scientific reports

Check for updates

OPEN

Analyzing cardiovascular disease hospitalization risks due to cold and heat waves in Dezful

Hamidreza Aghababaeian[1,2,3], Rahim Sharafkhani[4]✉, Nasim Hamidipour[5] & Ladan Araghi Ahvazi[2,6]

Given the increasing health risks associated with climate change, particular attention is focused on the elderly as a vulnerable group. This study aimed to analyze how these climate extremes impact the health and hospitalization rates of these patients. In this ecological time series study, daily Meteorological and environmental pollutants data for Dezful and hospitalization records for cardiovascular diseases based on International Classification of Diseases, 10th codes were collected from 2013 to 2019. Definitions for heat waves and cold waves were established Based on previous studies in this field. The study utilized a combination of Distributed Lag Nonlinear Models and Quasi Poisson analysis to investigate the association between each definition of cold and heat waves and hospitalization. The results indicate that heat waves are associated with an increased risk of hospital admissions due to cardiovascular disease in individuals over 75 years of age. Additionally, cold waves significantly increase the risk of hospitalization due to cardiovascular disease in individuals aged 65 to 74 years. Specifically, in the section on added effects, the results show that Cold Wave impacts the risk of hospitalization in patients aged 56 to 74 years (added effects: lags of 0, 0–2, 0–6, and 0–13). This study highlights the significant impact of heat and cold waves on the risk of hospitalization for cardiovascular diseases in Dezful. Older adults, especially those over 65, are particularly vulnerable to these climate-related health risks. As climate change progresses, it is essential to implement public health strategies that protect at-risk populations during extreme weather events.

Keywords Health, Heat wave, Cold wave, Climate change, Disaster, Emergencies

The excessive use of fossil fuels and the expansion of industrial activities have led to significant changes in the planet's climate, notably the increase in average global temperatures. Most of this warming has occurred over the past four decades, becoming a primary concern for climatologists and world leaders[1]. Climate change is intensifying extreme weather events[2,3] and the relationship between these events—such as cold and heat waves—and human health has become increasingly evident[4,5]. Epidemiological evidence indicates that heat and cold waves across various regions are associated with heightened risks of mortality and morbidity, largely due to the body's diminished capacity to regulate its temperature[4–11].

Research on cold waves highlights that exposure to low temperatures increases vulnerability through alterations in cardiovascular functions[8,12–14]. This can result in prolonged hospital stays and elevated healthcare costs due to cardiovascular and respiratory complications, not only during cold spells but also for several days afterward[15,16]. The physiological effects of cold exposure, such as vasoconstriction and increased blood viscosity, blood pressure, cholesterol levels, and red blood cell counts, can significantly elevate the risk of myocardial infarction and stroke[17]. Conversely, heat waves have been shown to exacerbate cardiovascular diseases, particularly among the elderly[18–22]. Key mechanisms linking rising temperatures to cardiovascular risk include an imbalance in the autonomic nervous system, characterized by increased sympathetic activity, which may lead to lower blood pressure and dehydration[18,23].

The adverse health effects of extreme temperatures can vary depending on population vulnerability and regional climate[24]. A study by Barnett et al. found that cold weather poses greater risks in warmer climate nations

[1]Department of Health in Emergencies and Disasters, Dezful University of Medical Sciences, Dezful, Iran. [2]Center for Climate Change and Health Research (CCCHR), Dezful University of Medical Sciences, Dezful, Iran. [3]Universal Scientific Education and Research Network (USERN), Dezful University of Medical Sciences, Dezful, Iran. [4]School of Public Health, Khoy University of Medical Sciences, Khoy, Iran. [5]Department of Nursing and Midwifery, Dezful University of Medical Sciences, Dezful, Iran. [6]Dezful University of Medical Sciences, Dezful, Iran. ✉email: R_sharafkhani@khoyums.ac.ir

Area of Study	Details
Location	Southwest of Iran (Longitude: 48.4235841, Latitude: 32.3830777)
Population	444,000 (2016)
Area	4762 square kilometers
Rank by Population	30th most populated city in Iran
Elevation	143 m above sea level
Climate	Hot and humid with hot summers and Mediterranean winters
Average Annual Rainfall	About 400 mm
Long-term Mean Annual Temperature	24.3 °C
Mean Annual High Temperature	32.3 °C
Mean Annual Low Temperature	16.3 °C
Lowest Annual Temperature	-3 °C
Highest Annual Temperature	51.8 °C

Table 1. Information about area of study (Dezful City).

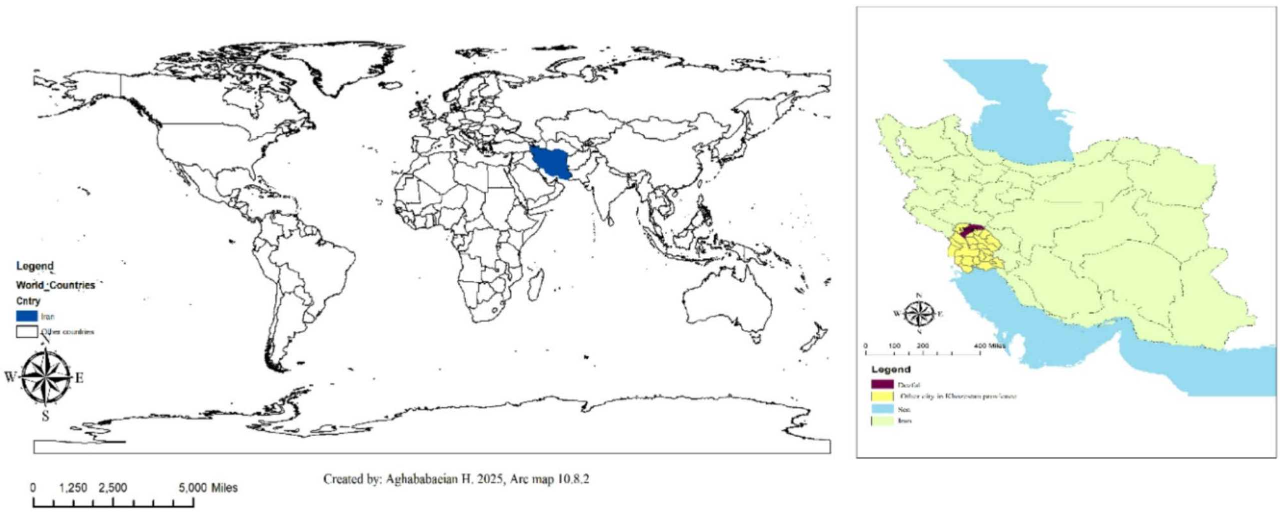

Fig. 1. Geographic Location of Dezful City in Iran and Its Global Context.

compared to colder ones, attributed to better acclimatization in colder regions[25]. Furthermore, research in tropical areas indicates that heat waves can adversely affect vulnerable populations when they exceed resilience thresholds[11,26]. Therefore, it is essential to conduct studies that examine the seasonality and duration of hot and cold periods in specific areas and their correlations with public health metrics to better understand disease patterns within populations[27–30].

