ASSESSMENT OF CHANGE ON THE DAILY MAXIMUM HEAT INDEX FOR THAI BINH CITY (VIETNAM)

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Abstract. Meteorological factors, especially temperature and humidity, have a great impact on human physiology. In the context of climate change, the impact of temperature on people's health in Thai Binh city (Vietnam) is becoming more and more serious. Based on meteorological data for the period of 1991-2021 and Vietnam climate change scenario data, the daily maximum heat index (HI_{max}) scenario for the period of 2024-2054 is calculated by the method of correlation evaluation and regression equations. The results show that in the future the trend of HI_{max} is 0.0875°C per year under the RCP 4.5 scenario (Medium Low Greenhouse Gases Concentration Scenario) and 0.0919°C per year under the RCP 8.5 scenario (High Greenhouse Gases Concentration Scenarios). The number of weeks per 5 years having daily HI_{max} at danger level (HI_{wave}) tends to increase 6.14 times for scenario RCP 4.5; 7.0 times for scenario RCP 8.5. Especially, the number of days at risk of heat stroke in the past 31-year period is 5 days, then in the future 31-year period there are 77 days with scenario RCP 4.5 and 116 days with scenario RCP 8.5 and this phenomenon mainly concentrated in the months of June, July, August.
Keywords: *climate change, heat stress, heat stroke, daily maximum heat index, human health*

Introduction

Each species of organism has a tolerance limit for a certain ecological factor, including factors of heat, humidity, wind, radiation, and water quality, etc. When environmental conditions change beyond ecological limits, organisms cannot survive. The favorable range is the range of ecological factors at the appropriate level, which ensures the best performance of life functions, or the range of ecological factor values in which the organism grows most favorably. Tolerance range is the range of ecological factors that inhibit the physiological activities of organisms or the range of ecological factor values within which the vitality of organisms gradually decreases to the ecological limits. Passing these limits, organisms will die.

Stress is the human body's response to pressures effecting the physical and mental existence of a person (Selye, 1936). Heat stress is defined as the body temperature of a species that is above the regulatory range for normal activities (Nardone et al., 2010).

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To quantify the degree of heat stress, scientists have built different indices, which are determined by a combination of several meteorological factors. Apparent Temperature (AT) is a measure of relative discomfort due to the combination of temperature and relative humidity (Steadman, 1979, 1984; WMO, 2022). Research on heat stress assessment based on effective temperature (ET) index with inputs including temperature, relative humidity and wind speed for the Chinese territory in the period of 1961-2014 shows that the area has high stress levels. Determination of real effective temperature (NET) with daily meteorological data including maximum temperature (T_{max}), relative humidity and wind speed for the period of 1960-2016 from more than 500 meteorological stations in China shows that in the context of the global temperature rise, the number of extreme hot days tends to increase in most areas of China, but a decreasing trend is detected instead of the Jianghuai region. The U.S. National Weather Service uses temperature and relative humidity to calculate the heat index (HI) as a measure of determining risk thresholds for public heat warnings. Heat index (HI) is how the human body feels when relative humidity is combined with air temperature (National Weather Service, 2021). Analysis of meteorological data in Quang Nam province (Vietnam) in the period of 1979 - 2019 shows that there is an increasing trend in HI and excess heat coefficient (Tai and Quang, 2020).

In the context of climate change, heat stress is becoming more and more serious. Research results on extreme weather phenomena show that heavy rain, heat, cold, damaging cold, and drought tend to increase markedly in the whole of Vietnam (Tan and Thanh, 2013). The assessment of heat stress based on the heat index of wet thermometers in South Asia (including Vietnam) with the data series for the period of 1976-2005 and climate change scenario data shows that wet-bulb temperature (TW) tends to increase by the end of the 21st century (Im et al., 2017). Research on heat stress in Hanoi city shows that in the period of 2021-2050, the HI is increasing both in occurrence frequency and intensity level (Thuy et al., 2022).

Urbanization is also a cause of increased heat stress risk. Due to the urban effect in Hanoi city (Vietnam), the temperature in the inner city is about 1 or 2°C higher than the suburban area, the relative humidity in the inner city is higher, and the wind speed in the suburban area is weaker (Dao, 2013; Thuy et al., 2022).

Many studies have found that there is a relationship between human health and heat stress. When temperature, humidity are high, wind is weak, and direct sunlight, which are ecological complexes, impairing the body’s ability to maintain core temperature, causing heat stress (McGregor and Vanos, 2018). An increase in heat stress due to climate change by 2030 will reduce labor productivity by the equivalent of 80 million full-time jobs (Kjellstrom et al., 2019). The results from using several different heat indices to determine the degree of heat stress for workers in the context of climate change in Da Nang using a series of meteorological data for the period of 1970-2011 show that the nighttime temperatures are still too high after hot days, making recovery from a day’s work uncertain and leading to heat stress (Opitz-Stapleton et al., 2016). The results of a study on heat stress in Beijing (China) show that there is an impact of extreme temperatures on respiratory diseases, the higher the temperature, the greater the number of people hospitalized due to respiratory diseases (Ma et al., 2019). According to statistics, when the temperature increases by 1°C, the hospitalization rate of children from 0 to 2 years old increases by 3.4%; from 3-5 years old increased by 4-5%, and children under 5 years old were hospitalized due to respiratory diseases increased by 3.8% (Phung et al., 2017). Research by Phung et al. (2017) has shown that, due to heat

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stress, the number of hospitalized people in Hanoi and Quang Ninh increased by 2.5%. People with elderly, obese, people with poor health and poorly adapted to high temperatures, infectious diseases, cardiovascular and respiratory diseases are susceptible to heat stress caused by heat. Heat stress has a significant impact on patients over 65 years old, patients with cardiovascular disease, diabetes, kidney disease, and epilepsy (Semenza et al., 1999).

