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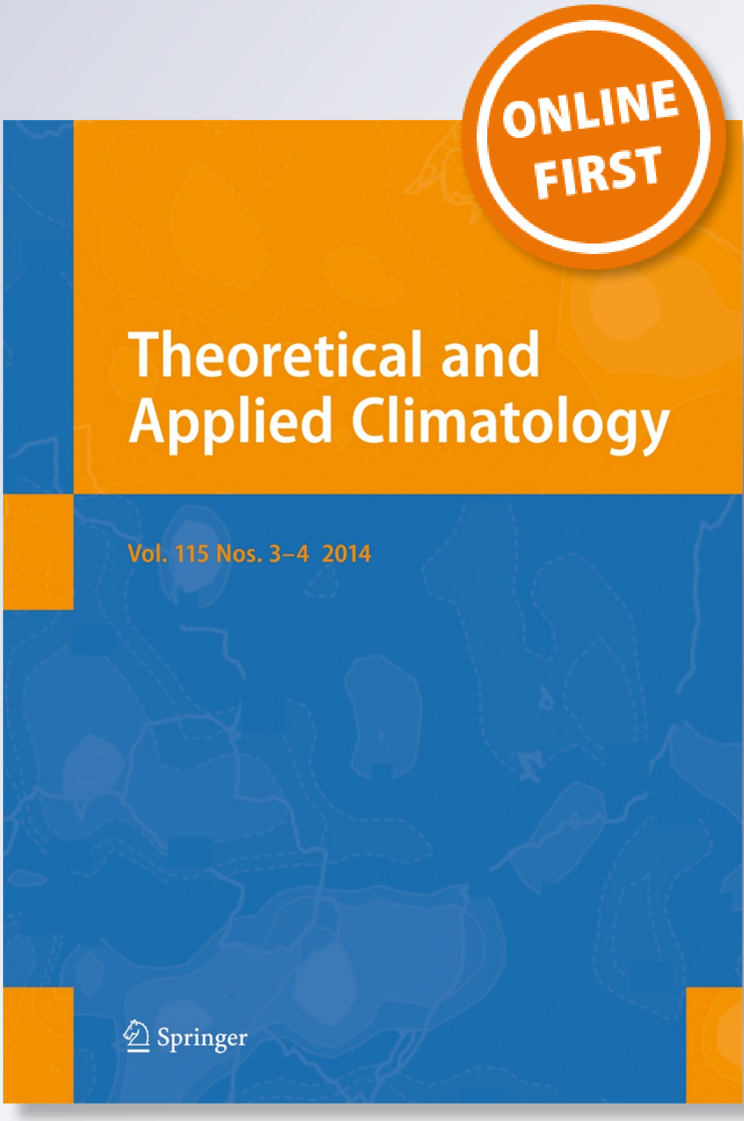

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ORIGINAL PAPER

Urbanization effect on long-term trends of extreme temperature indices at Shijiazhuang station, North China

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Abstract Based on daily temperature data from an urban station and four rural stations of Shijiazhuang area in Hebei Province, North China, we analyzed the trends of extreme temperature indices series of the urban station (Shijiazhuang station) and rural stations during 1962–2011 and the urbanization effect on the extreme temperature indices of the urban station. The results showed that the trends of annual extreme temperature indices of the urban station and the rural stations are significantly different in the recent 50 years. Urbanization effect on the long-term trends of hot days, cold days, frost days, diurnal temperature range (DTR), extreme maximum temperature, and extreme minimum temperature at the urban station were all statistically significant, reaching 1.10 days/10 years, −2.30 days/10 years, −2.55 days/10 years, −0.20 °C/10 years, 0.16 °C/10 years, and 0.70 °C/10 years, respectively, with the urbanization contributions to the overall trends reaching 100, 38.0, 42.2, 40.0, 94.1, and 47.0 %, respectively. The urbanization effect on trend of ice days was also significant, reaching −0.47 days/10 years. However, no significant urbanization effect on trends of minimum values of maximum temperature and maximum values of minimum temperature had been detected. The urbanization effects in the DTR and extreme minimum temperature series of Shijiazhuang station in wintertime were highly significant.

1 Introduction

Extreme weather and climate phenomena are the small probability events, but they can have major impacts on the human and natural systems, arousing much attention from the governments and academic community. Many researchers examined the long-term change in extreme temperature events (e.g., Karl et al. 1991; Plumner 1996; Easterling et al. 1997; Zhai and Pan 2003; Alexander et al. 2006; Zhou and Ren 2011). They found that the annual mean minimum temperature (Tmin) of global continents and mainland China experienced significant rising trends for the past decades. The annual mean maximum temperature (Tmax) also witnessed rising trends, but they were less significant than the annual mean Tmin. In addition, they also found that the frequency and intensity of extreme cold events generally decreased, but those of extreme warm events mostly increased.

Studies also showed that changing trends of annual mean surface air temperature (SAT) observed by the meteorological stations were clearly influenced by the urban warming in many land areas of eastern Asia including mainland China (Kalnay and Cai 2003; Choi et al. 2003; Chung et al. 2004; Chu and Ren 2005; Ren et al. 2007, 2008; Fujibe 2008; Yang et al. 2011). For example, urbanization effect accounted for more than 38 % of the overall annual mean SAT increase for the national stations in North China during the time period 1960–2000 (Ren et al. 2008). A recent work revealed that urbanization effect on annual mean SAT trends observed by the national reference climatic stations and the national basic meteorological stations in mainland China was also significant, explaining at least 27 % of the overall warming trend (Zhang et al. 2010). Apparently, the urbanization effect on the changing trends of the local and regional annual mean SAT cannot be ignored.

It is natural to assume that the urbanization or the enhanced urban heat island (UHI) effect will also affect the linear trends of frequency and intensity of extreme temperature events due to the close linkage between the mean SAT and the Tmax and Tmin. There is little systematic investigation addressing this issue, however, and the relevant literatures are also scant. Recently, Zhou and Ren (2009) analyzed the urbanization

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effect on the changing trends of the mean maximum and minimum temperature for different categories of metrological stations in North China during 1961–2000, and they found significant increasing trends of annual mean Tmin caused by the urbanization for most of the national stations, with the region-averaged urbanization effect for the national stations reaching 0.20 °C/10 years, which accounted for 52.6 % of the overall warming. Zhang et al. (2011) analyzed the urbanization effect on annual and seasonal mean trends of the extreme temperature indices at Beijing Meteorological Station during 1960–2008 and found that urbanization effects on the trends of the indices series related to daily Tmin were all significant, and the contributions of the urbanization effect to the overall changing trends of the Tmin-based annual mean extreme indices series were all as high as 100 %, indicating that the changes caused by the urbanization effect were overwhelming. However, the urbanization effects on the trends of the indices series related to daily Tmax were mostly insignificant at the urban station.

The urban station of Shijiazhuang was originally located in the western suburbs of the city. The observational environment was good and representative for the monitoring of regional climate before the 1980s. The area around the station was desolate, with only a few small villages and barracks of the garrison army being dotted in the vast plain. Since the early 1990s, however, buildings near the station have been increasing gradually as the urbanization process accelerates. At present, the observational ground is well-surrounded by high-rising buildings, and it has now become a typical urban station. The UHI effect near Shijiazhuang station is remarkable, and the urban warming trend in terms of annual mean SAT was estimated to be 0.19 °C/10 years during 1962–2009, accounting for 67.9 % of the overall warming trend (Bian 2010). The urbanization effect on the Tmin trend is more significant, because the largest UHI intensity is registered between 20 and 07 h of nest day Beijing Time.

