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RESEARCH ARTICLE

A Response of Water Temperature to Wind Speed and Air Temperature in Lake Laut Tawar, Aceh Province, Indonesia

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Abstract

Changes in water temperature impact the dynamics of lake ecosystems. Changing climate factors, including wind speed and air temperature, influence the water temperature of lakes. This research aims to analyze the response of water temperature to wind speed and air temperature in Lake Laut Tawar. Observations were conducted from August to September 2023, with a sampling frequency of every two weeks. The results revealed that water temperature, wind speed, and air temperature in Lake Laut Tawar fluctuated according to the presence of light, namely day and night factors. Variations in sunlight intensity lead to hourly fluctuations in air temperatures, while wind speeds vary hourly due to changes in air pressure, consequently resulting in hourly variations in water temperature as well. During daylight hours, air temperature surpasses water temperature, whereas during nighttime hours, water temperature exceeds air temperature. Heat transfer from the air to the water contributes to an increase in water temperature, while the release of heat energy from the surface water into the air leads to a decrease in water temperature. Changes in the water temperature of Lake Laut Tawar are primarily influenced by changes in wind speed and air temperature by 80 percent simultaneously. However, while air temperature showed a partial response, wind speed did not exhibit a significant response. The relationship between these variables can be expressed through a mathematical model $Tw = 0.356\ Ta + 0.025\ W + 15.674$, where Tw is water temperature (°C), Ta is air temperature (°C), and W is wind speed (km/minute). Another factor that influences the water temperature of Lake Laut Tawar is the inlet water temperature, which was not observed in this research.

Keywords: Air Pressure, Climate Factors, Relationship Model, Regression, Sunlight Intensity.

1. Introduction

Lakes generally function as water sources, food sources, flood control, tourism service providers (Ho & Goethals, 2019), microclimate regulators, and habitats for various species and biodiversity (Wondie, 2018). Many lakes have experienced changes in their biophysical and chemical structure and function due to warming attributed to climate change and anthropogenic pressures (Janssen, et al., 2021), resulting in a reduction in the effectiveness and capacity of ecological services. Such changes can pose significant risks to human health, global food security, and economic development (Legionosuko, et al., 2019). Over the last few decades, there has been a notable increase in surface water temperatures in many lakes (O'Reilly, et al., 2015). The surface water temperature of Lake Dillon increased by 2.5 °C over 35 years, which corresponds to an average increase of 0.76°C per decade (Lewis, et al., 2019). Lake Tahoe experienced surface water warming at an average rate of 0.015°C/year between 1970 and 2002 (Coats, et al., 2006). Lake Superior surface temperatures in summer have increased by 2.5°C from 1979 to 2006 (Austin & Colman, 2007), and Lake Baikal has experienced surface water warming over the past 60 years, with temperatures increasing by 1.21°C since 1946 (Hampton, et al., 2008). Globally, the average rate of increase in lake surface water temperature worldwide is 0.34 °C/decade (Woolway, et al., 2020). Lake Toba, situated in Indonesia, has exhibited a discernible pattern of temperature rise, with an annual increase of 0.006 °C observed between 1981 and 2020. Notably, over the past decade, a substantial temperature surge of 0.24 °C has been recorded (Irwandi, et al., 2023).

Changes in lake water temperature have a direct impact on all organisms in it (Haddout, et al., 2022) because water temperature plays a major role in controlling various physical, biogeochemical, and ecological processes in lakes (Woolway, et al., 2016; Dugdale, et al., 2018; Haddout, et al., 2022). It impacts the water quality and the function of lake ecosystems (Haddout, et al., 2018), whereas changes in lake water temperature impact the water biota and change lake ecosystems (Woolway, et al., 2021). Several studies have shown that an increase in lake water temperature has an impact on the water quality of the lake system (Magee & Wu, 2017; Yang, et al., 2018; Szumińska, et al., 2020), thus affecting the dynamics of the lake ecosystem. An observed consequence of elevated lake water temperature is the alteration in both the composition and number of planktonic organisms (Rice, et al., 2015), which encourages the growth of cyanobacteria (Huisman, et al., 2018) which causes the dominance of cyanobacteria (Joehnk, et al., 2008) and cyanobacterial blooms (Paerl & Paul, 2012). It affects the photosynthesis rate, respiration, and the physical structure of lake waters (Yvon-Durocher, et al., 2012). Lake water temperature also affects the development of aquatic biota (Jia, et al., 2022), especially spawning rates (Besson, et al., 2016) and fish growth

(Collas, et al., 2019), so it can change fish populations (Lynch, et al., 2015).

