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*Research Article*

# The Analysis of Daily Dynamics of Microclimate Air Temperature and Humidity in Lake Tondano

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***Abstract -*** *The goal of this study was to analyze the daily dynamics of air temperature and humidity patterns, as well as their correlative relationship, at various distances from the shoreline of Lake Tondano. This analysis aimed to provide a comprehensive scientific overview of the region's microclimatic conditions. Simultaneous air temperature and humidity measurements were taken every 30 minutes from 6:00 a.m. to 6:00 p.m. WITA using a 4-in-1 sensor at three observation points located 0, 50, and 100 m from the lake's edge. The primary param investigated were air temperature and relative humidity. Pearson correlation analysis was employed to quantify their interrelationship. Key findings revealed a strong, consistent negative correlation between air temperature and relative humidity across all three observation points. Pearson correlation coefficients (r) were -0.80 at 0 m, -0.97 at 50 m, and -0.94 at 100 m, indicating that the very strength of this inverse relationship intensifies with increasing distance from the shoreline. This phenomenon aligns with atmospheric thermodynamic principles: an increase in air temperature enhances its capacity to hold water vapor, leading to a decrease in relative humidity if the absolute water vapor content remains constant. The coefficient of determination ($R^2$) further indicated that 58% to 81% of the variation in relative humidity could be explained by fluctuations in air temperature. In conclusion, the study found that air temperature is the main factor influencing humidity conditions.*

***Keywords -*** *Lake Tondano, Microclimate, Air temperature, Relative humidity, PEARSON correlation, The shoreline of the lake.*

## I. INTRODUCTION

Climate change and atmospheric dynamics across various regions of the world have emerged as critical issues in the realm of modern environmental and earth sciences. Dynamic atmospheric conditions exert a profound influence on ecosystem stability and human comfort at multiple spatial scales, including global, regional, and local domains. At the micro-scale, this phenomenon manifests as microclimates local atmospheric conditions shaped by the interplay of physical surface factors such as land cover, vegetation, topography, and water bodies. It is imperative to comprehend microclimates, as they elucidate environmental variations at small scales that frequently evade detection by macro-weather observations. Specifically, the intricate interplay among oceanic dynamics, wind patterns, and local topography can give rise to distinctive precipitation patterns, thereby impacting temperature and humidity within a specific region (Alfiandy et al., 2020) (Irwandi et al., 2023).

Temperature and air humidity are two primary param that define a microclimate. The two param are inter-related and together they have an effect of controlling the energy balance on the surface of the earth. The temperature of air in a specific region can be called air temperature as it is the amount of heat present in the air changed by the sun, and the amount of moisture in the atmosphere can be called air humidity. This, in its turn, predetermines thermal comfort and possible condensation processes. It is noted that the two variables exhibit diurnal patterns of fluctuation as the temperature rises during the day as a result of increased radiation, and falls at night. On the other hand, humidity of air has an opposite trend with temperature. The comprehensive study of the daily fluctuations in these two param can tell about the features of the microclimate and the energy balance in a particular area. Land cover and vegetation type as well as water bodies, lakes in particular, have been known to play important roles in the diurnal patterns of temperature and humidity variation, producing certain micro-climatological differences (Pabalik et al., 2025). Lake coastal areas have distinct microclimatic regions because the interaction of the water bodies with the atmosphere is complicated. The large surface area of a lake also acts as a heat absorber and storage during the day, which is then seen to be emitted at night. This effect causes comparatively stable temperatures of the atmosphere around the lake compared to the terrestrial regions. Also, the surface water evaporating off the lake increases humidity in the atmosphere in the nearby vicinity especially in the morning and evening hours. Temperature and humidity variations may develop local air circulation patterns e.g. land breezes and lake breezes which subsequently interfere with micro-weather patterns. As a result, the detailed monitoring of the daily processes of air temperature and humidity in the coastal regions of lakes is an urgent task in understanding the time and space functioning of microclimatic systems. In recent years there has been a body of literature that points out that urban heat island effect can be alleviated by the existence of water bodies, which in this case are lakes. This phenomenon occurs through evaporative cooling and the high specific heat capacity of water (Qi et al., 2025)( Ampatzidis et al., 2020).

