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Climate change trends in Vietnam: Evidence from 14 provinces and cities

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ABSTRACT

Climate change progresses gradually but remains a challenge that humanity must actively address in the most constructive and positive manner. Understanding specific trends in temperature change is essential for developing proactive and effective solutions. The study was conducted to analyze surface temperature trends using econometric and machine learning models. Data was collected monthly from January 2002 to December 2023 across 14 provinces and cities in Vietnam, ranging from Tuyen Quang to Ca Mau Cape. The results show that, on average, temperatures increase by 0.38754°C every decade. All provinces exhibit a tendency of rising temperatures, ranging from 0.2016°C to 0.57228°C per decade. Northern provinces show higher temperature increases, with Hanoi experiencing the highest rise. The main trend indicates that temperatures during the hot season increase more significantly than during the cold season, exacerbating negative impacts. The research highlights the critical need to focus on measures to minimize temperature increases in Vietnam. Therefore, it is essential to prioritize green economic development in alignment with environmental protection goals. These findings deepen the understanding of environmental changes, emphasizing the importance of connecting economic and social development goals with environmental protection and sustainable development objectives for the future.

Contribution/ Originality: This study provides a unique analysis of environmental temperature trends in Vietnam. Unlike previous studies, this research combines econometric models and machine learning models with updated data (2022-2023) from 14 provinces and cities nationwide, ensuring robust findings that reliably reflect the current situation.

1. INTRODUCTION

Climate and climate change are current issues attracting the attention of many countries worldwide. Initially, this phenomenon received little notice, as shifts in the Earth's temperature trends are often imperceptible in the short term. Following the four industrial revolutions, research on climate change has become increasingly compelling, supported by various pieces of evidence.

One of the earliest studies on climate change was conducted by Callendar [1]. Using 50 years of CO_2 emissions data and absorption coefficients, the study calculated the amount of infrared radiation reflected back from the atmosphere to the Earth's surface and correlated these changes with surface temperature. The results indicated that anthropogenic CO_2 emissions contribute to a temperature increase of approximately 0.003°C per year. A comparative analysis of data from 200 weather stations revealed an annual increase in the Earth's average temperature of approximately 0.005°C over the past half-century (from 1938 to 1978). The discussion section reflects views from scientists of that period, some of whom were skeptical. They argued that climate is driven by multiple other factors, including atmospheric circulation, ground temperature, and natural variability. However, the article proved highly influential and paved the way for modern research on climate change.

Multiple studies provide evidence of regional warming across the Earth, with the warming process varying by region and over time. Research by Easterling et al. [2] based on data covering 54% of the global land area during the 1961–1985 period reported decadal temperature increases of 0.088°C for maximum temperatures and 0.186°C for minimum temperatures. When the dataset was regionally extended through 1993, the findings indicated that the magnitude of warming varied both spatially and seasonally. An expanded analysis in Vose et al. [3], incorporating updated data from 1950 to 2004 and covering 71% of global land area revealed significantly greater increases: 0.141°C per decade for maximum temperatures and 0.204°C per decade for minimum temperatures (all trends estimated using least squares regression). Notably, during the 1979–2004 subperiod, warming rates accelerated to 0.287°C per decade (maximum) and 0.295°C per decade (minimum). The average global land temperature trend during this interval reached 0.296°C per decade, with geographical disparities.

Some researchers have suggested that global warming appeared to pause in the early 21st century. Studies by Kosaka and Ping [4] and England et al. [5] indicate that this interruption is associated with natural climate variability, including a prolonged La Niña event and an intensified Walker circulation. Yongxiao et al. [6], using data from the Coupled Model Intercomparison Project Phase 6 (CMIP6) developed by the World Climate Research Programme, adjusted for observed warming trends, found that the upper range of model projections is significantly reduced. However, other studies, Iselin et al. [7] and Kevin and Robert [8], argue that the so-called "hiatus" is largely attributable to gaps in observational data coverage, rather than a genuine slowdown in the global warming trend.

The United Nations Framework Convention on Climate Change (UNFCCC) was signed by 154 countries in Rio de Janeiro in June 1992, demonstrating widespread recognition that climate change posed a significant threat to both the environment and global economic development. The ultimate goal of the Convention is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic (human-induced) interference with the climate.

Vietnam, located in the Southeast Asian region, is part of the inner tropical belt between the two tropic lines 23°27' South and 23°27' North resulting in high temperatures and humidity. With a coastline of 3,260 kilometers and two high mountain ranges, such as the Hoang Lien Son and the majestic Truong Son range, Vietnam's climate varies according to each region. The continental climate affects the northern mountainous regions, which border mainland China. Additionally, the East Sea profoundly influences the humid tropical monsoon nature of the mainland, especially in the coastal provinces. The north is influenced by the northeast monsoon, resulting in lower average temperatures than in the southern provinces. Due to the influence of monsoons and complex terrain conditions, the humid tropical monsoon climate is not uniform throughout Vietnam, leading to the formation of different climate zones: the north has a humid subtropical climate, the central region has a tropical monsoon climate, and the south has a tropical climate.