Understanding the patterns of cardiovascular diseases in relation to sudden temperature changes is vital for addressing the health consequences of climate change globally[31]. Dezful experiences hot and semi-humid weather conditions, with summer temperatures sometimes exceeding 50 degrees Celsius. Given the critical nature of this issue, this study aims to evaluate the impact of heat and cold waves on hospitalization rates for cardiovascular diseases in Dezful, Iran. By elucidating these patterns, we can develop more effective public health strategies to mitigate the adverse effects of climate change on affected populations.

Method

This study was an ecological time series study conducted in 2023 based on data from 2013 to 2019 (before the spread of the COVID- 19) in the city of Dezful, Khuzestan province in Iran. Table 1 contains key details about Dezful, located in the southwest of Iran Fig. 1[11]. It provides information such as geographic location, population, area, elevation, climate, and average annual temperatures[11].

Data gathering

The archive list of registered cardiovascular patients hospitalized data in Dezful health centers from 2013 to 2019, based on the International Classification of Diseases (ICD-10) for cardiovascular diseases (CVD) (I00-I99), along with gender, age, and hospitalization data, was obtained from the Health Deputy of Dezful University of Medical Sciences.

Meteorological data and environmental pollutants were obtained from the City Meteorological Center and the Department of Environment. There is no missing data in the morbidity and meteorological database. However, there is less than 7.2% missing data in the environmental pollutant database, estimated using the Expectation Maximization method. In this study, the amount of ozone gas in Dezful city was not fully recorded, so this variable was not included in the analysis. In the city of Dezful, considering the city's remarkable climate and based on other aligned studies[11,32], we divided the year into two parts: the cold months and the warm months. Accordingly, we analyzed heatwave data based on the warm months and cold wave data based on the cold months of the year.

Heat wave definitions

In this study, based on previous studies[33–37], two definitions were used to estimate the effects of heat waves on risk of hospitalization for cardiovascular patients in Dezful.

1. Heat Wave Definition 1 (HW1):

HW1= {$Tmean \geq P95$| for at least 2 consecutive days} Where:

- *Tmean*: Daily mean temperature.
- *P*95: 95th percentile of the annual distribution of daily mean temperatures specific to the community.

2. Heat Wave Definition 2 (HW2):

HW2= {$T_{max} \geq P90$| for at least 3 consecutive days} Where:

- T_{max}: Daily maximum temperature.
- *P*90: 90th percentile of the annual distribution of daily maximum temperatures specific to the community.

The definitions of the cold wave were presented as follows to define the heat wave based on the logic of Sharafkhani et al. study[33].

Cold wave definitions

1. Cold Wave Definition 1 (CW1):

CW1= {$Tmin \leq P10$| for at least 3 consecutive days} Where:

- *Tmin*: Daily minimum temperature.
- *P*10: 10th percentile of the annual distribution of daily minimum temperatures specific to the community.

2. Cold Wave Definition 2 (CW2):

CW2= {$Tmean \leq P5$| for at least 2 consecutive days} Where:

- *Tmean*: Daily mean temperature.
- *P*5: 5th percentile of the annual distribution of daily mean temperatures specific to the community.

Statistical analysis

Given that cardiovascular hospital admissions exhibited a Quasi Poisson Distribution, we employed a combination of Distributed Lag Nonlinear Models (DLNM) alongside the quasi-Poisson model to assess the nonlinear and delayed impacts of heat and cold waves on hospital admissions (HA) both in total and within specific subgroups. Based on previous studies in this field[11,32], we utilized a similar model to account for both the Main effect (The main effect of heatwaves refers to the intensity of temperature during these events, which can significantly increase hospitalizations rates) and the Added effect (The added effect accounts for additional risks that can be attributed to heatwaves, such as a percentage increase in hospitalizations beyond the main effect) of heatwaves and cold waves[38].

Heat wave

To account for the harvesting effect of heat on HA, a maximum of 10 lags was selected, allowing for a comprehensive evaluation of the heat wave's impact on HA[33]. The statistical model utilized for this analysis (HW1, HW2 methods) is represented as follows:

$$\begin{aligned} LogE\left[Yt\ \right] \ &= a + cb\left(T1,\ 2,\ 2\right) + cb\left(T2,\ 2,\ 2\right) + ns\left(_{PM2.5},\ 3\right) + ns\left(PM_{10},\ 3\right) \\ &\quad + ns\left(RH,\ 3\right) + ns\left(season,\ 2\right) + ns\left(time,\ 7\right) + holidays + DOW \end{aligned}$$

where Yt denotes the daily observed number of HA, T1: represents the main effect and, T2: indicates the added effect. Two DLNM matrices were constructed to capture the effects of temperature and waves, each with 2 df (degrees of freedom) for the variables and another 2 df for the lags. The Natural Spline (NS) function was applied to the variables and their respective lags. To mitigate confounding from air pollutants, NS with 3 df were implemented for PM2.5, PM10, and relative humidity (RH). The temporal effect was adjusted using 7 df per year, while seasonal variations during the hot season were controlled with 2 df. Additionally, holiday effects were incorporated as a categorical variable.

Cold wave

For the cold wave analysis, the following model was applied in the CW1 and CW2 methodologies:

$$LogE\,[Yt\,] = a + cb\,(T1,\ 2,\ 2) + cb\,(T2,\ 2,\ 2) + ns\,(PM2.5,\ 3) + ns\,(PM10,\ 3) + ns\,(RH,\ 3) + ns\ (season,\ 2) + ns\ (time,\ 7) + holidays + DOW$$

Considering the long-term accumulation of deaths associated with cold weather (lingering effect), the impact of cold waves was analyzed up to 30 lags[39]. Dezful city has faced dust storms and fine particulate matter over recent decades, with evidence suggesting adverse health effects from these environmental pollutants[39,40]. Consequently, this study accounted for the influence of these pollutants using Natural Spline adjustments. We used Cumulative Excess Risk (Cumulative Excess Risk (CER) is defined as the total excess risk accumulated over a specified number of periods) to calculate the effect of heat waves on cardiovascular disease (CVD) using the following equations:

$$CER = \sum{}_{i=1}^{n}(RR_i - 1) \times\ 100$$

where: RR = Raltive Risk.