Lake Tondano in Minahasa Regency, North Sulawesi Province, serves as an ideal location for investigating the phenomenon of daily air temperature and humidity dynamics. The Tondano, the largest natural lake in the area has ecological and economic value and a climatological role of the lake as the controller of local temperatures and humidity. But little has been done in studies of pattern of micro climatic conditions in the vicinity of the Lake Tondano coastline particularly with regard to the daily change in air temperature and humidity. Most of the surviving literature has been on hydrological or water quality or degradation of the environment. This study was therefore carried out to examine the daily variations of air temperature and humidity in Lake Tondano coastal region. The objective of this analysis was to provide a more comprehensive scientific overview of the microclimatic conditions in this aquatic region and to support sustainable environmental management efforts.

## II. MATERIALS AND METHODS

The present study was conducted in the coastal area of Lake Tondano, with three measurement points located at distances of 0 m, 50 m, and 100 m from the lake's edge, respectively. The air temperature and humidity dynamics were observed at 30-minute intervals between 06:00 and 18:00 WITA in order to determine the daily behavior of air temperature and humidity. The main tool applied was a 4-in-1 sensor, which had an accuracy of ±0.1°C of temperature and ±2 percent of humidity. To measure distances, a 100m tape measure was used, and a smartphone with GPS was used to check time and location coordinates. Calibration of all the instruments was carefully done before the start of data collection in order to measure accurately. All measurements were carried out simultaneously at the three points after every 30-minutes and the data was carefully recorded. The collected data were subsequently analyzed using Pearson correlation analysis with the aid of Python 3 software, with the objective of ascertaining the relationship between changes in air temperature and humidity at each observation point throughout the study period. The following table presents the Pearson correlation coefficient (r) categories.

**Table 1. The Pearson Correlation Coefficient (r) Categories (Lolombulan, 2023)**

| Correlation Coefficient | The Significance of Interpersonal Connections |
|---|---|
| $r = 0$ | No relationship |
| $0 < r < 0.2 \; or \; -0.2 < r < 0$ | Very weak |
| $0.2 \leq r < 0.4 \; or \; -0.4 < r =< 0.2$ | Weak |
| $0.4 \leq r < 0.6 \; or \; -0.6 < r \leq 0.4$ | Fairly strong |
| $0.6 \leq r < 0.8 \; or \; -0.8 < r \leq 0.6$ | Strong |
| $1 \leq r < 0.8 \; or \; -0.8 \leq r < -1$ | Very strong |
| $r = 1 \; or \; r = -1$ | Perfect |

## III. RESULTS AND DISCUSSION

This study analyzed the relationship between changes in air temperature and humidity in the coastal area of Lake Tondano. The analysis is significant in issues of microclimate dynamics in the coastal part of the lake and minimizing possible bias due to the large-scale temporal variability. The period of data collection involved 6:00 a.m. to 6:00 p.m. WITA, which gave the possibility to observe the tendencies of every day in detail. The microclimate variables, such as air temperature and humidity were recorded in the morning, afternoon and evening and daily averages were obtained. The measuring instruments were placed 100 m above ground level. Also, the data were measured at three distances on the lake shore, including near the shore, 50 m and 100 m in different directions. The data obtained were statistically processed to determine trends and correlation of temperature and humidity. This discussion is crucial in the overall interpretation of microclimate within the region of the coastal environment of the Lake Tondano. The following will be the findings of this analysis.

***A. Correlation Analysis Between Air Temperature and Humidity at the shoreline of the lake (x = 0 m)***

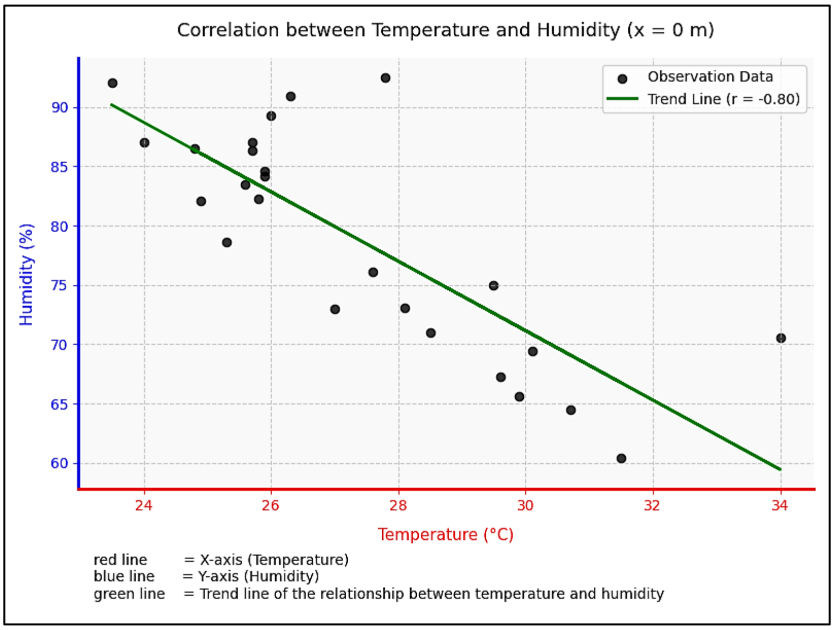


***Figure 1. Relationship between Air Temperature and Relative Humidity at 0 m from the Lake Tondano Shoreline ($r = -0.80$, $R^2 = 0.64$, $p < 0.05$, $n = 25$)***

