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Cardiovascular mortality during heat and cold events: determinants of regional vulnerability in Taiwan

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ABSTRACT

Objectives To identify the vulnerable regions with underlying susceptibility and poor adaptive capability in response to cold and heat events in Taiwan, and to characterise the determinants associated with such an increasing risk to design better adaptive strategies in view of predicted weather changes in the future.

Methods The authors used spatial regression models to measure the relationships between the spatial characteristics of temperature, extracted factors from demographic and socio-economic parameters, and the mean cardiovascular mortality 2 weeks before and after cold or heat events from 1994 to 2003.

Results Metropolitan regions were found to have a substantially lower mortality than rural areas after cold and heat events. Events of cold, compared with heat, had greater impacts on the mortality ratio in most townships. A negative association was identified, using a spatial lag model, between the mortality after cold and heat events and urbanisation, and the availability of medical resources. A higher percentage of older people, vulnerable and aborigines might have contributed to the increasing vulnerability of townships during cold and heat events.

Conclusions These data, using an island-wide spatial analysis, suggest that urban areas have a greater adaptive capability than rural areas, plausibly because people in urban areas have a higher socio-economic status and more medical resources. Social inequality across urban and rural townships is apparent and developing customised adaptation programmes for vulnerable regions to cope with heat and cold event should be prioritised.

What this paper adds

1. Previous studies have reported that factors including climate zone, age, genetic predisposition, health care access, and different lifestyles are potential determinants when studying the association between temperature and premature mortality.
2. This paper uses an island wide spatial analysis to identify the vulnerable regions with underlying susceptibility in response to cold and heat events in Taiwan with subtropical characteristics.
3. People in rural areas have less adaptive capability to extreme temperature exposure than those of urban areas, potentially attributable to lower socioeconomic status and less availability of medical resources.
4. This is also the first study to provide scientific evidence that the aboriginal population is uniquely vulnerable to exposure of extreme temperatures.

INTRODUCTION

Exposure to cold temperatures is a documented trigger for cardiac attacks. Further, the cardiovascular mortality is a major contributor to excess mortality in winter,[1–3] even in regions with relatively mild winters.[4 5] Cold exposures may lead directly to cardiovascular stress, resulting in an increase in platelets, red blood cell counts, blood viscosity, blood pressure, vasoconstriction, and plasma cholesterol and fibrinogen.[6–8] Haemoconcentration is believed to promote arterial thrombosis, and rapid death is caused by ischaemic heart diseases and cerebrovascular diseases. Several European countries, which are situated in the temperate zone, experienced the detrimental impacts of heatwaves in 2003.[9–11] Heat exposure stresses the thermoregulatory system, increasing blood viscosity and cholesterol levels.[12] People with an underlying cardiovascular illness tend to fall in the category of a vulnerable subgroup in terms of adverse health outcomes.[13]

Previous studies have reported that higher excess deaths due to cold are generally found in less severe, milder winter climates, where people have less adaptive capacity to cold exposure[14]; older people are also found to be more susceptible to cold and heat exposures.[15] In addition, the influence of other factors, including genetic predisposition, environmental variability, healthcare access and different lifestyles, have been given sizeable considerations when studying the association between weather variability and impaired health and premature mortality.[16 17] Yet, only a few studies have attempted a multivariate analysis of the relative contribution of the aforementioned factors on the excess mortality following exposure to extreme cold or heat. There is far less research on the major determinants of mortality in extreme cold or heat events in subtropical or tropical regions, particularly the socio-economic determinants of mortality.[5 18] Taiwan is located in a humid, subtropical region and has hot summers and mild winters compared with many countries at higher latitudes. Cardiovascular diseases, including ischaemic heart diseases, cerebrovascular diseases and hypertensive diseases, cause around 20% of the annual total deaths and are three of the 10 leading causes of deaths in Taiwan.[19] A U-shaped temperature–mortality relationship, particularly for older people, was observed for coronary artery disease and cerebral infarction.[13] Further, a cohort study in which blood coagulating factors were measured reported that there was a greater tendency for clot formation in the circulatory system in cold weather.[20] Identification of vulnerable subpopulations is, therefore, of particular concern as they are often hit hardest when a disastrous situation, such as extreme temperature, occurs. Therefore, their needs should be prioritised during preventive policy-setting. We conducted this study to assess the impact of cold and heat events on the cardiovascular mortality in Taiwan by using a high-spatial-resolution analysis not only to identify vulnerable regions but also to characterise factors determining the vulnerability, integrated with susceptibility and adaptive capability under cold and heat events.