Vietnam is one of the most vulnerable countries in the world due to the negative trends of climate change. Warming causes direct harm to the agriculture, forestry, and fishery industries in Vietnam, reducing the country's global competitiveness. Research by Kien et al. [9] demonstrates that climate change negatively affects agricultural crop productivity. According to Channing et al. [10], climate change could reduce Vietnam's national income by 1% to 2% by 2050, with damages doubling under more extreme scenarios. The World Bank [11] classifies Vietnam as one of the five countries most at risk of being severely affected by climate change. The impact of climate change on Vietnam's economy and national welfare is already significant; in 2020, it accounted for about 3.2% of the gross domestic product. Without drastic and timely actions, the impacts are projected to escalate rapidly.

The issue of climate change has been a concern for the Vietnamese government. The government has approved several policies to minimize the impact, such as: Resolution No. 24-NQ/TW dated June 3, 2013, on proactively responding to climate change and strengthening natural resource management and environmental protection; Decision No. 2139/QD-TTg dated December 5, 2011, of the Prime Minister on the approval of the national strategy for climate change; and most recently, Decision No. 896/QD-TTg of the Prime Minister dated July 26, 2022, on the approval of the national strategy on climate change for the period up to 2050. Accordingly, the government has affirmed that climate change is a major challenge for humanity, impacting all aspects of global economics, politics, diplomacy, and security.

To provide policymakers with evidence-based foundations for developing and adjusting climate strategies, tracking surface temperature changes in Vietnam is essential. Existing studies indicate that temperature rise varies across historical periods and geographical regions, consistent with observed spatial and temporal patterns. Within the Vietnamese context, this paper addresses the following research question.

Q1: Has there been a recent increase in temperature?

Q2: Does temperature change vary seasonally?

The article is structured as follows: Section 2 provides a theoretical framework, identifies research gaps, and suggests a research model. Section 3 analyzes the dataset and details the model selection process. Section 4 presents the findings. Section 5 offers policy implications, discusses limitations, and suggests directions for future research.

2. LITERATURE REVIEW

The decomposition method has been applied for a long time; economists have used these methods since the early 20th century to identify the business cycle. Decomposition techniques are applied in research on the tendency of a quantity over time. According to Diego [12], studies often decompose dependent variables into components represented in a general model of the following form.

$$y = c + \alpha T + \beta C + \gamma S + f(u) + e \ (*)$$

Where T is the time variable representing the trend.

C is the cyclical component of the data series over time, which repeats every two years or more.

S is the seasonal cyclical component, representing the changing component of the data series over time within a year.

f(u) captures the influence of exogenous variables.

e is the residual with a mean of zero, which represents the uncaptured irregular components.

Not all components in the above equation are necessary for the model. According to Diego [12], it is quite common for the decomposition into trend, seasonal, cyclical, and uncaptured irregular components to be sufficient for a significant number of monthly and quarterly economic time series. Specifically, in this study, the dependent variable is temperature, collected monthly, and it is decomposed into three components: trend, seasonal cyclical, and uncaptured irregular (residue e).

Research results from around the world indicate a trend of increasing global temperatures. According to NASA's Goddard Institute for Space Studies [13], Earth was approximately 1.36 degrees Celsius warmer in 2023 than in the late 19th-century (1850-1900) preindustrial average, and the ten most recent years are the warmest on record. A report by the Intergovernmental Panel on Climate Change [14] states that human activities have directly caused greenhouse gas emissions, leading to global warming, which has increased incrementally over time. Using the period 1850-1900 as a baseline, the temperature difference for 2001-2020 is 0.99°C, while for 2011-2020, it is 1.09°C. The increase is more pronounced over land (1.59 [1.34 to 1.83] °C) than over the ocean (0.88 [0.68 to 1.01] °C). The report suggests that under a low-emission scenario (SSP1-2.6), the temperature increase is likely to remain below 2°C with a probability greater than 66%. Conversely, a study by Yongxiao et al. [15] employs linear regression to analyze near-surface air temperature trends after removing natural climate fluctuations in the eastern tropical Pacific. Their findings indicate a stronger warming trend than IPCC projections, with an average increase of 2.16°C (compared to the IPCC's 1.8°C) under SSP1-2.6, and a 'likely' probability of exceeding 2°C.