Based on Figure 1, Pearson's correlation analysis reveals a strong and significant negative relationship between temperature and humidity at a distance of 0 m from the shore of Lake Tondano. The Pearson correlation coefficient (r), shown on the “Trend Line” in the figure, is r = -0.80. This value of r = -0.80 indicates that there is a strong inverse linear relationship between temperature and air humidity; that is, when the air temperature increases, the air humidity tends to decrease, and vice versa (Mertikas et al., 2020). The strength of this relationship, although not reaching perfect correlation (r = −1), shows that temperature is a very influential factor on humidity variability at this location. The quality of this correlation does not result in perfect correlation (r = −1), but indicates that temperature is a highly powerful variable affecting the variability of humidity at this place. This can be explained thermodynamically by the capacity of air to keep water vapor that varies with temperature (Mendoza et al., 2021). Warmer air has a greater capacity to hold water vapor than cooler air. Thus, when the total amount of water vapor in the atmosphere does not change radically, a rise in temperature will lead to a drop in the relative humidity because the available space where the water vapor can exist will be increased (Mendoza et al., 2021). On the other hand, the colder the temperature, the lower the amount of water vapor the air can hold, and thus, the relative humidity increases, and can even be nearly at the level of saturation (Giorgio et al., 2017; Zhmakin, 2023).

The coefficient of determination ($R^2$), which can be calculated from the Pearson value (r), is 0.64. This indicates that approximately 64% of the variability in air humidity at a distance of 0 m from the lake is explained by temperature changes (John et al., 2023; Magang et al., 2024). This large percentage shows that the linear regression between temperature and humidity is much applicable and predictive in the microclimate of lake Tondano. This relationship is important to understand microclimate analysis, local weather forecasting and ecological studies that require the use of hydrometeorological conditions. Other studies have also shown that temperature negatively correlates with relative humidity in different lake environments, though the strength of this correlation varies depending on local geographical and climatic characteristics (Gong et al., 2021).

### *B. Correlation Analysis Between Air Temperature and Humidity x=50 m from the Lake Tondano Shoreline*

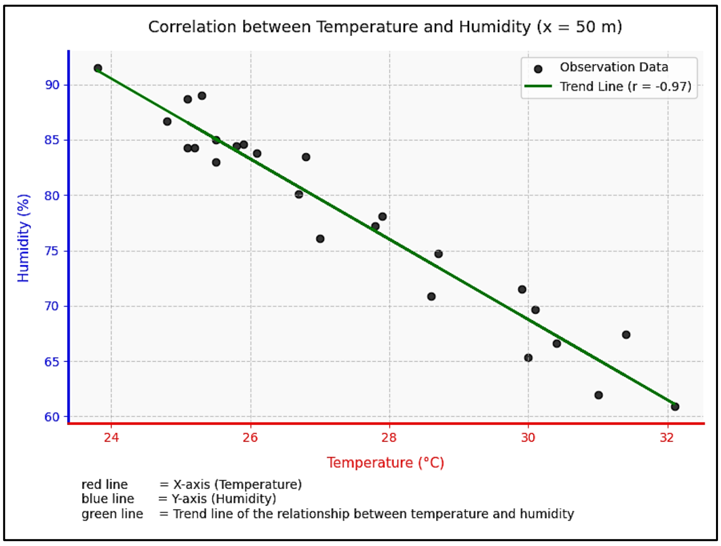


***Figure 2. Relationship between Air Temperature and Relative Humidity at 50 m from the Lake Tondano Shoreline ($r = -0.97$, $R^2 = 0.94$, $p < 0.05$, $n = 25$).***

