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Association Between Climatic Factors and Malaria Incidence in Papua, Indonesia

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ABSTRACT

Malaria remains a major public health concern in many countries, including Indonesia, particularly in endemic regions such as Papua. The province of Papua records the highest number of malaria cases, contributing approximately 92% of the national burden. Fluctuations in morbidity and mortality rates due to malaria in this region underscore the urgency of targeted control measures. Several environmental and climatic factors are believed to influence malaria transmission, yet comprehensive analyses in Papua remain limited. This study aimed to determine the relationship between climatic factors and the incidence of malaria in Papua.This type of research is descriptive observational with ecological study design. The data source was secondary data from the Indonesian Health Survey for malaria cases and the Meteorology Climatology and Geophysics Agency (BKMG) for climate factor data. Based on the results showed that Rainfall (p=0.187; r=-0.445), humidity (p=0.627, r=-0.176), temperature (p=0.091, r=0.802), wind speed (p=0.004, r=0.818), and duration of sunshine (p=0.038, r=0.661). Findings suggest that wind speed and solar irradiation are significant predictors of malaria incidence, thus environmental management strategies should consider consider thes variables.

Keywords: Climate Factors, Malaria, Duration of Sunshine, Rainfall

INTRODUCTION

Malaria is a mosquito-borne disease caused by *Plasmodium* parasites, transmitted primarily through *Anopheles* mosquitoes. Globally, it remains a major public health challenge, affecting around 249 million people and causing over 600,000 deaths in 2022, with the highest burden in Africa, Asia, and Latin America. In Indonesia, Papua is the most affected region, contributing approximately 89% of the 443,530 reported cases in 2022 (SKI, 2023). Despite various elimination programs, Papua continues to report the highest malaria incidence nationally, accounting for about 92% of all cases.

The transmission of malaria is closely linked to environmental and climatic conditions. Rising global temperatures, increased rainfall, and high humidity exacerbated by climate change are known to influence mosquito breeding and parasite development. Climate change can shift transmission patterns by expanding vector habitats into new areas and intensifying transmission in vulnerable populations with low immunity (Leal Filho et al., 2023).

In Indonesia, especially in Papua, research on the climatic determinants of malaria has mostly focused on selected areas or aggregated data at the provincial level, lacking spatial granularity at the district level. This presents a significant gap in understanding how environmental variables affect malaria transmission across the diverse geographical and ecological zones of Papua. Given the spatial variability in climate and socio-environmental conditions across districts, district-level analysis is essential to capture local transmission dynamics and to inform targeted interventions.

There are various factors that can influence the occurrence of a disease. Disease in a community usually arises from interactions between people and the environment around them. Several studies have shown that ambient temperature can influence the interaction between infectious disease vectors and the parasites or pathogens that cause the disease. This leads to the understanding that the dynamics of the spread of vector-borne infectious diseases can be affected by climate change. One example of a vector-borne infectious disease is malaria. Climate change can also act as an important factor in assessing the impact of malaria. However, this theory is only relevant for areas that experience seasonal changes in malaria case trends (Widyati & Mukono, 2022).

Numerous studies have explored the association between climatic variables such as temperature, rainfall, humidity, wind speed, and duration of sunshine and malaria incidence. While some research in Africa and Asia reports strong correlations, findings remain inconsistent across regions. For example, rainfall is commonly associated with increased malaria cases (Diouf et al., 2020; Liu et al., 2024), but associations with temperature and humidity vary depending on local conditions (Mau et al., 2021; Nurdin et al., 2022; Olela et al., 2022).These mixed results highlight the need for localized studies that consider region-specific environmental and demographic contexts.

Papua's unique geography and climate, combined with socio-demographic challenges, create favorable conditions for malaria transmission. Understanding the role of climatic factors in this region is essential for improving surveillance systems, developing predictive models, and enhancing targeted interventions such as early warning systems and weather-based control strategies. This study aims to analyse the relationship between climatic factors and malaria incidence in Papua Province in 2023.

