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Epidemiological features and climatological effects on future malaria control in Indonesia

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Abstract

Purpose: Malaria is a leading cause of death worldwide, including in Indonesia. Climate change should be considered when addressing malaria control in Indonesia. This study examined the relationship between climatological parameters (temperature, wind speed, humidity, and rainfall) and malaria cases in Indonesia from 2006 to 2015. **Methods:** Data on climatological parameters were obtained from Indonesia's 2022 statistics, while malaria case data were taken from the annual report of Indonesia's Ministry of Health. Results were presented using maps, diagrams, and graphs. The associations between climatological parameters and malaria cases were analyzed annually using GraphPad Prism 9 software. **Results:** Between 2006 and 2015, the API fluctuated each year. Papua province had the highest malaria incidence in Indonesia (25.5%). A significant decline in malaria cases was observed outside Papua province, whereas cases in Papua tended to increase annually. During this period, annual temperature ranged from 23.39°C to 28.44°C, wind speed from 1.01 m/s to 17.54 m/s, relative humidity from 70.85% to 85.84%, and rainfall from 99.74 to 3,838.2 mm3. **Conclusion:** From 2006 to 2015, annual temperature, rainfall, and relative humidity showed weak positive correlations with the API, whereas annual wind speed showed a negative correlation.

Keywords: *Anopheles*; climate change; Indonesia; malaria; vector control

INTRODUCTION

Malaria remains one of the leading causes of death worldwide, including in Indonesia. The Indonesian Ministry of Health plans to submit an assessment for malaria elimination certification to the World Health Organization (WHO) in 2030. The Ministry of Health (MoH) reported 254,055 malaria cases in Indonesia in 2020. Meanwhile, in 2020, 97% of suspected malaria cases were confirmed in the laboratory using microscopy and rapid diagnostic tests (RDT), with a positivity rate (PR) of 14% [1].

The Indonesian malaria control program aims to gradually eliminate malaria in Indonesia by 2030. Many provinces, such as DKI Jakarta, Jawa Timur, Bali, and Banten, have reached the elimination stage. High malaria-endemic areas are concentrated in eastern Indonesia, including Papua Barat, Papua, and Nusa Tenggara Timur. One factor that influences malaria incidence in certain regions is the presence of the malaria vector, the Anopheles mosquito. A Basic Health Research (Riskesdas) report by the MoH has reported findings of various Anopheles species in Indonesia, including *Anopheles aconitus, An. sundaicus, An. letifer, An. maculatus, An. subpictus, An. vagus, An. balabacensis, An. minimus, An. ludlowae, An. nigerian, An. flavirostris, An. farauti, An. bancrofti, An. punctulatus,* and *An coliensis* [2].

The global ambient temperature is rising continuously. The rate of global warming has been more than 0.18°C per decade since 1981 [3]. Climate change can affect the spread and transmission of various diseases, including vector-borne diseases. The life cycle and vector competence of mosquitoes are influenced by climatic factors, such as temperature, rainfall, humidity, and wind speed [4–6]. For example, the *Aedes aegypti* mosquito, a dengue vector, is sensitive to climate variability. The temperature negatively correlates with the incidence of dengue hemorrhagic fever (DHF). In contrast, humidity and rainfall positively correlate with the incidence of DHF in Surabaya, Indonesia [7].

The Plasmodium parasites, including *Plasmodium vivax, Plasmodium falciparum, Plasmodium ovale*, and *Plasmodium malariae,* cause malaria. It is transmitted to humans through the bite of an infected female Anopheles mosquito. Various climatological factors have been reported to affect the duration of the gonotrophic cycle, mosquito longevity, fecundity, bite frequency, and the development of adult Anopheles mosquitoes [4,8,9]. For example, mosquito development at 23-31°C results in smaller larval sizes and slower development from hatching to adulthood [10]. Additionally, more *Anopheles gambiae* mosquitoes die at each degree increase in the base temperature for larval rearing [9,11].

Climate change is an essential factor to consider when managing malaria in Indonesia. Malaria cases will fluctuate as the environment changes because the organisms responsible for malaria depend on mosquitoes for transmission. This study examines the relationship between meteorological parameters (temperature, humidity, wind speed, and rainfall) and malaria cases in Indonesia from 2006 to 2015. The findings are expected to aid malaria control efforts in Indonesia, particularly by helping understand how climate change affects vector management.

METHODS

The data on climatological parameters (humidity, temperature, wind speed, and rainfall) were obtained from the Statistics of Indonesia in 2022 (available at https://www.bps.go.id). The climatological data for each province from 2006 to 2015 were manually analyzed in a Microsoft Excel spreadsheet. Data on malaria cases (suspect cases, total cases, and annual parasite incidence/API) were obtained from the annual report of the Ministry of Health of Indonesia (available at https://www.malaria.id). The malaria cases presented in each province by year were analyzed manually using a Microsoft Excel spreadsheet.

The analysis results were presented in a distribution map, a diagram, and a graph. The annual relationships between climatological parameters and malaria cases were studied using GraphPad Prism 9.

RESULTS

Figure 1 shows that between 2006 and 2015, Papua province had the highest number of malaria cases, making up 25.5% of all cases in Indonesia. Most cases were reported in Papua Barat and Nusa Tenggara Timur, with rates of 20.6% and 11.3%, respectively. This indicates that most malaria cases are concentrated in eastern Indonesia. The provinces with the lowest cases were Jakarta at 0%, Banten at 1.3%, and Yogyakarta at 1.8%. North Kalimantan also has a low number of APIs, at 0.12%; however, North Kalimantan was established as a new province in 2014.