METHODS

Data collection

Extreme temperature events

Cold events

The East Asian cold surge is one of the most common features of the Asian winter monsoon. The arrival of a cold surge is generally characterised by a steep rise in surface pressure, a sharp drop in surface temperature and strengthening of northerly surface winds.[21 22] According to the Central Weather Bureau (CWB) in Taiwan, a cold surge is characterised by the following: (1) the surface maximum temperature dropping at least 8°C within 24 h; or (2) the minimum temperature in Taipei city dropping to below 10°C. There were 24 cold events identified from 1994 to 2003, which was our study period.

Heat events

According to the weather records from 1994 to 2003, the daily maximum temperature in summer (June–September) ranged from 20.6°C to 38.8°C in Taipei. The highest maximum temperature, 38.8°C, occurred at noon on 9 August 2003. Our study defined the days with heat events using the following criteria, since no prior guidelines in this regard were promulgated by Taiwan's CWB: (1) maximum summer temperatures ≥35°C for more than 6 h per day; or (2) maximum temperatures ≥35°C for more than 9 h within 3 days in Taipei. A total of 13 heat events were identified for data-analysis purposes.

Island-wide meteorological data

The weather monitoring stations in Taiwan are mostly clustered in urban areas, along the east coastline, and on the island. We, therefore, could not obtain a good estimation of temperature distribution around the whole island, especially in rural areas. Therefore, we collected daily data from approximately 80 routine monitoring stations that had complete temperature records. Data from approximately 300 monitoring stations of the CWB that had complete rainfall records from 1994 to 2003 were also obtained. Kriging estimation obtained using ArcGIS 8.1 was used to interpolate and extrapolate the available temperature data into raster data with a spatial resolution of 1000 m per pixel in order to generate a representative temperature for each township, which was the basic, smallest geographical unit for diseases notification and also to reduce the probability of misclassification. Ordinary kriging was used to interpolate the temperature and rainfall data of a random field at an unobserved location from the values at nearby locations.[23] Zonal estimation was used to aggregate the estimation of weather parameters falling into each cell of the target grid and to calculate the mean temperature from the cells within the township polygon. This approach allowed us to obtain the relative representative temperature for each township during the cold or heat events.

Mortality data

In Taiwan, all deaths are reported to the township and district household registry office; the National Death Registry database was obtained from the Department of Health (no personal information involved). The cardiovascular mortality (per 100 000) for 358 townships within 14 days before a cold or heat event was estimated using the number of deaths due to cardiovascular illness (ICD-9: 390–459) as the numerator and the total population in the corresponding region as the denominator. Cardiovascular mortality within 14 days after the event (including the event day) was also estimated.

Demographic and socio-economic factors

Selected socio-economic and demographic variables for each township, including medical resources (the number of clinics and doctors and demographic characteristics (percentage of aborigines, older persons, older persons living alone and disabled persons) occupation (residents engaged in service and those engaged in agriculture) and socio-economic conditions (household ownership, uneducated population, unemployment rate and percentage of labourers working outside their county of residence) were estimated using the health statistics obtained from the Department of Health and also Taiwan Census 2000.

Data analysis

We used a geographic information system (GIS) to demonstrate the spatial patterns of cardiovascular mortality, and climatic and non-climatic factors of all 358 townships in Taiwan. The cardiovascular mortality 2 weeks before and after the event days, demographics and socio-economic factors were converted to polygon data for each township. Daily maximum, mean and minimum temperatures for each township were also converted using kriging and zonal estimations. Principal-component analysis (PCA) was used to summarise the patterns of intercorrelation among 12 demographic and socio-economic factors for each township. Major factors accounting for most of the model variance were then extracted. We used spatial regression models implemented in GeoDa 0.9.5i to measure the relationships between the spatial characteristics of temperature, extracted factors from demographic and socio-economic parameters, and the mean cardiovascular mortality 2 weeks before and after the cold or heat events from 1994 to 2003. The mortality due to cardiovascular diseases for 358 townships was estimated using the number of deaths in the population of the year in the 2-week period before and after the cold and heat events.[24] In the spatial regression analysis, the mortality at 14 days after the events was a dependent variable (included the event day), and that at 14 days prior to the events was a covariate. Determining factors attributable to the geographical variation in the cardiovascular mortality were then identified under the threats of cold and heat events in Taiwan.

