ASSESSING DAILY MAXIMUM HEAT INDEX IN THE CONTEXT OF CLIMATE CHANGE FOR HANOI (VIETNAM)

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Abstract. Hanoi is the second largest city in Vietnam. The effects of climate change, coupled with rapid, unchecked urbanization and population increase are resulting in a severe rise in incidents of heat stress, which has serious ramifications for community health. In this study, a multivariable linear regression, heat index (HI) methods, and climate change scenarios for Vietnam in 2020 are used as input data to calculate the daily maximum heat index (HI_{max}) for Hanoi during 2024-2028. Findings indicate that HI_{max} at danger level has already occurred and will happen again in the future, with seasonal characteristics mainly distributed in June, July, August. For the years 2024-2028, HI_{max} at the danger level increases in two scenarios compared to 2017-2021. Notably, the number of days with HI_{max} at the extreme danger level, which may be the main cause of heat stroke, has 0.4 days/year occurring during 2017-2021. However, it will also appear in the years 2024-2028 in both RCP 4.5 and RCP 8.5 scenarios from June to August, at 0.6 days/year and 2.6 days/year, respectively. Knowing the daily maximum heat index for the future at specific times is crucial information for acting on the risk of heat stress in Hanoi given the current danger posed by climate change.
Keywords: *climate change, heat stress, daily maximum temperature, daily minimum relative humidity, daily maximum heat index, Hanoi*

Introduction

Stress is a physiological response to physical, emotional or cognitive pressure (Selye, 1936). Heat stress occurs when the body's core temperature exceeds the range for normal activity (Nardone et al., 2010). When first experiencing heat stress, the body's core temperature rises as does the heart rate. As the body continues to heat up, a person begins to lose the ability to focus on his or her tasks, experiences a loss of appetite, becomes irritable, and their health deteriorates. The next stage is often fainting and even death if the body is not cooled down (The University of IOWA, 2023).

There is a statistical relationship between temperature and the number of people hospitalized due to heat stress, the mortality rate in developing tropical countries, and the ability to adapt to harsh weather conditions (Dang et al., 2019). Due to the heat, in recent times in Hanoi city and Quang Ninh province, the number of hospitalized people has risen by 2.5%, which is a relatively high level compared to the world average (Phung et al., 2017). Extreme weather causes heat stress in humans, especially in older people, those

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who are overweight, people experiencing poor health, and those who are not accustomed to the heat (Kjellstrom et al., 2019). Studies have also shown that people with infectious diseases, cardiovascular disease, and respiratory diseases are more likely to experience heat stress. The increase in stress also diminishes labor productivity, and the impacts of climate change are equivalent to the loss of 80 million full-time jobs (International labour office Marek Harsdorff Mous, 2019). Based on the studies cited above, we found that heat exerts a significant impact on community health, particularly in large cities.

Climate change is occurring, and meteorological factors are definitely changing, such as a general increase in temperature, and most regions of the Earth are experiencing more rainfall. The consequences of this include increased evaporation and relative humidity (IPCC. Climate Change, 2023). For the past two decades, the average global temperature has been recorded as the highest for the period from 1850 to the present day (Sun et al., 2021). Climate change increases the likelihood of extreme heat events on a monthly or seasonal basis (Luo et al., 2022) and increases the frequency of heat waves (Kovats and Hajat, 2008; Thuy et al., 2022).

Due to the ongoing urbanization that is occurring in eastern China, heat stress in this region is also much more evident. Especially, urban areas have experienced substantial increases in heat stress compared to rural areas (Luo and Lau, 2018). In the case of Hanoi city (Vietnam), due to the urban heat island effect, the temperature of the inner city is higher than in the outer city by 1-2ºC (Dao, 2013). Based on this finding, it can be concluded that climate change and urbanization increase the level of heat stress.

To evaluate the impact of heat on the human body, scientists have developed various heat indices, for example Apparent Temperature (AT), Wet Bulb Temperature (Tw), Wet Bulb Globe Temperature (WBGT), Effective Temperature (ET), etc. AT measures relative discomfort due to the combination of high temperature and high humidity (WMO, 2022). AT is the balance between heat and the human body's experience of it, and can be calculated directly from standard meteorological variables (Steadman, 1984). In general, AT is warmer than air temperature in Australia, increasing the expected level of discomfort due to global warming in tropical regions (Jacobs et al., 2013). Meanwhile, Tw is the lowest temperature to which air can be cooled by the evaporation of water in the air at a constant pressure (WMO, 2022). Furthermore, Tw is indicating an increasing trend in the 21st century, and deadly heatwaves are projected to occur in the densely populated agricultural regions of South Asia (Im et al., 2017).

The WBGT was developed by Yaglou and Minard in 1957 and it combines four variables: air temperature, humidity, air velocity and radiation (Moran et al., 1998). This index is a good reflection of the impact of the environment on the human body. Summer mean WBGT has increased almost everywhere in China since 1961 because of human-induced climate change. By the 2040s, almost every summer in China will be at least as hot as the hottest summer in the historical record (Li et al., 2020). ET is an arbitrary index that is empirically determined in terms of temperature, humidity, and air movement. It refers to the physiological sensation of warmth or cold felt by the human body (WMO, 2022). In evaluating heat stress based on the ET index for China during the period 1961-2014, it was discovered that due to the increase in temperature and decline in wind speed, in the southern regions of China the number of annual comfortable days fell in warm regions (Wu et al., 2017).

The National Weather Service of the United States relies on temperature and relative humidity to develop the heat index (HI) as a measure to determine heat risk thresholds in order to warn communities. The NOAA website also provides heat forecasting tools,

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including a heat stress assessment table and a map predicting heat stress areas in the US based on HI (National Weather Service, 2021). The HI index in Hanoi exhibits a significantly increasing trend during the years 2021-2050 in the context of climate change, particularly given that the number of days with HI_{max} > 54ºC in the past was only 4 days. However, the future scenario is 73 days according to the RCP 4.5 scenario and 116 days according to the RCP 8.5 scenario (Thuy et al., 2022).

