Climate change impacts on health in Viet Nam, COP 26, AFD GEMMES

Manh-Hung Nguyen

▶ To cite this version:

Manh-Hung Nguyen. Climate change impacts on health in Viet Nam, COP 26, AFD GEMMES. Climate change in Viet Nam, impacts and adaptation: a COP26 assessment GEMMES Viet Nam project, pp.144-176, 2023. hal-04044520

HAL Id: hal-04044520

https://hal.inrae.fr/hal-04044520

Submitted on 24 Mar 2023

Chapter 3

Climate change impacts on health in Viet Nam

COORDINATOR

Manh-Hung Nguyen [TSE, INRAE]

AUTHORS

Manh-Hung Nguyen [TSE, INRAE]
Nguyen Viet Cuong [MDRI]
Nguyen Lan Anh [IREEDS]
Toan Nguyen [Queensland Univ]
Aditya Goenka [Birmingham Univ]

REVIEWERS

Nguyen Thanh Chung [NIHE, Ministry of Health]
Vo Tat Thang [HAPRI]

Abstract

In this chapter, we look at the effects of climate variability on a range of tropical diseases and on general mortality. We find a strong impact of temperature on vector-borne and water-borne disease, where the incidence of infection is significantly decreased at temperatures below 15°C, but increased on the bin above 30°C for vector-borne disease. The impact is weaker on airborne diseases than the two other types. The effect of weather changes on the incidence of major diseases differs by climate region. Provinces located in the South and Southern Central Coast appear to have a higher level of sensitivity to infections at 15°C–18°C temperatures than other provinces. Regarding mortality, we find robust evidence on the positive effects of cold and heat waves on mortality. An additional day in a cold wave is estimated to increase the monthly mortality rate by 0.6%. The corresponding figure for a day in a heat wave is 0.7%. The effect of cold waves as well as heat waves tends to increase when the cold and heat waves last for a longer time. Compared with a cold wave, the effect of a heat wave on the mortality rate is more significant and of a larger magnitude. All climate change scenarios also imply an increase in the number of heat waves with a clear impact on mortality.

KEYWORDS
Climate change # Infectious disease # Mortality # Health policy # Viet Nam

Tóm tắt

Chương này xem xét tác động của biến đổi khí hậu đối với một loạt các bệnh nhiệt đới và tỷ lệ tử vong nói chung. Kết quả cho thấy tác động mạnh của nhiệt độ đối với bệnh lây truyền qua véc tơ và nguồn nước, trong đó tỷ lệ nhiễm bệnh giảm đáng kể ở nhiệt độ dưới 15°C, nhưng tăng lên trên ngưỡng 30°C đối với bệnh do véc tơ truyền. Tác động được tìm thấy yếu hơn đối với các bệnh lây truyền qua đường không khí so với hai loại nêu trên.

Ảnh hưởng của biến đổi khí hậu đến tỷ lệ mắc các bệnh nhiệt đới chính là khác nhau tùy theo vùng khí hậu của Việt Nam. Các tỉnh phía Nam và duyên hải Nam Trung Bộ có mức độ dễ bị nhiễm bệnh ở nhiệt độ từ 15°C–18°C cao hơn các tỉnh còn lại. Về tỷ lệ tử vong, chúng tôi tìm thấy bằng chứng rõ ràng về tác động gia tăng của các đợt nóng và lạnh đối với tỷ lệ tử vong. Thêm một ngày trong đợt lạnh được ước tính sẽ làm tăng tỷ lệ tử vong hàng tháng thêm 0,6%. Con số tương ứng cho một ngày trong đợt nắng nóng là 0,7%. Ảnh hưởng của các đợt nóng, lạnh có xu hướng gia tăng khi các đợt rét đậm, rét hại càng kéo dài. So với một đợt lạnh, ảnh hưởng của một đợt nắng nóng lên tỷ lệ tử vong là đáng kể hơn và có cường độ lớn hơn. Tất cả các kịch bản biến đổi khí hậu cũng hàm ý sự gia tăng số lượng các đợt nắng nóng với tác động rõ ràng đến tỷ lệ tử vong.

TỪ KHÓA
Biến đổi khí hậu # Bệnh truyền nhiễm # Tỷ lệ tử vong # Chính sách y tế # Việt Nam

Résumé

Dans ce chapitre, nous examinons les effets de la variabilité climatique sur une série de maladies tropicales et sur la mortalité générale. Nous constatons un fort impact de la température sur les maladies vectorielles et hydriques, où l'incidence de l'infection est significativement réduite à des températures inférieures à 15°C, mais augmentée au-dessus de 30°C, particulièrement pour les maladies vectorielles. L'impact est en revanche plus faible sur les maladies transmises par l'air que sur les deux autres types. L'effet des changements climatiques sur l'incidence des principales maladies tropicales diffère selon la région climatique du Viet Nam. Les provinces situées dans le sud et la côte centrale sud semblent avoir un niveau de sensibilité aux infections plus élevé à des températures de 15°C–18°C que les autres provinces. En ce qui concerne la mortalité, nous trouvons des preuves solides d'effets positifs des vagues de froid et de chaleur sur la mortalité. On estime qu'un jour supplémentaire dans une vague de froid augmente le taux de mortalité mensuel de 0,6%. Le chiffre correspondant pour un jour de vague de chaleur est de 0,7%. L'effet des vagues de froid et de chaleur tend à s'accentuer lorsque les vagues de froid et de chaleur durent plus longtemps. Par rapport à une vague de froid, l'effet d'une vague de chaleur sur le taux de mortalité est plus significatif et d'une plus grande ampleur. Tous les scénarios de changement climatique impliquent par ailleurs une augmentation du nombre de vagues de chaleur avec un net impact sur la mortalité.

MOTS CLÉS
Changement climatique # Maladies infectieuses # Mortalité # Politique de santé
Viet Nam.

1. Introduction

A direct effect of weather extremes is the deterioration of health of individuals. High temperature is found to be associated with cardiovascular, respiratory, cerebrovascular and blood cholesterol problems [Huynen *et al.*, 2001; Barreca *et al.*, 2016]. Climate variability can also affect the survival rate, and transmission of viruses and bacteria. There is extensive evidence on the positive association between temperature and infectious diseases [*e.g.*, Jahani and Ahmadnezhad, 2011; Levy *et al.*, 2016; Wu *et al.*, 2016].Extreme weather can increase mortality and malnutrition in children [*e.g.* Deschenes and Moretti, 2009; Anderson *et al.*, 2011; Deschenes and Greenstone, 2011; Simeonova, 2011; Barreca *et al.*, 2016]. In-utero exposure to extreme weather returns low birth weights [*e.g.*, Deschênes *et al.*, 2009].

Although there is no doubt about the harmful effect of extreme weather and climate events, there is no consistency in the magnitude of the effect on health and disease infection [*e.g.*, see review from Nichols *et al.*, 2009; Jahani and Ahmadnezhad, 2011; Phalkey *et al.*, 2015; Levy *et al.*, 2016]. The impact of climate events differs between nations, regions, communities and individuals, due to differences in their exposure and resilience to climate events [Phalkey *et al.*, 2015]. Existing studies display a wide diversity of empirical results; more empirical findings are required, to better understand the effects of climate on health status.

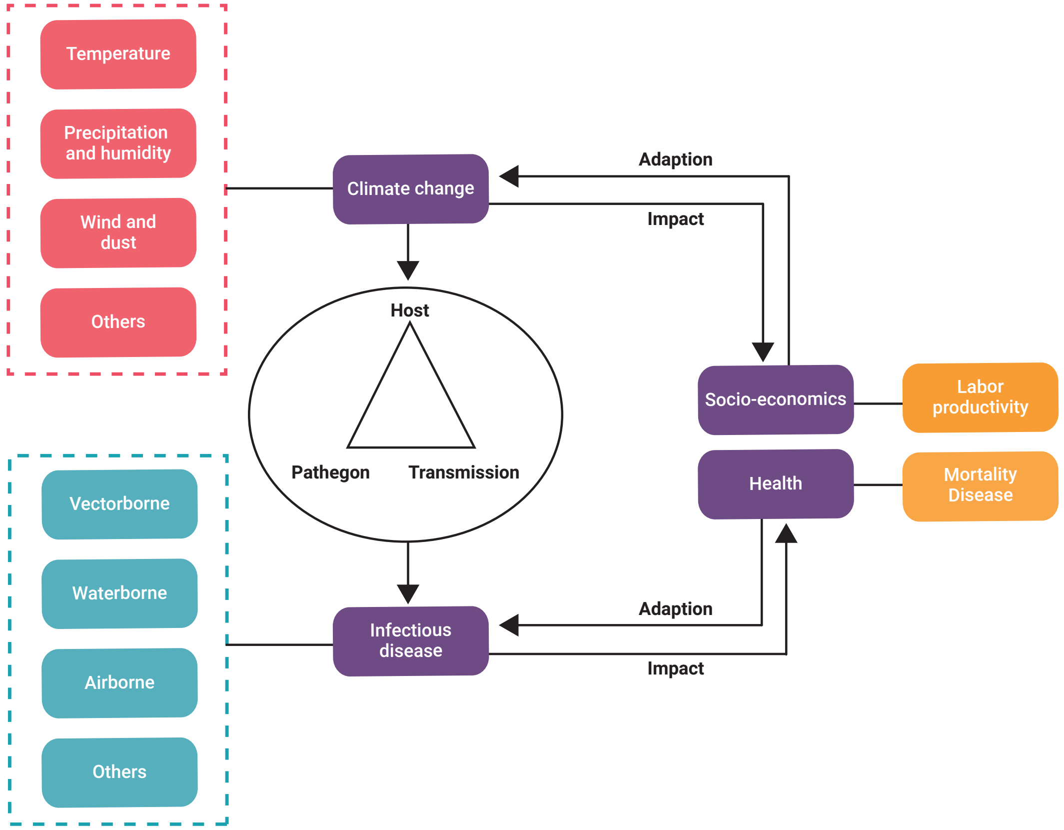
With a slim S-shape hugging more than 3,200 km of coastline in the monsoon belt of Southeast Asia, Viet Nam is considered to be one of tropical countries at highest risk from the impacts of climate change and weather-related loss events (hurricanes, floods, drought, etc.) [Eckstein *et al.*, 2019; Yusuf and Francisco, 2009]. With all meteorological projections pointing to the severe scenario, the number of people at risk of climate-sensitive diseases will increase dramatically in the absence of public interventions [Rockl¨ov *et al.*, 2014].

Previous studies have found a potential link between climate change and infectious diseases, but have mostly revealed the correlation with single diseases in a local context. Here, we provide a comprehensive study at the national level of Viet Nam, in the face of the acceleration in global warming.

This chapter has two objectives. Firstly, it estimates the short-term effects of weather variation (temperature, rainfall, wind speed, heatwave) and long-term effects of climate on the incidence of multiple infectious diseases (i.e., water-borne, airborne, and vector-borne) in Viet Nam, taking the role of public health expenditures for adaptation into account. In addition, the indirect economic costs of infectious disease is estimated through labour productivity loss due to diseases. Secondly it examines the effect of cold and heat waves on mortality in Vietnam. The findings of this study are essential for health policy associated with climate change and adaptation strategies. A conceptual framework is presented in Figure 3.1.