The relationship between the cardiovascular mortality before the cold or heat events, temperature on the day of the event and sociodemographic factors extracted using PCA were examined using spatial regression. Ordinary least square (OLS) was first used for these data, and multicollinearity condition, normality, and spatial dependence and heteroscedasticty were diagnosed by GeoDa 095i.[25] Spatial lag model estimation, which estimates the maximum likelihood of a spatial regression model that includes a spatially lagged dependent variable, was then chosen for our analysis according to Lagrange multiplier tests.

RESULTS

Disease mapping

The mortalities for cardiovascular diseases before and after cold events were significantly higher than that after heat events. Compared with the mean cardiovascular mortality before cold events (7.64 per 100 000 people), a significantly increase could be found after events (8.29 per 100 000 people). In contrast, cardiovascular mortality only increases slightly after heat events (table 1). Figure 1A,B illustrates the cardiovascular mortalities 14 days after cold or heat events in Taiwan between 1994 and 2003. The range of cardiovascular mortalities after cold events was from 2.4 to 27.0 per 100 000 people and from 1.1 to 21.0 per 100 000 people after heat events. In Taiwan, urban areas had spatial patterns of lower cardiovascular mortalities than rural and mountain areas, suggesting vulnerable regions and populations for higher reported cardiovascular mortalities after exposure to extreme temperatures.

Sociodemographic factors

The descriptive statistics of 12 sociodemographic factors among 358 townships is shown in table 2. PCA was further applied to reduce the number of variables and to classify them into integrated factors that reflect their demographic or socio-economic characteristics. Four explanatory factors, including medical resources and urbanisation, percentage of susceptible population and aborigines, and lack of economic opportunity, were found to account for 71.97% variance of the total 12 variables, with each factor accounting for 24.43%, 24.57%, 15.05% and 10.92% variance, respectively (table 3). Factor 1 was a composite factor denoting 'medical sources and level of urbanisation,' where dominant variables included the number of clinics and doctors per 10 000 people (loading (L): 0.820, 0.683), home ownership rate (L:−0.812), percentage of people engaging in service-related occupations (L: 0.784) and percentage of the population engaged in agricultural occupations (L: −0.484). The rate of older persons living alone (L: 0.902), rate of the older population (L: 0.902) and disability rate (L: 0.690) were the variables that together represented factor 2, the factor of the percentage of susceptible population. The level of social disadvantage, factor 3, included the aborigine population rate (L: 0.873) and uneducated rate among persons older than 15 years (L: 0.770). Factor 4, lack of economic opportunity, was expressed by integrating the variables of unemployment rate (L: 0.634) and percentage of labourers working outside the county of residence. The scores of these four explanatory factors served as independent variables in the following spatial regression models to avoid multicollinearity. The geographical distribution of four extracted factors is also shown in figure 1s in the supplemental material.

Table 1 Mean cardiovascular mortality 14 days before/after events across all townships (N=358)

Cardiovascular mortality (1/100 000)*	Cold events (24 events)	Heat events (13 events)	p Value†
14 days before events	7.64 (3.63)	5.87 (3.06)	<0.001
14 days after events	8.29 (3.76)	5.91 (3.26)	<0.001
p Value‡	<0.001	0.782	

*Mean (SD).
†p Value for independent-sample t test.
‡p Value for paired-sample t test.

Spatial analysis and regression

With an island-wide high-resolution analysis, the cardiovascular mortalities in each township after the cold events were not only well explained by the cardiovascular mortalities prior to the events but also significantly explained by sociodemographic factors with explanatory power of the full model (R^2) of 0.767 for cold events and 0.569 for heat events (table 4). Except factor 4, lack of economic opportunity, three sociodemographic factors were significantly related with the mortalities after the cold and heat events. Independent of temperature changes, the higher score of factor 2, the 'susceptible population,' implied that a higher percentage of older people, older people living alone and the disabled was associated with rising mortalities at the township level, with both cold (β=1.338) and heat (β=0.954) events. Elevated cardiovascular mortalities after the events were inversely associated with the score of factor 1, 'medical resources availability and the degree of urbanisation,' with similar regression coefficients for both cold (β=−0.601) and heat (β=−0.456) exposures. To some extent, the explanatory power of these variables that was attributed to their in-township value, was really due to the neighbouring locations.

