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https://doi.org/10.5109/7395739

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 11, pp.1739-1744, 2025-10-30. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

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Abstract: *Rainfall plays crucial role in hydrological balance and ecosystem sustainability. This research investigates the rainfall trends and spatial distribution using isohyet and thiessen polygon method. Monthly and annual rainfall data from four stations were analysed by decade to identify temporal and geographical variations. Isohyetal maps were generated using ArcGIS software version 10.7.1 for three time periods which were 1995-2004, 2005-2014, and 2015-2024. The data demonstrates significant changes in rainfall distribution, with ST02-Pos Gob receiving the most rainfall (3,140 mm between 2005 and 2014) and ST03-Pos Tohoi receiving the least (1,933 mm between 2015 and 2024). The isohyetal maps showed increasingly irregular rainfall patterns, notably in the most recent decade (2015-2024). These findings underscore the critical need for adaptive water management methods and environmental measures to mitigate the effects of changing rainfall patterns, ensuring sustainability for future generations.*

Keywords: Climate Variability, Isohyet, GIS, Rainfall

1. INTRODUCTION

Rain is essential to life on Earth since it provides water for ecosystem. Moreover, rainfall is an important climatic element that affects water resources, agriculture, and the frequency of flood disasters, particularly in monsoon-prone areas [1]. States like Kelantan in Malaysia are particularly vulnerable to heavy rains during the northeast monsoon, which frequently causes extensive flooding. These floods endanger ecosystems by destroying forests, rivers, and wildlife habitats [2], as well as bring impact on public health by increasing waterborne diseases, contaminating drinking water, disrupting agriculture, resulting in food insecurity, and damaging critical infrastructure for community well-being [3]. Effective rainfall mapping is critical for disaster mitigation and long-term hydrological planning.

Malaysia has a humid tropical climate typified by high temperatures, with constant humidity, and heavy rainfall throughout the year [4]. The two principal monsoon systems that influence the country are the Southwest Monsoon (May-September) and the Northeast Monsoon (November-March) [5]. The northeast monsoon causes heavy and sustained rainfall in the east coast states such as Terengganu, Pahang, Kelantan, and others. This seasonal rainfall surge frequently causes riverine flooding, landslides, and interruptions to agriculture and transportation systems. Large-scale ocean-atmosphere phenomena like El Niño and La Niña also impact Malaysia's rainfall variability. El Niño causes drier weather and lower rainfall, while La Niña intensifies monsoon effects, resulting in above-average rainfall and severe flooding [6].

Conventional techniques for tracking rainfall depend on point-based data from separate stations, which are inaccurate and lack spatial continuity in diverse environments. Recent research in Malaysia have effectively used GIS-based isohyet and interpolation approaches to assess rainfall distribution, such as the work done in the Pahang River basin by [7]. These methods make it possible to visualize rainfall patterns across regions more realistically. This approach has also proven valuable for identifying high-risk flood zones and supporting integrated watershed management. Kelantan was chosen as a case study because of its regular floods, hydrological complexity, and socioeconomic vulnerability to climatic extremes. In 2014, Kelantan experienced a massive flood which also one of the worst in decades, causing widespread damage and displacement [8,9].

This research examines the regional distribution of rainfall in Kelantan using 30-year data (1995-2024) from four meteorological stations. The aim of this research is to investigates the rainfall trend and spatial distribution of rainfall in Kelantan. The data were divided into three decades which are 1995-2004, 2005-2014, and 2015-2024 and analyzed using inverse distance weighting (IDW), isohyet mapping, and Thiessen polygons inside a geographical information system (GIS) context. The generated maps provide insight into changing rainfall patterns and increased spatial variability. This study also correlates with global priorities outlined in the United Nations Sustainable Development Goals (SDGs), including SDG 6 (Clean Water and Sanitation) and SDG 13 (Climate Action). This study helps to improve understanding of rainfall distribution and variability, which adds to sustainable environmental planning and climate resilience.

