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ASSESSING RAINFALL PATTERNS AND TREND DISTRIBUTION IN THE KELANTAN RIVER BASIN, MALAYSIA AND KLANG RIVER BASIN, MALAYSIA

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Abstract

This study examined rainfall patterns and trends in the Kelantan and Klang River Basin in Malaysia over a ten-year period from 2010 to 2020. The analysis revealed that the Kelantan River Basin experienced an upward trend in rainfall during the Southwest Monsoon season, indicating a gradual increase in precipitation levels over the years. On the other hand, the Klang River Basin showed a relatively stable rainfall pattern without a significant trend observed. The study employed an independent t-test to compare the mean yearly rainfall between the two basins, with the findings showing no significant difference in overall precipitation levels ($t(22) = -0.8$, $p = 0.07$). However, the timing and duration of rainy seasons varied between the two basins. The Kelantan River Basin experienced a rainfall pattern that is aligned with the regular monsoon season. In contrast, the Klang River Basin displayed a notable gap in rainfall during a later month in the monsoon season. Moreover, the analysis considered the spatial variability of precipitation patterns within each basin. Specific stations in the Kelantan River Basin showed a positive trend in rainfall during the monsoon seasons (March, $p = 0.013$), whereas stations along the Klang River exhibited a declining trend (August, $p = 0.119$). These findings emphasize the influence of geographical locations, local climate conditions, and topographical features on rainfall distribution within the same country. In conclusion, this research highlights the need for further investigation into the factors driving these patterns, emphasizing the importance of effective water resource management and climate adaptation strategies in these basins to mitigate the impact of climate change.

Keywords: Rainfall patterns, Kelantan River Basin, Klang River Basin, Trend Distribution, Sen's Slope Estimator, Geospatial Analysis

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INTRODUCTION

Malaysia's climate is generally hot and humid, with varying rainfall patterns influenced by monsoons. Increased rainfall during monsoon seasons has recently caused flash floods in the Kelantan and Klang River Basins (Yahya, 2022). Climate change has significantly disrupted global and regional hydrological cycles, impacting natural rainfall patterns crucial to these systems (Gat, 2010). While past studies have focused on hydroclimatic variables such as rainfall, evaporation, and temperature (Theng Hue et al., 2022; Ata et al., 2021), limited attention has been given to long-term rainfall trends, leaving gaps in understanding climate variability and its impacts.

Monsoon rainstorms in Malaysia provide essential water resources to support agriculture. However, it also poses significant flood risks (Othman et al., 2015). Although they replenish water supplies, their unpredictable intensity can cause severe economic losses and damage infrastructure. Previous analyses have highlighted trends in wet days and total rainfall during monsoons but often focused on short periods using conventional methods (Suhaila et al., 2010). Long-term studies revealed that Malaysia's rainfall patterns involved cycles of wet and dry conditions lasting over 50 years, complicating resource management (Khan et al., 2019).

Mann-Kendall and Sen slope analyses are vital tools in hydrology to identify trends and estimate the magnitudes of rainfall data. These methods inform water availability, flood risks, and ecosystem sustainability, as demonstrated in studies of the Himalayan River Basins (Dawood, 2017) and coastal regions (Mayowa et al., 2015). Integrating Geographic Information System (GIS) technology further enhances rainfall forecasting, helping stakeholders analyze and visualize heavy rainfall patterns (Saha et al., 2022; Rasam et al., 2023). GIS tools allow authorities to prioritize flood mitigation and disaster preparedness, providing actionable insights for decision-making.

This research examined rainfall trends in the Kelantan and Klang River Basins between 2010 and 2020 to identify factors influencing precipitation and visualizing patterns. The study aims to inform flood management strategies and ensure sustainable water resource use by assessing spatial variations and long-term trends. The objectives are to (i) analyze rainfall trends in both basins, (ii) investigate significant differences between them, and (iii) visualize rainfall patterns. The findings are expected to support policymakers, researchers, and stakeholders in developing adaptive measures for managing Malaysia's changing climate.

RESEARCH METHODOLOGY

Study Areas

The study area encompassed two distinct regions: the Kelantan River Basin and the Klang River Basin. In Figure 1, the Kelantan River Basin, located in northeastern Peninsular Malaysia, is characterized by the Kelantan River and its surrounding areas. It covers a large land area and comprises various states separated by the Kelantan River, the South China Sea, and district boundaries. The Kelantan River Basin is a vital ecological and economic resource for the region. It plays a significant role in supporting local agriculture, providing water for irrigation, and sustaining diverse ecosystems. The study area of the Kelantan River Basin extends across approximately 11,900 square kilometers, including both urban and rural landscapes.

