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A Long-Term Impact Study of Mean Annual Temperature on the Incidence Rate of Chikungunya in Brazil (2014–2023)

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Abstract:

This study examines the long-term association between mean annual temperature and the annual incidence rate of Chikungunya in Brazil. Using national-level data from the Pan American Health Organization (PAHO) and World Bank for 2014-2023 (N=10), an Ordinary Least Squares (OLS) regression model was employed. Descriptive analysis revealed stable annual temperatures (25.20°C) alongside highly volatile Chikungunya incidence (mean=66.66 per 100,000). The regression model identified a strong positive trend (β=+33.41, 95% CI: -3.88 to 70.70), indicating that each 1°C increase in temperature is associated with an increase of 33.41 cases. While this result did not reach conventional statistical significance ($p = 0.0728$), likely due to the small sample size, the effect's direction is consistent with established vector biology. The model explained 26.6% of the annual variance (Adjusted $R^2 = 0.2662$), highlighting temperature as a significant macro-climatic driver while underscoring the role of unmeasured confounding factors. These findings provide critical empirical evidence for long-term risk assessment and offer vital policy insights for developing climate-based early warning systems in vulnerable subtropical regions, such as Guangdong, China.

Keywords: Chikungunya; Climate Change; Brazil; Public Health Early Warning; Epidemiology

1. Introduction

In the contemporary era of anthropogenic climate change, the epidemiology of climate-sensitive vector-borne diseases is undergoing a profound and concerning transformation. The geographical expansion of competent vectors into previously non-endemic regions and the increasing frequency and intensity of outbreaks in endemic areas have emerged as preeminent challenges to global public health in the 21st century [1]. Among these threats, Chikungunya virus (CHIKV), an alphavirus transmitted predominantly by *Aedes aegypti* and *Aedes albopictus* mosquitoes, presents a particularly formidable challenge. The

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disease is characterized by an acute onset of high fever, maculopapular rash, and severe, often debilitating, polyarthralgia. This joint pain can persist for months or even years, leading to chronic rheumatic conditions that impose a substantial long-term burden on public health systems, national economies, and individual quality of life through significant healthcare costs and lost productivity [2].

Latin America (and to an even greater degree Brazil) has emerged as one of the global hotspots of Chikungunya transmission since its introduction into the Americas. As one of the world's countries with the highest population morbidity of the disease per 100 of the world population, Brazil has experienced several large-scale, nationwide epidemics of the disease, causing a tremendous and repeated burden on its socioeconomic structure and national health care system. The extensive mix of tropical and subtropical climatic zones, uncontrolled and, in most cases, illegal urbanization, systemic social inequalities and poor sanitation in many areas confer a natural ecological niche of Aedes vectors, within which influenza virus infection can be sustainably transmitted indefinitely [3].

2. Literature Review

It is a widely accepted scientific consensus in the epidemiological literature that temperature is a basic environmental variable that can influence the transmission efficiency of a vector-borne disease. This proposed relationship can be justified theoretically based on Vector Capacity Theory, one of the pillars of medical entomology [4]. It is a model that conceptualizes in a mechanistic manner the multiplicity of environmental (mainly thermal) influence upon the innate vectoral capacity of a vector to carry an agent. In the case of Aedes, the vector for Chikungunya, there are at least three temperature-sensitive non-linear dynamics pathways [5]. At the least they shorten the Extrinsic Incubation Period (EIP), the time it takes for the virus to replicate in the salivary glands of mosquitos and become infective. Under the best of thermal conditions, this time can be tremendously shortened, which likewise increases the number of possible secondary infections a particular mosquito may be responsible for in its lifetime. Second, it directly affects the frequency and activity of the mosquito, because the frequency of the metabolic rates increases, and the blood meal frequency required to develop eggs increases directly with warming [6]. Third, it controls the survival of the vectors, the speed of their development in the water, and their reproduction, thus the total population density of the vectors.