Based on different heat indices to determine the level of heat stress for workers in the context of climate change in Da Nang province during 1970-2011, it emerged that night-time temperatures were still too high after a hot day, making it difficult for people to recover after working all day and producing conditions of stress (Opitz-Stapleton et al., 2016). From these studies, we concluded that heat wields a significant impact on community health, particularly in large cities like Hanoi. Heat stress studies have attracted increasing interest and been conducted by many researchers in recent times. However, no specific heat stress scenario for each day for the future of Hanoi has yet been attempted.

Building a specific HI scenario for each day for the next 5-year period is undertaken in this study. The objective of this research is to provide HI scenarios for the period 2024-2028 so that the relevant management agencies can enhance the healthcare system, develop the right infrastructure, and provide information to the community about the risk and likelihood of heat stress given that the risks of climate change are increasing.

Materials and Methods

Study area

The city of Hanoi is located in the center of the Red River Delta, at 20º34' to 21º18' North latitude and 105º17' to 106º02' East longitude. The city covers an area of 3,358.6 km², accounting for 1% of the area of the whole country. The city’s population in 2021 amounted to 8.2 million people, accounting for 8.5% of the country’s population. The population density is 2,455 people/km², 8.3 times higher than the average population density of the whole country (General Statistics Office, 2022). Hanoi has a monsoon-influenced humid tropical climate, and according to the Köppen climate classification is Cfa (Ahrens, 2009) with cold winters compared to other cities of the world at the same latitude. This is due to the influence of cold air from the north (Ngu and Hieu, 2004). The study area is the center of Hanoi city (*Figure 1*) which has an average elevation of 5-6 m above sea level and the city’s highest population density (Thao, 2004). The average annual temperature is 24.5ºC. The period from May to October, monthly temperature >20ºC, especially June, July, and August, is the hottest time of the year, temperature >29ºC (Vietnam Center of Hydro-Meteorological Data, 2024). Correspondingly, during these months, relative humidity is at its lowest, fluctuating between 58-63% with average monthly minimum humidity during 1991-2020 (Vietnam Center of Hydro-Meteorological Data, 2024) (*Figure 2*). The Lang Meteorology Station is marked in red in *Figure 1*.

Data

In this study, the following data were used:

- Daily maximum temperature, daily average temperature, total daily precipitation, daily minimum relative humidity observed by Lang Meteorological Station (Hanoi) during the period 1991-2021 (Vietnam Center of Hydro-Meteorological Data, 2024).

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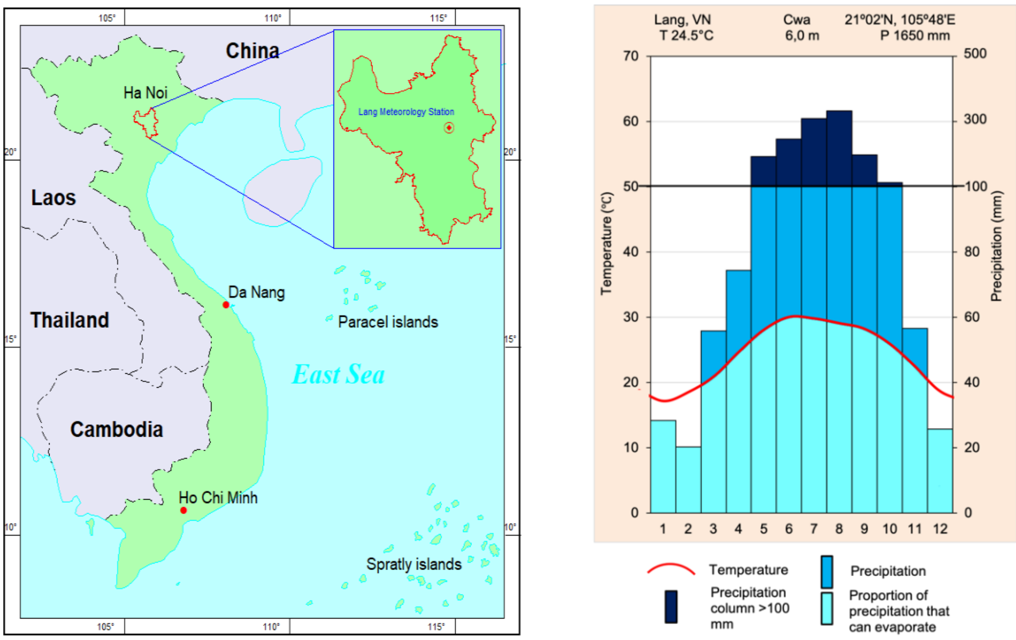
- Daily maximum temperature, daily average temperature, total daily precipitation according to the Medium-Low Greenhouse Gases Concentration Scenario (RCP 4.5), the High Greenhouse Gases Concentration Scenario (RCP 8.5) in the period 2024-2054 for Hanoi issued by the Ministry of Natural Resources and Environment in 2020 (Vietnam Ministry of Natural Resources and Environment, 2021).



(a) (b)

Figure 1. *Location (a) and key climate characteristics (b) at Lang station (Hanoi)*

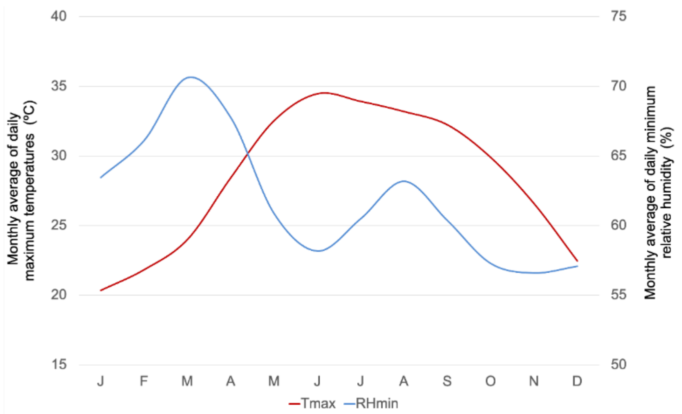


Figure 2. *Annual variation in monthly average of daily maximum temperatures and daily minimum relative humidity at the Lang Meteorology Station (Hanoi) during the period 1991-2020*

Method

HI calculation

The general algorithms deployed to estimate HI are shown in *Figure 3*.

