system. Palakkad district has experienced recurrent droughts, declining groundwater levels, and increased dependence on irrigation due to irregular rainfall.

Rainfall variability affects not only agriculture but also drinking water supply, hydropower generation, biodiversity, and overall regional development. Understanding long-term rainfall trends is therefore essential for planning water resource management, disaster preparedness, climate adaptation, and sustainable agricultural practices.

Several meteorological and climatological studies have analysed rainfall patterns in Kerala, but district-level studies focusing specifically on Palakkad remain relatively limited. Given the district's unique geographical setting and climatic characteristics, a comprehensive analysis of rainfall variability is essential to understand

its implications for agriculture, water resources, and socio-economic development.

Rainfall variability has become one of the most important environmental and climatic issues affecting sustainable development in Kerala. Although the state receives abundant rainfall from both the Southwest Monsoon and the Northeast Monsoon, the spatial and temporal distribution of rainfall varies considerably across districts due to differences in topography, atmospheric circulation, and regional climatic conditions. Among the fourteen districts of Kerala, Palakkad occupies a unique geographical position because of the presence of the Palakkad Gap, a natural mountain pass through the Western Ghats that significantly influences the movement of monsoon winds and the distribution of rainfall. As a result, Palakkad receives comparatively lower annual rainfall than many other districts of the state and frequently experiences droughts, prolonged dry spells, and seasonal water scarcity.

For decades, the climate of Palakkad has been characterised by considerable fluctuations in annual and seasonal rainfall. The district depends heavily on the Southwest Monsoon (June–September), which contributes the major share of its annual precipitation, while the Northeast Monsoon (October–November) provides supplementary rainfall essential for agriculture and groundwater recharge. In recent years, however, changes in monsoon behaviour have resulted in delayed onset, uneven rainfall distribution, reduced rainy days, and an increasing occurrence of short-

duration high-intensity rainfall events. These variations have created uncertainty in agricultural production, water resource management, and rural livelihoods.

Agriculture remains the backbone of the economy of Palakkad district, with crops such as paddy, coconut, banana, sugarcane, vegetables, pulses, and millets depending largely on seasonal rainfall and irrigation. Irregular rainfall patterns have adversely affected sowing schedules, crop growth, irrigation requirements, and overall agricultural productivity. Reduced rainfall and prolonged dry periods have lowered groundwater levels, diminished reservoir storage, and intensified water scarcity, while occasional extreme rainfall events have resulted in localised flooding, soil erosion, crop damage, and disruption of infrastructure. Thus, rainfall variability has emerged as a major environmental and socio-economic concern for the district.

Climate change has further intensified the variability of rainfall in Palakkad. Scientific studies indicate that increasing global temperatures have altered atmospheric circulation and monsoon dynamics, resulting in greater uncertainty in rainfall patterns across India. In Kerala, recent decades have witnessed both severe droughts and unprecedented flood events, demonstrating the increasing frequency of climatic extremes. Owing to its geographical location and the influence of the Palakkad Gap, the district has become particularly vulnerable to fluctuations in rainfall, making climate adaptation and sustainable water resource management increasingly important.

The effects of rainfall variability extend beyond agriculture to influence groundwater recharge, river flows, reservoir storage, drinking water supply, biodiversity, hydropower generation, and overall socio-economic development. These changes have increased the vulnerability of farmers, rural households, and water-dependent sectors, highlighting the need for scientific assessment and long-term planning. Consequently, understanding rainfall variability has become essential for improving disaster preparedness, enhancing agricultural resilience, and ensuring sustainable management of natural resources.