Climate change poses a significant threat to lake ecosystems (O'Reilly, et al., 2015). Remarkably, this is evidenced by changes in surface temperature, evaporation, and lake water level (Woolway, et al., 2020). Similarly, Lake Toba is experiencing rising temperatures, altered rainfall patterns, and fluctuations in water levels (Irwandi, et al., 2021; Irwandi, et al., 2023). Climate change refers to alterations in climate variables primarily influenced by the phenomenon of global warming. Climatic factors subject to change encompass variations in wind speed and air temperature. The temperature fluctuations in water bodies, such as lakes, are believed to be influenced by alterations in climatic variables. These changes in water temperature can be attributed to variations in both air temperature and wind speed (Toffolon, et al., 2014; Magee, et al., 2016; Magee & Wu, 2017; Jasalesmana, et al., 2019; Yu, et al., 2021).

This research aims to analyze the response of the water temperature of Lake Laut Tawar to changes in wind speed and air temperature. The scope of this research is limited to studying the response of Lake Laut Tawar in the form of water temperature to climate factors, such as wind speed and air temperature. This research is a part of efforts to understand Lake Laut Tawar's response to climate change. It is a component of endeavors aimed at comprehending how Lake Laut Tawar responds to the phenomenon of climate change. There is a concerted effort to proactively predict the adverse consequences of climate change on water supplies, a concern that has global implications (IPCC, 2013).

Lake Laut Tawar plays a crucial role ecologically, economically, in terms of public health, aesthetics, and as a source of energy for the surrounding community and the people of Aceh in general (Adhar, 2020; Adhar, et al., 2021; Adhar, et al., 2021; Adhar, et al., 2022; Adhar, et al., 2022; Adhar, et al., 2023). Changes to the Lake Laut Tawar ecosystem will have a significant and far-reaching impact on ecology, the economy, and social life. Therefore, anticipatory and mitigation efforts are urgently needed and of utmost importance. The current phenomenon observed in Lake Laut Tawar includes an increase in its trophic status attributed to the growth of phytoplankton (Adhar, et al., 2023). The observed phenomenon is believed to be attributed to climate change, specifically the rise in global warming, along with human-induced factors. Implementing mitigation measures requires the ability to accurately assess the magnitude of the problem and the level of risk it poses. Before implementing mitigation strategies, it is crucial to understand how the Lake Laut Tawar ecosystem responds to variations in climate conditions. Therefore, it is vital to comprehend the response of water temperature to wind speed and air temperature in Lake Laut Tawar.

2. Methods

2.1. Research Location and Time

This research was conducted in August and September 2023 at Lake Laut Tawar, Takengon, Aceh Tengah Regency. The lake is located geographically between $4^{0}38'34"$- $4^{0}34'46"$ N and $96^{0}51'25"$- $96^{0}59'48"$ E, with an area of 58.62 km^2 and a coastline length of 49.75 km (Adhar, et al., 2021). Lake Laut Tawar is surrounded by a catchment area of 18,878 hectares with land use consisting of plantations, rice fields, settlements, forests, and shrubs (Adhar, 2020). The location map is shown in Figure 1.

