Journal of Population and Social Studies, Volume 22 Number 2 July 2014: 192 - 201
DOI: 10.14456/jpss.2014.13

Association between Temperature and Mortality among the Working Age Population in Thailand from 1999 to 2008

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Abstract

This study identifies the temperature-mortality association of the working age (15-64 years) population in a tropical setting, Thailand. The research covers a 10-year period (1999-2008) and is country-wide. Alternating Multivariable Fractional Polynomial (MFP) regression analysis is used to sequentially build models of the associations between temperature and death rates. Model A is developed to test the links between weather and mortality. Model F produces an optimal weather-death model adjusted for air pollution effects and estimates expected mortality with a 4 °C increase in temperature as projected for Thailand by the year 2100. There are highly significant associations between weather variation and mortality for the working age population with a threshold temperature at 36°C (Model A); after adjusting for air pollution effects, the threshold temperature is 33°C (Model F) and forms a J- or U-shaped pattern. The overall increase in mortality among the working age population expected with a 4 °C increase is 11%. The largest effects of maximum temperature on mortality are in the Central region where this effect will be especially prominent, due to urbanization and the heat island effect. Therefore, ongoing future climate change with increasing temperatures will cause death rates of working age Thais to increase substantially and this will have economic impacts in the future.

Keywords

Temperature; mortality; working age groups; heat stress; climate change; multivariable fractional polynomial regression

Introduction

Heat stress can cause serious occupational injury and ill-health among workers who are exposed to hot and humid work environments (Kjellstrom, Holmer & Lemke, 2009). The heat wave in France in August 2003 caused almost 1,000 documented additional deaths in the age range 20-60 years (Hémon & Jougla, 2003). This age group includes people in the workforce who may be exposed to heavy labor outdoors during hot weather (Kjellstrom, Holmer & Lemke, 2009). With climate change, such workers will be exposed to very high heat even more frequently, leading to prolonged heat stress if they are without sufficient heat protection and experience prolonged dehydration (Kjellstrom & Weaver, 2009). For

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these reasons, research on heat stress among the working population provides important insight into the impact of climate change, in particular for tropical developing countries.

Conceptual framework

Thailand is a tropical developing country with around 65 million people, more than 39 million of whom are now in the workforce (National Statistical Office (NSO), 2012). A study of occupational heat stress in Thailand by Langkulsen, Vichit-Vadakan & Taptagaporn(2010) indicated that heat stress in Thailand is a very serious problem (rated as "extreme caution" or "danger") in a wide variety of work settings such as a pottery factory, a power plant, a knife manufacturing site, a construction site, and an agricultural site. This rating follows the heat categories of the Heat Index combining air temperature and humidity (National Oceanic and Atmospheric Administration's National Weather Service, 2009). This study indicated that Thai workers in industrial and agricultural workplaces face excessive heat conditions in which heat-related illness is likely to happen. Another study found that salt production workers in Thailand worked under heat stress, as the average temperature in the working environment was 33.8°C; those workers who worked under heat stress were more likely to have heat symptoms (acute heat-related illness or heat stroke) compared to an unexposed group (Jakreng, 2010).

Physically active workers especially those who work outdoors are more likely to have health impacts from heat stress effects even if they are fit and healthy (Kjellstrom, Gabrysch, Lemke & Dear, 2009). These may result from a lack of awareness that they are becoming ill from high temperature; therefore they ignore dehydration symptoms and do not take action to reduce heat exposure. If workers have insufficient water intake and sweat substantially, they will increase body fluid loss and become dehydrated, which can create adverse health impacts (such as heat stroke or heat-related illness) (Bridger, 2003). Moreover, they can get exhausted from heat stress and perform their work disregarding safety precautions. Consequently, heat stress can increase unsafe working conditions and also occupational injuries (Ramsey, Burford, Beshir & Jensen, 1983; Mathee, Oba & Rose, 2010).