2. METHODOLOGY

2.1 Study Area

The study was conducted in Nenggiri, which located in the Gua Musang district that was at southern part of Kelantan, Malaysia. Geographically, the Nenggiri catchment is located between 4.6°N and 5.3°N latitude and 101.4°E to 101.8°E longitude. This area is part of the Nenggiri River Basin, which flows into the greater Sungai Kelantan, a main river system in the region. The basin area known for its mountainous terrain, forested landscapes, and extensive river network. The region experiences tropical climate with heavy rains during the northeast monsoon season, which normally lasts from November to January. These climatic conditions, combined with physical factors, keeping the area particularly vulnerable to seasonal flooding and erosion, particularly during the El Niño and La Niña cycles. Flood events frequently affect the neighboring towns, especially during years of heavy rainfall. The area was chosen for this study because of its socio-environmental importance, history of recurring flood disasters, and representativeness as a monsoon-influenced catchment in Peninsular Malaysia. Figure 1 shown the Nenggiri study area.

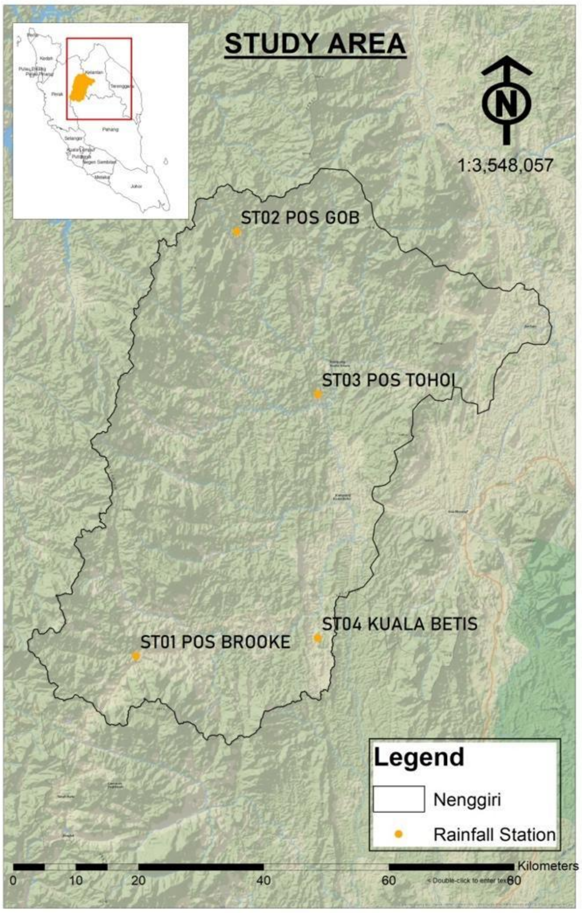

Fig 1. The study area of Nenggiri River Basin.

2.2 Data Collection

This study analyzed monthly and annual rainfall data from four meteorological stations in Kelantan from 1995 to 2024. The selection of the rainfall stations was based on the availability of long-term, reliable records and their closeness to the Nenggiri River Basin. The data were obtained from the Malaysian Meteorological Department (MET Malaysia) in form of tabulated data. The stations include ST01- Pos Brooke, ST02- Pos Gob, ST03 - Pos Tohoi and ST04 - Kuala Betis which are located within the Nenggiri river basin. The rainfall data were divided into three decades; 1995–2004, 2005–2014, and 2015–2024 in order to examine temporal changes. The decadal mean rainfall for each station was calculated by averaging the monthly rainfall measurements each year and then grouping them. The cleaned and standardized dataset was georeferenced in ArcGIS with the stations' latitude and longitude coordinates for spatial analysis. This organized dataset serves as the starting point for further interpolation and mapping techniques.

2.3 Isohyet Method

The isohyet method was a well-known approach used in hydrology for representing geographical rainfall distribution by lines of equal precipitation [10]. This technique, which used in flood risk analysis and watershed management, offers a continuous, clear visual representation of rainfall intensity over a geographic area. Rainfall contour lines, or isohyets, aid in identifying areas of concentration of rainfall that might not be readily apparent from point-based measurements [11]. In this research, rainfall patterns in the Nenggiri catchment area during a three-decade period were analyzed using Geographic Information Systems (GIS) and the isohyet technique. Lines of equal rainfall are known as isohyetals, and the mean annual rainfall (P) can be found using:

$$P = \frac{\sum_{i=1}^{n} A_i P_i}{\sum_{i=1}^{n} A_i} \qquad \text{(Eq 1)}$$

where Pi the average rainfall between Isohyets, Ai the area within each isohyet. The Inverse Distance Weighting (IDW) method in ArcGIS was applied to interpolate the rainfall data, which were averaged by decade for each of the four sites. IDW was a deterministic spatial interpolation method that makes the assumption that rainfall values become less significant as one gets farther away from the known site [12]. For the isohyet interpolation, IDW was selected over Kriging because it works better with sparse data and produces fair estimations based on distance, while Kriging's ability to generate a credible variogram was hindered by the small number of rainfall stations (only four) [13]. The formula for IDW were:

