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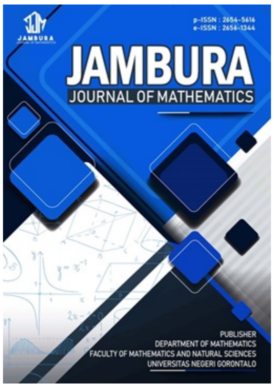

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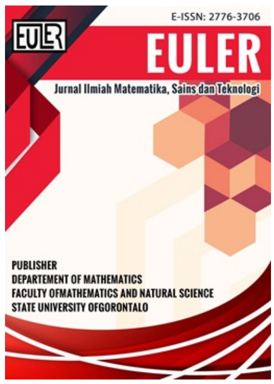

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Research Article

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Microclimatic Temperature Variability and Trends in Bengkulu Province: ANOVA and Regression-Based Analysis

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ABSTRACT. *This study investigates the microclimatic variability and trends of air temperature across three meteorological stations—Fatmawati, Bengkulu, and Kepahiang–in Bengkulu Province, Indonesia. Using five years of daily data (June 2020 to May 2025), minimum (Tmin), maximum (Tmax), and average (Tavg) temperatures were analyzed to understand both spatial patterns and temporal changes in surface air temperature. One-way ANOVA was conducted to assess whether mean temperatures differed significantly across stations, followed by Tukey post hoc test for pairwise comparisons. The analysis revealed a consistent and statistically significant difference in all temperature variables ($p < 0.05$), particularly between the inland highland station (Kepahiang) and the two coastal stations. In addition, monthly averages of Tavg were analyzed using simple linear regression, with significance tested via regression-based ANOVA. All three stations exhibited statistically significant warming trends ($p < 0.005$), with slopes ranging from $+0.0152$ to $+0.0213$ °C/month (∼0.18–0.26 °C/year), despite relatively modest coefficients of determination ($R^2 = 0.14$–0.24). These results highlight a dual climatic dynamic in the region: strong seasonal and spatial variability, overlaid with emerging baseline warming. The study underscores the importance of localized climate analysis for adaptation planning, particularly in topographically diverse tropical regions facing increased exposure to climate variability and change.*

1. Introduction

Indonesia, as part of the tropical maritime continent, experiences substantial microclimatic variability due to its complex topography, diverse land cover, and seasonal atmospheric circulation. In tropical regions, small-scale climate differences can significantly influence local thermal environments, particularly in areas with elevation gradients and rapid land-use change [1]. Microclimatic contrasts are especially notable across adjacent meteorological stations, shaped by factors such as altitude, vegetation, and urban expansion [2, 3]. These conditions are evident in Bengkulu Province, located along the southwestern coast of Sumatra Island, where the juxtaposition of coastal lowlands and hilly interiors creates strong spatial heterogeneity in temperature patterns.

Recent research highlights that Indonesian cities are warming at a steady rate, with intensified Urban Heat Island (UHI) effects amplifying minimum temperature increases [4]. In addition, observational studies across Sumatra reveal consistent warming trends, shifts in seasonal cycles, and altered diurnal temperature ranges, reflecting broader patterns of climate change in tropical Southeast Asia [5, 6]. Such warming trends are of particular concern in coastal–inland transition zones, where both natural and anthropogenic drivers interact to influence temperature variability.

While many studies have investigated large-scale temperature trends in Indonesia, fewer have examined spatial and temporal variability at a fine scale within a single province. Addressing this gap requires the application of robust statistical tools to assess whether differences among stations are statistically significant and to quantify seasonal–monthly trends. The use of one-way ANOVA is a well-established method to determine whether mean differences among multiple groups are greater than expected by chance, and Tukey's post hoc comparisons allow identification of specific station pairs with significant contrasts [7, 8].

Previous studies in Sumatra have explored microclimate–topography relationships [2, 3], rainfall–temperature interactions [5], and city-scale warming [4], but they have not jointly assessed seasonal and monthly temperature differences among closely spaced stations, nor integrated these with recent short-term warming trend analysis. This represents a critical gap in localized climate diagnostics.

Therefore, this study aims to analyze the spatial and temporal variability of surface air temperature (minimum, maximum, and average) across three meteorological stations—Fatmawati, Bengkulu, and Kepahiang—over the period June 2020 to May 2025. Specifically, (1) we test for statistically significant differences among stations using one-way ANOVA and Tukey-style pairwise comparisons, and (2) we assess seasonal and monthly trends through linear regression with significance testing. The results are expected to provide an updated and fine-scale perspective on

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temperature variability in a tropical coastal–inland setting, contributing to local climate change adaptation planning.

