A comparison of the effect of diurnal temperature range and apparent temperature on cardiovascular disease among farmers in Qingyang, Northwest China

Guangyu Zhai1,2 · Jintao Qi1 · Xuemei Zhang1 · Wenjuan Zhou3 · Jiancheng Wang3

Received: 20 August 2021 / Accepted: 23 November 2021 / Published online: 6 January 2022
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2021

Abstract
Climate change is increasing the incidence of extreme weather events which have a significant impact on public health. Cardiovascular diseases (CVDs) are the number one cause of death globally (40%). Apparent temperature (AT) and diurnal temperature range (DTR) have been extensively used to evaluate the effects of temperature on cardiovascular disease (CVD). However, the relevant information is quite limited from analysis and comparison of effects and differing pathogenesis of DTR and AT on CVD especially in less-developed, rural areas of China. This is the first attempt to analyze different effects between AT and DTR on CVD using distributed lag nonlinear modeling (DLNM) in rural area. Data on CVD hospital admission in Qingyang (Northwest China) in 2014–2017 originated from the New Rural Cooperative Medical System (NRCMS) of Gansu Province, and meteorological variables were provided by the Meteorological Science Data Sharing Service. Both AT and DTR had significant nonlinear and delayed impacts on hospital admissions for CVD. DTR had a stronger and more persistent effect on CVD incidence than AT. Females were more affected by high AT and low DTR than were males, while males were more vulnerable to low AT and high DTR. Temperature effects were not significantly different between people above and below 65 years of age. These findings provide local public health authorities with reference concerning sensitive temperature indices for susceptible populations with a view to improve CVD preventive strategies in rural areas.

Keywords · Diurnal temperature range · Apparent temperature · Cardiovascular diseases · Distributed lag nonlinear · Farmer

Introduction
Cardiovascular diseases (CVDs) are the number one cause of death globally (40%) (WHO 2018; Michelozzi et al. 2009; Lin et al. 2009) and the most preventable disease worldwide (Ghiasmand et al. 2017). Climate change is increasing the incidence of extreme weather events which have a significant impact on public health (Rumsey et al. 2014). It was well-established that extreme weather events are one of the most important factors leading to increased morbidity and mortality (Ghiasmand et al. 2017; Wilson et al. 2013). The effects of AT and DTR on cardiovascular disease (CVD) have become a focus of research. Previous studies have reported that CVD mortality is highly sensitive to apparent temperature (AT) (Almeida et al. 2010; Krstic 2011), with non-linear and reverse J-shaped correlations being demonstrated (Moghadamnia et al. 2018; Wichmann et al. 2011). Diurnal temperature range (DTR) is generally used to evaluate temperature impacts on CVD. For example, in China (Kan et al. 2007; Zhou et al. 2014), Korea (Lim et al. 2012b), and the USA (Ebi et al. 2004), DTR was found to have nonlinear relationships with CVD morbidity and mortality.

The occurrence of CVDs is known to be related to nutritional, socioeconomic, and environmental factors (Marilyn et al. 1998; Patricio et al. 2008). CVD accounts for 41% and 43% of deaths in middle-income and low-income countries, respectively. This compares to 23% in high-income countries (WHO, 2018). However, most studies on the relationship between AT and CVD morbidity...
have been conducted in large cities in developed countries (Liu et al. 2011; Mo et al. 2012) with few studies being performed in rural areas in developing countries. China, the largest of the developing countries, has a high incidence of CVD. The number of deaths arising from CVD in China accounts for 24.7% of global deaths arising from CVD (Vos et al. 2020). Farmers are more susceptible to temperature changes compared with urban residents (Mutekwa 2009). In rural Northwest China, Zheng investigated association between DTR and blood pressure (Zheng et al. 2020). Wang studied the impact of ambient temperature on CVD in farmers (Wang et al. 2020a, b). These studies provided limited information on the differing impacts of DTR and AT on CVD of farmers in China. However, uncertainty remains as to which temperature indicator is most suitable for early warning of cardiovascular disease in different groups of people. In less-affluent areas of Northwest China where medical facilities are relatively poor, it is necessary to identify appropriate weather indicators for early warning of cardiovascular disease-prone populations.

This is the first study to analyze different effects between AT and DTR on CVD using distributed lag nonlinear modeling among different populations in rural area. The objective of this study was to assess and compare the efficacy of two temperature indicators of CVD morbidity among farmers in Qingyang between 2014 and 2017. This exploration of the relationship between thermometric variables and CVD risk may help local public health departments develop sensitive temperature indicators for susceptible populations and to instigate alleviation and prevention strategies (Yang et al. 2015).

Materials and methods

Study area

Qingyang is an eastern city of Gansu Province, Northwest China, at latitude 35° 15' N and longitude 106° 20' E (see Fig. 1). It has 5071.4 km² of sown area and is known as “the granary of Gansu Province” as well as the city in China with the second largest energy resources. Qingyang is dominated by agriculture, with less air pollution. In 2019, the permanent population of Qingyang was 2.28 million, of which farmers accounted for approximately 60%. It has a typically warm temperate continental monsoon climate with distinct alternating cold winters and warm summers (average annual temperatures 9.8 °C). The topography of Qingyang is basin, surrounded by mountains on three sides with the low and gentle middle.