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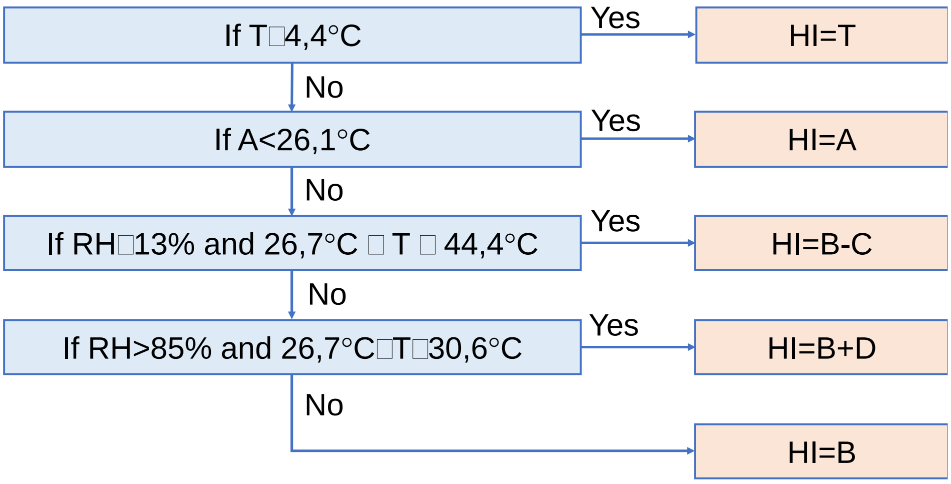

Figure 3. *Algorithms to calculate HI (Anderson et al., 2013)*

where:

$$A = -3{,}9444444 + 1{,}1 * T + 0.0261111 * RH \qquad \text{(Eq.1)}$$

$$\begin{aligned} B = -8{,}7847 &+ 1{,}6114 * \mathrm{T} + 2{,}33854884 * \mathrm{RH} \\ &- 0{,}14611605 * \mathrm{T} * \mathrm{RH} - 0{,}012308094 * T^2 \\ &- 0{,}016424828 * RH^2 + 2{,}211732 * 10^{-3} * T^2 \\ &* RH + 7{,}2546 * 10^{-4} * T * RH^2 - 3{,}582 \\ &* 10^{-6} * T^2 * RH^2 \end{aligned} \qquad \text{(Eq.2)}$$

$$C = \left[\frac{13-RH}{7{,}2}\right] * [(17 - |1{,}8 * \mathrm{T} - 63|)/17)]^{0.5}\text{-}17{,}77778 \qquad \text{(Eq.3)}$$

$$D = 0.0111111 * (RH - 85) * (55 - 1{,}8 * T) - 17{,}77778 \qquad \text{(Eq.4)}$$

Values HI_{max} are divided into four categories according to the level of danger to human health as documented in *Table 1* below.

Table 1. *Heat stress classification*

Classification	**Heat Index**	**Effect on the body**
Caution	27°C - 32°C	Fatigue possibly 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: Anderson et al., 2013

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The HI is usually calculated an hourly timestep (Dahl et al., 2019) and the HI_{max} is the most important factor in health risk. Subsequently, it is very important to identify which is the highest value of HI during each day and what variables are significant for estimating this highest HI (HI_{max}). Many studies have reported that daily temperature fluctuations on clear days reach their maximum during 03:00 pm - 04:00 pm each day (Matveev, 1976; Ahrens, 2015; Thuy et al., 2022). Daily relative humidity also varied on clear days and has been going in the opposite direction to temperature, reaching its minimum at 03:00 pm - 04:00 pm (Matveev, 1976; Opitz-Stapleton et al., 2016; Thuy et al., 2022). Analysis of the hourly data series for the years 2011-2021 at Lang meteorology station (Hanoi) discovered that at the highest temperature of the day (93.2% at 03:00 pm), this agreed with the minimum relative humidity (92.1% at 3:00 pm) (*Figure 4*). Consequently, the daily maximum temperature (T_{max}) and daily minimum relative humidity (RH_{min}) served to estimate daily maximum heat index HI_{max} values and we have the function $HI_{max} = f(T_{max}, RH_{min})$. In this study the assumption made is: firstly, T_{max} and RH_{min} are inversely related; and secondly, this relationship does not change in the future.

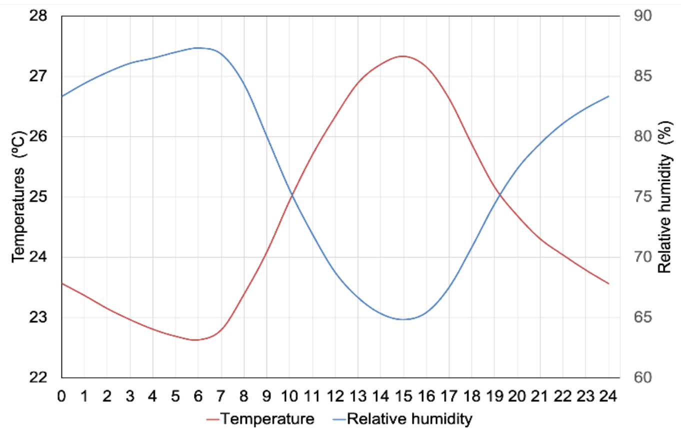

Figure 4. *Daily change in temperature and relative humidity for the period 2011-2020 at the Lang Meteorology Station*