This chapter is structured into four sections. The second section presents the effect of weather variations on the incidence of multiple infectious diseases in Viet Nam. The third section presents the effect of weather extremes on mortality. Finally, the fourth section summarizes the main findings and discusses several policy implications.

[Figure 3.1]
Climate change, infectious disease and humans



The figure presents the relationship between climate change, infectious disease and humans. Climate change is the variation of climate variables such as temperature, precipitation, wind. While pathogens are disease agents such as virus, bacterium, hosts are living organisms such as animals or plants where the pathogens dwell in. The change in climate will influence the life cycle and distribution of pathogens, hosts and their transmission environment. This impact of climate change will lead to the outbreak of many types of human infectious disease such as vector-borne, water-borne and air-borne disease. Climate change and infectious disease have an impact on socio-economics (*e.g.* labor productivity) and health (*e.g.* an increased rate of mortality and other health disease). In the long term, humans will respond to climate change and infectious disease by applying several adaptation measures.
Source: adapted from Wu *et al.*, 2016)

2. Climate change and infectious diseases

2.1 Climate change and infectious diseases in Viet Nam

Since 1980, the growing literature on climate change and infectious diseases has focused on water-, vector-, and mosquito-borne diseases [Sweileh, 2020].

Vector-borne disease

A vector-borne disease is transmitted from a host with an infectious pathogen to a susceptible human by an organism (mainly an arthropod). Major vector-borne diseases are malaria, dengue, rabies, and several neglected tropical diseases[1]. The complexity of climate impacts on ecosystem services and the adaptation dynamics of pathogens, animals, and humans can change the transmission dynamic, the seasonal and geographical spread of vectors, and the virulence of the infectious pathogen. Temperature can impact several life-history traits of a vector, including egg viability, larval development, and adult lifespan [Couret and Benedict, 2014; Brady *et al.*, 2013]. In the temporal range of larval survival, higher temperatures can boost the development of larvae [Christofferson, 2016; Brady *et al.*, 2013]. In Viet Nam, with its variety of geographic and climatic conditions, outbreaks of vector-borne disease will differ for each region and time scale. Several well-researched and comprehensive studies have attempted to correlate climatic factors linked to climate change with cases of dengue and malaria, two common vector-borne infectious diseases in Viet Nam (see, for example, Kien *et al.* 2010 in 6 provinces, Toai *et al.* 2016 in Khanh Hoa and Can Tho). These studies confirm evidence suggesting that the monthly number of dengue fever cases strongly correlates with major climatic factors and vector index (*i.e.*,vector density, Breteau index).

Water-borne disease

Water-borne disease (WBD) is prevalent across the Viet Namese territory. With the dynamic of economic and environmental factors (*i.e.*, living standards, clean water supply, behaviour changes, nutrition), the role of climate change and climate variability can be captured with a relevant experimental design. Like many other tropical countries, Viet Nam often records the peak of WBD cases during the rainy season or after extreme weather events (*i.e.*, floods, storms, droughts), mainly due to the shortage of clean drinking water [Checkley *et al.*, 2000; Phung *et al.*, 2015]. Diarrheal diseases and dysentery vary by season, with the number of cases increasing in the hot-rainy season and vice versa. In particular, in a study for Thua Thien Hue and Danang, the authors found that rainfall and extreme weather events significantly affected the incidence of WBD [Kien *et al.*, 2010]. The authors also suggest the role of adaption measures such as an efficient management policy for water quality deterioration, an early warning system for epidemic risk, and moderating influences in the reduction of cholera cases.

Airborne diseases

In the context of global climate change, the effect of climatic factors on airborne disease has been examined by numerous studies. Researchers and authorities have focussed on airborne disease, especially when an outbreak has occurred, such as Hand-mouth-foot (HMFD), avian influenza, and zoonotic diseases[2]. Pathogens of airborne infectious diseases (*i.e.*, influenza, coronavirus, measles) tend to be sensitive to humidity conditions. For example, warm and wet conditions decrease the risk of COVID-19 spreading via aerosols [Mecenas *et al.*, 2020]. In contrast, absolute humidity in the wintertime boosts influenza transmission efficiency and survival more significantly than relative humidity [Xu *et al.*, 2014; Shaman and Kohn, 2009], but low relative humidity is also favourable for virus transmission [Lowen *et al.*, 2007]. Literature also suggests increased morbidity and mortality from communicable respiratory diseases as a result of heatwaves [Kan, 2011], inter-regional dust storms, and wind [Hamnett *et al.*, 1999; Chen *et al.*, 2010].

HFMD is currently a significant public health issue not only in Viet Nam, but also in other Asia-pacific countries. Phung *et al.* (2017) use a Generalized Linear Model with Poisson family to assert that HFMD increased by 7% and 3.1% for a 1°C increase in monthly temperature above 26°C, and a 1% increase in monthly humidity above 76%. While HFMD decreases by 3.1% in connection with a 1mm increase in monthly cumulative rainfalls at the national scale, the results varied at a regional scale. Using temporal and space-time analysis by Nguyen, HX (2020), this dissertation finds that a 1°C increase in temperature was associated with a 1.7% increase of HFMD, and a 1% increase in humidity was associated with a 0.3% increase in HFMD.

2.2 Impact of climate change and infectious disease

Using monthly data of infectious disease incidence for 28 common diseases, public health expenditure, and weather in 63 provinces in Viet Nam (see Box 3.1), we aim to explore the influence of weather on disease infections, and the heterogeneous marginal effect of weather on infections across provinces based on provincial long-term climate and public health expenditure. We use a two-stage panel approach. In the first stage, we estimate the response function of disease-infected cases to the changes in weather. In the second stage, the local effect of weather variation is crossed with long-term climate and public health expenditure to capture the heterogeneous marginal effect of response function: the sensitivity of infection to temperature varies according to the provincial long-term climate and health budget (see Box 3.2).

Effects of weather on infectious diseases

Table 3.1 presents influences of daily temperature on infections by all types of diseases. Columns (1) to (3) incorporate a different range of fixed effects, from the province, month, and different category in column (1), to category-province in column (2), and category-province and category-month in column (3).

The results in column (2) show that disease infections significantly increase by a number of days with temperature under the bin of 15°C–18°C and 24°C–30°C compared to the reference bin. Specifically, one additional day with temperature under the bin 15°C–18°C, 24°C–27°C, and bin 27°C–30°C increases infectious disease incidence by approximately 1.021, 1.016 1.014 cases, respectively.

---

[1] https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases

[2] 36% zoonotic pathogens are transmitted through airborne transmission.

Table 3.1

Weather effects on for 28 common diseases

Variables	Infectious disease incidence (1)	(2)	(3)
Temperature			
≤15°C	0.002 (0.004)	−0.004 (0.003)	−0.004 (0.003)
15°C - 18°C	0.012*** (0.004)	0.009*** (0.003)	0.009*** (0.003)
18°C - 21°C	−0.008** (0.004)	−0.011*** (0.003)	−0.011*** (0.003)
21°C - 24°C	-	-	-
24°C - 27°C	0.006*** (0.002)	0.007*** (0.002)	0.007*** (0.002)
27°C - 30°C	−0.001 (0.002)	0.005*** (0.002)	0.005*** (0.002)
≥30°C	0.001 (0.004)	0.005 (0.003)	0.005 (0.003)
Windspeed	0.128*** (0.016)	0.137*** (0.013)	0.137*** (0.013)
Rainfall	−0.004 (0.002)	−0.001 (0.002)	−0.001 (0.002)
Constant	6.422*** (0.103)	5.408*** (0.126)	5.408*** (0.122)
Fixed Effects			
Province	x	X	x
Month	x		
Category	x		x
Category x Province		X	x
Category x Month		X	x
Observations	22,680	22,680	22,680
R2	0.223	0.855	0.488
Adjusted R2	0.220	0.850	0.483
F Statistic	78.242*** (df = 83; 22596)	94.746*** (df = 198; 22481)	97.868*** (df = 219; 22460)

Note: *p<0.1; **p<0.05; ***p<0.01.

[Box 3.1]

Data sets

Data on the monthly mortality rate of provinces during the 2000–2018 period are provided by General Statistics Office of Viet Nam (GSO). The mortality rate is computed from Population Change and Family Planning Surveys, which have been conducted annually by GSO since 2000. The sample size of these surveys is representative at the provincial level. Health care expenditure data is taken from Medical Statistical Yearbook from 2009 to 2018, published by the Ministry of Health. It is a yearly health budget at the provincial level of 63 provinces. The health budget accounts for treatment and preventative expenditures and healthprograms. Data on infectious disease is taken from the Infectious Diseases Statistical Yearbook from 2009 to 2018, published by the Department of Preventive Health, Ministry of Health. It is the number of monthly infections and deaths by each infectious disease at the provincial level of 63 provinces. We select 12 common diseases and separate them into three main categories, including vector-borne type (malaria, rabies, encephalitis, dengue), airborne type (mumps, chickenpox, influenza, measles), and water-borne type (dysentery, diarrhea, hepatitis, cholera). The number of infections of each category is then calculated as the sum of infections by four selected common diseases in this category.

Weather and climate data are obtained from over 172 weather stations across Viet Nam with the average temperature, rainfall, and wind speed from 2001 to 2018. According to WHO (1990, 2019), temperatures lower than 15°C with humidity above 65% were associated with respiratory hazards. A range from about 21–30°C was associated with minimal-risk high temperature. Based on these studies and the distribution of temperature in the data set, we then classified temperature into bins of 3°C, and the 21–24°C is selected as the reference of the comfortable indoor temperature. Average temperature is divided into 7 bins (below 15°C, 15°C–18°C, 18°C–21°C, 21°C–24°C, 24°C–27°C, 27°C–30°C, above 30°C).

On the other hand, we find a negative relation between disease infections and the number of days with the temperature under the bin 18°C–21°C. Nonetheless, there is no evidence for the impact of extreme temperature (below 15°C and above 30°C) on disease infections, which can be explained by the fact that the optimal life span of pathogens is typically found around 15°C–30°C [Rohr and Cohen, 2020]. However, this window will change as a result of climate change [Caminade *et al.*, 2014]. For example, areas which were previously below the temperature threshold for infectious disease transmission, such as the Highlands, may cross the threshold as a result of climate change. Evidence for the impact of temperature on disease infections can be found in the literature. For example, Phung *et al.* (2017) point out that a 1°C increase in monthly temperature above 26°C increases infections by hand-foot-mouth disease in Viet Nam by 3.1%. One of the mechanisms could be rooted in the impact that temperature has on the life traits of pathogens [Couret and Benedict, 2014; Brady *et al.*, 2013, Christofferson, 2016].

Moreover, the results indicate that wind-speed significantly and positively impacts the number of disease infections, which is in line with Hamnett *et al.* 1999; Chen *et al.* 2010 on analysing the relationship between interregional dust storms and wind, and communicable respiratory diseases.

Heterogeneous marginal effect of weather sensitivity of disease infections

In this section, we estimate the relationship between provincial long-term climate, the health budget and the sensitivity of infections to temperature. The provincial long-term climate and the health budget are the moving average of annual average temperature and annual total health budget in a given province from 2009 to 2018.