Data collection

The data of CVD hospital admission were collected from New Rural Cooperative Medical System (NRCMS) of Gansu Province, the government agency responsible for farmer health data collection in Gansu Province. These records encompassed 30 Qingyang city and county hospitals covering 1 January 2014 to 27 March 2017 and included patients’ sex, age, hospitalization time, residential address, and disease classification. Diagnoses were coded according to the 10th edition of the International Classification of Diseases (ICD-10). CVD classifications included chronic rheumatic heart disease (I05–I09), hypertension (I10–I15), ischemic heart disease (I20–I25), and other types of heart disease (I30–I52).

Meteorological data were collated from the China Meteorological Science Data Sharing Service (http://data.cma.cn/). These included mean temperature ($T_{\text{mean}}$), minimum and maximum temperatures ($T_{\text{min}}$ and $T_{\text{max}}$), wind speed ($W_{3}$), relative humidity ($RH$), and atmospheric pressure (AP). Daily mean concentration of air pollutants in the city from 2014 to 2017 was obtained from the China National Environmental Monitoring Center (http://webinterface.cnemc.cn/) and included PM$_{2.5}$, PM$_{10}$, and SO$_{2}$.

Statistical analysis

Poisson generalized linear regression modeling combined with distributed lag nonlinear modeling (DLNM) was applied to examine the impact of temperature variables on CVD admissions. DLNM using the cross-basis function can simultaneously measure nonlinear exposure–response dependencies and delayed effects (Gasparrini 2014). Cubic spline smoothing was adopted to explain variations in the temporal behavior of potential predictors. The smoothed predictors, that is the meteorological indicators, were added in a fashion similar to multiple linear regression. This approach is commonly applied in weather epidemiology and has been used in similar studies (Guo et al. 2016; Lee et al. 2018). The general model was as follows:

$Y_{i} \sim \text{Poisson} \left( \mu_{i} \right)$

$\log(Y_{i}) = \alpha + \beta(X_{i,t}) + ns(Temp, df) + ns(Time, df)$

$+ ns(AP, df) + ns(WS, df) + ns(RH, df)$

$+ Holiday_{i} + Dow_{i}$

where $Y_{i}$ is the daily observed count of emergency visits to CVDs for day $t (i = 1, 2, 3 ... 21)$, $\alpha$ is the intercept, $X_{i,t}$ is the cross-basis matrix of temperature indicators in DLNM (AT and DTR were compared in two dependent models), $l$ is lag
days, $\beta$ is the vector of the coefficients for temperature variations, $AP$ is atmospheric pressure, $WS$ is wind speed, $RH$ is relative humidity (meteorological factors were applied in the model using a natural cubic spline to control their potential implications), $ns$ is natural cubic spline, and $df$ is degrees of freedom, while the dummy variables $Dow$ (day of the week) and $Holiday$ are a category variable where 1 indicates that day $t$ is a public holiday while 0 is not.

Previous studies proved that long-term tendency, atmospheric pressure, relative humidity, and wind speed were potential confounders having an impact on CVD hospital admission visits (Zhao et al. 2018; Wang et al. 2020a, b; Goggins and Chan 2017). Natural cubic splines were applied in DLNM to estimate the independent impact of temperature variations on hospital admission admissions for CVD (three equally spaced knots were placed per year for the continuous dependent variables). A 3-df natural cubic spline was used to control the effects of humidity, wind speed, and atmospheric pressure (Guo and Han 2011; Song et al. 2017), 4-df to eliminate the impacts of mean temperature (Huang et al. 2014; Zhao et al. 2018), and 7-df to remove long-time tendency (Huang et al. 2014; Lim et al. 2012b). Some studies have demonstrated that air pollutants are also associated with CVD (Hoek et al. 2013). However, in rural regions, the impact of air pollution does not appear to be significant (Ding et al. 2015; Liang et al. 2008) as concentrations of air pollutants are very low (Ebi et al. 2004). Furthermore, air pollutant sensitivity analysis was performed (see Fig S1), and no differences were observed. Air pollution was not included in the model in order to avoid overfitting. The degrees of freedom for DTR and lag in the cross-basis matrix were chosen according to a modified quasi Akaike’s Information Criterion (QAIC) (Table S1): 4-df for AT and 3-df for lag in AT cross-basis.

![Fig. 1 Geographical location of Qingyang, China](image-url)
matrix and 6-df for DTR and 3-df for lag in DTR cross-basis matrix.

