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Mortality and morbidity associated with ambient temperatures in Taiwan

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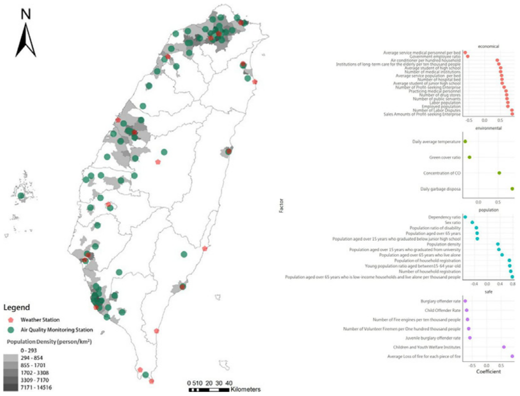
HIGHLIGHTS

- Meta-analysis showed low temperature increased the risk of mortality and outpatient visits
- Emergency room visits risk was significant in high temperature
- Socio-economic variables modified the effects of mortality risk

GRAPHICAL ABSTRACT



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ABSTRACT

Background: This study evaluated integrated risks of all-cause mortality, emergency room visits (ERVs), and outpatient visits associated with ambient temperature in all cities and counties of Taiwan. In addition, the modifying effects of socio-economic and environmental factors on temperature-health associations were also evaluated.
Methods: A distributed lag non-linear model was applied to estimate the cumulative relative risks (RRs) with confidence intervals of all-cause mortality, ERVs, and outpatient visits associated with extreme temperature events. Random-effect meta-analysis was used to estimate the pooled RR of all-cause mortality, ERVs, and outpatient visits influenced by socio-economic and environmental factors.
Results: Temperature-related risks varied with study area and health outcome. Meta-analysis showed greater all-cause mortality risk occurred in low temperatures than in high temperatures. Integrated RR of all-cause mortality was 1.71 (95% confidence interval [CI]:1.43–2.04) in the 5th percentile temperature and 1.10 (95% CI: 1.05–1.15) in the 95th percentile temperature, while the lowest mortality risk was in the 60th percentile temperature (22.2 °C). Risk for ERVs increased when temperature increased (RR was 1.21 [95% CI: 1.17–1.26] in 95th percentile temperature), but risk of outpatient visits increased at low temperatures (RR was 1.06 [95% CI: 1.01–1.12] in the 5th percentile temperature). Certain socio-economic factors significantly modified low-temperature-related mortality risks, including number of employed populations, elders living alone from lower-income families, and public and medical services.
Conclusions: This study found that mortality and outpatient visits were higher at low temperature, while ERVs risk was higher at high temperature. Future plans for public health and emerging medical services responding to extreme temperatures should consider regional and integrated evaluations of temperature-related health risks and modifying factors.

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1. Introduction

Increasing frequency and intensity of extreme temperature events have been forecasted due to climate change (Climate Phenomena and their Relevance for Future Regional Climate Change), which raises important concerns for public health (Frumkin et al., 2008). Many studies have considered ambient temperature and air pollution as risk factors for diseases and mortality, and have explored associations between ambient temperature and diseases and increased mortality risk (Benmarhnia et al., 2014; Guo et al., 2014a; Huang et al., 2012; Wang et al., 2012; Zhang et al., 2014). Numerous studies have reported increased mortality risk associated with variations in daily ambient temperature; this relationship has been characterized as a U-,V-, or J-shaped curve (Curriero, 2002; McMichael et al., 2008), with increased mortality at extreme cold and/or hot temperatures (Anderson and Bell, 2009; Baccini et al., 2008).

Researchers have reported associations between high temperatures and all-cause mortality and outpatient visits varying by region, health outcomes, and selected high temperature indices (Lin et al., 2012). In Hong Kong, mortality from cardiovascular and respiratory infections was more sensitive to high temperatures; children aged 0–4 years old, people aged 65 years and above, and people with chronic diseases, such as ischemic heart disease, ischemic stroke, cardiac dysrhythmia, hypotension, diabetes, hypertension, intestinal infection, dehydration, acute renal failure, and heat illness, were found to be susceptible to extreme temperatures (Basu et al., 2012). Another study in China reported 2.5% increasing in mortality caused by chronic lower respiratory diseases if the temperature increases 1 °C in warm period (Liu et al., 2011). A meta-analysis reported greater all-cause heat-related mortality for people aged 65 years and above compared to cold-related mortality for people aged 50 years and above (Yu et al., 2011).