Table 3.2

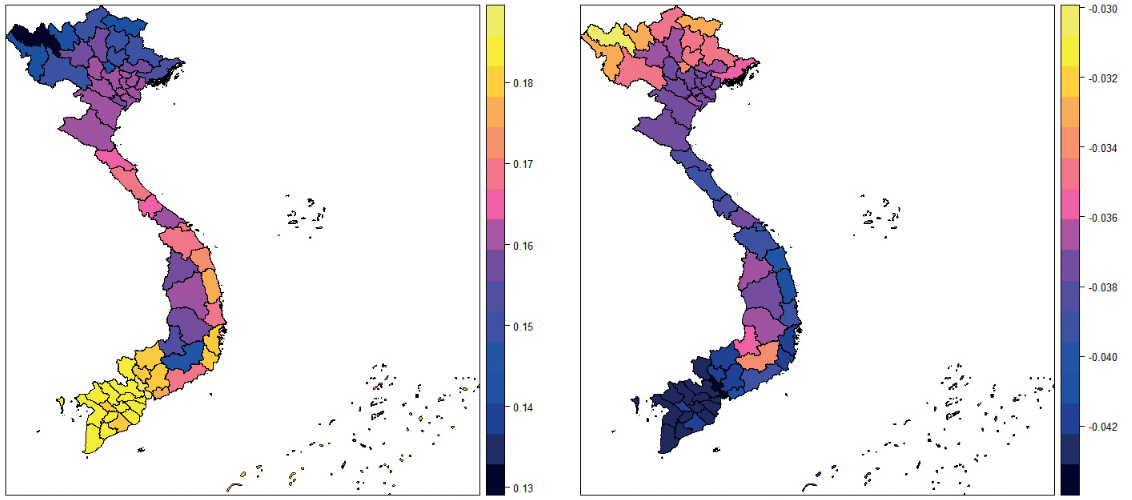
Marginal effect of provincial climate and health budget in sensitivity of disease infections to temperature

Variables	Infections by disease							
	All types		Waterborne diseases		Airbornes diseases		Vector-borne diseases	
	MeanT	MeanBudget	MeanT	MeanBudget	MeanT	MeanBudget	MeanT	MeanBudget
≤ 15°C	−0.002 (0.002)	−0.006 (0.007)	−0.002 (0.003)	0.005 (0.006)	−0.002 (0.003)	0.004 (0.006)	0.002 (0.003)	−0.005 (0.006)
15°−18°C	0.007*** (0.002)	−0.001 (0.007)	0.007*** (0.003)	−0.011* (0.006)	0.004 (0.003)	−0.007 (0.006)	0.004 (0.003)	−0.005 (0.006)
18°C−21°C	0.001 (0.002)	−0.012* (0.007)	0.001 (0.003)	−0.002 (0.005)	−0.001 (0.001)	0.001 (0.003)	0.004 (0.003)	−0.009* (0.005)
21°C−24°C	-	-	-	-	-	-	-	-
24°C−27°C	−0.002* (0.001)	−0.007 (0.004)	−0.002 (0.001)	0.004 (0.002)	−0.002* (0.001)	0.004* (0.003)	0.002* (0.001)	−0.004 (0.003)
27°C−30°C	−0.002* (0.001)	−0.005 (0.004)	−0.001 (0.003)	0.003 (0.005)	−0.003** (0.001)	0.006** (0.002)	0.002 (0.001)	−0.003 (0.002)
≥ 30°C	−0.001 (0.002)	−0.003 (0.005)	0.001 (0.003)	−0.002 (0.005)	−0.004 (0.003)	0.006 (0.005)	0.003 (0.003)	−0.005 (0.005)
Observations	22,680				22,680			
R2	0.489				0.490			
Adjusted R2	0.484				0.485			
F Statistic	92.979*** (df = 231; 22448)				86.710*** (df = 249; 22430)			

Note: *p<0.1; **p<0.05; ***p<0.01.
Estimation with fixed effects including category x province and category x month.

[Figure 3.2]

Marginal effect of provincial climate on sensitivity of infections to temperature



(a) Sensitivity to 15°C -18°C.

(b) Sensitivity to 27°C -30°C.

The figures represent log of the ratio of number of infections in the year of 2050 to number of infections in the year 2015. The number of infections in the year of 2050 is projected under the SSP2 scenario and RCP 4.5. The scenario with the adaption controls for the effect of annual provincial health budget and long-run climate on the sensitivity of disease infections to temperature. Health budget is assumed to follow growth rate as GDP under the SSP2 scenario.

The results indicate that a province with long-term climate at a high temperature is less sensitive for all types of infection to one additional day under the temperature 24°C–30°C (α1 = −0.002), but more affected by one additional day under the temperature 15°C–18°C (α1 = 0.007). It indicates that in hotter provinces, infectious diseases are more impacted by colder weather but less affected by higher temperature. And vice versus, in cold provinces, infectious diseases are less influenced by colder temperature, but more sensitive to hotter temperature. This finding reflects a sign of adaptability in the climate of hotter provinces to a hot range, and in colder provinces to a cold range of temperature. Similar evidence of adaptation has been found in other settings, for example, health [Carleton *et al.*, 2020], and agriculture [Bulter and Huybers, 2013]. Figure 3.2 shows the marginal effect of provincial climate on the sensitivity of infections to temperature. Provinces located in the south and southern central coast appear to have a higher level of sensitivity to infections at 15°C–18°C, but a lower level of being affected at 27°C–30°C, whereas the Northern and Tay Nguyen provinces are less sensitive to infections at 15°C–18°C, but more sensitive at 27°C–30°C. With respect to marginal effect by health budget, the results suggest that the health budget lessens the sensitivity of infections to all bins of temperature (although only sensitivity to the bin 18°C–21°C is found to be significant), reflecting the significant effect of public budget on disease control.

The study finds different marginal effects of the long-term climate and health budget on the incidence of infection across three disease groups. For waterborne disease, provinces with hotter climates have higher sensitivity to infections at the colder range of temperature (15°–18°), but the health budget lessens the impact of this temperature range on infectious incidence. In the vector-borne type, a province with higher long-term temperatures has a higher level of sensitivity to infections at temperatures at the bin 24°C–27°C. The results are in line with previous theoretical models suggesting the development of the pathogen or vector was inhibited at temperatures below 21°C, but from 24°C, the incidence rate of vector-borne disease increases significantly with the rise in temperature [Brady *et al.*, 2014]. For airborne diseases, their sensitivity to one additional day at temperature is lessened in a province with higher long-term temperature. However, the health budget is intensified by the increase in the provincial health budget. Although the positive relationship between budget and airborne diseases is unexpected, it should be re-examined with the lag time, because the actions of public agencies usually lag behind the outbreak of disease. For example, by observing the rise of disease occurrence, authorities spend a higher budget on control activities then the effects might delay in the successive periods. Moreover, public health care expenditure typically rises in line with public investment (*i.e.*, infrastructure, traffics), contributing to water and air pollution in developing countries [Chen *et al.*, 2010; Chung and Sobsey, 1993). Infectious diseases have a higher risk of spreading during economic expansion [Adda, 2016] with the idea of mortality and business cycle by Ruhm (2000). Therefore, the no environmental-friendly outlay could increase the risk of communicable diseases to the local community.

Table 3.3

Impact of infections by diseases on labor productivity

Variables	Dependent variable ln (Hourly Earning)
Age 36-50	1.558** (0.753)
Age 51-60	0.265 (0.745)
Male	1.854*** (0.654)
Having vocational degree	0.168 (0.689)
Elementary and secondary education	−0.048 (0.389)
College education	0.912** (0.433)
University graduate or above	−0.427 (0.535)
Insurance	1.537*** (0.118)
Infection	−0.049* (0.029)
Constant	1.308** (0.562)
Observation	567
R2	0.302
Adjusted R2	0.291
F Statistic	26.753*** (df = 9; 557)

Note: *p<0.1; **p<0.05; ***p<0.01.

2.3 Disease and productivity

We have tested the effect of disease infections on labour productivity. Labour data is taken from Labor Force Survey from the period 2010–2018. A dependent variable that represents labor productivity is the average hourly wage of labour in a given province in a specific year. Explanatory variables for labour characteristics are included in the model, including education, gender, and age. The results suggest a negative influence of infections on labor productivity. Specifically, a 1% increase in disease infections leads to a decrease in the average hourly wage of approximately 0.05%.

A lower wage premium for sicker workers indicated that the social rate of return to a relevant public health policy for infectious disease prevention is high. Integrating health insurance and educational attainment may play an important role when these non-disease factors significantly boost worker productivity. The higher average hourly wage for better-educated workers may indeed be not only a high private return to education but also a potential link to immeasurable health literacy.

2.4 Projection of future climate change impacts and adaptation

To capture the implications of adaptation to short-term weather shocks and long-term climate changes, we have used a two-stage model to illustrate the differences in future impacts between adapted and non-adapted infection responses by climate projections. Data on the future evolution of the climate is obtained from Chapter 1. To comprehensively simulate spatial heterogeneity in climate impact, we have used a high-resolution (0.1°) set of global, bias-corrected climate projections produced by the Bias Correction and Spatial Downscaling (BCSD) approach (see Chapter 1 for the description of the technique). We use projected emissions from two Representative Concentration Pathways (RCP 4.5 and RCP 8.5) to simulate emissions under those two emission scenarios up to 2100 [Figure 3.3]. The gridded data are aggregated to impact regions at district and province levels. For the health budget, we assume that the annual growth rate of the provincial health budget is similar to GDP growth rate following the SSP2 (Shared Socioeconomic Pathways).

Table 3.4 lists the results of future impacts on infection corresponding to RCP 4.5 and RCP 8.5, with and without adaption in some representative provinces. The second column is the average number of annual provincial infection cases. The last 8 columns are the rate of the number of infections in the year of projection over the number of infections in the year of 2015 that are induced by temperature. The effects of climate change are considerably decreasing in all scenarios across the country. The average provincial incidence of infection increases by 29% between 2015 and 2050 under RCP4.5 without adaption, but is reduced by 91% with adaption. The increase/decrease of incidence of infection varies across provinces. For example, in Hanoi City, the incidence of infection declines by 69% between 2015 and 2050 with adaptation, but increases by 26% without adaptation in the RCP 4.5 scenario.