All data were stratified according to sex (male and female) and age (adult and old) for subgroup analyses. The threshold for age was set at 65 years—China’s retirement age. The median value of the temperature indicators was used as the reference to calculate relative risk (RR) with a 95% confidence interval. Cumulative lag effect of the thermal indicators was assessed with a 30-day lag (Guo et al. 2016; Gasparrini et al. 2015). Various lag periods (0, 3, 7, 14, and 30 days) were examined to determine the impact of temperature indicators on CVD visits. The impact of lag denotes the effect of DTR on CVD incidence after x days. Previous studies suggest that there is a cumulative lag effect of DTR on CVD admissions (Song et al. 2017; Ye et al. 2012). Most studies used a lag of 21 or 28 d (Guo et al. 2016; Gasparrini et al. 2015; Davis et al. 2020). However, the current study assessed a lag of 0 to 30 days to evaluate the cumulative effect of a month-long lag. Moreover, to assess the robustness of the model, several df of the meteorological variables were evaluated in a sensitivity analysis, including temperature (df = 3–5), relative humidity (df = 4–6), atmospheric pressure (df = 4–6), and wind speed (df = 3–5), (see Fig S2-S5). All statistical analyses and chart preparation were performed using the “dlnm” package in the R statistical software (Version 3.4.1).

Results

Descriptive statistics for CVD cases and meteorological variables are presented in Table 1. A total of 32,567 cases of CVD were included in the study from 2014 to 2017, of which approximately 54% were males and 46% were females. Adult patients accounted for 43% of these cases, and old patients accounted for 57%. The mean apparent temperature was 8.13 °C (with a large standard deviation of 12.08 °C) ranging from –19.75 to 32.41 °C, being slightly lower than the mean temperature (10.15 °C). The average DTR was 12.82 °C (with a moderate standard deviation of 5.46 °C).

Figure 2 shows the 30-day cumulative RR (95% CI) of CVD hospital admission in all subgroups. Overall, the impact of DTR on CVD was greater than of AT for total CVD hospital admission cases (95% CI, RR: AT 1.595 DTR 2.243). Both DTR and AT were associated with CVD hospital admission with M-shaped curve. Table 2 depicts the RR (95% CI) of CVD hospital admission with low and high AT and DTR referenced at 12 °C at different lags in all subgroups. As for total, the first peak was evident at AT of −4 °C or DTR of 6 °C (95% CI, RR: AT 1.083, DTR 2.243) and the second at AT of 20 °C or DTR of 19 °C (95% CI, RR: AT 1.596, DTR 1.875). As for gender subgroup, DTR posed more of a risk of CVD incidence to male than to female when DTR was at 19 °C on high DTR side (95% CI, RR: male 2.061, female 1.662), while this was reversed when DTR was 6 °C on low DTR side (95% CI, RR: male 2.167, female 2.491). Females suffered more risk than men when AT was 20 °C on high AT side (95% CI, RR: male 1.125, female 2.220), while the opposite held when AT was −4 °C on low AT side (95% CI, RR: male 1.348, female 0.859). In the age-specific study, the first maximum RR of CVD occurred at the lowest DTR (95% CI, RR: adult 2.327, old 2.368) and then increased to its second maximum when DTR was 19 °C (95% CI, RR: adult 2.527, old 2.752). The impact of AT on RR of CVD was most significant at 0 °C (95% CI, RR: adult 1.508, old 1.497), and there was no significant difference between the age groups.

The single lag effect of the AT and DTR on RR of CVD was examined by contour map (Fig. 3, reference 12 °C).

Table 1 Summary statistics for daily variables and cardiovascular diseases (CVD) cases in Qingyang, China, 2014–2017

| Variable                        | Number of measurements | Mean ± SD     | Frequency distribution |
|--------------------------------|------------------------|--------------|-----------------------|
|                                |                        | Min | P25 | P50 | P75 | Max |
| Number of daily hospitalizations for CVD |                        |     |     |     |     |     |
| Total                          | 32,567                 | 20.0 ± 5.08 | 0  | 9  | 18 | 29 | 211 |
| Male                           | 17,586                 | 11.0 ± 9.27 | 0  | 4  | 8  | 16 | 97  |
| Female                         | 14,981                 | 9.0 ± 6.87  | 0  | 4  | 8  | 13 | 114 |
| Adult (age < 65 years)         | 14,004                 | 8.0 ± 9.58  | 0  | 7  | 13 | 20 | 59  |
| Old (age ≥ 65 years)           | 18,563                 | 12.0 ± 7.32 | 0  | 7  | 12 | 17 | 65  |
| Meteorological data            |                        |     |     |     |     |     |
| Mean temperature (°C)          | 1460                   | 10.15 ± 10.14 | −14.7 | 1 | 11.3 | 19.2 | 30.6 |
| Relative humidity (%)          | 1460                   | 65.33 ± 16.99 | 14 | 53 | 66 | 79 | 100 |
| Atmospheric pressure (hpa)     | 1460                   | 892.87 ± 6.27 | 877.6 | 887.8 | 892.7 | 897.6 | 916.3 |
| Wind speed(m/s)                | 1460                   | 1.84 ± 0.72  | 0.3 | 1.4 | 1.7 | 2.2 | 5.9  |
| AT(°C)                         | 1460                   | 8.13 ± 12.08 | 19.75 | −2.89 | 8.95 | 18.99 | 32.41 |
| DTR(°C)                        | 1460                   | 12.82 ± 5.46 | 1  | 8.7 | 12.9 | 16.9 | 29.6 |
Fig. 2. The 30-day cumulative RR (95% CI) of CVD hospital admission in all subgroups (reference 12 °C)
Overall, the AT models demonstrated a 2% increase in RR when AT rose from 16 to 24 °C on high AT side, but this disappeared after about 2 weeks. A weaker and shorter cold effect was observed from −10 to 0 °C on low AT side. The heat effect also lasted longer than cold effect. However, the RR of CVD hospital admission decreased gradually by 1~5% across the lag days when DTR was 6 °C, while a 3% increment was sustained for a month when DTR was 19 °C. There was also a protective effect at high DTR ≥ 25 °C. Overall, DTR exerted a stronger and longer single lag impact on RR of CVD incidence in all people compared with AT (95% CI, RR: AT 1.020 lasting for 15 days; DTR 1.05 lasting for 22 days).

