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Impacts of cold and hot temperatures on mortality rate in Isfahan, Iran

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ABSTRACT

Exposure to cold and hot temperatures is known to have negative impacts on human health. It is the aim of the present study to assess the health effects of cold and hot temperatures on the population living in the city of Isfahan. Daily data on average temperature and mortalities during the nine-year period 2008–2016 were obtained. Mortalities were stratified by causes (non-accidental, cardiovascular, respiratory, and stroke) and by age groups (0–14 years, 15–64 years, and ≥65 years). A standard time-series analysis was conducted using the Poisson model for cause-age-specific mortality effects of temperature, adjusted for seasonal and long-term trends as well as day of the week. Moreover, a distributed non-linear lag model (DNLM) with a 21-day lag time was used to determine the cumulative effects of cold and hot temperatures on mortality using the minimum mortality temperature (hereafter MMT) as the reference. A meta-analytical model was then used to pool the data thus obtained. Extreme temperatures were defied using cutoffs at 2.5th and 97.5th temperature percentiles and mortalities were reported as attributable to temperatures below and above MMT. A U-shaped curve was derived capturing the relationship between average temperature, on the one hand, and all the age and all the mortality cause groups, on the other. MMT was found to vary substantially for different age and cause groupings. Both cold and hot temperatures were found to increase the mortality risks, with a stronger effect of extreme temperatures. Cold temperature was responsible for a higher portion of the mortality than heat was. The cold effect on respiratory and stroke mortalities was higher than that on non-accidental and cardiovascular mortalities. Exposure to cold and hot temperatures increased relative risks of mortality in all age and cause groupings in Isfahan. Our findings can have important implications for mortality prevention in Isfahan.

1. Introduction

Climate change is characterized by increased frequency and intensity of extreme (hot and cold) temperatures worldwide (Guo et al., 2016; Madrigano et al., 2013). Extreme temperatures pose serious risks to human health and understanding their impacts on mortality is the key to efficient prevention, management, and mitigation of long-term consequences. Numerous epidemiological studies have been devoted to the investigation of temperature-mortality associations, focusing on the impact of extreme temperatures (Sandsurd et al., 2007; Gronlund et al., 2014; Ma et al., 2014; Tsangari et al., 2016; Bunker et al., 2016; Lim et al., 2012; Ranandeh Kalankesh et al., 2015; Sharafkhani et al., 2017; Zheng et al., 2018; Mohammadi et al., 2018; Abobakri et al., 2019). Varying greatly with geographic location and climatic conditions, mortality risks associated with cold and hot temperatures are heterogeneous across the nations as a consequence of their population, demographic, and socio-economic characteristics as well as the healthcare systems available (McMichael et al., 2006; Baccini et al., 2008; Gasparrini et al., 2015a, 2015b; Hajat and Kosatky, 2010; Analitis et al., 2008; Gosling et al., 2009; Anderson and Bell, 2009; Curriero et al., 2002; Son et al., 2011; Pourshaikhian et al., 2019). Due to their poor public health infrastructure, people living in developing countries are more sensitive to and jeopardized by extreme temperatures than those living in industrialized countries (Zhange et al., 2016; McMichael et al., 2008). It has been reported that people living in warmer climates tend to exhibit a greater sensitivity to cold extremes, and vice versa (Analitis et al., 2008; Ng et al., 2014).

Despite the long period of research on the impacts of extreme temperatures on human health in different cities around the world (Basu et al., 2008), few studies have been done in middle east region (Farajzadeh and Darand, 2009). Developing effective human responses to temperature extremes and to evaluate and design adaption measures,

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studies need to be conducted in this area with mainly harsh climate aimed at evaluating the impacts of extreme temperatures on human health. Considering the lack of epidemiological studies in Iran with information on the underlying thermal impacts on human health (Sharafkhani et al., 2017), this study aims to assess the effects of cold and hot temperatures on mortality rates in the city of Isfahan.