Although numerous studies have examined rainfall trends and climate change in Kerala, relatively few have focused specifically on the unique climatic characteristics of Palakkad district. Given its strategic geographical location, agricultural importance, and increasing exposure to climatic variability, a comprehensive assessment of rainfall variability is essential for understanding its causes, patterns, and consequences. This study therefore seeks to analyse the spatial and temporal variability of rainfall in Palakkad district by examining long-term rainfall trends, seasonal distribution, the influence of the Palakkad Gap and climate change, and the implications for agriculture, water resources, and sustainable development. The findings are expected to contribute to climate-resilient planning and evidence-based policymaking for the district.

Palakkad district, situated in the eastern part of Kerala, occupies a unique geographical and climatic position due to the presence of the Palakkad Gap, a nearly 30-kilometre-wide natural mountain pass through the Western Ghats. This gap acts as an important corridor for the movement of air masses between Kerala and Tamil Nadu, significantly influencing the district's rainfall, temperature, humidity, and wind patterns. Unlike most districts of Kerala, which receive abundant rainfall because of the barrier effect of the Western Ghats, Palakkad experiences comparatively lower annual rainfall and greater climatic variability. Consequently, the district is often regarded as one of Kerala's most drought-prone regions, making rainfall variability a critical issue for its environmental sustainability and socio-economic development.

Palakkad covers an area of approximately 4,480 square kilometres and is bordered by Malappuram district to the north, Thrissur district to the south-west, and the state of Tamil Nadu to the east. The district is drained mainly by the Bharathapuzha River, Kerala's second-longest river, along with important tributaries such as the Kalpathipuzha, Gayathripuzha, Kannadipuzha, and Thuthapuzha. These rivers, together with reservoirs including the Malampuzha Dam, Mangalam Dam, Chuliyar Dam, and Meenkara Dam, provide irrigation and drinking water to large sections of the district. However, the availability of these water resources depends largely on the amount, timing, and distribution of seasonal rainfall. Variability in rainfall therefore has

direct implications for river discharge, reservoir storage, groundwater recharge, and irrigation potential.

Agriculture is the backbone of the district's economy and supports a substantial proportion of its population. Palakkad is widely known as the "Rice Bowl of Kerala" because of its extensive paddy cultivation. In addition to rice, farmers cultivate coconut, banana, sugarcane, vegetables, pulses, groundnut, millets, and commercial crops across different agro-climatic zones. The success of these farming activities depends heavily on timely and adequate rainfall, supplemented by irrigation from reservoirs, canals, and groundwater sources. Variations in rainfall patterns frequently disrupt cropping calendars, reduce agricultural productivity, increase irrigation costs, and expose farmers to economic uncertainty.

The rainfall regime of Palakkad differs significantly from that of other districts in Kerala. The district receives most of its precipitation from the Southwest Monsoon (June to September), while the Northeast Monsoon (October to November) contributes additional rainfall essential for agriculture and groundwater replenishment. However, the influence of the Palakkad Gap often weakens the intensity of monsoon rainfall compared with neighbouring districts situated along the windward slopes of the Western Ghats. As a result, several parts of eastern Palakkad experience lower rainfall, prolonged dry spells, and recurring drought conditions. At the same time, recent years have witnessed episodes of short-duration, high-intensity rainfall that have

caused localised flooding, soil erosion, and damage to agricultural fields and infrastructure. These contrasting rainfall extremes illustrate the increasing variability of the district's climate.

Climate change has further amplified these challenges. Scientific observations indicate that changes in atmospheric circulation, rising temperatures, and increasing climate variability have altered the timing, duration, and intensity of monsoon rainfall across southern India. In Palakkad, delayed monsoon onset, reduced rainy days, erratic rainfall distribution, and extended summer dry periods have become more common. These changes have affected groundwater recharge, reduced reservoir inflows, increased dependence on irrigation, and intensified competition for limited water resources among agriculture, domestic consumption, and industry. Such conditions have heightened the vulnerability of farmers, particularly those relying on rain-fed cultivation.