However, it is unclear if, or in what extent, the rapid urbanization and the increasing UHI intensity around the station have affected the linear trends of the extreme temperature indices. Solving this question or answering this question enables us to better understand the respective trends of the regional and near-station extreme temperature event frequencies and to further explore the mechanism and causes of the regional climate change. We can also provide the accurate observation data for evaluating the climate change impacts on natural ecosystem, water resources, and agricultural production in the area.

Based on daily SAT data from Shijiazhuang station and four nearby rural stations during the past 50 years, we compare the changing trends of the extreme temperature indices of the urban and rural stations and evaluate the urbanization effect on the trends of extreme temperature indices for the urban station. We show that the extreme temperature events recorded by the urban and rural stations experience obviously different trends, indicating a significant urbanization effect at the Shijiazhuang station.

2 Data and methods

The daily maximum, minimum, and average temperature records of five meteorological stations during 1962–2011 were used. They were respectively Shijiazhuang, Gaocheng, Yuanshi, Pingshan, and Xinle stations in Shijiazhuang area (Fig. 1). The data had been quality controlled by the Shijiazhuang Meteorological Bureau, and the wrong records caused by manual factors had been corrected. Seasonal division was as follows: spring (3–5 months), summer (6–8 months), autumn (9–11 months), and winter (12 to 2 months of the next year).

Shijiazhuang, the capital city of Hebei Province, is located in the east of the Taihang Mountains and in the west of the North China Plain. It is a large city with a rapid urbanization process during the past 60 years and a permanent population of 2.7 million at present. Shijiazhuang station is located in the mid-west of the city, and it is a typical urban station by any means. It is not only within the built-up areas of the city but also heavily surrounded by the nearby buildings, as seen in Fig. 1. The four rural stations are all located near the four small towns in the east, south, northwest, and northeast of Shijiazhuang station, with a distance of more than 20 km from the urban areas of Shijiazhuang City. The permanent population in the built-up areas is about 0.1 million for each of the small towns (Table 1), and the locations of the observational stations are generally at the periphery zones of the built-up areas. The rural stations have been influenced by the urbanization in some extents as seen in Fig. 1, in spite of the fact that they are the most rural stations available in the study region. A few of the buildings near the rural stations can be seen, but they are usually not tall, and the micro-environment around the observational grounds is somehow good. Real rural stations actually do not exist in any regions of North China Plain. The rural stations have an average altitude of 80.4 m above sea level and an average latitude of 38.09°N, which are close to the altitude and latitude of the urban station (81.0 m and 38.03°N), enabling the direct comparison of the mean temperature and extreme temperature indices between them.

Shijiazhuang station has not been moved since its establishment in 1954. This enables it to be an ideal station for examining the urban climate change and particularly the urbanization effect on mean and extreme temperature trends because there is no major problem with data inhomogeneity probably caused by relocations. This is extremely unusual in mainland China because majority of the large city stations, usually also the national reference climate stations or national basic meteorological stations, have been moved for at least

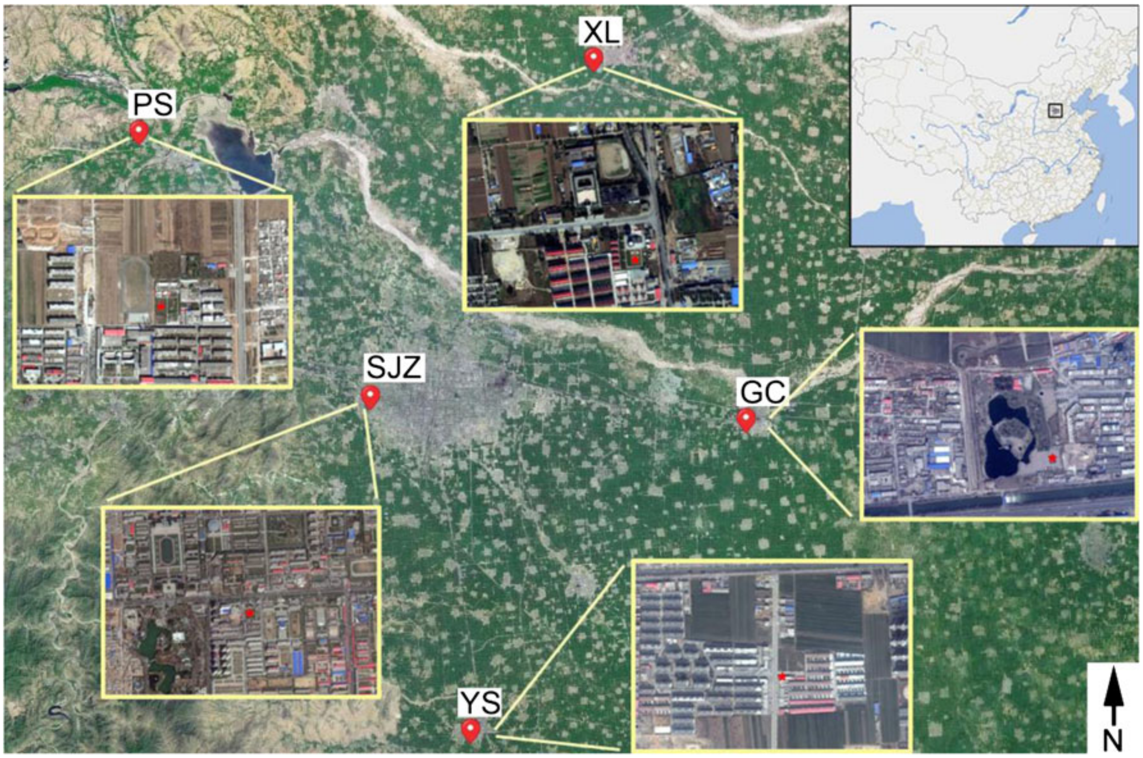

Fig. 1 Distribution and settings of the five meteorological stations used in this study. *SJZ* Shijiazhuang, *GC* Gaocheng, *YS* Yuanshi, *PS* Pingshan, and *XL* Xinle

one time, leading to obvious temporal inhomogeneities in SAT data (Yan et al. 2001; Li et al. 2004). Therefore, the SAT data from Shijiazhuang station does not need any adjustment for inhomogeneities related to relocation. The introduction of the autonomous weather stations (AWS) around 2004 may in certain extent have affected the SAT data homogeneity, but Wang et al. (2007) showed that the influence was small and could be ignored.

However, each of the four rural stations has been moved, with Xinle station moved for four times (Table 1). The breakpoints of data series caused by relocations were examined for Tmin, Tmax, mean temperature (Tmean), and diurnal temperature range (DTR) for the rural stations. The method was to calculate the difference between each rural station series and the reference series to obtain the difference series and to detect the breakpoints by using moving t test (Fig. 2). The reference series are obtained by averaging the nearby five station data series having the largest correlation coefficients with the target station series, from a bigger dataset in Hebei Province. Based on whether or not the values of t statistics exceed the significance level, locations of the change points could be determined (von Storch and Zwiers 2003; Wei 2007). If the change points could be proved to be real in reference to the metadata, then the adjustments could be made. Here, n= 60, the length of the subsequences $n1$=$n2$=4. Given the significant level α=0.01, with a freedom degree of t distribution v=n_1+n_2−2=6, $t_{0.01}$=3.71 could be obtained.