2. Data and methods

2.1. The study area

The city of Isfahan with an urban population of 1.96 million (Statistical Centre of Iran, 2016) is located between 32° 38′N and 51° 39′E at an elevation of 1580 m above sea level in the center of Iran (Fig. 1). The city is characterized by a warm and arid climate with continental climatic characteristics where maximum average temperature rises to as high as 35.3 °C in the summer months and its minimum usually drops to as low as −7.4 °C during the winter.

2.2. Meteorological data

The meteorological data used for our analysis included daily average temperatures (in ° C) obtained from Iran Meteorological Organization for the period from January 1st, 2008 to December 31st, 2016.

2.3. Mortality data

Daily mortality data from January 1, 2008 through December 31, 2016 were obtained from Isfahan Death Records Reporting system. According to the 10th revision of the International Classification of Diseases and Related Health Problems (ICD-10), the daily mortality data were classified into the following four categories: non-accidental mortality (ICD-10 codes A00–R99), Cardiovascular disease (ICD-10 codes I00–I99), respiratory disease (ICD-10 codes J00–J99), and stroke (ICD-10 codes I60-I69). Mortality counts of different causes were also stratified by age (0–14 years, 15–64 years, and ≥65 years).

2.4. Statistical analysis

A standard time-series quasi-Poisson was employed to estimate county-specific mortality effects of temperature (Gasparrini et al., 2010; Gasparrini and Armstrong, 2010). Previous studies indicated that the effects of temperature on mortality might be delayed in time. Accordingly, we fitted a distributed non-linear lag model (DNLM), recently described and employed in several studies, to qualify the effects of temperature (Gasparrini et al., 2015). In order to assess the association between daily average temperature and daily mortality rate, a DLNM was also used with a natural cubic B-spline with 3 internal knots placed at the 10th, 75th, and 90th percentiles of temperature distribution with