Thai Binh city is one province in the Red River delta, with a population of 295,902 people, and nearly 2,650 people/km² of population density with many industrial zones (Thai Binh Statistics Office, 2022). It is demographic factors, socio-economic activities, along with the heat island effect that make Thai Binh city have a higher maximum temperature value than surrounding areas. In the context of climate change, heat stress in Thai Binh is becoming more and more serious. However, there is currently no assessment of future heat stress based on a daily scenario for Thai Binh city.

The purpose of this study is to evaluate the change of heat index in the context of climate change for warning the potential future impacts of temperature on communities in Thai Binh city.

Data and research methodology

Study area

Thai Binh city is located in the Southeast of the Red River delta (*Fig. 1*) with a total area of 68 km², accounting for about 4.3% of the Thai Binh province's total area (Thai Binh Statistics Office, 2022). The terrain of Thai Binh city is relatively flat, with an average height of 1-2 m above sea level. Thai Binh city has a tropical monsoon climate, with an average annual temperature of 23.6°C, in which 3 months of temperature below 18°C, 5 months of temperature above 25°C. Thai Binh's climate has an average annual relative humidity of 84%, the precipitation is 1552 mm which is relatively high compared to other areas in Vietnam (Vietnam Center of Hydro-Meteorological Data, 2021).

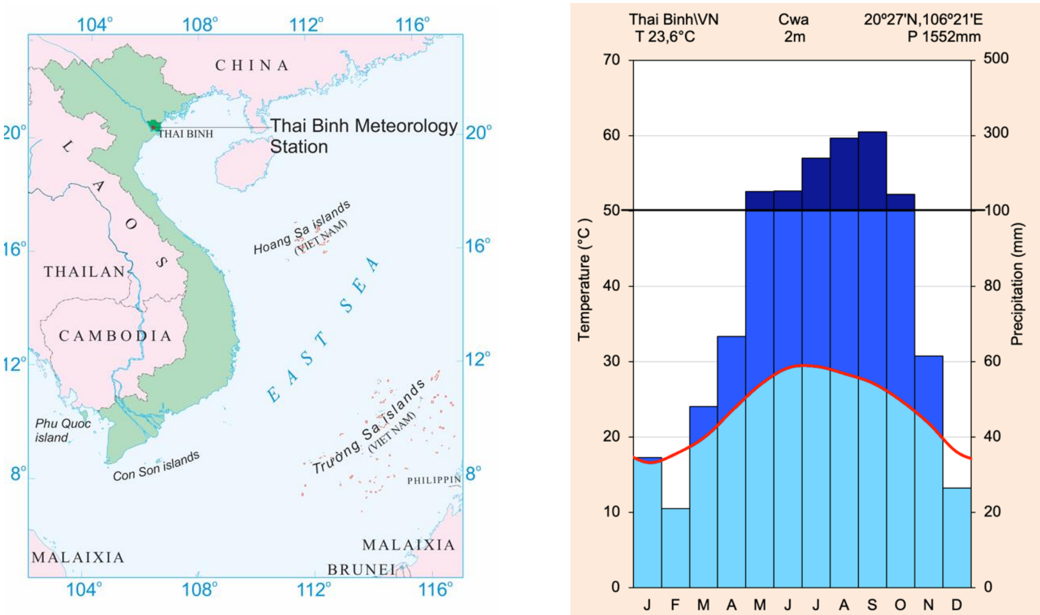

Figure 1. Location map and representative climate chart for the study area

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Data

In this study, the following data were used:

- Daily maximum temperature, daily minimum temperature, daily average temperature, daily minimum relative humidity observed by Thai Binh Meteorological Station (Thai Binh province) in the period of 1991-2021 (Vietnam Center of Hydro-Meteorological Data, 2021).
- Daily maximum temperature, daily minimum temperature, daily average temperature according to the Medium-Low Greenhouse Gases Concentration Scenario (RCP 4.5), the High Greenhouse Gases Concentration Scenario (RCP 8.5) in the period of 2024-2054 issued by the Ministry of Natural Resources and Environment in 2020 (Vietnam Ministry of Natural Resources and Environment, 2021).

Methodology

Heat index

To assess heat stress for Thai Binh City, there are many different methods of calculating heat stress index. However, the method of calculating the HI is appropriate, because it is possible to use meteorological data included the climate change scenario to interpolate heat stress values.

The HI is usually calculated using instantaneous or hourly temperature (T) and relative humidity (RH) data (Dahl et al., 2019). This is the algorithm that the National Weather Service (NWS) uses for heat forecasting and warning (National Weather Service, 2021a). The heat index is determined based on the air temperature in degrees Fahrenheit (T) and relative humidity in percent (RH) (*Fig. 2*).