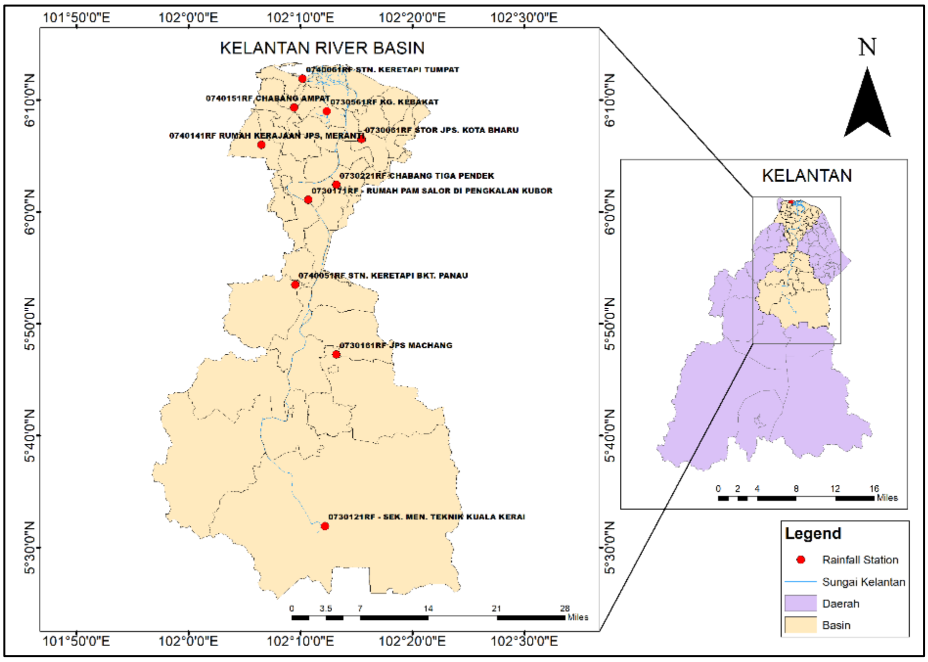


Figure 1: Kelantan River Basin Map

Meanwhile, the Klang Valley, located in the Klang River Basin, as shown in Figure 2, is a highly developed and densely populated region in Malaysia. The Klang Valley is Malaysia's primary economic, business, and commercial center, comprising several major cities and towns. It is a vibrant hub of industrial, commercial, and residential activities, contributing significantly to the country's economic growth. The study area of the Klang River Basin covers approximately 1,288 square kilometers, spanning urban, suburban, and rural areas. The region showcases a dynamic mix of infrastructure, residential neighborhoods, commercial zones, and natural landscapes.

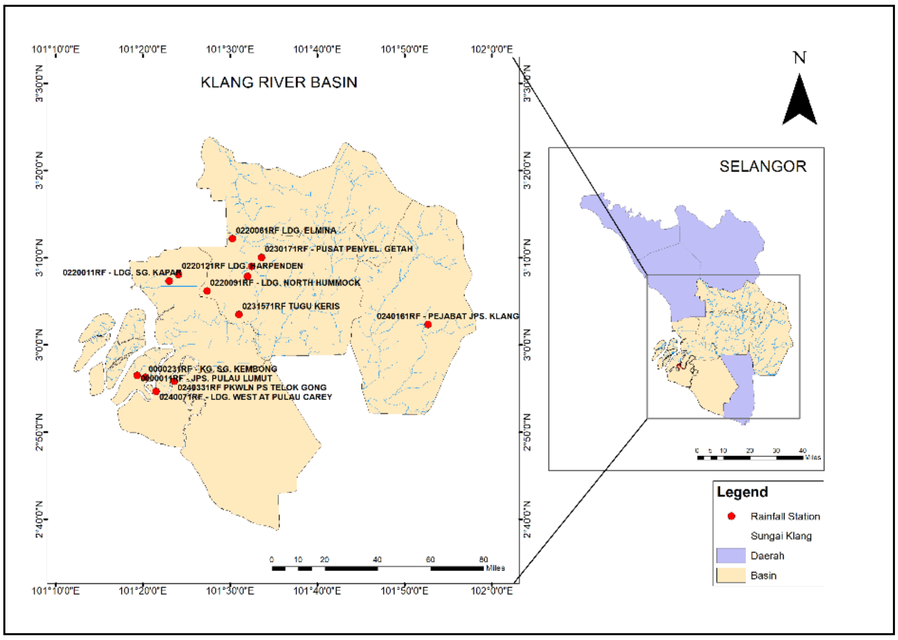


Figure 2: Klang River Basin Map

Secondary Data

The study analyzed rainfall patterns in the Kelantan and Klang River Basins from 2010 to 2020, using ground-based data from the Department of Irrigation and Drainage (DID). Data from the Kota Bharu and Klang Valley stations underwent thorough validation to ensure accuracy. The validation process included verifying data authenticity, assessing consistency, addressing missing values, and cross-referencing with weather stations and satellite data to identify discrepancies. Quality control measures by DID, such as regular maintenance and calibration of rain gauges, were also acknowledged, alongside evaluations of metadata like installation details and gauge locations.

