The Relationship Between Temperature, Greenhouse Gas Emissions, and Malaria Cases in Indonesia

Fairuz Haniyah Ramadhani[1*], R. Azizah[2], Mir Atudz Dzikro[1]

[1] Faculty of Medicine, Universitas Pembangunan Nasional Veteran Jawa Timur, Surabaya, Indonesia

[2] Department of Environmental Health, Faculty of Public Health, Universitas Airlangga, Surabaya, Indonesia.

Corresponding Author

Name: Fairuz Haniyah Ramadhani

Affilition: Faculty of Medicine, UPN Veteran Jawa Timur

Address: Rungkut Madya Street, Gn. Anyar Sub District, Surabaya, East Java, Indonesia

Tel/Fax: 082233409817

Email: fairuz_haniyah.fk@upnjatim.ac.id

ABSTRACT

Malaria is still a public health problem in Indonesia and had the potential to be affected by climate change due to greenhouse gas emissions. This study aimed to analyze the correlations among greenhouse gas emissions across sectors, temperature, humidity, and malaria incidence in Indonesia. The study used an ecological design with a quantitative observational approach based on national aggregate data for the period 2000–2019. Greenhouse gas emission data were obtained from national inventory reports, temperature and humidity data from BMKG, and malaria data from BPS. Statistical analysis was carried out using the Spearman rank correlation test. The results showed that only the emissions of the Industrial Processes and Product Use (IPPU) sector had a strong and significant positive correlation with temperature ($p = 0.025$). In contrast, the other emission sectors were not significant. In addition, temperature and humidity showed a strong, significant negative correlation with malaria incidence ($p = 0.007$ and $p = 0.005$). These findings confirm that the relationship between climate and malaria is complex and non-linear, and is influenced by non-climatic factors such as strengthening of health systems and vector control.

Keywords: Greenhouse Gas Emissions, Global Warming, Malaria, Temperature

Introduction

Globally there will be 263 million cases of malaria in 83 countries in 2023 [1]. Indonesia is one of the malaria endemic countries. In 2020 there was an increase in malaria cases per year in the world by 14 million cases from the previous year. There were 241 million total cases of malaria in the world in 2020. In that year, almost most people in the world are at risk of developing malaria. In line with

the increase in cases that occurred that year, there was an increase in the death rate due to malaria, which was 6,900 deaths compared to 2019 [2]. There was an increase in malaria cases in Indonesia in 2021 when compared to cases in 2020. Malaria cases in Indonesia were 304,607 cases in 2021. There was an increase of 68,827 cases that year. However, when viewed from the overall data from 2010-2020, there is a tendency to decrease in cases in almost all regions in Indonesia [3]. However, from 2020 to 2025 there will be an increase in malaria cases because there is an increase in the number of examinations carried out. In 2025, there will be 543,965 positive cases of malaria and only 506,831 cases will be treated [4].

Malaria is one of the tropical diseases (*tropical diseases*) which can be found in tropical or subtropical regions. In general, this disease is widely found in the Asian and African continents which have tropical and subtropical climates. Warm climate conditions cause many diseases that spread through human-to-human, water, food or disease vectors or zoonoses [5]. Malaria is included in the disease *Zoonoses* which is spread through mosquitoes that carry the parasite plasmodium. Anopheles mosquitoes live in tropical and subtropical environments that have warm temperatures. Along with the increase in air temperature on earth, some cold regions become warmer, allowing Anopheles mosquitoes to move from place to place [6].

Climate change is closely related to tropical diseases or commonly called *tropical diseases*. Climate change is the impact of changes in temperature and weather on earth. Climate change is caused by human activities, especially since the industrial revolution that occurred in 1800. Gas emissions from fossil burning cause the earth to be trapped in a blanket called the greenhouse gas effect. These conditions cause the sun's heat to be trapped in the earth and cause the earth's temperature to increase [7]. The projected temperature increase in Indonesia until 2050 is estimated at 0.8°C – 1.4°C. Indonesia, as a tropical country consisting of an archipelago, is ranked third in the world as the country with the highest risk of being affected by climate change [8].