Mortality has always been a key health endpoint in epidemiological studies. It is a well-defined health outcome and widely used in studies of the effect of heat stress. Most studies on temperature-mortality associations have been conducted in temperate developed countries (Baccini, Biggeri, Accetta, Kosatsky, Katsouyanni & Analitis, 2008; Anderson & Bell, 2009; D'Ippoliti, Michelozzi, Marino, de'Donato, Menne & Katsouyanni, 2010; Khalaj, Lloyd, Sheppeard & Dear, 2010; Liu & Zhang, 2010). These studies leave unanswered questions about the effects of hot and humid weather in tropical countries, where very high heat will become even more frequent under global climate change.

The average temperature in Thailand has increased 0.74 degrees Celsius (°C) over the last century (Limsakul, Limjirakan & Sriburi, 2009). From 1951 to 2003, the monthly mean maximum temperature in Thailand increased by 0.56 ˚C and the monthly mean minimum temperature increased even more by 1.44 ˚C (Limsakul & Goes, 2008). Increasing heat stress under climate change is anticipated in Thailand; an additional 4˚C increase in maximum temperature is projected for Thailand by 2100 (Thai Meteorological Department (TMD), 2009). Also, existing air pollution will potentially interact with heat effects, with heat making the air pollution worse and both contributing to excess mortality (Dear, Ranmuthugala, Kjellström, Skinner & Hanigan, 2005). Studies on heat-related deaths found that the combined exposure to high temperatures and air pollutants such as ozone (O3), nitrogen dioxide (NO2), and particulate matter with diameter under 10 microns (PM10) appears to be a critical risk factor for cardiovascular mortality (Ren, Williams, Morawska, Mengersen & Tong, 2008; Ren, Williams, Mengersen, Morawska & Tong, 2009).

Thus, heat stress is already a problem in Thailand and there is a need for greater concern about the effects of temperature on health outcomes of Thai workers. There is a large working population in the industrial sector, a growing and vital part of the Thai economy, and ongoing climate change will lead to higher heat exposure for Thai workers. Therefore, this study addresses an unanswered issue from previous study (Tawatsupa, Dear, Kjellstrom & Sleigh, 2012) by exploring the temperature-mortality association for working age groups (15-64 years). The research covers a 10-year period (1999-2008) and is country-wide. The results reported here shed light on the situation confronting those at high risk of heat stress in Thai society.

Methods

To analyze the association between temperature and mortality for the working age population in Thailand, we used four national databases. These covered 1999 to 2008 and included data on mid-year populations, mortality, weather and air pollution.

Mid-year population data: The Ministry of Public Health, Thailand supplied mid-year population estimates by age-group and sex for each of Thailand's 76 provinces from 1999 to 2008 (Bureau of Health Policy and Strategy, 2010b). These population data allowed the calculation of age-sex specific death rates for each province (ADR per 100,000 population).

Mortality data: The Ministry of Public Health supplied daily all-cause mortality data for Thailand's 76 provinces (a total 3,805,638 deaths) from the 1st of January 1999 to the 31st of December 2008 (Bureau of Health Policy and Strategy, 2010a). For each province, daily death counts were averaged each month and then divided by the population for each age-sex group to calculate monthly age-sex death rates across the 10-year period. For each year, the provincial monthly age-sex death rates were then weighted and adjusted to the average age-sex structure for the whole of Thailand, updated annually. This adjustment corrects the number of deaths observed in each of 76 provinces to estimate deaths that would have occurred (per 100,000) with a standard age-sex structure.

Weather data: The Meteorological Department supplied daily weather data for a total of 120 stations in 65 provinces from 1999 to 2008 (Meteorological Development Bureau, 2010). The daily weather data include six weather variables for calculating monthly weather profiles of Thailand: mean, minimum, maximum and average dew point temperatures (°C), maximum wind speed (m/s), and average precipitation in 24hrs (mm).

