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Hydro-climatic Time Series Analysis between Evaporation, Temperature, Relative Humidity and Rainfall: Case Study in Pahang

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ABSTRACT

Hydro-climatic time series analysis is critical in understanding the dynamic interactions between atmospheric and hydrological variables, particularly in regions vulnerable to climate variability. This study investigates the temporal relationships between evaporation, temperature, relative humidity, and rainfall in Pahang, Malaysia, using 13 years (2008–2020) of hydro-climatic data. Regression analysis (RA) was employed to quantify these interactions, revealing that temperature is the dominant driver of evaporation, with a strong correlation at the Temerloh station (R^2 = 0.748) and moderate correlations at Muadzam Shah (R^2 = 0.676) and Kuantan (R^2 = 0.544). Conversely, rainfall and relative humidity exhibited weak correlations with evaporation, with R^2 values ranging from 0.004 to 0.351, indicating indirect influences. The study highlights the efficacy of time series analysis in detecting long-term climate trends and underscores the necessity of incorporating additional climatic factors, such as wind speed and solar radiation, for improved predictive accuracy. The findings contribute to a deeper understanding of regional hydro-climatic variability, informing sustainable water resource management and climate adaptation strategies.

1. Introduction

The impact of climate changes is increasingly evident through the rising frequency of extreme atmospheric events such as flash flood, drought, and the heightened intensity of the El Nino-Southern Oscillation (ENSO) phenomenon [5]. These events not only disrupt ecosystems but also pose significant risks to human livelihood and infrastructure, underlining the urgency of comprehensive climate studies.

The Hydro-climatic time series analysis, which integrated the study of hydrological and climatic variables, plays a pivotal role in climate research. By analysing temporal patterns, this method enhances our understanding of the dynamic relationship within the water cycle and climate systems. Hydrological components such as rainfall, streamflow, groundwater level, and evaporation are studies alongside climatic elements like temperature, humidity, wind speed and solar radiation. These

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variables form the foundation of hydro-climatic studies, as they collectively define the state and behaviour of water within the Earth's climate system.

Key components of the hydrological cycle, including river water levels, rainfall, temperature, and evaporation, are particularly influential in hydro-climatic time series analysis. For instance, rainfall act as output of the meteorological system while simultaneously acting as an input for the hydrological system. This dual role underscores the interdependence of climatic and hydrological processes [10]. Understanding such interconnection is crucial for modelling and predicting water-related challenges in the context of a changing climate. Climate change has altered rainfall patterns in Malaysia, affecting the hydrological cycle and highlighting the importance of monitoring rainfall, temperature, and evaporation for effective water resource management [1].

Hydro-climatic time series offers valuable insight into climate studies, enabling researchers to perform trend analysis, correlation studies, forecasting, and impact assessment. For example, regression and correlation analyses are instrumental in evaluating how climatic conditions influence hydrological processes within a watershed [7]. A range of methods is available for conduction such analyses, including statistical techniques, frequency analyses, advanced time series method, and visualization tools. Advances in these methodologies have expanded the scope of hydroclimatic research, providing deeper insights into long-term climate dynamics.

One noteworthy development in the high-resolution rainfall estimation technique known as Artificial Neural Network-Climate Data Record (PERSIANN-CDR). As describe by Tan et al. [13], this tool facilitates the analysis of long-term hydroclimatic data. However, its application in different study areas remains a challenge. The analysis by Tan et. Al revealed that PERSIANN-CDR tends to slightly underestimate and overestimate rainfall in different locations, highlighting the need for further refinement and validation to improve its reliability.

Trend analysis of hydro-climatic variables is crucial for understanding long-term changes that influence water balance components such as evaporation. In a past study, Gocic et al. [6] applied the Mann-Kendall test and Sen's slope estimator to detect trends in several meteorological variables (temperature, relative humidity, vapour pressure, etc.) over a 30-year period across 12 stations in Serbia. They found significant upward trends in both minimum and maximum temperatures, while relative humidity showed a decreasing trend in summer and autumn, and vapour pressure exhibited increasing trends in multiple seasons. Importantly, they also used change-point analysis to identify abrupt shifts in the time series, and noted that their results have direct implications for reference evapotranspiration estimations. Their methodology and findings provide a strong precedent for applying non-parametric trend tests in hydro-climatic time series analyses.