It was found that the Tmax, Tmean, and DTR series witnessed no significant breakpoint (Figure omitted), but the Tmin series of Pingshan and Yuanshi stations each had a

Table 1 Information of the five meteorological stations used in this study

Station		Longitude (E)	Latitude (N)	Altitude (m.a.s.l.)	Time of starting records	Relocations and time	Population (million)
Urban	Shijiazhuang	114.42°	38.03°	81.0	1954.12.01	0	2.70
Rural	Gaocheng	114.81°	38.01°	53.5	1958.08.01	2 (1969.07, 1999.01)	0.12
	Yuanshi	114.53°	37.75°	66.4	1960.01.01	3 (1982.02, 1998.01, 2007.01)	0.08
	Pingshan	114.02°	38.25°	131.0	1959.01.01	3 (1961.09, 1964.01, 2000.01)	0.13
	Xinle	114.68°	38.35°	70.8	1959.03.01	4 (1961.05, 1963.12, 1989.05, 2003.01)	0.11
	Rural average	114.51°	38.09°	80.5	–	–	0.11

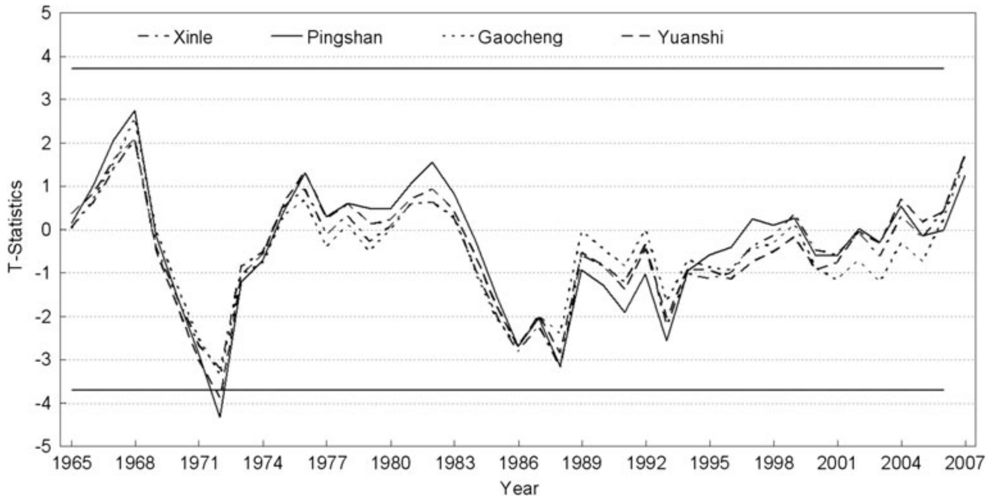

Fig. 2 Detection of inhomogeneities of annual mean Tmin for four rural stations (*black straight lines* mark the 0.01 significance level) during 1962–2011

breakpoint in 1972. There were no indication for station relocation and instrument change around 1972 for the two stations, however, and the breakpoints were not adjusted in this study.

The extreme temperature indices analyzed are listed in Table 2. These indices were defined with reference to the work of the Expert Team on Climate Change Detection and Indices (ETCCDI) (Alexander et al. 2006) and the operational standards of China Meteorological Administration (CMA). Relative threshold method based on percentile values was not used, but annual counts of days with the actual temperature above certain fix thresholds and the extreme Tmax and Tmin values were adopted. Cold days were defined as the number of days with daily mean temperature equal to or less than 0 °C, according to the local operational standard. Because the study area was relatively small and the distances among the stations were short, a method of simple arithmetic average was applied to calculate average of the extreme temperature indices for the rural stations. The method of least squares was used to calculate the linear trends of the extreme temperature indices series, and Student's t test method was used to examine the significance of the linear trends of the time series, with the different significance levels given as α=0.05, α=0.01, and α=0.001 (von Storch and Zwiers 2003).

Table 2 Definition of the extreme temperature indices applied in this study

No.	Index	Definition	Unit
1	Hot days	Annual count when Tmax≥35 °C	Day
2	Cold days	Annual count when Tmean≤0 °C	Day
3	Frost days	Annual count when Tmin< 0 °C	Day
4	Ice days	Annual count when Tmax<0 °C	Day
5	DTR	Annual (seasonal) mean difference between Tmax and Tmin	°C
6	Maximum Tmax	Annual (seasonal) maximum value of Tmax	°C
7	Minimum Tmin	Annual (seasonal) minimum value of Tmin	°C
8	Maximum Tmin	Annual (seasonal) maximum value of Tmin	°C
9	Minimum Tmax	Annual (seasonal) minimum value of Tmax	°C

In evaluating urbanization effect on trends of the extreme temperature indices, the following terms were defined with reference to Zhou and Ren (2009) and Zhang et al. (2011). The urbanization effect referred to the linear trends in extreme temperature indices recorded at urban station caused by strengthening UHI intensity and/or other local anthropogenic factors, which was expressed as ΔXur:

$$\Delta Xur = Xu - Xr \qquad (1)$$

where X_u was the linear trend of an extreme temperature index series at the urban station, and X_r was the linear trend of the average extreme temperature index series at the rural stations. If $\Delta X_{ur}>0$, the extreme temperature index series at urban station has an upward change related to that of rural station due to the urbanization effect, and if $\Delta X_{ur}<0$, the extreme temperature index series at urban station has a downward change related to that of rural station due to the urbanization effect.

Contribution of urbanization effect or urbanization contribution referred to the proportion of the statistically significant urbanization effect to the overall trend of the extreme temperature index series at the urban station, expressed as E_u (%)

$$Eu = |\Delta Xur/Xu| \times 100\% = |(Xu - Xr)/Xu| \times 100\% \qquad (2)$$

Considering the urbanization effect can be negative in some circumstances, absolute value was taken for E_u in order to enable $0 \le E_u \le 100$ %. If E_u=0, it denotes that the urbanization effect has no contribution to the overall trend of the extreme temperature index series at the urban station; if E_u=100 %, it shows that the linear trend of the extreme temperature index series at the urban station is entirely caused by the urbanization effect. In practical calculations, E_u may exceed 100 % in a few cases, indicating that unknown local anthropogenic factors might have had an effect, but it was adjusted to 100 % in this paper. As indicated in the definition, if the urbanization effect is not statistically significant, the urbanization contribution will not be calculated.

The differences of year-to-year extreme temperature indices between Shijiazhuang station and the four rural station averages were calculated to obtain the difference series, which can be regarded as year-to-year urbanization effect series. Because the altitude difference and latitude difference between Shijiazhuang station and the four rural station averages were only 0.6 m and 0.03°N, the temperature difference caused by the altitude and latitude change can be negligible, and the difference of the extreme temperature indices can well represent the yearly urbanization effect (mainly the UHI effect) on the extreme temperature of Shijiazhuang station. Therefore, the linear trend of the difference series was actually another expression of the urbanization effect as defined in this paper, or it was equal to ΔX_{ur}. The equality had been proved by comparing the values of trends of the difference series with the urbanization effects with regard to the annual and monthly mean temperature series of Shijiazhuang station. For example, the trend of the annual mean difference series was 0.181 °C/10 years, and the difference of trends of the urban station and the reference series was 0.181 °C/10 years. No significant difference was found in estimates obtained by using the two methods.