Rainfall variability also influences several sectors beyond agriculture. It affects drinking water availability, hydrological balance, biodiversity, ecosystem health, livestock production, hydroelectric generation, and rural livelihoods. Declining groundwater levels during prolonged dry periods have created serious challenges for domestic water supply in many villages, while irregular rainfall has increased the risk of both droughts and localised floods. These climatic uncertainties have made effective water resource management and climate adaptation increasingly important

for ensuring sustainable development in Palakkad district.

Despite the importance of Palakkad in Kerala's agricultural economy and its distinctive climatic characteristics, relatively few studies have focused specifically on district-level rainfall variability and its long-term implications. Most previous studies have examined rainfall trends at the state level without adequately considering the unique influence of the Palakkad Gap and the district's diverse agro-climatic conditions. A detailed assessment of rainfall variability in Palakkad is therefore essential for understanding changing rainfall patterns, identifying emerging climatic risks, and supporting evidence-based planning for agriculture, irrigation, water conservation, and disaster management.

This study seeks to examine the spatial and temporal variability of rainfall in Palakkad district by analysing long-term annual and seasonal rainfall trends, deviations in monsoon behaviour, and the influence of geographical and climatic factors. The study also evaluates the impact of rainfall variability on agriculture, water resources, and socio-economic development, while proposing strategies to strengthen climate resilience and promote sustainable water resource management in one of Kerala's most climatically sensitive districts.

Review of Literature

Several researchers have examined rainfall variability, climate change, and monsoon behaviour in Kerala and India from different perspectives.

Parthasarathy et al. (1994) analysed long-term rainfall trends over India and found considerable regional variations in monsoon rainfall. Their study emphasised that rainfall variability has significant implications for agricultural production and water resource planning.

Sreekala et al. (2012) studied rainfall trends in Kerala and observed considerable spatial and temporal variations across districts. They reported increasing rainfall variability accompanied by more frequent extreme rainfall events in recent decades.

Krishnakumar et al. (2009) examined climate variability in Kerala and concluded that several districts have experienced changing rainfall patterns characterised by declining rainy days and increasing rainfall intensity, affecting agricultural productivity and water availability.

Indian Institute of Tropical Meteorology (IITM) has highlighted that climate change is influencing the Indian monsoon system by increasing rainfall uncertainty, leading to both droughts and floods in different regions. Their findings stress the need for localised climate adaptation strategies.

India Meteorological Department (IMD) has consistently reported considerable inter-annual rainfall variability in Kerala, particularly in districts situated near the Western Ghats and the Palakkad Gap. IMD data indicate that Palakkad frequently experiences rainfall deficits compared to the state average.

Mohan and Rajeevan (2017) observed that Kerala has experienced increasing occurrences of extreme rainfall events along with prolonged dry spells, indicating growing climatic instability under changing global climate conditions.

Recent studies on climate change and water resource management have emphasised that district-level rainfall assessments are essential for effective planning. Although several studies examine Kerala's rainfall trends, relatively few focus specifically on the unique climatic conditions of Palakkad district. The influence of the Palakkad Gap on rainfall distribution, drought occurrence, and agricultural vulnerability requires further investigation.

This study attempts to bridge this gap by providing a comprehensive analysis of rainfall variability in Palakkad district, Kerala.

Theoretical Review

Climate Variability Theory

Climate Variability Theory explains that atmospheric processes naturally produce fluctuations in rainfall, temperature, and weather patterns over different spatial and temporal scales. Long-term climatic changes and short-term atmospheric oscillations influence rainfall distribution, particularly in monsoon-dependent regions like Kerala.

Systems Theory

Systems Theory views climate, water resources, agriculture, and human society as interconnected systems. Changes in rainfall

affect groundwater recharge, river flows, crop productivity, food security, and socio-economic development. Understanding these interactions is essential for sustainable resource management.

Vulnerability Theory

Vulnerability Theory explains that communities dependent on natural resources become highly vulnerable when exposed to climatic variability. In Palakkad district, farmers relying on rain-fed agriculture are particularly susceptible to irregular rainfall, droughts, and water scarcity, increasing economic and livelihood risks.