Figure 2 shows that the highest number of malaria cases (APIs) was recorded in 2007, at 28.02 cases per 1,000 people. Meanwhile, the lowest API figure was recorded in 2015 at 2.63. Malaria cases gradually decreased by the end of 2007 and were significantly reduced by 2009. However, they tend to stagnate around 2010.

Figures 3a and 3b present the climatological data recorded in Indonesia. The annual average temperature ranged from 23.39°C to 28.44°C. Jawa Barat had the lowest average annual temperature at 23.39°C. Meanwhile, the highest annual average temperatures were recorded in Jawa Timur at 28.44°C. Figure 3b shows the average temperature range in Indonesia from 2011 to 2015, ranging from 23.44 to 28.32°C. Jawa Barat had the lowest average annual temperature at 23.44°C. Meanwhile, the highest annual average temperatures were recorded in DKI Jakarta at 28.32°C.

Figure 4a and Figure 4b show the annual wind speed data (m/s) that we also tracked. Figure 4a shows Indonesia's average wind speed from 2006 to 2010. The yearly average ranged from 1.5 to 17.54 m/s. The lowest annual average wind speed was recorded in Sumatra Barat at 1.5 m/s, while the highest was in Riau at 17.54 m/s. Figure 4b displays Indonesia's average wind speed from 2011 to 2015, ranging from 1.01 m/s to 10.19 m/s. The lowest was in Sumatra Barat at 1.01 m/s, and the highest was in Jawa Timur at 10.19 m/s.

Figures 5a and 5b show the statistics of Indonesia's recorded rainfall, ranging from 900.5 to 3,756 mm³ across the country during 2006-2010. The highest average rainfall was documented in Sumatra Barat, with 3,756 mm³. Conversely, the lowest average rainfall occurred in Sulawesi Tengah at 900.5 mm³ (Figure 5a). During 2011-2015, the annual rainfall volume varied from 699.74 to 3,838.2 mm³ (Figure 5b). The lowest average rainfall was in Sulawesi Tengah, at 699.74

mm³, while the highest was in Sumatra Barat, with 3,838.2 mm³.

As shown in Figures 6a and 6b, from 2006 to 2010, the relative humidity ranged from 70.85% to 85.84%. The highest average humidity was recorded in Kalimantan Barat at 85.84%. The lowest average humidity was in Jawa Timur at 70.85% (Figure 6a). Similarly, from 2011 to 2015, the annual average humidity ranged from 74.54% to 84.95%. The highest average humidity was in Kalimantan Barat at 84.95%, while the lowest was in Nusa Tenggara Timur at 74.54% (Figure 6b).

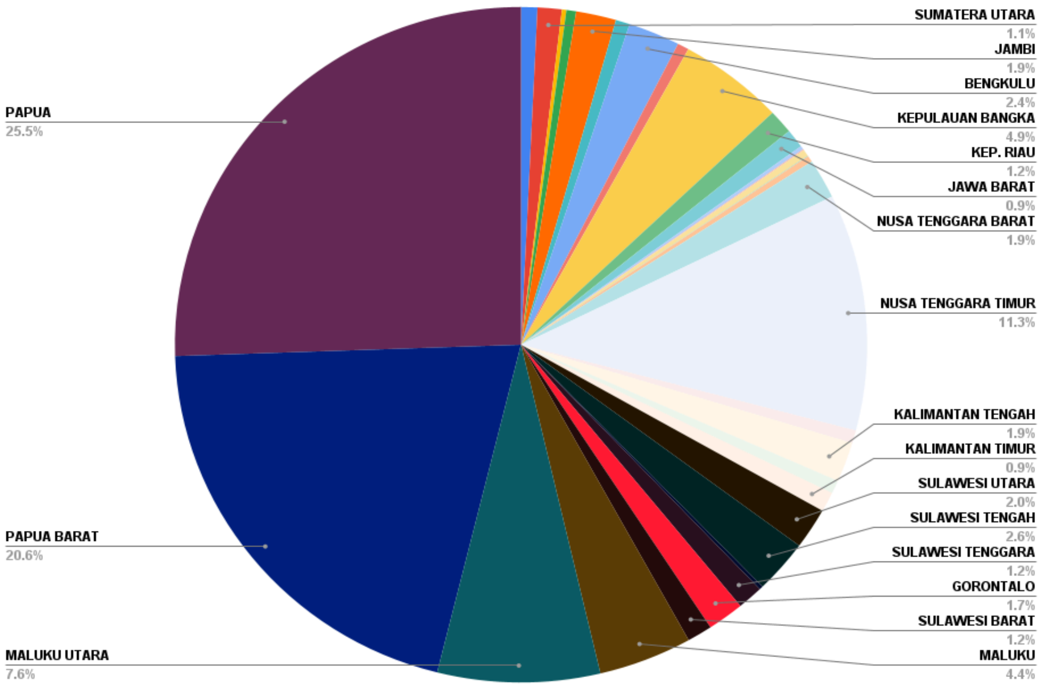

Figure 1. Percentage of annual parasite incidence (API) in Indonesia from 2006 to 2015 by province, based on the annual report from the MoH, Indonesia