3 The results

3.1 Annual mean trends and urbanization effects

Table 3 provides the linear trends of annual extreme temperature indices for all urban station and rural stations and urbanization effect and urbanization contribution for Shijiazhuang station; and Figs. 3, 4, 5, 6 show the yearly values and linear trends of the difference series of extreme temperature indices between Shijiazhuang station and the four rural stations during 1962–2011.

During the past 50 years, hot days of Shijiazhuang station had a weak increasing trend (Fig. 3) at a rate of 0.83 days/10 years, while the hot days of the rural stations experienced a weak decreasing trend at a rate of −0.27 days/10 years, but both were not statistically significant (Table 3). The decrease in hot days of the rural stations might have been caused by the increasing aerosol concentration in the lower troposphere, and the increase in hot days of the urban station might have resulted from the combined influence of the enhanced UHI intensity and the increased aerosol concentration, but this issue needs to be further investigated.

Urban-rural differences of annual hot days significantly increased with time (Table 3 and Fig. 4), indicating that the influence of urbanization on the trend of the hot days series at Shijiazhuang station was large, with an urbanization effect reaching 1.1 days/10 years which was statistically significant at α=0.001 confidence level (Table 3). The contribution of urbanization effect to the overall trend of annual hot days was as high as 100 %, indicating that the increase in annual hot days at the urban station had been totally caused by urbanization. Because of the urbanization effect, the frequency of annual hot days at Shijiazhuang station increased by more than 5 days in the last 50 years.

Annual cold days of Shijiazhuang station and the rural stations all decreased during the time period 1962–2011 (Fig. 3), and the decreasing trends, −6.06 and −3.76 days/10 years, respectively, both passed the significance test at α=0.001 level. The urban-rural difference series of annual cold days also showed a significant downward trend (Fig. 4) with a rate of −2.3 days/10 years, which passed the significance test at α=0.001 level. The contribution of urbanization effect was 38.0 %, indicating that more than one third of the decrease in annual cold days had resulted from urbanization effect. In the recent 50 years, therefore, annual cold days observed at Shijiazhuang station decreased by 32 days, of which at least 12 days were due to the urbanization effect.

Table 3 and Fig. 3 show that annual frost days of Shijiazhuang station and the rural stations also highly significantly decreased during the last 50 years, with linear trends reaching −6.04 and −3.49 days/10 years, respectively. The highly significant downward trend, with a rate of −2.55 days/10 years, can also be seen from the urban-rural difference series (Fig. 4). The contribution of urbanization effect accounted for 42.2 %. Therefore, the overall reduction of annual frost days for the last 50 years at Shijiazhuang station was 31 days, and urbanization effect contributed a portion of at least 13 days.

Although annual ice days for Shijiazhuang station and the rural stations decreased, and a little bit larger reduction can be seen for the urban station, the downward trends had not passed the significance test at α=0.05 level (Table 3 and Fig. 3). The urban-rural difference series of the annual ice days showed an obvious downward trend with a rate of −0.47 days/10 years (Fig. 4), which was statistically significant at the α=0.05 confidence level. Therefore, the urbanization effect on the long-term trend of annual ice days at Shijiazhuang station was significant. This contrasted the urbanization effect on annual hot days in spite of the fact that the two indices were all defined based on daily Tmax, implying that the increase in Tmax at Shijiazhuang station in the last 50 years was less significant in summer than in other seasons.

Table 3 Linear trends of annual extreme temperature indices for Shijiazhuang station and rural stations (average of four rural stations) and the urbanization effects and urbanization contributions for the time period 1962–2011

Index	Urban station (days or °C/10 years)	Rural stations (days or °C/10 years)	Urbanization effect (days or °C/10 years)	Urbanization Contribution (%)
Hot days	0.83	−0.27	1.10***	100
Cold days	−6.06***	−3.76***	−2.30***	38.0
Frost days	−6.04***	−3.49***	−2.55***	42.2
Ice days	−1.08	−0.60	−0.47*	43.5
DTR	−0.50***	−0.30***	−0.20***	40.0
Maximum Tmax	0.17	0.01	0.16**	94.1
Minimum Tmin	1.49***	0.79***	0.70***	47.0
Maximum Tmin	0.28	0.21	0.07	–
Minimum Tmax	0.38***	0.25***	0.14	–

*significant at α=0.05 confidence level; **significant at α=0.01 confidence level; ***significant at α=0.001 confidence level

During 1962–2011, highly significant decreasing trends of annual mean DTR occurred for both Shijiazhuang station and the rural stations (Fig. 5), but obviously the decrease was much more evident at the urban station (−0.5 °C/10 years) than the rural stations (−0.3 °C/10 years) (Table 3). The urban-rural difference series of annual mean DTR showed a highly significant downward trend of −0.2 °C/10 years (Fig. 6), which had passed the significance test at α=0.001 level (Table 3). Therefore, the urbanization effect on the long-term downward trend of annual mean DTR recorded at Shijiazhuang station was large and highly significant, with almost half of the overall reduction resulting from the urbanization. It is interesting to note that the last decade witnessed a rebound of urban-rural difference of annual mean DTR. This might have been related to the recent urbanization processes around the four rural stations, which might have led to the

