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ASSESSMENT OF CHANGES IN THE DAILY MAXIMUM HEAT INDEX FOR QUANG NINH PROVINCE

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Abstract: In the context of climate change and socio-economic development, the number of hot days in Quang Ninh province has shown an increasing trend in both intensity and frequency. This study utilizes meteorological data from 1991 to 2020, alongside climate change scenario data for Vietnam from 2021 to 2050. Additionally, the research applies the Heat Index (HI) method and employs multivariable linear regression analysis. The results indicate that over the next three decades (2021 - 2050), the trend in the increase of HI_{max} at the danger level (from 41 °C to 54 °C) is projected to be 5.857 - 6.514 weeks/5 years under the RCP 4.5 scenario, and 5.457 - 6.514 weeks/5 years under the RCP 8.5 scenario. Under the RCP 4.5 scenario, the number of days with HI_{max} at the extreme danger level (≥54 °C) is projected to be 22 - 80 days/30 years, whereas under the RCP 8.5 scenario, it is projected to be 35 - 118 days/30 years. Notably, in Quang Ha, the number of days with HI_{max} at the extreme danger level is expected to surge in the future compared to the past (1991 - 2020), increasing by a factor of 4.4 (RCP 4.5) and by a factor of 6.5 (RCP 8.5). Analysis of the spatial distribution of HI_{max} contours reveals significant changes, adhering to a latitudinal rule in the past and transitioning to a non-latitudinal rule in the future. The number of days with a risk of heat stress is expected to be more prevalent and intense in the future than in the past, potentially exerting a negative impact on public health and diminishing the quality of life in Quang Ninh.

Keywords: climate change, heat stress, hot days, heat stroke, Quang Ninh.

1. Introduction

The global temperature increase due to climate change is a pressing global issue. A report from the World Meteorological Organization (WMO) notes that in 2022, the average temperature of the Earth increased by 1.15 °C ± 0.13 °C compared to the pre-industrial period [1]. This record high temperature increase serves as clear evidence of the severe impact of climate change. According to WMO, in 2015, greenhouse gas concentrations reached a record level, with CO_2, CH_4, and N_2O concentrations standing at 144 %, 256 %, and 121 % of their 1750 levels, respectively [2]. Heatwaves are becoming more intense and more frequent, posing a major challenge to the human body's adaptive capacity. During the period from May 30 to September 4, 2022, a total of 4,807 deaths in France were attributed to heat-related causes [3]. In the summer of 2003, Europe recorded more than 70,000 deaths [4]. Severe and prolonged heat has seriously affected all aspects of human life.

Worldwide research has demonstrated a close relationship between heat stress and severe health issues. The study "Heat Stress and Public Health: A Critical Review" applied a time-series regression model to describe the surge in mortality during a heatwave, noting that many sudden heat-related deaths occurred without medical attention [5]. When environmental temperature rises rapidly and remains high, it can trigger clinical syndromes such as heat stroke, heat exhaustion, fainting, and heat cramps [6]. Heat stroke has a very high fatality rate and can quickly progress to death; even survivors may suffer neurological sequelae [7]. Heat stress is extremely dangerous and can occur suddenly in anyone. Individuals requiring special attention include those working outdoors, the elderly, children, and infants [5], and those with pre-existing medical conditions. Heat stress poses a serious threat to the health and work productivity of millions of outdoor laborers worldwide [8]. Especially in tropical regions like Southeast Asia, high humidity amplifies the heat index, intensifying heat stress and adversely affecting public health [9].

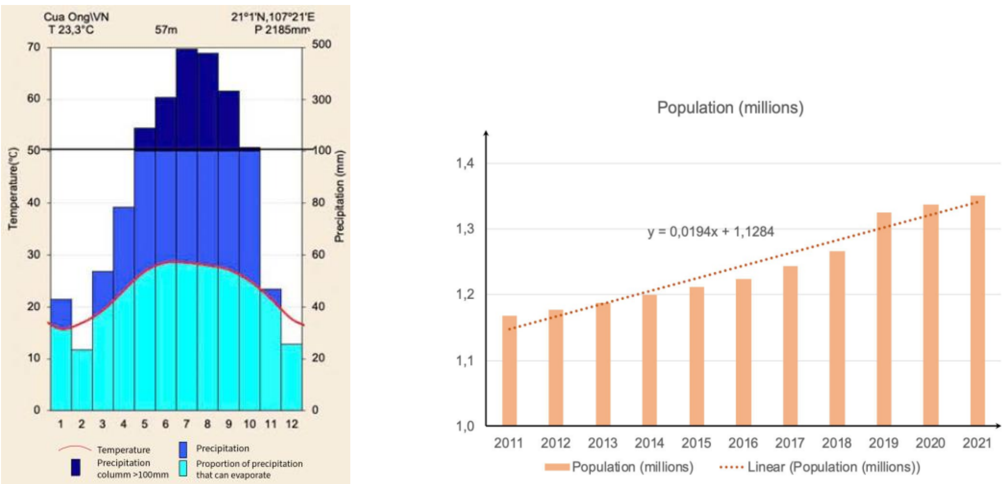
Vietnam's tropical monsoon climate is significantly affected by climate change. Consequently, numerous studies in the country focus on heatwaves and heat stress. In many of Vietnam's provinces, heat waves have led to a notable rise in hospital admissions [10]. A study on heatwaves in Hanoi utilized the Heat Index (HI) methods to evaluate heat-stress levels under RCP 4.5 and RCP 8.5 scenarios. Under both scenarios, heat-stress days are expected to increase; specifically, the annual average of HI_{max} is projected to rise by about 0.0875 °C/year under RCP 4.5 and by 0.09 °C/year under RCP 8.5 for the 2021 - 2050 period [11]. Research conducted in Ninh Binh Province, also using the HI method, shows an upward trend of HI_{max} is 0.100 °C/year (RCP 4.5) and 0.105 °C/year (RCP 8.5) [12]. Quang Ninh Province is located in the major economic region of northern Vietnam, with Ha Long City playing a key role in the area's development triangle. Rapid industrialization and urbanization here are major causes of urban heat-island effects. Increasing frequency, intensity, and duration of heatwaves undermine the quality of life and public health. Heatwaves are further intensified by phenomena like El Niño [13]. A noteworthy example is the long-lasting heat of the summer of 2023, during which local medical centers received about 500 pediatric visits/day and around 450 elderly patients/month [14].

No previous research has focused specifically on heat stress and its impacts on the residents of Quang Ninh in the context of climate change, creating a research gap. This gap is especially significant, given Quang Ninh's unique geography, climate, and rapid socio-economic growth. Therefore, the authors selected the topic, "Assessment of changes in the daily maximum heat index for Quang Ninh Province". The research aims to evaluate historical heat stress patterns, determine future heat-stress conditions under two climate-change scenarios, and map the spatial distribution of heat stress in the study area. On this basis, the study issues relevant warnings and proposes adaptation measures to enhance the quality of life for Quang Ninh's residents.