As illustrated in Figure 2, a robust and statistically significant negative correlation is evident between temperature and humidity, particularly at a distance of 50 m from the shoreline of Lake Tondano. The Pearson correlation coefficient of r = -0.97 indicates that these two variables move in opposite directions with almost perfect linear strength. A value of -0.97, which is proximate to -1, signifies that each augmentation in temperature is invariably succeeded by a diminution in air humidity in a highly predictable proportion, and vice versa (Mertikas et al., 2020).Through the thermodynamic approach, this is a negative relation that can be sufficiently described in the context of the atmospheric science (Mendoza et al., 2021). Hot air has been found to have a higher ability to carry water vapor as compared to cold air. The ability of the air to retain water vapor also increases with increase in ambient temperature. It means that the volume of water vapor in the atmosphere could be the same, but the relative humidity (the proportion between real vapor and the possible amount of water at a certain temperature) will decline because of the increased space that water vapor could have (Kim et al., 2021; Mendoza et al., 2021). In contrast, lowering temperature causes a decline in the ability of the air to retain water vapor, which causes an increase in relative humidity, which often nears saturation, despite no change in the absolute volume of water vapor (Giorgio et al., 2017).

The high correlation coefficient (r = -0.97) indicates that temperature is the dominant factor influencing air humidity variation at this location, and this relationship is very stable and predictive. The coefficient of determination ($R^2$) derived from this value (approximately 0.94) indicates that approximately 94 % of the variability in air humidity can be explained by temperature variability (John et al., 2023). There is an urgent need to understand the importance of such a strong correlation with the microclimatology research. Such knowledge helps to create more accurate models and predict the changes in local weather conditions. These conditions can subsequently influence ecological and hydrological processes within the vicinity of Lake Tondano.

### *C. Correlation Analysis Between Air Temperature and Humidity x=100 m from the Lake Tondano Shoreline*

As illustrated in Figure 3, the implementation of Pearson's correlation analysis reveals a remarkably robust and statistically significant negative correlation between temperature and humidity, with a distance of 100 m from the shoreline of Lake Tondano serving as the context for this relationship. The Pearson correlation coefficient (r), as indicated on the "Trend Line" in the figure, is r = -0.94. The value of r, which is -0.94, indicates a very strong inverse linear relationship between temperature and air humidity. Consequently, an increase in air temperature invariably leads to a decrease in air humidity, and vice versa (Mertikas et al., 2020). The strength of this relationship, which approaches a perfect correlation (r = -1), demonstrates that temperature is the predominant factor and exerts a substantial influence on humidity variability at this location. According to

Mendoza et al. (2021), the phenomenon can be explained by the fundamental principle of thermodynamics that the capacity of air to hold water vapor is highly dependent on its temperature. As has been shown, warm air has a higher water vapor capacity than cooler air. As a consequence, the rise in temperature will lead to a drop in relative humidity, which is the ratio of the amount of actual water vapor in the air to the total amount of water vapor that can be retained by air at a certain temperature (Kim et al., 2021; Mendoza et al., 2021). Nevertheless, the total area of water vapor in the air can still stay unchanged, although such shifts in relative humidity occur (Mendoza et al., 2021). Conversely, a decrease in temperature results in a reduction of the air's capacity to hold water vapor, leading to an increase in relative humidity that frequently approaches the saturation point (Giorgio et al., 2017).

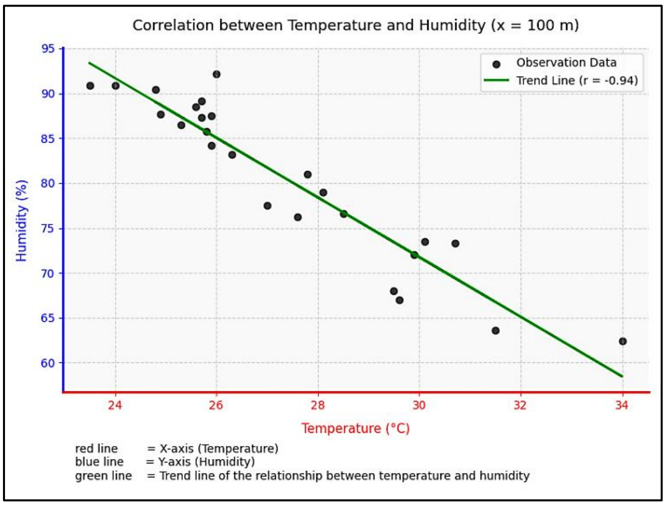


***Figure 3. Relationship between Air Temperature and Relative Humidity at 100 m from the Lake Tondano Shoreline ($r = –0.94$, $R^2 = 0.80$, $p < 0.05$, $n = 25$).***

The coefficient of determination ($R^2$), calculated from the Pearson value (r), is $(-0.94)^2 \approx 0.88$. This suggests that approximately 88% of the variability in air humidity at a distance of 100 m from the lake can be attributed to changes in temperature (John et al., 2023; Magang et al., 2024). This high percentage indicates the applicability and prediction abilities of the linear model between temperature and humidity in micro climate set up of Lake Tondano shore. A comprehensive understanding of this robust correlation is imperative for microclimate analysis, local weather forecasting, and ecological studies contingent on hydrometeorological conditions, thereby facilitating more precise modeling and prediction of local atmospheric conditions.