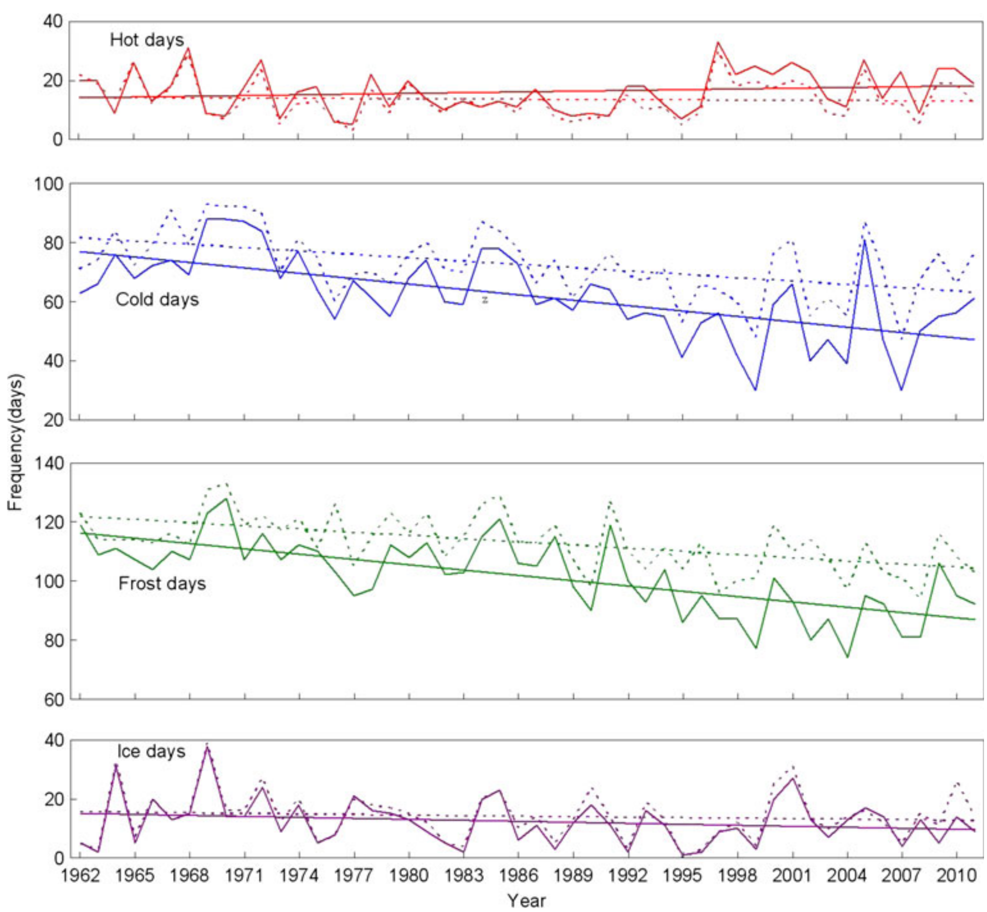

Fig. 3 Yearly series of hot days, cold days, frost days, and ice days between Shijiazhuang (*solid lines*) and rural stations (average of four rural stations, *dotted lines*) and their trends (*straight lines*) during 1962–2011

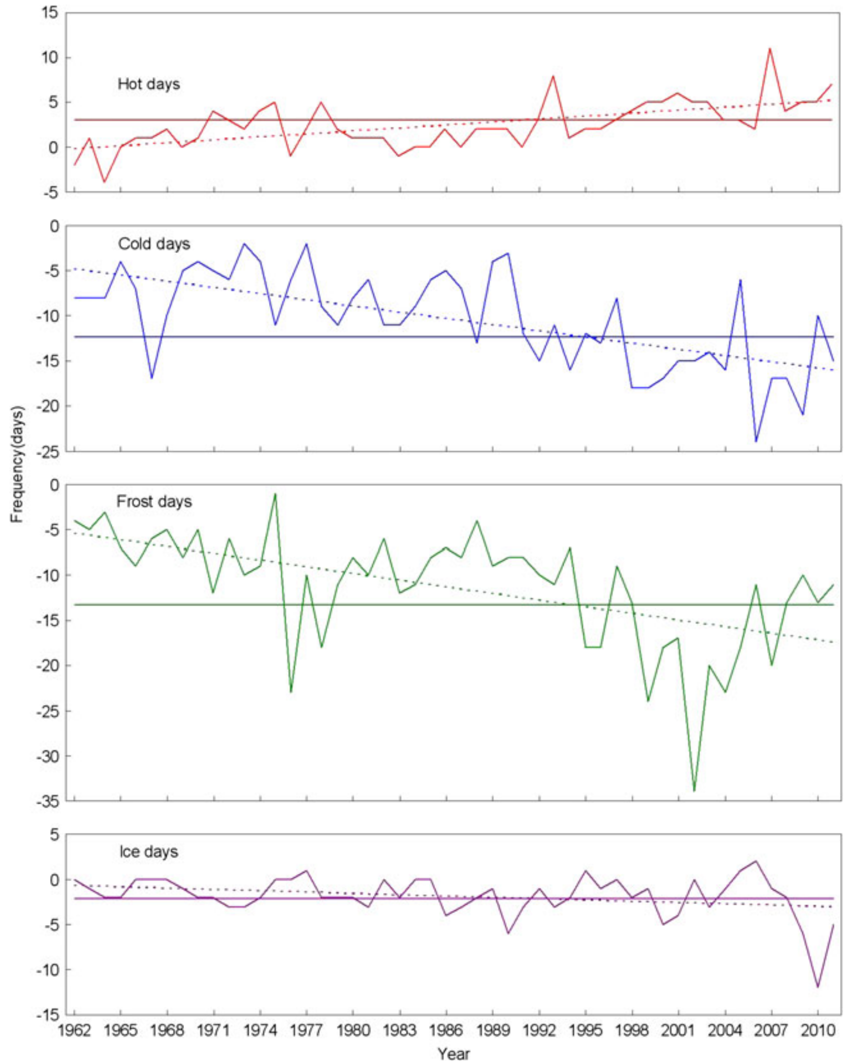

Fig. 4 Yearly difference series of hot days, cold days, frost days, and ice days (*curve lines*) between Shijiazhuang and rural stations (average of four rural stations) and their trends (*dotted lines*). *Straight lines* denote the averages during 1962–2011

relative increase in Tmin of the rural stations. It is also possible that the decrease in calm weather frequency in winter during the last decade (Jin et al. 2012) was weakening the urban-rural difference of annual mean Tmin and DTR.

During the last 50 years, maximum Tmax of Shijiazhuang station and the rural stations both had insignificant increasing trends at rates of 0.17 and 0.01 °C /10 years, respectively (Fig. 5), with the urban station trend being more obvious than the rural stations, leading to a significant urbanization effect of 0.16 °C/10 years (Table 3 and Fig. 6). The urbanization contribution was large, reaching 94.1 %, indicating that the rise of annual extreme Tmax at Shijiazhuang station had been caused mostly by the urbanization effect. Different from the maximum Tmax, minimum Tmin of both Shijiazhuang station and rural stations showed highly significant increasing trends, reaching 1.49 and 0.79 °C/10 years, respectively, and all passed the significance test at the α=0.001 level. The urban-rural difference series of annual minimum Tmin also had an upward trend of 0.7 °C/10 years (Fig. 6), which was highly significant at α=0.001 confidence level (Table 3), indicating a larger urbanization effect on the lowest annual Tmin at Shijiazhuang station. The urbanization contribution was estimated to be 47.0 %, or nearly half of the minimum Tmin increase at Shijiazhuang station had been induced by urbanization effect.

Maximum Tmin of Shijiazhuang station and the rural stations increased during the last 50 years (Fig. 5), but the respective trends of 0.28 and 0.21 °C/10 years were not significant at α=0.05 confidence level. The linear trend of the urban-rural difference series of maximum Tmin, 0.07 °C/10 years (Fig. 6), was not significant at α=0.05 confidence level either, indicating a less obvious urbanization effect on annual maximum Tmin. Although the minimum Tmax of both urban and rural stations experienced highly significant increasing trends, reaching 0.38 and 0.25 °C/10 years, respectively, the upward trend of the urban-rural difference series, 0.14 °C/10 years (Fig. 6), was not significant at the α=0.05 confidence level (Table 3), indicating that urbanization was