T_{max} derives from climate change scenarios for Vietnam (Vietnam Ministry of Natural Resources and Environment, 2021). However, RH_{min} is not available in climate change scenarios for Vietnam. RH_{min} has a good relationship with daily maximum temperature, mean temperature and precipitation. Therefore, in this study, RH_{min} is estimated by using the multivariable linear regression model depending on maximum and mean temperature; and precipitation as follows: RH_{min}.

$$RH_{min_i} = a + b_1 * T_{max_i} + b_2 * T_{mean_i} + b_3 * P_i \qquad \text{(Eq.5)}$$

where:

RH_{min_i}: daily minimum relative humidity at day i,

a: constant (y-intercept),

$T_{max_i}, T_{mean_i}, P_i$: Maximum, mean temperature and precipitation at timestep i respectively,

b_1, b_2, b_3: regression coefficient of the variables $T_{max_i}, T_{mean_i}, P_i$ respectively,

i: i^{th} observation.

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The model permits the computation of a regression coefficient b_i for each independent variable.

Based on daily maximum temperature, daily average temperature, daily precipitation, this study calculates daily minimum relative humidity using the multivariable regression equation. It means that Heat index (HI) is calculated using the method to calculate HI based on daily maximum temperature and daily minimum relative humidity data.

Model performance

Our model employs data collected for the period 1991-2021. The data for the years 1991 to 2010 served to calibrate the model while data for 2011-2021 were used to validate the models. The model parameters after calibration and validation were utilized to simulate the impacts of climate change on HI_{max}, and subsequently, the risk posed by climate for public health.

Calibration and validation process:

Nash–Sutcliffe model efficiency coefficient, which is written as follows:

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

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

Model calibration employs the period from 01/01/1991 to 31/12/2010 while the validation process is from 01/01/2011 to 31/12/2021.

Building multivariable regression equation using SPSS Statistical software

The procedure for calculating HI_{max} for the future involves constructing a complex regression equation using the SPSS software, with the independent variables being $T_{max_i}, T_{mean_i}, P_i$ and the dependent variable being RH_{min}. To assess the reliability of the equation, the study compares the HI_{max} values calculated through the complex regression equation with those derived from the measured values of $T_{max_i}, T_{mean_i}, P_i$. The results strongly suggest that the complex regression equation is reliable. Based on $T_{max_i}, T_{mean_i}, P_i$ in the climate change situation as it applies to Vietnam, the RH_{min} scenario for the future can be calculated. With the future RH_{min} scenario and T_{max} for the future from the climate change scenario, HI_{max} for the future can be determined.

Results

Calibration process

In this study, it emerged that there is a good correlation between the dependent variable (RH_{min}) and independent variables (daily maximum temperature, daily mean temperature, daily precipitation). Using SPSS software for data from 1/1/1991 to 31/12/2011, the study devised a regression equation between RH_{min} and T_{max}, T_{mean} and P it is written as follows:

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$$RH_{min} = 87{,}510 - 5{,}635 \times T_{max} + 5{,}458 \times T_{mean} + 0{,}165 \times P \qquad \text{(Eq.7)}$$

The regression statistic results are summarized below:

- Adjusted $R^2 = 0.56$ meaning that the independent variables can explain 56% of the RH_{min}. Durbin-Watson value equals 1.11, meaning that there is no autocorrelation between the independent variables. This is a sound basis for building a complex regression equation between the dependent and independent variables.

- The sig value of the F test for Mean Square is less than 0.05, signifying that the regression model is suitable, while the sig value in the t-test of the regression coefficient less than 0.05 confirms that the independent variable affects the dependent variable. Based on the histogram (*Figure 5*), it is evident that the Regression Standardized Residual mean is close to zero, Std. Dev=1, hence the distribution is Standardized normal approximately. The P-P Plot reveals the percentiles in the distribution of the residuals diagonally, and consequently two things emerge: the assumption of normal distribution of the residuals is valid in this case and the regression equation is reliable.

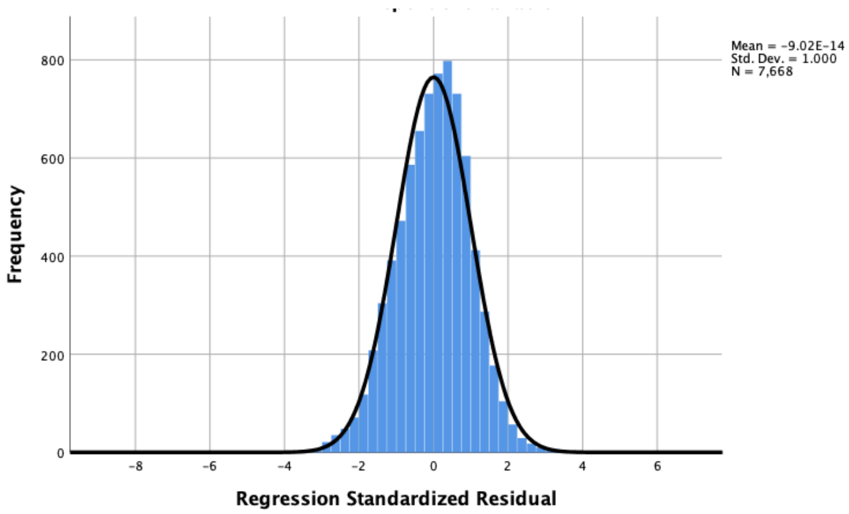

Figure 5. *Histogram Dependent Variable: RH*

Equation 7 can therefore determine the value of daily minimum relative humidity based on daily mean temperature, daily maximum temperature, and daily precipitation. This RH_{min} can be applied in the algorithms in *Figure 3* to calculate HI_{max} for the period 1/1/1991 to 31/12/2011. To assess how well the model functioned, the model HI_{max} and the "observed" HI_{max} were compared. The NSE is 0.97 (*Figure 5*) and this means there is good agreement between the model and observed HI_{max}. Hence the regression model fits the calibration period.