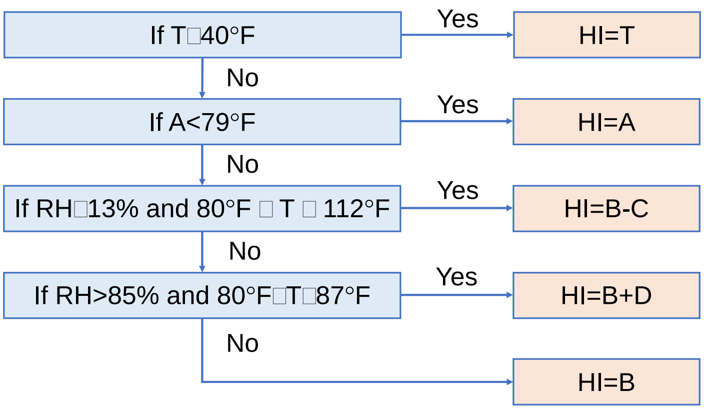

Figure 2. *Algorithms used to calculate HI (Anderson et al., 2013)*

$$A = -10.3 + 11 * T + 0.047 * H \qquad \text{(Eq.1)}$$

$$B = -42.379 + 2.04901523 * \mathrm{T} + 10.14333127 * \mathrm{H} - 0.22475541 * \mathrm{T} * \mathrm{H} - 6.83783 * 10^{-3} * T^2 - 5.481717 * 10^{-2} * H^2 + 1.22874 * 10^{-3} * T^2 * H + 8.5282 * 10^{-4} * T * H^2 - 1.99 * 10^{-6} * T^2 * H^2 \qquad \text{(Eq.2)}$$

$$C = \left[\frac{13 - \mathrm{H}}{4}\right] * [(17 - |\mathrm{T} - 95|)/17)]^{0.5} \qquad \text{(Eq.3)}$$

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$$D = 0.02 * (H - 85) * (87 - T) \quad \text{(Eq.4)}$$

HI is converted to degrees to align with the temperature unit used in Vietnam. The conversion is accomplished using the following equation: T°C = (T°F – 32) × 5/9. The heat stress is divided into 6 levels shown in *Table 1*.

Table 1. *Classification of heat stress*

Classification	Heat index	Effect on the body
Caution	27°C - 32°C	Fatigue possible due to prolonged exposure and/or physical activity
Extreme caution	32°C - 41°C	Heat stroke, heat cramps, or heat exhaustion possible with prolonged exposure and/or physical activity
Danger	41°C - 54°C	Heat cramps or heat exhaustion likely, and heat stroke possible with prolonged exposure and/or physical activity
Extreme danger	54°C or higher	Heat stroke highly likely

Source: National Weather Service (2021b)

Multivariable regression equation

In the multivariable regression model (Taylor, 1997), the dependent variable is described as a linear function of the independent variables Xi, as follows:

$$\hat{y}_i = a + b_1 \times x_{i1} + b_2 \times x_{i2} \dots b_n \times x_{in} \quad \text{(Eq.5)}$$

where: y: dependent variable, b_i: regression coefficient of the independent variable x_{ij}, a: constant, i: observation i, x_{ij}: Independent variables.

The model allows to calculate the regression coefficient b_i for each independent variable x_{ij}.

In this study, the selection of a multivariable regression equation to determine the minimum relative humidity of the day is based on meteorological factors included the climate change scenario. The value of daily maximum HI_{max} is determined based on the daily minimum relative humidity value and the daily maximum temperature value.

Nash-Sutcliffe efficiency (NSE)

Nash-Sutcliffe model efficiency coefficient (NSE) is an objective function used for evaluating how well the model performs:

$$NSE = 1 - \frac{\sum_{t=1}^{T}(HI_{model}^{t} - HI_{observed}^{t})^2}{\sum_{t=1}^{T}(HI_{observed}^{t} - \overline{HI}_{observed})^2} \quad \text{(Eq.6)}$$

where: HI_{model}^{t} is model HI_{max} at day t, $HI_{observed}^{t}$ is observed HI_{max} at day t, and $\overline{HI}_{observed}$ is average observed HI_{max} during the simulation period T.

Statistical software SPSS (Statistical Package for the Social Sciences) is used in this paper. The software allows to process large volume of data systematically and identify parameters of these statistic relationship. F test is also calculated to identify significancy of the three independent variables.

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SPSS is applied for Thai Binh Meteorological Station which has observed data from 01/01/1991 to 31/01/2021. This data are divided into 2 periods. The first period is used for model calibration and the second method is used to validate the model performance. NSE is used to evaluate the model performance.

Results

Results of model calibration and validation

The period from 1/1/1991 to 31/12/2011 was selected as served to calibrate the model parameters. The period from 1/1/2012-31/1/2021 are used to validate the model.

Calibration process

HI_{max} is calculated based on T_{max} and RH_{min}. In this study, there is a good correlation between the dependent variable (RH_{min}) and the independent variables (daily maximum temperature, average daily temperature, daily minimum temperature). Using the SPSS software for data from 1/1/1991 to 31/12/2011, the study results a regression equation between RH_{min} and T_{max}, T_{min} and T_{mean} which is written as follows:

The result is the following regression equation:

$$RH_{min} = 95{,}688 - 4{,}891 \times T_{max} + 1{,}594 \times T_{mean} + 3{,}403 \times T_{min} \quad \text{(Eq.7)}$$

where: RH_{min}: daily minimum relative humidity; T_{max}: daily maximum temperature; T_{mean}: daily average temperature; T_{min}: daily minimum temperature.

The regression statistic results are summarized below:

Adjusted $R^2 = 0.6$, so that the independent variables (T_{max}, T_{min} and T_{mean}) can explain 60% of the daily minimum relative humidity, and there is a basis for building a multivariable regression equation between the independent variables and the dependent variable. The Durbin-Watson value is used to test the phenomenon of first-order series autocorrelation. The Durbin-Watson value is equal to 1.02, so no autocorrelation occurs. The sig value of the F test for Mean Square is less than $F < 0.05$ shows that the regression model is suitable, the sig value in the t test of the regression coefficient < 0.05 shows that the independent variable affects the dependent variable.