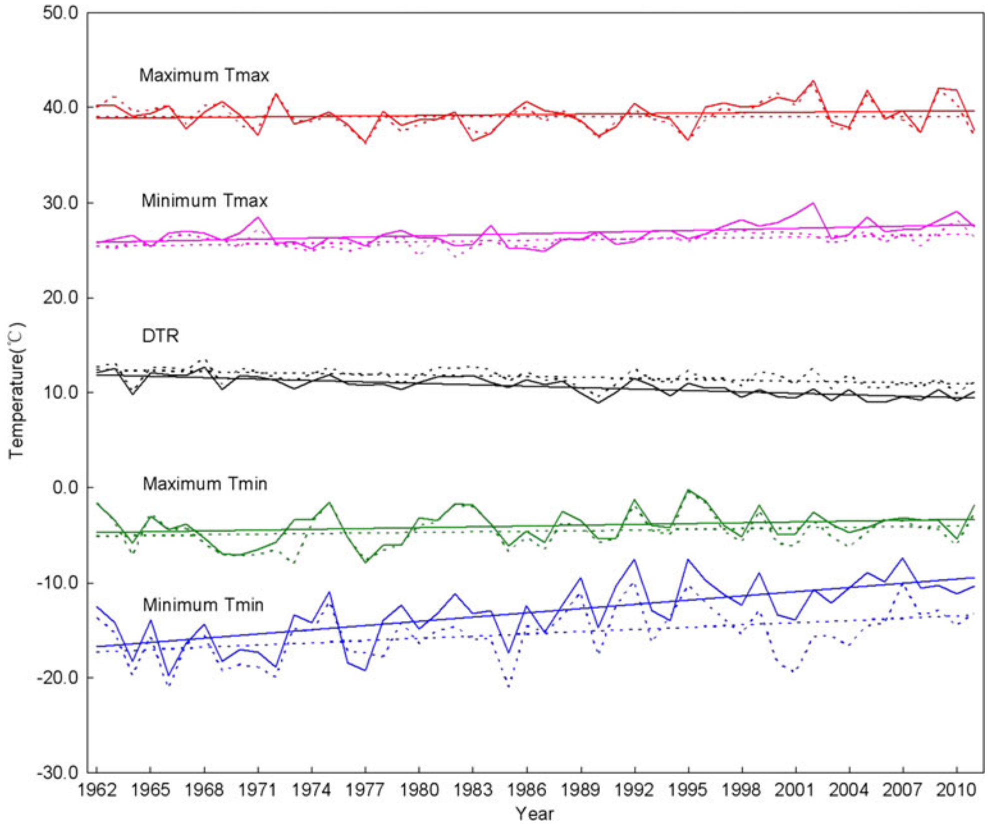

Fig. 5 Yearly series of DTR, maximum Tmax, minimum Tmin, maximum Tmin, and minimum Tmax between Shijiazhuang (*solid lines*) and rural stations (average of four rural stations, *dotted lines*) and their trends during 1962–2011

not exerting substantial net influence on the change in annual minimum Tmax at Shijiazhuang station.

3.2 Seasonal mean trends and urbanization effects

Seasonal analysis was given to DTR and the extreme values of Tmin and Tmax because the other extreme events (cold days, hot days, frost days, and ice days) occurred only on specific seasons. Table 4 shows the seasonal mean trends of the extreme temperature indices for Shijiazhuang station and the rural stations and the urbanization effect and urbanization contribution for Shijiazhuang station.

For every season, the seasonal mean DTR of Shijiazhuang station and rural stations significantly decreased during the time period analyzed (Table 4), and the largest decline of both urban station and rural stations appeared in winter, with summer witnessing the smallest decline. The urban-rural difference series of DTR in every season also showed a clear downward trend, indicating that the urbanization effects were evident at Shijiazhuang station. The urbanization effects were −0.18, −0.10, −0.19, and −0.24 °C/10 years, respectively, for spring, summer, autumn and winter, and the urbanization contributions were 39.1, 32.3, 36.5, and 36.9 %, respectively, for the four seasons (Fig. 7). Although the largest urbanization effect occurred in winter, followed by autumn, spring, and summer, the largest urbanization contribution was recorded in spring, followed by those in winter, autumn, and summer.

During the last 50 years, the trends of maximum Tmax for four seasons at Shijiazhuang station and rural stations were not significant, and they showed only slight increase or decrease. The urban-rural difference series of maximum Tmax in spring and summer showed significant increasing trends at α=0.001 confidence level, reaching 0.24 and 0.18 °C/10 years, respectively, and the urbanization contributions were 100 and 72 %, respectively. However, the trends of the urban-rural difference series of maximum Tmax in autumn and winter were very weak and not significant.

Minimum Tmin of four seasons at Shijiazhuang station and rural stations during the last 50 years all showed highly significant increasing trends, and the largest increase appeared in winter and the smallest increase in summer. The urban-rural difference series of minimum Tmin in all the seasons also showed highly significant upward trends, indicating the large and significant urbanization effects in the minimum Tmin series at Shijiazhuang station for every season. The largest urbanization effect occurred in winter, reaching 0.67 °C/10 years, followed by those of spring, summer, and autumn (0.35, 0.31, and 0.29 °C/10 years, respectively). The urbanization contributions in spring, summer, autumn, and winter were 36.5, 37.3, 32.2, and 48.2 %, respectively.

Maximum Tmin of Shijiazhuang station and rural stations showed increasing trends for the seasons except for summer, but only the upward trends of spring and winter for the urban station were statistically significant. Although the maximum