Air pollution data: The Pollution Control Department supplied air pollution data for 23 provinces with fixed air quality monitoring stations (Air Quality and Noise Management Bureau, 2010). The monthly maximum and monthly average of daily mean concentrations for five air pollutants are used in this study; one-hour average of sulfur dioxide (SO_2), one-hour average of nitrogen dioxide (NO_2), one-hour average of carbon monoxide (CO), one-hour average of ozone (O_3), and 24-hour average of particulate matter of less than 10 micrometer in diameter (PM_{10}).

Statistical analysis

This study follows the methods described in a more general paper modelling death rates for all age groups (Tawatsupa et al, 2012). However the analyses are restricted to working aged persons (15-64 years). The main question of interest was how the monthly provincial age-sex adjusted death rate (ADR per 100,000 population) related to weather conditions. The dependent variable was monthly provincial ADR from 1999 to 2008. Explanatory monthly provincial weather data were included if they were available for all weather variables. In this study, the models were built with the statistical package Stata/SE12 (Stata, 2011) to mathematically define relationships between deaths and weather variables and their interactions at a significance level of $p \leq 0.001$.

The alternating Multivariable Fractional Polynomial (MFP) regression is suited to continuous, multivariable, non-linear associations (Royston& Sauerbrei, 2008). The MFP model devised optimal transformations for the raw (untransformed) weather variables and stepwise linear regression analyses selected the most significant explanatory variables produced by the MFP models. The sequence of formats used was as follows. **Model A** is a single MFP function with ADR as the dependent variable and significant transformed ("functional form") weather variables as the independent variables. Model A was adjusted for year, month, and province as factor variables exploring the overall relationship between weather condition and ADR for the whole country and it shows why maximum temperature is the most important variable.

To investigate potential modifier and confounding effects of air pollution, we gathered available air pollution data and explored the influence of air pollution on the weather-mortality effects revealed by Model A. So, **Model F** (Final model) is an MFP model that transforms the weather, air pollution, and interaction variables into optimal functional forms. It is therefore used in this report to show how maximum temperature relates to death rates after adjusting with air pollution variables and enabled a series of season-region specific mortality function plots that displayed a "best-fit" for the mortality data.

The estimation of heat-related death should take into account regional, seasonal and demographical differences (Kim, Ha & Park, 2006; Chung, Honda, Hong, Pan, Guo & Kim, 2009). Therefore, the function plots in this study show the link between maximum temperature and change in ADR for each of the 12 season-region combinations including the interaction between 3 seasons (Cold, Hot, Wet) and 4 regions of Thailand (North, Northeast, Central, South). Each graph shows the magnitude of temperature effects on mortality, and the threshold temperature for minimum mortality. This threshold temperature is defined as a temperature with minimum effect on mortality. It is commonly used to estimate the health effects from exposure to high or low temperature (Ballester, Corella, Perez-Hoyos, Saez & Hervas 1997; Curriero, Heiner, Samet, Zeger, Strug & Patz, 2002; McMichael, Wilkinson, Kovats, Pattenden, Hajat &Armstrong, 2008).

For climate change scenario, we also used Model F to estimate the ADR expected with an additional 4˚C increase of maximum temperature as taken from the future climate projection in Thailand in 2100 (TMD, 2009).

Results

Model A: Association between mortality and weather variables among working age Thais

Model A is a single MFP regression showing that maximum temperature is the most important variable. There is a strongly significant non-linear association between monthly maximum temperature and mortality ($p<0.001$). The polynomial plot of average monthly provincial age-sex adjusted death rate (ADR) by the functional maximum temperature terms is displayed in Figure 1. Fluctuation of the maximum temperature in Thailand during the last 10 years (1999 to 2008) across the Celsius temperature range of 24 to 40 produced substantial variation in mortality. As the maximum temperature rises from 24°C to 36°C, ADR exponentially falls; but when maximum temperature rises further, ADR exponentially increases. This crude analysis indicates that 36°C is the average threshold maximum temperature in Thailand for those of working age (15-64 years).