2. Content

2.1. Study area, data, and research methods

2.1.1. Study area



(a) *(b)*

Figure 1. Bio-climate chart at the Cua Ong Meteorological Station (Quang Ninh) (a) and the chart of average population and population growth trends from 2011 to 2021 in the study area (b)

Quang Ninh Province has a large area of 6,110.8 km^2 [15], geographically spanning approximately 20°42′ - 21°40′N and 106°26′ - 108°05′E [16]. Quang Ninh is a mountainous province in the Northeast mountainous region, endowed with a diverse range of landforms, including hilly and mountainous areas, plains, islands, and a continental shelf. The climate is tropical monsoon, with a northeasterly winter monsoon and a southeasterly summer monsoon. The average temperature is about 22.7 °C - 23.7 °C, and the mean annual humidity is above 80 %. Winter runs from November of the previous year until April, lasting around six months, significantly influenced by the winter monsoon, which lowers temperatures (below 20 °C in January). Summer lasts from May to October, characterized by heat and abundant rainfall, influenced by the summer monsoon, the Intertropical Convergence Zone, and tropical cyclones. The average temperature in July in most parts of the province (except mountainous areas) is over 28 °C.

Quang Ninh Province has a territorial expanse extending from north to south, bordering the sea, and characterized by mountainous terrain. Consequently, the climate in this region is influenced by both latitudinal and non-latitudinal factors.

With a population exceeding 1.35 million (2021) and an upward trend of 0.02 million people/year, Quang Ninh's average population density is 221 persons/km^2 [17].

2.1.2. Research data

This study uses the following data series: daily maximum temperature, daily minimum relative humidity for the period 1991 - 2020 [18], and daily maximum temperature, daily mean temperature, and daily minimum temperature for the period 2021 – 2050 [19].

2.1.3. Key research methods

- Heat index (HI) calculation method

The heat index calculation method (HI) uses meteorological factors from climate change scenarios to interpolate relative humidity (RH) values, from which HI is computed. Commonly, HI is calculated using instantaneous or hourly temperature (T) and relative humidity (RH) data [20]. The heat index (HI) is determined from air temperature in °F(T) and relative humidity in percent (RH). This algorithm is used by the U.S. National Weather Service (NWS) to assess and warn about heat stress levels [21].

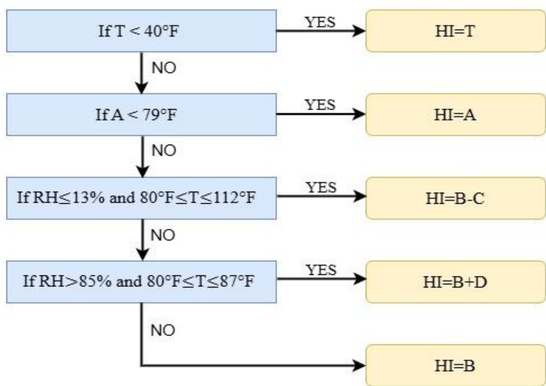


Figure 2. The algorithm used by the NWS to calculate the heat index (HI)

The general algorithms deployed to estimate HI [22] are the following:

$$A = -10.3 + 11 \times T \times RH \quad (1)$$

$$B = -42.379 + 2.049 \times T + 10.14 \times RH - 0.225 \times T \times RH - 6.838 \times 10^{-3} \times T^2 - 5.48 \times 10^{-2} \times RH^2 + 1.23 \times 10^{-3} \times T^2 \times RH + 8.528 \times 10^{-4} \times T \times RH^2 - 1.99 \times 10^{-6} \times T^2 \times RH^2 \quad (2)$$

$$C = \left[\frac{13 - RH}{4}\right] \times \left[(17 - |T - 95|\right]^{0.5} \quad (3)$$

$$D = 0.002 \times (RH - 85) \times (87 - T) \quad (4)$$

These equations require two variables: daily temperature (T) and daily relative humidity (RH). This study applies them to compute the HI_{max}, designated as HI_{max}.

Specifically, the daily maximum temperature (T_{max}) and daily minimum relative humidity (RH_{min}) are used. Daily maximum temperature data are provided by climate-change models, but daily minimum relative humidity is not. Therefore, we estimate it via a multivariable linear regression, described below. Once daily minimum relative humidity and daily maximum temperature have been determined, the daily maximum heat index (HI_{max}) can be calculated. Heat stress values (HI_{max}) are classified into four danger levels based on their impacts on human health, as shown in Table 1.

Table 1. Heat Index classification table

Classification	Heat Index	Effect on the body
Caution	27 °C - 32 °C	Fatigue possibly due to prolonged exposure or physical activity.
Extreme Caution	32 °C - 41 °C	Heat stroke, heat cramps, or heat exhaustion are possible with prolonged exposure or physical activity.
Danger	41 °C - 54 °C	Heat cramps or heat exhaustion are likely, and heat stroke is possible with prolonged exposure or physical activity.
Extreme Danger	≥ 54 °C	Heat stroke is highly likely.

Source: [22]

- *Multivariable linear regression*

In a multivariable linear regression [23], the outcome variable depends on independent variables in a linear form, as follows:

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

where *y*: dependent variable; *a*: constant; x_{ij}: independent variable; b_j: the regression coefficient of the independent variable; x_{ij}; *i*: the i^{th} observation.

The model allows for the calculation of the regression coefficient bi for each independent variable x_{ij}. The study employs a multivariable regression equation to determine the lowest daily relative humidity based on the meteorological factors in the climate change scenarios. Subsequently, the HI_{max} value is determined based on the lowest daily relative humidity and the highest daily temperature.

- Nash - Sutcliffe Efficiency (NSE):

The Nash-Sutcliffe efficiency coefficient (NSE) is used to assess the reliability between observed values and model-computed values [24]. The formula is

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

where HI_{model}^{t} is model HI_{max} at day t

HI_{ob}^{t} is observed HI_{max} at day t

$\overline{HI}_{ob}$ is the average observed HI_{max} during the simulation period T

NSE values closer to 1 indicate a more reliable model.

- Geographic Information Systems (GIS):

The topographic map of Quang Ninh Province was created using GADM data on the ArcMap application. The author applied spatial interpolation [25] using data from four known points, specifically from four meteorological stations (Tien Yen, Uong Bi, Quang Ha, and Cua Ong), to estimate values at unknown points. Based on this, the author generated HI isopleths, producing spatial distribution maps of HI_{max} at the danger level and HI_{max} at the extreme danger level. As a result, the author developed six spatial distribution maps of HI_{max} for Quang Ninh during the periods 1991 - 2020 and 2021 - 2050.

In addition, this study uses other methods: data collection and processing, analysis and synthesis, comparison, and field surveys.