Climate change also exerts a profound influence on hydroclimatic extreme events, amplifying their frequency and intensity due to shifts in mean climate conditions [14]. These extreme events, which exceed or fall below observed threshold values, often near the upper or lower limits of the recorded data. They include severe, unusual, or unseasonal occurrences, such prolonged droughts, flash floods or unexpected temperature spikes, which, although brief, can have devastating impacts. The consequences of these events are far-reaching, resulting in damages to infrastructure, disruptions in agriculture, losses in business, and setbacks in manufacturing, among other sectors. This study focusses on critical relationship in hydro-climatic time series analysis, specifically examining the interactions between, i) Evaporation and temperature, ii) Evaporation and relative humidity, and iii) Evaporation and rainfall.

Understanding these relationships is essential for advancing our understanding of climate and water dynamics, thereby aiding in the development of sustainable solution to mitigate the impacts of climate change and extreme events.

Fig. 1. Map of Pahang showing the river basins.
Source: Department of Irrigation and Drainage (DID) Malaysia

2. Study Area

Pahang is one of the states in Peninsular Malaysia, located on the eastern region of peninsula. The Pahang River Basin (PRB) lies between latitudes 2˚48’ 45’’ N and 3˚40’’ 24’N, and longitudes 101˚ 16’31’’E and 103˚29’34’’E. The catchment area spans a maximum length of 205 km and a breadth of 236 km. Pahang, situated on the east coast Peninsular Malaysia, is significantly affected by annual flooding due to the Northeast Monsoon [12]. Notably, December marked the worst flood disaster in Pahang, with substantial losses, particularly in Kuantan and Temerloh, Pahang [8]. This study is essential to deepen the understanding of hydrological cycle and climate to develop effective mitigation plans. Such plans aim to reduce the impact of extreme climatic events, like flooding, and enhance community resilience against these disasters. Figure 1 shows the location of Pahang in Peninsular Malaysia.

3. Methodology

The methodology of this research study begins with the collection of hydrological data, including evaporation and rainfall and climatic data, such as temperature and relative humidity. These variables are crucial for understanding the dynamic interactions within the hydro-climatic system. Data was

sourced from Department of Irrigation and Drainage Malaysia (DID) and Department of Meteorological Malaysia (MET).

For this study, data was gathered from six (6) stations of evaporation data, twelve (12) stations of rainfall data, nine (9) stations of temperature data, and nine (9) stations of relative humidity data, strategically distributed across the study area. The variables analyzed include daily evaporation, temperature, relative humidity, and rainfall recorded over a 13-year period from 2008 to 2020. This temporal range was chosen to provide a robust dataset for trend analysis, allowing for a better understanding of long-term patterns and variations in the region's hydro-climatic conditions. Table 1 summarized the hydro-climatic data collected in the Pahang. To analyse temporal trends in temperature, a hybrid non-parametric approach combining the Mann–Kendall (MK) test for determining the statistical significance of trends and Sen's slope estimator for quantifying trend magnitude was applied. This combined approach has been widely used in climatic and meteorological trend analyses [3,6,9] and was employed in this study to assess long-term temperature variations in Pahang.