Sensitivity analysis

The degrees of freedom for all model variables have been determined based on results from similar studies[41,42]. In addition, references related to the configuration of the lags are included. The analysis covers heat waves extending to log 10 and cold waves reaching log 30, in line with previous research[32,43]. Importantly, the degrees of freedom were established by identifying the minimum value of the Quasi-Akaike Information Criterion (The Quasi-Akaike Information Criterion (QAIC) is a statistical measure used to evaluate the quality of statistical models, particularly in nonlinear models and time-dependent data. It assists in identifying models that best describe the data while considering model complexity and the number of parameters. Key advantages of QAIC include the ability to compare different models to select the best one, the identification of overly complex models that may overfit the data, and the optimization of degrees of freedom (df) for model variables by utilizing the minimum QAIC value, which ultimately enhances the accuracy of predictions) for each respective season. The df for the seasonal component were determined based on the lowest QAIC value, referencing prior studies for guidance[33,44]. To establish df for additional model variables, we noted that the relationship between temperature and hospital admissions is influenced by factors such as age and gender. Therefore, the interactions between heat/cold waves were examined separately across subgroups defined by gender (male, female) and age brackets (under 15, 15 to 64, 65 to 74, and 75 and older). Data analysis was conducted using DLNM version 2.3.5 and R software (version 3.5.1).

Results

Descriptive results

During the study period, the average number of daily cardiovascular hospitalizations in Dezful was 19.2 (± 6.7). The mean daily temperature recorded was 24.6 °C (± 9.3), with maximum and minimum temperatures reaching 33 °C (± 10.7) and 17.1 °C (± 7.8), respectively. Additionally, the average daily humidity during this period was noted. Further descriptive statistics are summarized in Table 2.

Table 3 presents the Cumulative Excess Risk (CER) of total hospital admissions due to cardiovascular disease following heat waves in Dezful. The findings indicate that the occurrence of heat waves has not significantly altered the risk of hospital admissions for cardiovascular patients in the general population.

Similarly, Table 4 outlines the CER of total hospital admissions due to cardiovascular disease associated with cold waves in Dezful. The data reveal that cold waves have not led to a significant increase in hospital admissions for cardiovascular patients within the general population.

In terms of specific demographics, Table 5 details the CER of hospital admissions due to cardiovascular disease following heat waves, categorized by sex and age groups. The results highlight a significant increase in the risk of hospital admissions for individuals over 75 years of age during heat waves. Notably, the analysis of added effects shows that HW1 is linked to an increased risk of hospital admissions in this age group (Added effects: lag0 10.74 (0.91, 21.53)).

Conversely, Table 6 examines the CER of hospital admissions due to cardiovascular disease following cold waves, segmented by sex and age groups. The findings indicate that cold waves significantly elevate the risk of hospital admissions for individuals aged 65 to 74 years. Specifically, the analysis of added effects reveals that CW1 notably increases the risk of hospital admissions for those aged between 65 and 74 years (added effects: CW1 for lag0, lag0-2, lag0-6, and lag0-13). The changes related to cumulative excess risk (CER) over the lags have been presented in figure format as Figures S1 and S2.

Discussion

The present study highlights the significant impact of both heat waves and cold waves on the risk of hospitalization due to cardiovascular diseases in the elderly population. Our findings demonstrate that individuals over 75 years of age are particularly vulnerable during heat waves, with an increased risk of hospitalization associated with high temperatures. In this regard, Ziebarth comprehensively reviewed the effects of extreme weather on 170 million hospitalizations and 8 million deaths in Germany from 1999 to 2008. According to the results, extreme heat significantly increased hospitalizations and deaths[45]. Son's study in Korea showed that hospitalization in cardiovascular hospitals was significantly associated with high temperatures, with the effect of

Variable	
Daily hospitalization **number by causes**	**Value**
Cardiovascular diseases	**Mean (SD)**
Daily hospitalization **number by Age** (Years)	19.22 (6.7)
<15	0.4 (0.65)
15–64	11.16 (4.72)
65–75	3.76 (2.25)
≥75	3.91 (2.18)
Daily hospitalization **number by Gender**	**Mean (SD)**
Male	10.8(4.3)
Female	8.44(3.7)
Heat waves and cold wave characteristic	
Number per year	**[Mean (Min, Max)]**
HW $_1$	3.2 (0, 5)
HW $_2$	2 (1, 5)
CW_1	3.2 (2, 6)
CW_2	4 (1,10)
Average heat wave intensity (°C)	**[Mean (Min, Max)]**
HW_1	38.30 (30.7, 41.9)
HW_2	48.25(44.4, 51.2)
CW_1	2.78 (-1.5, 4.7)
CW_2	9.08 (3.5, 11)
Average heat wave duration (Day)	**[Mean (Min, Max)]**
HW_1	3.9 (2, 5)
HW_2	4.9 (3, 12)
CW_1	4.31 (3, 8)
CW_2	3.6 (2, 7)

Table 2. Meteorological characteristics and hospital admission due to cardiovascular disease in Dezful City (2013–2019). SD: Standard deviation; Min: Minimum; Max: Maximum; °C: Centigrade.

Hospital admission	Wave effect		Lag0	Lag0-2	Lag0-6	Lag 0–10
CVD	Main effect	HW_1	-4.48(-29.09,28.66)	-8.15(-62.98,60.83)	-14.65(-125.07,119.10)	-50.63(-216.07,153.20)
		HW_2	4.53(-4.12,13.97)	11.03(-6.26,29.50)	15.50(-16.98,49.75)	11.24(-30.90,62.98)
	Added effect	HW_1	1.22(-3.16,5.81)	2.18(-7.13,11.83)	2.34(-15.99,21.20)	6.61(-22.44,36.52)
		HW_2	0.18(-4.10,4.67)	1.17(-7.78,10.44)	4.96(-12.37,22.78)	10.15(-17.01,38.07)

Table 3. CER of hospital admission due to cardiovascular disease following heat wave.

Hospital admission	Wave effect		Lag0	Lag0-2	Lag0-6	Lag 0–13	Lag 0–30
CVD	Main effect	CW_1	8.11(-1.57,18.74)	21.17(-3.97,48.50)	36.82(-8.22,85.07)	46.74(-25.01,122.74)	104.35(-45.68,262.54)
		CW_2	4.47(-5.43,16.080)	13.53(-12.81,42.35)	28.17(-17.24,77.02)	46.65(-2.78,119.28)	70.35(-68.80,217.80)
	Added effect	CW_1	1.80(-2.05,5.82)	5.25(-5.05,15.93)	11.42(-7.64,31.05)	19.47(-8.86,48.50)	20.93(-27.02,69.81)
		CW_2	0.70(-2.70,4.24)	2.19(-6.82,11.48)	5.29(-11.03,22.03)	10.14(-14.10,34.89)	10.76(-31.48,53.71)

Table 4. CER of hospital admission due to cardiovascular disease following cold wave.

heat waves increasing by 4.5% compared to hospitalization at 15–25 °C[23]. Ma's study in China also indicated that heat waves increased total cardiovascular hospital admissions[46]. Sheridan's study, which examined the rates of hospital admissions and deaths related to heat waves, showed that heat waves are associated with cardiovascular deaths and hospital admissions[47].