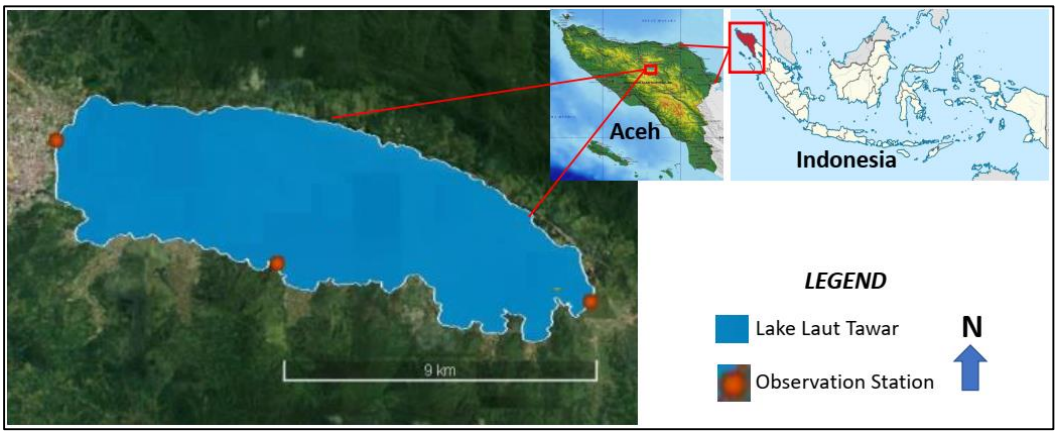

Fig 1. Map of research locations

2.2. Data Collection Methods

Figure 1 illustrates the spatial distribution of three observation stations situated along the periphery of the lake, specifically designated for monitoring lake water temperature, wind speed, and air temperature. In situ measurements were conducted to observe lake water temperature, wind speed, and air temperature.

Wind speed and air temperature were measured with a Wintact WT87A digital anemometer, and lake water temperature was measured with a digital thermometer series TP3001. For accurate wind speed measurements, a location is open and free from obstruction, at least 100 – 200 meters from trees and buildings.

The water temperature was measured at a distance of approximately 5-10 meters from the shore to minimize the impact of land on the water temperature. Previous research has shown that the water quality in Laut Tawar Lake is consistent throughout its spatial area (Adhar, et al., 2021; Adhar, et al., 2022; Adhar, et al., 2022; Adhar, et al., 2023; Adhar, et al., 2023). Therefore, the influence of depth on water temperature is not considered.

To collect data, the temperature of lake water, wind speed and air temperature were observed every hour for a period of 24 hours. The observations were conducted for 3 days every two weeks between August and September 2023.

Fig 2. The visual of Measurement of wind speed, air temperature and water temperature

2.3. Data Analysis

The data analysis encompassed descriptive, comparative, and associative approaches. Descriptive analysis was utilized to elucidate the understanding of the distribution of research data. The temporal comparison of research findings relies on the outcomes of Comparative Analysis, which may be conducted using either One-way ANOVA or Kruskal-Wallis tests. The choice between these tests depends on the distribution and homogeneity of the data. The purpose of associative analysis is to examine the correlation and impact of independent factors on the dependent variable using Regression Tests (Misbahuddin & Hasan, 2013). The output of this research is a model of the relationship between air temperature, wind speed, and lake water temperature obtained from the results of regression analysis in the form of the equation: $T_w = \alpha_1 + \beta_1 T_a + \beta_2 W + \varepsilon_1$. Where T_w is lake water temperature (°C), T_a is air temperature (°C), W is wind speed (km/minute), α_1 is intercepts β_1 and β_2 are regression coefficients, ε_1 is error.

3. Results and Discussion

Observations of water temperature, wind speed, and air temperature in Lake Laut Tawar for 4 (four) observations showed that the air temperature ranged from 16.6 – 36.0 °C with an average of 22.77±4.61 °C. Wind speeds ranged from 0.01 km/minute to 0.73 km/minute, with an average of 0.133 ± 0.101 km/minute. The average water temperature of Lake Laut Tawar is 23.78 ± 1.83 °C with a range of values between 19.8 and 29.3 °C. The descriptive statistics of observation data are shown in Table 1. The graph of the hourly average of the air temperature, wind speeds, and water temperature of Lake Laut Tawar is shown in Figure 2.