Rainfall data, covering intensity, duration, frequency, and seasonal variations, were collected for hydrological modeling, water resource planning, and flood forecasting. Reliable data are essential for stakeholders, including government agencies, urban planners, and researchers, enabling evidence-based strategies for flood management, water supply planning, and sustainable development. Insights from this study support efforts to enhance the resilience and sustainability of the Kelantan and Klang River Basins, ensuring community well-being and ecosystem preservation.

Data Analysis
Mann–Kendall's Statistic and 'Sen's Slope Statistic Analyses
The Mann-Kendall and 'Sen's slope tests were applied to determine the magnitude and slope trends. Rainfall, temperature, and evapotranspiration time series were subjected to the Mann-Kendall test to detect movement. Additionally, the Mann-Kendall test was used to examine hydroclimatic data's regional variance and temporal trends. This test helps to determine whether a set of time-ordered data has an increasing or decreasing trend at a predetermined significance level.

For the Mann-Kendall test, the data series is defined as xk, where k – 1, 2, …, n – 1, and xj, where j = 1, 2, …, n. Each data point xk serves as a reference point and is compared with the data point xj. The test is calculated using the following equation:

$$S = \sum_{\mathrm{k}-1}^{n-1} \sum_{j-k=1}^{n} sign\ (xj - xk)$$

The values of S and Var(S) were used to compute the standardized test statistics Z, calculated as follows:

$$\begin{array}{ll} \dfrac{S-}{\sqrt{VAR}} & \text{If S} > 0 \\ Z = 0 & \text{If S} = 0 \\ \dfrac{S\ +}{\sqrt{VAR}} & \text{If S} < 0 \end{array}$$

Sen's slope test is one of the statistical tests used alongside the Mann-Kendall test to determine the magnitude of changes in each region. The test identifies the rate of increase and decrease by calculating the slope based on the Mann-Kendall values. This simple non-parametric approach can help determine the correct pitch when a linear trend is observed.

Independent T-test Analysis
An independent t-test was conducted to analyze the Kelantan and Klang River Basin rainfall patterns. The test compared the mean between two independent groups, dividing rainfall data into two groups representing each basin. Mean rainfall values were calculated to identify statistically significant differences in average rainfall between the two regions. These findings are useful for managing water resources, preventing flooding, and enhancing environmental sustainability. In this test, the independent variable was the basin, and the

dependent variable was the recorded rainfall patterns. The independent t-test allowed the comparison of mean rainfall values, providing statistical evidence of any significant differences in rainfall patterns between the two areas.

Geospatial Analysis

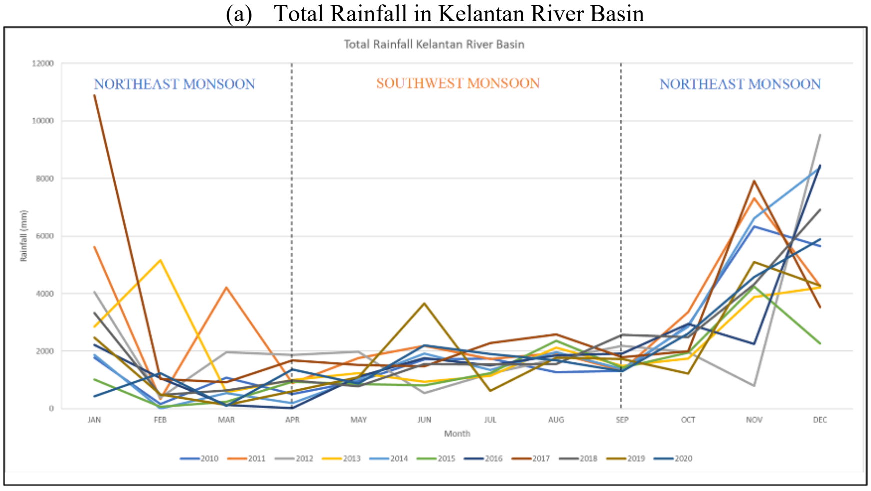
In the geospatial analysis, GIS interpolation was used to interpret statistical tests' results on rainfall data and visually represent them through a trend distribution map. The process started by plotting the location of rainfall stations using GPS coordinates and mapping yearly rainfall data across the study area to assess precipitation variations. GIS tools were used to generate an isohyet map to show the spatial distribution of rainfall over the study period, with an increase trend shown in green and a decrease shown in red. This analysis significantly improved the understanding of rainfall's spatial and temporal variations in the Kelantan and the Klang River Basin, which is essential for water resource management, flood prevention, and environmental sustainability.