Validation process

The model was validated using data from 1/1/2012 to 31/12/2021. *Figure 6* shows scatters between model HI_{max} and observed HI_{max}. There is a good correlation between the observed and model values indicated by NSE of 0.95. Based on these findings, the model can be used to simulate HI_{max} for future climate change scenarios.

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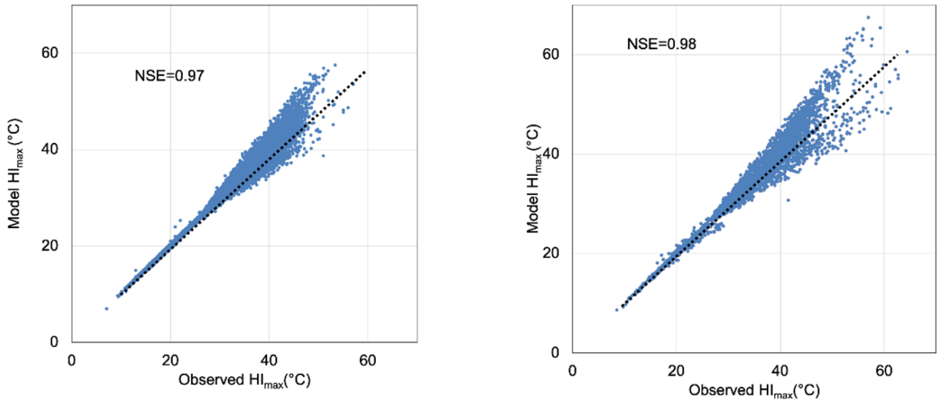

(a) **(b)**

Figure 6. *Scatter plot between Observed HI_{max} and Model HI_{max} during the period 1991-2011 (a) and for the period 2012-2021 (b)*

Number of days with HI_{max} at danger level during 2017-2021

In the first two years from 2017 to 2018, the number of days with HI_{max} at danger levels fluctuated over 60 days per year. In the next three years, i.e. 2019, 2020, and 2021 the number of days with HI_{max} at danger levels exceeded 100 days per year, with an average of 90 days per year for the entire period from 2017 to 2021. There were 2 days with HI_{max} at the extreme danger level in 2021 (*Figure 7*).

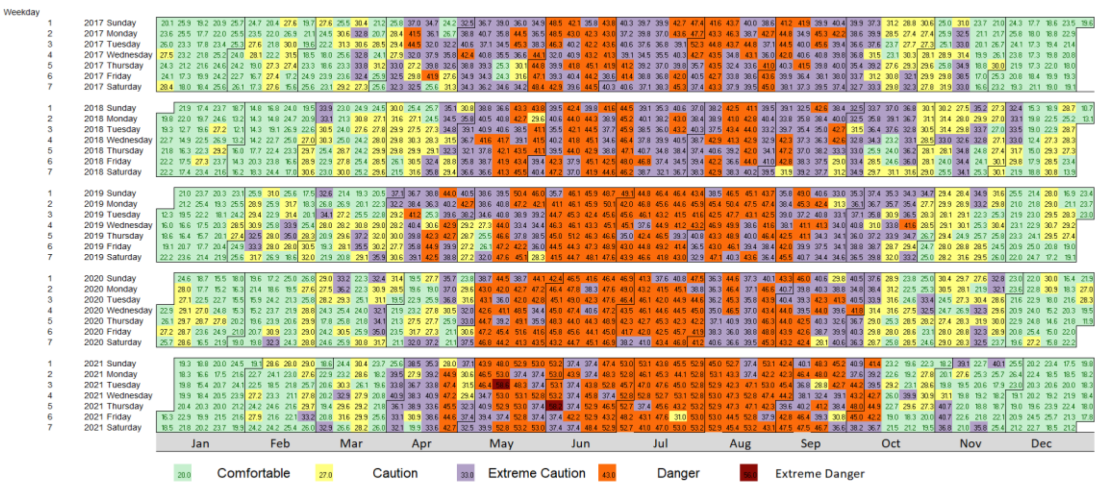

Figure 7. *HI_{max} during the period 2017-2021 (levels of impact on the human body represented by color)*

When analyzing the fluctuation in monthly of HI_{max} in the period 2017-2021, days with HI_{max} at danger levels were mainly concentrated from May to September. The most danger occurred in June at 19.7 days, followed by July with 18.6 days, August with 15.3 days, May with 11.5 days, and September with 5.7 days. This finding is consistent with the climate patterns in Hanoi, where the highest temperature days tend to occur in June. HI_{max} at extremely dangerous levels only appears twice, once in May and once in June 2021.

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Number of days with HI$_{max}$ at danger level for the period 2024-2028 based on the RCP 4.5 scenario

Based on climate change situation for Vietnam in 2020 (RCP 4.5 and RCP 8.5 scenarios) with input being the daily average temperature, daily maximum temperature, daily precipitation, using *Eq.7*, the results obtained are the lowest relative humidity scenario for the future. This minimum relative humidity scenario and the daily maximum temperature of the Vietnam under climate change conditions are inputs to equations 1, 2, 3, 4 and methods illustrated in *Figure 1* to calculate the HI$_{max}$ scenario for the future.

Figure 8 shows that for the period 2024-2028 with reference to the RCP 4.5 scenario, the HI$_{max}$ is as follows: the HI$_{max}$ at the danger level fluctuates from 112 days/year to 139 days/year, the average for the entire period is 126 days/year, 1.4 times more than in the past.