Table 1. Descriptive Statistics of Observation Data on Air Temperatures, Wind Speeds, and Water Temperatures of Lake Laut Tawar

	N	Minimum	Maximum	Mean	Std. Deviation
Air Temperature (°C)	864	16.6	36.0	22.768	4.6093
Water Temperature (°C)	864	19.8	29.3	23.782	1.8346
Wind Speeds (km/minute)	864	.01	.73	.1328	.10116
Valid N (listwise)	864				

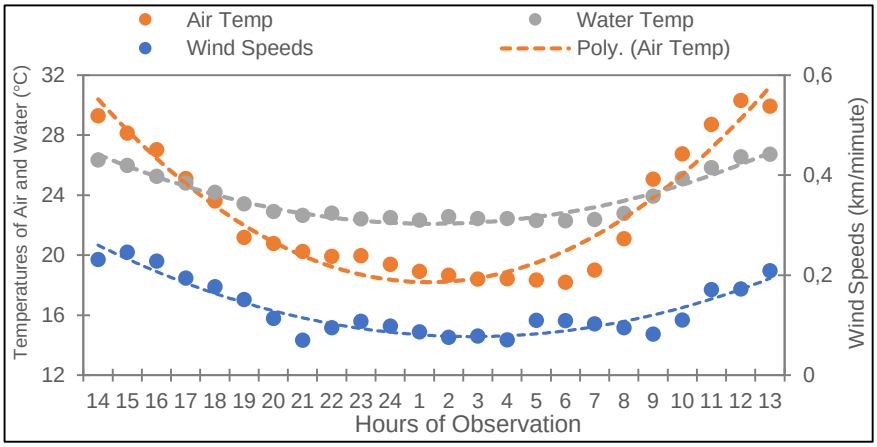

Fig 2. Average Air temperatures, Wind Speeds, and Water Temperatures in Lake Laut Tawar

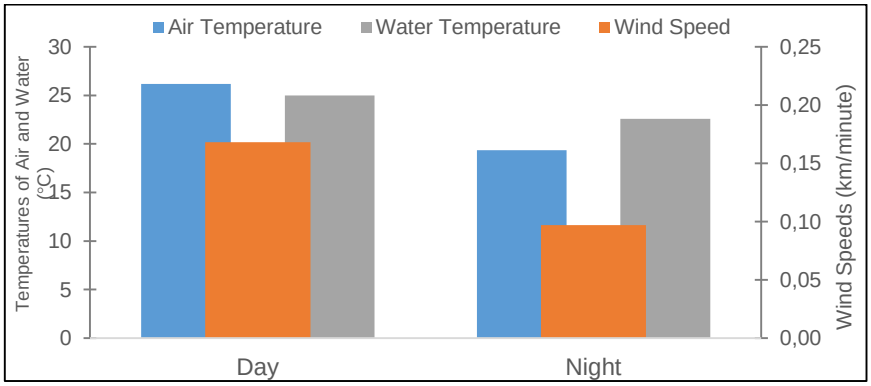

Fig 3. Average Water Temperature, Wind Speed, and Air Temperature at Day and Night in Lake Laut Tawar

Figure 2 depicts the water temperature, wind speed, and air temperature of Lake Laut Tawar decreasing from midday to midnight, with these parameters increasing from midnight to noon. It illustrates a phenomenon wherein water temperature, wind speed, and air temperature in Lake Laut Tawar reach their highest peak during the day and their lowest point at night. Based on this phenomenon, the average water temperature, wind speed, and air temperature during the day would likely be higher compared to the averages during the night (07.00 – 18.00 o'clock) and night (19.00 – 06.00 o'clock) at Lake Laut Tawar are illustrated as shown in Figure 3.

As shown in Figure 3, the average water temperature of Lake Laut Tawar during the day is 24.99 ± 1.74 °C, and at night the average is 22.58 ± 0.90 °C. The average wind speed during the day is 0.17 ± 0.12 km/minute, while at night it is only 0.10 ± 0.06 km/minute. The average air temperature during the day is 26.17 ± 4.20 °C, while at night it is 19.37 ± 1.32 °C. Comparative tests for water temperature, wind speed, and air temperature using the Mann-Whitney Test showed that these parameters had significant mean differences (Asymp Sig = 0.00, < 0.05). This indicates that the parameters fluctuated between day and nighttime.