RESULTS AND DISCUSSION

Total Rainfall, Average Rainfall, and Mann–Kendall's and Sen's Slope Analyses

Figure 3 shows the annual and monthly rainfall trends in the Kelantan and Klang River basins. Kelantan River Basin consistently recorded a higher annual rainfall than Klang, which was influenced by its hilly terrain and higher elevation. The highest rainfall in Kelantan was in 2014 (8,383.5 mm), followed by 2011 (7,321 mm) and 2018 (6,915.5 mm), with the lowest in 2020 (5,884.5 mm). Conversely, the Klang River Basin experienced its peak in 2012 (5,105 mm) and the lowest in 2020 (2,115.125 mm).

(a) Total Rainfall in Kelantan River Basin



(b) Total Rainfall in Klang River Basin

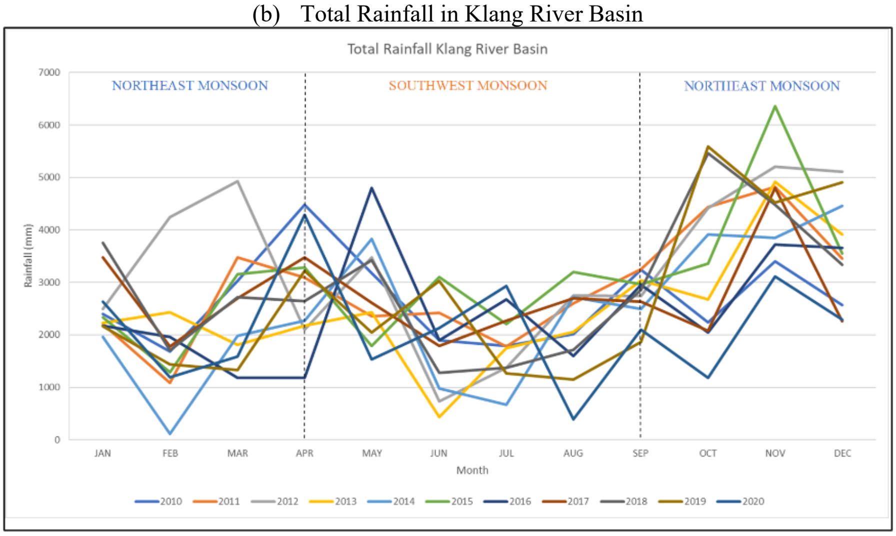


Figure 3: The Monthly Record of the a) Total Rainfall of Kelantan River Basin and b) Total Rainfall of Klang River Basin from 2010 to 2020

November and December consistently recorded the highest rainfall in both basins, exceeding 5,000 mm in specific years. This aligns with the Northeast Monsoon (NEM), which is generally active from October to March and brings intense rainfall due to moist air from the South China Sea. Local factors such as weather patterns, topography, and regional influences also contribute to rainfall distribution. Annual rainfall variations are also impacted by climate oscillations like the El Niño-Southern Oscillation (ENSO), which globally affects rainfall patterns (Wang et al., 2014). Understanding these phenomena is crucial for managing local water resources and implementing effective flood prevention strategies.

In Figure 4, the Kelantan River basin's annual rainfall ranged from 1,453.50 mm in 2015 to 3,138.13 mm in 2017, with 2017 experiencing the highest levels and 2015 the lowest. Meanwhile, the Klang River basin's annual rainfall ranged from 2,115.13 mm in 2020 to 3,297.71 mm in 2012, with the highest levels in 2012 and the lowest in 2020. Both basins showed no clear trend of increasing or decreasing rainfall over the 11-year period, although the interannual variability in the Kelantan River's basin was evident. The basins experienced fluctuations in annual rainfall, suggesting interannual variability without a distinct long-term trend.