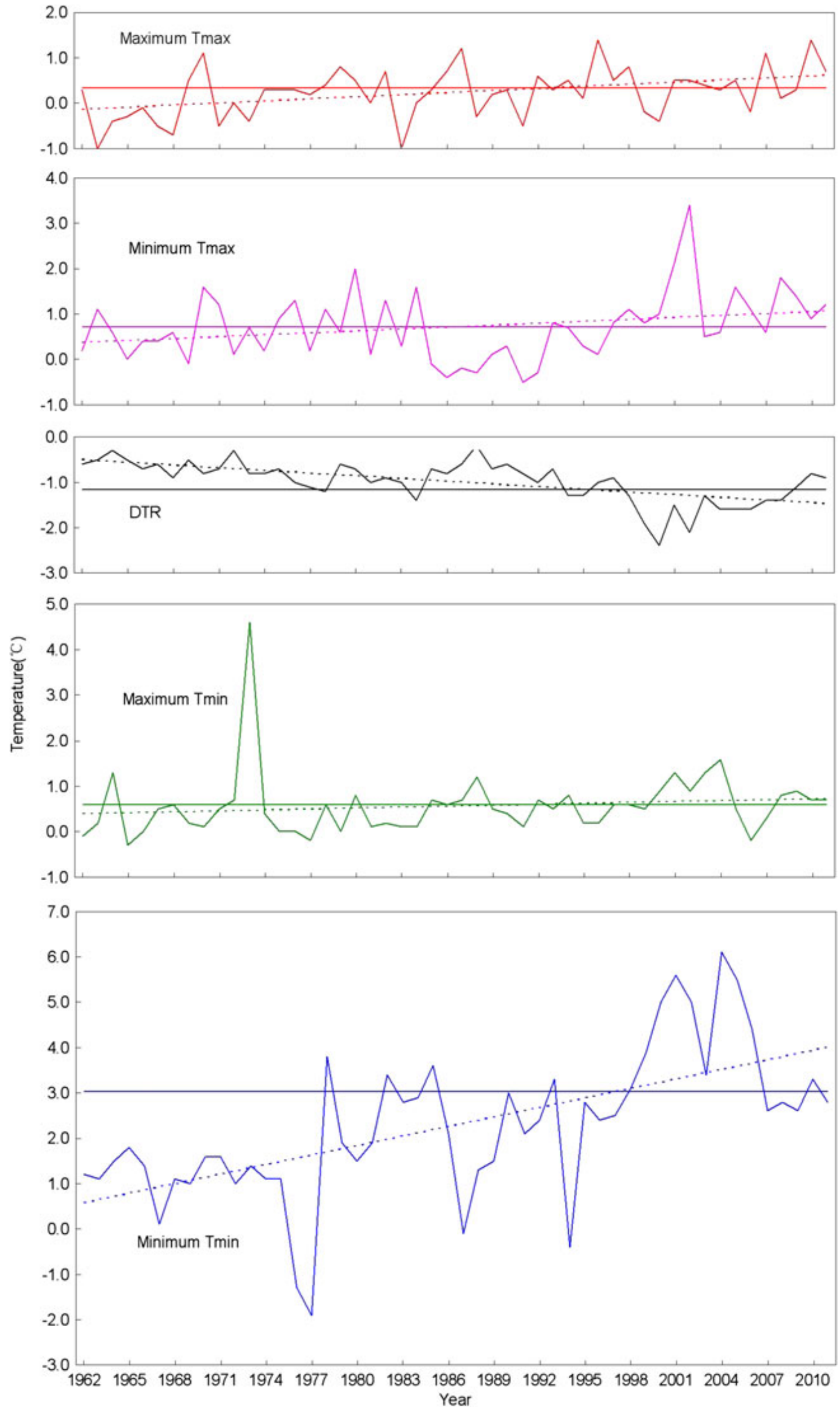

Fig. 6 Yearly difference series of DTR, maximum Tmax, minimum Tmin, maximum Tmin, and minimum Tmax (*solid lines*) between Shijiazhuang and rural stations (average of four rural stations) and their trends (*dotted lines*). *Straight lines* denote the averages during 1962–2011

Tmin trends of the urban station and the rural stations were not the same in direction for every season, the urbanization effects in maximum Tmin series were significant for all the seasons, with the most significant urban-induced increase occurring in autumn, reaching 0.17 °C/10 years, and the urbanization contributions were 21.3, 100, 68.0, and 52.0 % for spring, summer, autumn, and winter, respectively.

Minimum Tmax of Shijiazhuang station and rural stations showed increasing trends for all the seasons, and the increases were significant except for that of the rural stations in spring. The urban-rural difference series of minimum Tmax in spring and autumn exhibited significant increasing trends at 0.29 and 0.15 °C/10 years, respectively, indicating large urbanization effects in these two seasons, and the urbanization contributions were 58.0 and 25.0 %, respectively. Urbanization effects for minimum Tmax series at the urban station were insignificant for summer and winter.

Table 4 Linear trends of seasonal extreme temperature indices for Shijiazhuang station and rural stations (average of four rural stations) and the urbanization effects and urbanization contributions for the time period 1962–2011

Index	Season	Urban station (°C/10 years)	Rural station (°C/10 years)	Urbanization effect (°C/10 years)	Urbanization contribution (%)
DTR	Spring	−0.46***	−0.28**	−0.18**	39.1
	Summer	−0.31***	−0.21**	−0.10***	32.3
	Autumn	−0.52***	−0.33***	−0.19***	36.5
	Winter	−0.65***	−0.41***	−0.24***	36.9
Maximum Tmax	Spring	0.09	−0.15	0.24***	100
	Summer	0.25	0.07	0.18***	72.0
	Autumn	0.04	0.01	0.03	–
	Winter	−0.07	−0.01	−0.06	–
Minimum Tmin	Spring	0.96***	0.61**	0.35***	36.5
	Summer	0.83***	0.52***	0.31***	37.3
	Autumn	0.90***	0.61**	0.29**	32.2
	Winter	1.39***	0.72**	0.67***	48.2
Maximum Tmin	Spring	0.61*	0.48	0.13*	21.3
	Summer	−0.08	−0.21	0.13***	100
	Autumn	0.25	0.08	0.17***	68.0
	Winter	0.25**	0.12	0.13**	52.0
Minimum Tmax	Spring	0.50**	0.21	0.29*	58.0
	Summer	0.38***	0.25**	0.13	–
	Autumn	0.61***	0.46**	0.15**	25.0
	Winter	0.50*	0.46**	0.04	–

*significant at α=0.05 confidence level; **significant at α=0.01 confidence level; ***significant at α=0.001 confidence level

It is clear from the description above that the extreme temperature indices associated with Tmin generally showed significant changing trends during the last 50 years, and the changes in urban-rural differences of the indices or urbanization effects were usually large and significant except for minimum Tmax. On the other hand, the trends of the extreme temperature indices associated with Tmax were generally weak and insignificant, but the changes in urban-rural differences of the indices or urbanization effects were not necessarily small, with the urbanization effects on trends of hot days,

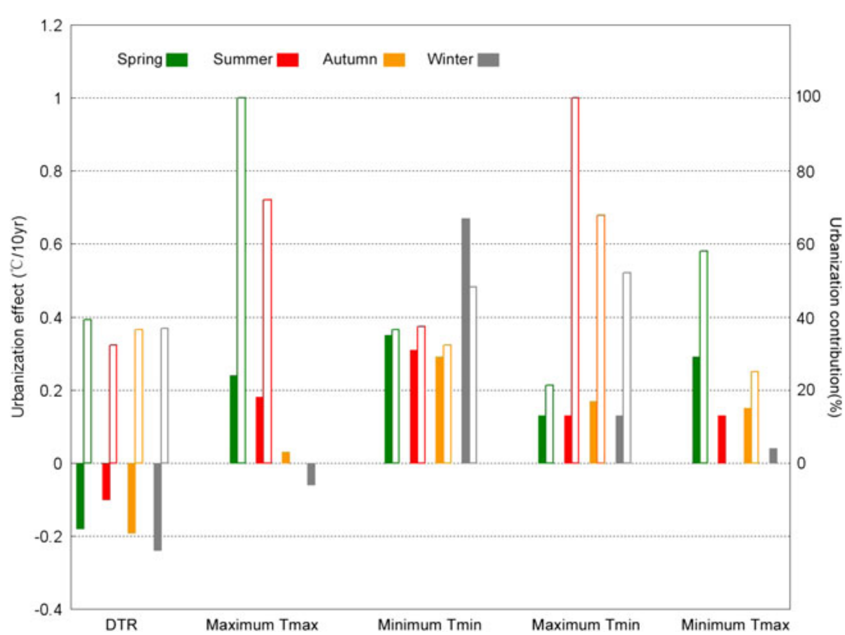

Fig. 7 Urbanization effects (*solid*) and the urbanization contributions (*blank*) of seasonal DTR, maximum Tmax, minimum Tmin, maximum Tmin, and minimum Tmax for Shijiazhuang station during 1962–2011

ice days, and maximum Tmax being statistically significant. Urbanization makes DTR, minimum Tmin, and maximum Tmin of Shijiazhuang station in every season to significantly change with time, among which the trends of DTR and minimum Tmin in winter and the trends of maximum Tmin in autumn were highly significant. The urbanization effects of maximum Tmax were more obvious in spring and summer, and those of minimum Tmax were more significant in spring and autumn.