The outdoor environment is not the only possible determinant for temperature-related health risks. Qualities of cities, neighborhoods, and homes, and individual behavior also have significant impacts on health (Vardoulakis et al., 2014; Zanobetti et al., 2013). A study in South Korea showed that mortality risks increased with high temperatures for elders (>65 years) and from lower-income families (Kim and Joh, 2006). Other socio-economic factors that have been shown to significantly contribute to increasing temperature-related risks are a higher percentage of manual workers, low socio-economic background, low education level, lack of sanitary services, and poor living neighborhoods (Carreras et al., 2015; Xu et al., 2013).

Urban areas dominated by buildings, impervious pavements with limited green spaces, and permeable surfaces can lead to an increased urban heat-island effect and can increase risk of illness and mortality in extreme temperatures (Reid et al., 2009). In Europe, studies showed that health effects related to heat were affected by age, race, sex, family characteristics, air-conditioning facilities, health status, and living areas; pregnant women and elderly, as well as people with low-incomes and chronic diseases, and people working outdoors were found to be more susceptible to extreme temperatures (O'Neill et al., 2009).

In Sweden and Denmark, people aged 60 years and above comorbid with acute myocardial infarction were more susceptible to ERVs risk during cold temperatures (Wichmann et al., 2012; Wichmann et al., 2013). In Cuneo, Italy, emergency room visits (ERVs) for urinary stones were associated with high temperatures, particularly for women aged above 65; diabetes and genitourinary morbidity increased with heat and longer lag periods (Condemi et al., 2014). Chronic diseases such as diabetes can trigger metabolic, cardiovascular, neurological, and behavioral dysfunctions that impair thermo-regulatory responses during heat stress (Kenny et al., 2009).

Taiwan is a highly developed subtropical island 150 km wide and 350 km long with an annual average temperature of 24 °C, which varies from north to south. Mean daily temperatures in urban areas range from 8 °C in winter to 33 °C in summer. Very few studies have reported the effects of socio-economic factors on associations between extreme temperatures and mortality, ERVs, and outpatient visits in Taiwan. Study conducted by Chen et al. (Chen et al., 2010) showed that social disadvantage is a significant predictor of post-cold-surge cardiovascular mortality. Another study from Lin et al. reported that the mortality risk in elderly is higher when the elderly exposed to cold temperature than high temperature (Lin et al., 2011). Our study comprehensively evaluated temperature-related health risks in Taiwan for different health outcomes, i.e. mortality and morbidity, and identified potential modifying effects of regional socio-economic conditions and environmental factors.

2. Materials and methods

2.1. Data sources

This study used vital statistics data from the Department of Health and Welfare from 1995 to 2008; health insurance claim records, such as ERVs and outpatient visits, from the National Health Research Institutes from 2000 to 2011; socio-economic data from the Executive Yuan from 1998 to 2013; meteorological records from the Central Weather Bureau (CWB) from 1994 to 2015; green coverage data from the Taiwan Climate Change Projection and Information Platform Project (TCCIP) from 1998 to 2015; and hourly air pollution monitoring records from Taiwan Environmental Protection Administration (EPA) from 1995 to 2015. Temperature-health risk associations were evaluated for mortality data from 1995 to 2008 and for both of ERV and outpatient visits data from 2000 to 2011.

The health insurance claim database contained medical records of a representative population of one million people randomly sampled from all insured Taiwan residents. All identification numbers had been scrambled into surrogate numbers to protect privacy. Daily area-specific all-cause mortality, ERVs, and outpatient visits (excluding injuries and external causes (as defined by *9th Revision* of the *International Classification of Diseases* codes 800–999)), were compiled for analysis.

The Executive Yuan provided socio-economic and environmental data for all cities and counties in Taiwan in four categories: population (47 variables), citizen security (41 variables), economic development (107 variables), and environment (22 variables).

The CWB provided 24-hour weather data (average temperature, maximum temperature, minimum temperature, relative humidity, wind speed, and barometric pressure) monitored at 25 real-time surface meteorological observatories around Taiwan. Fig. 1 displays the locations of these weather stations. For areas without stations, such as Taoyuan, Miaoli, Changhua, Yunlin, and Nantou, weather data were obtained from the nearest surface meteorological observatory.

Taiwan EPA established an Air Quality Monitoring Network in 1993, consisting of 74 stationary monitoring stations distributed throughout the island. Temperature and concentrations of ambient air pollutants, including PM_{10}, $PM_{2.5}$, sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), and carbon monoxide (CO) were measured and recorded hourly at each station. Detailed information on the monitoring instruments, stations, and quality assurance criteria is available from the webpage https://taqm.epa.gov.tw/taqm/en/default.aspx. Fig. 1 illustrates the locations of the ambient air quality monitoring stations.

2.2. Statistical models

2.2.1. Modifying factor selection with a Generalized Linear Model (GLM)

Population, socio-economic, and environmental factors were converted to standardized values to equalize the variance of each parameter using following equation (Inostroza et al., 2016):

$$Z = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$