To the best of our knowledge, our study provides the first scientific evidence, obtained via a nationwide data analysis, substantiating the critical contribution of medical resources availability in preventing deaths associated with exposure to extreme temperatures. Regarding factor 3, the higher percentage of the aborigine population was also found to be more vulnerable to extreme temperature exposures, particularly heat events (β=0.760 vs β=0.308 in cold events). Moran's I test statistic of the spatial residues was −0.022 for cold events and −0.041 for heat events, implying that including the spatially lagged dependent variable term in the model eliminated spatial dependence.

DISCUSSION

Our results suggest that no independent effect could be assumed for the levels of temperature exposure on the higher cardiovascular mortalities during the cold and heat events because these rates appeared to be significantly modified by sociodemographic factors. The susceptible population (older people and disabled) and aborigine population in Taiwan are vulnerable subgroups whose needs should be prioritised when framing future adaptation policies. Improving healthcare resources could be a critical determinant of the effectiveness of adaptation strategies. This is a tremendous public health challenge that will require some form of feasible and effective community-wide support and emergency response plans for persons with relatively fewer healthcare resources.

Our study reaffirms that older people are the most susceptible to temperature-related mortality, particularly exposure to extreme cold.[26–28] Ageing populations often have more underlying diseases; they also have poorer thermoregulation. Furthermore, disabled persons are susceptible to dramatic changes in temperature and also not able to adapt to the changes because of self-care difficulties.

We believe that this is the first study to provide scientific evidence that the aboriginal population is uniquely vulnerable to exposure to extreme temperatures, particularly heat. The underlying risk factors present in the aboriginal population could possibly justify, to a great extent, why the observations are plausible. Researchers have offered the several biological and genetic differences in the thermoregulatory system of aborigines, along with a higher prevalence of chronic illnesses in this

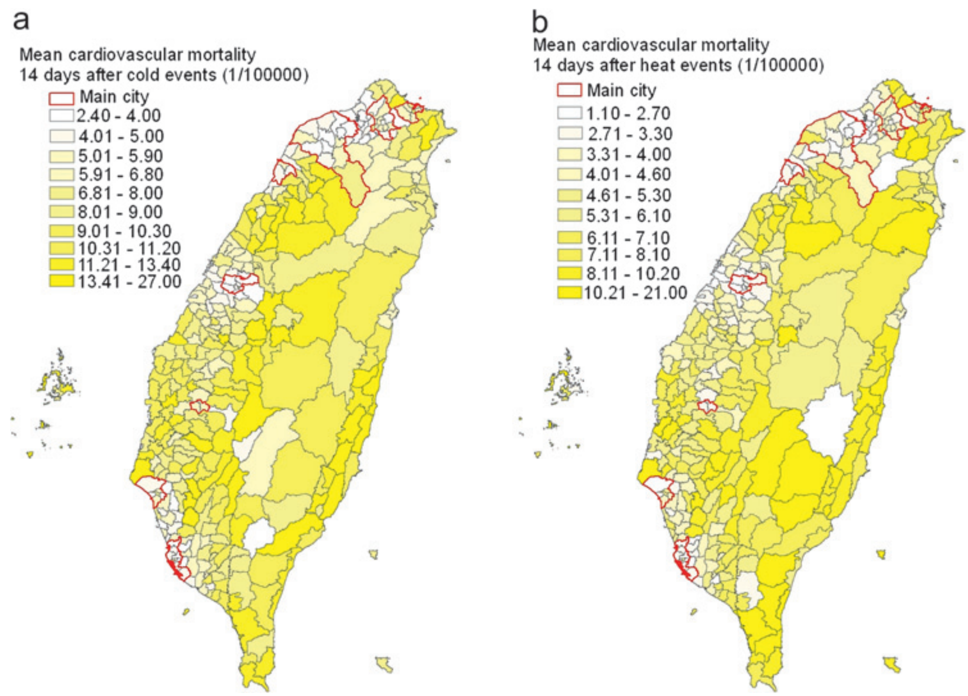

figure 1 Mean cardiovascular mortality 14 days after (A) cold and (B) heat events.