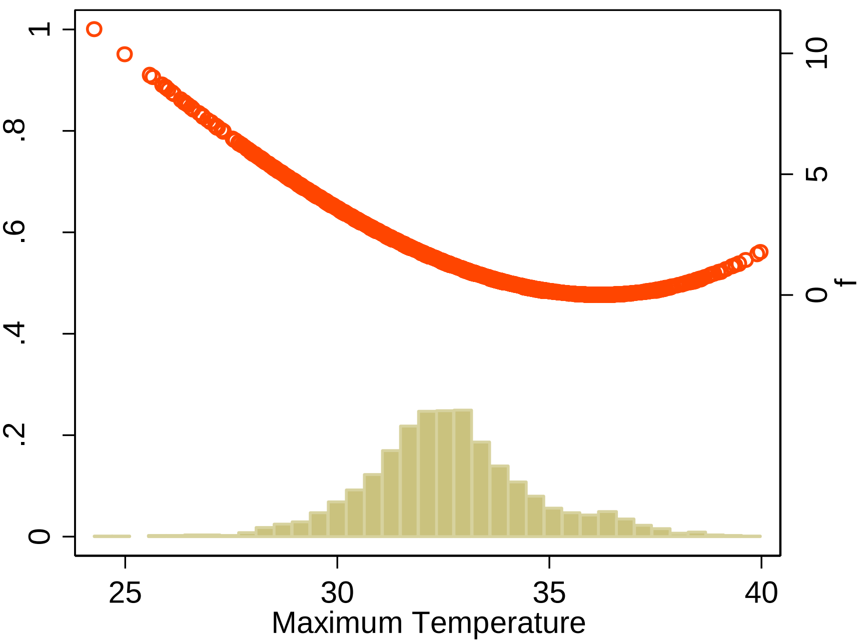

Figure 1: Polynomial plot linking maximum temperature function (Model A) to change in ADR (age 15-64 years), Thailand 1999-2008 (N=5,599 province-months)

Model F: Association between mortality, weather and air pollution by region-season

Model F is statistically the best model with the lowest Akaike's information criterion (AIC) and clearly interpretable exposure-response curves for the maximum temperature and mortality relationship, adjusting for other weather variables, air pollution, and their interactions for each region (North, Northeast, Central , South) - season (hot, wet, cold), as seen in Figure 2. Each graph shows the magnitude of temperature effects on mortality and the threshold temperature for minimum mortality. However, these data for both weather and air pollution are somewhat restricted, available for only 13 provinces over 1,025 province-months. Overall, for the 13 provinces with air pollution and weather data, the hottest and most polluted area was the Central region (which includes Bangkok).