2. Methods

This study utilized daily temperature data retrieved from Indonesia's Meteorology, Climatology, and Geophysics Agency (BMKG), from June 2020 to May 2025 in three meteorological stations in Bengkulu Province, Indonesia: Fatmawati-Soekarno Airport Station, Bengkulu City Station, and Kepahiang Geophysics Station. The data included daily minimum $(Tmin)$, maximum $(Tmax)$, and average $(Tavg)$ temperatures. Missing values in the dataset were originally marked with hyphens (-) and were programmatically handled as NaN (Not a Number) during processing. All data handling and analysis were performed using MATLAB.

After preprocessing, the daily data were aggregated into both monthly and seasonal means to allow comparisons at different time scales. Seasons were defined as JJA (June–August), SON (September–November), DJF (December–February), and MAM (March–May), with DJF assigned to the year of January–February for consistency.

To test whether temperature means differed significantly among the three stations, a one-way analysis of variance (ANOVA) was performed separately for each temperature variable ($Tmin$, $Tavg$, $Tmax$). The null hypothesis (H_0) stated that all station means were equal, while the alternative hypothesis (H_1) stated that at least one mean differed. ANOVA partitions the total variability into between-group (SSB) and within-group (SSW) sums of squares, with corresponding degrees of freedom (dfB, dfW). The F-statistic was computed as:

$$F = \frac{SSB/dfB}{SSW/dfW}. \tag{1}$$

Critical F-values were taken from standard statistical tables at the 5% significance level ($\alpha = 0.05$) [7].

When ANOVA indicated significant differences, Tukey's Honestly Significant Difference (HSD) test was applied to identify which station pairs differed. This post hoc method controls the family-wise error rate for multiple comparisons [8]. The HSD was calculated as:

$$HSD = q_\alpha \sqrt{\frac{MSW}{n}}, \tag{2}$$

where q_α represents the studentized range, determined by the number of groups and the degrees of freedom. The absolute differences between station means were then compared against the calculated HSD threshold. If a mean difference exceeded this value, it was considered statistically significant.

To analyze temperature trends over time, simple linear regression was conducted using the monthly average temperatures from each station. The model is expressed as:

$$Tavg_m(t) = \beta_0 + \beta_1 t + \varepsilon, \tag{3}$$

where $Tavg_m(t)$ is the average temperature at month, t is time in months, β_1 is the slope in °C/month, and ε is the residual error. The model coefficients, β_0 and β_1, were estimated using the ordinary least squares (OLS) method. To assess the significance of the trend, we applied ANOVA-based significant testing [9] with this equation:

$$SST = SS_{model} + SS_{residual}, \tag{4}$$

where SST is the total sum of squares, SS_{model} is the model sum of squares, and $SS_{residual}$ is the residual sum of squares. The F-statistic was computed from the ratio of model to residual mean squares as follows:

$$F = \frac{MS_{model}}{MS_{residual}} = \frac{(SS_{model}/1)}{(SS_{residual}/(n-2))}, \tag{5}$$

where MS_{model} is the mean square of model and $MS_{residual}$ is the mean square of residual. From this, the coefficient of determination was also calculated as

$$R^2 = \frac{SS_{model}}{SST}. \tag{6}$$

The p-value was derived from the F-distribution with $(1, n-2)$ degrees of freedom, based on the cumulative probability of exceeding the observed F-statistic.

3. Results and Discussion

3.1. Descriptive Analysis of Temperature Data

This section presents a summary of the key statistical characteristics of the temperature dataset, including measures such as mean, mode, and median, supported by visual plots that highlight these metrics.