Based on this good theoretic foundation, empirical researchers have collected ample evidence to show that ambient temperature was positively related with Chikungunya. Empirical research carried out at large scales has often associated epidemic outbreaks with episodically high temperatures [7,8]. More clearly, the recent outbreaks of explosions in the Americas should be seen as consequences of the pre-existing experience of the heatwave and of the abnormal loads in the spring, which have been correctly explained by Pan American Health Organization (PAHO), in objectively realistic hypotheses, which are based on practice [9]. But the academic literature is no single. A competing and important school of thought challenges a deterministic climate background and argues instead that epidemics are complex socio-ecological emergent properties [10]. This interaction theory is multifactorial in nature and as such, while climate is viewed as a powerful enabling condition, its effects can be strongly moderated and hidden by a myriad of other factors such as socioeconomic status, sanitation, human behavior, and the ability of a population to maintain its health. The current debate reveals the following key gaps in the literature to date.

First, a temporal scale defect is evident, as most existing studies are constrained to short-term analyses that may not fully capture the impact of long-term climatic trends. Second, a viral specificity bias persists, with a disproportionate focus on dengue fever despite Chikungunya's unique virological characteristics, such as a potentially lower temperature threshold for replication. Finally, many studies suffer from model simplification issues, often failing to adequately control for the confounding effects of other critical environmental and social variables.

To address the research gaps and contribute to a more nuanced understanding of the climate-Chikungunya nexus, this study undertakes a quantitative analysis of national-level panel data for Brazil from 2014 to 2023. It aims to achieve three core, interconnected objectives. Primarily, the study seeks to test for a statistically significant linear association between the macro-climatic indicator of mean annual temperature and the annual incidence rate of Chikungunya at a national level over a full decade. Subsequently, it aims to quantify the strength and direction of this association by estimating the marginal effect (β coefficient), which provides a concrete, interpretable measure of how incidence rates respond to annual temperature changes. Finally, based on these empirical findings, the study will explore the tangible policy implications for constructing and refining climate-driven early warning systems for infectious diseases, with a special focus on offering transferable insights for other at-risk subtropical regions. The remainder of this paper is structured to logically pursue these objectives, with dedicated sections for methods, results, discussion, and conclusions.

3. Methods

This study employs a quantitative analytical approach centered on an Ordinary Least Squares (OLS) linear regression model. This method was selected for its widespread use, clarity, and direct interpretability in examining the linear relationship between a continuous independent variable and a continuous dependent variable.

The primary hypothesis test for this model is formally stated. The null hypothesis posits that $\beta_1=0$, indicating no linear relationship, while the alternative hypothesis posits that $\beta_1\neq 0$, indicating a linear relationship exists. A p-value was calculated for the coefficient, with a conventional alpha level of $\alpha = 0.05$ used as the threshold for determining statistical significance. To provide a more complete picture of the effect size and its uncertainty, the 95% confidence interval (CI) was also calculated. The overall fit of the model was assessed using the R-squared (R^2) and adjusted R-squared values. A post-hoc diagnostic analysis of the model's residuals, including a formal Shapiro-Wilk test for normality, was conducted to ensure that the core assumptions of OLS were not egregiously violated.

The data for this study were compiled from two publicly available, highly reputable international sources, covering a ten-year period from 2014 to 2023. The Chikungunya incidence data, specifically the annual reported case numbers, were obtained from the comprehensive epidemiological bulletins of the Pan American Health Organization (PAHO). To standardize for population changes, these raw numbers were converted into an annual incidence rate using annual mid-year population estimates from the World Bank's official data repository. Concurrently, the national mean annual temperature data for Brazil were sourced from the World Bank Climate Change Knowledge Portal. This macro-level indicator was deliberately chosen to assess the overall, long-term climatic signal. This study is based exclusively on the analysis of publicly available, aggregated, and anonymized data and was therefore exempt from institutional review board (IRB) review.

4. Results

A descriptive statistical analysis of the core variables was conducted to characterize the data. The key statistics are summarized in Table 1. As detailed in Table 1, Brazil's national mean annual temperature exhibited remarkable stability over the ten-year period, with a mean of 25.20°C and a very low standard deviation.

Table 1. Descriptive Statistics Summary (2014–2023)

Variable	Mean	Std.Dev	Min	Max
Avg.Temperature(°C)	25.2	0.21	24.9	25.49
Incidence Rate (per 100k)	66.66	46.9	1.8	128.81

The dual-axis trend graph in Figure 1 provides an intuitive visualization of these dynamics. The Pearson correlation coefficient between the two-time series is $r = 0.59$, which did not reach conventional statistical significance ($p \approx 0.07$) but is strongly suggestive of a potential trend. In stark contrast, the Chikungunya incidence rate demonstrated extreme volatility, underscoring the epidemic's characteristic pattern of explosive outbreaks interspersed with periods of lower transmission. Visually, the graph reveals clear periods of synchronous fluctuation, with major incidence peaks in 2016 and 2022-2023 occurring during years with above-average temperatures. A notable deviation is the sharp drop in incidence in 2020, likely an artifact of non-pharmaceutical interventions during the COVID-19 pandemic.