***D. A thoroughgoing Interpretation of Pearson's Correlation between Temperature and Air Humidity is Presented, with Particular Attention to Distances of 0, 50, and 100 m from Lake Tondano. The Present Study Explores the Role of the Clausius-Clapeyron Equation in Blue-Space Microclimate***

Pearson's correlation analysis reveals a consistent and significant negative relationship between air temperature and humidity at various distances from the shore of Lake Tondano (0, 50, and 100 m). This relationship is evident in the editor's document. This relationship suggests a positive correlation between air temperature and air humidity, with increasing air temperature corresponding to decreasing air humidity, and vice versa. However, the strength of this correlation is found to vary with distance from the lake. The ensuing text presents a synopsis of the Pearson correlation coefficient (r) and the coefficient of determination ($R^2$) outcomes derived from the aforementioned analysis.

**Table 2. the Pearson Correlation Coefficient (r) and the Coefficient of Determination ($R^2$)**

| Distance from the Lake (m) | Pearson's Correlation Coefficient ($r$) | Coefficient of Determination ($R^2$) |
|---|---|---|
| 0 | -0.80 | 0.64 |
| 50 | -0.97 | 0.94 |
| 100 | -0.94 | 0.88 |

*a. Fundamentals of Thermodynamics: The Clausius-Clapeyron Equation*

The persistent negative correlation between temperature and air humidity is primarily governed by the Clausius-Clapeyron equation. This equation is an atmospheric thermodynamic principle that explains the exponential relationship between saturated vapor pressure (the capacity of air to hold water vapor) and temperature (Bastin et al., 2019; Iribarne & Godson, 1981; Mendoza et al., 2021). Specifically, this equation posits that the air's capacity to hold water vapor increases exponentially with rising temperature (Koutsoyiannis, 2012; Mendoza et al., 2021).

Consequently, if the absolute amount of water vapor in the atmosphere remains constant, an increase in temperature will inherently cause a decrease in relative humidity, because warmer air has more "space" to hold water vapor (Kim et al., 2021; Mendoza et al., 2021). Conversely, a decrease in temperature results in a substantial reduction of the air's capacity to hold water vapor. This, in turn, leads to a rapid increase in relative humidity, often reaching a point of saturation, and subsequently causing condensation (dew, fog) (Giorgio et al., 2017; Zhmakin, 2023). The Clausius-Clapeyron equation provides a negative relationship between temperature and humidity, thereby explaining their tendency to move in opposite directions (Mendoza et al., 2021).

*b. The Present Study Explores the Influence of Blue-Space Microclimate*

The presence of Lake Tondano exerts a substantial influence on the surrounding blue-space microclimate, thereby contributing to the observed temperature and humidity dynamics. Large bodies of water, such as lakes, possess high specific heat capacities and thermal inertias, thereby functioning as thermal buffers that moderate the surrounding air temperature (Ampatzidis & Kershaw, 2020; Zhao et al., 2023). Lakes during the diurnal period are known to have the ability to take in heat and consequently cool the air around them, through the process of evaporation. On the other hand, the stored heat has the opportunity to be emitted during the night, and the excessive high and low temperatures could decrease (Zhao et al., 2023). The loss of water through evaporations at the lake surface adds to the local atmosphere, which enhances the humidity of air in the area (Chakraborty et al., 2023; Probst et al., 2022).

Studies have also shown that the lake cooling and humidifying effects may reach tens of m out of the shore (Qi et al., 2025).The distance is measured at 0 m ($r = -0.80$). At this distance, the moderating influence of the lake is very dominant. The lake functions as a cooling agent for the atmosphere through the process of evaporation, thereby regulating the ambient temperature. Additionally, it serves as a constant source of water vapor, contributing to the overall moisture in the atmosphere. While the negative relationship remains robust, the correlation coefficient of -0.80 suggests that other factors associated with direct proximity to water, such as increased direct evaporation leading to slightly higher relative humidity at a given temperature, may also be contributing factors. This results in a slight decrease in the perfection of the correlation when compared to the 50-meter distance. The coefficient of determination $R^2 = 0.64$ indicates that 64 % of the variability in humidity is attributable to temperature, leaving 36% that may be influenced by complex interactions at the air-water interface.