Research by Mohammadi et al. (2019) found that exposure to extreme temperatures significantly increased the risk of cardiovascular disease hospital admissions, reporting a relative risk of 1.33 (95% CI, 1.11: 1.61) when comparing the 99th percentiles of temperature relative to the mean. Additionally, the study underscored that the highest risk was observed during extremely hot conditions, particularly within the first few days of exposure[48]. Furthermore, a systematic review by Arsad et al. (2022)[49] emphasized that heat waves not only increase mortality

Disease	Variable		Wave effect		Lag0	Lag0-2	Lag0-6	Lag 0–10
CVD	Age group	< 15	M	HW_1	112.57 (-71.60, 1491.23)	165.08 (-191.26, 2107.5)	86.01 (-469.8, 2557.8)	160.6 (-724.9, 3933.6)
				HW_2	-1.09)-45.14, 78.33)	-2.34)-96.35, 144.79)	1.03)-185.21, 267.90)	15.735)-276.15, 430.37)
			A	HW_1	-10.78 (-33.96, 20.53)	-8.01 (-62.77, 60.85)	26.88 (-87.76, 165.23)	-12.11 (-184.64, 196.16)
				HW_2	-11.97 (-34.52,18.35)	-16.17 (-66.75,47.04)	8.94 (-94.53, 132.62)	-1.48 (-161.01, 188.63)
		15–64	M	HW_1	-5.78 (-36.23, 39.18)	-5.58 (-75.30, 88.49)	-2.15 (-144.65, 180.77)	-59.53 (-270.69, 211.00)
				HW_2	5.05 (-6.28, 17.75)	11.09 (-11.54, 35.79)	13.67 (-28.78, 59.22)	13.43 (-51.02, 82.40)
			A	HW_1	-1.10 (-6.62,4.73)	-2.70 (-14.52, 9.63)	-0.95(-24.44, 23.42)	11.42 (-26.21, 50.48)
				HW_2	1.81 (-3.83, 7.80)	2.40 (-9.32, 14.65)	1.75 (-20.78, 25.11)	14.78 (-20.78, 51.65)
		65–74	M	HW_1	39.73(-26.66, 166.23)	54.52(-77.43, 276.25)	-8.93(-234.13, 341.89)	-25.88(-373.22, 511.10)
				HW_2	12.36(-6.47, 35.00)	27.93 (-9.54, 71.06)	33.86 (-35.00, 111.01)	22.01 (-80.50, 136.41)
			A	HW_1	1.14 (-7.98, 11.18)	5.81 (-13.87, 27.01)	13.67 (-25.30, 55.10)	3.07 (-57.43, 67.41)
				HW_2	-3.76(-12.33, 5.62)	-3.05(-21.34, 16.58)	11.02(-25.09, 49.3)	9.00(-47.10, 68.43)
		< 75	M	HW_1	-35.19 (-64.31, 17.68)	-67.08 (-143.76, 52.63)	-34.51 (-227.51, 244.42)	-27.52 (-340.22, 426.67)
				HW_2	-2.32 (-18.00, 16.34)	-1.33 (-33.70, 35.60)	5.95 (-57.06, 76.05)	-6.52 (-102.18, 99.57)
			A	HW_1	**10.74 (0.91, 21.53)**	16.14 (-4.09, 37.91)	-0.02 (-38.24, 40.59)	-0.94 (-61.08, 62.98)
				HW_2	0.40 (-8.40, 10.05)	3.35 (-15.18, 23.24)	8.29 (-27.76, 46.49)	-2.46 (-58.28, 56.64)
	Sex	Male	M	HW_1	-7.90(-36.57,33.73)	-16.21(-80.98,70.10)	-31.13(-162.65,135.96)	-85.93(-284.36,165.80)
				HW_2	5.01(-5.72,16.97)	12.37(-9.11,35.70)	15.83(-24.45,58.89)	3.45(-56.95,67.84)
			A	HW_1	1.08(-4.34,6.81)	1.28(-10.22,13.30)	0.32(-22.32,23.79)	7.49(-28.49,44.79)
				HW_2	1.18(-4.14,6.81)	2.63(-8.47,14.21)	4.11(-17.26,26.23)	7.13(-26.30,41.72)
		Female	M	HW_1	-1.20(-34.85,49.81)	-0.32(-75.93,104.03)	3.90(-149.41,204.49)	-5.15(-243.19,306.05)
				HW_2	3.52(-8.18,16.74)	8.26(-15.28,34.07)	13.25(-31.29,61.20)	19.46(-48.84,92.83)
			A	HW_1	1.26(-4.78,7.79)	3.03(-10.06,16.79)	4.50(-21.28,31.36)	4.54(-36.21,46.99)
				HW_2	-1.30(-7.20,4.96)	-1.18(-13.57,11.81)	5.37(-18.84,30.54)	12.93(-25.08,52.44)

Table 5. CER of hospital admission due to cardiovascular disease after heat waves, stratified by age and sex groups.