Air temperature is a key parameter for describing climate change and energy exchange between the Earth's surface and the atmosphere (Su, et al., 2013). Therefore, the fluctuations in air temperature in this research are the main parameter because they are related to other parameters. The observations showed that the air temperature ranges from 16.6 to 22.8 °C at night and from 17.7 to 36.0 °C during the day in Lake Laut Tawar. In this study, the difference between day and night is represented by the presence and absence of sunlight.

Therefore, the existence of air temperature in Lake Laut Tawar is influenced strongly by the presence of solar radiation, with high light intensity during the day and no solar radiation intensity at night. The effect of sunlight intensity on changes in air temperature ranges from 92.4 to 96.1% (Sandy, 2017).

The lowest average wind speed was measured at night in Laut Tawar Lake, while the highest average wind speed was obtained during the day. The wind speed during the day ranged from 0.01 to 0.73 km/minute, while at night, it ranged from 0.01 to 0.37 km/minute. This difference was caused by variations in air pressure between day and night in the Lake Laut Tawar area. Wind moves from high-pressure areas to low-pressure areas, a process influenced by the Earth's rotation and the heating of areas by the sun (Grebner, et al., 2013). Heating by the sun causes the difference in wind speed during the day and night at Lake Laut Tawar.

The lowest water temperature was recorded at night, while the highest was during the day. The water temperature of Lake Laut Tawar during the day ranges from 20.5 to 29.3 °C. At night, the water temperature ranges from 19.8 to 24.9 °C. Water temperature is influenced by factors such as solar radiation, air temperature, weather, and climate (Boyd, 2015). With no solar radiation at night and a decrease in air temperature, the water temperature in Lake Laut Tawar also decreases.

An analysis of Figure 2 and Figure 3 reveals a notable disparity between the diurnal water temperature and air temperature. Specifically, the air temperature surpasses the water temperature during daylight hours. Conversely, during nighttime hours, the water temperature exceeds the air temperature. The diagram depicted in Figure 2 illustrates the occurrence of air temperature and water temperature coinciding at two distinct instances within 24 hours. Specifically, these instances transpire between the hours of 17:00 and 18:00, as well as between 08:00 and 09:00.

The phenomenon is displayed in Figure 2 and Figure 3, where the air temperature is higher than the water temperature during the day. At night, the opposite happens, with the water temperature being higher than the air temperature. The decrease in air temperature between 17:00 and 18:00 o'clock was not followed by a decrease in water temperature, nor was the increase in air temperature between 08:00 and 09:00 o'clock followed by an increase in water temperature. This phenomenon is caused by the physical properties of water, which has a higher specific heat than air (Lee & An, 2013). So, though the air temperature decreases, the decrease in water temperature is delayed and occurs more slowly (Jeppesen & Iversen, 1987).

Water temperature in the epilimnetic and hypolimnetic correlates most closely correlates with air temperature (Magee, et al., 2016). It causes an increase or decrease in water temperature caused by air temperature. The decrease in water temperature is caused by the heat energy released from the surface water into the air (Jasalesmana, et al., 2019). It occurs at night in Lake Laut Tawar, where the water temperature is higher than the air temperature, resulting in a transfer of heat energy from water to air. Conversely, heat transfers from the air to the water during the day because the air temperature is higher than the water temperature of Lake Laut Tawar.

Comparative analysis between observation stations using the Kruskall-Wallis Test showed that air temperature and wind speed were significantly different (Asymp. Sig 0.002 and 0.000, <0.05), while only water temperature was not different (Asymp. Sig 0.310, >0.05). This indicates that the selected observation stations differ in characteristics in responding to factors that influence air temperature and wind speed. Therefore, appropriate location selection is crucial to obtain values representing Lake Laut Tawar. The consistency in lake water temperature across observation stations suggests that measurements of water characteristics in Lake Laut Tawar did not differ spatially. This finding extends to other parameters, such as chlorophyll-a, water clarity, TN, and TP concentrations, which also showed no significant spatial differences (Adhar, 2020; Adhar, et al., 2023), and TSS (Adhar, et al., 2022).