Gas emissions are the cause of the formation of a greenhouse effect that causes heat to be trapped on earth. Gas emissions come from several sectors based on the source of the cause. The energy sector accounts for 36% or 33 gigatons of CO2 in global emissions. Emissions from the sector *Forest and other land uses* (FOLU) through deforestation are a contributor to 24% or 51 billion tons/year of current global emissions [9]. Meanwhile, energy emissions from a global perspective are divided into two categories: those from developed and those from developing countries. Emissions in developed countries continue to decline from 2010, but conversely, in developing countries emissions from the energy sector have increased every year since 2010 [10]. According to the same source, agricultural emissions are estimated to contribute 478,503.66 Gg CO2 eq to greenhouse gas emissions by 2030. In addition, emissions from industrial processes and product use or Industrial Processes and Product Use (IPPU) are the result of various industrial activities [11]. IPPU emissions are one of the sizable CO2-emitting sectors in China, at around 1,628 million metric tons in 2020 [12].

Therefore, the purpose of this study is to see the correlation pattern between greenhouse gas emissions, temperature, humidity and malaria incidence in Indonesia.

Material and Methods

Table 1. Correlation Between Gas Emission and Temperature

Variable	R	P
Temperature x IPPU Emissions	0.732	0.025*
Temperature x Energy Emissions	0.421	0.260
Temperature x Agricultural Emissions	0.363	0.363
Temperature x FOLU Emissions	0.523	0.148
Temperature x Forest Fire Emissions	0.052	0.894
Temperature x Waste Emissions	0.601	0.087
Temperature x Total Greenhouse Gas Emissions	0.383	0.308

**Data Statically Significant (p < 0.05)*

There is only a statistical analysis of the relationship between temperature variables and significant emissions, namely temperature variables and IPPU emissions, with a p-value of 0.025. This relationship shows a strong positive correlation, as indicated by R = 0.732. These results show a strong positive correlation: as IPPU emissions increase, temperature increases linearly. Meanwhile, other emission variables showed a positive but not statistically significant trend. In the relationship between temperature and waste emissions and FOLU, there was a moderate positive correlation, while in the Energy variable, Total Greenhouse and Agricultural Gases showed a weak relationship. The variable that does not have a real correlation is forest fire emissions which statistically shows no real correlation and is not statistically related.

Table 2. Correlation Between Temperature and Malaria

Variable	r	P	N
Malaria Cases x Temperature	-0.790	0.007*	10
Malaria x Humidity Cases	-0.802	0.005*	10

**Data Statistically Significant (p < 0.05)*

There was a very strong and significant negative relationship between malaria cases and temperature, as shown in this analysis. In both climate variables, namely temperature and humidity, there is a strong negative relationship, namely r -0.790. This statistical data shows that rising temperatures are negatively associated with a decrease in malaria cases. To check other climate variables, namely climate, the malaria variable, and humidity variables, were also statistically tested. In accordance with the results for the temperature variable, the results are significantly related to the strength of the negative relationship, which is r = -0.802. This means that when both climate variables increased, malaria cases tended to decrease in the study's data.

Discussion

The results of the analysis of the relationship between greenhouse gas emissions and temperature in this study show that the emissions that are positively and significantly related are IPPU emissions. These results are supported by the 6th IPCC (Intergovernmental Panel on Climate Change) assessment report which reports that IPPU emissions are sourced from industrial processes and the use of HFC refrigerant gas products. IPPU emissions have a strong correlation with increased temperature. The main emissions from the IPPU sector are CO2 and fluorinated gases from industrial processes which have a strong link with the radiative forcing that causes global warming [13]. Other studies also support the results of the analysis in this study. IPPU emissions derived from industrialization activities and energy intensity from industrial processes that produce emissions that cause atmospheric warming [14]. However, there is research that states that there is a need to consider lag time in the analysis of emission and temperature variables. In this study, other variables in this study that were not included such as rainfall were not included as lag time, so statistical analysis showed that the results were not significant in the relationship between emissions and climate factors and malaria [15]. IPPU industry emissions mostly contain HFCs that contribute to global warming. This sector of the industry may amount less than other emissions, but the impact per molecule is enormous [16].