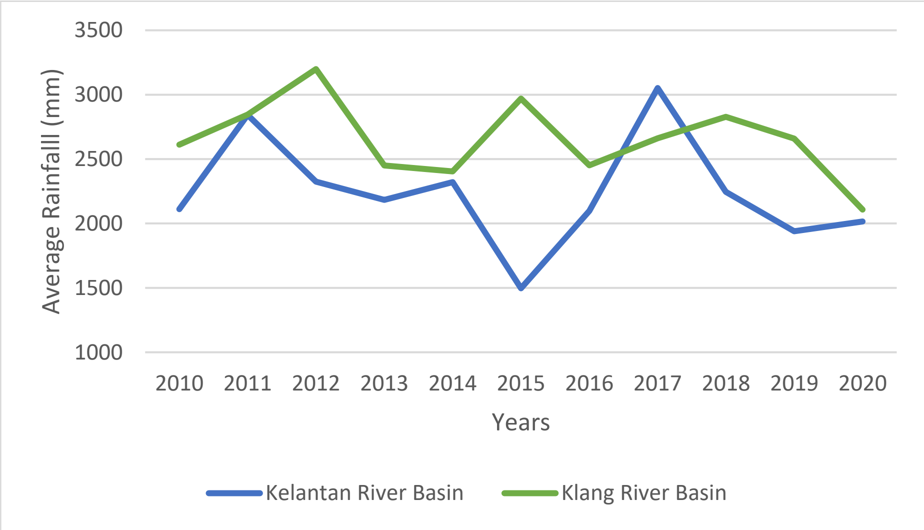


Figure 4: Average Rainfall (mm) in Kelantan and Klang River Basins

The high rainfall levels in the Klang region were influenced by the urban heat island effect, where urbanization increases convection and rainfall (Morris et al., 2017; Wang et al., 2019). In contrast, primarily rural Kelantan displayed less urban impact on rainfall except during the NEM.

In 2014 showed that Kelantan's severe floods occurred despite its lower rainfall distribution compared to the Klang Valley (Figure 4). Since 2013, rainfall trends have shown an increase in Kelantan and a decrease in Klang, which explains the flooding in Kelantan. Meanwhile, similar issues have been avoided in Selangor due to effective water catchment areas and drainage systems.

Limited data from the DID highlights notable rainfall changes in Klang (2012, 2015) and Kelantan (2015, 2017). A substantial data discrepancy becomes apparent when calculating the averages. However, a month-to-month analysis revealed no significant influence on the data (Figures 3a and 3b).

Rainfall trends in the Kelantan and Klang River basins from 2010 to 2020 revealed changing precipitation patterns, underscoring the importance of adaptive water resource management. Strategic planning is essential to mitigate flood risks, ensure water supply during dry periods, and support sustainable agriculture amidst changing climate conditions.

Both basins exhibited notable monthly trends, highlighting potential impacts on water availability and ecosystems. In January, both basins experienced positive rainfall trends, suggesting an increase in precipitation patterns (Table 1). This finding is consistent with the theory that climate change is shifting rainfall regimes (Mitra et al., 2015). These localized increases in rainfall could impact water resource planning and management.

Furthermore, negative trends regarding rainfall patterns were observed in some months. In February, the Kelantan River basin showed an 81.5% increase in rainfall. However, in March, there were decreases of 22.7% and 16.4% in the Kelantan and Klang River basins, respectively (Table 1). These fluctuations raised concerns about water availability and agricultural productivity. Jha et al. (2013) emphasized the vulnerability of river basins to shifting precipitation patterns, underscoring the need for adaptive water management strategies.

In April, both basins exhibited a positive rainfall trend, creating opportunities for improved water resource planning. Nevertheless, this also highlights the need to address challenges such as flood risks and infrastructure demands. In May, there was a negative trend, albeit statistically insignificant, suggesting only minor potential impacts on water availability and ecosystems (Chua et al., 2003).

In June, a positive trend was shown, which was beneficial for water availability and agriculture (Table 1). However, the increase in rainfall raised concerns about risks such as soil erosion and nutrient leaching, which could affect water quality and ecosystem health. Both July and November showed stable rainfall patterns with no significant trends, offering consistency that is beneficial for water management. Despite this, ongoing monitoring and adaptive strategies remain critical.

August and September showed negative rainfall trends in both basins, raising concerns about water scarcity during these months. These findings emphasize the importance of careful water management. As highlighted by Shaaban et al. (2011), it is crucial to address the impacts of shifting precipitation patterns on water resources through sustainable management practices.

The annual analysis revealed a negative rainfall trend for both basins (Table 1). This emphasizes the importance of robust water resource management, including conservation measures, water storage facilities, and diversified water sources, to ensure the resilience of the region's water supply in the face of changing climatic conditions.

Table 1: Mann - Kendall's and Sen's Slope Analysis a) Kelantan River Basin and b) Klang River Basin from 2010 - 2020