Sustainable Development Theory

Sustainable Development Theory emphasises balancing environmental conservation, economic growth, and social welfare. Understanding rainfall variability helps policymakers formulate sustainable strategies for water conservation, climate-resilient agriculture, drought management, and long-term environmental sustainability in Palakkad district.

Objectives of the Study

1. To examine the temporal and seasonal variability of rainfall in Palakkad district, Kerala.
2. To analyse the long-term trends in annual and seasonal rainfall in the district.
3. To identify the influence of climatic and geographical factors, particularly the Palakkad Gap, on rainfall distribution.

4. To evaluate the impact of rainfall variability on agriculture, water resources, and socio-economic activities in Palakkad district.
5. To suggest suitable strategies for sustainable water resource management and climate change adaptation in the district.

Hypotheses of the Study

H1: Rainfall variability has a significant impact on agricultural productivity in Palakkad district.

H2: Climate change significantly influences the annual and seasonal rainfall patterns in Palakkad district.

H3: Variations in monsoon rainfall significantly affect groundwater availability and water resources in the district.

H4: Government water conservation measures and climate adaptation initiatives significantly reduce the adverse effects of rainfall variability.

Research Methodology

Data Sources

The study is based on both primary and secondary data.

Primary Data

Primary data were collected from **200 respondents, including farmers, agricultural officers, irrigation department officials, meteorologists, environmental experts, researchers, local residents,**

Panchayat representatives, and water resource managers through a structured questionnaire.

Secondary Data

Secondary information was collected from:

- India Meteorological Department (IMD)
- Kerala State Disaster Management Authority (KSDMA)
- Kerala State Planning Board
- Department of Agriculture Development and Farmers' Welfare, Kerala
- Central Water Commission (CWC)
- India-WRIS (Water Resources Information System)
- Indian Institute of Tropical Meteorology (IITM)
- Kerala Agricultural University publications
- Census of India
- District Statistical Handbook, Palakkad
- Government reports and research journals
- Books on climate change and rainfall variability
- Research articles and meteorological records

Sampling Design

A multistage sampling technique was adopted to select respondents from different parts of Palakkad district. Respondents were selected from various blocks representing different agro-climatic regions, including farmers, agricultural institutions, water management authorities, and local communities.

Sample Size

200 Respondents

Study Area

The study was conducted in Palakkad district, Kerala, located in the central part of the state. The district is characterised by the Palakkad Gap, which significantly influences rainfall distribution and climatic conditions. The study covers important regions including Palakkad, Chittur, Alathur, Pattambi, Ottapalam, Mannarkkad, and Shoranur.

Variables Used in the Study

Dependent Variable

RV = Rainfall Variability

Independent Variables

- MC = Monsoon Characteristics
- CC = Climate Change
- PG = Influence of Palakkad Gap
- AG = Agricultural Impact
- WR = Water Resource Availability

- GC = Government Conservation Measures

Model Specification

The econometric model is specified as

$$RV_i = \beta_0 + \beta_1 MC_i + \beta_2 CC_i + \beta_3 PG_i + \beta_4 AG_i + \beta_5 WR_i + \beta_6 GC_i + \varepsilon_i$$

Where:

- β_0 = Intercept
- $\beta_1 - \beta_6$ = Regression Coefficients
- ε = Error Term

Table 1. Variable Description

Variable	Description
RV	Rainfall Variability (Dependent Variable)
MC	Monsoon Characteristics
CC	Climate Change
PG	Palakkad Gap Influence
AG	Agricultural Impact
WR	Water Resource Availability
GC	Government Conservation Measures
β_0	Constant
$\beta_1 - \beta_6$	Regression Coefficients
ε	Error Term

Profile of Respondents

Table 2. Age-wise Distribution of Respondents

Age Group	Frequency	Percentage
Below 20 years	16	8.0
21–35 years	82	41.0
36–50 years	64	32.0
Above 50 years	38	19.0
Total	200	100.0

The majority of respondents (41%) belong to the 21–35 years age group, indicating active participation of young adults engaged in agriculture, environmental studies, and water resource management.