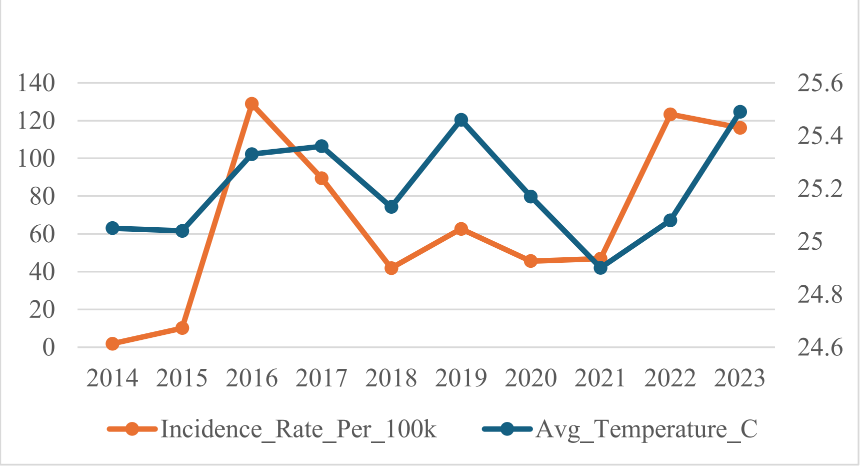

Fig.1 Chikungunya Incidence Rate and Mean Annual Temperature in Brazil (2014-2023)

Picture credit: Original

To formally quantify the relationship between temperature

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and incidence, a univariate linear regression model was constructed, with detailed results presented in Table 2 and a visual fit shown in Figure 2.

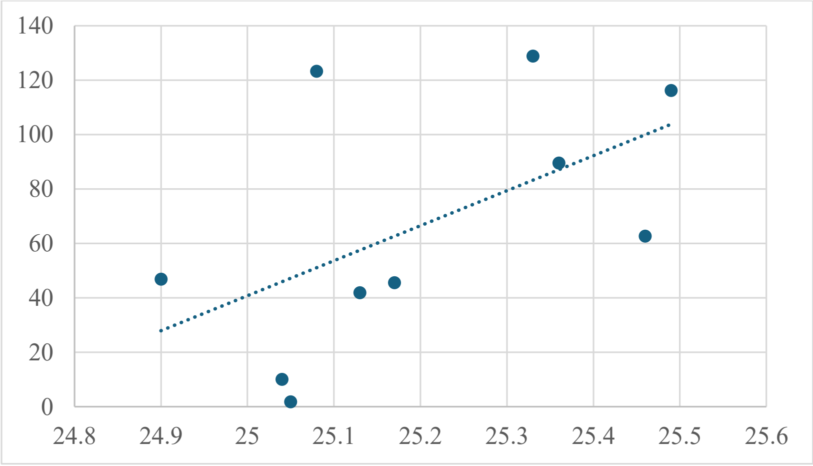

Fig.2 Linear Regression Analysis

Picture credit: Original

The model's primary finding relates to the Temperature Effect (β_1). According to Table 2, the estimated regression coefficient is $\beta = +33.41$, with a 95% Confidence Interval of [-3.88 to 70.70]. The practical interpretation is that a 1°C increase in mean annual temperature is associated with an average increase of 33.41 Chikungunya cases per 100,000 population. However, this result did not reach the conventional $p<0.05$ threshold for statistical significance ($p = 0.0728$). As previously noted, this is likely influenced by the small sample size, yet the strong positive trend remains clinically and epidemiologically meaningful. The Model's Explanatory Power (R^2), as shown in Table 2, indicates that temperature explains approximately 26.6% (Adjusted R^2) of the year-to-year variance in national incidence, identifying it as a key macro-level driver.