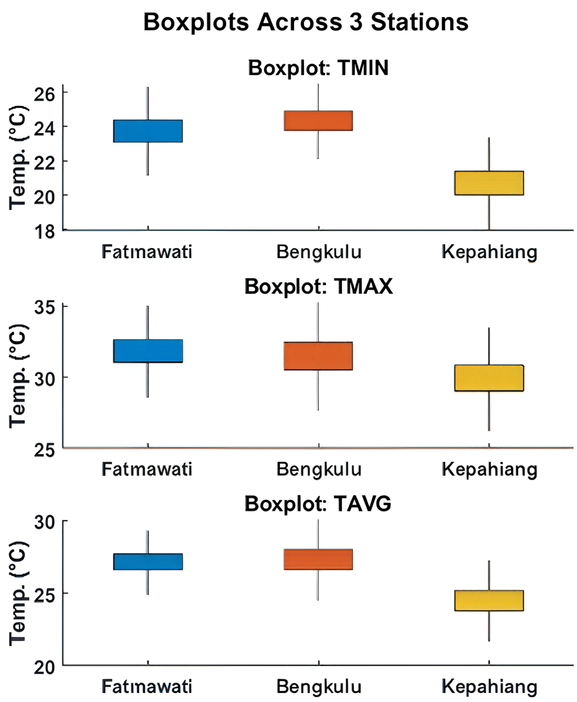

Figure 1. Boxplot of minimum (TMIN), maximum (TMAX), and average (TAVG) temperatures across three meteorological stations in Bengkulu Province: Fatmawati-Soekarno Airport Station (red), Bengkulu City Station (green), and Kepahiang Geophysics Station (blue)

Figure 1 presents the boxplots of each variable ($Tmin$, $Tmax$, $Tavg$) in all the meteorological stations, derived from the daily temperatures. The result shows that the median is typically in range between 20 °C and 35 °C, which denotes the average temperature in tropical regions. The median of $Tavg$ in Fatmawati-Soekarno Airport Station is ∼27°C with the data ranges from 26°C to 28°C between the first and third quartiles, which is similar to Bengkulu City Station, but slightly higher than in Kepahiang Geophysics Station (median=∼24°C, Q1=23.8°C, Q3=25.2°C). Similarly, the median of $Tmin$ in Fatmawati-Soekarno Airport Station is 23.8°C, slightly similar to Bengkulu City Station (24.35°C) and quite higher than in Kepahiang Geophysics Station (20.8°C) with the interquartile range follows a similar pattern to the median values for each station. A similar trend is observed for $Tmax$, where the values at Fatmawati Fatmawati-Soekarno Airport Station is >31°C, closely aligned with the values in Bengkulu City Station, while in Kepahiang Geophysics Station, the value is lower (30°C).

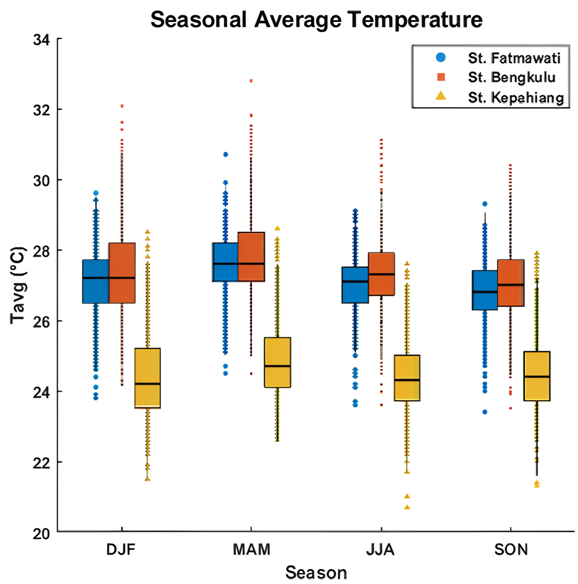

Figure 2. Boxplot of the average temperature (TAVG) across three meteorological stations in Bengkulu Province, classified into four seasons: December to February (DJF), March to May (MAM), June to August (JJA), and September to November (SON)

Figure 2 illustrates the boxplots of daily average temperature ($Tavg$) categorized by the climatological seasons in Indonesia: June–August (JJA), September–November (SON), December–February (DJF), and March–May (MAM). Given the similar distribution patterns observed in all variables ($Tmin$, $Tmax$, $Tavg$) in Figure 1, which median temperature values are closely aligned between Fatmawati-Soekarno Airport Station and Bengkulu City Station, in contrast to Kepahiang Geophysics Station in all seasons, we further focused the seasonal analysis primarily on $Tavg$, under the assumption that $Tmin$ and $Tmax$ trends would exhibit similar behavior as $Tavg$. To support this claim, Figure 3 presents the deviations between $Tavg$ and its corresponding $Tmin$ and $Tmax$ values. The result shows supporting the observed pattern in which Kepahiang Geophysics Station consistently records lower temperatures, while Fatmawati-Soekarno Airport Station and Bengkulu City Station exhibit similar thermal characteristics.