The AT single lag effect was more significant and longer with female (95% CI RR: 1.03) than with male (95% CI RR: 1.01) at AT above 20 °C, but there was no effect at colder temperatures. The adverse effects of DTR for male were greater and longer than for female at both low and high DTR (95% CI male: RR 1.04 for 1 month, female: RR 1.04 for half a month). Overall, the effect of AT on male was gradually attenuated and disappeared after 5 days, while the effect of DTR was longer and stronger. However, the lag effect of AT was more obvious on female. Male suffered a longer and stronger RR of CVD when exposed to high DTR than did female, while female experienced a longer lag effect at high AT than male.

A comparison of adult vs. old CVD incidence showed that DTR exerted a stronger single lag effect on CVD for both adults and old people (95% CI RR: AT 1.04, DTR 1.075). Both age groups exhibited the same pattern of impact of DTR on CVD (95% CI RR: adult 1.075, old 1.075).

However, adults experienced a greater risk in days of low AT of 0 °C compared with the elderly (95% CI RR: adult 1.04, old 1.02). The protective impact of temperature occurred at the extremes: below −10 °C and above 30 °C for AT but only at high DTR.

### Discussion

To our knowledge, this study is the first to compare and analyze the effects of DTR and AT on the onset of CVD in rural areas. Both AT and DTR had significant nonlinear, delayed effects on CVD morbidity. Whether cumulative or single lag, the effect of DTR on CVD incidence was greater and more persistent than AT in total group. Females were more affected by AT above 20 °C than males, but this was reversed at AT below 0 °C. However, males appeared to be more vulnerable to high DTR (19 °C) than females, while this was reversed at low DTR (6 °C). There was no difference in cumulative lag impact on age subgroups in both the DTR and AT models, but the single lag impact of low AT on adult was greater than on the elderly.

Previous studies have reported that both DTR and AT had significant impacts on cardiovascular morbidity (Krstić 2011; Almeida et al. 2010; Lim et al. 2012a; Kim et al. 2016), which was consistent with our study. The possible reasons are, first, DTR affects cardiovascular mortality through alterations in autonomic nervous functions. A large DTR can induce disturbances of the autonomic nervous system, resulting in elevated heart rate and decreased heart rate variability, which indicate impacts on the sympathetic and parasympathetic nervous systems.

### Table 2 The RR (95% CI) of CVD with low and high AT and DTR referenced at 12 °C at different lags in all subgroups

|                       | Total     | Male        | Female      | Adult      | Old        |
|-----------------------|-----------|-------------|-------------|------------|------------|
| AT (−4 °C, 20 °C)     |           |             |             |            |            |
| Lag 0–30              | (1.083, 1.595*) | (1.348, 1.125) | (0.859, 2.220*) | (1.297, 0.914) | (1.187, 0.760) |
| Lag 0                 | (1.013, 1.018)  | (1.026, 1.011)  | (1.000, 1.026)  | (0.980, 1.004)  | (0.994, 1.005)  |
| Lag 3                 | (1.011, 1.017)  | (1.023, 1.009)  | (0.999, 1.026*) | (0.986, 1.003)  | (0.996, 1.002)  |
| Lag 7                 | (1.008, 1.017)  | (1.019, 1.007)  | (0.998, 1.026*) | (0.993, 1.001)  | (0.999, 0.998)  |
| Lag 14                | (1.003, 1.015*) | (1.011, 1.004)  | (0.995, 1.026*) | (1.007, 0.998)  | (1.005, 0.992)  |
| Lag 21                | (0.998, 1.014)  | (1.003, 1.001)  | (0.993, 1.026*) | (1.020, 0.994)  | (1.010, 0.986)  |
| Lag 30                | (0.992, 1.012)  | (0.993, 0.997)  | (0.990, 1.027)  | (1.038, 0.990)  | (1.017, 0.978)  |
| DTR (6 °C, 19 °C)     |           |             |             |            |            |
| Lag 0–30              | (2.243*, 1.875*) | (2.167*, 2.061*) | (2.217*, 1.662*) | (1.986, 2.527*) | (1.832, 2.752*) |
| Lag 0                 | (1.039*, 1.021)  | (1.035*, 1.020)  | (1.042*, 1.020)  | (1.009, 0.999)  | (1.004, 1.001)  |
| Lag 3                 | (1.036*, 1.021*) | (1.033*, 1.021)  | (1.039*, 1.019)  | (1.012, 1.005)  | (1.008, 1.008)  |
| Lag 7                 | (1.033*, 1.021*) | (1.031*, 1.022*) | (1.035*, 1.019*) | (1.016, 1.014)  | (1.012, 1.017)  |
| Lag 14                | (1.028*, 1.021*) | (1.026*, 1.024*) | (1.027*, 1.017*) | (1.023*, 1.030*) | (1.020*, 1.033*) |
| Lag 21                | (1.022*, 1.021*) | (1.022*, 1.026*) | (1.020*, 1.016*) | (1.029*, 1.046*) | (1.028*, 1.050*) |
| Lag 30                | (1.015, 1.022*)  | (1.017, 1.029*)  | (1.011, 1.014)  | (1.038*, 1.068*) | (1.038*, 1.071*) |