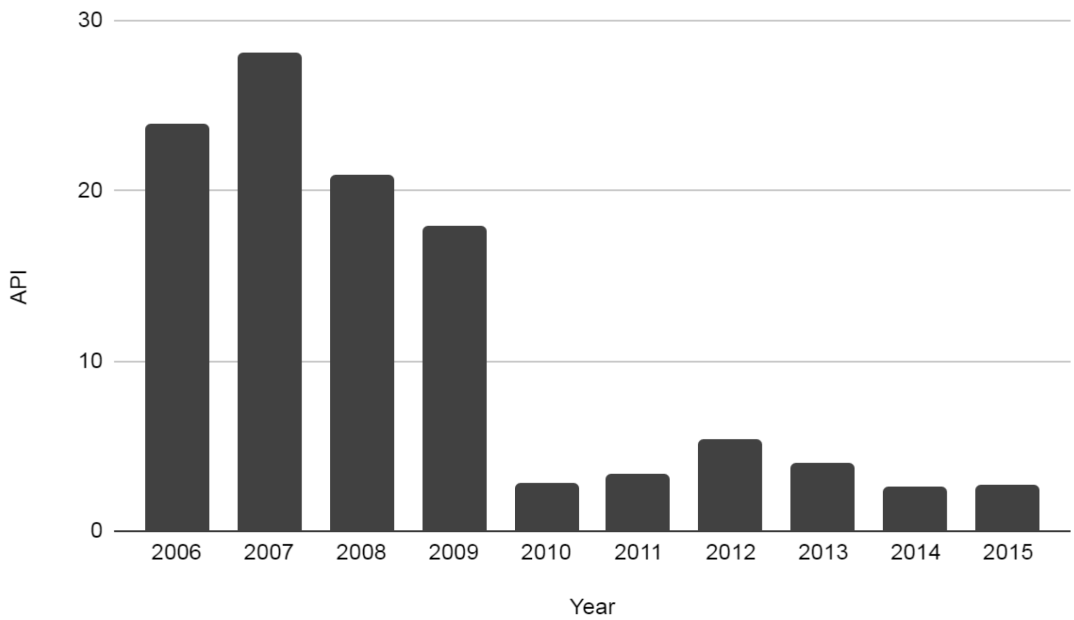

Figure 2. Annual parasite incidence (API) in Indonesia from 2006 to 2015 by year, based on the annual report from the MoH, Indonesia