2.2. Research results

2.2.1. Calibration

In this study, it emerged that there is a good correlation between the dependent variable (RH_{min}) and the independent variables (daily maximum temperature, daily mean temperature, daily precipitation). Using SPSS software for data from 01/01/1991 to 31/12/2010 to calculate for all 4 meteorological stations (Tien Yen, Cua Ong, Quang Ha, and Uong Bi) in the study area, the study developed a regression equation (7) between RH_{min} and T_{max}, T_{mean} and T_{min}.

$$RH_{\min} = 88.879 - 4.038 \times T_{\max} + 0.533 \times T_{mean} + 3.948 \times T_{\min} \quad (7)$$

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

T_{min}: daily minimum temperature; T_{mean}: daily mean temperature.

The regression results using the Cua Ong station as a representative are as follows:

The adjusted $R^2 > 0.62$ indicates that the independent variables can explain more than 62 % of the RH_{min}, providing a solid foundation for constructing a complex regression equation between the independent and dependent variables. The Durbin-Watson value of 1.0 suggests that there is no first-order autocorrelation in the residuals, indicating that the model does not suffer from $RH_{\min} = 88.879 - 4.038 \times T_{\max} + 0.533 \times T_{mean} + 3.948 \times T_{\min}$ m serial correlation issues. The F-test results show that the Sig value is less than 0.05, confirming that the regression model is suitable. Additionally, the Sig value in the t-test for the regression coefficients is also less than 0.05, indicating that the independent variables have a significant effect on the dependent variable. Based on the histogram (Figure 3b), it is evident that the regression standardized residuals have a mean close to 0 and a standard deviation (Std. Dev) of 1, indicating that the residuals are normally distributed. The P-P plot (Figure 3a) shows that the residuals are distributed along the diagonal, confirming that the assumption of normal distribution of the residuals holds and the regression equation is reliable.

Thus, the regression equation (7) can be used to predict the daily minimum relative humidity (RH_{min}) in the future, based on T_{max}, T_{mean}, and T_{min} values derived from climate change and sea level rise scenarios for Vietnam [19].

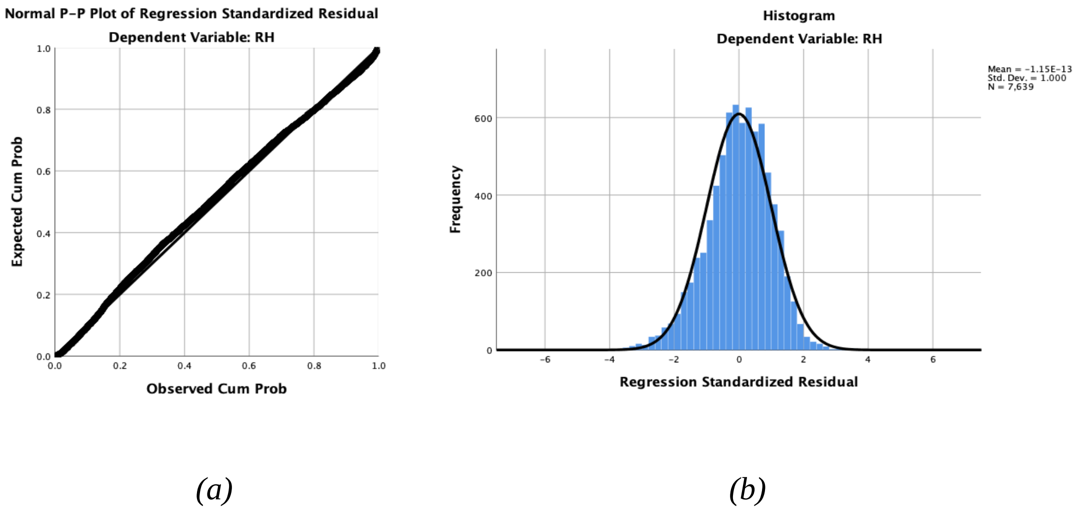


Figure 3. Normal P-P plot of regression standardized residual dependent variable: RH (a) histogram dependent variable: RH (b)

2.2.2. Validation

The HI_{max} model was validated with data from 01/01/2011 to 31/12/2020. In Cua Ong station (Figure 4), a strong correlation between the observed and modeled values was found, as reflected by an NSE of 0.96. These results suggest that the model is capable of simulating HI_{max} under future climate change scenarios.

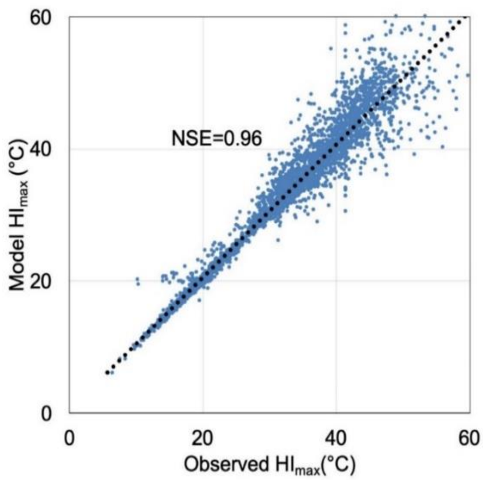


Figure 4. Scatter plot between observed HI_{max} and mode HI_{max} for the period 2011 - 2020

2.2.3. Temporal variation

**** The number of days with HI_{max} at danger level***

During the historical period 1991 - 2020, the four meteorological stations recorded 145 - 251 days at a dangerous level HI_{max}: Quang Ha (145 days), Tien Yen (198 days), Cua Ong (224 days), and Uong Bi (251 days).

In the future 2021 - 2050, under the RCP 4.5 scenario, the number of days with HI_{max} at danger level ranges from 384 to 434 days; specifically, Tien Yen (384 days), Uong Bi (417 days), Cua Ong (429 days), and Quang Ha (434 days). Under RCP 8.5, it is 418 - 454 days: Tien Yen (418 days), Uong Bi (440 days), Cua Ong (444 days), Quang Ha (454 days). Both scenarios project a substantial increase from past values. Under RCP 4.5, Uong Bi's figure grows by 1.7 times, Tien Yen and Cua Ong by 1.9 times, and Quang Ha by 3 times. Under RCP 8.5, the increases are even more severe: 1.8 times (Uong Bi), 2 times (Cua Ong), 2.1 times (Tien Yen), and 3.1 times (Quang Ha).