METHODS

The type of research used in this study is descriptive observational with ecological research design. Ecological research examines the relationship between independent variables and dependent variables, along with the strength and direction of the relationship. The population in this study is the number of Malaria cases in Papua in 2023 totaling 1.817 cases of the 10 districts in Papua. Malaria and climate data were collected using secondary data. Malaria data was obtained from the Ministry of Health in 2023 and climate data was sourced from the Papua Province BMKG Station recorded in the BMKG official database application for the period January to December 2023.

The dependent variable in this study is the incidence of Malaria. The independent variables include rainfall, air humidity, temperature, wind speed, and duration of sunshine. The units for the independent variables are as follows: rainfall (mm), air humidity (%), temperature (°C), duration of sunshine (hours/day), and wind speed (m/s).

Descriptive distribution measurements were carried out to obtain the mean, median, standard deviation, and minimum-maximum values of malaria incidence and climatic factors, including rainfall, humidity, temperature, wind speed, and duration of sunshine. For the bivariate analysis, statistical tests were selected based on the distribution characteristics of each variable. The Spearman Rank correlation test was used for all variables because the data did not meet the assumption of normality. This test was applied to assess the correlation between climate factors including temperature, humidity, rainfall, duration of sunshine, and wind speed with malaria incidence. The strength of the correlation was interpreted using the following coefficient (r) criteria: 0.0–<0.2 = very weak, 0.2–<0.4 = weak, 0.4–<0.6 = moderate, 0.6–<0.8 = strong, and 0.8–1 = very strong. The direction of the correlation could be either positive or negative. A p-value of > 0.05 indicated no statistically significant correlation, while a p-value of < 0.05 indicated a statistically significant correlation.

Several limitations should be acknowledged in the methodological approach. First, the sample size was limited to 10 districts, due to the restricted availability of complete climatic data. This may affect the generalizability of the findings to the broader Papua region. Second, the study utilized aggregated district-level secondary data, which may mask spatial heterogeneity and introduces the ecological fallacy when interpreting individual-level risk. Third, potential confounding variables such as population mobility, local malaria control interventions (e.g., indoor residual spraying, insecticide-treated nets), urbanization, altitude, and access to healthcare were not included in the analysis due to data unavailability. These factors may independently influence malaria transmission and thus could confound the observed relationships between climatic factors and malaria incidence.

RESULTS AND DISCUSSION

Table 1

Distribution of Malaria Incidence and Climate Factors in 10 Districts on Papua Island in 2023

District	Malaria occurrence	Temperature (°C)	Humidity (%)	Rainfall (mm)	Duration of sunshine (hours/day)	Wind speed (m/s)
Merauke Regency	334	27.38	85.31	7.34	4.81	2.76
Jayawijaya Regency	416	19.64	78.94	7.28	5.04	2.61
Jayapura Regency	16	27.06	88.36	12.45	4.65	0.31
Nabire Regency	327	28.02	81.58	16.98	5.36	2.03
Yapen Islands Regency	22	27.71	82.86	7.6	4.91	1.48
Biak Numfor Regency	205	27.38	86.65	12.46	4.87	2.25
Paniai Regency	60	19.14	79.53	10.24	4.62	1.85
Mimika Regecy	45	26.4	87.35	13.23	3.77	1.45

District	Malaria occurrence	Temperature (°C)	Humidity (%)	Rainfall (mm)	Duration of sunshine (hours/day)	Wind speed (m/s)
Sarmi Regency	382	27.47	88.83	11.31	5.13	1.67
Boven Digoel Regency	10	27.09	84.19	13.25	4.22	1.23

Based on the data in Table 1, the highest incidence of malaria occurred in Jayawijaya district with 416 cases, while the lowest incidence was recorded in Boven Digoel district with 10 cases. In terms of temperature, the district with the highest average temperature was Nabire (28.02°C), while the lowest temperature was in Paniai (19.14°C).