The study by Leon et al. [16] employed an ARIMA (Auto Regressive Integrated Moving Average) model to analyze temperature trends, with 172 observations covering the period from 1850 to 2021. The model analyzed the dependent variable through its lags and error lag terms. Results demonstrate an accelerating warming trend: 0.006691°C/year over the 172-year period, increasing to 0.015502°C/year for the most recent 71 years, and further rising to 0.019795°C/year over the last 51 years. Complementing these findings, Hamdan et al. [17] used an LSTM model with data from 1958 to 2020. The research findings indicate that global temperatures have been rising, with projections suggesting an increase of 3.8°C by 2100 relative to 2020 levels and 4.8°C compared to pre-1960s. Research by Hamed et al. [18] applied non-parametric methods (Sen's slope and modified Mann-Kendall tests), revealing pronounced warming patterns during 1981-2020. The analysis identified particularly strong warming (>2.5°C) across Canada, Alaska, Russia, and North Africa compared to the preceding 40-year period. At decadal scales, the warming rate reached 0.06°C/year in regions including the Middle East, North Africa, and China.

Considering the ASEAN region, research by Kuo et al. [19] on the variation characteristics of Asian surface temperature in the early 21st century shows that the Asian continent is currently in a cold phase and will become warmer in the future. Research by James et al. [20] indicates that global surface temperatures have increased by approximately 0.2°C per decade over the past 30 years, consistent with the warming trend predicted in the 1980s. Warming in the Western Equatorial Pacific has been greater than in the Eastern Equatorial Pacific over the past century. Jeong-Hyeong and Keon-Tae [21] estimated the random trend of global surface temperature. The results showed that after 20 years, the average temperature in Northeast Asia increased by 0.031ºC in 2007 compared to 1997, with temperature fluctuations between 0.268ºC and 0.336ºC. Research by Dadang [22] in Indonesia a country in Southeast Asia showed a trend in the average surface air temperature of Jakarta, estimated to reach about 28.5°C in 2050 and 29.23°C in 2100, increasing at an average rate of about 0.152°C per decade. Chooprateep and McNeil [23] studied surface air temperature changes in Southeast Asia. During the period 1941–1976, five of six regions experienced an increase ranging from 0.005°C to 0.148°C per decade, but during 1973–2008, all regions saw rises ranging from 0.082°C to 0.222°C per decade.

The study by Rantanen et al. [24] analyzed data from 1950 to 2021, using temperature anomalies compared to the average value during the period 1981-2010 and applying a linear temperature trend model to the 1979-2021 period. It revealed a global warming trend of 0-1.25°C across most regions. Notably, the Arctic exhibited the most pronounced increase, with temperatures rising to 1.25°C per decade. In Figure 1b of Rantanen et al. [24], Southeast Asia (including Vietnam and other ASEAN countries) falls within the orange zone, indicating a temperature increase of 0.25-0.5°C per decade.

Research on Vietnam, Tran et al. [25] studied data from Ho Chi Minh City, and the results showed that, during the period 1989-2006, the temperature trend in Ho Chi Minh City increased significantly. The average temperature of the entire city reached 29.8°C in early 1989 and rose to 33.3°C by the end of 2006. Nguyen, et al. [26] examined temperature variability in Vietnam over 40 years, from 1971 to 2010, using non-parametric methods such as Sen's slope and the Mann–Kendall test. The results indicated that Vietnam's average temperature increased at a rate of 0.26 ± 0.10°C per decade since the 1970s, approximately twice the global warming rate during the same period. Le Van [27] studied changes in sea surface temperature in the East Vietnam Sea during the 20th century and projected future changes under three emission scenarios in the 21st century. The findings suggest that, by the end of the 21st century, the annual sea surface temperature is expected to rise by 0.5-2.0°C according to the three typical emission scenarios.

No studies have examined land surface temperature in Vietnam using quantitative methods and updated datasets in recent periods. This study employs econometric models combined with machine learning, disaggregates data over the past 22 years (2001-2023), to identify current temperature trends in 14 provinces and cities of Vietnam, and assesses compatibility with various Representative Concentration Pathways (RCP) scenarios from previous studies.

3. DATA AND MODEL

Data was collected monthly in 14 provinces and cities in Vietnam over a period of 22 years, from January 2002 to December 2023. Data for these 14 provinces is publicly available on the website of the General Statistics Office of Vietnam.

Due to Vietnam's specific climate, temperatures vary significantly between regions. For example, the North experiences four distinct seasons, whereas the South has only two seasons. The North has winter, but the climate in the South remains hot year-round. Descriptive statistics for the Temp variable in 14 provinces (corresponding to the Northern, Central, and Southern provinces) are provided in Table 1.