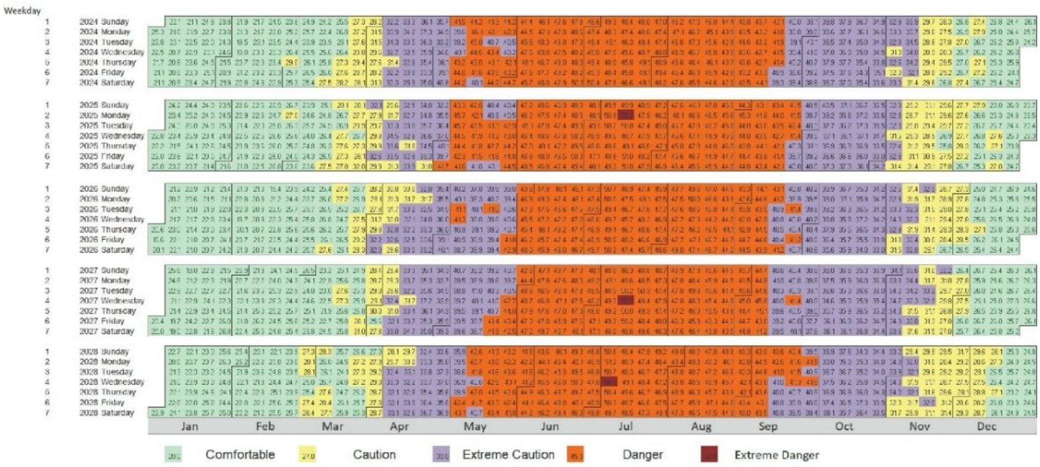

Figure 8. *HImax during the period 2024-2028 according to the RCP 4.5 scenario represented by color*

The HI$_{max}$ at the extreme danger level proceeds as follows. In 2024 and 2026 there is not any day where HI$_{max}$ is at the extreme danger level. In 2025, 2027, and 2028 there is only 1 day. Therefore, the HImax at the extreme danger level is distributed evenly across the years, with about 0.6 days per year, 1.5 times higher than the 2017-2021 period.

Referring to variability in the year, there is not any day with HI$_{max}$ at the danger level from October to April. Days with HI$_{max}$ at the danger level are found in May to September. Notably, the total number of days with HI$_{max}$ at the danger level is evident for every day in June, July, and August. HI$_{max}$ at the extreme danger level remains relatively stable in July with an average of 0.6 days in July/year.

Number of days with HI$_{max}$ at danger level for health during the period 2024-2028 based on the RCP 8.5 scenario

Figure 9 below shows that during the 2024-2028 5-year period, using the RCP 8.5 scenario, the HI has the following characteristics: HI$_{max}$ at the danger level fluctuates from 124 days/year to 144 days/year, with an average of 135 days/year throughout the period. In all years, there are days when HI$_{max}$ is at the extreme danger level, and on average, there are 2.6 days/year with a high risk of causing seizures. It occurs annually and most frequently in the year 2028.

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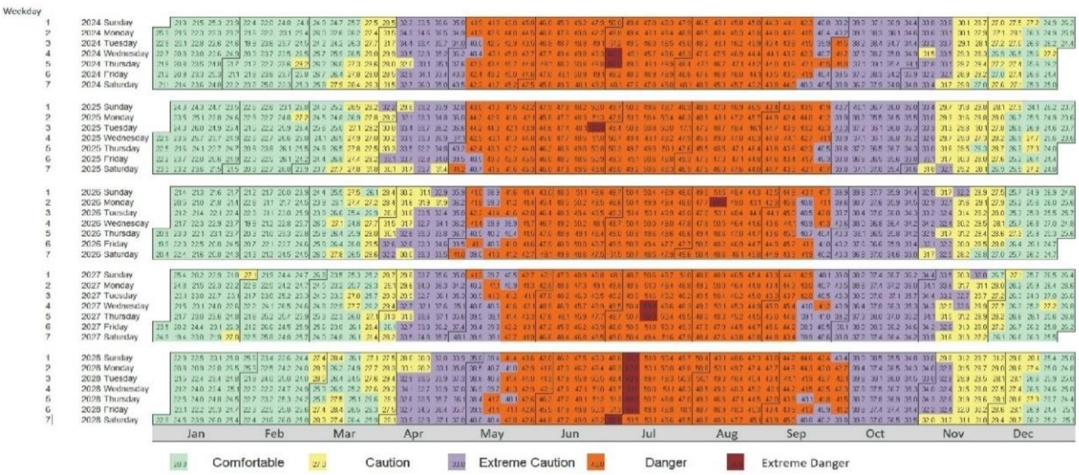

Figure 9. *HI_{max} during the period 2024-2028 with the RCP 8.5 scenario represented by color*

In terms of variability throughout the year, there are no days of HI_{max} at the danger level from November to April. Days of HI_{max} at the danger level are mainly concentrated in June to September. HI_{max} at the danger level occurs on all days of June, July and August. HI_{max} at the extreme danger level appears in the months of June, July and August, but they are concentrated in July with an average of 2.2 days in July/year.

Discussion

Risk of heat stress in the future

Analysis of HI_{max} at the danger level reveals the following. Previously, the climate change trend was relatively clear with more days at the danger level during the 2017-2021 period. Comparing number of days, the danger level of HI_{max} for the RCP 4.5 scenario during 2024-2028 is 90 days/year, while for 2017-2021, there are 126 days/year. Thus, HI_{max} at the danger level according to the RCP 4.5 scenario occurs more than 1.4 -fold more compared to the past. Comparing the number of days, the danger level of HI_{max} in the RCP 8.5 scenario during the years 2024-2028 occurs 1.5 times more than in the past. For the number of days, when comparing the danger level of HI_{max} between RCP 8.5 and RCP 4.5, HI_{max} during the former scenario occurs 1.1 times more than the latter scenario.