Disease	Variable		Wave effect		Lag0	Lag0-2	Lag0-6	lag 0–13	Lag 0–30
CVD	Age group	**< 15**	M	CW_1	4.31(-41.32, 85.46)	7.26(-113.15, 207.24)	-4.37(-223.51, 328.99)	-43.75(-397.52, 458.74)	62.75(-714.46, 1129.41)
				CW_2	-3.60(-48.97, 82.12)	-9.90(-131.35, 201.71)	-19.58(-238.49, 323.81)	-32.51(-369.32, 453.26)	-87.09(-772.07, 854.14)
			A	CW_1	4.66(-16.91, 31.84)	13.43(-44.59, 84.81)	28.47(-80.03, 157.49)	44.53(-118.46, 232.58)	12.29(-266.22, 324.98)
				CW_2	-0.22(-18.94, 22.80)	-0.718(-50.51, 59.17)	-1.91(-93.02, 104.20)	-5.11(-142.69, 150.80)	-22.34(-268.33, 249.82)
		15–64	M	CW_1	6.26(-5.87, 19.97)	16.51(-15.16, 51.77)	29.57(-27.48, 91.92)	41.91(-49.59, 140.45)	122.71(-70.73, 329.81)
				CW_2	3.13(-9.63, 17.70)	9.10(-23.95, 46.19)	19.92(-37.31, 82.77)	36.19(-50.47, 129.75)	68.73(-109.10, 259.10)
			A	CW_1	1.09(-3.80, 6.2)	3.40(-9.69, 17.09)	8.24(-16.03, 33.43)	15.69(-20.48, 53)	14.01(-47.34, 76.91)
				CW_2	1.87(-2.51, 6.45)	5.35(-6.22, 17.39)	11.30(-9.64, 32.93)	18.49(-12.62, 50.45)	19.79(-34.45, 75.21)
		65–74	M	CW_1	7.00(-10.80, 28.37)	17.75(-28.70, 72.29)	28.36(-55.32, 123.94)	28.52(-105.75, 178.63)	59.14(-221.92, 370.62)
				CW_2	9.99(-10.08, 34.57)	28.68(-23.38, 90.77)	61.12(-29.03, 165.14)	104.39(-31.75, 257.43)	156.52(-117.08, 460.15)
			A	CW_1	**9.31(1.32, 17.92)**	**25.40(4.18, 48.11)**	**48.53(9.55, 89.80)**	**68.11(10.79, 128.21)**	66.87(-28.47, 165.91)
				CW_2	1.20(-5.43, 8.31)	3.25(-14.29, 21.90)	6.01(-25.77, 39.43)	7.14(-39.92, 56.18)	-4.64(-86.16, 79.59)
		< 75	M	CW_1	14.65(-4.17, 37.19)	38.84(-10.12, 96.22)	69.66(-18.04, 169.70)	88.43(50.02, 243.08)	102.21(-178.54, 412.96)
				CW_2	5.02(-13.31, 27.26)	13.56(-33.97, 69.78)	25.10(-57.31, 19.57)	31.83(-92.88, 171.29)	10.32(-242.00, 289.14)
			A	CW_1	-3.12(-10.12, 4.41)	-8.29(-27.05, 11.77)	-14.66(-49.63, 22.32)	-16.53(-69.02, 38.41)	-0.83(-91.01, 92.71)
				CW_2	-3.06(-9.31, 3.60)	-7.81(-24.42, 9.80)	-12.39(-42.75, 19.49)	-10.22(-55.66, 37.07)	1.31(-78.48, 83.70)
	Sex	Male	M	CW_1	5.27(-6.08, 18.00)	13.61(-16.01, 46.37)	23.14(-30.23, 81.16)	29.99(-55.62, 121.80)	99.58(-81.87, 293.09)
				CW_2	1.30(-10.37, 14.51)	4.06(-26.22, 37.77)	10.15(-42.42, 67.50)	22.45(-57.57, 108.36)	59.67(-106.24, 236.43)
			A	CW_1	1.28(-3.36, 6.15)	3.69(-8.70, 16.63)	7.94(-14.99, 31.71)	13.85(-20.30, 49.01)	22.46(-35.55, 81.85)
				CW_2	2.53(-1.59, 6.84)	7.06(-3.84, 18.37)	14.12(-5.60, 34.46)	22.11(-7.21, 52.17)	34.18(-16.95, 86.35)
		Female	M	CW_1	11.29(-1.89, 26.26)	29.67(-4.55, 67.92)	52.24(-8.89, 119.29)	65.80(-31.19, 170.59)	108.85(-91.07, 323.48)
				CW_2	9.35(-4.89, 25.74)	25.94(-10.77, 67.43)	51.37(-11.67, 120.99)	76.76(-17.38, 178.87)	81.61(-105.56, 282.76)
			A	CW_1	2.59(-2.62, 8.09)	7.54(-6.39, 22.14)	16.36(-9.42, 43.18)	27.15(-11.15, 66.72)	19.29(-45.30, 85.57)
				CW_2	-1.58(-6.103, 3.14)	-3.92(-15.88, 8.54)	-5.77(-27.49, 16.71)	-4.65(-36.95, 28.57)	-17.58(-73.89, 40.015)

Table 6. CER of hospital admission due to cardiovascular disease after cold waves, stratified by age and sex groups.

but also significantly elevate morbidity rates, particularly among vulnerable populations such as the elderly. The review indicated that the elderly are at heightened risk, with studies showing that hospital admissions for cardiovascular-related issues increased by 14% during heat wave events[49,50]. Numerous studies have shown consistent evidence that older adults are among the most at-risk populations[25]. Another study in Portugal concluded that individuals aged 65 years and older are the most affected by high temperatures[51]. Similarly, research conducted in Australia found that patients aged 65 and above were more likely to be impacted by heat waves[52]. The susceptibility of older adults is influenced by both physiological and social factors, including living alone, the presence of chronic illnesses, and diminished physiological function. As people age, their ability to regulate body temperature declines, and the prevalence of chronic conditions increases, making them more vulnerable to temperature-related effects[53,54].

In contrast, a study by Nhung et al. (2023) conducted in Southern Vietnam reported a negative relationship between heat waves and the risk of cardiovascular disease admissions for individuals over the age of 60 (ER = − 7.28 (− 13.97, − 0.08) in Ca Mau)[55]. Additionally, a meta-analysis that aggregated data from 18 studies worldwide found no statistically significant relationship ($p = 0.6$) between heat waves and cardiovascular morbidity[56] .

Among the reasons for the inconsistency of the results of these studies with our findings, we can name geographical diversity, differences in the severity of exposure, the perceived importance and sensitivity in the studied populations, the implementation of preventive and response measures, the heterogeneity in health services, care admission policies, and disparities in access to healthcare[49]. This can shed light on how quickly heat waves can lead to increased death rates. Those who are more vulnerable might experience serious effects within a few hours during a heat event. Some may pass away before they can be hospitalized, so they won't be included in the statistics for illness rates[55,57].

Regarding other results of this study concerning the relationship between heat wave occurrences and the increase in hospital admissions in exposed individuals in the city of Dezful, aside from the significant association between heat waves and the increased risk of hospitalization in the elderly, no other significant relationships were observed in the overall previous vascular admissions and age groups under 75 years with the occurrence of heat waves during the study period. This finding contrasts with some studies that have indicated a significant relationship between heat wave occurrences and an increased risk of cardiovascular problems[58–60], but it may align with the results of some other studies[56,61]. Dezful is a city with a hot climate, where the residents have long been accustomed to heat and have devised and implemented adaptation strategies[62]. Therefore, this may explain the lack of significant association between heat wave occurrences and increased previous vascular admissions in other age groups under 75 years. In this context, the results of the study by Aghababaian et al. in 2025 indicated that cardiovascular admissions in the city of Dezful did not show significant changes at high Physiological Equivalent Temperature (PET) levels[63]. Additionally, in another study conducted in the same city that assessed another thermal index on health indicators, the results indicated that daily fluctuations in extreme temperatures not only did not cause significant changes in the number of cardiovascular admissions in many cases but also had a significant relationship with a reduction in the number of cardiovascular admissions under certain conditions[64]. This finding may reinforce our hypothesis regarding the adaptive effects of individuals exposed to climate changes, leading to reduced health impacts. However, the need for further research and the conduct of future cohort studies in this area becomes more evident.