Table 1
The list of hydro-climatic data in Pahang

Evaporation Data	
Station	**Period**
Cameron Highlands	January 2008 – December 2022
Batu Embun	January 2008 – December 2022
Kuantan	January 2008 – December 2022
Temerloh	January 2008 – December 2022
Muadzam Shah	January 2008 – December 2022
Rainfall Data	
Station	**Period**
Cameron Highlands	January 2008 – December 2022
Batu Embun	January 2008 – December 2022
Kuantan	January 2008 – December 2022
Temerloh	January 2008 – December 2022
Muadzam Shah	January 2008 – December 2022
Temperature Data	
Station	**Period**
Cameron Highlands	January 2008 – December 2022
Batu Embun	January 2008 – December 2022
Kuantan	January 2008 – December 2022

Temerloh	January 2008 – December 2022
Muadzam Shah	January 2008 – December 2022
Relative Humidity Data	
Station	**Period**
Cameron Highlands	January 2008 – December 2022
Batu Embun	January 2008 – December 2022
Kuantan	January 2008 – December 2022
Temerloh	January 2008 – December 2022
Muadzam Shah	January 2008 – December 2022

The collected data were preprocessed to ensure their quality and reliability. The preprocessing procedure included the treatment of missing data using the Inverse Distance Weighted (IDW) method, which has been demonstrated as an effective approach for handling missing rainfall data [2]. Previous findings indicated that IDW could provide better performance than other techniques, including Expectation Maximization (EM) and Multiple Imputation (MI), under the conditions evaluated. These quality-control procedures were essential for maintaining data integrity and minimising potential biases in the subsequent analyses.

Regression analysis (RA) was subsequently performed to examine the relationships between evaporation and selected climatic variables, namely temperature, rainfall, and relative humidity. The strength of each relationship was evaluated using the coefficient of determination (R^2). Regression-based approaches have been applied in previous studies to examine relationships among environmental and related variables [7]. Regression methods have also been employed in hydro-climatic assessments to evaluate relationships among climatic variables and support the analysis of long-term hydro-climatic patterns [13]. Given the complex interactions among variables within hydro-climatic systems, RA provides a useful statistical approach for identifying and quantifying dominant relationships among the selected variables.

During the validation stages, the findings from RA analysis were compared with the previous research study to ensure consistency and reliability. This step involved a detailed examination and interpretation of relationships among the hydro-climatic variables, such as evaporation, temperature, rainfall and relative humidity, as revealed by the analysis. The observed patterns and correlations were carefully interpreted. Figure 2 summarized the methodology of hydro-climatic time series analysis between evaporation, rainfall, temperature, and relative humidity.