Table 1. Descriptive statistics of temperature.

Province/City	Temp				
	Obs.	Mean	Std. dev.	Min.	Max.
Tuyen Quang	264	24.073	4.641	12.5	30.7
Son La	264	21.737	3.925	11	27.5
Quang Ninh	264	23.851	4.601	12.8	30.7
Ha Noi	264	24.795	4.751	12.8	32.1
Nam Dinh	264	24.299	4.735	12.5	31.5
Nghe An	264	24.879	4.651	13.8	32.8
Hue	264	25.200	3.470	15.8	31.1
Da Nang	264	26.248	2.964	19	31.4
Binh Dinh	264	27.366	2.471	22	31.6
Gia Lai	264	22.418	1.674	17.8	26.6
Khanh Hoa	264	27.216	1.820	23.1	30.8
Lam Dong	264	18.313	1.220	14.8	20.8
Ba Ria - Vung Tau	264	27.851	1.109	25	30.6
Ca Mau	264	27.732	0.946	25.1	30.3

In Ca Mau, the standard deviation is very small (0.946), but in Hanoi, the temperature fluctuation between months is much larger (4.751). Gia Lai and Lam Dong provinces located on the Tay Nguyen Plateau have a temperate climate year-round, with lower average temperatures and lower standard deviations. In addition to the temperature differences between provinces (Figure 1), temperature also exhibits its own monthly cycle and follows an annual pattern (Figure 2).

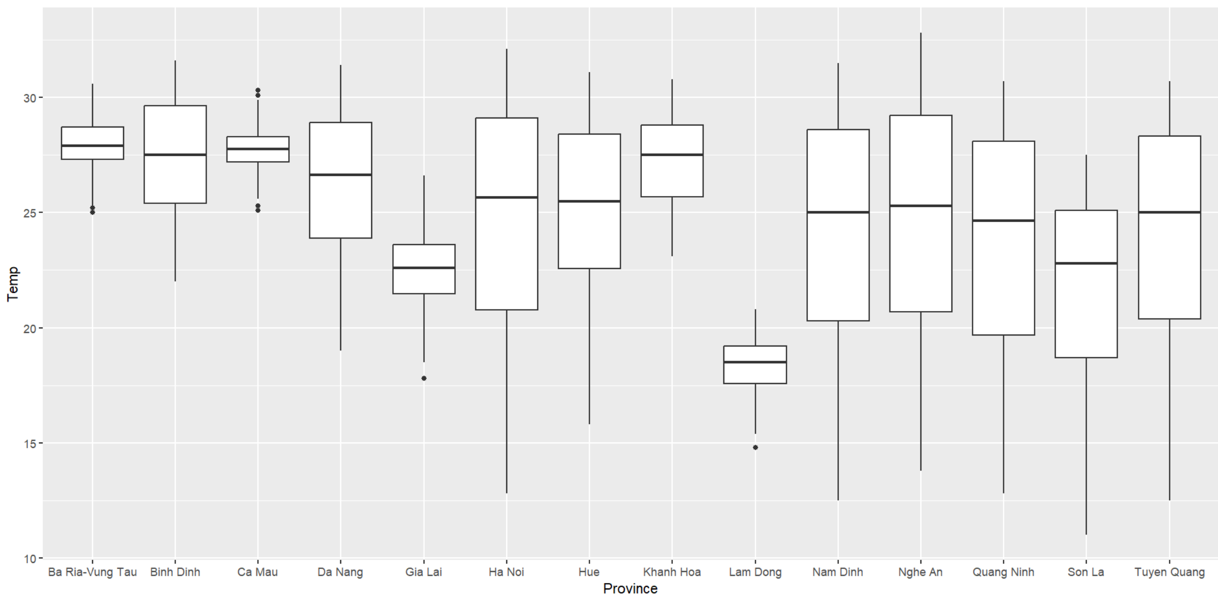

Figure 1. Compare temperatures by province.