In addition to heat, the results of this study indicated that cold waves also pose a significant risk, particularly for individuals aged 65 to 74 years in our study. Research by Mohammadi et al. (2019) further supports this, showing that short-term exposure to extreme cold temperatures significantly raises the likelihood of hospital admissions for cardiovascular diseases (RR of 1.33 (95% CI: 1.11–1.61))[48].Moreover, a study by Chen et al. (2020) examined the relationship between extreme temperature events, including cold waves, and cardiovascular mortality across 31 major Chinese cities. Their findings revealed a striking 54.72% increase in cardiovascular mortality risk during cold waves. The study highlighted that the impact of cold waves varied based on their characteristics, such as intensity and duration. For instance, for every additional day of cold wave duration, the cardiovascular mortality risk increased by 1.52%[5]. In this regard, Jipei Du (2022) states that the cardiovascular effects of cold waves increase with age and can heighten the risk for elderly patients[65]. Additionally, Silva and Ribeiro (2012) conducted a cross-sectional study in São Paulo, Brazil, focusing on hospitalizations of individuals aged 60 and older. They discovered that experiencing thermal discomfort was associated with a higher likelihood of developing heart-related issues in this age group. Specifically, an uptick in hospitalizations for circulatory system issues was noted on cold days with significant tempreture variations, irrespective of socio-environmental conditions[66] .

Although some studies have reported no significant association between cold waves and increased hospitalization risk for cardiovascular patients[46,67,68], a meta-analysis review demonstrated that cold spells had a notable impact on cardiovascular outcomes. This analysis indicated a 32.4% increase in cardiovascular disease-related mortality (RR = 1.324;)1.234–1.421)(and a 13.8% rise in morbidity (RR = 1.138 (1.015–1.276))[69]. The increase in hospitalizations due to cold waves is influenced not only by temperature effects but also by various underlying factors, such as population adaptation, socio-economic and structural differences, infrastructure designed for extreme temperatures, and disparities in access to healthcare services[24]. This can help explain the discrepancies between some findings and our results as well as those of other studies.

Other results of this study also indicated that there was no significant relationship between the occurrence of cold waves in the city of Dezful and the increased risk of total cardiovascular admissions and admissions of patients with cardiovascular issues under 65 years of age. This discrepancy in results may be due to the relatively tolerable temperatures of the cold waves in this region, which did not ultimately drop below − 3 degrees. However, the results of a study conducted in the same area in 2025 suggested that the adaptation of the people in this city to low temperatures may also account for the lack of significant increase in cardiovascular admissions across other age and gender groups, in general[64]. Nevertheless, the increase in certain admissions during cold waves may be attributed to non-compliance with adaptation principles related to climate fluctuations and the increased vulnerability of individuals exposed. This issue also highlights the need for further research and the conduct of future cohort studies in this area.

Seasonal variations, along with heat and cold waves, significantly impact cardiovascular diseases in vulnerable individuals, especially the elderly, leading to increased hospitalizations of these individuals. These are critical health concerns that must be addressed, especially in light of climate change, which is altering the duration and intensity of such temperature extremes. This issue may pose greater challenges for populations in milder climates that are less equipped to handle more severe weather fluctuations throughout the year. This complex situation goes beyond just specific physiological reactions to varying temperatures; it involves intricate interactions between individuals and their environments. As a result, the potential to alleviate the impact of temperature changes on vulnerable groups has not yet been fully explored or implemented. Given that multiple factors contribute to this phenomenon, and some may be targeted for intervention, there is an opportunity for comprehensive strategies to mitigate negative cardiovascular and respiratory effects associated with temperature variations[70]. , which requires more research to identify and implement interventions.

Conclusion

This study examined the significant impacts of heat waves and cold spells on the hospitalization risk associated with cardiovascular diseases in the elderly population of Dezful. The results indicate that older adults are more vulnerable to temperature fluctuations, influenced by various physiological, social, and environmental factors. Given the increasing frequency and intensity of temperature extremes due to climate change, it is essential for policymakers and public health officials to develop preventive programs and health interventions aimed at mitigating the negative effects of these changes on cardiovascular health. Although the evidence from this study suggests positive adaptation effects for individuals exposed to temperature changes on health, which could reinforce our hypothesis of reducing the harmful health effects associated with extreme weather changes due to climate change, raising public awareness and providing education about potential risks and coping strategies for extreme weather conditions can contribute to community health improvement. Ultimately, this study underscores the need for further research to identify and investigate the factors influencing the vulnerability of different populations to temperature changes. Considering Iran's climatic diversity, addressing this issue could enhance public health and reduce the burden of cardiovascular diseases in the future.

Limitations

In this research, only the effects of the outside temperature were investigated. On the other hand, due to the lack of ozone gas registration in the city of Dezful, the effects of this pollutant were not tested. In addition, the city of Dezful has been exposed to the health effects caused by dust storms in the last two decades[39,71]. Hence, the effects of PM^{10} and $PM^{2.5}$ were calculated and controlled as confounding variables.

Data availability

The data that support the findings of this study are available from Dr. Hamidreza Aghababaeian. However, there are restrictions on the availability of these data, as they were used under license for the current study and are not publicly available. Nonetheless, data can be obtained from the authors upon reasonable request and with the permission of Dr. Hamidreza Aghababaeian.

Received: 9 October 2024; Accepted: 14 April 2025
Published online: 15 May 2025

References

1. Baldwin, J. W., Dessy, J. B., Vecchi, G. A. & Oppenheimer, M. Temporally compound heat wave events and global warming: an emerging hazard. *Earth's Future*. **7** (4), 411–427 (2019).
2. Seneviratne, S. I. et al. Weather and climate extreme events in a changing climate. (2021).
3. Bell, C. & Masys, A. J. Climate change, extreme weather events and global health security a lens into vulnerabilities. Global health security: Recognizing vulnerabilities, creating opportunities. :59–78. (2020).
4. Shaposhnikov, D. & Revich, B. Toward meta-analysis of impacts of heat and cold waves on mortality in Russian North. *Urban Clim.* **15**, 16–24 (2016).
5. Chen, J. et al. The modifying effects of heat and cold wave characteristics on cardiovascular mortality in 31 major Chinese cities. *Environ. Res. Lett.* **15** (10), 105009 (2020).
6. USGCRP. The Impacts Of Climate Change On Human Health. In The United States: A Scientific Assessment. Washington,: U.S. Global Change Research Program; DC, 2016 [Available from: https://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=236389
7. De Blois, J. et al. The effects of climate change on cardiac health. ;**131**(4):209–217. (2015).
8. Abrignani, M. G., Lombardo, A., Braschi, A., Renda, N. & Abrignani, V. Climatic influences on cardiovascular diseases. *World J. Cardiol.* **14** (3), 152 (2022).
9. Costa, I. T. et al. Extreme weather conditions and cardiovascular hospitalizations in Southern Brazil. *Sustainability* **13** (21), 12194 (2021).
10. Hadei, M. et al. Association of heat and cold waves with cause-specific mortality in Iran: a systematic review and meta-analysis. *Sci. Rep.* **14** (1), 23327 (2024).
11. Aghababaeian, H. et al. Mortality risk related to heatwaves in Dezful City, Southwest of Iran. *Environ. Health Insights*. **17**, 11786302231151538 (2023).
12. Corcuera Hotz, I. & Hajat, S. J. I. health p. The effects of temperature on accident and emergency department attendances in London: a time-series regression analysis. ;17(6):1957. (2020).
13. Baaghideh, M. & Mayvaneh, F. J. I. Climate change and simulation of cardiovascular disease mortality: A case study of Mashhad. *Iran* **46** (3), 396 (2017).
14. Bai, L. et al. Increased coronary heart disease and stroke hospitalisations from ambient temperatures in Ontario. ;**104**(8):673–679. (2018).