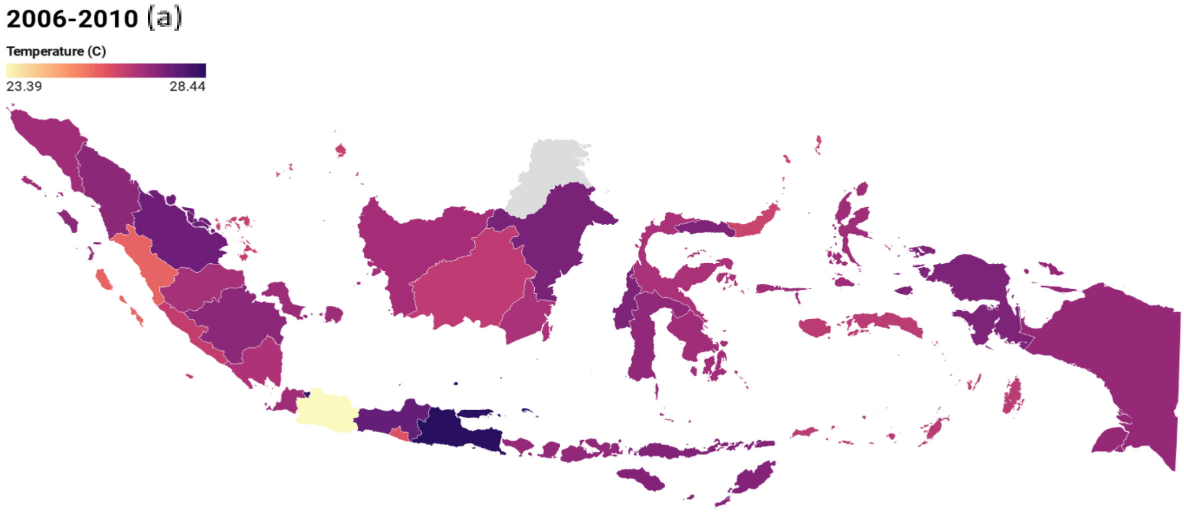

Figure 3a. The average annual temperature in Indonesia from 2006 to 2010

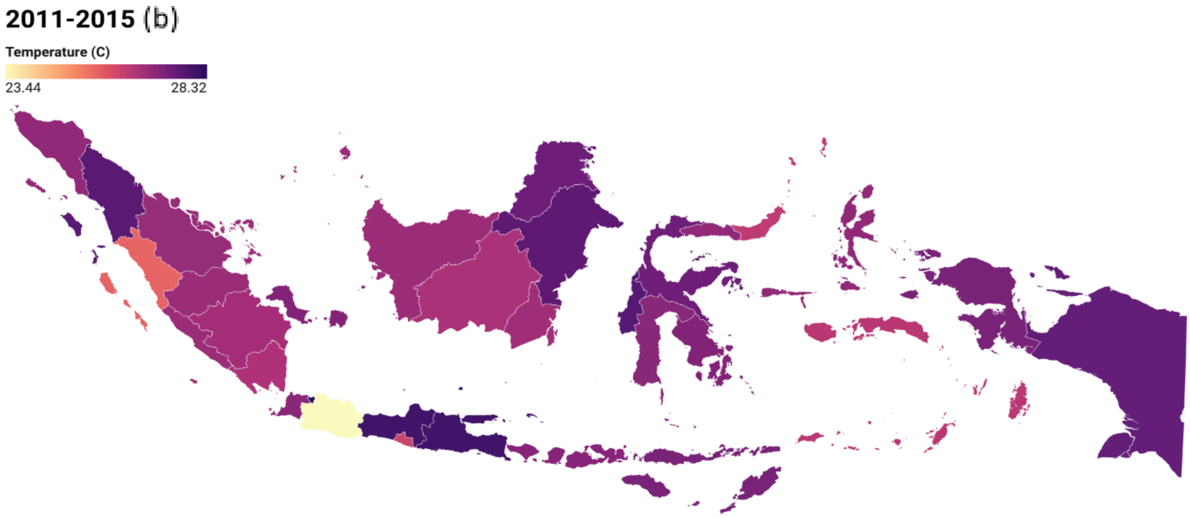

Figure 3b. The average annual temperature in Indonesia from 2011 to 2015

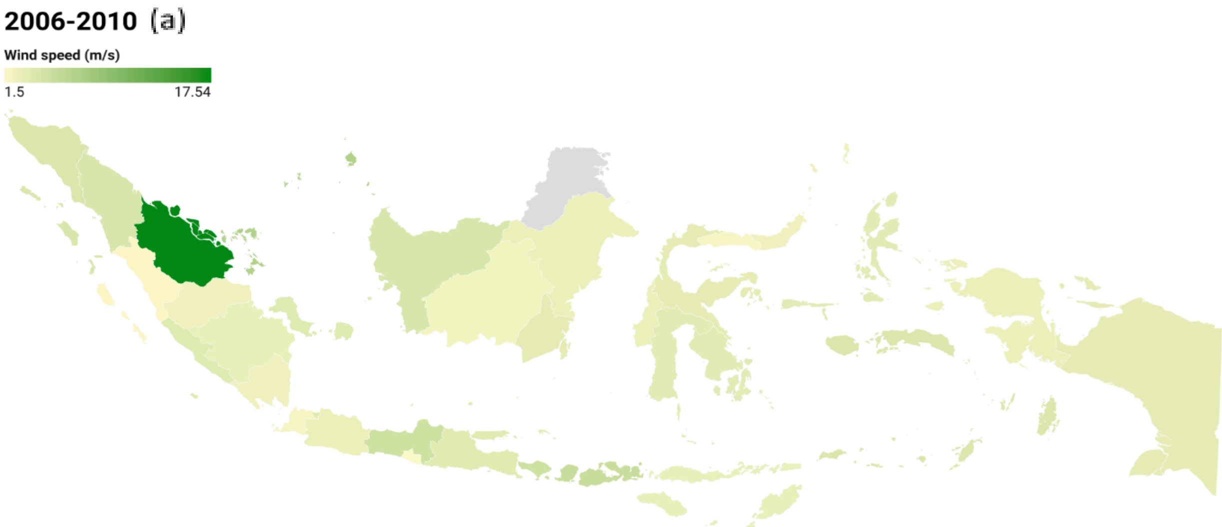

Figure 4a. The average annual wind speed in Indonesia from 2006 to 2010

Figure 4b. The average annual wind speed in Indonesia from 2011 to 2015

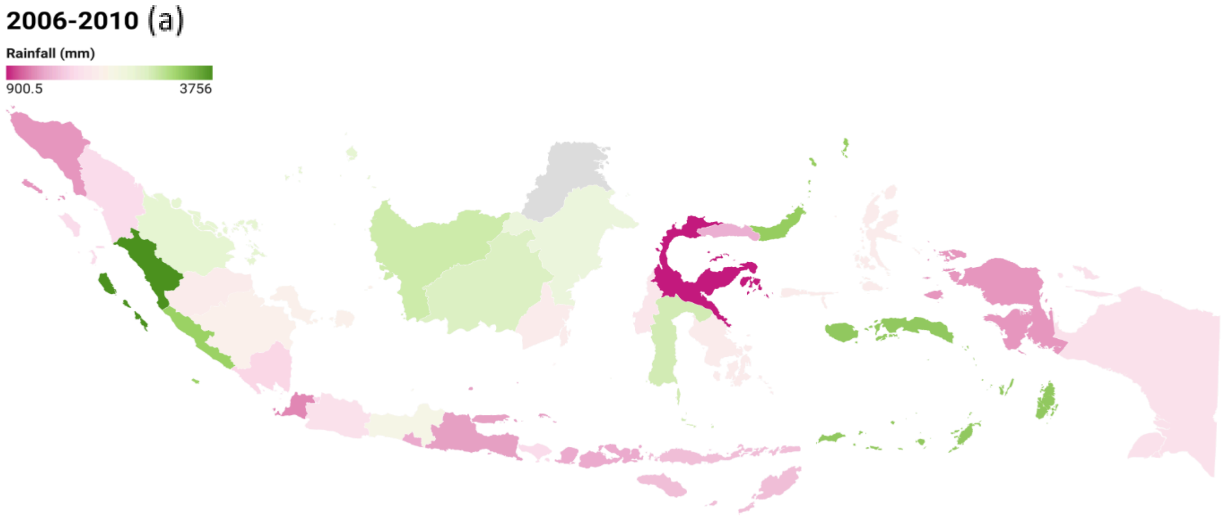

Figure 5a. The average annual rainfall in Indonesia from 2006 to 2010

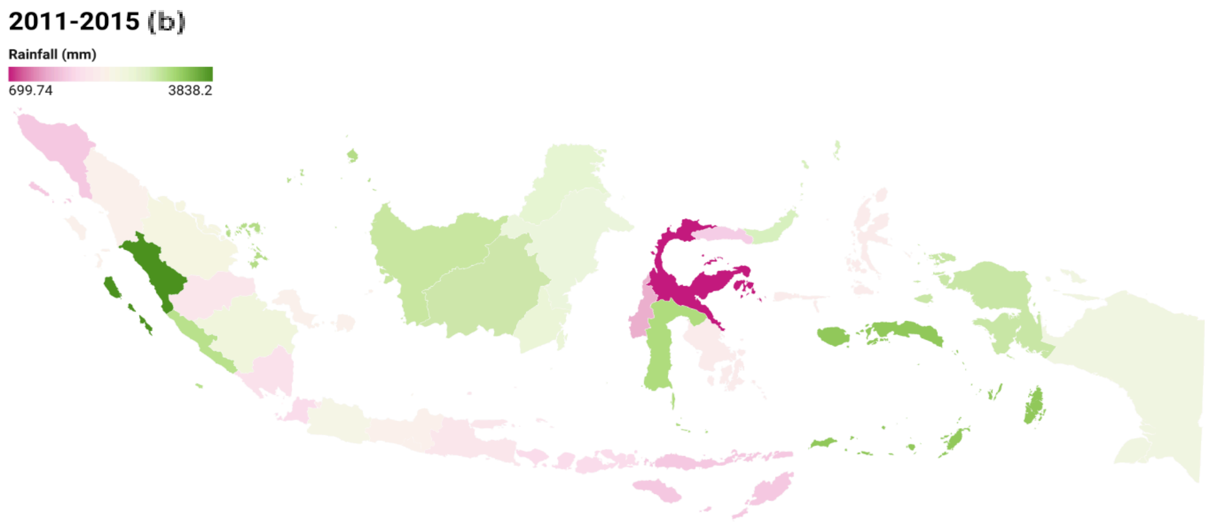

Figure 5b. The average annual rainfall in Indonesia from 2011 to 2015

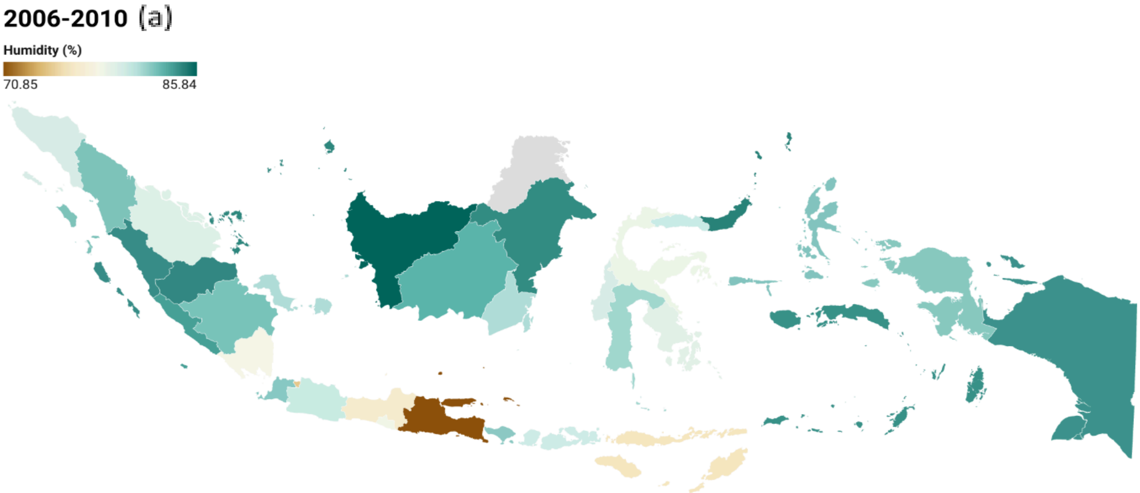

Figure 6a. The average annual humidity in Indonesia from 2006 to 2010

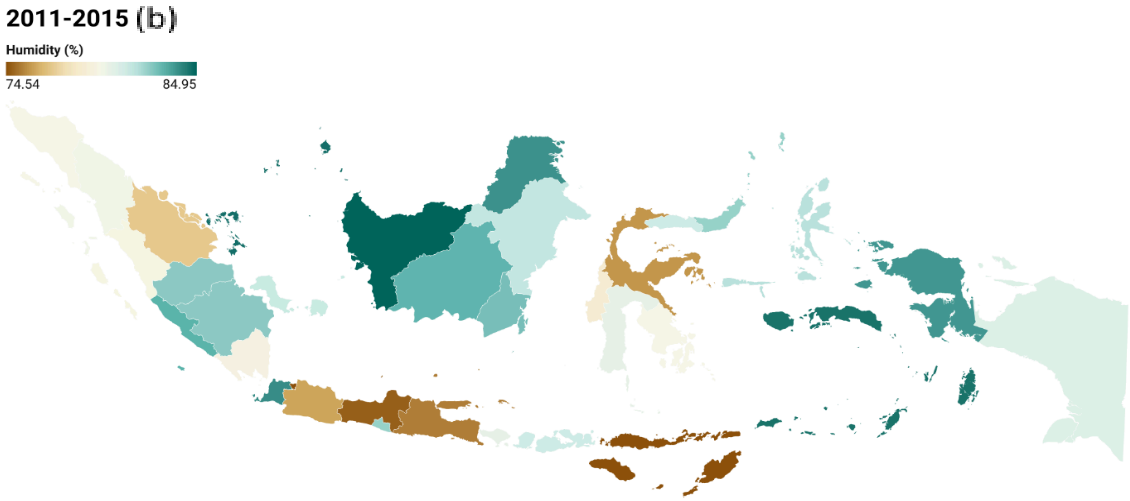