Analysis of HI_{max} at extreme danger level shows that during 2017-2021, there were 2 days. However, during 2024-2028, there were 3 extreme days with HI_{max}, according to the RCP 4.5 scenario. This was more than 1.5 times the number of days characterized by extremely high HI_{max} in the past. For the RCP 8.5 scenario, which is 13 days, the number of days with HI_{max} at extreme danger level was 6.5-fold higher than in the past. HI_{max} at extreme danger level under the RCP 8.5 scenario occurs 4.3 times more than under the RCP 4.5 scenario. Thus, the risk of future climate change causing heat shock is very evident, especially with scenario RCP 8.5. Given this warning, the Vietnamese government must find solutions for climate change-triggered problems urgently.

The results also align with the findings of other studies on heat stress (Dao et al., 2023; Chien et al., 2024). What this study does is provide specific timings for the days at risk of heat stress over the next 5 years.

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Risk of heat stress according to the season

Looking at the issue of annual variability for both the past and the future, there are no days at danger level from November to March. In the past, days having HI_{max} at danger level appeared mainly in May to September, but mostly in June, July, and August. Thus, similar to the past, in the future the months of June, July and August have a high number of days with HI_{max} at extreme danger level. However, unlike what happened in the past, on all the days for the three months noted above, HI_{max} at extreme danger level, this is the time when the health risks from heat stress are at their highest. This outcome demonstrates the clear seasonal characteristics of Hanoi's climate featuring cool winter and the deep influence of Arctic air masses blowing in from the north. The results in this study also follow a similar pattern to those documented in studies at nearby meteorological stations (Dao et al., 2023; Chien et al., 2024).

Analysis of HI_{max} at extreme danger level shows that in the past, it only appeared during 2 days in May and June in 2021. However, in the future, HI_{max} at extreme danger level will appear in July with the RCP 4.5 scenario, and in June, July, August with the RCP 8.5 scenario. July marks the month when it is at its most concentrated. The important point is that we have provided specific timeframes for the risk of extremely high HI during 2024-2028, and we hope that this will be very useful information to improve the health of the community.

The results of this study would be more meaningful if combined with statistical data on the number of people with infectious diseases, cardiovascular disease, and respiratory diseases. These are more likely to experience heat stress, as will older people, overweight people, people suffering poor health, and those who are not accustomed to the heat. These are the groups that are easily stressed by heat and they make possible a direct correlation between heat and medical conditions or diseases.

Future research

Our study can be expanded by evaluating the spatial variability of HI in the Red River Delta region, which is a region with high temperatures due to its lowland characteristics and urban heat island effect. This has been caused by rapid urbanization in cities in the region, and the subsequent increase in temperature that is worsening climate change.

Conclusions

The number of days with HI_{max} at a danger level will rise in the future, which is estimated to be 1.4-fold according to the RCP 4.5 scenario and 1.5-fold according to the RCP 8.5 scenario, when assessing the 2017-2021 period. The number of days with HI_{max} > 54°C in the 2017-2021 period amounted to 2, but the number of days with HI_{max} > 54°C according to the RCP 4.5 scenario appeared to be 3 days. Meanwhile according to the RCP 8.5 scenario, it happens on 13 days. Consequently, the number of days that carry a high risk of heat stroke for the human body will increase significantly compared to the past.

In the past and future, days with HI_{max} > 41°C are mainly distributed in June, July, August, but the difference between the past and the future is that in the latter case, every day in June, July, and August represent the danger level. This outcome illustrates the clear seasonal characteristics of the climate in Hanoi city with the winter being deeply influenced by the extremely cold air caused by the northern winds.

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In the past, HI_{max} occurred twice in the months of May and June in 2021, but in the future, HI_{max} focuses mainly on July. Especially with the RCP 8.5 scenario, the number of days with a high risk of heat stroke was 4.3 times higher when compared to the RCP 4.5 scenario. This study represents an important documentary reference for management agencies to urgently improve the healthcare system, modernize equipment, and enhance the capacity of medical staff to respond to days with a high risk of HI_{max}.

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REFERENCES

[1] Ahrens, C. D. (2009): Drought. – In: Meteorology today, USA, Brooks/Cole: 95.
[2] Ahrens, C. D. (2015): Meteorology today: an introduction to weather, climate, and the environment. – Cengage Learning Canada Inc.
[3] Anderson, G. B., Bell, M. L., Peng, R. D. (2013): Methods to calculate the heat index as an exposure metric in environmental health research. – Environmental health perspectives 121(10): 1111-1119.
[4] Chien, N. Q., Hung, D. N., Phuong, C. T., Hien, N. T. T., Chi, L. H., Hien, V. T., Hue, D. T. (2024): Assessment of change on the daily maximum heat index for Thai Binh city (Vietnam). – Applied Ecology and Environmental Research 22(2): 1479-1494.
[5] Dahl, K., Licker, R., Abatzoglou, J. T., Declet-Barreto, J. (2019): Increased frequency of and population exposure to extreme heat index days in the United States during the 21st century. – Environmental Research Communications 1(7): 075002.
[6] Dang, T. N., Honda, Y., Do, D. V., Pham, A. L. T., Chu, C., Huang, C., Phung, D. (2019): Effects of extreme temperatures on mortality and hospitalization in Ho Chi Minh City, Vietnam. – International journal of environmental research public health 16(3): 432.
[7] Dao, N. H. (2013): Assessing the impact of traffic on the effect of heat island Hanoi. – Vietnam Journal of Hydro-Meteorology 626: 46-50.
[8] Dao, N. H., Chi, L. H., Chien, N. Q., Phuong, T. C., Hien, N. T. T., Hien, V. T. (2023): Assessment of the variation on maximum daily heat index in Ninh Binh city. – HNUE Journal of Science 68(1): 133-144.
[9] General Statistics Office (2022): Administrative Unit, Land and Climate. – Statistical Yearbook of Vietnam, Statistical publishing house 44.
[10] Im, E.-S., Pal, J. S., Eltahir, E. B. (2017): Deadly heat waves projected in the densely populated agricultural regions of South Asia. – Science advances 3(8): e1603322.
[11] International Labour Office Marek Harsdorff Mous (2019): Working on a warmer planet: The impact of heat stress on labour productivity and decent work. – International Labour Organization.
[12] IPCC Climate Change (2023): The Physical Science Basis. – IPCC_AR6_WGI_Full_Report. pdf. Retrieved 12 November 2023, from https://www.ipcc.ch/report/ar6/wg1/.
[13] Jacobs, S. J., Pezza, A. B., Barras, V., Bye, J., Vihma, T. (2013): An analysis of the meteorological variables leading to apparent temperature in Australia: Present climate, trends, and global warming simulations. – Global and Planetary Change 107: 145-156.
[14] Kjellstrom, T., Grimshaw, D., van Vuuren, V. (2019): Heat stress is projected to reduce total working hours worldwide by 2.2 per cent and global GDP by US$2,400 billion in 2030. Working on a warmer planet: The impact of heat stress on productivity and decent work. – International Labour Organization 13.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_47094723