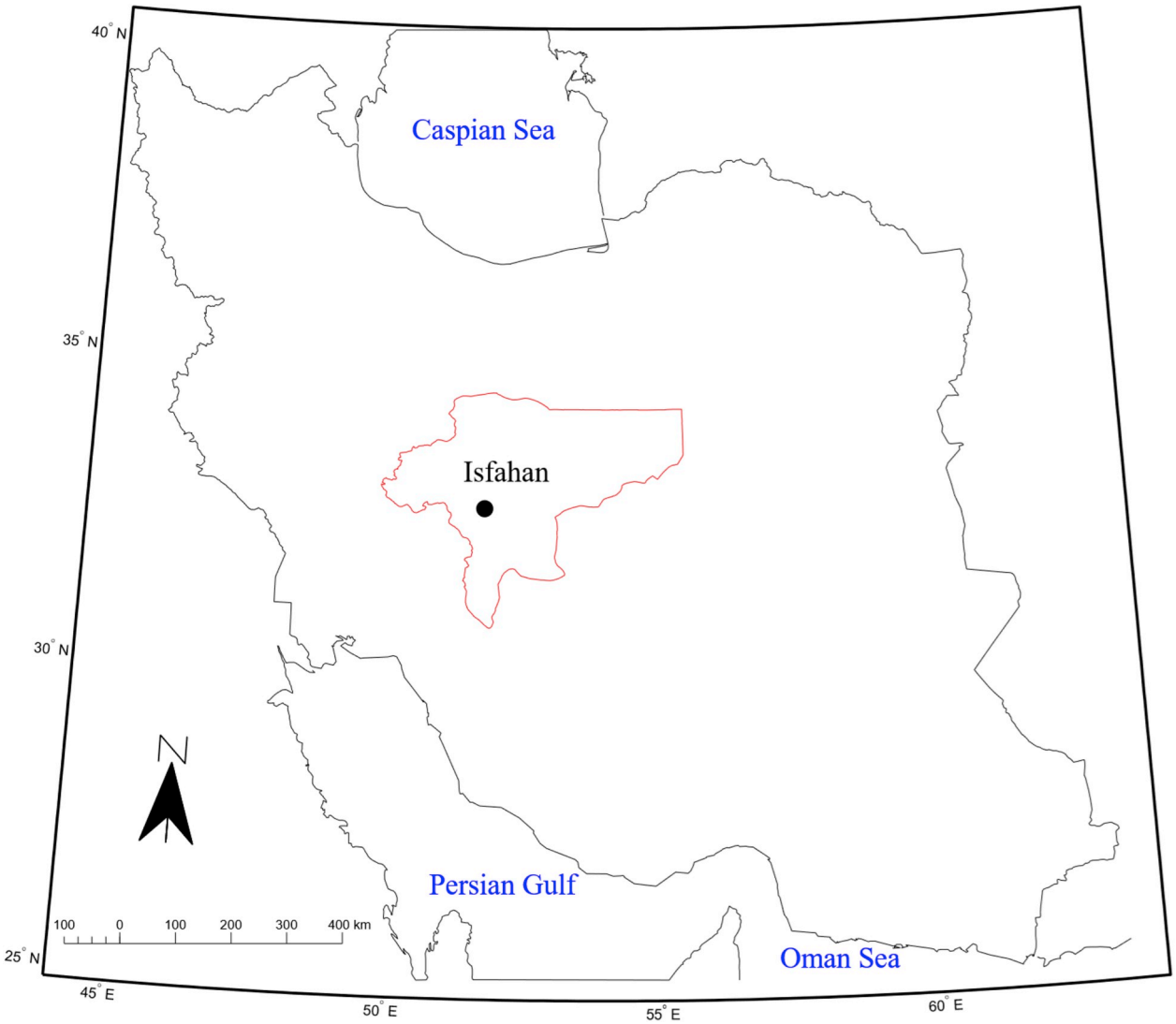

Fig. 1. Geographic location of Isfahan city in Iran.

8 degrees of freedom per year to control seasonal and long-term model trends. Indicator of day of the week was also included to control any confounding weekly patterns. Finally, the lag period was extended to 21 days in order for the overall temperature effect to be completely captured.

The fitted meta-analytical model was used to derive the best linear unbiased prediction of the overall cumulative exposure-response association. To estimate the related mortality risk (RR), we used the minimum mortality temperature (MMT) as the reference temperature at which the mortality risk was the lowest between the first and the 99th percentiles (Gasparrini et al., 2015a). Extreme temperatures were defied using cutoffs at 2.5th and 97.5th temperature percentiles. To explore specifically the effects of cold and heat, mortalities attributable to temperatures below and above MMT, respectively, were also reported. The significant level was set at $P < 0.05$. Finally, all the analyses were performed in the R software (version 3.1.3) using the packages dlnm and mvmeta.

3. Results

During the study period (Janaurary 1st 2008 to December 31st, 2016), a total of 60762 deaths occurred in Isfahan, out of which 19938 (33%) were caused by cardiovascular diseases, 3701 (6%) by respiratory diseases, and 4235 (7%) by stroke diseases (Table 1). Descriptive statistics for temperature, all the ages surveyed, and mortality cause groupings are summarized in Table 2. The average daily temperature (standard deviation) was 17.52 °C (9.8 °C), ranging from −7.4 °C to 35.4 °C. The average daily mortality counts (standard deviation) were 15.68 (4.54 °C) for non-accidental deaths, 5.53 (2.52 °C) for cardiovascular deaths, 1.01 (1.02 °C) for respiratory deaths, and 1.17 (1.01 °C) for stroke deaths (Table 2). More than half (59.2%) the non-accidental mortalities occurred in the ≥65 year-old age group, compared to 25.8% in the 15–64 year-old age group and 14.9% in the 0–14 year-old age group.

Fig. 2 presents the pooled results for the overall cumulative exposure-response curves association between all the age and mortality cause groupings with temperature along with Minimum Mortality Temperature (MMT) and the cutoffs to define extreme temperatures over a total lag period of 21 days. The graphs show nonlinear relationships between temperature and all the age groups and all the mortality cause groupings. Clearly, the pooled curves for all the age and all cause groupings are U shaped, indicating that both low and high temperatures are associated with increased mortality risks, with a greater effect observed for exposure to the extreme high and low temperatures. The MMT varied substantially for different age and cause groupings such that those for non-accidental and cardiovascular causes were 10.2 °C and 6.9 °C while those for respiratory and stroke were 30.3 °C and 27.4 °C, respectively. The cold and hot temperatures had higher effects on respiratory and stroke causes. The effects of temperature on mortality in the two cause and age groups followed similar patterns. Finally, mortality risk increased rapidly below and above MMT.