Based on the histogram, the mathematical expectation of the Regression Standardized Residual mean is close to zero, the variance is close to 1, so the distribution is approximately normal. Observing the PP Plot chart (*Fig. 3*) shows the percentiles in the distribution of the diagonally concentrated residuals, so the assumption of the normal distribution of the residuals does not violate and the regression equation is reliable.

Thus, *Equation 7* can be used to determine the minimum relative humidity of the day in the future based on the daily mean temperature, daily maximum temperature, daily minimum temperature from the climate change and sea level rise scenarios for Vietnam (Vietnam Ministry of Natural Resources and Environment, 2021).

Apply the algorithm in *Figure 2* and *Equations 1, 2, 3,* and *4* to calculate:

Observed HI_{max} for the period from 1/1/1991 to 31/12/2011 is based on historic values of daily maximum temperature and daily minimum relative humidity.

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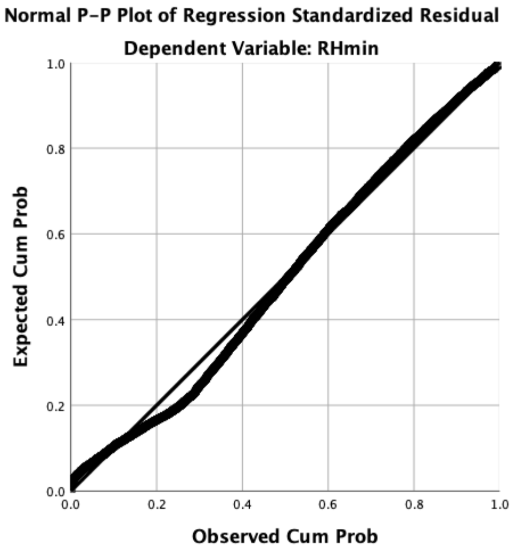

***Figure 3**. P-P plot chart*

Model HI_{max} for the period from 1/1/1991 to 31/12/2011 is based on historic values of daily maximum temperature and daily minimum relative humidity calculated *Equation 7*.

Nash-Sutcliffe model efficiency coefficient (NSE) will evaluate the model efficiency through Observed HI_{max} and Model HI_{max} values.

The NSE is 0.95 and this reveals there is good calculation between the model and observed HI_{max} (*Fig. 4*). Hence the regression model fits the calibration period.

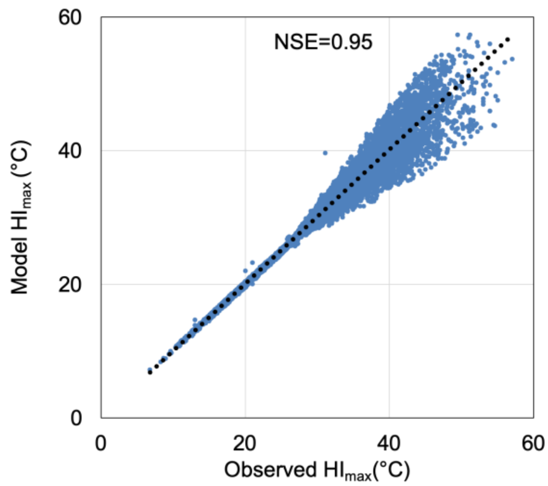

***Figure 4.** Scatter plot between Observed HI_{max} and model HI_{max} for the period of 1991-2011*

Validation process

The model was validated using data from 1/1/2012 to 31/12/2021. *Figure 5* shows scatters between the model and observed HI_{max}. There is a good calculation between the observed and model values indicated by NSE of 0.98. Based on these findings, the model can be used to simulate HI_{max} for the future climate change scenarios.

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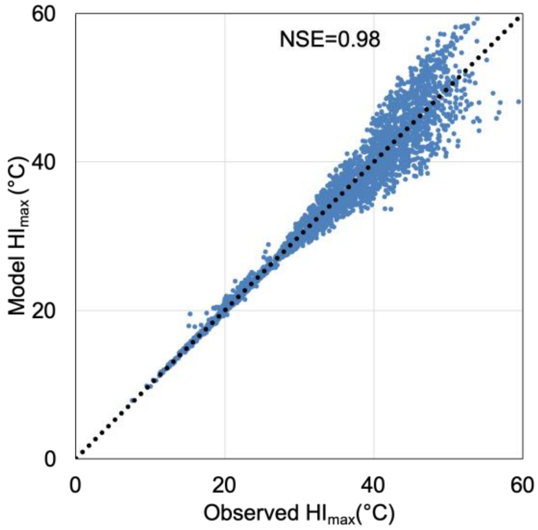

***Figure 5.** Scatter plot between observed HI_{max} and mode HI_{max} for the period of 2012-2021*

Yearly change of HI_{max}

Annual average HI_{max} calculated from daily maximum temperature with HI_{max} is shown in *Figure 6*. It can be seen from historical data that annual average HI_{max} tends to increase in the period of 1991-2021. In the future, for the period of 2024-2054, by the RCP 4.5 scenario there is a linear fit between annual average HI_{max} over time with strong confidence: $R^2 = 0.89$. This shows that the annual average HI_{max} increasing trend of 0.088°C/year is very reliable, by the RCP 8.5 scenario the annual average HI_{max} increasing trend is 0.093°C/year with very tight confidence: $R^2 = 0.93$. The uptrend of HI_{max} by the RCP 8.5 scenario is more than 6% larger than the uptrend of HI_{max} by the RCP 4.5 scenario.