Table 3.4

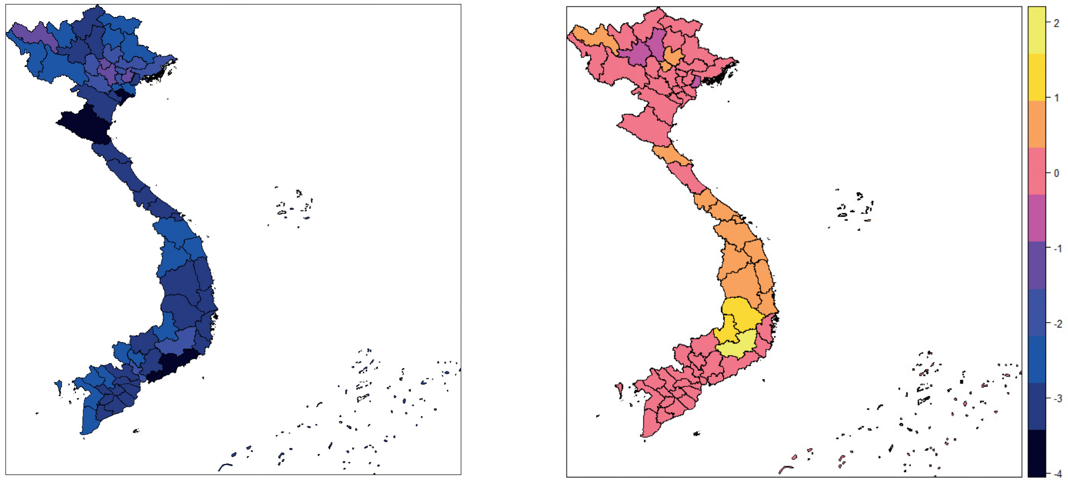
Future impacts of climate change on diseases with and without adaptations in some provinces

Province	Annual Infections (cases)	Changes in number of infections*							
		2050				2100			
		RCP4.5		RCP8.5		RCP4.5		RCP8.5	
		without adaption	with adaption	without adaption	with adaption	without adaption	with adaption	without adaption	with adaption
Mean of 63 provinces	368395.3	1.29	0.09	1.29	0.09	1.29	0.02	1.36	0.04
Bac Ninh	283959	1.24	0.21	1.03	0.16	1.07	0.04	0.77	0.02
Binh Dinh	188191	1.53	0.05	1.47	0.05	1.42	0.01	1.28	0.02
Da Nang	202563	1.62	0.04	1.86	0.04	1.86	0.01	1.69	0.01
Dak Lak	529613	2.92	0.04	2.70	0.06	2.55	0.02	2.25	0.03
Dak Nong	74612	3.55	0.06	3.19	0.08	3.04	0.02	3.02	0.03
Dien Bien	367329	0.89	0.07	1.35	0.10	1.38	0.02	1.43	0.03
Dong Nai	279986	0.78	0.04	0.77	0.05	0.77	0.01	0.76	0.05
Gia Lai	262012	1.82	0.04	1.76	0.05	1.71	0.01	1.49	0.02
Ha Giang	439621	0.90	0.06	1.10	0.10	1.20	0.02	1.34	0.03
Ha Nam	251054	1.01	0.09	1.10	0.11	0.83	0.01	0.89	0.01
Ha Noi	1217263	1.26	0.31	1.22	0.26	0.85	0.02	0.85	0.01
Ha Tinh	432982	1.41	0.03	1.62	0.05	1.71	0.01	2.12	0.01
Ho Chi Minh	697497	0.88	0.15	0.87	0.17	0.87	0.06	0.86	0.27
Lao Cai	456009	1.15	0.07	1.40	0.10	1.45	0.02	1.67	0.04
Quang Binh	241620	1.03	0.06	1.20	0.08	1.51	0.03	1.83	0.02
Quang Nam	662230	1.51	0.11	1.73	0.10	1.96	0.02	1.82	0.02
Quang Ninh	148798	1.16	0.17	1.09	0.14	0.78	0.01	0.95	0.02
Thua Thien Hue	338460	1.78	0.05	1.79	0.06	2.15	0.01	2.24	0.01

Note: Number of infection is measured by Cases in the year of projection/Cases in the year 2015. Health budget is assumed to follow growth rate as GDP under the SSP2 scenario.

[Figure 3.3]

Infections change between 2015 and 2050 under the RCP4.5 and SSP2



(a) With adaption.

(b) Without adaption.

The figures represent log of the ratio of number of infections in the year of 2050 to number of infections in the year 2015. The number of infections in the year of 2050 is projected under the SSP2 scenario and RCP 4.5. The scenario with the adaption controls for the effect of annual provincial health budget and long-run climate on the sensitivity of disease infections to temperature. Health budget is assumed to follow growth rate as GDP under the SSP2 scenario.

3. Impacts of cold and heat waves on mortality

3.1 Mortality and weather extremes

Mortality in Viet Nam

Along with economic growth, Viet Nam has experienced an improvement in health. Life expectancy increased from 73 to 75 during the 2000–2018 period [World Bank, 2020]. However, the crude mortality rate did not decline during this period[3]. Estimates from the Population and Planning Surveys show that the all-age mortality rate was around 5 deaths per 1000 people [Figure 3.4]. A key reason why the mortality rate has not declined over the past two decades is the reduction in the fertility rate. The government has recommended family planning with a limit of two children per family since 1988. The dramatic decline in childbirth rates is the most important reason for population aging in Viet Nam[4]. When the mortality rate is computed for different age groups, we can see

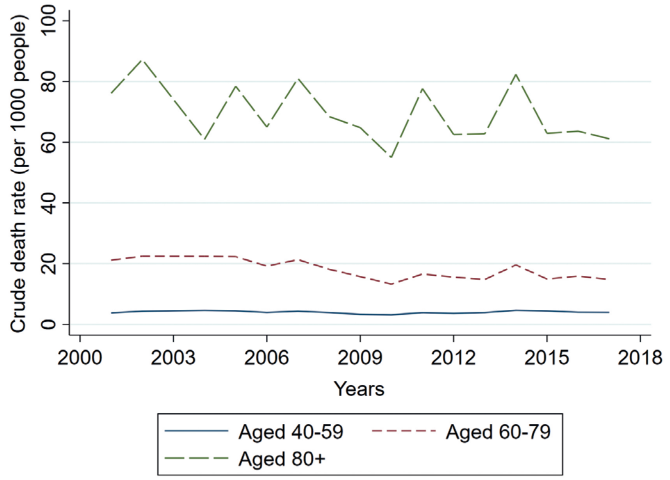
[3] The crude mortality rate is the number of deaths per 1,000 mid-year total population of the given geographical area during the same year.

[4] Viet Nam is among the most rapidly ageing countries in the world. According to GSO (2019), the aging index, which is equal to the ratio of the number of people from 60 to the number of children below 15 (measured in percent), has increased over time. The aging index increased by 13.3 percentage points from 35.5% in 2009 to 35.3% in 2019.

[Figure 3.4]
The crude mortality rate (per 1000 people) by age groups

Panel A. People aged 0-39

Panel B. People aged 40+



This figure reports the crude mortality rate for different age groups during the 2000-2018 period. Panel A presents the mortality rate for all the population and population groups below 40 years old, while Panel B presents the mortality rate for population aged from 40. Panels A and B have different scales of the y-axis.

the decline in the mortality rate, especially for children under 5 and people aged 60 and older [Figure 3.4].

Like other countries, chronic diseases are the main cause of mortality in Viet Nam [WHO, 2014]. The leading cause of mortality in Viet Nam is stroke, which killed 112.6 thousand people, 21.7% of all deaths in Viet Nam [WHO, 2015]. The second cause of mortality is ischemic heart disease, accounting for 7% of deaths in Viet Nam. Other causes of mortality include Chronic Pulmonary Obstructive Disorder (accounting for 4.9% of deaths), lower respiratory infections caused by bacteria, viruses, or fungi (accounting for 4.8% of all deaths), accidents, cancers and other diseases [WHO, 2015].

There are 63 provinces in Viet Nam, and these provinces are grouped into 6 geographic regions: Red River Delta, Northern Midlands and Mountains, and Central Coast in the North and Central Highlands, Southeast and Mekong River Delta in the South. Figure 3.5 presents the geographic maps of the mortality rate and temperature (averaged over the 2000–2018 period). The poverty rate as well as the average temperature is fairly similar between provinces within a region. The correlation between mortality and temperature is not clear from these maps. However, it shows that the mortality rate is higher in the North, which has a lower average temperature, than in the South.

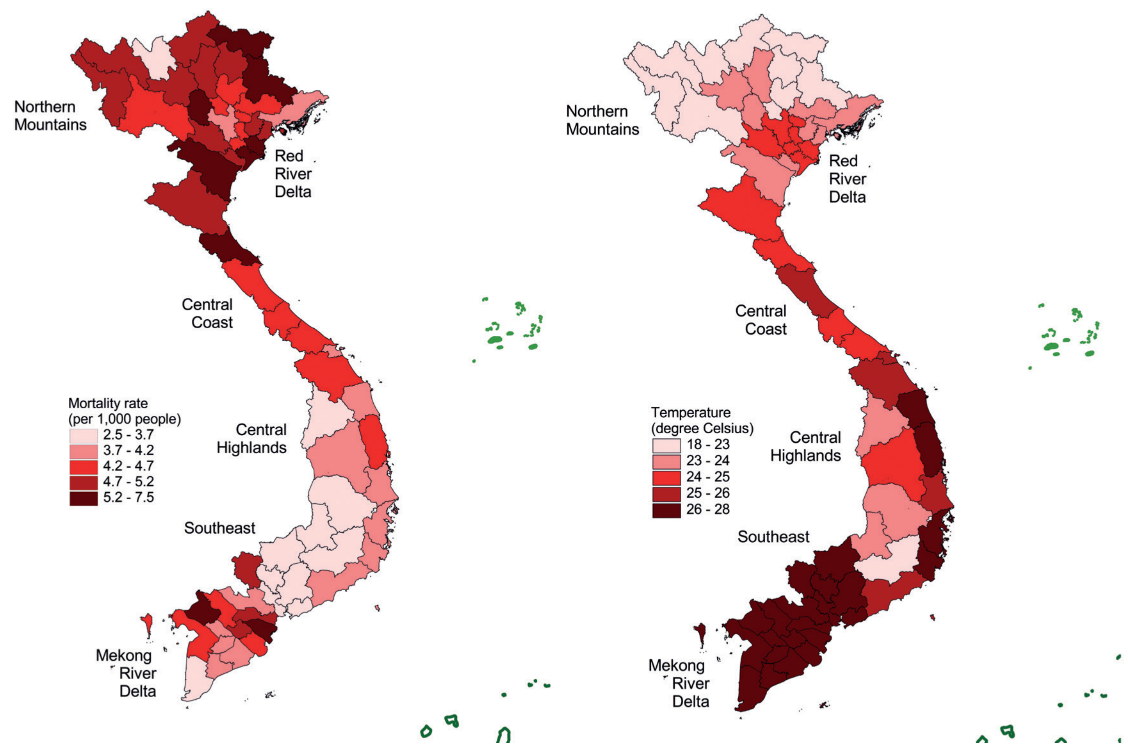
There are different ways to examine the relationship between temperature and mortality. A population-focused way is to estimate the temperature bins on mortality [*e.g.*, Deschênes and Moretti, 2009; Deschenes and Greenstone, 2011; Burgess *et al.*, 2017; Carleton *et al.*, 2020]. The WHO (2018) suggests that the range of minimal-risk high temperatures is about 15–30°C. Low and high temperature can cause health problems and result in risk of death. Temperatures lower than 16°C (61°F) with humidity above 65% were associated with respiratory hazards. The temperature-humidity index can be used to explore the effect of temperature and humidity on health [*e.g.*, McGregor and Vanos, 2018]. In this study, we have tried to estimate the number of days within the temperature bins, but did not find significant effects for the number of days with low or high temperatures on mortality. Possibly, people in cold or hot areas have adapted to their local temperature. However, temperature shocks can cause health problems for people.

The effect of weather extremes, which are assessed by cold and heat waves occurring within a month, is the emphasis of this chapter. A heat wave is a term used to describe a period of very high temperatures. There are two issues in defining a heat wave: selection of a temperature threshold, and definition of the number of consecutive days of prolonged heat. Most studies use a threshold of a given percentile, such as the 90th, 95th or 98th percentile of the temperature distribution in a specific location [*e.g.*, see review Perkins and Alexander, 2013; and Perkins, 2015]. The second issue in defining a heat wave is the duration of consecutive days equal to or above the temperature thresholds. Exposure to hot weather for a number of consecutive days has a more detrimental effect on health than exposure to few hot days that are spaced apart. A heat wave is often defined as at least 3 or 5 consecutive days with daily temperature above a given threshold [*e.g.*, see review Perkins and Alexander, 2013; and Perkins, 2015]. Unlike the number of days in temperature bins, cold and heat waves can have harmful effects on health, since they are more extreme and last for several consecutive days.