Table 3 shows the corresponding RRs for all the age and mortality cause groupings associated with cold and hot temperatures. The district range of mortality risk attributable to both hot and cold temperatures were 5.84–49.06%, respectively. These ranges for non-accidental, cardiovascular, respiratory, and stroke causes were 11.73%, 6.47%, 20.72%, and 18.86%, respectively. The fraction attributable to cold temperatures for respiratory and stroke causes was large (19.18% and 15.43%, respectively) while that attributable to hot temperatures was small (1.54% and 3.43%, respectively).

In contrast, a reverse trend was detected for the effects observed on non-accidental and cardiovascular causes, for which the fraction attributable to hot temperatures was large (10.5% and 5.87%, respectively) and that attributable to cold temperatures was small (1.23% and 0.6%, respectively). Compared to the fraction attributable to extreme hot temperature effects, that of cold temperature effects was high for all causes aged ≥ 65 years, cardiovascular and respiratory ≤ 14 years, and stroke and respiratory 15–64 years. The greatest cold effect was observed in those cause-aged cardiovascular ≤ 14 years, with an overall cumulative effect of 47.19%. For hot temperatures, the effects were stronger in the cause-aged cardiovascular 15–64 years, with the greatest overall cumulative effect being 24.71%. The high fraction attributable to cold temperatures is a function of the cold slope and the relatively high minimum mortality temperature. This difference was mainly attributed to the high MMT for non-accidental and cardiovascular causes as well as the small MMT for respiratory and stroke, which led to most of the mean daily temperatures being lower and higher than the MMT, respectively.

Table 1
The causes of mortality in Isfahan.

Causes	Number of deaths	Frequency (%)
Cardiovascular	19938	33
Respiratory	3701	6
Stroke	4235	7
Neurology and Psychiatry	1323	2
Accident	3120	5
Other-causes	28445	47

Table 2
Descriptive statistics of mortality by different ages- and -Causes-specific.

Statistic	Mean	SD	Min	Max
Average temperature	17.52	9.8	−7.4	35.3
Non accidental	15.68	4.54	3	39
Cardiovascular	5.53	2.52	0	17
Respiratory	1.01	1.02	0	7
Stroke	1.17	1.01	0	7
Age-specific mortality				
Non accidental ≥ 65 years old	9.39	3.34	2	23
Cardiovascular ≥ 65 years old	4.16	2.17	0	14
Respiratory ≥ 65 years old	0.71	0.86	0	5
Stroke ≥ 65 years old	1.01	1.02	0	6
Non accidental ≤ 14 years old	2.37	1.76	0	15
Cardiovascular ≤ 14 years old	0.11	0.33	0	3
Respiratory ≤ 14 years old	0.07	0.27	0	2
Stroke ≤ 14 years old	0.002	0.046	0	1
Non accidental 15–64 years old	4.09	2.1	0	21
Cardiovascular 15–64 years old	1.25	1.12	0	7
Respiratory15-64 years old	0.22	0.48	0	3
Stroke15-64 years old	0.16	0.4	0	3

4. Discussion and conclusions

Cold and hot temperature-mortality associations were explored with different causes and in different age groups in the city of Isfahan during the nine-year period from January 1, 2008 to December 31, 2016. To the best of the present authors' knowledge, this is the first study to provide comprehensive evidence on air temperature as an important factor affecting mortality rate in Isfahan. The results are expected to fill an important knowledge gap on the relative impact of cold and hot temperatures on triggering mortality.