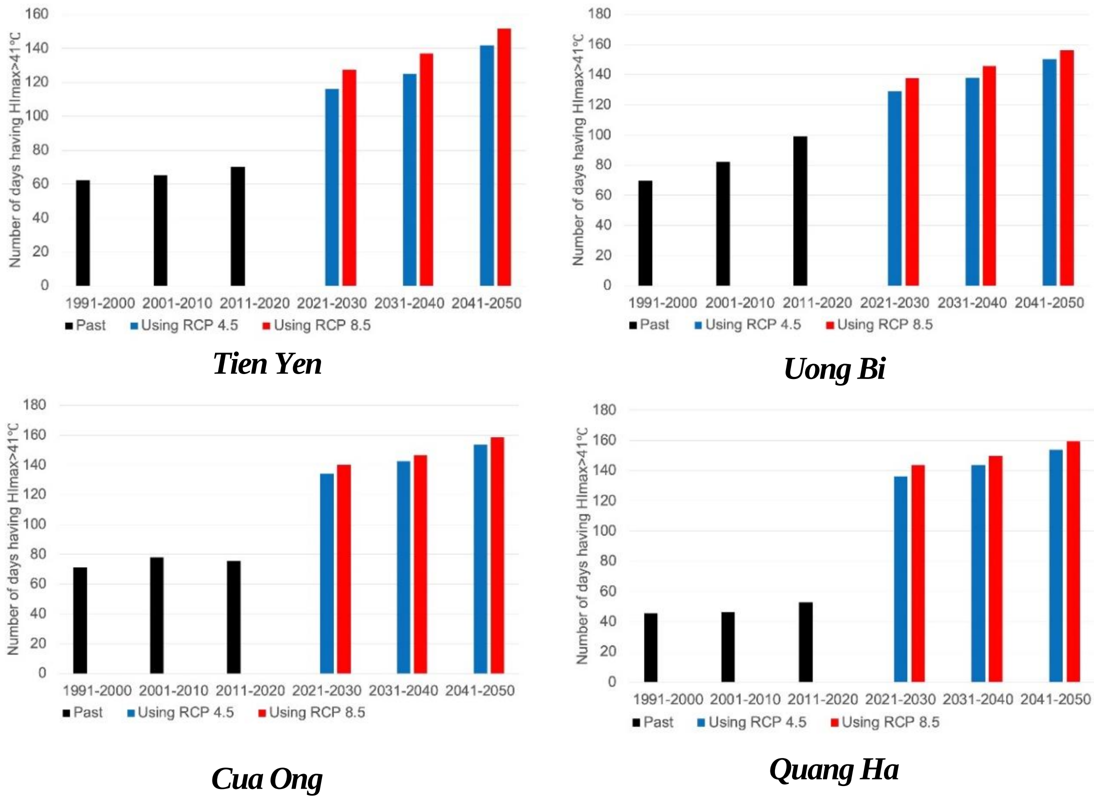


Figure 5. Variation in the number of days with HI_{max} at the danger level during the periods 1991 - 2020, and 2021 - 2050 under the RCP 4.5 and RCP 8.5 scenarios at four meteorological stations in Quang Ninh Province

**** The number of weeks with HI_{max} at danger level***

Based on the regression equation for the four HI_{max} variation charts at the danger level, the R^2 value indicates that the regression model is reliable, showing a strong correlation between HI and time. According to the regression equation for the climate change scenarios, both scenarios exhibit a degree of reliability with $R^2 > 0.62$. This suggests that the increasing trend of HI_{max} is reliable for use in this study. Under the RCP 4.5 scenario, the number of weeks with HI_{max} at the danger level is expected to increase, with an average increase of 5.857 - 6.514 weeks/5 years. Under the RCP 8.5 scenario, the number of weeks with HI_{max} at the danger level is projected to increase by 5.457 - 6.514 weeks/5 years.

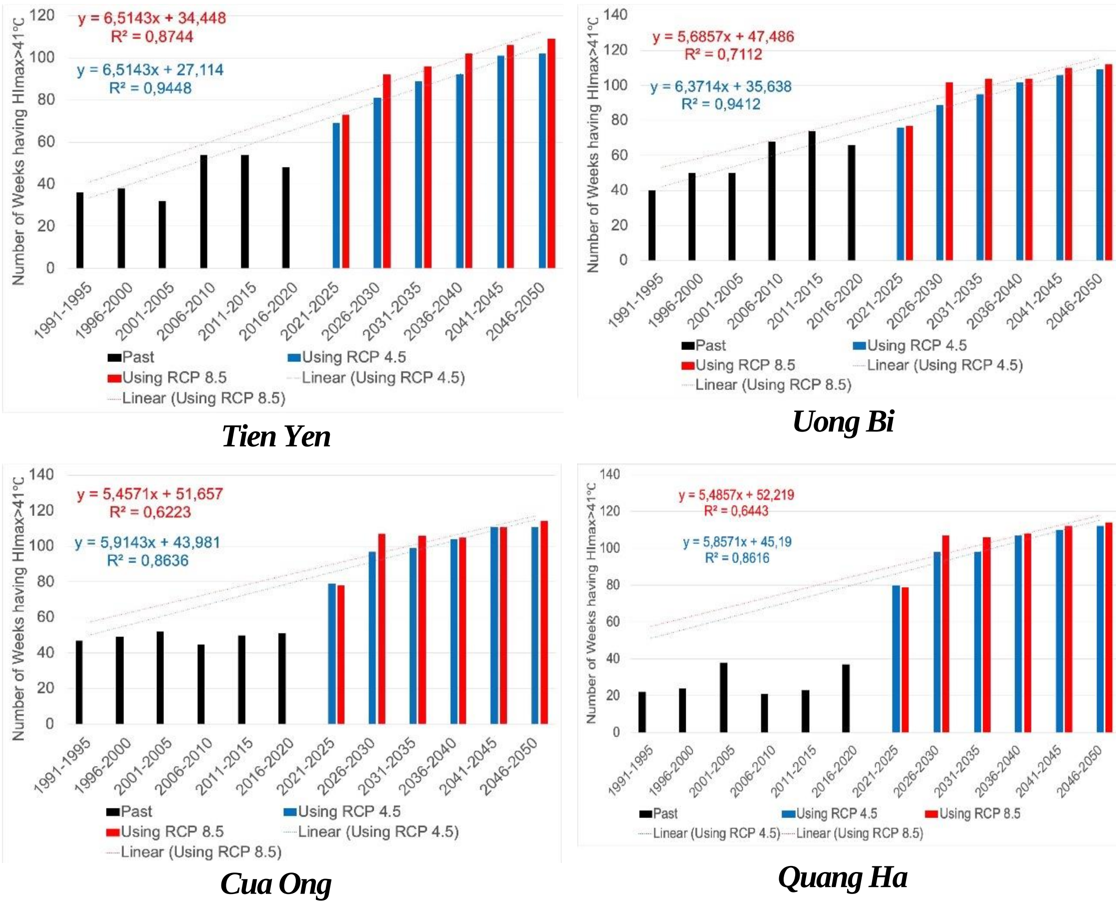


Figure 5. Variation in the number of weeks with HI_{max} at the danger level during the periods 1991 - 2020, and 2021 - 2050 under the RCP 4.5 and RCP 8.5 scenarios at four meteorological stations in Quang Ninh Province

**** The number of days with HI_{max} at an extreme danger level***

The extreme danger of HI is a combination of high temperature and humidity, with an HI value of ≥ 54 °C. With such high heat stress values, the incidence of heatstroke on these days will increase, posing a threat to human life.