$$Z(x_0) = \frac{\sum_{i=1}^{n} \frac{Z(x_i)}{d(x_0, x_i)^p}}{\sum_{i=1}^{n} \frac{1}{d(x_0, x_i)^p}} \qquad \text{(Eq 2)}$$

where Z(*xo*) interpolated value, Z(*xi*) the amount of rainfall *i*, *p* power parameter, and *d* distance. The contour tool in ArcGIS was utilized to extract isohyet lines at regular intervals after the raster rainfall surfaces for each decade were created using IDW. Zones of equal rainfall are represented by these contour lines, which were designed for ease of comprehension. Administrative borders and hydrographic characteristics were then overlaid on top of the isohyet layers to provide geographical context and emphasize variations in rainfall intensity among the various study zones [14].

2.4 Thiessen Polygon Method

The Thiessen polygon method, sometimes referred to as the Voronoi diagram technique, is a spatial interpolation technique that uses the closest available station to assign rainfall amounts to particular geographic locations [15]. The "Create Thiessen Polygons" feature in ArcGIS was used in this study to build Thiessen polygons from the four rainfall stations situated around the Nenggiri River Basin. Every point inside a polygon is positioned so that it was closer to its matching rainfall station than it was to any other station. Unlike IDW or Kriging, the Thiessen approach does not include any smoothing or quantitative weighting of the distance. Instead, it assumes a homogeneous rainfall value over each polygon, which corresponds to the recorded value at the station it represents. This results in a distinctive, blocky pattern of rainfall distribution. The Thiessen approach's simplicity makes it computationally efficient and interpretable, but it does not describe progressive geographical fluctuation in rainfall. The mathematical form of the Thiessen approach for predicting average areal rainfall was as follows:

$$P = \sum_{i=1}^{n} A_i \cdot P_i$$

In this equation, P represents the weighted average rainfall over the study region, A represents the fractional area of polygon i, and P represents the rainfall measured at station i. This equation makes it simple to calculate regional rainfall, which is useful for hydrological modeling and water balance estimation. By creating Thiessen polygon maps for each decade, it was feasible to assess how rainfall zones migrated spatially and how station effect regions changed over time.

3. RESULTS AND DISCUSSION

This section presents the rainfall patterns in the Nenggiri catchment, Gua Musang, Kelantan, from 1995 to 2024, both spatially and temporally. Rainfall distribution was shown using isohyet maps derived by Inverse Distance Weighting (IDW) and compared to Thiessen polygon representations via software ArcGIS version 10.7.1. The analysis involves three decades: 1995-2004, 2005-2014, and 2015-2024. The aim was to detect geographical rainfall variation trends and evaluate the strengths and limits of each mapping technique.

Over the course of three decades, the four stations ST01-Pos Brooke, ST02 - Pos Gob, ST03 - Pos Tohoi, and ST04 - Kuala Betis showed diverse rainfall trends. ST02 - Pos Gob station had the highest rainfall overall, peaking at 3,140 mm between 2005 and 2014, while ST03 - Pos Tohoi station had the lowest, averaging about 1,900 mm. Figure 2 shown the isohyet maps of the stations and figure 3 display the annual rainfall for 30 years (1995-2024) in Nenggiri River Basin.