In the comparative analysis of water temperature, wind speed, and air temperature using the Kruskal-Wallis test by the observation factor, only the air temperature showed no significant mean difference (Asymp. Sig 0.962, >0.05). The water temperature and wind speed averages differed significantly by observation (Asymp. Sig 0.00, <0.05). These results indicate no fluctuations in air temperature at Lake Laut Tawar during the observations. Wind speed and water temperature fluctuated between August and September 2023 in 4 observation times.

It means that during the study period, there were no changes in weather that could cause variations in air temperature. Because the air temperature is affected by the sunlight intensity (Sandy, 2017), so is assumed that the sunlight intensity in the period was relatively stable. This period did not show differences in weather and climate because the air temperature is influenced also by weather and climate factors (Boyd, 2015). Wind speeds

showed mean differences indicating that there have been variations or changes in air pressure in the period (Grebner, et al., 2013). It caused a difference in the water temperature in Lake Laut Tawar.

Comparative analysis based on hours of observation of the Kruskal-Wallis and Post Hoc tests showed that the water temperature, wind speed, and air temperature averages are significantly different. The results showed that the water temperatures, wind speeds, and air temperatures of Lake Laut Tawar fluctuated between hours of observation.

It indicates that the sunlight intensity varies at each hour in Lake Laut Tawar, thereby affecting variations in air temperature (Boyd, 2015; Sandy, 2017). Likewise, air pressure varies during each hour, so it influences variations in wind speed (Grebner, et al., 2013) in Lake Laut Tawar. Variations in these two parameters in turn affect variations in water temperature in Lake Laut Tawar.

Spearman rho correlation analysis (data not normally distributed) of air temperature and water temperature of Lake Laut Tawar showed a correlation coefficient of 0.83 and a linear relationship as indicated by a Sig Deviation from Linearity value of 0.323 (>0.05). Figure 4 shows the relationship between air temperatures and water temperatures of Lake Laut Tawar.

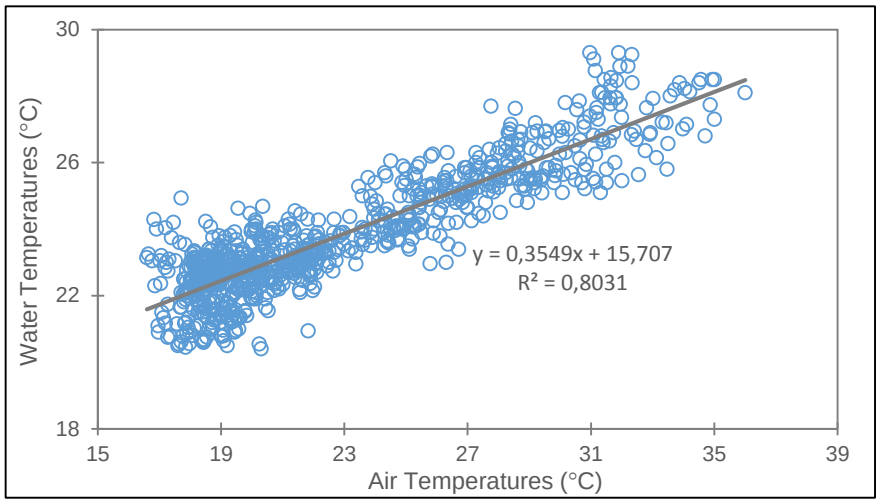

Fig 4. Relationship of Air Temperatures and Water Temperatures of Lake Laut Tawar

Figure 4 illustrates the relationship between air temperatures and water temperatures of Lake Laut Tawar. It shows a coefficient determinant (R-square) of 0.8031, indicating that air temperatures strongly affect the water temperature. The data explains how the water temperature reacts to changes in air temperature. Specifically, a change of 0.35 units in air temperature results in a one-unit change in the lake water temperature. It indicates that if the air temperature in Lake Laut Tawar increases due to climate factors, it will have a significant impact on the lake water temperature, causing it to rise.