The distance was measured at 50 m ($r = -0.97$). A distance of 50 m has been shown to exhibit an almost perfect negative correlation ($r = -0.97$), with an $R^2$ of approximately 0.94. This finding suggests that approximately 94% of the variability in air humidity can be attributed to variations in temperature. A moderating effect of the lake on temperature can still also be observed in this distance but the effect of the highly localized direct evaporation can be somewhat diminished, thus enabling the Clausius-Clapeyron-governing thermodynamic relationship between temperature and humidity to manifest with almost a pure linear strength (Kim et al., 2021). This finding indicates that, within this range, temperature is a highly reliable predictor of humidity, with minimal interference from other factors. The distance was measured at a precise interval of 100 meters ($r = -0.94$).

At a distance of 100 meters, the correlation remains highly significant ($r = -0.94$), with an $R^2$ close to 0.88. Despite a slight decrease in correlation when the distance is reduced to 50 meters, the strength of the correlation remains high. This observation indicates that the moderating effect of the lake (blue-space microclimate) on the temperature and humidity conditions is not less important. The reduction in the strength of the correlation, as in case of 50 meters, might be the indication of slight decrease of the impact of blue space, which would be accompanied by the growing impact of other local factors of the microclimate, e.g. vegetation or topography. Nevertheless, the Clausius-Clapeyron principle is the most common cause of the temperature-humidity correlation (Giorgio et al., 2017). In summary, the present findings emphasize the preeminence of atmospheric thermodynamic principles, as delineated by the Clausius-Clapeyron equation, in the regulation of the relationship between temperature and humidity. This analysis underscores the pivotal function of the blue-space microclimate facilitated by Lake Tondano in modulating local hydrometeorological conditions, exhibiting varying yet substantial impacts contingent on proximity to the water body (Gong et al., 2021). A comprehensive understanding of these interactions is imperative for microclimate modeling, weather forecasting, and environmental impact assessments in lake ecosystems.

## IV. CONCLUSION

The findings of this study indicate a robust and persistent negative correlation between air temperature and relative humidity within the coastal region of Lake Tondano. The strength of this relationship demonstrates a specific pattern in relation to distance from the coastline. Specifically, the Pearson correlation coefficient demonstrates a marked enhancement in the strength of this relationship, initially increasing from -0.80 at a proximity of 0 meters, and then further increasing to -0.97 at a distance of 50 meters. Thereafter, there is a slight decrease to -0.94 at a distance of 100 meters from the lake.

This phenomenon aligns closely with the Clausius-Clapeyron equation of thermodynamics, which stipulates that an augmentation in air temperature, as witnessed in the study area, results in a proportional rise in the air's capacity to retain water vapor. This phenomenon is evident in the field data, wherein elevated temperatures are consistently associated with diminished relative humidity across all measurement distances. Furthermore, the blue-space microclimate induced by the presence of Lake Tondano exerts a significant role in regulating the surrounding thermal and humidity conditions. The proximity to the lake, with a value of 0 meters, exhibited a marginally lower correlation coefficient of -0.80. This phenomenon is presumably attributable to the substantial direct influence of evaporation and the intricate nature of air-water interface interactions. However, at a distance of 50 meters, the correlation peaks at -0.97, indicating a strong dominance of thermodynamic principles without significant interference from micro-local factors. This correlation then decreases slightly at a distance of 100 meters (-0.94), as the influence of the lake begins to weaken.

This finding suggests that air temperature is the predominant factor influencing humidity conditions in the study area. The coefficient of determination ($R^2$) further corroborates this finding, explaining approximately 64% of the variation in relative humidity at a distance of 0 meters from the coastline, 94% at a distance of 50 meters, and 88% at a distance of 100 meters. To enhance comprehension, it is advised that subsequent research extend the observation period to encompass a complete 24-hour cycle and consider seasonal variations. Furthermore, it is imperative to conduct a more extensive spatial mapping with a higher density of observation points, integrate additional meteorological parameter measurements such as wind speed and solar radiation, and investigate the ecological and social impacts of these microclimate patterns on local ecosystems and communities. The development of predictive models and comparative studies with other tropical lakes will also greatly enrich this field of science.

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