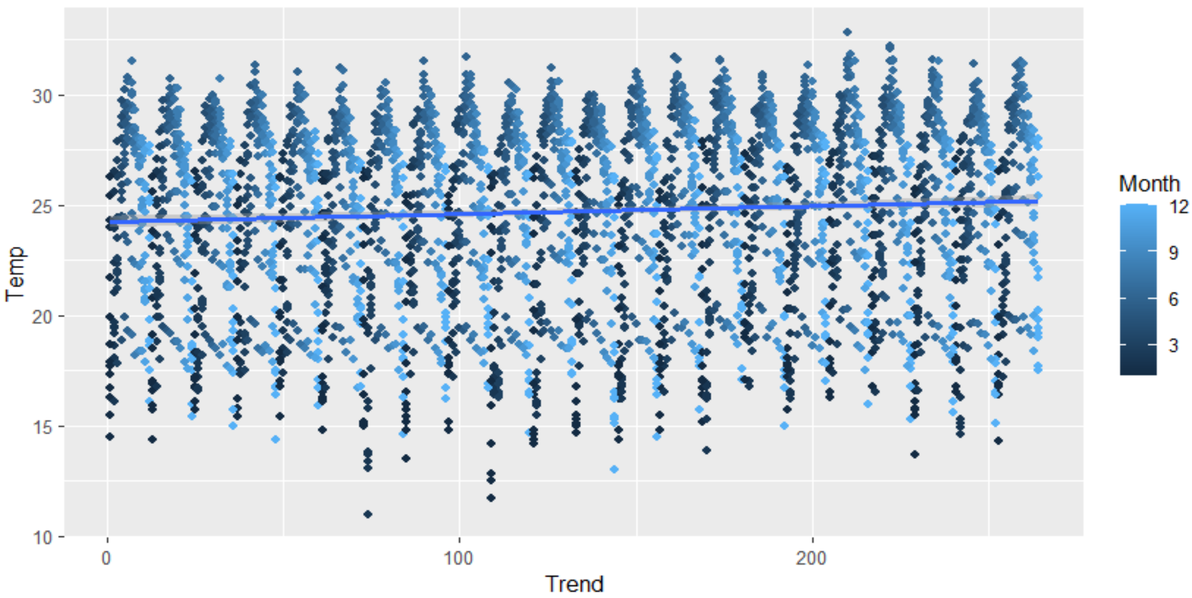

Figure 2. Temperature by Month (01/2002 - 12/2023).

The graph in Figure 2 is cyclical by year, with 22 peaks repeating annually. The analysis and the above figures suggest that it is best to use model (*) with an annual separation period. The research model is as follows:

$$Temp = a + b.Trend + \sum_{j=2}^{12} b_j D_j + e \ (**)$$

In there:

Temp: Average monthly temperature (°C).

Trend: Time variable (monthly order from 1 to 264).

D_j: Dummy variable for month j (D_j = 1 if month j, D_j = 0 otherwise).

The study utilizes OLS models, panel data models, and machine learning models to compare and select the best model, ensuring quality.

For the panel data model, equation (**) takes the form:

$Temp_{it} = a + b.Trend_{it} + \sum_{j=2}^{12} b_j (D_j)_{it} + v_i + u_{it}$ with i = 1; 2; … N= 14 and t = 1; 2; … T = 264.

Here, u_{it} is the error term that varies over time and space, following a normal distribution N(0; σ^2), with no autocorrelation over time and space ($E(u_{i\,t_1}; u_{i\,t_2}) = 0$ for all constant years $t_1 \neq t_2 \in [1; 2; \ldots, T]$ and $E(u_{i_1\,t}; u_{i_2\,t}) = 0$ for all constant cross-sectional units $i_1 \neq i_2 \in [1; 2; \ldots, N]$).

v_i represents the effect caused by the individual-specific characteristics of unit i (the coefficient v_i can be either constant or time-varying). If $v_i = 0\ \forall i$, the model is Pooled OLS (POLS). Otherwise, we have either the FE (Fixed Effects) or RE (Random Effects) model. In other words, both FE and RE models are based on the variation of independent variables across individuals. Therefore, for the right-hand side, which consists of factors that depend only on time, the FE and RE models are not suitable; only the pooled OLS model is appropriate.

The pooled model assumes that all provinces have the same coefficients for the variables D_j, which implies that the provinces share the same monthly temperature cycle. However, Figure 2 suggests otherwise.

All the above analyses suggest the use of time series models for each province. In addition to the standard OLS model, the study will compare results with machine learning models. Initially, the model is trained on 80% of the observations, and the remaining 20% is used as test data. The process is repeated over multiple iterations to calculate the average R^2 and Root Mean Squared Error (RMSE), which are used to evaluate the accuracy of the model.

4. RESULT RESEARCH

The POLS model: All variables in the model are statistically significant, but R^2 = 0.46, indicating that only 46% of the temperature variation is explained. Therefore, the best choice is to use separate models for each province.

Using the ordinary least squares (OLS) estimation method with robust standard errors and a machine learning model computed over 10,000 iterations, the results are presented in Table 2.

Table 2. Temperature trends in 14 provinces from North to South.