However, the water temperature was not entirely affected by air temperature, as it varies according to the region and various other factors (Lee & An, 2013), such as the intensity of sunlight, cloud cover, the temperature of influent river water and groundwater, and heat transfer at the water surface (Yu, et al., 2021). The effect of wind speed on water temperature also plays an important role, sometimes exerting even greater influence than air temperature (Magee & Wu, 2017).

The correlation between wind speed and water temperature of Lake Laut Tawar showed a Spearman rho correlation coefficient of 0.321. This relationship occurs linearly, as indicated by the Sig Deviation from Linearity value of 0.349 (>0.05). Figure 5 illustrates the relationship between these two parameters.

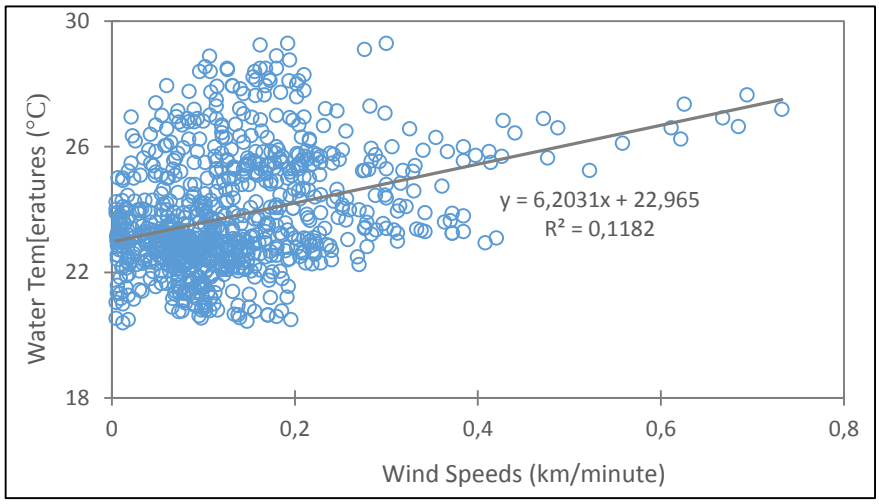

Fig 5. Relationship of Wind Speeds and Water Temperatures in Lake Laut Tawar

Figure 5 illustrates the relationship between wind speeds and water temperatures in Lake Laut Tawar. It has a coefficient determinant of 0.1182, which means the response of water temperature to wind speed changes is low. The response of Lake Laut Tawar's water temperature to wind speed is minimal, suggesting that changes in temperature due to wind speed are insignificant. This is contrary to the claim made by Magee & Wu (2017), who stated that wind speed plays a crucial role and has a more significant impact on water temperature than air temperature.

Figure 4 and Figure 5 show that water temperature is related to both wind speed and air temperature in Lake Laut Tawar. Likewise, the relationships formed are linear. The Multiple Correlation Test analyzed the response of water temperature to wind speed and air temperature simultaneously. The test results obtained a Sig F Change value of 0.00 (<0.05), indicating a significant correlation between these variables.

Regression analysis of wind speed and air temperature on water temperature results in a mathematical relationship model: *Tw = 0.356 Ta + 0.025 W + 15.674*. Where Tw is water temperature (°C), Ta is air temperature (°C), and W is wind speed (km/minute). The result shows a correlation coefficient (R) of 0.895, a coefficient of determination (R-square) of 0.801, an adjusted R-square of 0.800, and a significance level of 0.000. The correlation coefficient (R) value shows that wind speed and air temperature with water temperature are strongly correlated with water temperature in Lake Laut Tawar.

Simultaneously, the water temperature responds to wind speed and air temperature in Lake Laut Tawar. It could be seen in the significance value obtained in the regression test, which is equal to 0.00 (<0.05). The influence caused by wind speed and air temperature on water temperature in Lake Laut Tawar is reflected in the adjusted R-square, which shows an influence of 80 percent. The t-test showed that the water temperature of Lake Laut Tawar responds to the air temperature partially, as indicated by a significance value of 0.00 (<0.05). However, wind speed in Lake Laut Tawar shows no partial response to water temperature, with a significance value of the t-test at 0.933 (> 0.05).