The variation in the number of days with HI_{max} at the extreme danger level shows an increasing trend over time, with a 30-year cycle. During the past period (1991 - 2020), the total number of days with HI_{max} at the extreme danger level was from 18 to 25 days/30 years. In the future, under the RCP 4.5 climate change scenario, the number of days with HI_{max} at the extreme danger level ranges from 22 to 80 days/30 years. Under the RCP 8.5 scenario, this increases to 35 to 118 days/30 years. Notably, in Quang Ha, the number of days with HI_{max} at the extreme danger level will increase rapidly in the future compared to the 1991 - 2020 period. Under the RCP 4.5 scenario, this figure will increase by 4.4 times, and under the RCP 8.5 scenario, the increase will be even more alarming, reaching 6.5 times.

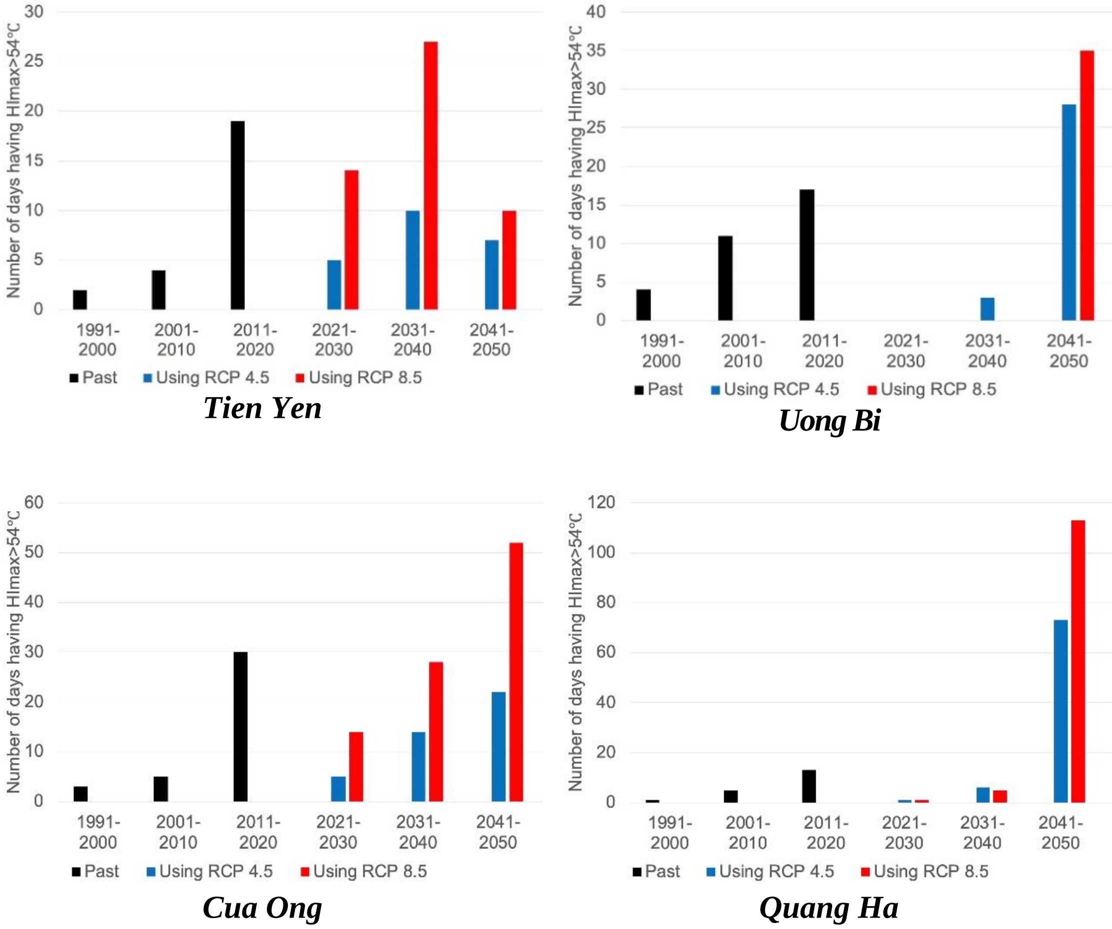


Figure 6. Variation in the number of days with HI_{max} at the extreme danger level during the periods 1991 - 2020, and 2021 - 2050 under the RCP 4.5 and RCP 8.5 scenarios at four meteorological stations in Quang Ninh Province

2.2.4. Spatial variation

**** Spatial distribution of the number of days with HI_{max} at danger level***

Figure 8 shows the spatial distribution of the number of HI_{max} days/year at the danger level during the period 1991 - 2020, following a latitudinal rule. Moving from north to south or towards lower latitudes, the number of HI_{max} days increases, with the HI_{max} contours gradually rising from 50 days to 80 days. The southern part of the study area experiences the highest number of HI_{max} days/year. In addition to the latitudinal rule, the map also illustrates the spatial distribution of HI_{max} according to a non-latitudinal rule. This is due to the topography of high mountains (where temperature decreases with altitude) and proximity to the sea (where temperatures are more moderated). As a result, the HI_{max} contours do not pass through high mountain regions, and their values tend to be lower as they move towards the coastline.

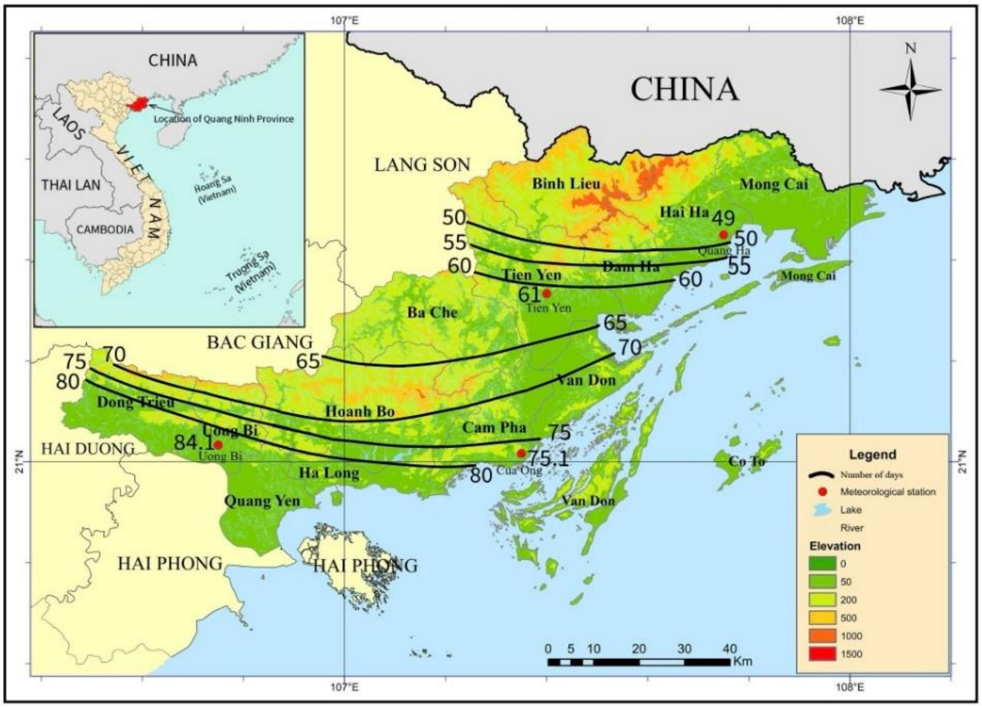


Figure 7. Spatial distribution of the annual number of days with HI_{max} at the danger level in Quang Ninh province during the period 1991 – 2020