*P < 0.05 The RR of CVD for AT at −4 °C and 20 °C compared with reference (12 °C) and for DTR at 6 °C and 19 °C compared with reference (12 °C)
parasympathetic nerves and on sinoatrial node frequency (i.e., regulation of neurohumoral factors of the cardiovascular system) (Lim et al. 2012a). Furthermore, heart rate, cardiac workload, and blood pressure changes triggered by wider temperature changes have been shown to contribute to the onset of CVD (Zheng et al. 2020; Wang et al. 2020a, b). Second, AT-related impacts on CVD can be explained by that body’s circulatory system responding to high or low temperatures by releasing platelets into circulation and the increasing red and white cell counts, blood viscosity, and plasma cholesterol resulting from water loss and reduced plasma volume under hot conditions (Yang et al. 2015). Another result in our study was that the relationship between the AT or DTR and risk of CVD was nonlinear with M-shaped curves. However, this was inconsistent with many prior studies that reported relationships between AT and RR of CVD having reverse J-shaped curves (Moghadamnia et al. 2018; Wichmann et al. 2011; Liu et al. 2011). This was also the case for DTR. Lim demonstrated a positive linear relation between DTR and Emergency Room admissions in Korea (Lim et al. 2012b). J-, V-, and U-shaped correlations between DTR and CVD have been demonstrated in the USA (Ebi et al. 2004), China (Kan et al. 2007; Zhou et al. 2014), and Korea (Lim et al. 2012a). These differences may be due to geographical effects, climatic characteristics, differences in use of cooling and heating equipment, and housing types (Zhou et al. 2014).

Notably, our findings revealed that DTR was associated with a greater risk of CVD than AT in total (95% CI, cumulative RR: DTR 2.37, AT 1.62). To date, few studies have compared the extent of the effects of AT and DTR. Increases of 33% and 3% in cumulative DTR-related risk of CVD were associated with 8.2 °C and 1 °C ranges in Southwest China (Ye et al. 2012) and Korea (Lim et al. 2012b), respectively. The risk of CVD mortality increased by 7% and 14% with 7 °C and 8 °C increases in AT in Iran (Moghadamnia et al. 2018) and Copenhagen (Wichmann et al. 2011), respectively. A study conducted in Virginia, USA, showed that DTR was associated with a higher incidence of Emergency Department visits than were AT and mean temperature (Huang et al. 2014). These studies support our finding that the RR of CVD was stronger and longer under the influence of DTR than AT, which can be attributed to their differing pathogenesis. The direct effects of DTR on the autonomic nervous system and the indirect effects of AT on the circulatory system explain that the impact of DTR was greater than AT on CVD. However, Danet et al. demonstrated that a 1.3% increase in fatal coronary events was associated with a 1 °C decrease in DTR in the USA (Danet et al. 1999), while a 1 °C increase in mean AT was associated with a 2.4% increase in cardiovascular events in Portugal (Almeida et al. 2010). These studies suggest that AT is associated with a higher risk of CVD than DTR, which is not consistent with our finding. Possible reasons for this inconsistency are differences in population demographics, exposure conditions, climatic characteristics, and climate-related behaviors (Wichmann et al. 2011; Song et al. 2017; Ding et al. 2016). To be more specific, first, our study area, Qingyang located in the Loess Plateau, has a continental climate which creates a large DTR but a relatively moderate AT. People in Qingyang suffer a greater risk of CVD due to DTR rather than AT because they are exposed to large temperature differences rather than extreme temperatures. Furthermore, farmers, especially those most susceptible to cardiovascular disease, tend to be more vulnerable to DTR because of their lack of awareness of how to protect against extreme DTR. Moreover, the weather forecast broadcasts temperature rather than DTR. People suffer more adverse effects from DTR than AT because it can be hard to respond quickly to sudden temperature changes, while people can deal with high and low temperatures by adding or removing clothing in advance, using air conditioning, and so on. It is proposed that relevant departments should broadcast DTR forecasts for the benefit of CVD-susceptible populations.