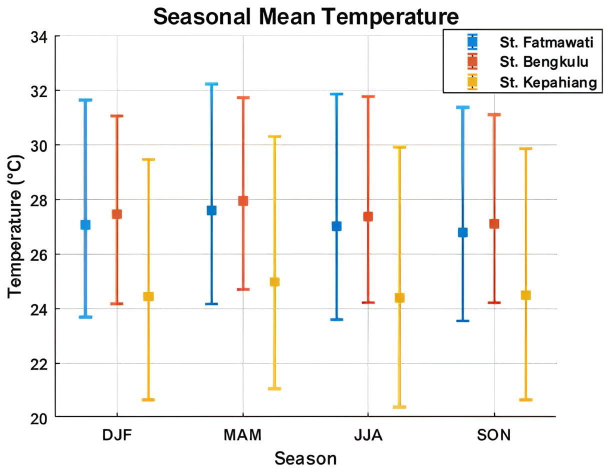

Figure 3. Plot of the distance of average temperature (rectangle) to the minimum temperature (low lines) and maximum temperature (high lines) classified into four seasons

Figure 4 displays the seasonal mean temperatures of all variables in all meteorological stations. Solid and dotted lines represent the average temperature ($Tavg$), while dashed lines indicate $Tmin$ (lower bounds) and $Tmax$ (upper bounds). Notably, the highest temperatures across all variables (averaged over the three stations) occurred during the SON period of 2023. A moderate El Niño event was active from mid-September 2023 through the end of the year, as confirmed by the Niño 3.4 index [10]. El Niño is known to suppress convection over Indonesia, resulting in clearer skies and decreased rainfall—factors that contribute to stronger solar heating and elevated surface temperatures [11]. Concurrently, the Dipole Mode Index (DMI) indicated a positive Indian Ocean Dipole (IOD) phase from August onward [10, 12]. A positive IOD typically leads to warmer sea surface temperatures in the western Indian Ocean and drier, hotter conditions over western Indonesia, including Sumatra [13], thereby amplifying the warming effects of El Niño.

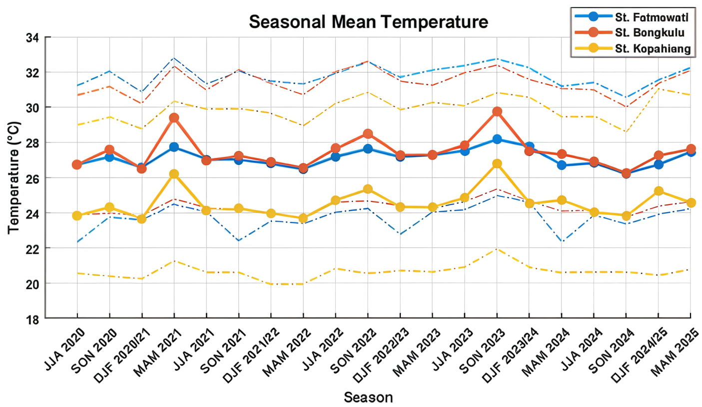

Figure 4. Seasonal mean temperature of average (solid lines), minimum and maximum (dashed lines) temperatures across three meteorological stations in Bengkulu Province

In contrast, the SON period of 2024 showed persistently lower temperatures across all three stations. The Bureau of Meteorology (BoM) reported that the El Niño–Southern Oscillation (ENSO) was in a neutral phase at that time, although several atmospheric indicators leaned toward La Niña-like conditions [14–16]. La Niña is associated with cooler-than-average Pacific Ocean sea surface temperature (SST) and enhanced atmospheric convection, which often lead to increased rainfall and reduced surface temperatures in Indonesia [17]. Additionally, the IOD trended negative toward the end of 2024 [12, 15, 16]. Negative IOD phases are characterized by warmer sea surface temperatures in the eastern Indian Ocean, which enhance atmospheric moisture convergence and cloud formation, further reducing surface temperatures due to diminished solar radiation and enhanced radiative cooling [18].

Further cooling during this period was likely influenced by a moderate to strong Madden–Julian Oscillation (MJO) pulse that moved across the Indian Ocean in late November 2024 [16]. MJO activity typically enhances rainfall and cloudiness, thereby reinforcing the cooling effects initiated by La Niña and the negative IOD [19].

3.2. Microclimatic Variability Across Stations

We used a one-way ANOVA in eq. (1) to examine spatial differences in temperature among the three meteorological stations, with a focus on seasonal variability as summarized in Table 1. The between-group degrees of freedom degrees of freedom (dfB) is 2, derived by subtracting one from the number of groups (stations). Given 180 observations across 3 groups, the within-group degrees of freedom is 177, calculated as $N - k$.