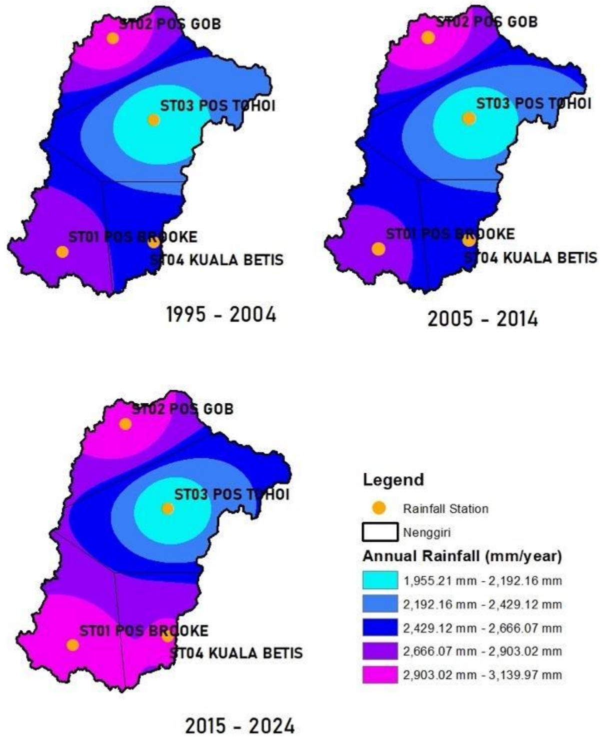

Fig. 2. The isohyet maps of Nenggiri by decade.

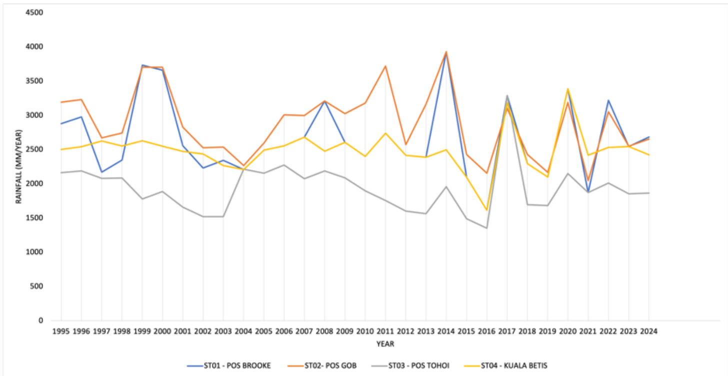

Fig. 3. The annual rainfall for 30 years (1995-2024) in Nenggiri River Basin.

3.1 Rainfall Pattern (1995 - 2004)

During the first decade, the average rainfall varied between 1,908.7 mm at ST03 - Pos Tohoi station and 2,939.42 mm at ST02 - Pos Gob station, demonstrating a moderate spatial variance. Isohyet maps from this period showed smooth rainfall gradients with regularly spaced contour intervals, indicating rather constant climatic conditions. The southeastern zone at ST03 - Pos Tohoi station continued to be the driest, while the northern portions of the catchment, particularly around ST02 - Pos Gob station, received the most rainfall, according to the IDW-based interpolation.

In contrast, the Thiessen polygons provided a broader perspective and lacked the contour information required to evaluate local variances. The overall rainfall variance of more than 1,000 mm across stations demonstrates the importance of both orography and localized microclimates in affecting rainfall patterns. Orographic precipitation occurs when moist air was pushed to rise above a mountain or highland location [16] and as the air rises, it cools, and moisture condenses to form clouds and rain. The higher rainfall around Pos Gob could be influenced by its location at higher elevation and proximity to the Banjaran Titiwangsa [17] which enhance orographic percipitation.

The areas near ST01 - Pos Brooke station and ST04 - Kuala Betis station had moderate rainfall, allowing for mixed land use and agricultural activity. The spatial consistency observed throughout this period indicates a more predictable hydrological regime, most likely due to low climate disturbances. This decade also serves as a valuable baseline because large hydrological interruptions or infrastructure developments did not significantly change regional flow systems. The Nenggiri region did not experience any severe floods during this period, which is consistent with the rather balanced rainfall pattern seen in both map types.

3.2 Rainfall Patterns (2005 - 2014)

The second decade experienced a significant change from the first in terms of rainfall intensity and spatial variability. ST02 - Pos Gob station received the most rainfall, 3,140 mm, which was a significant increase of more than 200 mm over the previous ten years. Furthermore, ST01 - Pos Brooke station had higher rainfall 2,741.74 mm, whereas ST03 - Pos Tohoi station and ST04 - Kuala Betis station maintained their comparatively modest profiles by staying below 2,600 mm. The isohyet map for this decade shows tighter, denser contour lines in the north, indicating rapid rainfall shifts over short distances.

One of the most notable environmental disasters during this period was the 2014 Kelantan flood, which was one of the worst in Malaysian history [18]. Although the maximum rainfall was not recorded at these stations in 2014, the overall pattern of higher rainfall preceding that year most certainly contributed to increased soil saturation and runoff potential. The rainfall concentration on the Isohyet map shifted northward, which was consistent with reports of upstream basin overflow during the 2014 monsoon. Reported by [19, 20] significant flooding occurred in the upper basin in December 2014 as a result of the Kelantan River and its tributaries overflowing due to excessive rainfall with water levels as high as 9.5 meters, around 220 km² of land were submerged under water.