The highest air humidity was recorded in Sarmi District (88.83%), while the lowest was in Jayawijaya District (78.94%). For rainfall, the district with the highest rainfall was Nabire (16.98 mm), while the lowest rainfall occurred in Merauke (7.34 mm).

The Duration of sunshine was highest in Nabire District (5.36 hours/day) and lowest in Mimika District (3.77 hours/day). Wind speed was highest in Merauke District (2.76 m/s), while the lowest was recorded in Jayapura District (0.31 m/s).

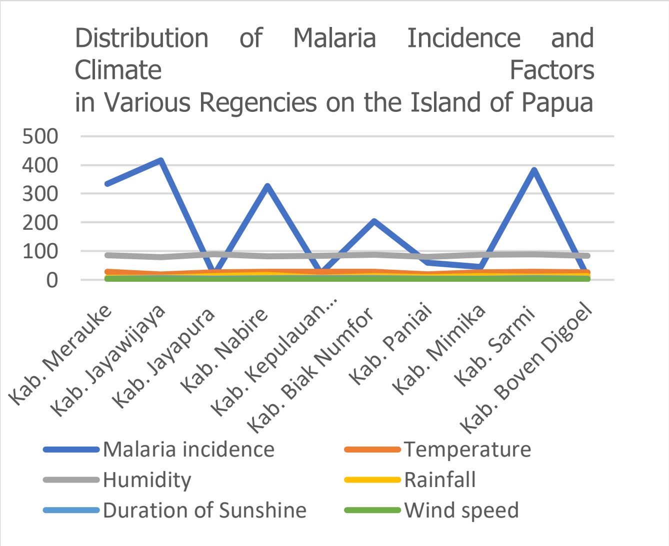

Figure 1. Distribution of Malaria Incidence and Climate Factors in 10 Districts in Papua Island in 2023

This figure 1 shows the distribution between malaria incidence and various climatic factors in several districts on Papua Island. From the graph, it can be seen that the number of malaria varies in each district, the highest district seems to be Jayawijaya District and the lowest is Boven Diogel District. Meanwhile, climatic factors such as temperature, humidity, and rainfall tend to be stable across the observed areas.

Tabel 2

Distribution of Malaria Incidence and Climatic Factors in Papua Island in 2023

Variable	n (year)	Mean	Min	Max
Malaria occurrence	1	181.7	10	416
Tempareture	1	25.72	19.14	28.02
Humidity	1	84.36	78.94	88.83
Rainfall	1	11.21	7.28	16.98
Duration of sunshine	1	4.73	3.77	5.36
Wind speed	1	1.76	0.31	2.76

Based on Table 2, the average incidence of malaria in Papua Island in 2023 was 181.7 cases, with the least number of cases being 10 cases and the most being 416 cases. The temperature in Papua Island in 2023 ranges from 19.14°C to 28.02°C, with an average temperature of 25.72°C. Annual air humidity in Papua Island in 2023 ranges from 78.94% to 88.83%, with an average humidity of 84.36%. Annual rainfall ranges from 7.28 mm to 16.98 mm, with an average rainfall of 11.21 mm. The Duration of sunshine on Papua Island ranges from 3.77 to 5.36 hours/day, with an average of 4.73 hours/day. Wind speed on Papua Island in 2023 ranges from 0.31 to 2.76 m/s, with an average wind speed of 1.76 m/s.