Another interesting finding was that females were susceptible to a high AT above 20 °C than males, whereas, when AT was below 10 °C, males were at higher risk. Previous studies are consistent our finding, confirming that females have a higher risk of CVD in hot conditions, while males are at greater risk in cold conditions (Moghadamnia et al. 2018; Huang et al. 2014; Zhao et al. 2018). This may be due to female being more susceptible to arrhythmia, ischemia, and high blood pressure, all of which are exacerbated by extreme hot temperatures (Douglas et al. 1995). Converse with our findings, cold conditions increased CVD risk in female in China (Wang et al. 2020a, b). This can be explained that females wear thinner clothes compared with males and are more sensitive to cold temperatures (Guo and Han 2011). Meta-analysis performed by Moghadamnia confirmed their finding of no difference in the impact of hot and cold temperatures on CVD in the two genders (Wang et al. 2020a, b; Ding et al. 2016). Effect modification by gender varied among different regions and population (Basu et al. 2005). This explains why these research conclusions are different from ours. To be specific, farmers, whether male or female, have increased exposure to high AT during the harvest and sowing seasons in mid-April and mid-September (Ding 2016; Zhan 2018; Jiang 2015) when temperatures range from 20 to 25 °C (see Fig S6). Both males and females work during these periods, but females bear the greater risk of CVD due to physical weakness (Hong et al. 2003). Thus, females should pay more attention than men to protective measures when AT > 20 °C.

Epidemiological studies have proven that CVD mortality in females was more strongly associated with high DTR than in males in China (Zhou et al. 2014; Huang et al. 2014),
To our knowledge, this is the first study to compare and analyze the impact of DTR and AT on CVD in a rural and less-developed area of Northwest China. The effect of DTR was larger and more persistent than AT in general. Females were more sensitive (and for longer periods) to high AT and low DTR compared with men, while males were more susceptible to low AT and high DTR. Adult experience more risk of CVD under the low AT compared with old. However, there was no significant difference in the effects of DTR on CVD in different age groups. Since temperature-associated adverse effects are potentially modifiable via preventive measures and lifestyle changes, these findings may have important implications for the prevention of cardiovascular disease in less-developed rural areas.

**Conclusion**

To the best of our knowledge, this is the first study to compare the effects of DTR and AT on the hospital admission of CVD in a rural and less-developed area of Northwest China. The effect of DTR was larger and more persistent than AT in general. Females were more sensitive (and for longer periods) to high AT and low DTR compared with men, while males were more susceptible to low AT and high DTR. Adult experience more risk of CVD under the low AT compared with old. However, there was no significant difference in the effects of DTR on CVD in different age groups. Since temperature-associated adverse effects are potentially modifiable via preventive measures and lifestyle changes, these findings may have important implications for the prevention of cardiovascular disease in less-developed rural areas.

**Abbreviations** DTR: Diurnal temperature range; AT: Apparent temperature; CVD: Cardiovascular diseases; NRCMS: New Rural Cooperative Medical System; DLNM: Distributed lag nonlinear model; RR: Relative risk of CVD

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s11356-021-17785-9.

**Author contribution** Zhai: Conceptualization, methodology, and software. Qi: Data curation and writing—original draft preparation. Zhang: Visualization and investigation. Zhou: Supervision. Wang: Software and validation.

**Funding** This was supported by the China Postdoctoral Science Foundation (No. 2016M600827), the National Natural Science Foundation of China (No. 71861026), Gansu Science and Technology Program “Knowledge-Driven Meteorological Environment for Public Health Economic Loss Evaluation” (No. 16JZD023), and the Gansu Natural Science Foundation Project “Evaluation and Spatial Differentiation of Green Competitiveness in Gansu Province from the Perspective of Ecological Civilization” (No. 20JR5RA474).

**Availability of data and material** The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Declarations**

Ethics approval and consent to participate The present study is considered exempt from institutional review board approval since the data used was collected for administrative purpose without any personal identities.

Consent for publication All consent.