a) Kelantan River Basin

Time Series	Min	Max	Mean	Std. dev	Kendall's tau (Z Value)	p-value	Sen's slope (S Value)	Rainfall Trends
JAN	426.5	10886.5	3320.2	2887.5	-0.164	0.533	-153.5	Negative
FEB	12.0	5166.0	951.7	1457.9	0.345	0.161	63.0	Positive
MAR	106.0	4221.0	959.0	1212.2	-0.600	0.013	-159.0	Negative
APR	14.5	1875.5	916.8	575.7	0.091	0.755	13.5	No Trend
MAY	786.0	1978.5	1202.1	390.8	-0.309	0.213	-39.6	Negative
JUN	536.0	3661.0	1708.8	846.2	0.273	0.276	107.8	Positive
JUL	615.0	2290.0	1482.7	444.0	0.055	0.876	15.3	No Trend
AUG	1264.5	2588.5	1893.8	369.0	0.018	1.000	7.143	No Trend
SEP	1305.5	2563.5	1676.8	411.0	0.200	0.436	40.2	Positive
OCT	1225.0	3354.0	2368.4	639.2	-0.200	0.436	-80.6	Negative
NOV	798.5	7911.0	4851.3	2137.5	0.055	0.876	66.5	No Trend
DEC	2269.0	9516.5	5761.8	2314.0	-0.055	0.876	-119.2	Negative
Annually	37592.0	57827.5	47243.8	5463.6	-0.273	0.276	-301.6	Negative
SWM	7517.5	11365.0	8881.2	1178.2	0.200	0.436	152.0	Positive
NEM	9798.0	26292.5	18212.6	4702.0	-0.273	0.276	-466.3	Negative

b) Klang River Basin

Time Series	Min	Max	Mean	Std. dev	Kendall's tau (Z Value)	p-value	Sen's slope (S Value)	Rainfall Trend
JAN	1958.5	3758.5	2530.6	570.6	0.127	0.640	32.7	Positive
FEB	114.0	4244.5	1719.6	1023.4	-0.164	0.533	-82.0	Negative
MAR	1180.5	4930.5	2536.4	1109.3	-0.382	0.119	-145.8	Negative
APR	1184.0	4485.0	2929.0	981.4	0.164	0.533	86.7	Positive
MAY	1539.5	4802.0	2862.4	978.1	-0.200	0.436	-91.1	Negative
JUN	433.0	3102.5	1790.9	875.3	0.164	0.533	91.6	Positive
JUL	670.5	2938.0	1827.6	659.5	0.091	0.755	68.6	No Trend
AUG	391.0	3202.0	2080.9	828.5	-0.382	0.119	-152.0	Negative
SEP	1864.5	3250.5	2739.1	443.1	-0.600	0.013	-86.8	Negative
OCT	1181.0	5592.0	3399.6	1475.5	-0.091	0.755	-33.4	No Trend
NOV	3114.5	6354.5	4472.2	917.9	-0.200	0.436	-62.5	Negative
DEC	2260.0	5105.0	3592.0	973.6	-0.127	0.640	-43.7	Negative
Annually	55681.5	69752.5	62705.8	3901.0	-0.164	0.533	-582.5	Negative
SWM	11875.5	16608.0	14230.0	1659.7	-0.236	0.350	-161.6	Negative
NEM	12000.0	26387.5	18250.7	3864.4	-0.091	0.755	-216.7	No Trend

Independent T-Test Analysis

In Table 2, an independent t-test was conducted to compare the mean rainfall between the Kelantan River and Klang River. This analysis provides insights into potential differences in rainfall patterns between these locations. The results of the t-test indicated that there were no statistically significant differences in mean rainfall between Kelantan River (M = 2257.82197, SD = 1590.393762) and Klang River (M = 2706.73485, SD = 825.353872). These findings suggest that, on average, the two locations experience similar levels of rainfall.

Table 2: a) Group Statistic, b) Independent Samples Test, and c) Independent Samples Effect Sizes comparison of Kelantan River and Klang River from 2010 – 2020

a) Group Statistics

	N	Mean	Std. Deviation
Rainfall			
Sg Kelantan	12	2257.8	1590.3
Sg Klang	12	2706.7	825.3

b) Independent Samples Test Results

	F	Sig	t	df	Mean Difference
Rainfall	3.488	0.07	-0.8	22	-448.9

c) Independent Samples Effect Sizes

	Effect sizes	Standardizer	Point Estimate
Rainfall	Cohen's d	1266.9	-0.4
	Hedges' correction	1312.3	-0.3
	Glass's delta	825.3	-0.5

The lack of a statistically significant difference in mean rainfall between the Kelantan and Klang River basins indicates that they experience similar meteorological conditions, including temperature (25°C–32°C), humidity, and wind patterns, which are characteristic of their shared tropical monsoon climate (Mohtar et al., 2020; Sidek et al., 2021). These findings highlight the influence of regional factors, such as topography and prevailing weather systems, on rainfall patterns.

Although the t-test did not show a significant difference, the calculated effect sizes (Cohen's d = 1.267, supported by Hedges' correction and Glass's delta) indicate a substantial practical difference in rainfall levels between the two basins. This suggests that rainfall variations in intensity and timing could have important implications, particularly for flood management. Local factors, such as land use, drainage infrastructure, and river basin characteristics, further influence flood outcomes (Hasan et al., 2019).