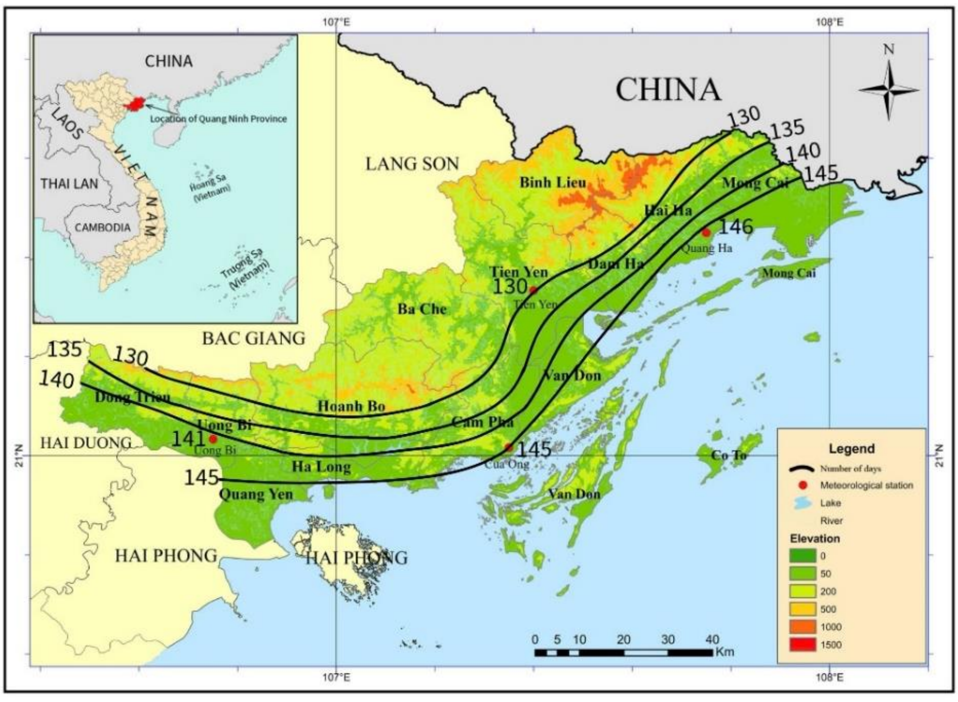


Figure 8. Spatial distribution of the annual number of days with HI_{max} at the danger level under the RCP 4.5 scenario in Quang Ninh Province during the period 2021 - 2050

Figure 9 clearly illustrates the spatial distribution of the number of HI_{max} days/year at the danger level under the RCP 4.5 climate change scenario for the period 2021 - 2050. In the next three decades, the spatial distribution in the study area mainly follows a non-latitudinal rule, specifically related to the topography. Additionally, the HI_{max} contours are densely distributed in the eastern and southern parts of the study area, where the terrain is flat. The contours follow the topography, with values increasing gradually from west to east, specifically with contour values from west to east in the order of 130, 135, 140, and 145.

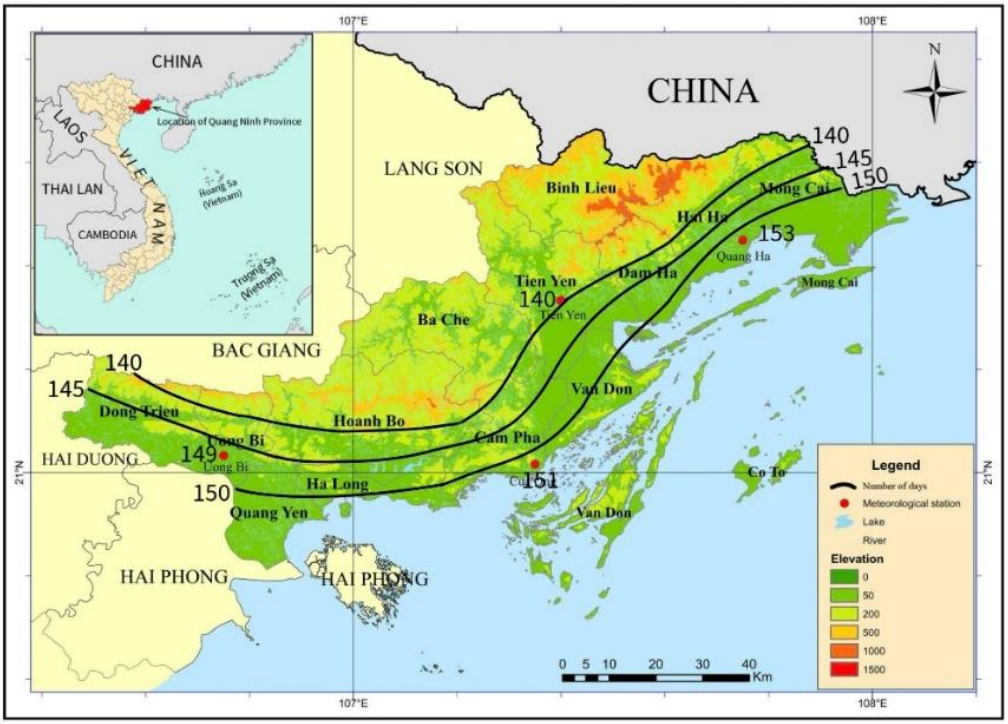


Figure 9. Spatial distribution of the annual number of days with HI_{max} at the danger level under the RCP 8.5 scenario in Quang Ninh Province during the period 2021 - 2050

Figure 10 shows the distribution of HI_{max} contours according to the topography, with values increasing gradually from west to east. The HI_{max} contours are concentrated in the eastern and southern parts of the study area. Under the RCP 8.5 scenario, the values of the HI_{max} contours increase significantly, with values from west to east being 140, 145, and 150, respectively.

**** Spatial distribution of the number of days with HI_{max} at extreme danger level***

Based on Figure 11, the spatial distribution of the number of HI_{max} days/year at the extremely dangerous level during the period 1991 - 2020 follows a latitudinal rule. This latitudinal distribution is evident in that as one moves toward lower latitudes, the number of HI_{max} days increases, with the HI_{max} contours gradually rising from 0.8 to 1.5.