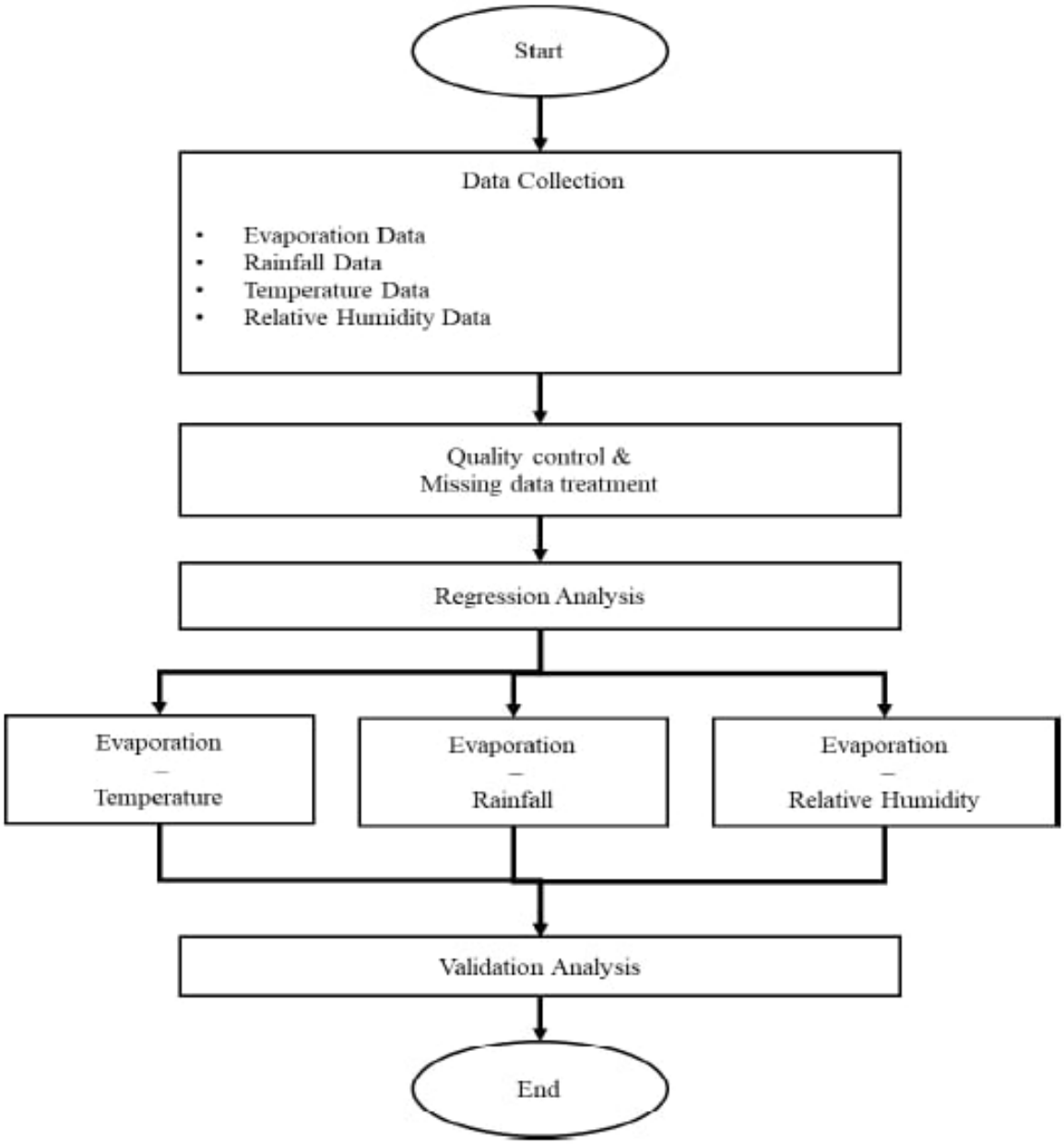

Fig. 2. The flowchart of methodology of hydro-climatic time-series analysis

4. Results and Discussion

This research study aims to understand the relationship between hydro-climatic variables, including evaporation, temperature, rainfall, and relative humidity. This section presents the results of the hydro-climatic time series analysis and discusses the relationship between those variables. The analysis employed Regression Analysis (RA) to evaluate the relationship between variables, with the coefficient of determination (R2) used to assess model fit.

The coefficient of determination (R^2) was used to evaluate the explanatory power of the regression models. An R^2 value of 1 indicates that the model explains all of the observed variance in the dependent variable, whereas values greater than 0.7 were interpreted as indicating a strong fit. Values between 0.5 and 0.7 were considered to represent a moderate fit, while values below 0.5 indicated relatively weak explanatory power [11]. These results provide insights into the relationships

among the hydro-climatic variables within the study area and contribute to a better understanding of their potential implications for hydrological and climate-related assessments.

The findings of the present study can also be considered in the context of projected hydro-climatic extremes. Multimodel ensemble approaches have been employed to assess the potential effects of climate change on hydro-climatic extremes and water resources [14]. In this context, observed changes in evaporation, temperature, relative humidity, and rainfall in Pahang may have implications for seasonal water availability and consequently for water-resource management and planning. However, the observed historical relationships should not be interpreted directly as projections of future conditions without appropriate climate-projection modelling. Table 2 summarises the findings of the hydro-climatic time-series analysis conducted at selected locations in Pahang, including Batu Embun, Kuantan, Temerloh, Muadzam Shah, and Cameron Highlands.