Figure 6b. The average annual humidity in Indonesia from 2011 to 2015

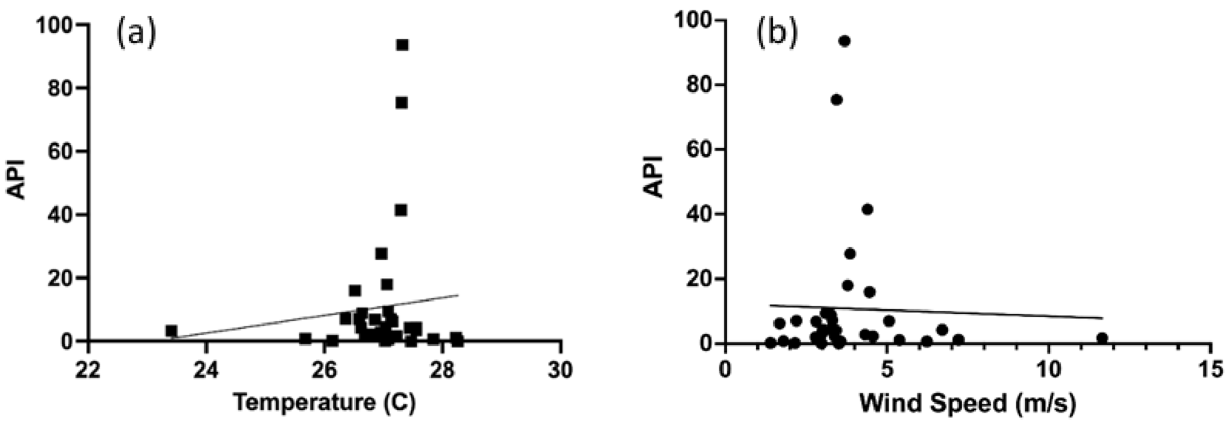

Figure 7 (a,b). The relationships between climatological factors (a. temperature; b. wind) and annual parasite incidence (API) across Indonesian provinces during 2006-2015

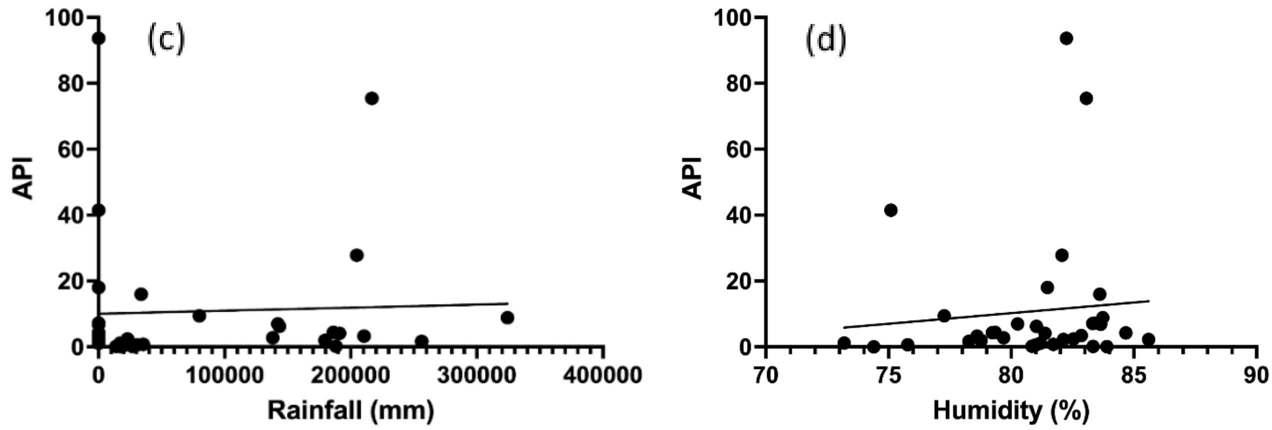

Figure 7 (c,d). The relationships between climatological factors (c. rainfall; d. humidity) and annual parasite incidence (API) across Indonesian provinces during 2006-2015

As shown in Figure 7 (a,b,c,d), the data were analyzed using GraphPad Prism 9 Software. The correlation levels were classified based on Sugiyono [12]. Therefore, the annual temperature (r = 0.1095), rainfall (r = 0.0428), and humidity (r = 0.0943) showed a very weak positive correlation with the API number from 2006 to 2015. Meanwhile, the annual wind speed (r = -0.0346) was negatively correlated with the API number from 2006 to 2015.

DISCUSSION

Malaria is the most significant global public health issue. It mainly occurs in developing countries in tropical and subtropical regions. The World Malaria Report 2015 states that malaria has affected more than 106 countries. Malaria has been identified as a risk to nearly half of the world's population by 2020 [13]. In 2020, the Ministry of Health (MoH) reported 254,055 malaria cases in Indonesia. Papua province had the highest percentage of malaria cases from 2006 to 2015, at 25.5%. It is also noted that most malaria cases are concentrated in eastern Indonesia, including Papua, Maluku, Papua Barat, Maluku Utara, and Nusa Tenggara Timur.