Table 2. Summary of Linear Regression Model Results

Variable	Estimate	Std.Error	95%Conf.Interval	t value	p-value
Intercept	-775.39	407.72	(-1714.4,163.6)	-1.902	0.0938
Avg_Temperature(°C)	33.41	16.17	(-3.88, 70.70)	2.066	0.0728
$R^2 = 0.2662$, F-statistic = 4.268 on 1 and 8 DF, Model p-value = 0.0728					

4. Discussion

The core finding of this study—a strong positive, albeit statistically non-significant, trend between mean annual temperature and Chikungunya incidence—is highly consistent with the established principles of the Vector Capacity Theory. The average annual temperature in Brazil (25.20°C) is already situated within a climatic range that is highly permissive for *Aedes aegypti* proliferation and CHIKV transmission. This result also provides a quantitative underpinning for the persistent regional disparities in disease burden observed within Brazil. The p-value of 0.0728, while not meeting the rigid threshold for significance, warrants a nuanced interpretation. It is likely an artifact of several factors, most prominently the small sample limitation which reduces statistical power. Furthermore, the simple univariate model is subject to potential omitted variable bias from factors like humidity and precipitation, as well as the data granularity issue of using annual data which averages out strong seasonal signals.

Despite these statistical limitations, the finding of $\beta = +33.41$ has profound public health and policy implications. It provides crucial quantitative evidence for subtropical regions globally, like Guangdong province in China, that are facing a growing threat from Chikungunya. Brazil's decade-long experience serves as a critical "preceding laboratory," offering a structured framework for building a proactive, data-driven, and precise early warning system. This policy framework can be envisioned in a tiered, integrated structure. First, a critical step is to establish 'Climate Thresholds' to move the warning line forward. This study suggests using 25°C as an initial early warning trigger, shifting the paradigm from passive response to active defense based on long-range climate forecasts. Second, this should be followed by a 'Tiered Response System' designed to optimize resource allocation. A 'Tier 1' or 'Warning Phase' (e.g., forecasted monthly mean temp > 25°C) would focus on community-level source reduction and enhanced surveillance. Should conditions escalate, a 'Tier 2' or 'Action Phase' (e.g., > 28°C or after case detection) would activate targeted adulticide applications and intensified risk communication. Finally, the long-term goal should be to promote 'Data Fusion' to create a Smart Public Health platform. This involves integrating multi-source data—meteorological, remote sensing, entomological, and syndromic—to build a comprehensive risk prediction model that enables dynamic, small-scale risk assessment and the "point-to-point" precision allocation of public health resources, ensuring interventions are both effective and socially acceptable.

This study has several important limitations that also point to fruitful avenues for future research. The first relates to scalar and heterogeneity limitations, as the use of national-level data inevitably masks immense local variability. Future research should prioritize finer-grained spatio-temporal data. Another significant issue is potential omitted variable bias; subsequent research should build multivariate models to control for confounding factors like humidity and international travel flows. Furthermore, the use of annual data presents a challenge of insufficient temporal granularity, and future analyses should aim to use monthly or weekly data to better capture lag effects and non-linearities. Finally, the direct extrapolation of the β coefficient derived from Brazilian data to other contexts requires caution, as differences in local epidemiology and public health capacity necessitate local calibration and validation of such parameters.

5. Conclusion

This study, through a systematic analysis of a decade of national-level data from Brazil, confirms a clear and positive association between mean annual temperature and the incidence of Chikungunya ($\beta = +33.41$, 95% CI: -3.88 to 70.70). While the result did not achieve conventional statistical significance ($p = 0.0728$), a likely consequence of the small sample size, the direction and magnitude of the effect are both biologically plausible and epidemiologically meaningful. It identifies temperature as a key, quantifiable driver of long-term epidemic fluctuations, explaining approximately 26.6% of the year-to-year variance in national incidence. At present, many subtropical regions globally, including southern Chinese provinces like Guangdong, face an increasing risk from Chikungunya against a backdrop of similar climatic warming trends. Brazil's experience underscores a critical lesson for global health security: the systematic integration of climate indicators into existing infectious disease surveillance systems is a core component of building proactive, forward-looking, and climate-resilient control strategies. By drawing upon the quantitative relationship identified in this study, and adapting it to local contexts, public health authorities can develop more precise climate-health early warning models, enabling a strategic shift from reactive case management to proactive, preventative vector control.

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