Table 2
Result of R2 between hydro-climatic time series variables in Pahang

Location	**Evaporation - Temperature**	**Evaporation - Rainfall**	**Evaporation - Relative Humidity**
Cameron Highlands	0.680	0.004	0.362
Batu Embun	0.544	0.135	0.152
Kuantan	0.748	0.005	0.223
Temerloh	0.676	0.351	0.308
Muadzam Shah	0.132	0.165	0.075

The analysis of the relationship between evaporation and temperature shows a strong correlation at the Temerloh station, with an R2 value of 0.748. In contrast, the Muadzam Shah and Kuantan stations exhibit moderate correlation, with R2 values of 0.676 and 0.544 respectively. The Cameron Highlands station, however, demonstrates a weak correlation between evaporation and temperature, with an R2 value of 0.132. The weakness of the dataset contributed to the unreliability of the model.

The relationship between evaporation and rainfall reveals a weak correlation across all five (5) stations in Pahang. The R2 values are 0.004 at Batu Embun, 0.135 at Kuantan, 0.005 at Temerloh, 0.351 at Muadzam Shah, and 0.165 at Cameron Highland. Similarly, the relationship between evaporation and relative humidity indicates a weak correlation at all five (5) stations. The R2 values are 0.362 at Batu Embun, 0.152 at Kuantan, 0.223 at Temerloh, 0.308 at Muadzam Shah, and 0.075 at Cameron Highland. Figure 3 presents the relationship between evaporation and temperature. As shown, there is a positive correlation between the two variables, indicating that higher temperatures tend to result in increased evaporation rates.