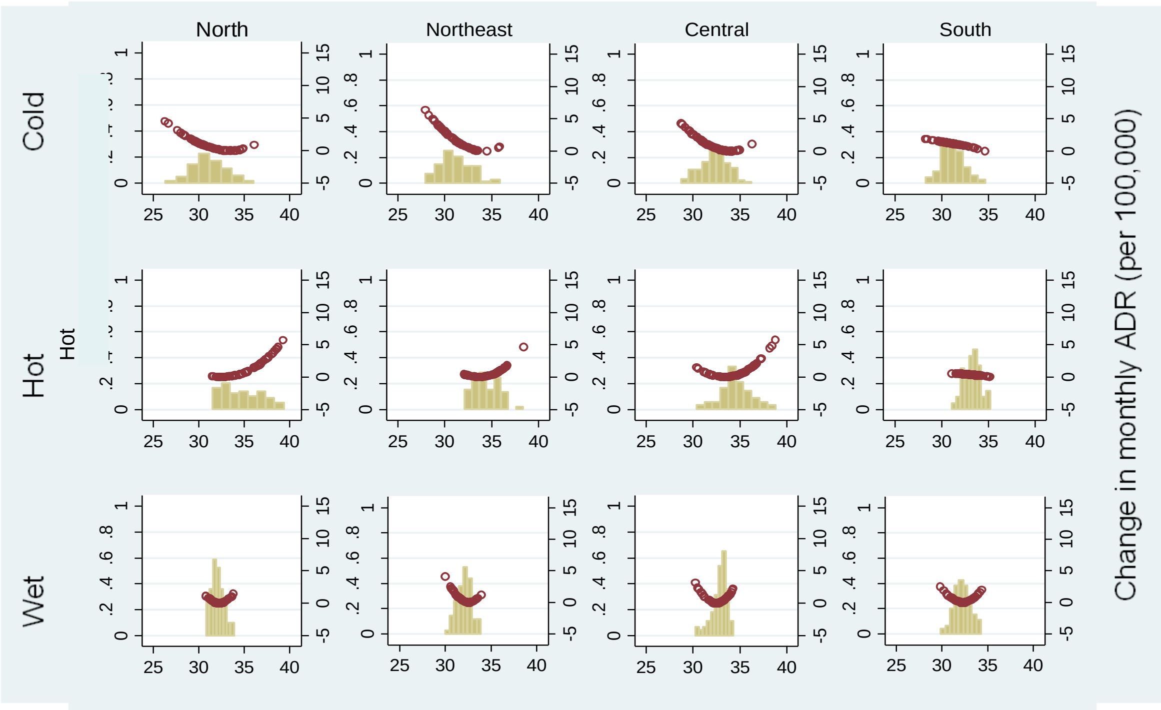

Figure 2: Function plot of maximum temperature on ADR by season and region plus temperature density distribution (Final Model F) (N=1,025 province-months)

The adjusted model (Model F – Figure 2) with air pollution, other weather variables and interactions shows J- or U-shaped associations between maximum temperature and mortality in all regions. It shows an increase in deaths during hot weather as well as cold weather, with the lowest mortality at bottom of the J- or U-shape (the threshold temperature). At high maximum temperature above the threshold temperature during the hot season and at low maximum temperature (below the threshold temperature) in the cold season, there are high mortality rates in the North, Northeast, and Central regions. There is little variation in maximum temperature especially in the equatorial South. In the wet season, threshold temperatures are similar for all regions, ranging from 32.2 to 32.6°C.

Climate change projections

For each region and each season in Thailand, we estimated the ADR expected with an additional 4°C increase of maximum temperature as projected for Thailand by 2100 (TMD, 2009).The Model F equation for linear regression and suitable functional transformations allowed modeling of the ADR for different maximum temperatures by region and season. Indeed, defining the threshold temperature for each region and each season allowed us to compare these ADRs to the region-season death rates expected at additional 4°C of maximum temperature as per the future climate projection in Thailand in 2100 (Table 1). The largest difference in mortality in the future in relation to the 4°C increase in maximum temperature is in the wet months, leading to a net increase in ADR of 18 to 40%, and especially severe in the Central region. Overall the net increase in mortality rates in the future for the full year of the +4°C scenario ranged by region from 7 to 19%. For the whole of Thailand, the increase in mortality expected with a 4ºC increase in maximum temperature would be 11.5%.

Table 1: Percentage changes in mortality rates (ADR) of the working age population if expected maximum temperature increases by 4˚C[a], by region and season, and for Thailand overall (Model F)

Season	Region	ADR[b] (deaths per 100,000)	ADR at Tmax +4°C[a]	Net changes in ADR	% change in ADR
Cold	North	46.04	45.96	-0.08	-0.18
	Northeast	32.84	31.79	-1.06	-3.22
	Central	36.08	37.01	0.93	2.58
	South	33.55	32.33	-1.22	-3.64
Hot	North	48.56	52.77	4.21	8.67
	Northeast	35.31	39.86	4.55	12.89
	Central	37.86	42.78	4.92	13.01
	South	35.02	34.10	-0.92	-2.63
Wet	North	46.33	54.87	8.54	18.43
	Northeast	33.74	42.32	8.58	25.42
	Central	37.26	52.39	15.12	40.59
	South	35.06	44.21	9.16	26.12
Overall	North	46.98	51.20	4.22	8.97
	Northeast	33.96	37.99	4.02	11.70
	Central	37.07	44.06	6.99	18.72
	South	34.55	36.88	2.34	6.61
	Thailand	38.14	42.53	4.39	11.50