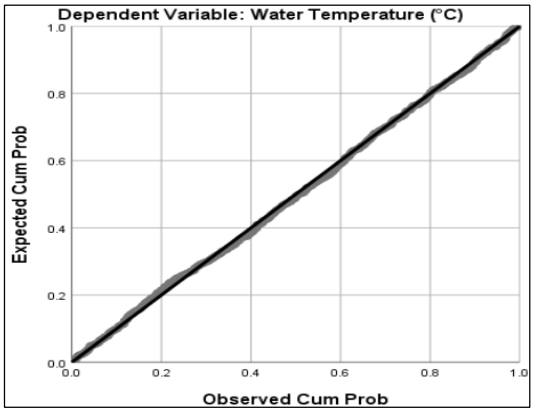

Fig 6. Normal P-P Plot of Regression Standardized Residual

The mathematical equation is considered a good model if it fulfills the normality assumption and is free from classical assumptions such as multicollinearity, heteroscedasticity, and the autocorrelation phenomenon (Ghozali, 2013; Sunyoto, 2016). For this test, The Normality Test using the One-Sample Kolmogorov Smirnov test for residual values shows an Asymp Sig value of 0.200 (> 0.05). This indicates that the residuals are normally distributed (Santoso, 2013). Besides, the Normal P-P Plot of Regression Standardized Residual also shows that the residuals were normally distributed . This is evidenced by the residual points aligning closely along a diagonal line (Ghozali, 2013), as shown in Figure 6.

Multicollinearity analysis aims to determine whether there is a linear relationship or correlation between independent variables (Mardiatmoko, 2020; Setiawati, 2021). The test results showed a tolerance value of 0.867 (>0.10) and a VIF value of 1.153 (<10), indicating no evidence of multicollinearity (Mardiatmoko, 2020; Setiawati, 2021). Heteroscedasticity symptoms are assessed to analyze the equality of error variances in the regression model (Mardiatmoko, 2020; Setiawati, 2021). Heteroscedasticity symptoms were examined based on the scatterplots (Figure 7).

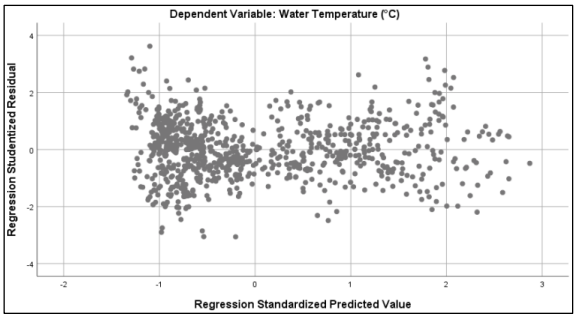

Fig 7. Scatterplots of Multiple linear regression analysis

Figure 6 displays scatterplots that show no clear pattern, with points distributed both above and below zero (0) on the Y axis. This absence of a clear pattern suggests the absence of heteroscedasticity symptoms (Ghozali, 2013).

The model meets classical assumptions, where the residual data were normally distributed, free from symptoms of multicollinearity and heteroscedasticity. Hence, the equation model obtained is deemed suitable (Ghozali, 2013; Sunyoto, 2016) for estimating the water temperature of Lake Laut Tawar based on wind speed and air temperature.

The equation model shows how water temperature responds to variations in wind speed and air temperature in Lake Laut Tawar. A one-unit change in wind speed corresponds to a 0.025-unit change in water temperature. Similarly, a one-unit change in air temperature results in a 0.356-unit change in water temperature.

4. Conclusion

The water temperatures, wind speeds, and air temperatures in Lake Laut Tawar exhibit fluctuations between day and nighttime and across different observation hours. During daylight hours, the air temperature surpasses the water temperature, while at nighttime hours, the water temperature exceeds the air temperature. The decrease in water temperature is caused by the release of heat energy from the surface water to the air. The increase in water temperature is due to the heat transfer from the air to the water. The water temperatures of Lake Laut Tawar respond to the changes in wind speeds and air temperatures simultaneously. However, only air temperature exhibits a partial response, while wind speed does not affect the water temperature of Lake Laut Tawar..

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