Province	OLS model				Machine learning (80% training; 20% testing)	
	Cons.	Trend	R^2	Ramsey R. test	Mean trend	RMSE/Mean(y)
Tuyen Quang	15.894*** (49.58)	0.003914*** (4.17)	0.94	0.7315	[0.00391-0.00392]	< 5%
Son La	14.728 *** (48.14)	0.003397*** (4.01)	0.92	0.9517	[0.00339-0.00340]	< 5%
Quảng Ninh	15.993*** (52.78)	0.003633*** (4.29)	0.94	0.9411	[0.00363-0.00364]	< 5%
Ha Noi	16.540*** (44.41)	0.004769*** (4.76)	0.94	0.7129	[0.00476-0.00477]	< 5%
Nam Định	16.369*** (48.23)	0.003177*** (3.68)	0.94	0.8290	[0.00317-0.00318]	< 5%
Nghe An	17.375*** (59.25)	0.003275*** (3.70)	0.93	0.8916	[0.00327-0.00328]	< 5%
Hue	19.329*** (77.76)	0.003639*** (4.71)	0.91	0.6546	[0.00363-0.00364]	< 5%
Da Nang	21.214*** (89.03)	0.003294*** (4.45)	0.92	0.3585	[0.00329-0.00330]	< 5%
Binh Dinh	23.346*** (132.14)	0.001680** (3.14)	0.93	0.9316	[0.00168-0.00169]	< 5%
Gia Lai	18.910*** (84.56)	0.004571*** (9.26)	0.85	0.8407	[0.00457-0.00458]	< 5%
Khanh Hoa	24.000*** (163.21)	0.002791*** (6.60)	0.91	0.9320	[0.00279-0.00280]	< 5%
Lam Đong	15.805*** (94.33)	0.002789*** (8.18)	0.88	0.9320	[0.00278-0.00279]	< 5%
Ba Ria - Vung Tau	25.775*** (187.93)	0.002128*** (5.91)	0.82	0.5849	[0.00212-0.00213]	< 5%
Ca Mau	26.058*** (177.95)	0.002156*** (5.81)	0.77	0.8804	[0.00215-0.00216]	< 5%

Note: ***, ** indicate significance respectively at 1% and 5%.

The results between the machine learning model and the standard OLS model are similar, with a discrepancy rate of less than 5%, indicating that the machine learning models are of good quality. Table 2 shows the P-values of Ramsey RESET tests. P-values > 5% indicate that all models are not missing any variables. The coefficients of the OLS model confirm a high level of reliability. The lowest R^2 coefficient reached 77% (in Ca Mau), and the highest reached 94% (in Tuyen Quang, Quang Ninh, Hanoi, and Nam Dinh).

According to the order of the estimated model of the provinces from North to South, the dummy variable coefficients for the months show clear differences, especially in the North, and gradually decrease when entering the South. For example, the temperature difference in Hanoi between July and January is 12.935°C, but in Ca Mau, it is only 1.373°C. This reflects the difference in seasonal variation by region and results in a low R^2 for the POLS model.

In terms of trends, all 14 provinces show an increase in temperature, and the results are statistically significant. The highest increasing trend is Hanoi, with an average growth of 0.004769°C per month, followed by Gia Lai with a coefficient of 0.004571°C. The lowest increase is Binh Dinh, with a coefficient of 0.00168, followed by Ba Ria - Vung Tau with a coefficient of 0.002128. To better understand the degree of temperature increase, the study calculated the equivalent increase over 10 years. The estimated temperature increases for the provinces are shown in Table 3.

Table 3. Estimated temperature increases per decade.

Province	The increased value (°C)
Tuyen Quang	+ 0.46968
Son La	+ 0.40764
Quang Ninh	+ 0.43596
Ha Noi	+ 0.57228
Nam Dinh	+ 0.38124
Nghe An	+ 0.39300
Hue	+ 0.43668
Da Nang	+ 0.39528
Binh Dinh	+ 0.20160
Gia Lai	+ 0.54852
Khanh Hoa	+ 0.33492
Lam Dong	+ 0.33468
Ba Ria - Vung Tau	+ 0.25536
Ca Mau	+ 0.25872
Average	+ 0.38754

The northern provinces (Son La, Tuyen Quang, Quang Ninh, Hanoi, and Nam Dinh) tend to experience a higher increase than the southern provinces (Vung Tau, Ca Mau). On average, across 14 provinces and cities, the temperature has increased by 0.38754°C over a decade. This result aligns with the warming trend in Asia reported by the World Meteorological Organization [28], which indicates an increase of above 0.4°C per decade from 1991 to 2023, significantly larger than the trend observed in the previous 30-year period.

Compared with the forecast model in The World Bank Group and Asian Development Bank [29], this is equivalent to the RCP8.5 scenario, the worst-case scenario with the highest emissions pathway, and corresponding to the greenhouse gases emissions scenarios SSP3-7.0 of the Intergovernmental Panel on Climate Change [14].