Table 1. Performance of one-way ANOVA in average (Tavg), minimum (Tmin), and maximum (Tmax) temperatures

One-Way ANOVA		
Critical F (α = 0.05) $\approx$ 3.05		
Degrees of freedom: dfB = 2, dfW = 177		
Significant difference exists among groups when F-Statistic > Critical F		
Variable	F-Statistic	Interpretation
Tavg	209.8743	Significant
Tmin	601.6272	Significant
Tmax	103.4312	Significant

Since the calculated F-statistic significantly exceeds the critical value, the null hypothesis—stating that there is no difference in mean monthly temperatures among the three stations—is rejected. This indicates a statistically significant difference in mean temperature between at least two of the stations.

Based on this result, post hoc comparisons in eq. (2) were conducted to identify which station pairs exhibit significant differences, as summarized in Table 2. A pairwise difference is deemed significant when it surpasses the Tukey HSD threshold.

The Tukey-style pairwise comparisons further clarified that Kepahiang Geophysics Station consistently shows significantly lower temperatures than both Fatmawati-Soekarno Airport Station and Bengkulu Station across all variables, which consistent from the previous results. This is likely influenced by the higher elevation of Kepahiang region, which is a common factor in cooler microclimatic conditions in tropical regions. While the comparison between Fatmawati-Soekarno Airport Station and Bengkulu Station shows no significant difference for $Tavg$, and the differences are either small or borderline significant for $Tmax$ and $Tmin$. This indicates that while the two coastal stations (Fatmawati-Soekarno Airport Station and Bengkulu City Station) share similar thermal patterns, Kepahiang region stands out as climatologically distinct. These spatial differences align closely with the influence of elevation and topographical gradient on local temperature regimes. Previous study [3] demonstrated that in North Sumatra, elevation differences—particularly between coastal lowlands and mountainous interiors—play a central role in modulating thermal comfort and air temperature, with variations linked to both altitude and land cover patterns. Similarly, other study [2] reported microclimatic temperature variability within Northern Sumatra forests, noting that even short-distance shifts in canopy structure and elevation significantly influenced local temperature measurements.

Table 2. Performance of post hoc Tukey-Style Pairwise comparison

(a) Tukey-style Pairwise Comparison (Tavg)

Comparison	Mean Difference	HSD	Interpretation
Fatmawati vs Bengkulu	0.339	0.519	Not significant
Fatmawati vs Kepahiang	2.545	0.519	Significant
Bengkulu vs Kepahiang	2.884	0.519	Significant

(b) Tukey-style Pairwise Comparison (Tmin)

Comparison	Mean Difference	HSD	Interpretation
Fatmawati vs Bengkulu	0.604	0.380	Significant
Fatmawati vs Kepahiang	3.040	0.380	Significant
Bengkulu vs Kepahiang	3.645	0.380	Significant

(c) Tukey-style Pairwise Comparison (Tmax)

Comparison	Mean Difference	HSD	Interpretation
Fatmawati vs Bengkulu	0.363	0.469	Not significant
Fatmawati vs Kepahiang	1.884	0.469	Significant
Bengkulu vs Kepahiang	1.522	0.469	Significant

Our findings reaffirm these conclusions, showing that Kepahiang region, which lies at a higher elevation and experiences more frequent cloud cover and upslope air movement, maintains a cooler thermal profile year-round compared to the more exposed and lower-elevation coastal stations. The consistency of these temperature differences across both daily and monthly scales highlights the stability of topography-driven microclimate separation, as seen in both previous studies and the current analysis.

This elevation-based cooling effect, evident in the statistically significant differences across all temperature metrics, not only contributes to understanding regional microclimatic variability but also supports the broader literature emphasizing the role of topography in shaping local climate in Sumatra and other tropical regions.

3.3. Trend Analysis of Temperature

We applied linear regression with ANOVA-based significance testing (eq. (3)–eq. (6)) to assess temperature trends across three meteorological stations in Bengkulu Province over the period from June 2020 to May 2025, using monthly mean temperature data. Table 3 outlines the structure and parameters of the regression model.