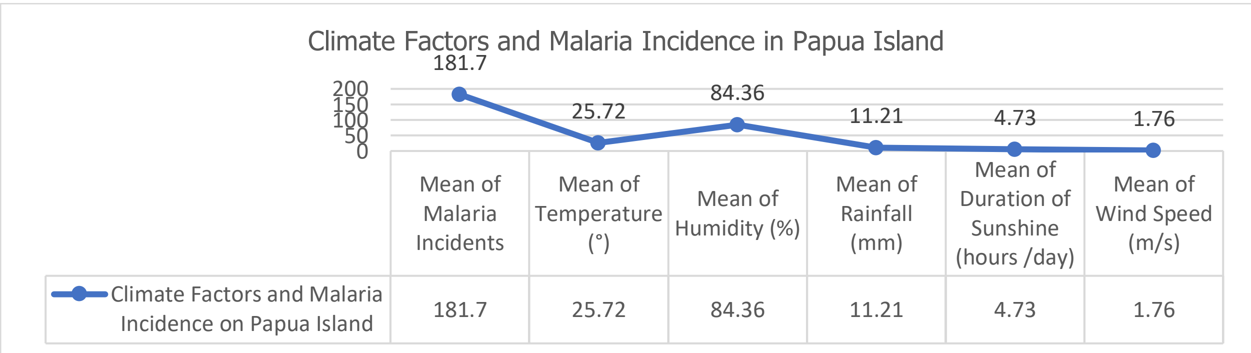

Figure 2. Climate Factors and Incidence of Malaria in Papua Island in 2023

Based on figure 2, it can be seen that an increase in rainfall is also accompanied by an increase in the incidence of Malaria. Malaria incidence also follows the trend of other variables, such as temperature, humidity, and wind speed. Thus, it can be concluded that the incidence of dengue fever can be influenced by several climatic variables, including rainfall, humidity, temperature, duration of sunshine, and wind speed.

Table 3

Results of Correlation Analysis between Climate Factors and Malaria Incidence in Papua Island in 2023

Malaria occurrence				
Variable	Correlation coefficient	Pvalue	Test	Interpretation
Temperature	0.091	0.802	spearman	The strength of the correlation is very weak, the direction of the correlation is positive, and the correlation is not significant
Humidity	-0.176	0.627	spearman	The strength of the correlation is very weak, the direction of the correlation is negative, and the correlation is not significant
Rainfall	-0.455	0.187	spearman	The strength of the correlation is moderate, the direction of the correlation is negative, and the correlation is not significant
Duration of Sunshine	0.661	0.038	spearman	Strong correlation strength, positive correlation direction, and significant correlation
Wind speed	0.818	0.004	spearman	Strong correlation strength, positive correlation direction, and significant correlation

Corellation between temperature and malaria incidence

The analysis showed that temperature had a very weak and non-significant correlation with malaria incidence ($r = 0.091$; $p = 0.802$). Biologically, temperature plays a crucial role in the life cycle of *Anopheles* mosquitoes and the development of *Plasmodium* parasites within the vector. However, in this study, the temperature range across districts was relatively narrow (19.14°C–28.02°C), which still falls within the optimal range for vector survival and parasite development, resulting in insufficient variability to produce a significant effect (Moser et al., 2023; Ogden et al., 2021).

Other studies have shown that the effect of temperature on malaria transmission is often non-linear and occurs with a time lag. For instance, an increase in minimum temperature can elevate malaria risk after 2 to 12 weeks (Okiring et al., 2021; Tapias-Rivera & Gutiérrez, 2023). Therefore, the absence of a significant relationship in this study may be due to the lack of analysis considering lag effects or critical temperature thresholds.

In conclusion, while temperature is a well-established factor in malaria transmission theory, its impact may not be evident in the context of Papua without accounting for time dynamics and interactions with other climatic variables.

In addition, this study utilized aggregated secondary data at the district level, assuming climatic homogeneity across geographically diverse areas. This assumption may not be valid in the context of Papua, where substantial microclimatic variation is expected between coastal and highland regions. The limited number of districts ($n = 10$) due to data availability constraints further restricts the statistical power and generalizability of the findings.

Corellation between humidity and malaria incidence

The analysis revealed a very weak and non-significant negative correlation between relative humidity and malaria incidence ($r = –0.176$; $p = 0.627$). While humidity is biologically known to affect adult *Anopheles* survival and biting behavior optimal conditions usually lie above 60% relative humidity the narrow humidity range observed in Papua (approximately 79%–89%) likely provides consistently suitable conditions for the vector, thus reducing its discriminative power across districts.