The Indonesian Government aims to certify 325 districts and cities as malaria-free and eliminate high-endemic areas by 2020 [1]. In reality, by 2022, several high malaria-endemicity areas, such as Papua, Maluku, Maluku Utara, Papua Barat, and Nusa Tenggara Timur, will remain. Nonetheless, the government has worked to reduce malaria cases across various regions by implementing acceleration, intensification, and elimination strategies. These strategies are implemented in high-malaria-endemic areas, particularly mining, transmigration, refugee, and forestry zones. In areas of low endemicity, the government focuses on early detection, prompt treatment, strengthening migration surveillance, and controlling vector breeding.

Malaria cases in Indonesia gradually declined by the end of 2007 and dropped significantly by 2009. The sharp decline after 2009 may have resulted from the effective implementation of the government's malaria control program. However, progress has plateaued in subsequent years. By 2010, Indonesia was entering the most challenging phase of efforts to reduce and eliminate malaria in the most difficult regions and situations. From 2006 to 2015, Papua province had the highest percentage of malaria cases in Indonesia, at 25.5%. While malaria cases outside of Papua reported significant declines, cases in Papua tended to increase year over year.

The number of districts and cities that have achieved malaria elimination has grown. From 2006 to 2015, DKI Jakarta, Banten, and Yogyakarta provinces recorded the lowest malaria incidence rates at 0%, 1.3%, and 1.8%, respectively. However, Indonesia's extensive connectivity via land, sea, and air increases the risk of importing malaria cases into malaria-free areas. Consequently, the API fluctuates each year. Several factors contribute to the rise in imported malaria cases, including population movement from high-endemic to low-endemic regions, the inability of local health professionals to conduct migration surveillance, and delayed case notifications between areas. Additionally, multiple natural disasters play a significant role, as many residents are displaced during such events and often settle in new locations where mosquitoes breed.

The climate in a region can influence the spread of disease. Indonesia, as a tropical country, has two seasons: the rainy (wet) season and the dry season.

Local and global climate change quickly impacts this pattern. The transmission of infectious diseases, such as vector- or mosquito-borne diseases, can be significantly affected by temperature, relative humidity, rainfall, and wind speed [14,15]. Climate change might also alter mosquito distribution and their geographical ranges [4-6]. Malaria cases could reemerge in provinces where the disease was previously low or eradicated, driven by favorable climatic conditions for mosquito breeding.

Mosquitoes have a complex life cycle that includes complete metamorphosis and four distinct stages: egg, larva, pupa, and adult. The first three stages occur in water, while adults fly and lay eggs with hematophagous females. The gonotrophic cycle is the period between blood feeding and egg laying; females undergo multiple gonotrophic cycles throughout their lives [16]. Due to changes in the ecology of malaria vectors, climate change may affect malaria incidence in Indonesia. Anopheles mosquitoes are poikilotherms, heavily dependent on environmental temperature. From 2006 to 2010, the annual average temperature in Indonesia ranged from 23.39°C to 28.44°C. Meanwhile, from 2011 to 2015, it ranged from 23.44°C to 28.32°C. Temperature affects the chemical and physiological processes inside the mosquito's body [16].

The optimal temperature range for mosquito development is 24°C to 30°C [17,18]. The annual temperature ($r = 0.1095$) has a weak positive correlation with the API number from 2006 to 2015. In endemic regions, the mean temperature is a strong predictor of malaria incidence in both tropical and sub-tropical countries [5,19–21]. For example, a study in China between 2006 and 2012 found that for every 1°C increase in temperature, the monthly number of malaria cases rose by 0.90% [21].

Temperature affects both the Anopheles mosquito and *Plasmodium* spp. When temperatures rise, the extrinsic incubation period shortens; when they fall, it lengthens [22]. Increasing temperatures from 21 to 32 °C can boost the biting rates of *Anopheles stephensi* [23]. This may influence mosquito feeding frequency and raise the risk of malaria parasite transmission to uninfected humans. Researchers have suggested that the optimal temperature for malaria transmission is 26°C, with a range of 17 to 35°C [23,24]. Higher temperatures also shorten the time required for Plasmodium's sporogony. For example, *Plasmodium* spp. It requires just 12 days to mature at 25°C. At 20°C, development and infectivity take over 30 days [8,18,24].

The annual average wind speed in Indonesia ranged from 1.5 to 17.54 m/s. Meanwhile, the average wind speed in Indonesia from 2011 to 2015 ranged from 1.01 m/s to 10.19 m/s. Wind speeds of 11–14 m/s can inhibit mosquitoes' flight [25]. The connection between malaria and wind speed is intriguing. The annual wind speed ($r = -0.0346$) was negatively correlated with the API number from 2006 to 2015. Wind speed is an indirect factor that affects the rise in malaria cases. Adult mosquito advection, CO_2 attraction, and aquatic-stage mortality due to high waves influence Anopheles mosquito behavior and malaria transmission [26].

Wind speed has a significant impact on malaria incidence in Nigeria [27]. It showed a negative, but insignificant, correlation between malaria cases and wind speed, suggesting that mosquitoes prefer to fly at low wind speeds. Most Anopheles mosquitoes are crepuscular or nocturnal (active at dawn or dusk). The likelihood of a malaria episode decreased by 18% when the average wind speed at 2 m above ground level increased by 1 m/s [28].