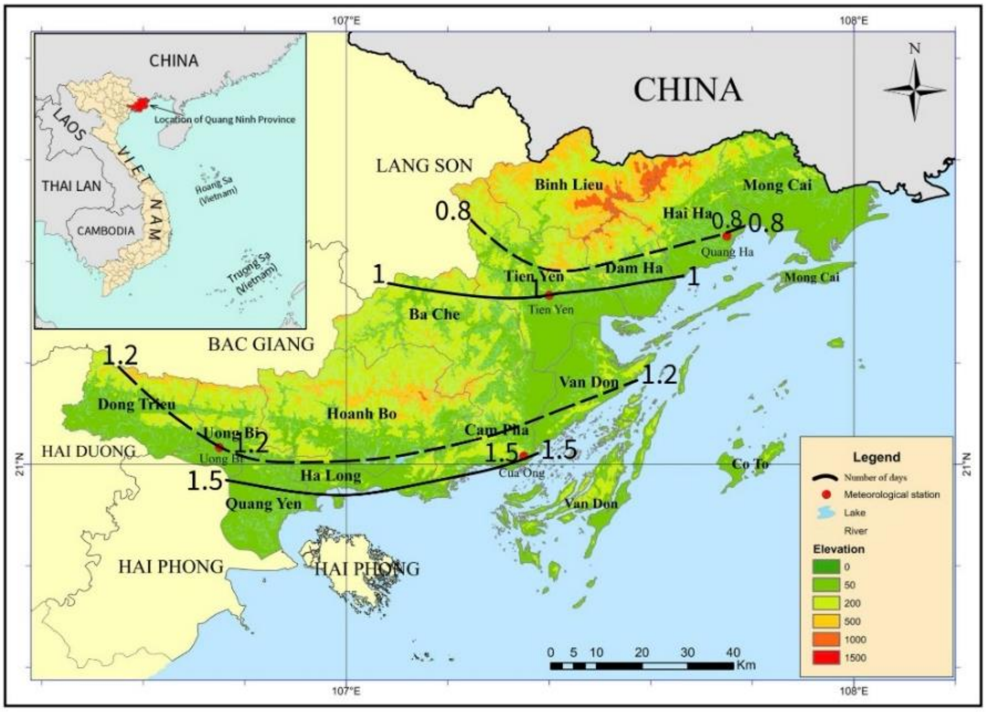


Figure 10. Spatial distribution of the annual number of days with HI_{max} at the extreme danger level in Quang Ninh province during the period 1991 - 2020

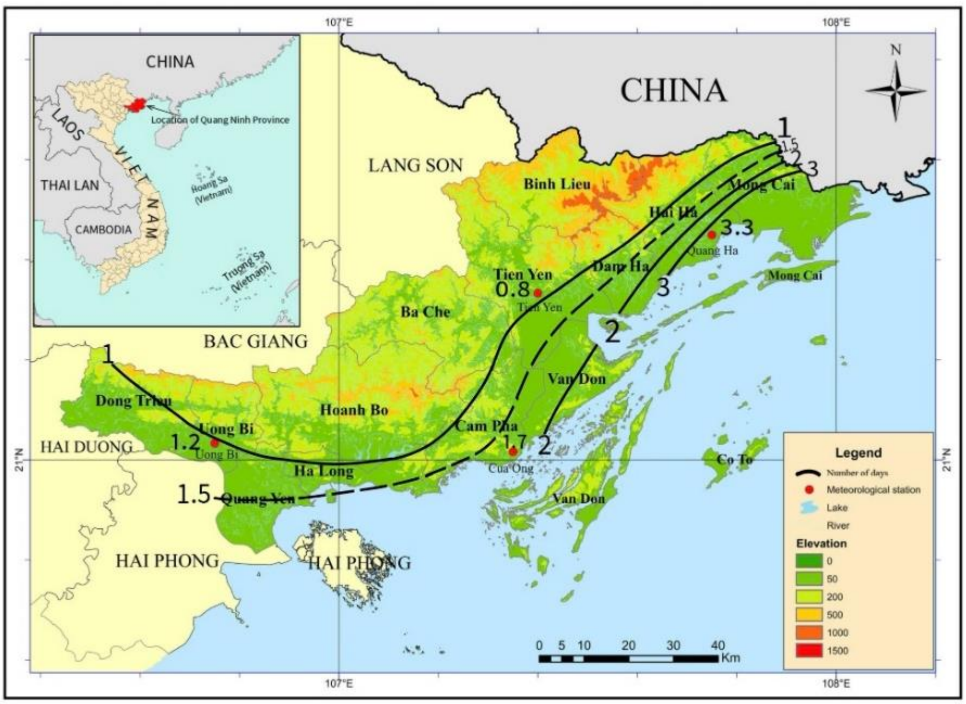


Figure 11. Spatial distribution of the annual number of days with HI_{max} at the extreme danger level under the RCP 4.5 scenario in Quang Ninh province during the period 2021 - 2050

Figure 12 clearly illustrates the spatial distribution of the number of HI_{max} days/year at the extremely dangerous level under the RCP 4.5 climate change scenario for the period 2021 - 2050. In the future, within the study area, the spatial distribution primarily follows a latitudinal rule, specifically influenced by topography. The contours conform to the terrain and exhibit a gradual increase in values from west to east, specifically with values of 1, 1.5, 2, and 3, respectively.

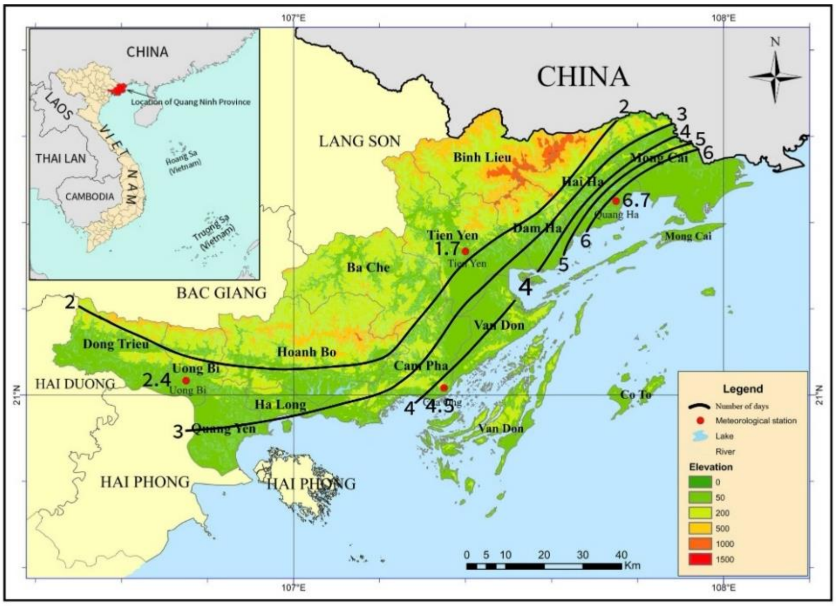


Figure 12. Spatial distribution of the annual number of days with HI_{max} at the extreme danger level under the RCP 8.5 scenario in Quang Ninh province during the period 2021 - 2050

Figure 13 illustrates the spatial distribution of the number of HI_{max} days/year at the extremely dangerous level under the RCP 8.5 climate change scenario for the period 2021 - 2050 in Quang Ninh. The HI_{max} contours follow the terrain and increase gradually from west to east. Under the RCP 8.5 scenario, the HI_{max} contour values increase progressively from west to east, with values of 2, 3, 4, 5, and 6, respectively. In the western regions, such as Tien Yen and Uong Bi, the HI_{max} values are 1.7 and 2.4, respectively, which are lower than those in the eastern areas of Quang Ha (6.7) and Cua Ong (4.5). Notably, in the northeastern part of Quang Ninh, the presence of HI_{max} contours with very high values (5 and 6) results in a dense concentration of heat contours in that region.