Competing interests The authors declare no competing interests.
References

Almeida SP, Casimiro E, Calheiros J (2010) Effects of apparent temperature on daily mortality in Lisbon and Oporto. Portugal Health Environ 9:12
Basu R, Dominici F, Samet JM (2005) Temperature and mortality among the elderly in the United States: a comparison of epidemiologic methods. Epidemiology 16:58–66
Danet S, Richard F, Montaye M, Beauchant S, Lemaire B, Graux C, Cottel D, Marécaux N, Amouyel P (1999) Unhealthy effects of atmospheric temperature and pressure on the occurrence of myocardial infarction and coronary deaths. A 10-year survey: the Lille-World Health Organization MONICA Project. Circulation 100:1–7
Davis RE, Markle ES, Windoloski S, Houcka ME, Enfield KB, Kang H, Balling RC, Kuehl DR, Burton JH, Farthing W, Rubio ER, Novicoff WM (2020) A comparison of the effect of weather and climate on emergency department visitation in Roanoke and Charlottesville. Virginia. Environ Res 191:110065
Ding DY (2016) Evaluation and optimization of winter wheat cultivation measures in Loess Plateau based on RZWQM2 simulation. Dissertation, Northwestern University
Ding Z, Guo P, Xie F, Chu HF, Li K, Pu JB, Pang SJ, Dong HG, Liu YH, Pi FH, Zhang QY (2015) Impact of diurnal temperature range on mortality in a high plateau area in southwest China: a time series analysis. Sci Total Environ 526:358–365
Ding Z, Li LJ, Xin LY, Pi FH, Dong WY, Wen Y, William WA, Zhang QY (2016) High diurnal temperature range and mortality effect modification by individual characteristics and mortality causes in a case-only analysis. Sci Total Environ 544:627–634
Douglas AS, Dunnigan MG, Allan TM, Rawles J (1995) Seasonal variation in coronary heart disease in Scotland. J Epidemiol Community Health 49:575–582
Ebi KL, Eruzvides KA, Lai E, Kelsh M, Barnaton A (2004) Weather changes associated with hospitalizations for cardiovascular diseases and stroke in California, 1983–1998. Int J Biometeorol 49:48–58
Gasparrini A (2014) Modeling exposure–lag–response associations with distributed lag nonlinear models. Stat Med 33:881–899
Gasparrini A, Guo YM, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, Tobias A, Tong SL, Rocklöv J, Forsberg B, Leonne M, Sario MD, Bell ML, Guo YLL, Wu CF, Kan HD, Yi SM, Michelinede SZ, Armstrong B (2015) Mortality risk attributable to high and low ambient temperature: a multi-country observational study. Lancet 386:369–375
Ghiasmand M, Moghadamnia MT, Pourshakibian M, Lili EK (2017) Acute triggers of myocardial infarction: a case-crossover study. Egypt Heart J 69:223–228
Goggins WB, Chan EYY (2017) A study of the short-term associations between hospital admissions and mortality from heart failure and meteorological variables in Hong Kong Weather and heart failure in Hong Kong. Int J Cardiol 228:537–542
Guo TJ, Han JM (2011) Discussion on the transfer of rural surplus labor force in Qingyang city. Gansu Agr Sci Tech 1:54–55
Guo YM, Barnett AG, Pan XC, Yu WW, Tong SL (2011) The impact of temperature on mortality in Tianjin, China: a case-crossover design with a distributed lag nonlinear model. Environ Health Perspect 119:1671-a525
Guo YM, Gasparrini A, Armstrong BG, Tawatsupa B, Tobias A, Lavigne E, Pan XC, Kim H, Hashizume M, Honda Y, Guo YL, Wu CF, Zanobetti A, Schwartz JD, Bell ML, Overcenco A, Punnasiri K, Li SS, Tian LW, Saldiva P, Williams G, Tong SL (2016) Temperature variability and mortality: a multi-country study. Environ Health Perspect 124:1554–1559
Hoek G, Krishnan RM, Beelen R, Peters A, Ostro B, Brunekreef B, Kaufman JD (2013) Long-term air pollution exposure and cardio-respiratory mortality: a review. Environ Health 12:43
Hong YC, Rha JH, Lee JT, Ha EH, Kwon HJ, Kim H (2003) Ischemic stroke associated with decrease in temperature. Epidemiology 14:473–478
Hu CX (2014) Study on the problem of migrant workers returning to their hometowns and returning to their hometowns under the vision of new countryside. Theory Research 19:85–87
Huang JX, Wang JF, Yu WW (2014) The lag effects and vulnerabilities of temperature effects on cardiovascular disease mortality in a subtropical climate zone in China. Int J Environ Res Public Health 11:3982–3994
Jiang YW (2015) Applicability evaluation of DSSAT model in Heihe River Basin and application research of water-saving irrigation. Dissertation, Lanzhou University
Kan HD, London SJ, Chen HL, Song GX, Chen GH, Jiang LL, Zhao NQ, Zhang YH, Chen BH (2007) Diurnal temperature range and daily mortality in Shanghai, China. Environ Res 103:424–431
Keatinge WR, Donaldson GC, Bucher K (1997) Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe. Lancet 349:1341–1346
Kim J, Shin J, Lim YH, Honda Y, Hashizume M, Guo YL, Kan HD, Yi S, Kim H (2016) Comprehensive approach to understand the association between diurnal temperature range and mortality in East Asia. Sci Total Environ 539:313–321
Krstić G (2011) Apparent temperature and air pollution vs. elderly population mortality in Metro Vancouver. Plos One 6:e25101
Lee W, Bell ML, Gasparrini A, Armstrong BG, Sera F, Huang S, Lavigne E, Zanobetti A, Micheline SZ, Hilario P, Saldiva N, Osorio S, Tobias A, Zeka A, Forsberg B, Rocklöv J, Hashizume M, Honda Y, Kim H (2018) Mortality burden of diurnal temperature range and its temporal changes: a multi-country study. Environ Int 110:123–130
Liang WM, Liu WP, Chou SY, Kuo HW (2008) Ambient temperature and emergency room admissions for acute coronary syndrome in Taiwan. Int J Biometeorol 52:223–229
Lim YH, Park AK, Kim H (2012a) Modifiers of diurnal temperature range and mortality association in six Korean cities. Int J Biometeorol 56:33–42
Lim YH, Hong YC, Kim H (2012b) Effects of diurnal temperature range on cardiovascular and respiratory hospital admissions in Korea. Sci Total Environ 417:55–60
Lin S, Luo M, Walker RJ, Liu X, Huang SA, Chinery R (2009) The impacts of temperature effects on cardiovascular disease mortality, respiratory disease, and all causes in warm and cold regions of Europe. Environ Health Perspect 117:387–391
Liu JH, Li GY, Mo YZ (2011) Relationship between ambient apparent temperature and cause-specific mortality measures in Loess Plateau based on RZWQM2 simulation. Dissertation, Northwest University
Mutekwa T (2009) Climate change impacts and adaptation in the agricultural sector: the case of smallholder farmers in Zimbabwe. J Sustain Dev Afr 11:237–256
Patricio LJ, Silva SY, Narella RS, Alvaro D, Walter M, Victor C (2008) Are nutrition-induced epigenetic changes the link between socioeconomic pathology and cardiovascular diseases? Am J Ther 15:362–372