Recent evidence supports the importance of humidity in malaria ecology. A study in urban India demonstrated that relative humidity during the pre-transmission season significantly influenced interannual malaria variability, emphasizing its role in epidemic dynamics (Santos-Vega et al., 2022). Similarly, research in Zambia identified that sustained nighttime humidity above 50% was strongly associated with increased malaria incidence, especially during the dry season (Duque et al., 2022). Moreover, (Brown et al., 2023) highlighted the interactive effects of temperature and humidity on mosquito fitness and pathogen transmission thresholds, calling for their joint inclusion in predictive models.

These findings suggest that in regions where humidity is uniformly high such as Papua the effect of humidity on malaria transmission may become apparent only when humidity drops below critical thresholds (<60%) or in interaction with other climatic factors. Therefore, the lack of significant correlation in our study may be due to both limited humidity variability and the absence of lagged or multivariate modeling.

Corellation between rainfall and malaria incidence

The analysis indicated a very weak and non-significant negative correlation between rainfall and malaria incidence ($r = -0.455$; $p = 0.187$). Theoretically, rainfall plays a key role in malaria transmission dynamics by creating breeding sites for *Anopheles* mosquitoes. However, excessive rainfall can also wash away mosquito larvae and destroy breeding habitats, leading to a complex and sometimes contradictory relationship.

In the context of Papua, the daily rainfall across the ten districts ranged moderately between 7.28 and 16.98 mm. This relatively narrow variation likely remained within the ecological tolerance of the vector, making rainfall a poor discriminator of malaria incidence between districts. Moreover, the observed non-significant correlation may reflect the dual role of rainfall: moderate rainfall tends to increase mosquito density, while extreme rainfall may reduce it (Amadi & Erandi, 2024).

Several recent studies have demonstrated that the relationship between rainfall and malaria is non-linear. For example, findings from Nigeria and Zambia show that malaria incidence increases at moderate rainfall thresholds but declines when rainfall becomes too intense (Chacha et al., 2024; Chanda et al., 2023). Additionally, rainfall does not act in isolation it often interacts with other climatic factors such as temperature and humidity in shaping the vector's habitat suitability and reproductive success.

The lack of a significant association in this study may also be due to the absence of lagged analysis, as the impact of rainfall on mosquito populations and malaria transmission is often delayed by 2 to 8 weeks depending on local ecological conditions (Musa et al., 2024). Therefore, without accounting for temporal patterns and interactions, rainfall alone may not be a strong predictor of malaria incidence in this setting.

Corellation between Duration of sunshine and malaria incidence

The analysis revealed a strong positive and statistically significant correlation between the Duration of sunshine and malaria incidence ($r = 0.661$; $p = 0.038$). This indicates that longer daily exposure to sunlight is associated with higher malaria incidence in the studied districts of Papua.

Biologically, the Duration of sunshine affects environmental conditions that are critical for vector breeding and parasite development. Increased sunlight can elevate ambient temperatures in stagnant water bodies, thereby accelerating the larval development of *Anopheles* mosquitoes and shortening the extrinsic incubation period (EIP) of *Plasmodium* parasites within the mosquito (Midega et al., 2021). Moreover, higher irradiation may enhance vector activity by influencing their circadian rhythms and feeding behaviors.

Several recent studies have found similar associations. For example, (Pathy et al., 2022) reported that increased solar radiation was associated with higher mosquito abundance in tropical regions, especially in environments where increased sunlight leads to evaporation and concentration of breeding sites. In a modeling study in Ethiopia, regions with higher annual solar radiation also reported elevated malaria risk, particularly when accompanied by stable temperatures and moderate humidity (Assefa et al., 2025). These findings suggest that sunlight, as a component of the local microclimate, may directly or indirectly enhance transmission efficiency.