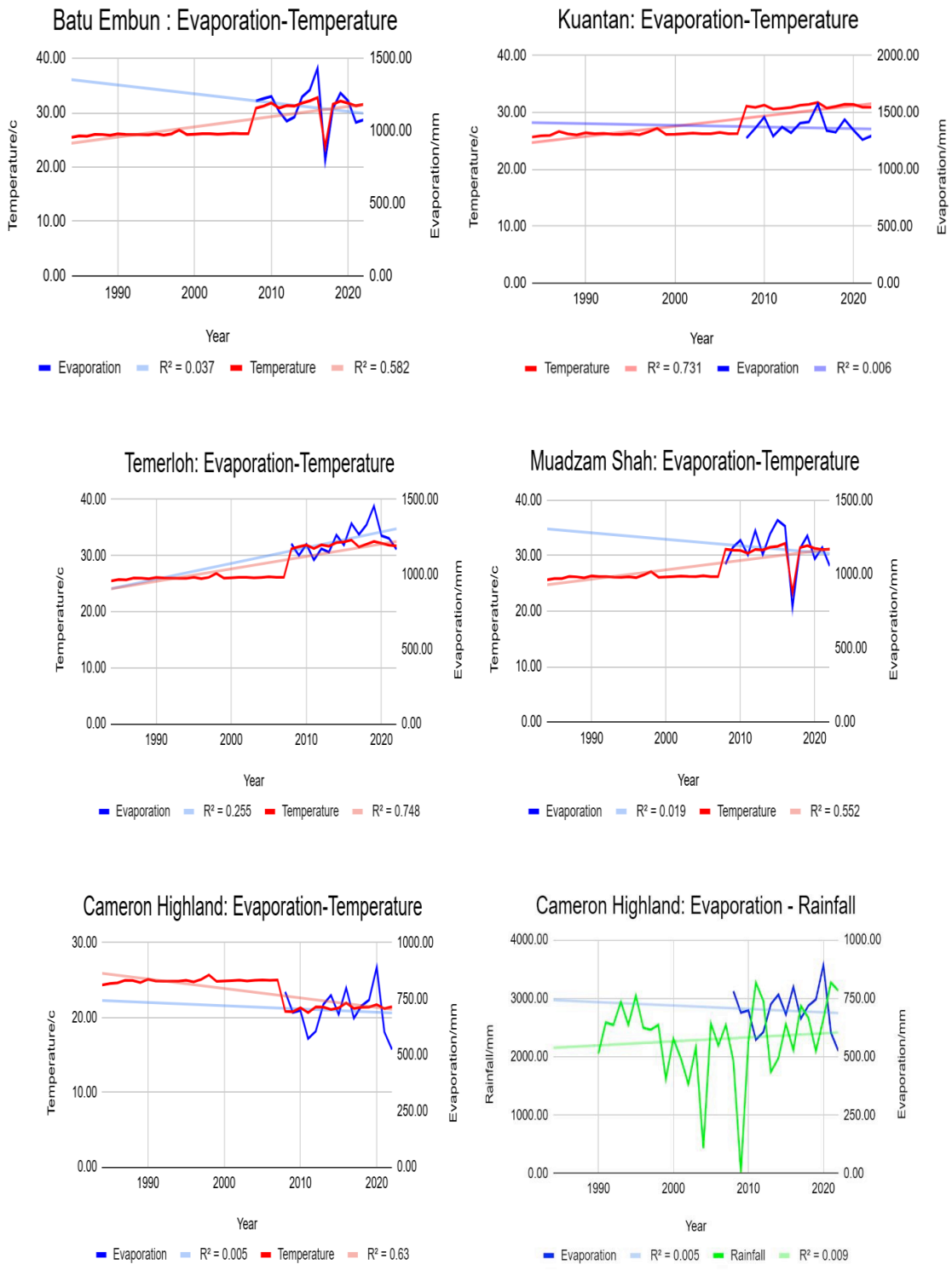

Fig. 3. The results of hydro-climatic time-series analysis in Pahang

5. Conclusion

The hydro-climatic time-series analysis in Pahang revealed spatial and temporal variations in the relationships among evaporation, temperature, relative humidity, and rainfall. Regression analysis (RA) indicated that temperature had the strongest relationship with evaporation among the climatic

variables examined. A relatively strong relationship was observed at Temerloh (R^2 = 0.748), while moderate relationships were recorded at Muadzam Shah (R^2 = 0.676) and Kuantan (R^2 = 0.544). In contrast, Cameron Highlands exhibited a weak relationship (R^2 = 0.132), which may be associated with its higher elevation and cooler climatic conditions. Previous studies have similarly applied regression-based approaches to investigate relationships among environmental variables [7].

Rainfall and relative humidity exhibited weaker relationships with evaporation, with R^2 values ranging from 0.004 to 0.351 for rainfall and from 0.075 to 0.362 for relative humidity. These findings indicate that rainfall and relative humidity explained considerably less variation in evaporation than temperature within the study area. Nevertheless, evaporation is influenced by multiple interacting climatic factors, and additional variables, particularly wind speed and solar radiation, should be considered in future analyses to provide a more comprehensive understanding of evaporation dynamics [11].

The time-series approach adopted in this study provided a framework for examining long-term variations and relationships among hydro-climatic variables over the 13-year period from 2008 to 2020. Missing observations were treated using the Inverse Distance Weighted (IDW) method, which has previously been evaluated for the treatment of missing rainfall data [2]. Appropriate treatment of missing observations is important for maintaining data consistency and reducing potential biases in subsequent statistical analyses.

However, the study is limited by its geographical coverage and the exclusion of potentially influential climatic variables such as wind speed and solar radiation. Future studies should incorporate additional climatic variables and consider more advanced analytical approaches to improve the characterisation and prediction of hydro-climatic variability. Although previous research has evaluated long-term climate datasets for hydro-climatic applications [13], the suitability of more advanced predictive approaches should be independently assessed using appropriate validation procedures. Furthermore, the heterogeneous effects of climate change across geographical and climatic contexts highlight the importance of extending future analyses to a wider range of regions and climatic zones [4]. Such comparisons could help assess the generalisability of the observed relationships and improve their relevance across different climatic settings.

In conclusion, the findings indicate that temperature has the strongest statistical relationship with evaporation among the climatic variables investigated, although the magnitude of this relationship varies considerably across locations. The results also demonstrate the usefulness of time-series and regression analyses for characterising hydro-climatic relationships in Pahang. These findings may contribute to a better understanding of regional hydro-climatic variability and provide supporting information for water-resource planning and climate-adaptation strategies.

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Wan Zunairah Othman: Data analysis support, validation, review of analytical methods and writing original draft.

Nurul Nadrah Aqilah Tukimat: Supervision, project administration, writing – review & editing.