[Figure 3.5]
Mortality rate and temperature

Panel A. **Mortality rate** (per 1,000 people)

Panel B. **Average daily temperature** (degree Celsius)



Panel A presents the crude death rate of province, measured as the number of resident deaths per 1000 population in a year. The map shows the mortality averaged over the 2000-2018 period. Panel B presents the average of the daily mean temperature of the province over the same period.

During the 2000–2018 period, we defined a heat wave as three or more consecutive days with daily mean temperatures at or above the 95th percentile of the year-round province-specific temperature distribution. Similarly, we define a cold wave as when the dail mean temperature is equal to or below the 5th percentile of the year-round province-specific temperature distribution for at least three consecutive days. We also define heat waves (and cold waves) as at least 5, 7, and 9 consecutive days with daily mean temperatures at or above the 95 percentile (and at or below the 5 percentile) of the province-specific temperature distribution for robustness analysis.

The average number of days per year in cold and heat waves is shown in Panel A of Figure 3.6, which is calculated using the 5th and 95th percentiles of the province-specific temperature distribution. The figures are calculated as an average across province-by-year. The first bar in Panel A, for example, shows that the province-by-year average number of consecutive days in cold waves (defined as at least 3 cold days) is 14. In cold waves defined as at least 9 consecutive cold days, the average number of consecutive days is only 5.2. It should be noted that this average is below 9, as several provinces have not experienced a cold wave in several years. In heat waves, the average number of consecutive days is lower. For example, in heat waves defined as at least 3 and 9 consecutive hot days, the average number of consecutive days is 10.4 and 2.4, respectively.

During the 2000–2018 period, panel B of Figure 3.6 shows the average percentage of months with at least one cold or heat wave. The percentage is calculated by adding together the percentages from all provinces. It shows that between 2000 and 2018, 16.7% of months had at least one cold wave (which is defined as at least 3 consecutive cold days). The average percentage of months with at least three consecutive hot days experienced by heat waves is 13.6 percent. The percentage of months with at least one cold or heat wave is lower when cold or heat waves are defined for a longer period of time (at least 5, 7, or 9 days).

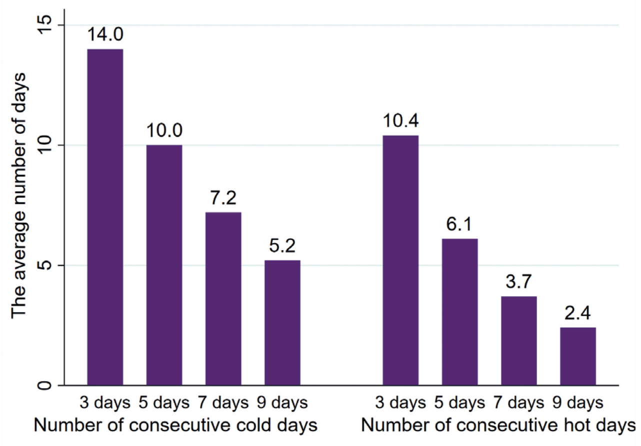
3.2 Impact of weather extremes on mortality

In this section, we explore the effect of cold and heat waves on the monthly mortality rate using a regression model. The regression model is presented in Box 3.2. We use both the mortality rate as well as log of the mortality rate as dependent variables. We regress these dependent variables on cold and heat waves and control variables. The control include average yearly temperature, total annual precipitation, province-by-month fixed-effects, year-month fixed-effects, and province-specific time trend. The effects of cold and heat waves on mortality are measured by the coefficients of cold and heat waves in the regressions. The effects are summarized in Figure 3.7. In this figure, we graph the point estimate and the 95% confidence interval of the effects of cold and heat waves on the monthly mortality rate (Panel A and B of the figure) and the log of the monthly mortality rate (Panel C and D of the figure). The log of the death rate and the estimated effects of cold and heat waves are remarkably comparable. The results of the effects on the log of the mortality rate are used to interpret the results.

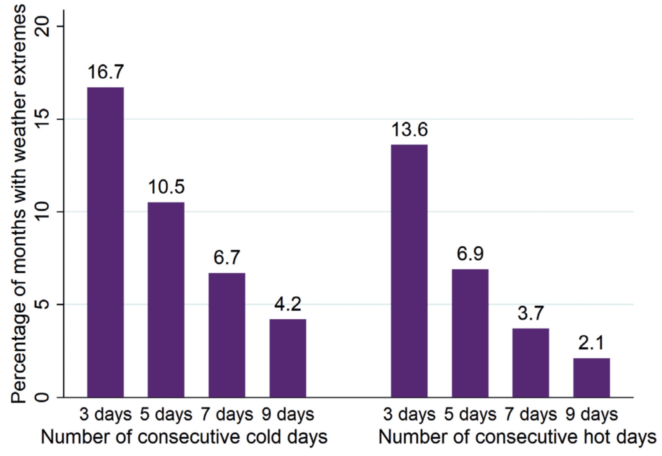
Overall, we find that both cold and heat waves increase the chance of death, and that the effect of both cold and heat waves increases as the cold and heat waves stay longer. The predicted coefficients of ocurrence of at least one cold or heat wave within a month are plotted in Panel C of Figure 3.7. A cold wave lasting at least 5 days raises the monthly mortality rate by roughly 4.9 percent (significant at the 10% level), whereas a cold wave lasting at least 9 days increases the mortality rate by 6.5 percent (significant at the 5 percent level). When compared to a cold wave, a heat wave has a higher and more significant impact on the death rate. If there is a heat wave that lasts for at least 9 days in a month, the death rate rises by 13.5 percent. This shows how a protracted severe heat wave can have a significant impact. However, a heat wave lasting at least 9 days is uncommon. The average percentage of months with at least 9 consecutive hot days occurred only 2.1 percent of the time between 2000 and 2018.

[Figure 3.6]
Cold and heat waves

Panel A. The average number of consecutive days in cold and heat waves



Panel B. The percentage of months with cold and heat waves



Panel A of this figure presents the average number of days per year in cold and heat waves, which are defined based on the 5th and 95th percentiles of the province-specific temperature distribution and different durations of consecutive days. Panel B of the figure presents the average percentage of months in which at least a cold or heat wave (defined based on different durations of consecutive days) occurs during the 2000–2018 period.
Source: Nguyen *et al.* (2021).

Panel D depicts the estimated coefficients of the number of days in cold and heat waves on log of mortality rates. All the estimates are positive and statistically significant at the 5% level. An additional day in a cold wave of at least 3 consecutive days (relative to a day within the 5th–95th percentile temperature range) leads to an increase in the mortality rate of 0.6 percent. The corresponding figure for a day in a heat wave is 0.7 percent. For a cold or heat wave defined as at least 9 consecutive days, an additional day in the cold and heat wave increases the mortality rate by 0.6 and 1.2 percent, respectively.

Children and the elderly are more susceptible to harsh weather than others [*e.g.*, see Basu, 2009; Arbuthnott and Hajat, 2017; Geruso and Spears, 2018]. Table 3.5 shows the coefficients of the number of days spent in cold and heat waves in death rate regressions for various age groups. There are 32 regressions in total, and the table only shows the estimated coefficients for each regression's number of days in cold and heat waves. The findings imply that only the elderly, particularly those over the age of 80, are harmed by weather extremes. For people under the age of 40, almost all cold and heat wave coefficients are statistically insignificant. All of the predicted coefficients of cold and heat waves are positive for adults over 40, indicating that they have a negative impact on their health. The death rate of adults over the age of 80 is significantly higher than that of younger people. In Table 3.5, we look at how the effects of cold and heat waves on mortality differ for men and women. Overall, there is no discernible difference in the influence on death rates between men and women.

We believe that cold and heat waves cause death primarily through a direct and detrimental influence on health for two reasons. Firstly, cold and heat waves only have short-term effects on mortality. To examine the medium-term effect of cold and heat waves, we include one-month and two-month lagged variables of cold and heat waves to examine the sensitivity of the effect estimates, as well as the medium-term effect of cold and heat waves. Most lagged variables of cold and heat waves are positive but not statistically significant at conventional levels. This suggests that cold and heat waves do not have medium- or long-term effects on mortality. Second, we conduct regressions of per capita income of provinces with cold and heat waves over the course of a year to see if cold and heat waves have indirect effects on health by reducing income. We find little evidence that cold and heat waves have a major impact on income. As a result, income is not a factor in the increased mortality caused by cold and heat waves.

3.3 Projection

In this section, we use projection of daily data for Viet Nam using different Representative Concentration Pathway (RCP) scenarios to predict cold and heat waves in the 2020–2100 period. In the IPCC's fifth Assessment Report in 2014, four paths were employed for climate modelling and research. Different climate futures described in the pathways are all considered feasible, depending on the amount of greenhouse gases emitted in the coming years. The RCPs are named after a possible range of radiative forcing values in the year 2100 (2.6, 4.5, 6, and 8.5 W/m^2, respectively) [IPCC, 2019].

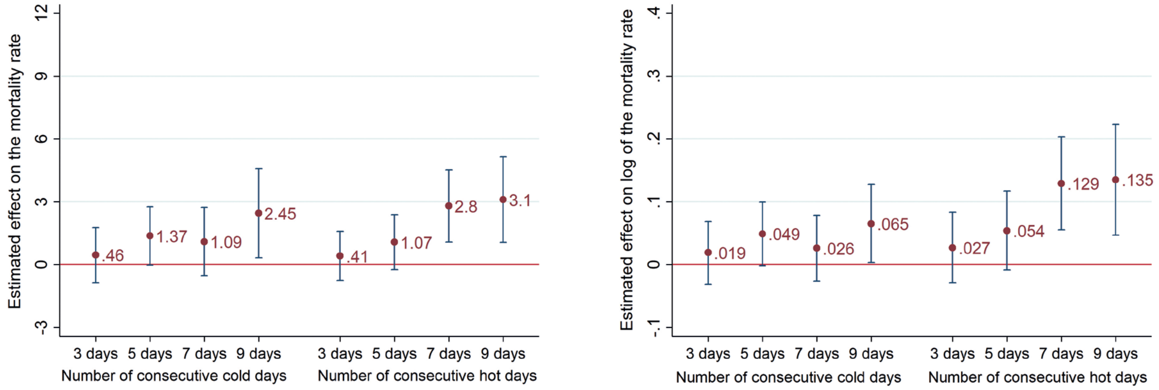
For the sake of simplicity, we assume that people's health and economic conditions, as well as their ability to adjust to climate change,

[Figure 3.7]

Estimated effects (and 95% confidence interval) of cold and heat waves on the all-age mortality rate

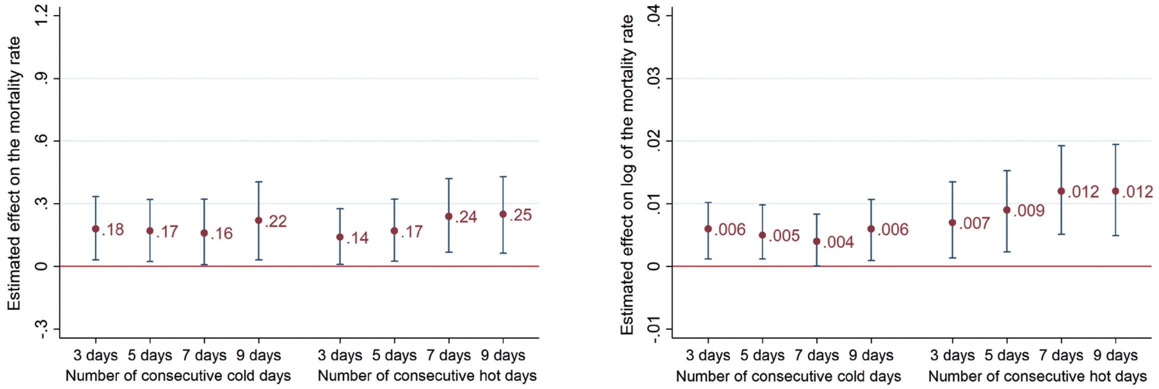
Panel A. Estimated effects of cold and heat waves on the mortality rate

Panel C. Estimated effects of cold and heat waves on log of the mortality rate



Panel B. Estimated effects of the number days in cold and heat waves on the mortality rate

Panel D. Estimated effects of the number days in cold and heat waves on log of the mortality rate



■ Source: Nguyen *et al.* (2021).