Due to the differences in weather patterns between the South, which has two seasons the dry season (from May to October) and the rainy season—and the North, which has four distinct seasons, it is recommended to further study temperature trends based on hotter and colder months rather than by season. Figure 3 illustrates the monthly temperature variations across 14 provinces/cities.

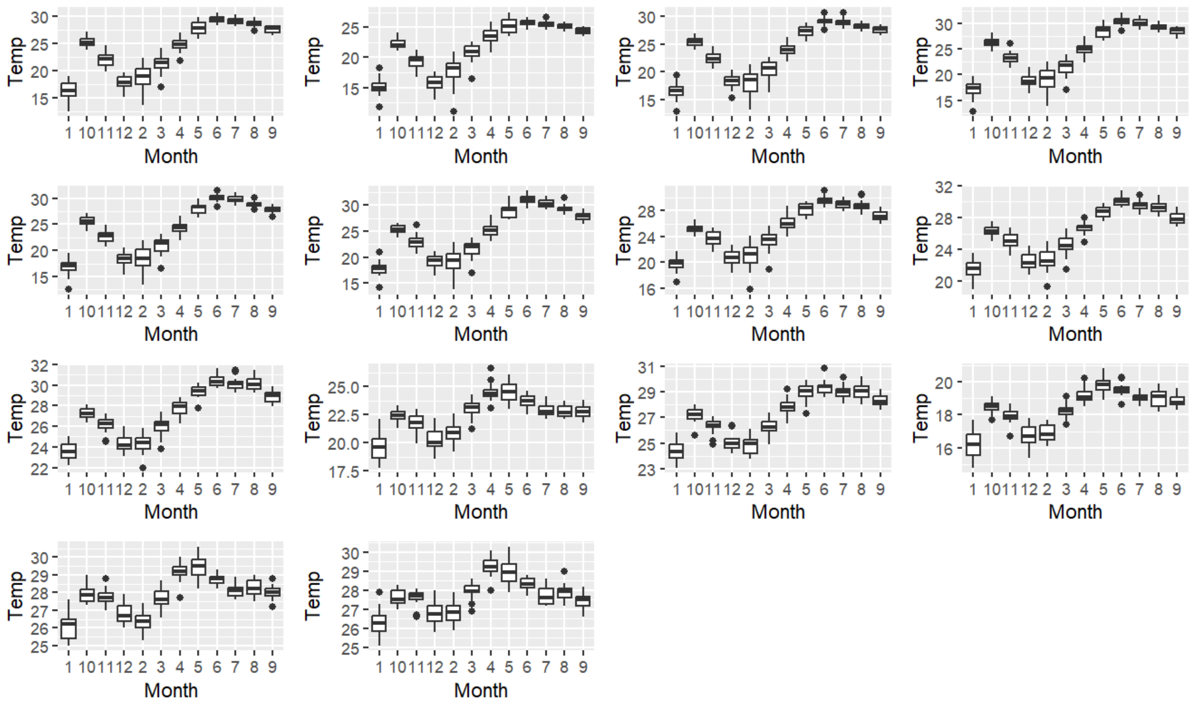

Figure 3. Compare temperatures by Month from Tuyen Quang to Ca Mau province.

The period of the year with the highest temperatures is from May to October in seven provinces located in the northern part of the Truong Son Range (Tuyen Quang, Son La, Quang Ninh, Hanoi, Nam Dinh, Nghe An, Hue). The highest temperatures occur from April to September in seven provinces in the southern part of the Truong Son Range. The common hot months across all regions are from May to September, and the common cold months are from November to March of the following year. April can be considered a hot month in some provinces (Gia Lai, Khanh Hoa, Ba Ria-Vung Tau, Ca Mau), but it can also be regarded as a cool month in others (Son La, Quang Ninh). October is typically cool in Lam Dong and Gia Lai, while northern provinces experience warmer temperatures during this month. Therefore, this study specifically considers the trends of the hotter months (Group 1: May to September) and the colder months (Group 2: November to March of the following year), incorporating monthly dummy variables. The results are shown in Table 4:

Table 4. Temperature trends by hotter and colder months in provinces.