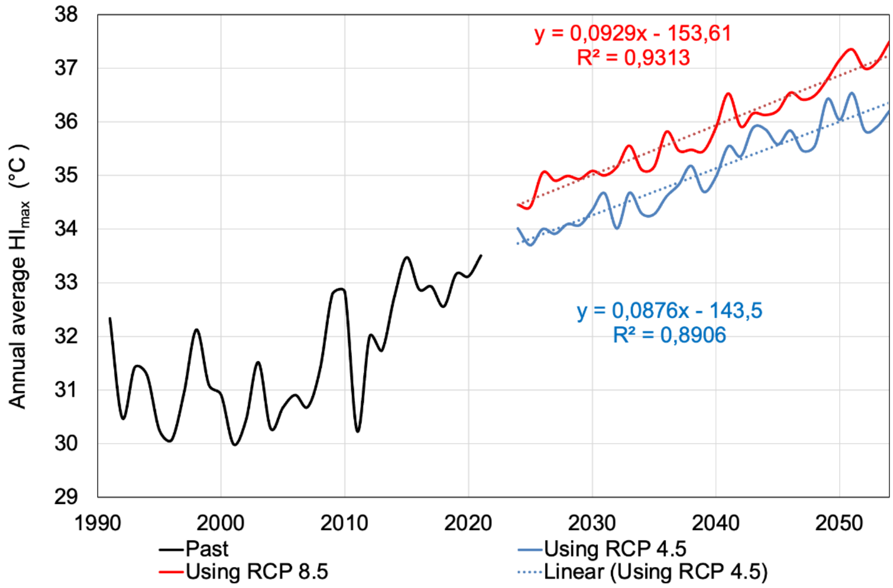

***Figure 6.** Historic and future annual average HI_{max} showing a linear fit to the trend for 2024-2054 under the RCP 4.5 (blue) and the RCP 8.5 (red)*

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The change in number of days with HI_{max} at the danger level per year

Based on *Figure 7*, it is found that the number of days with HI_{max} at dangerous levels tends to increase both in the past and in the future. With the RCP 4.5 scenario, the reliability of the correlation between the number of days with HI_{max} at the danger level and time is shown by the value $R^2 = 0.86$ - this is a very close relationship, proving that the regression equation is reliable. According to the regression equation, the tends number of days with HI_{max} at the danger level to increase in the future, an average of 1.12 days/year. Similarly for the RCP 8.5 scenario shows that the tends number of days with HI_{max} at the danger level to increase in the future, on average increasing by 1.24 days/year with confidence $R^2 = 0.84$. Thus, there is no significant difference in change in number of days with HI_{max} at the danger level under the RCP 4.5 and RCP 8.5 scenarios.

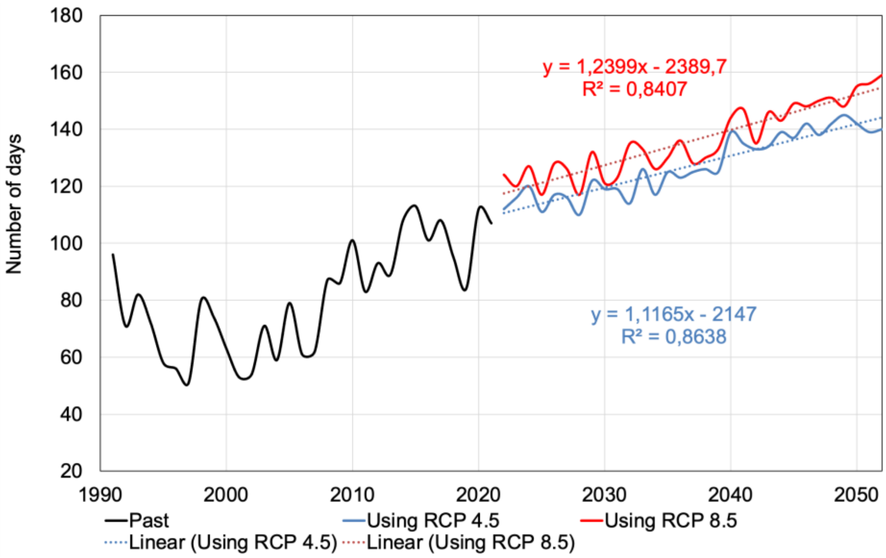

Figure 7. *Historic and future daily HI_{max} showing a linear fit to the trend fo2024-2054 under the RCP 4.5 (blue) and the RCP 8.5 (red)*

The change in number of days with HI_{max} at the extreme danger level in the past and future

Based on *Figure 8*, it is found that the number of days with HImax at the extreme danger level (HImax > 54°C) is minor in the past but this increases significantly in the period of 2039 to 2054. With the RCP 4.5 scenario, it shows that the number of days with HI_{max} at the extreme danger level in the years 2039, 2041, 2044, 2046, 2041, 2050, 2051 is about 1-3 days per year. Especially in the years 2049, 2054, the number of days with HI_{max} > 54°C will be 5 days per year. Under the RCP 8.5 scenario, the number of days with HI_{max} at extreme danger level increases markedly and tends to increase sharply from 2039 to 2054. The number of days with HI_{max} at the extreme danger level in the years 2039, 2041, 2044, 2045, 2046, 2047, 2048 appears 1-3 days per year, especially from the years 2049 to 2054 appear from 8-15 days per year.