This study reveals that the MMT varied substantially for different age and cause groupings. The MMT for non-accidental and cardiovascular causes were 10.2 °C and 6.9 °C while those for respiratory and stroke were 30.3 °C and 27.4 °C, respectively. A nonlinear (U-shaped) relationship was identified between average temperature and all the age and all the mortality cause groupings. The results indicated that both cold and hot temperatures increased mortality risks, with a stronger effect of extreme temperatures. The results were consistent with those reported elsewhere (Gasparrini et al., 2015; Lian et al., 2015; Ma et al., 2014; Chen et al., 2013; Guo et al., 2011, 2013; Wu et al., 2013; Xie et al., 2013; Li et al., 2018; Zheng et al., 2018). For example, Chen et al. (2013) and Guo et al. (2013) reported cold and hot temperatures had increased mortality risks due to stroke and ischemic heart diseases, respectively, in

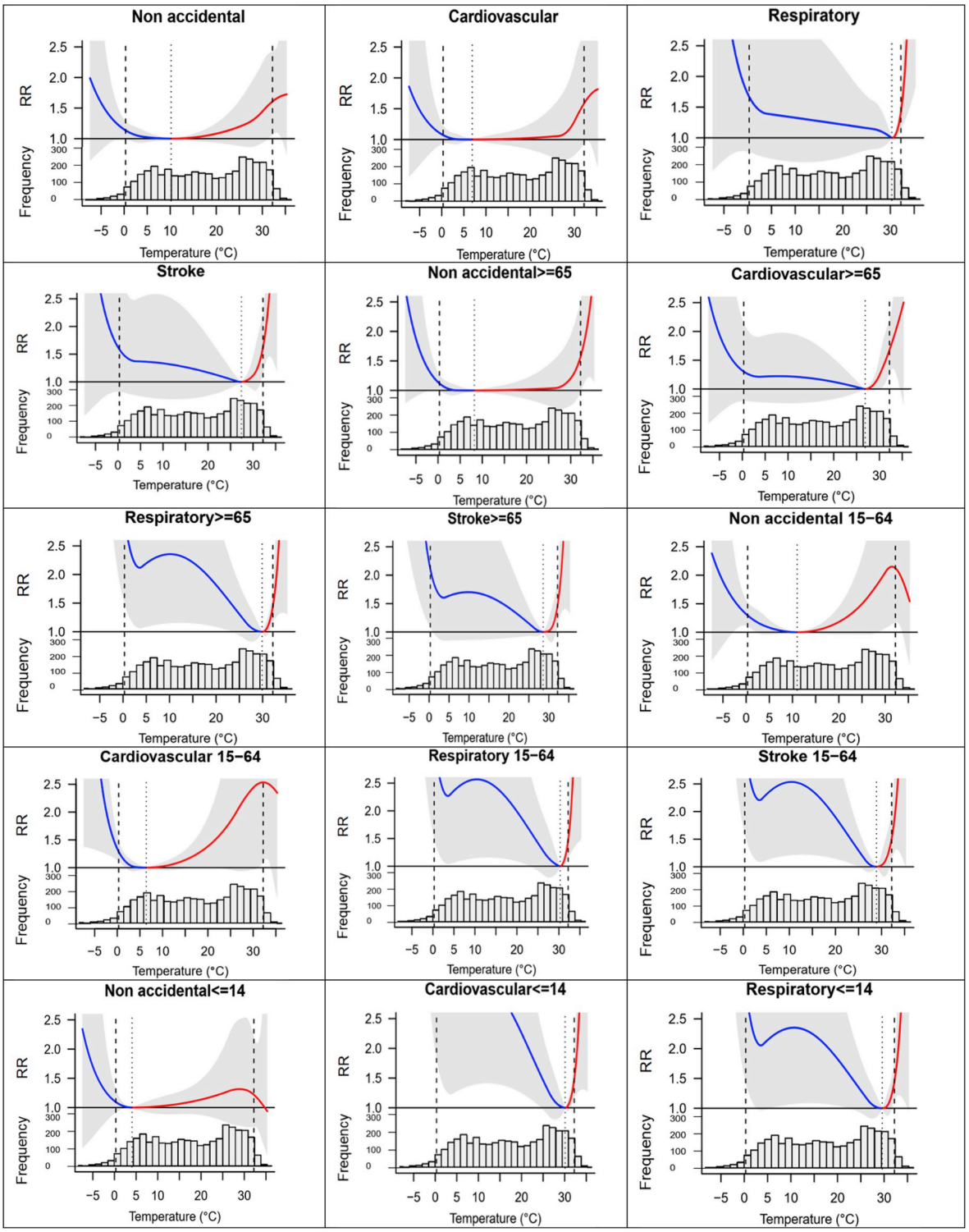

Fig. 2. Overall cumulative exposure-response of mortality associated with average temperature for different cause and age groups over a 21 day lag period in Isfahan. Dashed lines show the minimum mortality temperature and dashed bold lines are the 2.5th and 97.5th percentiles. The gray area indicates the 95% confidence interval.