Province	Group 1		Group 2		Obs.
	Trend	R^2	Trend	R^2	N
Tuyen Quang	0.005335*** (6.40)	0.62	0.003928* (2.26)	0.65	110
Son La	0.004005*** (4. 60)	0.43	0.003486* (2.15)	0.67	110
Quang Ninh	0.004169 *** (5.36)	0.63	0.004354* (2.59)	0.68	110
Ha Noi	0.006006*** (7.35)	0.67	0.005131** (2.94)	0.67	110
Nam Dinh	0.004044*** (5.02)	0.69	0.004005* (2.37)	0.66	110
Nghe An	0.004621*** (5.11)	0.70	0.003204' (1.87)	0.59	110
Hue	0.004713*** (5.32)	0.61	0.003212* (2.23)	0.57	110
Da Nang	0.004651*** (5.91)	0.67	0.002413' (1.82)	0.59	110
Binh Dinh	0.0001501' (1.91)	0.54	0.002155* (2.40)	0.61	110
Gia Lai	0.004905*** (8.61)	0.73	0.004639*** (4.90)	0.71	110
Khanh Hoa	0.002531*** (4.14)	0.38	0.003075*** (4.48)	0.64	110
Lam Dong	0.003443*** (8.44)	0.69	0.002418*** (3.79)	0.68	110
Ba Ria - Vung Tau	0.002658*** (5.91)	0.66	0.002002** (3.02)	0.62	110
Ca Mau	0.002880*** (5.90)	0.69	0.001914** (2.94)	0.58	110

Note: ***, **, * and ' indicate significance respectively at 1‰, 1%, 5% and 10%.

The results indicate that the main trend, considering a statistical significance level of 10% across 11 out of 14 provinces, is that hotter months experience a greater increase in temperature. In other words, the hot season is becoming hotter, which negatively impacts rainfall and water resources. To reinforce this finding, the study employs the POLS model across all 14 provinces to identify the overall trend while accounting for individual constants. The results are shown in Table 5:

Table 5. Temperature trends by hotter and colder months in 14 provinces/cities.

	Group 1	Group 2
Trend	0.003961*** (15.55)	0.003281*** (7.97)
R^2	0.9405	0.8687
N	1540	1540

Note: *** indicates significance respectively at 1%.

The coefficient in Group 1 is higher than that in Group 2, and the R^2 value is high, indicating that the model results are reliable. Therefore, in addition to the overall trend of increasing temperature, the main trend suggests that temperatures during the hot months increase faster than during the cold months, with coefficients of 0.47532ºC/decade and 0.39372ºC/decade, respectively.

5. CONCLUSION AND RECOMMENDATIONS

Rooted in empirical data and guided by theoretical frameworks and dataset characteristics combined with insights into temperature across Vietnam's provinces and cities this study meticulously details the selection process of the optimal research model tailored to the available data. The selected model achieves a high R^2 coefficient, demonstrating strong explanatory power for the target variable. A comparative synthesis of OLS, POLS, and machine learning models yields consistent results, robustly reinforcing the research outcomes. In essence, this study is data-centric, allowing the data to narrate its own story.

Research shows that temperatures in 14 provinces and cities tend to increase over time (ranging from 0.20160 to 0.57228 over 10 years). This provides evidence of climate warming in Vietnam. Hotter seasons tend to increase more rapidly than colder seasons, especially in the northern provinces, causing more adverse impacts on the climate. Therefore, alongside economic development, the government needs to prioritize addressing climate change, promote a clean environment, and ensure sustainable development.

First, the problem of waste and emissions needs to be thoroughly addressed, such as separating waste at the source, improving waste treatment technology, controlling plastic waste, and moving towards the complete use of biodegradable bags. It is also necessary to control factories and vehicles that pollute the environment, especially overloaded construction material trucks, which cause dust to accumulate on the roads.

Reasonable land use planning and strict control of urban and rural planning, including both short-term and long-term plans, are necessary. It is essential to increase the proportion of land designated for planting trees, especially in urban areas. Additionally, efforts should be made to increase the green cover on bare land and hills with perennial or short-term crops in rotation.

Provide recommendations to the government on the issue of managing water flows, increasing water reserves through dredging rivers and streams, and renovating regulating lakes with a focus on expansion. This includes measures to solidify regulating lakes, especially those in urban areas, to prevent encroachment. Additionally, it is important to construct more artificial lakes and avoid filling in regulating lakes, as lakes play a vital role in regulating and cooling the climate, significantly contributing to slowing the current trend of rising temperatures.

Promote awareness-raising campaigns to improve people's understanding of environmental sanitation. Limit the issue of abandoned land. This should be supported by the state through initiatives such as developing a favorable irrigation system and expanding the network by building an underground pipeline system to deliver irrigation water for agricultural production, which plays an important role alongside the clean water supply system. Furthermore, it is crucial to strictly control pesticide and fertilizer suppliers to protect land and water resources, moving towards clean, sustainable, and modern agriculture.

Limitations and future research directions: This article proposes recommendations based on common causes of temperature rise in Vietnam that remain insufficiently quantified. This study suggests further research into the direct effects of temperature rise on rainfall patterns and frequency, as well as the impacts on agriculture, forestry, fisheries, and broader socio-economic aspects in Vietnam.

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