[a]Expected temperature increase by 2100 for Thailand (see text)
[b]ADR = monthly age-sex adjusted death rates

Discussion and Conclusion

During the 10-year period analyzed (1999–2008) there were highly significant associations between weather variation and mortality among the working population age 15-64 years in Thailand. For Model A, the relationship between maximum temperature and ADR for working age group across country was in a J-shape pattern. The trough of the J-shape represents the comfort zone and the short arm of the J- shape represents the steeper slope of ADR increase with rising temperature above threshold—which averaged 36°C overall.

Comparing exposure-response curves between the overall Thai population at all ages from the previous study (Tawatsupa et al., 2012) and the working age population in this study, the threshold temperatures from Model A are higher than the 31°C found earlier (Tawatsupa et al., 2012). This may be because the working-age group has higher heat tolerance. As seen in Model F, the association between maximum temperature and mortality rates adjusted for air pollution in both all age and the working-age group are similar, presenting as a J- or U-shape.

Climate change risks and working age Thais

Our additional analyses adds to the evidence on the adverse effects of high maximum temperature on the working age-group population in tropical developing countries(Kjellstrom, 2009; Kjellstrom, Holmer & Lemke, 2009; Hyatt, Lemke & Kjellstrom., 2010; Mathee et al, 2010; Tawatsupa, Lim, Kjellstrom, Seubsman, Sleigh & the Thai Cohort Study team, 2010; Kjellstrom& Crowe, 2011; Tawatsupa, Lim, Kjellstrom, Seubsman, Sleigh & the Thai Cohort Study team, 2012). The working age population in Thailand is at risk of heat stress if they often do heavy labor outdoors or indoors without air conditioning/ proper ventilation during hot weather (Tawatsupa et al, 2010; 2012; Tawatsupa, Yiengprugsawan, Kjellstrom, Berecki-Gisolf, Seubsman & Sleigh, 2013). The results show that the rising temperatures resulting from climate change will cause an increase in heat-related deaths that is larger than the cold-related deaths avoided in the hot and wet months. Overall the net increase in expected mortality by region will range from 7 to 19% unless humans adapt physiologically or adopt preventive behavior. And, the overall increase in mortality expected with a 4ºC increase in the future will be higher for the working age group than for the population as a whole (11% vs 8%) (Tawatsupa et al, 2012).

Working age Thais in the Central region will be most severely affected by heat-related mortality effects, with the highest increase in mortality rates (3% in the cold months, 13% in the hot months, and 40% in the wet months). This effect will be especially prominent due to the large degree of urbanization and the heat island effect in the Central region, which includes the Bangkok Metropolitan Area (BMA). The heat island effect is a phenomenon resulting from the fact that urban areas are significantly warmer than surrounding rural areas due to human activities, buildings, roads and other heat-absorbing infrastructure. A large number of people in urban areas are at risk from the combined effects of heat stress with existing urban heat island effects and air pollution problems. Future climate will result in economic impacts in the future.

Recommendations

Thai workers who are at high risk of heat stress exposure must take safety precautions while working under high temperatures. Also, policymakers should be concerned with the prevention of heat stress-related health outcomes to avoid the economic impact from production loss. This attention is urgently needed given the looming threat of global warming for tropical Thailand.

Acknowledgement

The authors would like to thank Department of Health, Ministry of Public Health, Thailand for their support and two anonymous reviewers for their helpful comments.

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