[Table 3.5]

Regression of morality rates for different population groups

Explanatory variables	Dependent variables Mortality rate of people aged 0-4 (deaths per 100,000 people) (1)	Mortality rate of people aged 5-15 (deaths per 100,000 people) (2)	Mortality rate of people aged 16-39 (deaths per 100,000 people) (3)	Mortality rate of people aged 40-59 (deaths per 100,000 people) (4)	Mortality rate of people aged 60-79 (deaths per 100,000 people) (5)	Mortality rate of people aged 80+ (deaths per 100,000 people) (6)	Mortality rate of males (deaths per 100,000 people) (7)	Mortality rate of female (deaths per 100,000 people) (8)
# days with at least 3 consecutive days below the 5th percentiles of temperature	0.0891 (0.1421)	0.0409 (0.0267)	-0.0401 (0.0587)	0.1513* (0.0760)	0.8443 (0.5369)	5.2655*** (1.9113)	0.2940** (0.1190)	0.0743 (0.0768)
# days with at least 3 consecutive days above the 95th percentiles of temperature	-0.0294 (0.1517)	-0.0002 (0.0382)	-0.0512 (0.0537)	0.2518** (0.1224)	0.4004 (0.4869)	4.5024** (2.0700)	0.1193 (0.1044)	0.1647* (0.0832)
# days with at least 5 consecutive days below the 5th percentiles of temperature	0.1617 (0.1482)	0.0318 (0.0224)	-0.0122 (0.0519)	0.1558* (0.0785)	0.8126 (0.4943)	4.3609** (2.0221)	0.2737** (0.1127)	0.0752 (0.0706)
# days with at least 5 consecutive days above the 95th percentiles of temperature	-0.1212 (0.1499)	0.0264 (0.0430)	-0.0254 (0.0627)	0.2554* (0.1342)	0.5119 (0.4683)	4.5884* (2.3812)	0.1525 (0.1035)	0.1924* (0.1090)
# days with at least 7 consecutive days below the 5th percentiles of temperature	0.1671 (0.1580)	0.0555* (0.0326)	-0.0505 (0.0544)	0.1288* (0.0749)	0.9184 (0.5677)	4.0651* (2.0609)	0.2349** (0.1161)	0.0972 (0.0729)
# days with at least 7 consecutive days above the 95th percentiles of temperature	-0.0297 (0.1548)	-0.0143 (0.0438)	-0.0439 (0.0616)	0.2302 (0.1649)	1.0251* (0.5177)	6.9202*** (2.4346)	0.1975* (0.1082)	0.2851** (0.1290)
# days with at least 9 consecutive days below the 5th percentiles of temperature	0.1640 (0.1717)	0.0485 (0.0299)	-0.0298 (0.0634)	0.1810* (0.1007)	1.3919** (0.6492)	4.1322** (2.0547)	0.3063** (0.1296)	0.1342* (0.0767)
# days with at least 9 consecutive days above the 95th percentiles of temperature	0.0282 (0.1683)	-0.0018 (0.0494)	-0.0748 (0.0680)	0.2076 (0.1813)	0.8034* (0.4470)	8.6812*** (2.4793)	0.2171** (0.1055)	0.2716** (0.1313)
Observations	12,639	12,639	12,639	12,639	12,639	12,639	12,639	12,639

Note: This table reports the coefficients of the number of days in cold and heat waves in regressions of the mortality rate of people at different age groups. A cold (heat) wave is defined as at least k (3, 5, 7, and 9) consecutive days which have daily mean temperature at or below the 5th percentiles (at or above the 95th percentile) of the temperature distribution of specific province. There are 32 regressions in total. The regression specifications are the same as those in Table A.1 in Appendix. The control variables include annual average temperature (°C), annual precipitation (mm), province-specific time trend, province-by-month fixed-effects, and year-by-month fixed-effects. Robust standard errors in parentheses. Standard errors are clustered at the province and year-by-month levels.

*** p<0.01, ** p<0.05, * p<0.1.

Source: Nguyen *et al.* (2021).

[Box 3.2]

Estimation of the effect of climate

Model to estimates the effects of climate on infectious disease

In the first stage, we estimate this equation

$$y_{cpmt} = \alpha + \sum_{k}^{7} \beta_{1,k} T_{kpmt} + \beta_2 Rainfall_{pmt} + \beta_3 Windspeed_{pmt} + v_c + \delta_p + \sigma_{cm} + \theta_{cp} + \epsilon_{pmt} \quad \mathbf{(1)}$$

where y_{cpmt} is the number of infected cases in disease-category *c* of province p in the month *m* of the year *t*, T_{kpmt} is the number of days in temperature bin *k* in province *p* in month *m* of year *t*, $Rainfall_{pmt}$ Windspeed_{pmt} are average rainfall and windspeed in the month *m*. We use four variables of fixed effects: v_c for category of diseases, δ_p for provinces, σ_{cm} for *category* x month and θ_{cp} for *category* x province.

The heterogeneous marginal effect of climate on infectious disease is captures in the function as:

$$y_{cpmt} = \alpha + \sum_{k}^{7} (\alpha_0 + \alpha_{1k} MeanT_{\{p)} + \alpha_{2k} Budget_p\} * T_{kpmt} + \beta_2 Rainfall_{pmt} + \beta_3 Windspeed_{pmt} + v_c + \delta_p + \sigma_{cm} + \theta_{cp} + \epsilon_{pmt} \quad \mathbf{(2)}$$

where $MeanT_p$ is the sample-period average temperature of province *p* and $Budget_p$ is the average of budget that province *p* allocating on medical heath care over sample period.

Model to estimates the effects of weather extremes on mortality

We estimate the effect of cold and heat waves on the mortality using the following regression:

$$\begin{aligned} \log(y_{pmt}) = {} & \alpha_2 + \beta_{2c} Cold_{pmt} + \beta_{2H} Heat_{pmt} \\ & + X_{pmt}\theta_2 + P_{pm} + M_{mt} + T_p\delta_{2p} + u_{pmt}, \end{aligned} \qquad (3)$$

where y_p is the mortality rate of province p in month *m* of year *t* (per 100,000). In this study, we use both the mortality rate and log of the mortality rate as the dependent variables. $Cold_{pmt}$ is the number of consecutive days in a cold wave and $Heat_{pmt}$ is the number of consecutive days in heat waves in province *p* in month *m* of year *t*. The cold wave is defined as at least a number of consecutive days (3, 5, 7 and 9 days) with daily mean temperature at or below the 5th percentile of the province-specific temperature distribution, while the heat wave is defined as at least a number of consecutive days (3, 5, 7 and 9 days) with daily mean temperature at or above the 95th percentile of the temperature distribution. *X_pmt* is a vector of control variables. Our main control variables include the average of yearly temperature, which is calculated by averaging the daily mean temperatures in the province, and the total annual precipitation. We also control for the province-by-month fixed-effects, P_{pm}, and year-month fixed-effects M_{mt}. In addition, we include the province-specific time trend, T_p, which allows for province-specific time trends in the mortality rate. We adopt the multiway clustering technique of Cameron *et al.* (2011), which allows us to deal with the correlation of error within provinces over time and between provinces within a month simultaneously.

will remain unchanged in the future. As a result, we create the cold and heat waves for the 2020–2100 timeframe using the same 5th and 95th percentiles as the temperature distribution 2000–2018. Panels A and B of Figure 3.8 present the projected number of consecutive days in cold and heat waves under different RCP scenarios. In this graph, a cold (heat) wave is defined as at least 3 consecutive days with daily mean temperature at or below the 5th percentiles (at or above the 95th percentile) of the temperature distribution of specific province. Since the average temperature is projected to decrease in the coming year, the number of days in cold waves decreases quickly and is close to 0 in years 2050s. On the other hand, the number of days in heat waves increases significantly and reaches maximum figures in around 2060. The number of heat waves is largest for the RCP 6.0 scenario and smallest for the RCP 2.6 scenario.

To anticipate the number of fatalities per 100,000 people caused by cold and heat waves in the next years, we multiplied the predicted number of days in cold and heat waves by the estimated influence of cold and heat waves on mortality rate (0.18 and 0.14, respectively, as shown in Panel B of Figure 3.7). For the projection, we use the effect estimates of cold and heat waves on the mortality rate rather than the log of the mortality rate. The mortality rate is a more accurate means of estimating the number of people who will die as a result of future temperature extremes. Since we utilize the constant effect estimates of cold or heat waves on mortality, the forms of the number of fatalities caused by cold and heat waves (shown in Panels C and D) are quite similar to the morphologies of cold and heat waves. Heat-related deaths are expected to rise in the future, reaching a peak around 2060. These findings raise severe concerns regarding the health effects of future heat in Viet Nam.

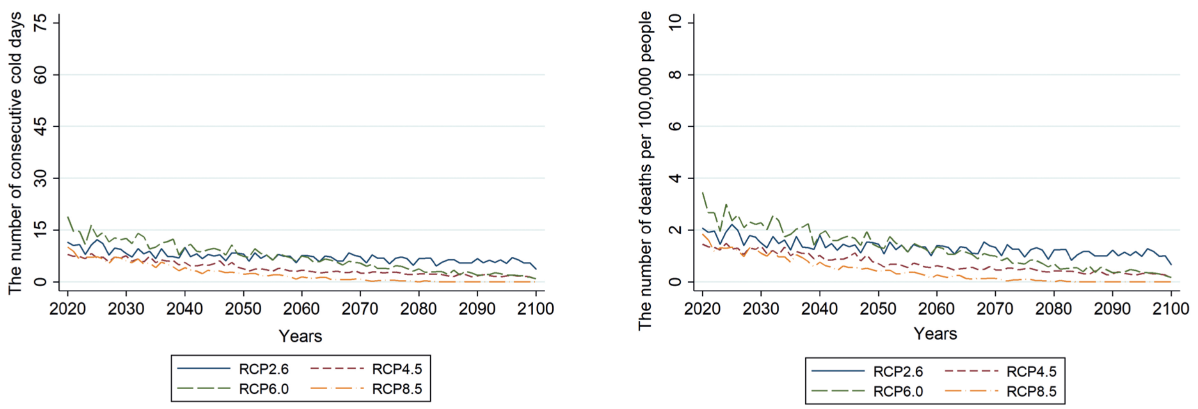
4. Main conclusions and policy implications

Understanding the effect of weather extremes on health has received great attention from scholars and practitioners. This chapter provides new insight into climate change's impact on infectious disease and mortality in Viet Nam. The diversity of climate in non-identical regions in Viet Nam generates different effects for climatic factors on communicable disease. We found that temperature and wind-speed affect infectious diseases — vector borne, airborne, and waterborne — for all regions. The effects vary across the regions. A stronger effect is found for vector-borne disease than others.