population, as explanatory rationales.[29] We have quantitatively demonstrated that newly identified socio-economic and lifestyle risk factors may be far more critical than the variables studied before. In Taiwanese society, the aborigines in general receive less formal education and earn less. A higher percentage of aborigines also engage in unhealthy lifestyles, such as heavy alcohol drinking and tobacco smoking.[30] Health statistics shows that the overall mortality in aborigine townships is about 70% higher than in the general population in Taiwan.[31] This underlying inequality in health status appears to have affected the aborigines, making them even more vulnerable to extreme weather events. Therefore, a health promotion policy should start by improving the socio-economic status of, and education opportunities for, this disadvantaged population. Moreover, traditional practices of biomass burning to keep warm might also contribute to severe indoor pollutants that have been known to be involved in the biological mechanism that triggers cardiovascular attacks.[32] This finding suggests that it is essential that local administrative agencies immediately implement an early warning and emergency response programme for aborigine communities, which includes air-conditioning of public buildings for cooling during heat events and an education programme about proper activities for keeping warm such as proper fuel selection and the use of an overcoat, gloves, scarf and hat during winter.

Table 2 Descriptive statistics of socio-economic factors (N=358)

	Minimum	Maximum	Mean	SD
No of clinics per 10 000 population	0.010	0.396	0.0616	0.042
No of doctors per 10 000 population	0.000	1.734	0.0944	0.141
Home ownership rate (percentage of residence household)	67.497	98.935	90.902	5.208
Service occupation rate (percentage of working population)	22.542	77.314	46.300	12.401
Agriculture occupation rate (percentage of working population)	0.084	0.588	0.157	0.142
Rate of older population (percentage of persons over 65)	0.038	0.230	0.108	0.037
Rate of older persons living alone (percentage of persons over 65 living alone)	0.004	0.048	0.017	0.008
*Disability rate (percentage of any disability item among total population)	0.818	11.610	2.011	0.872
Aborigine population rate (percentage of total population)	0.024	97.588	9.320	24.084
Uneducated rate (percentage of uneducated among persons over 15)	0.000	14.286	1.203	1.381
†Unemployment rate (percentage of unemployment among persons over 15)	10.007	47.489	24.348	5.016
Rate of labourers working outside the county of residence (percentage of working population)	6.667	66.652	36.974	10.320

*Disability: percentage of any disability item (self-care difficulty, independent living difficulty and ambulatory difficulty) among the total population.
†Unemployment rate was estimated by the sum of subjects not studying at school and also unemployed among persons over 15.

Table 3 Factors loading and percentage of variance explained by social and demographic factors

Components	Percentage variance explained	Loading
Factor 1: Medical resources and urbanisation	24.43	
No of clinics per 10 000 population		0.82
No of doctors per 10 000 population		0.68
Home ownership rate		−0.81
Service occupation rate		0.78
Agriculture occupation rate		−0.48
Factor 2: Susceptible population	21.57	
Rate of older persons living alone		0.90
Rate of older population		0.90
Disability rate		0.69
Factor 3: Aborigine population	15.05	
Aborigine population rate		0.87
Uneducated rate		0.77
Factor 4: Lack of economic opportunity	10.92	
Unemployment rate		0.63
Rate of labourers working outside the county of residence		0.75
Sum of variance explained	71.97	

Table 4 Examining the spatial relationships among cardiovascular mortality after the cold and heat events, baseline of mortality, event temperature, socio-economic and demographic factors by using the spatial lag model.

	Cold events (24 events), $R^2=0.77$		Heat events (13 events), $R^2=0.57$	
	Coefficients	95% CI	Coefficients	95% CI
Cardiovascular mortality before cold or heat events	0.54†	0.44 to 0.64	0.40†	0.29 to 0.51
Mean temperature of cold or heat events	<0.01	−0.08 to 0.08	0.03	−0.07 to 0.12
Factor 1: Medical resources and urbanisation	−0.60†	−0.83 to −0.37	−0.46†	−0.71 to −0.21
Factor 2: Susceptible population	1.34†	1.01 to 1.66	0.95†	0.61 to 1.29
Factor 3: Aborigine population	0.31†	0.10 to 0.51	0.76†	0.50 to 1.02
Factor 4: Lack of economic opportunity	−0.08	−0.27 to 0.12	−0.21*	−0.44 to 0.02
Constants	4.19†	2.66 to 5.71	2.30*	−0.44 to 5.04
Rho	<−0.01	−0.09 to 0.08	0.10*	−0.01 to 0.21
Moran's I value residues	−0.022		−0.04	

*p<0.1.
†p<0.05.