The number of weeks per 5 years having an average HI_{max} at danger level

The heat waves pose a serious danger and are particularly dangerous for vulnerable people such as the elder and children. In this study, heat wave was calculated as the

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period where HI_{max} > 41°C continuously for 7 days or more and in this study denoted HI_{wave}. According to historical data, HI_{wave} has continuously increased over the past per 5 years (*Fig. 9*). In the future, the uptrend of HI_{wave} in both scenarios is very clear. According to the RCP 4.5 scenario, the linear of the HI_{wave} has a confidence $R^2 = 0.96$ (that the multivariable regression equation is reliable), showing that the HI_{wave} trend is up 6.14 week per 5 years with high confidence. By the RCP 8.5 scenario, HI_{wave} is strongly correlated with time with $R^2 = 0.9$, that the multivariable regression equation is reliable. It can be seen from the multivariable regression equation that the HI_{wave} will increase by 7 weeks per 5 years.

In summary, in the context of climate change, it is estimated that the HI_{wave} will increase between from now to the year of 2054. The HI_{max} increase under different the RCP scenarios is approximately more than a week per year.

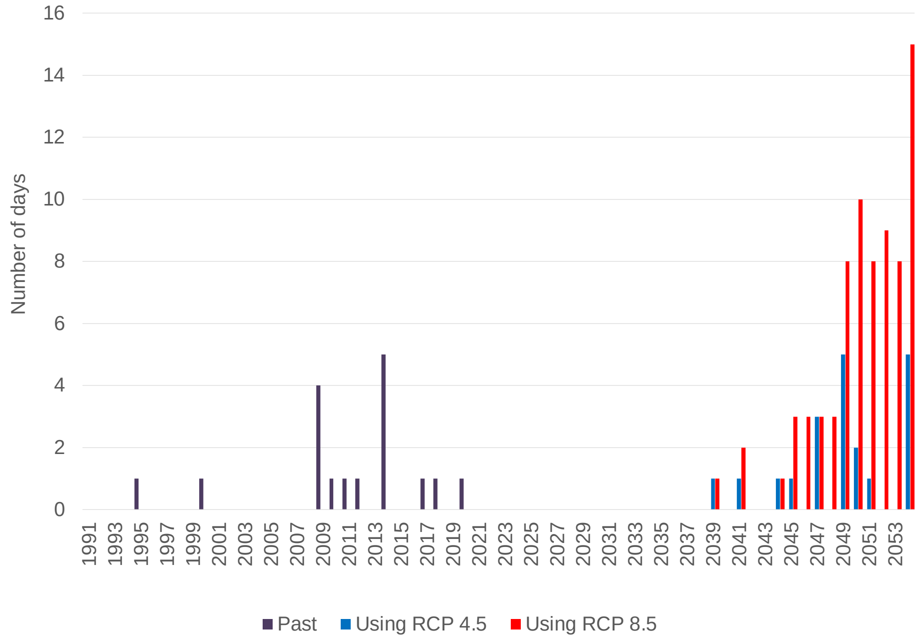

Figure 8. *Historic (black) and future of days having HI_{max} > 54^0C for period of 2024-2054 under RCP 4.5 (blue) and RCP 8.5 (red)*

Fluctuation in monthly average of number of days having HI_{max} > 41°C in the past and future

In the past (period of 1991-2021) the number of days with HI_{max} > 41°C per month reached the highest value in the months of June, July, August, 16-20 days, from November to March there was no date HI_{max} > 41°C (*Fig. 10*). In March and September, the average number of days with HI_{max} > 41°C per month is 10 and 8 days, respectively. Thus, it can be seen that HI_{max}/month shows a clear seasonal variation.

There is a difference between the number of days having HI_{max} per month in the future and in the past. The months with the highest number of days having HI_{max} > 41°C over 15 days in the period of 2024-2054 under both the RCP 4.5 and RCP 8.5 scenarios are May, June, July, August, and September, which is longer than in the period of 1991-2020 (June, July, August). In the period of 1991-2021, the number of days with HI_{max} > 41°C is 20 days in June, while in the period of 2024-2054, all days in June, July, August have HI_{max} > 41°C.

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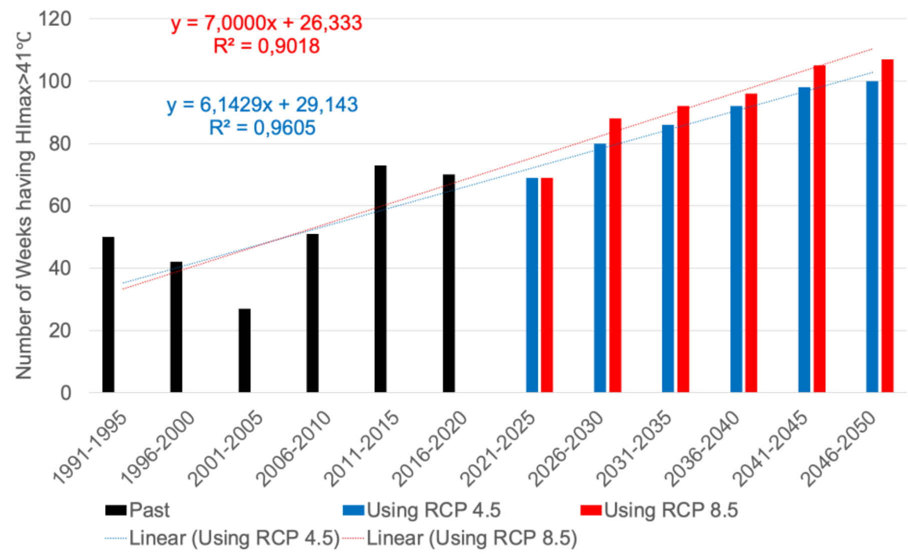