The rainfall pattern during this decade shows the increasing impact of climate variability, which may be caused by global occurrences like El Niño and La Niña or by modifications in monsoon behavior. The observed increasing spatial disparity raises the risk of erosion and flash floods by making some sub-regions more susceptible to localized high-intensity rains. In terms of spatial hydrology, the decade demonstrates the capabilities of isohyetal mapping to capture both regional intensity and local anomaly zones. This period marks a turning point in the Nenggiri basin's climatic profile, emphasizing the significance of dynamic rainfall mapping technologies as well as the need for proactive measures by policymakers to address emerging environmental challenges.

3.3 Rainfall Patterns (2015 - 2024)

The distribution of rainfall in the Nenggiri basin exhibited greater irregularity and spatial variation in the last decade (2015–2024) than in the previous decades. ST02 - Pos Gob station continued to have the highest rainfall average 2,576.98 mm based on the observed figures, despite a significant drop of more than 560 mm from the previous decade 3,140 mm in 2005–2014. Likewise, ST04 - Kuala Betis station observed a minor decline from 2,524.71 mm to 2,458.85 mm, and ST01 - Pos Brooke station observed a decline from 2,741.74 mm to 2,509.90 mm. Remarkably, ST03 - Pos Tohoi station remained the driest station during all decades, with only a slight decrease from 1,955.2 mm to 1,933.48 mm, suggesting that the southeastern zone has lower but generally constant rainfall patterns.

The Isohyet map for this period clearly displays a less uniform contour distribution, indicating more regional variability. The concentration of rainfall gradually shifted to the center region, particularly around ST01 - Pos Brooke station and ST04 - Kuala Betis station, with smaller gradients in the southern zone near ST03 - Pos Tohoi station. This shift is consistent with increased anecdotal reports of localized flash floods and soil erosion episodes, particularly in forested and agricultural areas. According to Greenpeace Malaysia, excessive logging and land encroachment were the main causes of Kelantan's loss of almost 179,000 hectares of primary forest between 2002 and 2023 [21]. These severe changes in land use and land cover (LULC) have diminished natural water absorption capacity, destabilized soil structure, and increased surface runoff, all of which contribute directly to the frequency and severity of flood events in vulnerable places such as the Nenggiri basin [22, 23].

The downward trend in rainfall seen at the majority of sites might also be an early indicator of changes in the local climate or human-caused effects such land use changes and deforestation. These incidents serve as a reminder of the necessity of dynamic and geographically precise rainfall mapping in order to aid in water management and disaster preparedness initiatives. Furthermore, such spatial studies might help policymakers identify high-risk zones, prioritize conservation areas, and implement more sustainable land development strategies throughout the basin. As highlight by [24], without timely and data-driven response, the cumulative consequences of climate change and LULC disruptions might worsen environmental vulnerability across the region.

3.4 Annual Isohyet Analysis (2015 - 2024)

This study examines the annual regional distribution of rainfall in the Nenggiri basin from 2015 to 2024 to improve comprehension of current hydrological variability. This decade was chosen because of Kelantan's notable land use changes, growing susceptibility to extreme weather events, and developing climatic challenges and threats. Previous research by [25,26] has mentioned that the increased geographical variability in rainfall during the post-2014 monsoon season, which has been partially attributed to global climatic oscillation such as El Niño and La Niña. These events change the patterns of air circulation; in Peninsular Malaysia, El Niño usually results in less rainfall, whereas La Niña contributes to wetter conditions.

The decision to evaluate annual rainfall rather than multi-decade averages was partly motivated by the need for high-resolution insights that can aid in localized flood preparation and water management initiatives. The annual Isohyet maps as shown in figure 4 indicate significant variation in rainfall across the basin. The maximum yearly rainfall, 3,103.28 mm in 2017 and 3,188.28 mm in 2020, was reported at ST02 - Pos Gob station which suggests that orographic uplift and higher atmospheric moisture during La Niña years may have contributed to localized storm strengthening. Besides, ST03 - Pos Tohoi station regularly had the least amount of rainfall during the decade, with 1,431.35 mm in 2016 and 1,489.32 mm in 2015. The isohyetal maps that are produced show significant geographical gradients between the catchment's central and southeast zones.