Table 3. Trends of average temperature (Tavg) in all stations

Station	Slope (°C/month)	R^2	p-value
Fatmawati	+0.0152	0.242	0.0001
Bengkulu	+0.0213	0.141	0.0031
Kepahiang	+0.0205	0.149	0.0023

Figure 5 presents the monthly temperature time series and corresponding linear trends for each station. The analysis revealed consistent warming across all locations, with statistically significant trends detected at the 0.005 level. While the model fits were modest—with R^2 values ranging from approximately 0.14 to 0.24—the results indicate a clear upward trajectory in temperature during the five-year study period. Although the regression model is relatively simple, these findings offer preliminary evidence of recent warming consistent with global climate observations. Notably, the results align with the Intergovernmental Panel on Climate Change (IPCC) assessment, which identifies Southeast Asia as a region experiencing increasingly rapid warming due to anthropogenic climate change [20].

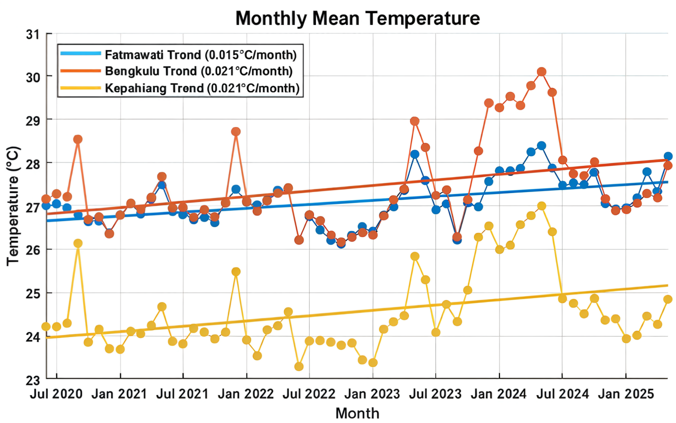

Figure 5. Monthly mean temperature trends of average temperature across three meteorological stations in Bengkulu Province

Differences in the strength of the model across stations suggest local influences. Fatmawati-Soekarno Airport Station exhibited the best model fit, while Bengkulu City Station and Kepahiang Geophysics Stations showed slightly steeper warming slopes but weaker correlations. These variations may stem from differences in elevation, land cover, and microclimatic exposure—factors known to modulate local temperature trends over short periods.

At the national scale, our findings are in line with broader climate trends. The World Bank's Climate Change Knowledge Portal [21] reports that Indonesia has experienced a warming rate of approximately 0.23 °C per decade between 1951 and 2020, accelerating to 0.28 °C per decade since 1971. The higher rates observed in our study likely reflect the shorter time window, as well as recent intensification of warming at urban and peri-urban scales.

Local study [22] reported a +1.07 °C increase in land surface temperature over 36 years in Bengkulu City (∼0.03 °C/year), attributing the rise to urban expansion and land cover change, supported this view. In comparison, our observed trends—averaging around +0.2 °C/year over just five years—suggest potential amplification of warming in recent periods, particularly at the Bengkulu lowland station. This may be linked to urban heat effects or increased sensitivity to regional climatic variability.

Comparable short-term warming has been reported in other tropical cities. For instance, studies in Singapore and Kuala Lumpur document similar warming rates of 0.2–0.3 °C per decade, often linked to the combined influence of climate change and urbanization [23, 24]. The consistency of our findings with both regional and global patterns highlights the climatic relevance of even modest warming trends in equatorial environments, where ecological systems and human communities are particularly vulnerable to temperature shifts.

4. Conclusion

This study examined seasonal variability and long-term temperature trends from June 2020 to May 2025 at three meteorological stations in Bengkulu Province: Fatmawati-Soekarno Airport Station, Bengkulu City Station, and Kepahiang Geophysics Station. Significant seasonal variations were observed, with higher temperatures in the dry season and lower values during the wet season. Additionally, linear regression revealed a consistent warming trend across all stations, with monthly increases ranging from +0.0152 to +0.0213°C/month (∼0.18–0.26°C/year). Despite relatively low R^2 values, these trends were statistically significant ($p < 0.005$), suggesting an ongoing temperature increase. The findings highlight a dual climatic dynamic in Bengkulu: a distinct seasonal cycle and a gradual warming trend. This aligns with broader regional warming patterns in Indonesia, where urbanization, elevation, and land-use changes likely influence local variability. Future research should expand the time series, consider additional climate drivers, and explore nonlinear trends to deepen understanding of climate change in this tropical maritime region.

Author Contributions. **S. H. Norfahmi:** Formal analysis, software, writing—original draft preparation, writing—review and editing, visualization. **R. Samdara:** Conceptualization, methodology, supervision, validation. **S. Supiyati:** Conceptualization, methodology, supervision, validation. **W. A. Lestari:** Methodology, supervision, validation. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest. The authors declare that there are no conflicts of interest related to this article.

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