Previous studies have indicated that the regional variation in cardiovascular mortalities could be attributed to treatment delays because of the distance from the emergency hospital or healthcare services.[33] We also identified that adequate medical resources, in terms of facilities or professionals, could have a significantly protective effect on the reported cardiovascular mortalities after cold or heat events. One can easily conclude from the established relationship that when formulating a related preventive public health policy, important considerations are improving the availability of prehospital care such as thrombolytic therapy for myocardial infarctions and enhancing ambulance services for remote communities or rural areas.

We have not seen in our study the influence of 'economic opportunities,' a factor integrating the unemployment rate and working opportunities in the township, on the reported cardiovascular mortalities after cold or heat events. This result might indicate that this factor may not properly explain the 'poverty' status and housing conditions that might play key roles in preventing exposure to extreme cold or heat.

Studies, using different geographical levels as the unit of analysis, including cross country, nationwide and inner city levels, have yielded inconsistent conclusions on how socio-economic factors, such as income poverty, social deprivation levels and fuel poverty, may be associated with diseases outcomes linked to environmental changes.[4 5 17 34–37] Future investigations should aim to clarify whether the differences found across regions with respect to the observed disease outcomes can be linked to ethnics or the related biological mechanisms.

Overall, cold exposures, rather than heat events, appear to have a higher impact on the reported cardiovascular mortalities of populations in Taiwan, which has warm summers and mild winters. Although the Taiwanese are expected to have developed physiological and behavioural adaptations to warmer temperatures, most buildings in Taiwan have air-conditioning, especially those in urban areas. We also found that the vulnerable populations were located in areas with relatively poor housing insulation and therefore were less protected from cold exposures compared with subjects of studies conducted in southern Europe.[14 17] More comprehensive comparative investigations should be conducted to evaluate how elevated temperatures during cold events in winter due to climate change may affect the burdens of mortality or morbidities. Moreover, research suggests that the effects of extreme heat on mortality have a shorter lag (0−1 day) than the effects of cold and might cause heat-related short-term mortality displacement.[38] This preliminary study, which used data from a 2-week window during cold and heat events, might not be able to detect heat-related increases in cardiovascular mortality. This might also explain why more substantial findings were obtained during cold events. High humidity is a well-known crucial factor in evaporative heat loss during heat exposure.[39] In the context of spatial analysis, spatial differences in relative humidity might also partially explain our model. In this study, we could not obtain geographic representative data for humidity because the monitoring stations lacked proper spatial distribution. The heat index in combination with temperature and humidity in certain vulnerable regions could be further used to examine the combined effects of these parameters in the future. Studies to detect transient cold- or heat-related increases in cardiovascular mortality should be conducted in regions with different vulnerabilities in Taiwan to develop response plans.

This spatial analysis used the highest quality of spatial data to identify the vulnerable regions in terms of climate-change-related health risks and to identify the variables that determine the vulnerability integrated with susceptibility and adaptive capability. Our study supports the hypothesis that cold events in winter may cause more deaths than heat in summer, even in many subtropical regions.[40] The percentage of the susceptible population comprising older people, disabled and aborigines, and the availability of medical resources are considered key determinants of the reported cardiovascular mortalities. Given our findings, a national intervention programme that prioritises the needs of these high-risk subgroups should be developed.

When considering our conclusions regarding cold and heat events, it is important to bear in mind that these results depend greatly on the definition of cold and heat events used in our region. We attempted to explore the geographical differences in vulnerability under the threat of heat and cold exposure, using cardiovascular mortality before and after the events in our spatial model. Instead of concerning ourselves with oversmoothing using a smoothing technique in displaying the map of mortality, we used mortality from 14 days after the event as the dependent variable and the mortality from 14 days prior to the event as a covariate in the full model. However, a potential bias might have resulted from estimating mortality, particularly from a small population at risk, and not using smoothing to adjust the data.[41] In the context of this study, a confounder is a factor that is statistically associated with the exposure and also an independent risk factor for diseases. In this study, many non-climatic factors such as change in urbanisation status, personal protection and housing quality are important potential confounders. Moreover, we cannot test the modifying effects of air pollution on cardiovascular mortality in this study due to the lack of high-spatial-resolution data on air pollution across Taiwan. Another limitation of this ecological analysis for making causal inferences is ecological bias, which is the failure of an expected ecological effect estimate to reflect the biological effect at the individual level.

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