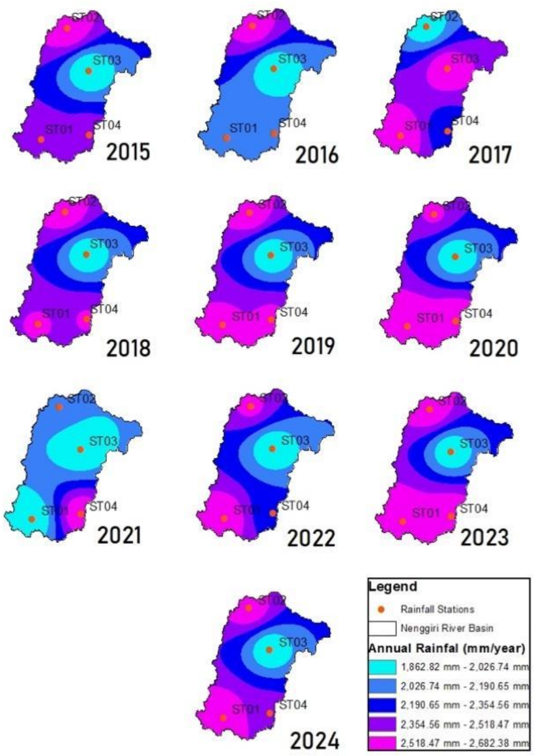

Fig. 3 The isohyet maps of Nenggiri by last decade (2015-2024)

The continuous shift in Kelantan's land cover, especially in the Gua Musang district, is one element causing this geographical variation. Widespread deforestation and the conversion of wooded hills into highways, towns, and oil palm plantations have been recorded by satellite-based analysis. Studies by [27] stated that the forest area in Kelantan significantly decreased between 2000 and 2015, decreasing by about 1,532 km², while oil palm and rubber plantations expanded to 2,142.48 km² and 3,076.24 km², respectively. Specially in Gua Musang, Kelantan, logging-related deforestation was responsible for 5.95% of land use changes between 2017 and 2019, with forest areas making up only 5.57% of the total land cover during this time as reported by [28].

These modifications modify microclimates and rainfall distribution patterns by decreasing canopy interception and evapotranspiration rates. During years with heavy rainfall, the loss of plant cover also increases the intensity of runoff and decreases infiltration, raising the danger of flooding. These spatially detailed rainfall patterns demonstrate how urgently localized planning systems that consider hydrometeorological dynamics in real time are needed. The annual-scale analysis from 2015 to 2024 emphasizes the importance of isohyetal mapping for early warning, adaptive land use planning, catastrophe resilience, and trend identification.

4. CONCLUSION

This study used GIS-based Isohyet mapping with Inverse Distance Weighting (IDW) to examine the temporal and spatial distribution of rainfall in the Nenggiri catchment, Kelantan, over a 30-year period (1995–2024). The findings show that rainfall varies significantly between locations and time periods. From 1995 to 2004, ST02 - Pos Gob station had the highest average annual rainfall at 2,939.42 mm, while ST03 - Pos Tohoi station had the lowest at 1,908.7 mm, demonstrating a moderate but continuous geographical gradient. Rainfall intensity increased throughout all stations over the next decade (2005-2014), with ST02 - Pos Gob station reaching a peak of 3,140 mm, indicating greater flood potential, particularly prior to the 2014 Kelantan mega flood. However, from 2015 to 2024, average rainfall values decreased at most sites, with ST02 - Pos Gob station dropping to 2,576.98 mm and ST01 - Pos Brooke station to 2,509.9 mm, indicating an approaching shift in rainfall distribution. Spatially, the isohyet maps indicated progressively irregular rainfall contours across the decades, notably during the third era, indicating isolated rainfall extremes. This trend reflects the increased impact of climate variability and human-caused land use changes like deforestation and development in highland areas. These findings highlight how urgently interventions are needed, especially in the areas of improved watershed management techniques, flood early warning systems, particularly in high-risk areas like Pos Gob and Kuala Betis, reforestation initiatives to restore the hydrological balance in catchment areas, and improved rainfall monitoring networks to facilitate high-resolution spatial design.

5. ACKNOWLEDGEMENTS

This study was supported by the Ministry of Higher Education (MOHE) through Fundamental Research Grant Scheme (FRGS/1/2023/WAB08/UNISZA/02/1) provided by Ministry of Higher Education of Malaysia (MOHE).

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