Rumsey M, Fletcher SM, Thiessen J, Gero A, Kuruppu N, Daly J, Buchan J, Willetts J (2014) A qualitative examination of the health workforce needs during climate change disaster response in Pacific Island countries. Hum Resour Health 12:9

Song XP, Wang SG, Li TS, Tian JH, Ding GW, Wang JX, Wang JX, Shang KZ (2017) The impact of heat waves and cold spells on respiratory emergency department visits in Beijing, China. Sci Total Environ 615:1499–1505

Vos T, Lim SS, Abbas KM, Abbasifard M (2020) Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet 396:1204–1222

Wang ZQ (2011) Investigation on education and training and employment stats of migrant workers in Qingyang City. SME Manage Tech 3:60

Wang B, Chai GR, Sha YZ, Zha QW, Su YN, Gao YY (2020a) Impact of ambient temperature on cardiovascular disease hospital admissions in farmers in China’s Western suburbs. Sci Total Environ 761:263–254

Wang QQ, Zhao Q, Wang GQ, Wang BX, Zhang YJ, Zhang JX, Li N, Zhao Y, Qiao H, Li WP, Liu XY, Liu L, Wang FX, Zhang YH, Guo YM (2020b) The association between ambient temperature and clinical visits for inflammation-related diseases in rural areas in China. Environ Pollut 261:261

Wichmann J, Andersen ZI, Ketzel M, Ellermann T, Loft S (2011) Apparent temperature and cause-specific mortality in Copenhagen, Denmark: a case-crossover analysis. Int J Environ Res Public Health 8:3712–3727

Wilson LA, Morgan GG, Hanigan IC, Johnston FH, Hisham AR, Broome R, Gaskin C, Jalaludin B (2013) The impact of heat on mortality and morbidity in the greater metropolitan Sydney region: a case crossover analysis. Environ Health 12:98

World Health Organization (2018) Climate change and health country profile 2017: Kiribati. WHO 15:51

Yang J, Yin P, Zhou M, Ou CQ, Guo YM, Gasparrini A, Liu YN, Yue YJ, Gu SH, Sang SW, Luan GJ, Sun QH, Liu QY (2015) Cardiovascular mortality risk attributable to ambient temperature in China. Heart 101:1966–1972

Ye XF, Wolf J, Yu WW, Vaneckova P, Pan XC, Tong SL (2012) Ambient temperature and morbidity: a review of epidemiological evidence. Environ Health Perspect 120:19–28

Yu WW, Guo YM, Ye XF, Wang XY, Huang CR, Pan XC, Tong SL (2011) The effect of various temperature indicators on different mortality categories in a subtropical city of Brisbane, Australia. Sci Total Environ 409(18):3431–3437

Zhan T (2018) Response and simulation of spring maize productivity to meteorological factors in semiarid area of Northwest China. Dissertation Gansu agricultural University

Zhao Q, Zhao Y, Li SS, Zhang YJ, Wang QQ, Zhang HL, Qiao H, Li WP, Huxley R, Williams G, Zhang YH, Guo YM (2018) Impact of ambient temperature on clinical visits for cardio-respiratory diseases in rural villages in Northwest China. Sci Total Environ 612:379–385

Zheng S, Zhu WZ, Wang MZ, Shi Q, Luo Y, Miao Q, Nie YH, Kang F, Mi XY, Bai YN (2020) The effect of diurnal temperature range on blood pressure among 46,609 people in Northwestern China. Sci Total Environ 730:138987

Zhou XD, Zhao A, Meng X, Chen RJ, Kuang XY, Duan XL, Kan HD (2014) Acute effects of diurnal temperature range on mortality in 8 Chinese cities. Sci Total Environ 493:92–97

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