We find evidence for heterogeneous effects across different climatic regions and the role of health-care expenditures. A colder region will be more impacted by hot temperatures than cold temperatures. In contrast, a hot region will be more sensitive to cold temperatures than hot temperatures. There will be direct economic costs through expenditures for controlling and treating disease. Our analysis also highlights the indirect cost of disease impact caused by global climate warming. In our report, the indirect economic costs of infectious disease is estimated through

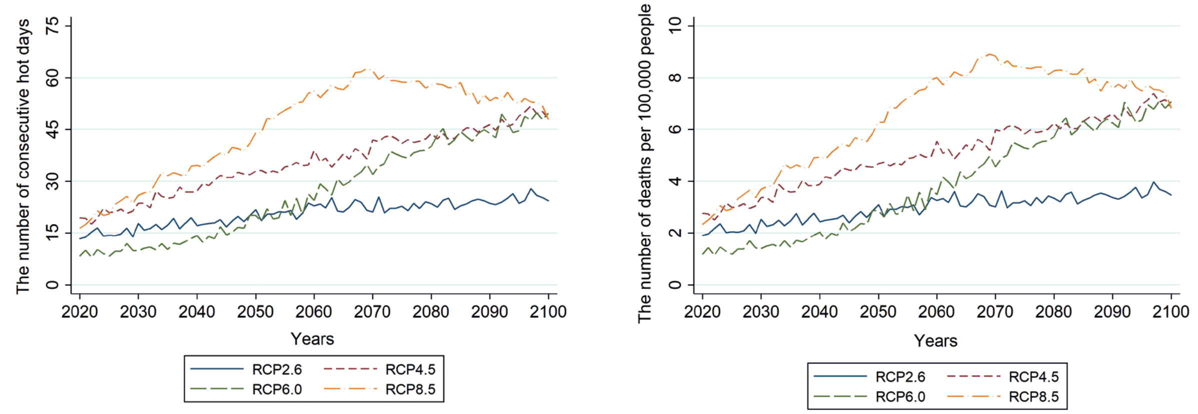
[Figure 3.8]

The projected number of consecutive days in cold and heat waves and the number of deaths under different Representative Concentration Pathway scenarios



Panel A. The projected number of consecutive days in cold waves

Panel C. The projected number of deaths per 100,000 people due to cold waves



Panel B. The projected number of consecutive days in heat waves

Panel D. The projected number of deaths per 100,000 people due to heat waves

This figure presents the projected number of consecutive days in cold and heat waves under different Representative Concentration Pathway scenarios and the estimated number of deaths due to these cold and heat waves over the 2020–2100 period. A cold (heat) wave is defined as at least 3 consecutive days which have daily mean temperature at or below the 5th percentiles (at or above the 95th percentile) of the temperature distribution of specific province.
Source: Nguyen *et al.* (2021).

labour productivity loss due to diseases: a 1% increase in disease infections leads to a decrease in the average hourly wage of approximately 0.05%. This is the marginal cost on worker productivity of an incremental change of temperature. Note that this is only part of the economic cost of infectious diseases. The direct costs will be the loss in wages and cost of preventing and treating the diseases. There are also substantial indirect costs, as incidence affects behaviour and investment in physical and human capital. Social costs include reduction of life expectancy and quality of life due to disease related disability. Estimating these are beyond the scope of the current study, but in other contexts these have been estimated to be significant [Goenka and Liu, 2020].

We find robust evidence on the positive effects of cold and heat waves on mortality. A cold wave with at least 5 consecutive cold days increases the monthly mortality rate by around 4.9 percent, while a cold wave with at least 9 consecutive cold days increases the mortality rate by 6.5 percent. The mortality rate in a month increases by 13.5 percent if there is a heat wave of at least 9 consecutive days in that month. The results also suggest that older people, especially those over 80, are mainly affected by the weather extremes. Cold and heat waves have negligible effects for people under 40.

Our findings raise some policy implications for policy makers as follows. First, human adaption and public health strategy play an essential role in the new scenario of infectious disease outbreaks. Since these vulnerabilities to climate change are not the same between regions, the adaption strategy should be based on the local context with respect to demography, socio-economic and geographical conditions, and the availability of preventive measures. Since extreme events are on the increase, preventive care for older adults is vital in the susceptible regions.

Second, the loss of working capacity would be a catastrophic non-medical cost for a highly vulnerable population with low education attainment, when household income mainly depends on labour-intensive products such as outdoor services and conventional agriculture. There is a double loss in the case of agricultural production in the vulnerable hot spots in Viet Nam. The vicious circle of a lower yield and loss of labour capacity will persist when crop failure leads to under-nutrition and weakens the immune system, thus increasing the risk of infection. Universal health care and insurance is a proven effective measure, along with the epidemic prevention.

Third, although it requires further examination, the health budget has an important role in lessening the sensitivity of infections to disease. Funding for infectious disease control and prevention mainly depends on local financial capacity. In the National Target Program, phase 2016–2020, the Project for communicable and noncommunicable diseases was allocated 1,576 billion VND from the State (58 million EUR), 735.384 billion VND (27 million EUR) from the local budget, and 2,150 billion VND (79 million EUR) from ODA and external assistance. However, poor provinces with low annual public spending on infectious disease control suffer a higher risk of epidemic. Moreover, improving primary healthcare such as commune health stations and district hospital enhancement is considered to be advisable in Viet Nam, in order to reduce overload at national or provincial level. Some national evidence showed that total cost of primary healthcare service is reasonable for ordinary people. Furthermore, medical insurance cover in Viet Nam is high (>90%), but discrepancies exist among levels of health care. Thus the government should have support programs for poor provinces and disadvantaged groups to cope with the adverse effects of climate change and weather extremes on health care. Finally, the effect of cold waves as well as heat waves tends to increase when the cold and heat waves last for a longer time. Compared with a cold wave, the effect of a heat wave on the mortality rate is more significant and of a larger magnitude. In the future, if the temperature rises, more people will die because of heat waves. The adverse effects of temperature extremes on health require the government to pay attention to adaptation and coping strategies.

For scholars and researchers, we have the following suggestion. Firstly, located in both a temperate and a tropical zone with a diverse topography, Viet Nam's climate has a considerable amount of sun, a high rate of rainfall, and high humidity that vary significantly between regions. Therefore, more attention should be paid to the spatial heterogeneity impacts, to capture the differences in sensitivity to infection disease and mortality-to-weather conditions across regions. Next, in this study, our main interest has been the impact of temperature on infectious disease, and of heat and cold waves on mortality. However, wind-speed, rainfall and humidity also play important roles. Future research on wind-speed, rainfall and humidity may benefit from better information on climate change impacts on health and disease. Moreover, climate change will induce changes in land use, potential changes in precipitation, flooding, and coastal erosion. These medium-to long-term changes are not covered in the study. All of these contribute to a change in the incidence of infectious diseases, and need to be monitored to see the patterns of change. Finally, adaptation and coping strategies for climate change should be explored in future studies. Information on these issues will be useful for the government in designing policies to mitigate the effect of climate change. For large-scale datasets used for this study, missing information on specific investments could cause an omitted variable bias. We should look for proxies, find instrument variables or collect other complementary data.

References

Adda, J. (2016, 02). Economic Activity and the Spread of Viral Diseases: Evidence from High Frequency Data. *The Quarterly Journal of Economics* 131(2), 891–941. https://doi.org/10.1093/qje/qjw005

Barreca, A., Clay, K., Deschenes, O., Greenstone, M., & Shapiro, J. S. (2016). Adapting to climate change: The remarkable decline in the US temperature-mortality relationship over the twentieth century. *Journal of Political Economy*, 124(1), 105-159. https://doi.org/10.1086/684582

Brady, O. J., M. A. Johansson, C. A. Guerra, S. Bhatt, N. Golding, D. M. Pigott, H. Delatte, M. G. Grech, P. T. Leisnham, R. Maciel-de Freitas, L. M. Styer, D. L. Smith, T. W. Scott, P. W. Gething, and S. I. Hay (2013, Dec). Modelling adult aedes aegypti and aedes albopictus survival at different temperatures in laboratory and field settings. *Parasites & Vectors* 6(1), 351. https://doi.org/10.1186/1756-3305-6-351

Brady, O. J., N. Golding, D. M. Pigott, M. U. G. Kraemer, J. P. Messina, R. C. Reiner Jr, T. W. Scott, D. L. Smith, P. W. Gething, and S. I. Hay (2014, Jul). Global temperature constraints on Aedes aegypti and Ae.albopictus persistence and competence for dengue virus transmission. *Parasites & Vectors* 7(1), 338. https://doi.org/10.1186/1756-3305-7-338

Butler, E. and P. Huybers (2013). Adaptation of us maize to temperature variations. *Nature Climate Change* 3, 68–72. https://doi.org/10.1038/nclimate1585

Burgess, R., Deschenes, O., Donaldson, D., & Greenstone, M. (2017). Weather, climate change and death in India. University of Chicago.