In the context of Papua, districts with longer average daily sunshine (e.g., Nabire with 5.36 hours/day) were among those with higher malaria cases. This implies that solar radiation may play a more critical role in malaria dynamics than previously recognized in equatorial settings, where temperature and humidity remain relatively constant, and sunlight variation could represent an important differentiating factor.

Corellation between wind speed and malaria incidence

The analysis showed a strong, positive, and statistically significant correlation between wind speed and malaria incidence ($r = 0.818$; $p = 0.004$). This finding suggests that increased wind speed is associated with higher malaria cases in the districts studied in Papua.

Wind speed plays a complex role in malaria transmission dynamics. While high wind velocities are often assumed to reduce mosquito activity and hinder flight, moderate wind speeds can actually facilitate the spatial dispersion of *Anopheles* mosquitoes, expanding their breeding range and enabling them to reach human settlements more easily (Wu et al., 2023; Yaro et al., 2022). In open tropical landscapes, gentle to moderate winds can support vector movement across longer distances, thus enhancing the reach of malaria transmission.

Recent studies have provided empirical support for this relationship. For example, in a spatial-temporal analysis in Uganda, (Dinku et al., 2022) found that areas experiencing moderate and sustained wind patterns showed increased malaria incidence, particularly when combined with high vector density and favorable temperature humidity conditions. Similarly, (Adepoju, 2019) reported that wind speed was positively associated with malaria cases in West Africa, likely due to its role in promoting the spread of infected mosquitoes and influencing local atmospheric moisture that supports breeding environments.

In the context of Papua, districts with higher average wind speeds such as Merauke (2.76 m/s) also reported higher malaria incidence. This suggests that wind may contribute not only to mosquito dispersion but also to microclimate regulation, influencing evaporation rates in breeding sites and potentially enhancing vector survivability.

CONCLUSIONS

Based on the analysis, this study found a significant positive correlation between wind speed ($r = 0.818$; $p = 0.004$) and Duration of sunshine ($r = 0.661$; $p = 0.038$) with the incidence of malaria in Papua. These findings suggest that increased wind speed and longer sunlight exposure may contribute to higher malaria transmission in the region. In contrast, rainfall ($r = –0.455$; $p = 0.187$), humidity ($r = –0.176$; $p = 0.627$), and temperature ($r = 0.091$; $p = 0.802$) were not significantly associated with malaria incidence. Environmental and vector control strategies should consider the influence of wind speed and irradiation in malaria-prone areas.

Therefore, environmental and vector control strategies in malaria-endemic areas such as Papua should incorporate wind speed and solar radiation patterns into planning and early warning systems. Future studies are encouraged to explore the combined effects of climatic variables and to apply time-lagged and multivariate models to improve the understanding of malaria transmission dynamics in tropical settings.

SUGGESTION

Based on the study findings, malaria prevention efforts should focus on environmental management to reduce the population of *Anopheles* mosquitoes. Effective measures include increasing sunlight exposure by pruning dense vegetation, improving household ventilation, and eliminating stagnant water around residential areas. Additional interventions such as maintaining proper drainage systems, removing standing water from discarded containers, and applying larvicides or introducing larva-eating fish have proven effective in reducing mosquito breeding sites.

In addition, duration of sunshine and wind speed were both found to be significantly associated with malaria incidence, indicating their role in influencing mosquito population dynamics. Therefore, vector control strategies should include mapping areas with high levels of sunshine duration to target them for intensified vector control interventions, such as environmental modification and sunlight exposure management. Similarly, in areas with high wind speed, targeted environmental management campaigns should be implemented to raise community awareness and promote practices that eliminate breeding sites, especially those that remain despite strong air circulation.

To support long-term malaria control, stakeholders should be encouraged to integrate climatic and environmental monitoring including data on sunshine duration and wind speed into early warning systems and local vector control policies, particularly in endemic regions such as Papua. These data-driven, geographically targeted strategies will enhance the precision and effectiveness of malaria prevention efforts.

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