Figure 9. *Number of weeks per 5 years having daily HI_{max} at danger levels in the past and future*

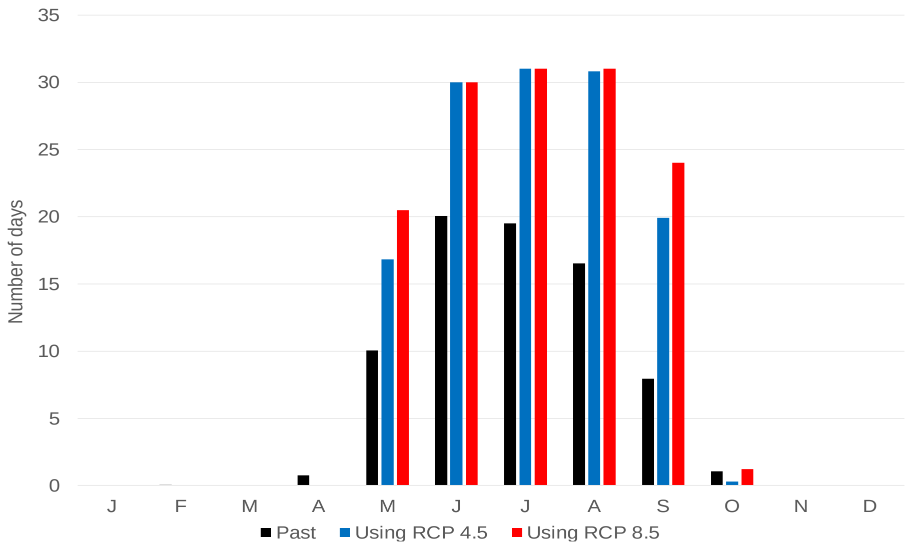

Figure 10. *Monthly average of number of days having HI > 41°C in the period of 1991-2021 and in the period of 2024-2054 under RCP 4.5 and RCP 8.5 scenarios*

The similarity between the past and future HI_{max} is the high number of days with HI_{max} > 41°C in the summer months. Months without a day with HI_{max} > 41°C fall in the period from November of the previous year to March of the next following year.

Fluctuation in number of days with HI_{max} > 54°C by month for the period of 2024–2054

The number of days having HI_{max} > 54°C over the past 31 years occurred 17 times, in May to September (*Fig. 11*). With such a small number, this can be considered a rare extreme weather event in the past.

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In the future the number of days HI_{max} is at extreme danger will be more than in the past. The month with the number of days with HI_{max} at extreme danger in the period of 2024-2054 under the RCP 4.5 scenario appears in June as 4 times in 31 years and in July as 16 times in 31 years; under the RCP 8.5 scenario appears only in June 14 times in 31 years; August is 1 time in 31 years and especially in July is 59 times in 31 years.

The similarity between HI_{max} in the past and in the future is that the number of HI_{max} days at extreme danger level all occur in the months of June and July. The months with no HI_{max} > 54°C days fall in the period from October in previous year to April next year. The difference between HI_{max} in the past and in the future is that in the future, the number of days with HI_{max} at extreme danger level is higher than in the past, especially under the RCP 8.5 scenario, more than 4 times, and only focus on the July.

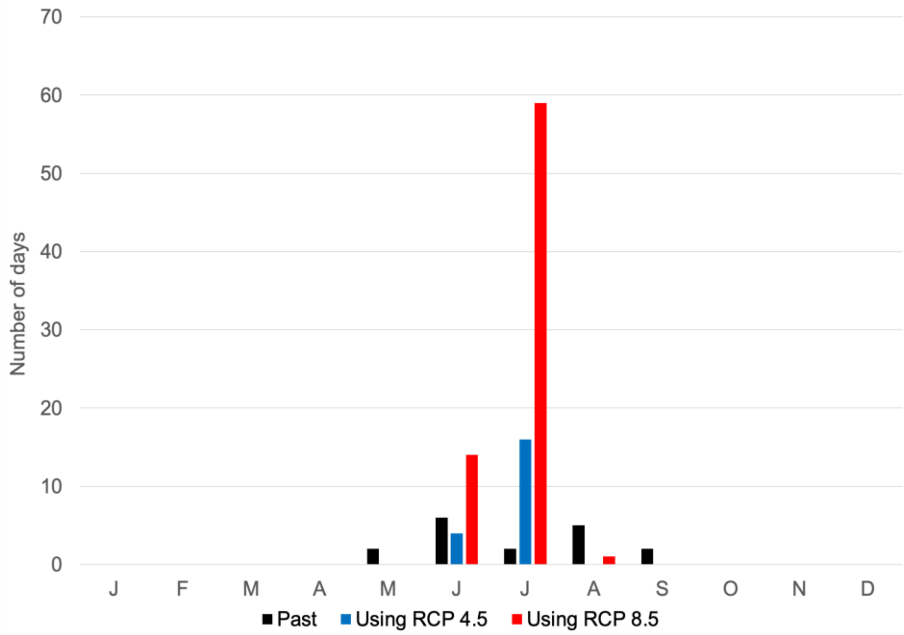

Figure 11. *Number of days having HI > 54°C in the period of 1991-2021 and in the period of 2024-2055 under RCP 4.5 and RCP 8.5 scenarios*

Discussion

Relationship between daily minimum relative humidity and daily maximum temperature

Previous studies have shown that the HI is maximum at the time when the day temperature is highest and relative humidity is also lowest (Matveev, 1976; Dahl et al., 2019). In this study, it is assumed that T and RH always have an inverse relationship and that relationship does not change in the future. HI_{max} is calculated based on T_{max} and RH_{min}.