Carleton, T. A., A. Jina, M. T. Delgado, M. Greenstone, T. Houser, S. M. Hsiang, A. Hultgren, R. E. Kopp, K. E. McCusker, I. B. Nath, J. Rising, A. Rode, H. K. Seo, A. Viaene, J. Yuan, and A. T. Zhang (2020, July). Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits. Working Paper 27599, National Bureau of Economic Research. http://www.nber.org/papers/w27599 Carrington, L. B., M. V. Armijos, L. Lambrechts, C. M. Barker, and T. W. Scott (2013, 03). Effects of fluctuating daily temperatures at critical thermal extremes on aedes aegypti life-history traits. *PLOS ONE* 8(3), 1–9. https://doi.org/10.1371/journal.pone.0058824

Chan, M. and M. A. Johansson (2012, 11). The incubation periods of dengue viruses. *PLOS ONE* 7(11), 1–7. https://doi.org/10.1371/journal.pone.0050972

Checkley, W., L. Epstein, R. Gilman, D. Figueroa, R. Cama, J. Patz, and R. Black (2000, 03). Effects of ei nino and ambient temperature on hospital admissions for diarrhoeal diseases in Peruvian children. *Lancet* 355, 442–50. https://doi.org/10.1016/S0140-6736(00)82010-3

Chen, P.-S., F. T. Tsai, C. K. Lin, C.-Y. Yang, C.-C. Chan, C.-Y. Young, and C.-H. Lee (2010). Ambient influenza and avian influenza virus during dust storm days and background days. *Environmental health perspectives* 118(9), 1211–1216. https://doi.org/10.1289/ehp.0901782

Christofferson, R. C. (06 Jul. 2016). Zika virus emergence and expansion: Lessons learned from dengue and chikungunya may not provide all the answers. *The American Society of Tropical Medicine and Hygiene* 95(1), 15–18. https://doi.org/10.4269/ajtmh.15-0866

Chung, H. and M. Sobsey (1993). Comparative survival of indicator viruses and enteric viruses in seawater and sediment. *Water Science and Technology* 27(3-4), 425–428. https://doi.org/10.2166/wst.1993.0385

Couret, J. and M. Q. Benedict (2014). A meta-analysis of the factors influencing development rate variation in aedes aegypti (diptera: Culicidae). *BMC Ecology*, 14(1), 3. https://doi.org/10.1186/1472-6785-14-3

Deschenes, O., and Greenstone, M. (2011). Climate change, mortality, and adaptation: Evidence from annual fluctuations in weather in the US. *American Economic Journal: Applied Economics*, 3, 152–185. https://doi.org/10.1257/app.3.4.152

Deschênes, O., and Moretti, E. (2009). Extreme weather events, mortality, and migration. *The Review of Economics and Statistics*, 91(4), 659-681. https://doi.org/10.1162/rest.91.4.659

Deschênes, O., Greenstone, M., and Guryan, J. (2009). Climate change and birth weight. *The American Economic Review*, 99(2), 211-217. https://doi.org/10.1257/aer.99.2.211

Dunne, John P., Stouffer, Ronald J., and John, Jasmin G. (2013).Reductions in labour capacity from heat stress under climate warming. *Nature Climate Change*, 3(6), 563-566. https://doi.org/10.1038/nclimate1827

Eckstein, D., V. Kunzel, L. Schafer, and M. Winges (2019). Global climate risk index 2020. Bonn: Germanwatch.Gage, K. L., T. R. Burkot, R. J. Eisen, and E. B. Hayes (2008). Climate and vectorborne diseases. *American Journal of Preventive Medicine* 35(5), 436–450. https://doi.org/10.1016/j.amepre.2008.08.030

Goenka, A.and Liu, L. (2020). Infectious diseases, human capital and economic growth. *Economic Theory*, 70, 1-47. https://doi.org/10.1007/s00199-019-01214-7

Hamnett, M. P., C. L. Anderson, and C. P. Guard (1999). The Pacific ENSO Applications Center and the 1997–98 ENSO warm event in the US-affiliated Micronesian Islands: Minimizing impacts through rainfall forecasts and hazard mitigation. Pacific ENSO Applications Center. Available online at http://edev3.socialsciences.hawaii.edu/temp/hazards/5%20Publications/HCEwebsite/PEACpaper1.pdf

Hoddinott J, Maluccio JA, Behrman JR, Flores R, Martorell R. (2008). Effect of a nutrition intervention during early childhood on economic productivity in Guatemalan adults. *The Lancet*. 371(9610), 411-6. https://doi.org/10.1016/S0140-6736(08)60205-6

Hoover, C. M., S. L. Rumschlag, L. Strgar, A. Arakala, M. Gambhir, G. A. de Leo, S. H. Sokolow, J. R. Rohr, and J. V. Remais (2020). Effects of agrochemical pollution on schistosomiasis transmission: a systematic review and modelling analysis. *The Lancet Planetary Health* 4(7), 280–291. https://doi.org/10.1016/S2542-5196(20)30105-4

Hoshen, M. B. and A. P. Morse (2004). A weather-driven model of malaria transmission. *Malaria journal* 3(1), 1–14. https://doi.org/10.1186/1475-2875-3-32

Huynen, M., Martents, P., Schram, D., Weijenberg, P., and Kunst, A. (2001). The impact of heat waves and cold spells on mortality rates in the Dutch population. *Environmental Health Perspectives*. 109, 463-70. https://doi.org/10.1289/ehp.01109463

Jahani, F., and Ahmadnezhad, E. (2011).A systematic review of climate change' impact and infectious disease. *Journal of Epidemiol Community Health*, 65. http://dx.doi.org/10.1136/jech.2011.142976p.34

Kien, T., T.-H. Tran, H. Cuong, and R. Shaw (2010). Chapter 20 identifying linkages between rates and distributions of malaria, water-born diseases and influenza with climate variability and climate change in Viet Nam. *Community, Environment and Disaster Risk Management*, 5, 417–449. https://doi.org/10.1108/S2040-7262(2010)0000005026

Kuhn, K., D. Campbell-Lendrum, A. Haines, and J. Cox (2004). Using climate to predict infectious disease outbreaks: A review. World Health Organization. https://apps.who.int/iris/handle/10665/84175

Levy, K., Woster, A., Goldstein, R., and Carlton, E. (2016).Untangling the impacts of climate change on water-borne diseases: A systematic review of relationships between diarrheal diseases and temperature, rainfall, flooding, and drought. *Environmental Science & Technology,* 50 (10), 4905–4922. https://doi.org/10.1021/acs.est.5b06186.

Lowen, A. C., S. Mubareka, J. Steel, and P. Palese. (2007). Influenza virus transmission is dependent on relative humidity and temperature. *PLoS Pathog* 3(10), 151. https://doi.org/10.1371/journal.ppat.0030151

McGregor, G. R., & Vanos, J. K. (2018). Heat: a primer for public health researchers. *Public Health*, 161, 138–146. https://doi.org/10.1016/j.puhe.2017.11.005

Maluccio JA, Hoddinott JF, Behrman JR, Quisumbing AR, Martorell R, Stein AD. (2009).The Impact of Nutrition During Early Childhood on Education among Guatemalan Adults. *Economic Journal* 119(537), 734–63. https://doi.org/10.1111/j.1468-0297.2009.02220.x

Mecenas, P., R. T. d. R. M. Bastos, A. C. R. Vallinoto, and D. Normando (2020). Effects of temperature and humidity on the spread of covid-19: A systematic review. *PloS one* 15(9), 0238339–0238339. https://doi.org/10.1371/journal.pone.0238339

Mullins, J. T. and C. White (2020). Can access to health care mitigate the effects of temperature on mortality?. *Journal of Public Economics*, 191, 104259. https://doi.org/10.1016/j.jpubeco.2020.104259

Murray, V. and K. L. Ebi (2012). IPCC special report on managing the risks of extreme events and disasters to advance climate change adaptation.

Nguyen, HX (2020). Factors influencing Hand-Foot-Mouth disease in the Mekong Delta Region in the Context of Climate Change and Potential Strategies to Improve Prevention and Control. https://doi.org/10.25904/1912/2541

Nguyen, C., Nguyen, M-H., Nguyen, T. (2021), Climate Change, Heat Waves, Cold Waves, and Mortality: Evidence from Monthly Data in Viet Nam, Background paper, the GEMMES VN project.

Nguyen, M-H and L.A Nguyen (2021), Climate change and infectious diseases in Viet Nam: From evidence to public health policy, Working paper, IREEDS, N° 08-2021.

Nichols, A., Maynard, V., Goodman, B. and Richardson, J. (2009). Health, climate change and sustainability: A systematic review and thematic analysis of the literature, *Environmental Health Insights*, 3, 63–88. https://doi.org/10.4137/EHI.S3003

Phalkey, K., Aranda-Jan, C., Marx, S., Höfle, B., and Sauerborn, R. (2015). Systematic review of current efforts to quantify the impacts of climate change on undernutrition. *Proceedings of the National Academy of Sciences*, 112(33), 4522-4529. https://doi.org/10.1073/pnas.1409769112

Phung, D., C. Huang, S. Rutherford, C. Chu, X. Wang, and M. Nguyen (2015). Climate change, water quality, and water-related diseases in the Mekong Delta Basin: A systematic review. *Asia-Pacific Journal of Public Health*, 27. https://doi.org/10.1177/1010539514565448

Phung, D., H. Nguyen, H. Nguyen, C. Do, Q. Tran, and C. Chu (2017). Spatiotemporal variation of handfoot-mouth disease in relation to socioecological factors: A multiple-province analysis in Viet Nam. *The science of the total environment*, 610-611, 983–991. https://doi.org/10.1016/j.scitotenv.2017.08.158

Rohr, J. R. and J. M. Cohen (2020). Understanding how temperature shifts could impact infectious disease. *PLOS Biology* 18(11), 1–13. https://doi.org/10.1371/journal.pbio.3000938

Ruhm, C. (2000). Are recessions good for your health? *The Quarterly Journal of Economics* 115, 617–650. https://doi.org/10.1257/aer.99.2.122

Shaman, J. and M. Kohn (2009). Absolute humidity modulates influenza survival, transmission, and seasonality. *Proceedings of the National Academy of Sciences*, 106(9), 3243–3248. https://doi.org/10.1073/pnas.0806852106

Simeonova, E. (2011).Out of sight, out of mind? Natural disasters and pregnancy outcomes in the USA. CESifo *Economic Studies*, 57(3) 403–431. https://doi.org/10.1093/cesifo/ifr005

Sweileh, P. W. (2020). Bibliometric analysis of peer-reviewed literature on climate change and human health with an emphasis on infectious diseases. *Globalization and Health*, 16. https://doi.org/10.1186/s12992-020-00576-1

Thuc, T., N. Van Thang, H. T. L. Huong, M. Van Khiem, N. X. Hien, and D. H. Phong (2016). Climate change and sea level rise scenarios for Viet Nam. Ministry of Natural resources and Environment. Hanoi, Viet Nam.

Tran, D. N., V. Q. Doan, V. T. Nguyen, A. Khan, P. K. Thai, H. Cunrui, C. Chu, E. Schak, and D. Phung (2020). Spatial patterns of health vulnerability to heatwaves in Viet Nam. *International Journal of Biometeorology*, 64(5), 863–872. https://doi.org/10.1007/s00484-020-01876-2

Victora CG, Adair L, Fall C, Hallal PC, Martorell R, Richter L, *et al.* (2008). Maternal and child undernutrition: consequences for adult health and human capital. *The Lancet*, 371(9609), 340-57. https://doi.org/10.1016/S0140-6736(07)61692-4

WHO (2014). Chronic diseases and Health Promotion, World Health Organization.

WHO (2015). Viet Nam: WHO Statistical profile 2015, World Health Organization.

Wu, X., Lu, Y., Zhou, S., Chen, L., Xu, B. (2016). Impact of climate change on human infectious diseases: Empirical evidence and human adaptation. *Environment International*, 86, 14-23. https://doi.org/10.1016/j.envint.2015.09.007

Zivin, J., and Neidell, M. (2010).Temperature and the allocation of time: Implications for climate change. NBER Working Paper No. 15717.

WHO (2018). WHO housing and health guidelines, World Health Organization.

Chapter 4

Agriculture in Viet Nam under the impact of climate change in the 21st century

COORDINATOR

Thuy Le Toan [CESBIO]

AUTHORS

Thuy Le Toan [CESBIO]
Nguyen Huu Quyen [IMHEN]
Michel Simioni [MOIRA, INRAE]
Hironori Arai [CESBIO]
Stephane Mermoz [GlobEO, CESBIO]
Alexandre Bouvet [GlobEO, CESBIO]
Irene de Eccher [IRD]
Yaro Diallo [CERDI]
Trinh Hoang Duong [IMHEN]
Vo Dinh Suc [IMHEN]
Lam Dao Nguyen [VNSC-STAC]
Marie-Noëlle Woillez [AFD]
Etienne Espagne [AFD]