15. Ponjoan, A. et al. Effects of extreme temperatures on cardiovascular emergency hospitalizations in a mediterranean region: a self-controlled case series study. ;**16**(1):1–9. (2017).
16. Qiu, H., Sun, S., Tang, R., Chan, K-P. & Tian, L. J. A. J. E. Pneumonia hospitalization risk in the elderly attributable to cold and hot temperatures in Hong Kong. *China* **184** (8), 570–578 (2016).
17. Ryti, N. R., Guo, Y. & Jaakkola, J. J. E. Global association of cold spells and adverse health effects: a systematic review and meta-analysis. ;**124**(1):12–22. (2016).
18. Caldeira, D. et al. do Global warming and heat wave risks for cardiovascular diseases: A position paper from the Portuguese Society of Cardiology. Revista Portuguesa de Cardiologia. ;42(12):1017-24. (2023).
19. Silveira, I. H., Cortes, T. R., Bell, M. L. & Junger, W. L. Effects of heat waves on cardiovascular and respiratory mortality in Rio de Janeiro, Brazil. *Plos One*. **18** (3), e0283899 (2023).
20. Campbell, S. L. et al. Ambulance dispatches and heatwaves in Tasmania, Australia: A case-crossover analysis. *Environ. Res.* **202**, 111655 (2021).
21. Schaffer, A., Muscatello, D., Broome, R., Corbett, S. & Smith, W. Emergency department visits, ambulance calls, and mortality associated with an exceptional heat wave in Sydney, Australia, 2011: a time-series analysis. *Environ. Health*. **11**, 1–8 (2012).
22. Organization, W. H. *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease* (WHO, 2016).
23. Hifumi, T., Kondo, Y., Shimizu, K. & Miyake, Y. Heat stroke. *J. Intensive Care*. **6**, 1–8 (2018).
24. Wang, X. et al. Effects of extreme temperatures on cause-specific cardiovascular mortality in China. ;**12**(12):16136–16156. (2015).
25. Barnett, A. G. et al. Cold periods and coronary events: an analysis of populations worldwide. *J. Epidemiol. Community Health*. **59** (7), 551–557 (2005).
26. Azhar, G. S. et al. Heat-related mortality in India: excess all-cause mortality associated with the 2010 Ahmedabad heat wave. *PloS One*. **9** (3), e91831 (2014).
27. Ornato, J. P., Peberdy, M. A., Chandra, N. C., Bush, D. E. & Infarction†, P. N. R. M. Seasonal pattern of acute myocardial infarction in the National registry of myocardial infarction. *J. Am. Coll. Cardiol.* **28** (7), 1684–1688 (1996).
28. Manfredini, R. et al. Seasonal and weekly patterns of hospital admissions for nonfatal and fatal myocardial infarction. *Am. J. Emerg. Med.* **27** (9), 1097–1103 (2009).
29. Abrignani, M. et al. Influence of Climatic variables on acute myocardial infarction hospital admissions. *Int. J. Cardiol.* **137** (2), 123–129 (2009).
30. Conlon, K. C., Rajkovich, N. B., White-Newsome, J. L., Larsen, L. & O'Neill, M. S. Preventing cold-related morbidity and mortality in a changing climate. *Maturitas* **69** (3), 197–202 (2011).
31. De Troeyer, K. et al. Heat related mortality in the two largest Belgian urban areas: A time series analysis. ;**188**:109848. (2020).
32. Sharafkhani, R., Khanjani, N., Bakhtiari, B., Jahani, Y. & Entezarmahdi, R. The effect of cold and heat waves on mortality in urmia a cold region in the North West of Iran. *J. Therm. Biol.* **94**, 102745 (2020).
33. Sharafkhani, R., Khanjani, N., Bakhtiari, B., Jahani, Y. & Entezarmahdi, R. J. J. The effect of cold and heat waves on mortality in urmia a cold region in the North West of Iran. *J Therm Biol.* **94**, 102745. (2020).
34. Barnett, A., Hajat, S., Gasparrini, A. & Rocklöv, J. Cold and heat waves in the united States. *JEr* **112**, 218–224 (2012).
35. Zeng, W. et al. The effect of heat waves on mortality and effect modifiers in four communities of Guangdong Province. *China* **482**, 214–221 (2014).
36. Xu, Y. et al. Differences on the effect of heat waves on mortality by sociodemographic and urban landscape characteristics. ;**67**(6):519–525. (2013).
37. Tong, S., Wang, X. Y. & Barnett, A. G. J. P. Assessment of heat-related health impacts in Brisbane, Australia: comparison of different heatwave definitions. ;**5**(8):e12155. (2010).
38. Dang, T. N. et al. Main and added effects of heatwaves on hospitalizations for mental and behavioral disorders in a tropical megacity of Vietnam. *Environ. Sci. Pollut. Res.* **29** (39), 59094–59103 (2022).
39. Aghababaeian, H. et al. Effect of dust storms on Non-Accidental, cardiovascular, and respiratory mortality: A case of Dezful City in Iran. *Environ. Health Insights*. **15**, 11786302211060152 (2021).
40. Aghababaeian, H. et al. Global health impacts of dust storms: a systematic review. *Environ. Health Insights*. **15**, 11786302211018390 (2021).
41. Ma, W. et al. The short-term effect of heat waves on mortality and its modifiers in China: an analysis from 66 communities. *Environ. Int.* **75**, 103–109 (2015).
42. Aboubakri, O., Khanjani, N., Jahani, Y. & Bakhtiari, B. The impact of heat waves on mortality and years of life lost in a dry region of Iran (Kerman) during 2005–2017. *Int. J. Biometeorol.* **63**, 1139–1149 (2019).
43. Zeng, W. et al. The effect of heat waves on mortality and effect modifiers in four communities of Guangdong Province, China. *Sci. Total Environ.* **482**, 214–221 (2014).
44. Sharafkhani, R., Khanjani, N., Bakhtiari, B., Jahani, Y. & Mahdi, R. E. J. J. Diurnal temperature range and mortality in urmia, the Northwest of Iran. ;**69**:281–287. (2017).
45. Ziebarth, N. R., Schmitt, M. & Karlsson, M. The short-term population health effects of weather and pollution: Implications of climate change. (2014).
46. Son, J-Y., Bell, M. L. & Lee, J-T. The impact of heat, cold, and heat waves on hospital admissions in eight cities in Korea. *Int. J. Biometeorol.* **58**, 1893–1903 (2014).
47. Sheridan, S. C. & Lin, S. Assessing variability in the impacts of heat on health outcomes in new York City over time, season, and heat-wave duration. *EcoHealth* **11**, 512–525 (2014).
48. Mohammadi, D., Zare Zadeh, M. & Zare Sakhvidi, M. J. Short-term exposure to extreme temperature and risk of hospital admission due to cardiovascular diseases. *Int. J. Environ. Health Res.* **31** (3), 344–354 (2021).
49. Arsad, F. S. et al. The impact of heatwaves on mortality and morbidity and the associated vulnerability factors: a systematic review. *Int. J. Environ. Res. Public Health*. **19** (23), 16356 (2022).
50. Kang, S-H. et al. Heat, heat waves, and out-of-hospital cardiac arrest. *Int. J. Cardiol.* **221**, 232–237 (2016).
51. Almeida, S. P., Casimiro, E. & Calheiros, J. Effects of apparent temperature on daily mortality in Lisbon and Oporto, Portugal. *Environ. Health*. **9**, 1–7 (2010).
52. Dalip, J., Phillips, G. A., Jelinek, G. A. & Weiland, T. J. Can the elderly handle the heat? A retrospective case-control study of the impact of heat waves on older patients attending an inner City Australian emergency department. *Asia Pac. J. Public. Health*. **27** (2), NP1837–NP46 (2015).
53. Gasparrini, A., Armstrong, B., Kovats, S. & Wilkinson, P. J. O. medicine e. The effect of high temperatures on cause-specific mortality in England and Wales. *Occup Environ Med.* **69**(1), 56–61 (2012).
54. Kenny, G. P., Yardley, J., Brown, C., Sigal, R. J. & Jay, O. J. C. Heat stress in older individuals and patients with common chronic diseases. **182**(10), 1053–1060 (2010).
55. Nhung, N. T. T. et al. Effects of heatwaves on hospital admissions for cardiovascular and respiratory diseases, in Southern Vietnam, 2010–2018: time series analysis. *Int. J. Environ. Res. Public Health*. **20** (5), 3908 (2023).
56. Cheng, J. et al. Cardiorespiratory effects of heatwaves: A systematic review and meta-analysis of global epidemiological evidence. *Environ. Res.* **177**, 108610 (2019).
57. Turner, L. R., Barnett, A. G., Connell, D. & Tong, S. Ambient temperature and cardiorespiratory morbidity: a systematic review and meta-analysis. *Epidemiology* **23** (4), 594–606 (2012).
58. Phung, D. et al. Heatwave and risk of hospitalization: A multi-province study in Vietnam. *Environ. Pollut.* **220**, 597–607 (2017).