During 2006-2010, the relative environmental humidity in Indonesia ranged from 70.85% to 85.84%. Similarly, the annual average humidity from 2011 to 2015 ranged from 74.54% to 84.95%. The optimal moisture level that supports blood-feeding mosquitoes is 82.6%. When humidity is below 60%, water evaporates from the mosquito's body. Higher humidity increases Anopheles' activity in blood feeding [25,29]. The relative humidity in Indonesia favors mosquito lifespan, distribution, parasite development, and transmission. Therefore, malaria incidence can occur at any time of year.

The annual relative humidity ($r = 0.0943$) has a weak positive correlation with the API number from 2006 to 2015. Some studies report that relative humidity correlates differently with malaria incidence in tropical and subtropical countries [21,29–33]. Higher humidity is associated with a higher likelihood of malaria. For example, a study conducted in China between 2006 and 2012 found that a 1% increase in relative humidity was associated with a 3.99% increase in malaria incidence [21].

Indonesian rainfall statistics ranged from 900.5 to 3,756 mm^3 across the country from 2006 to 2010. During 2011-2015, the annual rainfall volume varied from 699.74 to 3,838.2 mm^3. Mosquitoes need 1.5 mm of rainfall per day to grow [34]. Rainfall is essential for aquatic life stages and significantly influences the existence, abundance, and duration of the malaria transmission season of Anopheles species [35]. For example, Anopheles mosquitoes laid more eggs during the rainy season than in the dry season. The first and second gonotrophic cycles lasted longer in the wet season, at 4.1 and 2.9 days, respectively [36].

The annual rainfall ($r = 0.0428$) is positively correlated with the API number from 2006 to 2015. The impact of rainfall on malaria incidence varies across different regions worldwide. Some studies report that rainfall is positively associated with malaria cases in tropical countries [37–40]. Rainfall may be linked to Anopheles occurrences. Low- and medium-intensity rainfall can create breeding sites for Anopheles mosquitoes, while high-intensity rain can destroy mosquito habitats. During the rainy season, more *Anopheles gambiae* were captured in Gambia [41]. Conversely, in sub-tropical countries, rainfall does not significantly influence malaria incidence [32,33,42].

A field study reported that malaria cases tend to rise during the peak of the rainy season in Indonesia [1]. Some studies found that significant rainfall is associated with increased malaria cases at the start of the rainy season. Exceptional cases occur in Papua province (Indonesia), where rainfall is annual, making malaria transmission non-seasonal [19,41,43]. This location differs from low— and moderate-endemic areas, where malaria case reports are infrequent, and the season does not seem to have a substantial impact compared to high-endemic regions.

Certain vector-borne illnesses are affected by climate change and may increase in one location while decreasing in another. Our current study found a weak, positive correlation between annual temperature, relative humidity, and annual malarial parasite incidence. The climatic conditions in Indonesia provide favorable circumstances for the survival and development of the Anopheles mosquito and *Plasmodium* spp. Medium rainfall increases the number of breeding sites for the Anopheles mosquito. Additionally, the warmer environment might influence mosquito feeding frequency, thus increasing the risk of malaria transmission to uninfected human hosts. Therefore, the government must make predictions and risk assessments of malaria transmission in Indonesia.

The findings of this study—specifically the observation of a weak positive correlation between annual temperature, rainfall, relative humidity, and the Annual Parasite Incidence (API), alongside a negative correlation with wind speed—carry significant social impact and policy implications for malaria control in Indonesia. The pronounced and increasing burden of malaria in Papua province (contributing 25.5% of cases) highlights a critical need for regionally specific public health interventions. From a social perspective, malaria disproportionately affects vulnerable populations, leading to lost productivity, increased healthcare costs, and hindered socioeconomic development [13]. By establishing an association between climate variables and malaria incidence, this research provides vital evidence for climate-informed public health planning. It allows provincial and national authorities to anticipate high-risk periods and allocate resources, such as insecticide-treated bed nets and diagnostic tools, more effectively. The continued high API in Papua, in contrast to the decline elsewhere, underscores a potential failure of current national control strategies to address the region's unique ecological and social determinants of health. This necessitates an immediate social equity review of malaria control efforts.

The broader implications of these climate-malaria relationships extend to both public health policy and future scientific inquiry. The weak yet positive correlations suggest that climate change—manifesting as shifts in temperature and precipitation—will likely exacerbate the challenge of malaria eradication in Indonesia. Therefore, the government should integrate climate change adaptation strategies into the national malaria action plan, possibly by adopting early warning systems that utilize meteorological forecasts to trigger targeted interventions.

For future research, several areas warrant attention. First, the analysis should move from annual to monthly or quarterly data to capture the lagged effects and seasonality of climate variables, which are often more relevant to mosquito life cycles and transmission. Second, future studies should focus on the local or district level in high-burden areas like Papua to account for spatial heterogeneity and the confounding effects of non-climatic factors, such as drug resistance, deforestation, mining, migration patterns, and the quality of healthcare infrastructure. Our current study has several limitations, including: 1) climatological data being limited from 2006-2015, during which the ambient temperature remained stable at 23-28°C; 2) the number of malaria cases in Indonesia is generally under-reported, which varies between specific provinces; 3) we did not evaluate the confounding factors of malaria transmission, such as vector abundance and population health status.

CONCLUSION

Indonesia's climate creates ideal conditions for the survival and growth of *Plasmodium* spp. and Anopheles mosquitoes. From 2006 to 2015, annual temperature, rainfall, and relative humidity showed a weak positive correlation with the API number. Meanwhile, annual wind speed had a negative correlation with the data. The government needs to make predictions and risk assessments of malaria transmission in Indonesia.

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