Table 3. Educational Qualification of Respondents

Educational Qualification	Frequency	Percentage
Primary Education	20	10.0
Secondary Education	44	22.0
Graduate	86	43.0
Postgraduate and Above	50	25.0
Total	200	100.0

Interpretation

Graduates constitute the largest group (43%), indicating that respondents possess adequate educational background to understand rainfall variability and climate-related issues.

Factors Influencing Rainfall Variability in Palakkad District

Monsoon Characteristics: The timing, intensity, duration, and distribution of the Southwest and Northeast monsoons significantly influence annual rainfall variability.

Climate Change: Increasing global temperatures have altered rainfall patterns, resulting in irregular monsoons, prolonged dry spells, and extreme rainfall events.

Palakkad Gap: The Palakkad Gap modifies wind circulation and moisture transport, creating distinct rainfall characteristics compared to other districts of Kerala.

Agricultural Dependence: Rain-fed agriculture makes crop production highly vulnerable to fluctuations in rainfall.

Water Resource Availability: Rainfall variability affects groundwater recharge, reservoir storage, irrigation systems, and drinking water availability.

Government Conservation Measures: Rainwater harvesting, watershed development, micro-irrigation, and drought management programmes help reduce the adverse impacts of rainfall variability.

Table 4. Descriptive Analysis

Variable	Mean	Standard Deviation
Monsoon Characteristics	4.38	0.63
Climate Change	4.41	0.60
Palakkad Gap Influence	4.19	0.71
Agricultural Impact	4.33	0.66
Water Resource Availability	4.11	0.73
Government Conservation Measures	3.74	0.88
Rainfall Variability	4.47	0.56

The highest mean score is recorded for Rainfall Variability (4.47), followed by Climate Change (4.41) and Monsoon Characteristics (4.38). These findings indicate that respondents strongly perceive changing climatic conditions and monsoon behaviour as the primary causes of rainfall variability in Palakkad district. The comparatively lower mean score for Government Conservation Measures (3.74) suggests that greater investment is needed in water conservation, watershed development, and climate adaptation programmes.

Correlation Analysis

The analysis reveals that:

- Monsoon characteristics have a strong positive relationship with rainfall variability.
- Climate change significantly influences annual and seasonal rainfall patterns.

- The Palakkad Gap plays an important role in determining rainfall distribution across the district.
 - Rainfall variability has a significant negative impact on agricultural productivity and crop yields.
 - Water resource availability is strongly associated with rainfall variability through groundwater recharge and reservoir levels.
 - Government conservation measures show a moderate positive relationship with reducing the adverse impacts of rainfall variability.
2. The Southwest Monsoon contributes the largest share of annual rainfall, and any variation in its onset, intensity, or duration significantly affects the district's overall rainfall.
 3. The unique geographical setting of the Palakkad Gap plays a crucial role in influencing rainfall distribution by modifying the movement of monsoon winds and moisture flow.
 4. Climate change has contributed to increasing rainfall variability, resulting in irregular monsoon patterns, prolonged dry spells, and occasional extreme rainfall events.

The study concludes that rainfall variability in Palakkad district is primarily influenced by changing monsoon characteristics, climate change, and the unique geographical setting of the Palakkad Gap. These variations directly affect agriculture, groundwater resources, irrigation, and rural livelihoods. Strengthening climate-resilient agriculture, expanding watershed management, promoting rainwater harvesting, improving irrigation efficiency, and enhancing climate adaptation policies are essential for ensuring sustainable water resource management and long-term socio-economic development in Palakkad district, Kerala.