The similar mean rainfall between the two basins does not imply identical timing or duration of rainy seasons. Differences in rainfall onset, duration, and intensity could affect water availability, agriculture, and flood risk, emphasizing the need to consider these temporal variations when assessing hydrological dynamics.

Spatial Maps

Figure 5 provides an insightful analysis of Mann-Kendall's tau, p-values, and Sen's slope for various stations in Kelantan River during the SWM and NEM seasons. The results reveal diverse levels of correlation and significance for the SWM across the stations.

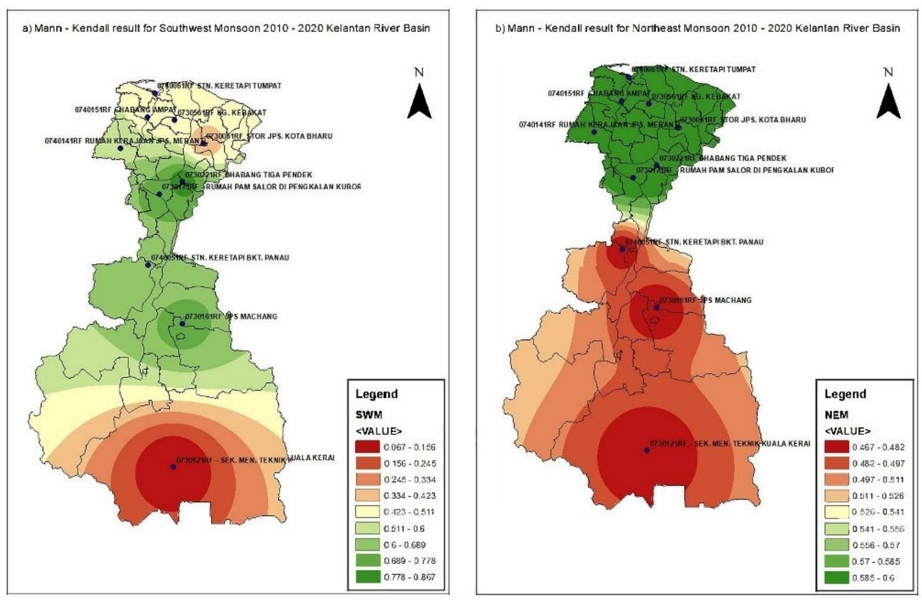


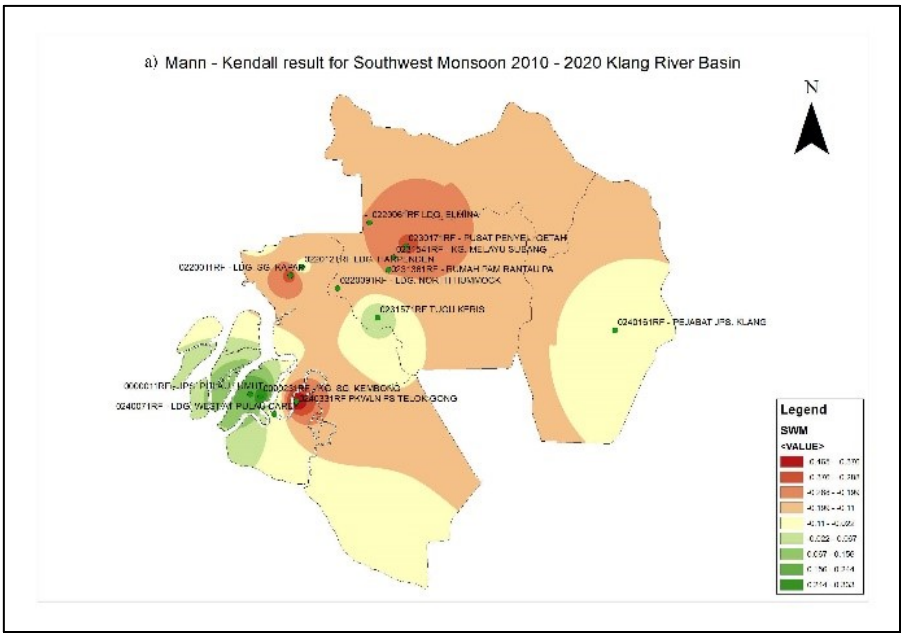
Figure 5: a) Mann–Kendall Results for the Southwest Monsoon Map and b) Mann–Kendall Results for the Northeast Monsoon Map Kelantan River Basin from 2010 - 2020

Some stations in Kota Bharu exhibited moderate to strong positive correlations and notable positive rainfall trends during the SWM. For example, the Stor JPS Kota Bharu and Sek. Men. Teknik Kurai showed moderate to weak correlations with slight positive trends. In contrast, stations like JPS Machang, Rumah Pam Salor Di, Chabang Tiga Pendek, Kg. Kebakat, and Stn. Keretapi Bkt. Pa showed strong correlations with significant Sen's slopes, indicating substantial positive trends. On the other hand, Stn. Keretapi Tumpat, Rumah Kerajaan JPS, M, and Chabang Ampat showed weaker correlations and modest trends.