59. Lindstrom, S., Nagalingam, V. & Newnham, H. Impact of the 2009 M Elbourne heatwave on a major public hospital. *Intern. Med. J.* **43** (11), 1246–1250 (2013).
60. Knowlton, K. et al. The 2006 California heat Wave: impacts on hospitalizations and emergency department visits. *Environ. Health Perspect.* **117** (1), 61–67 (2009).
61. Phung, D. et al. The effects of high temperature on cardiovascular admissions in the most populous tropical City in Vietnam. *Environ. Pollut.* **208**, 33–39 (2016).
62. Aghababaeian, H. et al. The practices of heat adaptation among elderly in Dezful: A qualitative study. *J. Educ. Health Promotion*. **13** (1), 85 (2024).
63. Aghababaeian, H. et al. Physiological equivalent temperature and hospitalized due to respiratory and cardiovascular diseases in Dezful. *Iran. Heliyon* (2025).
64. Aghababaeian, H. et al. Diurnal temperature range and hospital admission due to cardiovascular and respiratory diseases in Dezful, a City with hot climate and high DTR fluctuation in Iran: an ecological time-series study. *Environ. Geochem. Health.* **45** (7), 4915–4927 (2023).
65. Du, J. et al. Extreme cold weather and circulatory diseases of older adults: A time-stratified case-crossover study in Jinan, China. *Environ. Res.* **214**, 114073 (2022).
66. Silva ENd, Ribeiro, H. Impact of urban atmospheric environment on hospital admissions in the elderly. *Rev. Saúde Pública*. **46**, 694–701 (2012).
67. Ren, C., Williams, G. M. & Tong, S. Does particulate matter modify the association between temperature and cardiorespiratory diseases? *Environ. Health Perspect.* **114** (11), 1690–1696 (2006).
68. Shaposhnikov, D., Revich, B., Gurfinkel, Y. & Naumova, E. The influence of meteorological and geomagnetic factors on acute myocardial infarction and brain stroke in Moscow, Russia. *Int. J. Biometeorol.* **58**, 799–808 (2014).
69. Fan, J-F. et al. A systematic review and meta-analysis of cold exposure and cardiovascular disease outcomes. *Front. Cardiovasc. Med.* **10**, 1084611 (2023).
70. Michelozzi, P. et al. High temperature and hospitalizations for cardiovascular and respiratory causes in 12 European cities. *Am J Respir Crit Care Med*. **179**(5), 383–389 (2009).
71. Aghababaeian, H. et al. Cardiovascular and respiratory emergency dispatch due to short-term exposure to ambient PM10 in Dezful, Iran. *J. Cardiovasc. Thorac. Res.* **11** (4), 264 (2019).

Acknowledgements
We would like to express our heartfelt appreciation to the Vice Chancellor for Research at Dezful University of Medical Sciences and the Center for Climate Change and Health Research for their financial support and assistance with this study (Grant No: 97062). Additionally, we extend our gratitude to Maryam Kiarsi for her contributions to the article, despite not meeting the criteria for authorship.

Author contributions
HA and RSH were responsible for designing the study; data collection was carried out by HA, NH, and LAA; data analysis and interpretation were conducted by HA and RSH. The manuscript was prepared by HA, LAA, and RSH. All authors participated in drafting and reviewing the final document, and they have all approved the final version.

Declarations

Ethics approval and consent to participate
In this study, no experiments involving human participants (including the use of tissue samples) were conducted; instead, only anonymized and confidential archived data was utilized. This study does not require informed consent from patients, as the ethics committee (Ethics Committee of Dezful University of Medical Sciences (DUMS)) waived the requirement for consent due to the use of non-identifiable data and the lack of identification of participants. Additionally, written authorization was obtained from the relevant authorities to use this data. All research procedures were conducted in compliance with ethical principles and regulations regarding data protection. Approval for this study was granted by the Ethics Committee of Dezful University of Medical Sciences (DUMS) with Ethics Code: IR.DUMS.REC.1399.032. The study adhered to all applicable guidelines and regulations.

Consent for publication
Not applicable. This study is an ecological time series analysis that does not involve human participants. All data were obtained from hospital archives, meteorological sources, and environmental databases, and were collected in a fully anonymized and confidential manner. Therefore, we did not obtain consent from participants, as no individuals were involved in the study. If you have any further questions or require additional information, please feel free to reach out.

Competing interests
The authors declare no competing interests.

Additional information
Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-025-98736-z.

Correspondence and requests for materials should be addressed to R.S.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.