2.3. Discussion

Quang Ninh Province is facing an increasingly severe issue of heat stress as a result of climate change. Even under the low greenhouse gas emission scenario (RCP 4.5), the number of weeks with HI_{max} at the danger level is projected to increase by an average of 5.857 to 6.514 weeks/5 years. This indicates that, despite efforts to mitigate climate change, the frequency of heat stress days will continue to rise. Under the high emission scenario (RCP 8.5), the situation is even more severe, with 5.457 to 6.514 weeks of HI_{max} at the danger level/5 years, suggesting that heat stress events could occur more frequently in the future. Consequently, residents, particularly outdoor workers, individuals engaged in physical activity, children, the elderly, and those with pre-existing conditions will be at a heightened risk of heat cramps, exhaustion, and even severe heatstroke. The occurrence of heatstroke is expected to become more common, characterized by sudden episodes of unconsciousness accompanied by shortness of breath and exhaustion. Severe cases of heatstroke may lead to neurological damage, resulting in acute cerebellar dysfunction, loss of speech, and rigidity.

The number of days with HI_{max} at the extreme danger level is projected to increase in the future. Under the RCP 4.5 climate change scenario, there will be 22 - 80 days/30 years with HI_{max} at extreme danger level, while under the RCP 8.5 scenario, this range is expected to be 35 - 118 days/30 years. In Quang Ha, the situation is particularly alarming, as the number of days with HI_{max} at extreme danger level is projected to surge by a factor of 4.4 under RCP 4.5 and up to 6.6 under RCP 8.5 compared to historical values. With such high heat stress levels, the incidence of stroke is expected to increase, potentially leading to fatalities. Even if patients survive heat-induced strokes, they may suffer from multiorgan dysfunction [26] and neurological sequelae [7].

The spatial distribution of the number of HI_{max} days clearly illustrates the changes depicted in the six maps (Figure 8 through 13). Both maps representing the past 30-year period (Figures 8 and 11) show that the HI_{max} contours gradually increase from north to south, following a latitudinal rule. However, the four maps representing the future 30-year period (Figures 9, 10, 12, and 13) reveal that the HI_{max} contours follow the terrain. In these future maps, the HI_{max} contours are concentrated in the eastern part of the province, with values gradually increasing from west to east, thus following a non-latitudinal rule. In the past, the phenomenon of heat stress in Quang Ninh primarily followed the principles of the latitudinal climate, influenced by the angle of solar radiation. However, in the context of climate change, atmospheric circulation factors are increasingly playing a more significant role. Air masses from the sea have a stronger impact, especially as temperatures rise. Therefore, in the future, the phenomenon of heat shock in Quang Ninh will be mainly governed by non-latitudinal factors, rather than being solely influenced by latitudinal factors as it was in the past. This trend is attributed to the fact that the eastern region is densely populated, with urban areas and active economic development. Notably, compared to the other maps, Figure 12 and 13 which illustrate the spatial distribution of the number of HI_{max} days/year at the extreme danger level under the two climate change emission scenarios exhibit a distinctive feature in the northeastern part of Quang Ninh Province, where the HI_{max} contours are densely distributed with high values. In the future, the northeastern region is projected to be the most strongly affected by heat stress.

In summary, under the trend of climate change, severe heat waves are increasingly frequent and intense, significantly impacting human health and posing challenges to community health services and local population protection. The study offers several adaptation strategies to mitigate heat stress and safeguard public health during extreme heat events. Every resident in Quang Ninh should continuously monitor public information and update weather forecasts, especially during the summer. Citizens are encouraged to proactively adjust their daily routines by ensuring adequate hydration and nutrition to enhance their immunity, as well as selecting appropriate sun protective clothing that facilitates heat dissipation. Moreover, it is advisable to limit outdoor activities during the peak hours of 11:00 a.m. to 3:00 p.m., when UV radiation is at its strongest [27]. Vulnerable groups that are particularly at risk for heat stress include the elderly, young children, individuals with pre-existing conditions, and outdoor workers.

3. Conclusions

Based on the study, the authors draw the following conclusions:

- The trend in heat stress events in Quang Ninh is consistent with the broader trend of climate change. Under both future climate change scenarios, the incidence of heat stress events is projected to increase rapidly. According to the regression equation for the RCP 4.5 scenario, the average number of weeks with HI_{max} at the danger level increases by 5.867 - 6.514 weeks/5 years. For the RCP 8.5 scenario, the corresponding increase is 5.457 - 6.514 weeks/5 years.

- In the future period of 2021 - 2050, the occurrence of days with HI_{max} at the extreme danger level (HI ≥ 54 °C) will become more frequent. The number of days with an extreme danger heat index is projected to range from 22 days/30 years to 80 days/30 years under the RCP 4.5 scenario and from 35 days/30 years to 118 days/30 years under the RCP 8.5 scenario.

- The spatial differentiation of the number of HI_{max} days across the province exhibits marked changes. Over the past 30 years, the HI_{max} contours have gradually increased from north to south, following a latitudinal rule. However, in the next 30 years, the HI_{max} contours in the study area will be predominantly distributed in the eastern and southern regions, with the contours meandering according to topography and their values increasing progressively from west to east, thereby following a non-latitudinal rule. In the future, the northeastern region is projected to be the most strongly affected by heat stress.

- Heat stress is a factor that negatively affects public health and reduces the quality of life for residents in Quang Ninh Province. It can lead to muscle cramps or heat-induced exhaustion, and if not treated promptly, may result in stroke or even death.

The authors offer the following recommendations:

- To elucidate the relationship between extreme heat and heat stress among the population, it is necessary to collect statistical data on the number of emergency cases related to heat-induced illnesses.

- Invest in healthcare infrastructure and strengthen the medical workforce to ensure sufficient healthcare services for patients suffering from heat stress; additionally, increase the number of healthcare personnel trained in the treatment of heat-related illnesses.

- The Quang Ninh provincial authorities should prioritize the establishment of an early warning system for heat stress, enabling residents to take proactive preventive measures. In addition, they should provide weather forecasts, particularly those detailing the anticipated levels of heat stress during the summer months.

- Promote public awareness of disaster adaptation and educate the younger generation in schools about the impacts of extreme heat and prevention strategies. Local educational programs should emphasize climate change, natural disasters, and sustainable development.

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