China. A similar association was reported by Scovronick et al. (2018) for cardiovascular and respiratory mortality causes in South Africa. Exposure to hot temperatures increases blood circulation, slat depletion, and dehydration, which increase death risks (Zhang et al., 2014). Exposure to cold temperatures, on the other hand, increases blood pressure fluctuation, blood cholesterol, and platelet viscosity, leading to cold-induced peripheral vasoconstriction and plasma fibrinogen to predispose the exposed subjects to arterial thrombosis (Keatinge and Donaldson, 1997; Woodhouse et al., 1994; Lin et al., 2013). Cold temperature also triggers the sympathetic nervous system, increasing oxygen demand (Chambers et al., 2000).

Based on the overall cumulative exposure-response curve, we also found that mortality risk attributable to cold temperatures was higher than those attributable hot temperatures in Isfahan, a warm and dry city

Table 3
Mortality risks attributable to hot and cold temperatures in Isfahan.

	Total Death	Minimum Mortality Percentile (Temperature)	Total (%)	Cold (%)	Heat (%)
Non accidental	52174	29 (10.2)	11.73	1.23	10.50
Cardiovascular	18189	19 (6.9)	6.47	0.60	5.87
Respiratory	3346	91 (30.3)	20.72	19.18	1.54
Stroke	3862	79 (27.4)	18.86	15.43	3.43
Non accidental ≥ 65	30903	23 (8.2)	5.84	0.90	4.94
Cardiovascular ≥ 65	13705	77 (26.9)	15.35	11.2	4.14
Respiratory ≥ 65	2367	89 (29.9)	40.43	38.62	1.8
Stroke ≥ 65	3322	84 (28.6)	28.17	25.99	2.17
Non accidental ≤ 14	7801	10 (4.07)	11.77	0.57	11.19
Cardiovascular ≤ 14	361	90 (30.1)	49.06	47.19	1.86
Respiratory ≤ 14	242	88 (29.6)	38.94	37.54	1.39
Stroke ≤ 14	7	–	–	–	–
Non accidental 15–64	13470	31 (11)	21.18	2.8	18.38
Cardiovascular 15–64	4123	17 (6.4)	26.52	1.81	24.71
Respiratory 15–64	737	91 (30.3)	45.73	44.34	1.38
Stroke 15–64	533	85 (28.9)	41.48	38.85	2.62

with continental climatic conditions.

Our findings showed that cold temperatures are responsible for a substantial friction of deaths by respiratory and stroke causes, 19.18% and 15.43%, respectively. The highest cold effect was observed in those cause-aged cardiovascular ≤ 14 years, with an overall cumulative effect of 47.19%.

These findings are in line with those reported elsewhere for populations living in warmer regions. Population living in areas with high annual average temperatures are more likely to acclimatize to the local hot weather but more vulnerable to cold temperatures; the reverse is true for people living in colder regions (Keatinge et al., 2000; Curriero et al., 2002; Guo et al., 2013; Analitis et al., 2008; Ng et al., 2014). Study has shown that cold temperature increases death risks due to stroke (Chen et al., 2017; Luo et al., 2018; Zeka et al., 2014; Zheng et al., 2016), cardiovascular (Scovronick et al., 2018; Zhang et al., 2014; Lin et al., 2013), and respiratory (Scovronick et al., 2018; Farajzadeh and Darand, 2008, 2009; Khanjani and Bahrampour, 2013) diseases, all of which agree well with our findings for the cold effect in our study area.

The findings can be used for creating and improving early warning systems and public health policy-making temperature-health action plans as attempts to reduce the relative risks associated with cold and hot temperatures.

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