[15] Kovats, R. S., Hajat, S. (2008): Heat stress and public health: a critical review. – Annu. Rev. Public Health 29: 41-55.
[16] Li, L., She, D., Zheng, H., Lin, P., Yang, Z-L. (2020): Elucidating diverse drought characteristics from two meteorological drought indices (SPI and SPEI) in China. – Journal of Hydrometeorology 21(7): 1513-1530.
[17] Luo, M., Lau, N. C. (2018): Increasing heat stress in urban areas of eastern China: Acceleration by urbanization. – Geophysical Research Letters 45(23): 13,060-013, 069.
[18] Luo, M., Lau, N-C., Liu, Z., Wu, S., Wang, X. (2022): An observational investigation of spatiotemporally contiguous heatwaves in China from a 3D perspective. – Geophysical Research Letters 49(6): e2022GL097714.
[19] Matveev, L. T. (1976): Atmospheric humidity. – Course of general meteorology, Physics of the atmosphere, Leningrad, Gidrometeoizdat 326.
[20] Moran, D., Shapiro, Y. A., Epstein, Y., Matthew, W., Pandolfi, K. B. (1998): A modified discomfort index (MDI) as an alternative to the wet bulb globe temperature (WBGT). – In: Hodgdon, J. A., Heaney, J. H., Buono, M. J. (eds.) Environmental Ergonomics VIII, pp. 77-80.
[21] Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M. S., Bernabucci, U. (2010): Effects of climate changes on animal production and sustainability of livestock systems. – Livestock Science 130(1-3): 57-69.
[22] National Weather Service (2021): The Heat Index Equation. – Retrieved 19th March, 2023, from https://www.wpc.ncep.noaa.gov/html/heatindex_equation.shtml.
[23] Ngu, N. D., Hieu, N. T. (2004): Climate and climate resources in Vietnam. – Hanoi, Agriculture Publisher.
[24] Opitz-Stapleton, S., Sabbag, L., Hawley, K., Tran, P., Hoang, L., Phuong, H. N. (2016): Heat index trends and climate change implications for occupational heat exposure in Da Nang, Vietnam. – Climate Services 2-3: 41-51.
[25] Phung, D., Chu, C., Rutherford, S., Huong, L. T. N., Cuong, M. D., Huang, C. (2017): Heatwave and risk of hospitalization: A multi-province study in Vietnam. – Environmental Pollution 220: 597-607.
[26] Selye, H. (1936): A syndrome produced by diverse nocuous agents. – Nature 138(3479): 32-32.
[27] Steadman, R. (1984): A universal scale of apparent temperature. – Journal of Applied Meteorology Climatology 23(12): 1674-1687.
[28] Sun, W., Li, Q., Huang, B., Cheng, J., Song, Z., Li, H., Dong, W., Zhai, P., Jones, P. (2021): The Assessment of Global Surface Temperature Change from 1850s: The C-LSAT2.0 Ensemble and the CMST-Interim Datasets. – Advances in Atmospheric Sciences 38(5): 875-888.
[29] Thao, L. B. (2004): Vietnam nature. – Hanoi, Vietnam Education Publishing House.
[30] The University of IOWA (2023): Heat Stress. – Environmental Health & Safety. Retrieved 10 February, 2023, from https://ehs.research.uiowa.edu/occupational/heat-stress.
[31] Thuy, L. T. H., Hung, N. D., Phuong, T. C., Van, T. T. T., Tuan, P. T., Son, T. H., Vu, V. V., Thang, N. N. (2022): Assessing heat index changes in the context of climate change: A case study of Hanoi (Vietnam). – Frontiers in Earth Science 7: 1892.
[32] Vietnam Center of Hydro-Meteorological Data (2024): Hydrometeorological data. – Hà Nội.
[33] Vietnam Ministry of Natural Resources and Environment (2021): Climate change and sea level rise scenarios for Vietnam in 2020. – Retrieved 12, January,2022, 2022, from http://vnmha.gov.vn/upload/files/kich-ban-bien-doi-khi-hau-phien-ban-cap-nhat-nam-2020.pdf.
[34] WMO (2022): Apparent temperature. – Retrieved 19th June, 2022, from https://unterm.un.org/unterm/display/record/unog/na?OriginalId=59108.

[35] WMO (2022): Effective temperature. – Retrieved 19th 2022, 2022, from https://unterm.un.org/unterm/display/record/wmo/na?OriginalId=30f0e9a8-b146-4d52-b404-45d9641cecd2.
[36] WMO (2022): Wet-bulb temperature. – Retrieved 19th June 2022, 2022, from https://unterm.un.org/unterm/display/record/wmo/na?OriginalId=e8962e68-5ed1-4726-b19e-0d35ba539964.
[37] Wu, J., Gao, X., Giorgi, F., Chen, D. (2017): Changes of effective temperature and cold/hot days in late decades over China based on a high-resolution gridded observation dataset. – International Journal of Climatology 37: 788-800.

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