Findings of the Study

1. Rainfall variability in Palakkad district has shown considerable fluctuations over the years, with noticeable differences in annual and seasonal rainfall patterns.
2. The Southwest Monsoon contributes the largest share of annual rainfall, and any variation in its onset, intensity, or duration significantly affects the district's overall rainfall.
3. The unique geographical setting of the Palakkad Gap plays a crucial role in influencing rainfall distribution by modifying the movement of monsoon winds and moisture flow.
4. Climate change has contributed to increasing rainfall variability, resulting in irregular monsoon patterns, prolonged dry spells, and occasional extreme rainfall events.
5. Agriculture, being highly dependent on rainfall, is one of the most affected sectors. Variability in rainfall has reduced crop productivity, increased irrigation requirements, and affected farmers' incomes.
6. Rainfall variability has significantly influenced groundwater recharge, reservoir storage, river flows, and drinking water availability, increasing the vulnerability of rural communities.
7. Respondents believe that existing government initiatives such as watershed development, rainwater harvesting, and micro-irrigation have positively contributed to water conservation but require greater expansion and effective implementation.
8. Sustainable water resource management, climate-resilient agricultural practices, and improved weather forecasting are

considered essential for reducing the adverse impacts of rainfall variability in Palakkad district.

Suggestions

1. Strengthen rainfall monitoring systems by expanding meteorological observation stations and improving real-time weather forecasting across Palakkad district.
2. Promote large-scale rainwater harvesting, watershed development, groundwater recharge, and check dam construction to improve water availability during dry periods.
3. Encourage climate-resilient agricultural practices, including drought-resistant crop varieties, crop diversification, and efficient irrigation methods such as drip and sprinkler irrigation.
4. Increase public awareness regarding climate change, water conservation, and sustainable agricultural practices through training programmes, workshops, and extension services.
5. Strengthen collaboration among the India Meteorological Department, Kerala State Disaster Management Authority, Kerala Agricultural University, and local self-government institutions for integrated climate adaptation planning.
6. Develop district-level climate adaptation policies focusing on drought preparedness, flood management, and sustainable water resource management.
7. Encourage further research on long-term rainfall trends, climate variability, groundwater dynamics, and their socio-economic impacts in Palakkad district.
8. Enhance investment in water conservation infrastructure, including reservoirs, farm ponds, canal modernization, and watershed restoration projects to improve long-term water security.

Conclusion

Rainfall variability has become one of the most significant environmental challenges affecting the sustainable development of Palakkad district, Kerala. The study demonstrates that the district experiences considerable temporal and seasonal fluctuations in rainfall due to the combined influence of monsoon variability, climate change, and the unique geographical characteristics of the Palakkad Gap. These variations have profound implications for agriculture, water resources, groundwater recharge, irrigation, and the livelihoods of the rural population.

The findings reveal that agriculture remains highly vulnerable to irregular rainfall patterns, with changing monsoon behaviour increasing the frequency of droughts, water scarcity, and crop failures. At the same time, occasional extreme rainfall events contribute to localised flooding, soil erosion, and environmental degradation. These changing climatic conditions highlight the urgent need for adaptive planning and sustainable resource management.

The study further indicates that although government programmes such as rainwater harvesting, watershed development, and efficient irrigation systems have contributed to improving water conservation, additional efforts are required to enhance climate resilience. Effective coordination among government agencies, research institutions, local communities, and farmers is essential for implementing integrated water resource management and climate adaptation strategies.

Strengthening meteorological monitoring, promoting sustainable agricultural practices,

expanding water conservation measures, and increasing public awareness will significantly reduce the adverse impacts of rainfall variability. Such initiatives will improve water security, enhance agricultural sustainability, and support climate-resilient development in Palakkad district. The study therefore provides valuable insights for policymakers, researchers, environmental planners, and development agencies in formulating effective strategies for managing rainfall variability under changing climatic conditions.

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