Identifying the daily minimum relative humidity

The Thai Binh city's climate is characterized by humid with mild and dry winters, not hot, but relatively high temperatures in the summer, high humidity all year round, and island heat effect due to rapid urbanization. The heat stress in Thai Binh city is becoming more and more intense and has bad effects on the human body. To assess the

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combined effects of temperature and humidity on the human body, the HI is a widely used and suitable index for Thai Binh city.

To build the HI_{max} scenario for the future, the input data is the daily maximum temperature scenario and the daily minimum relative humidity scenario. However, the climate change scenario for Vietnam does not provide a daily relative humidity scenario, so it is necessary to interpolate this daily relative humidity from other meteorological factors.

To determine the daily minimum relative humidity, it is necessary to rely on available factors in the climate change scenario including maximum temperature, minimum temperature and average daily temperature.

Through the analysis, it was found that there is a good correlation between the daily minimum relative humidity and the daily maximum temperature, daily minimum temperature and daily mean temperature.

Assessing the seasonality of HI_{max}

The Research results show that in the past and future scenarios, from November to March there is no day with HI_{max} > 41°C. The fluctuations in the number of HI_{max} days at danger level and extreme danger levels follow a general rule for both scenarios. In this study, the months with the highest number of days with HI_{max} are at danger level and extreme danger level, focusing on the months of June, July, August. In the past, the extreme danger level was simply rare, then in next time, it will appear more often and mainly in the hottest months of summer. Especially in July, the number of days with HI_{max} at extreme danger levels increased dramatically with the RCP 8.5 scenario. This result confirms the distinct seasonality of Thai Binh's climate with winters heavily influenced by polar air masses blowing from the north.

Risk of heat stroke in the period of 2024-2054

The manifestation of climate change is clearly shown in the trend of increasing the average annual $HI_{max,}$ the increasing trend in the number of day with HI_{max} > 41°C and the number of days with HI_{max} > 54°C between the past and the future, that lead to the increase in the number of weeks with HI_{max} > 41°C and the number of days with HI_{max} > 54°C which is particularly clear and regular in the future.

The comparison between the past and the future shows that the number of days with HI_{max} > 41°C under the RCP 4.5 scenario is 1.6 times larger than in the past, under the RCP 8.5 scenario is 1.7 times larger than in the past, according to the scenario RCP 8.5 version is 1.1 times larger than under the RCP 4.5 scenario. These are days where heat stroke is highly likely.

The comparison between the past and the future shows that the number of days with HI_{max} > 54°C under the RCP 4.5 scenario is 1.2 times larger than in the past, under the RCP 8.5 scenario is 4.4 times larger than in the past, according to scenario RCP 8.5 version is 3.7 times larger than under RCP 4.5 scenario.

The determining of timing and intensity of HI_{max} is important in protecting the health of everyone in the community, especially those who work outdoors, people with cardiovascular disease, high blood pressure and other diseases. This study results will support the health sector for preparing medical facilities and increasing medical staffs and doctors when the number of heatstroke patients' spikes. This study will have practical significance if the research results are combined with the statistics on the

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number of people with heat stroke in Thai Binh city, Vietnam. These findings can also help local authorities and policy makers to assess spatial variation of HI_{max} in Thai Binh City and other cities.

Conclusion

Research results show that extreme meteorological factors change much faster than average daily meteorological values. The combination of high temperature, high relative humidity and the increasing trend of the daily maximum temperature in the future combined with the characteristics of Thai Binh city as an urban area with rapid urbanization is the reason for the number of days with HI_{max} at danger and at extreme danger levels tends to increase faster in the future. The results show that under both RCP 4.5 and RCP 8.5 scenarios, the HI_{max} is at risk of increasing both in intensity and number of days. The intensity of HI_{max} will increase by 0.088°C per year with the RCP 4.5 and 0.093°C per year with the RCP 8.5 scenarios for the period of 2024-2054.

The change in number of days per year with HI_{max} at the danger level and extreme danger level both tend to increase whether with the RCP 4.5 or RCP 8.5 scenarios. Especially in the period from 2039 to 2054, the trend of increasing the number of extreme danger levels is very clear. With these days, the weather can cause heat cramps or heat exhaustion, and possible heat stroke from prolonged exposure and/or physical activities.

Particularly, in the past there were only 17 days with HI_{max} at extreme danger levels, but in the period of 2024-2054, the number of days with HI_{max} at extreme danger levels under the RCP 4.5 scenario, was 20, under the RCP 8.5 scenario is 74 and mainly concentrated in July. With these days, the weather has a high risk of causing stroke.

With the fluctuation of HI_{max} over time as above, it is necessary to develop specific plans for infrastructure and medical staff to protect outdoor workers, the elderly, and people with background diseases against the potential risk of weather shown by the heat index getting stronger and stronger in intensity in June, July, August, especially in June.

The results of this study will be a useful information channel for policy makers for Thai Binh city to have an orientation on developing health infrastructure to adapt to climate change in the future. The limitation of the study is that there are no actual statistics on the number of people affected by heat and especially stroke. The authors will develop future research when actual medical data are available.

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Data availability statement. The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

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