Based on the analysis of data in this study, the relationship between malaria incidence and climate factors showed a strong but negative correlation, indicating that increased temperature and humidity were not always followed by an increase in malaria cases. These findings are in line with the results *systematic review* which suggests that the relationship between temperature and malaria is not linear[17]. Mosquitoes *Anopheles* has an optimal temperature range for survival and transmitting *Plasmodium*, with a maximum temperature of around 30°C, so an increase in temperature above that threshold can lead to a slowdown in mosquito development as well as an increase in vector mortality [10]. Recent modelling studies show that increasing ambient temperatures can reduce mosquitoes' lifespan *Anopheles* and lowering the vector capacity, although at the same time higher temperatures can shorten the extrinsic incubation period of the parasite in the mosquito's body. These opposing interactions cause the relationship between temperature and malaria transmission potential to be complex and non-linear[18]. In line with these findings, the meta-analysis also showed that the relationship between temperature and malaria incidence is complex and non-linear with the presence of optimal temperatures for transmission, while climate change plays a role in modifying the pattern of malaria spread in the tropics through changes in environmental temperature that affect the dynamics of vectors and parasites[19]. In the context of Indonesia, which is in the tropics with relatively high ambient temperatures throughout the year, the impact of climate change has the potential to push the environmental temperature beyond the optimal threshold of the vector. As a result, areas that were previously too cold for mosquitoes can become more susceptible to malaria transmission, while areas that already have high temperatures have the potential to experience a decrease in malaria

incidence due to environmental conditions that become less than optimal for vector survival [519].

Regional studies in Indonesia show that the relationship between climate factors and malaria incidence is contextual and strongly influenced by regional characteristics. Research in several endemic areas in Indonesia reports that variations in temperature, humidity, and rainfall contribute to mosquito population dynamics *Anopheles*, but the influence does not stand alone. Non-climatic factors such as residential environmental conditions, population density, community mobility, and access to health services also play an important role in determining the pattern of malaria incidence at the regional level. The interaction between climate and non-climate factors causes differences in the pattern of temperature and malaria relationships between regions in Indonesia, so that climate change is not always followed by a uniform increase in malaria cases across regions[19].

Another article conducted in Southeast Asia also had a similar opinion, namely, that climate factors do not play a major role in the increase in malaria cases. Socio-economic factors and the capacity of a country's health system are the main determinants of the reduced burden of malaria [20]. Strengthening the health system, vector control programs and increasing public awareness are one of the main keys in eliminating malaria cases in Indonesia. The Government of Indonesia's commitment to malaria elimination is contained in the National Medium-Term Development Plan and the National Strategy for Malaria Elimination with the target of malaria elimination by 2030 [21]. In the latest publication in Papua, it is stated that the malaria program made by Indonesia has succeeded in reducing the Annual Parasite Incidence (API) in Papua Province by 31.81 cases per 1000 population by increasing the number of health centers [22]. The increasing number of first-level health service programs, it helps to reduce the incidence of malaria in the community through various programs that have been planned by the government.

This research has several methodological limitations. As a study with ecological design, the results obtained represent a relationship at the population level so that it cannot be drawn as a cause-and-effect relationship at the individual level, and has the potential to cause *ecological fallacy*. In addition, the use of annual aggregate data can obscure more detailed temporal variations and does not fully capture the effects of lag *time* between changes in greenhouse gas emissions, climate factors, and malaria incidence. The exclusion of other climatic variables such as rainfall and vegetation index can also affect the strength of the observed associations.

The findings of this study have important implications for public health policy and climate change adaptation. The integration of climate data into malaria surveillance systems can help identify risk areas and strengthen early *warning systems*. In addition, climate change adaptation policies in the health sector need to be focused on strengthening primary health services and vector control programs, especially in regions with high climate vulnerability, so that malaria elimination efforts remain effective amid the dynamics of environmental change.

Further research is recommended using data with higher temporal resolution, such as monthly or weekly data, and considering the *lag time* between climate variables and malaria incidence. The

addition of other climate variables such as rainfall and vegetation index, as well as spatial analysis approaches, is expected to provide a more comprehensive picture of the relationship between climate change and malaria in Indonesia.

Conclusion

This study shows that of all sectors of greenhouse gas emissions, only the *Industrial Processes and Product Use* (IPPU) sector has a strong and significant positive correlation with temperature increase in Indonesia. In contrast, the rest of the emissions sector did not show a statistically significant relationship. In addition, temperature and humidity show a strong and significant negative correlation with malaria incidence, indicating that an increase in such climatic factors is not always followed by an increase in malaria cases. These findings confirm that the relationship between climate change and malaria is complex and non-linear, and is strongly influenced by the interaction between climate and non-climate factors, including strengthening health systems and vector control programs, which play an important role in reducing malaria incidence in Indonesia.

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