During the NEM, similar positive trends were observed. Stations such as JPS Machang (0730161RF), Rumah Pam Salor Di (0730171RF), Chabang Tiga Pendek (0730221RF), Kg. Kebakat (0730561RF), Stn. Keretapi Bkt. Pa (0740051RF), Rumah Kerajaan JPS, M (0740141RF), and Chabang Ampat (0740151RF) consistently exhibited positive Kendall's tau values ranging from 0.467 to 0.6, and Sen's slopes ranging from 78.705 to 123.97, with p-values between 0.133 and 0.26.

These trends underscore the influence of station-specific characteristics on rainfall patterns in the Kelantan River basin, reflecting an increasing rainfall during the monsoon seasons. This observation aligns with climate change projections made by Tang (2019) and Pour et al. (2022), which predict greater intensity and variability in monsoon rainfall. The findings enhance the understanding of local precipitation trends and their broader implications in the context of climate change, aiding regional adaptation efforts.

Subsequently, Figure 6 shows rainfall trends in Klang River stations during SWM and NEM. The Kendall's tau values and p-values varied, providing insights into precipitation patterns in the region.



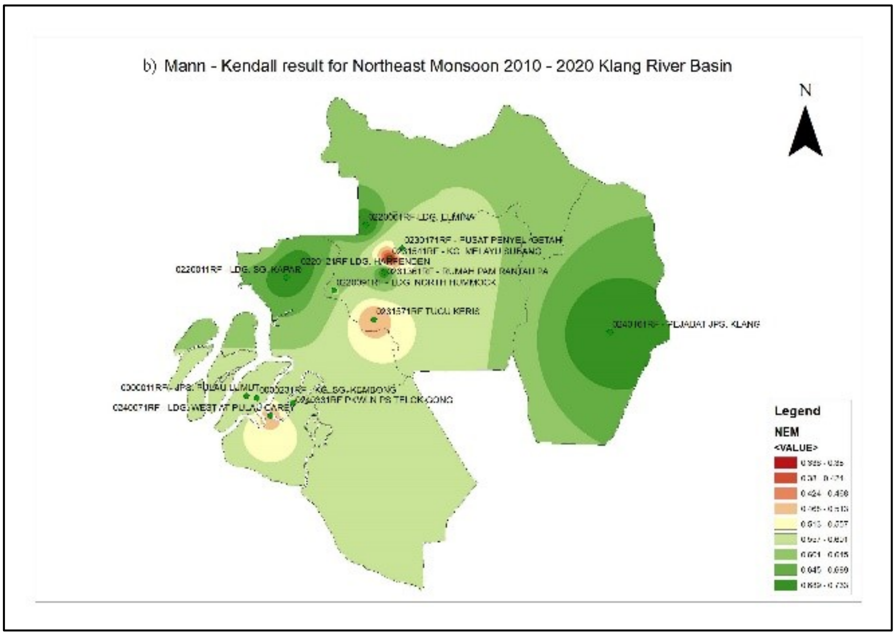


Figure 6: a) Mann – Kendall Results for the Southwest Monsoon Map and b) Mann – Kendall Results for the Northeast Monsoon Map Klang River Basin from 2010 – 2020

During both the SWM and NEM seasons, several stations in Malaysia showed negative correlations with rainfall, indicating a declining trend in precipitation during the monsoon seasons. These stations include LDG. Sg. Kapar, LDG. Elmina, LDG. North Hummock, LDG. Harpenden, Pusat Penyel. Getah and KG. Melayu Subang. However, Tugu Keris station showed a weak positive correlation, suggesting a slightly positive trend in NEM rainfall. Although some p-values were not statistically significant, Sen's slopes confirmed the observed trends. These findings align with previous studies that indicated a decreasing trend in rainfall during the monsoon seasons.

Declining rainfall trends in Klang River during monsoon seasons have implications for water resource management and flood mitigation strategies. As such, the government must develop adaptive measures to address potential challenges related to water availability and extreme weather events. These observations contribute to a better understanding of changing climate dynamics.

CONCLUSION

The analyses of rainfall data from 2010 to 2020 in the Kelantan and Klang River Basin revealed distinct patterns in precipitation trends. The Kelantan River Basin exhibited an upward trend in rainfall during the SWM season, while the Klang River Basin showed a relatively stable rainfall pattern without a significant trend observed during the same timeframe. The independent t-test revealed no significant difference in mean rainfall between Kelantan and Klang Rivers. The analysis also demonstrated varying levels of correlation and significance across different stations within each basin during both the SWM and NEM seasons.

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