4 Discussion

Little had been done to analyze the urbanization effect on extreme temperature change. Zhang et al. (2011) examined the urbanization effect on trends of extreme temperature indices during 1960–2008 at Beijing Meteorological Station, about 260 km northeast of Shijiazhuang station. They found that, for frost days and DTR, urbanization effects on the linear trends of Beijing station were −5.78 days/10 years and −0.73 °C /10 years, respectively, all statistically significant at the α=0.01 confidence level, and the contributions of urbanization effect all reached 100 %, but no significant urbanization effect was detectable for the trends of ice days and hot days. In contrast, although urbanization effects on trends of frost days and DTR at Shijiazhuang station were similarly significant, the urbanization contributions were smaller than those for Beijing station, but urbanization effects on trends of ice days and hot days at Shijiazhuang station were larger and more significant than those for Beijing station. This study revealed that urbanization effects on trends of the extreme temperature indices associated with Tmin were generally larger and more significant than those associated with Tmax at Shijiazhuang station, which is very consistent with the conclusions drawn from the analysis for Beijing station.

Recently, Zhou and Ren (2011) analyzed urbanization effect on the change of the extreme temperature indices and dataset commonly used for analyses of climate change in North China during 1961–2008. They found that urbanization effect had significantly aggravated the linear trends of the cold and warm indices associated with Tmin, and the urbanization contributions to the overall trends of the extreme temperature indices formulated with Tmin for national reference climate stations and basic meteorological stations all reached over 40 %. However, urbanization effects for the indices associated with Tmax were much weaker. These features are well consistent with the analysis results in this paper. Although urbanization effects on the long-term trends of DTR at Shijiazhuang station and the national reference climate stations and basic meteorological stations of North China were all highly significant, the contribution of urbanization effect was only 45.1 % for the former, and it reached 100 % for the latter, more consistent with that obtained for Beijing station (Zhang et al. 2011).

Main uncertainty in the analysis could originate from the data inhomogeneities and the representativeness of the selected rural stations. Although the discontinuous points of the SAT records caused by relocations had been examined, problems probably introduced by the application of automatic weather stations (AWS) in the last decade had not been carefully evaluated. Previous analysis pointed out that, compared with manual stations, Tmax measured by AWS are generally higher, while Tmin are slightly lower (Wang et al. 2007). These biases might have certain influences on the trend estimation of extreme temperature indices and the calculated results of urbanization effects. The rural stations selected in this paper should be representative for long-term record of background climate change and variability in the study area, but these stations are located in small towns around Shijiazhuang station, and inevitably, the SAT records from the rural stations will still be affected by urbanization in a certain extent (Karl et al. 1988; Ren et al. 2008; Zhou and Ren 2009). Actually, the urbanization effects and urbanization contributions estimated for a few of extreme temperature indices in this paper are lower than those reported for Beijing station and the national stations of North China, and this might be related in a large extent to the use of the rural stations in the present analysis. It is therefore safe to point out that the urbanization effects on the trends of the extreme temperature indices series at Shijiazhuang station as given in this paper be regarded as the lowest estimates.

Nevertheless, the results of this analysis showed that urbanization effects on the trends of extreme temperature indices at Shijiazhuang city station were large and mostly significant, especially for those associated with Tmin. Frost days, DTR, and minimum Tmin recorded on Shijiazhuang station, for example, were all significantly reduced due to urbanization. Considering the representativeness of the rural stations, the actual urbanization effects and the contributions of urbanization effects might have been larger. These results indicate that the long-term trends of extreme temperature event frequencies previously estimated based on the data from Shijiazhuang station and from all stations in Shijiazhuang area had been overestimated. There is a need to pay more attention to the urban biases in SAT data in analyses of mean and extreme temperature changes in this area as well as in the whole North China.

5 Conclusions

This paper analyzed urbanization effects on the long-term trends of extreme temperature indices at Shijiazhuang station during 1962–2011. The following conclusions were drawn:

1. Urbanization effects on the long-term trends of annual hot days, cold days, frost days, DTR, maximum Tmax, and

minimum Tmin at Shijiazhuang station for the time period 1962–2011 were highly significant, reaching 1.1 days/10 years, −2.3 days/10 years, −2.55 days/10 years, −0.2 °C/10 years, 0.16 °C/10 years, and 0.7 °C/10 years, respectively, with contributions of the urbanization effect to the overall trends being 100, 38.0, 42.2, 40.0, 94.1, and 47.0 %, respectively.

2. Urbanization effect on the long-term trend of annual ice days at Shijiazhuang station for the last 50 years was also significant, reaching −0.47 days/10 years, and the contribution of urbanization effect to the overall trend was 43.5 %. Urbanization effects on the trends of annual minimum Tmax and maximum Tmin at Shijiazhuang station for the last 50 years, however, were not statistically significant.
3. The urbanization effect made DTR, minimum Tmin, and maximum Tmin of Shijiazhuang station in every season to significantly change with time, with the downward trend of winter DTR and upward trends of winter minimum Tmin and autumn maximum Tmin being the largest and most significant.
4. The urbanization effects on the trends of extreme temperature indices reported in this paper might have been underestimated, because the selected rural stations are all located in small towns and they cannot fully represent the regional baseline temperature change and variability. The results, however, indicated that the urbanization effects on the trends of extreme temperature indices related to Tmin were large and significant at the urban station examined.

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References

Alexander LV, Zhang X, Peterson TC et al (2006) Global observed changes in daily climate extremes of temperature and precipitation. J Geophys Res 111(3):D05109

Bian T (2010) Characteristics of urban climate and climate change in Shijiazhuang City. Master dissertation of Lanzhou University (in Chinese)

Choi J, Chung U, Yun JI (2003) Urban-effect correction to improve accuracy of spatially interpolated temperature estimates in Korea. J Appl Meteorol 42:1711–1719

Chu ZY, Ren GY (2005) Change in urban heat island magnitude and its effect on mean air temperature record in Beijing region. Acta Meteorol Sin 63(4):534–540 (in Chinese)

Chung U, Choi J, Yun JI (2004) Urbanization effect on observed change in mean monthly temperature between 1951–1980 and 1971–2000 in Korea. Clim Chang 66:127–136

Easterling DR, Horton B, Jones PD (1997) Maximum and minimum temperature trends for the globe. Science 277:364–367

Fujibe F (2008) Detection of urban warming in recent temperature trends in Japan. Int J Climatol 29:1811–1822

Jin W, Ren G, Qu Y (2012) Change in surface mean wind speed of Northeast China during 1971–2010. Arid Zone Res 29(4):648–653

Kalnay E, Cai M (2003) Impact of urbanization and land use change on climate. Nature 423:528–531

Karl TR, Diaz HF, Kukla G (1988) Urbanization: its detection and effect in the United States climate record. J Clim 1988(1):1099–1123

Karl TR, Kukla G, Razuvayev VN et al (1991) Global warming: evidence for asymmetric diurnal temperature changes. Geophys Res Lett 18: 2253–2256

Li QX, Liu XN, Zhang HZ, Peterson TC, Easterling DR (2004) Detecting and adjusting on temporal inhomogeneity in Chinese mean surface air temperature data. Adv Atmos Sci 21(2):260–268

Plumner N (1996) Temperature variability and extreme over Australia: part 1-recent observed changes. Aust Meteorol Mag 45:233–250

Ren GY, Chu ZY, Chen ZH, Ren YY (2007) Implications of temporal change in urban heat island intensity observed at Beijing and Wuhan stations. Geophys Res Lett 34, L05711

Ren GY, Zhou YQ, Chu ZY, Zhou JX, Zhan AY, Guo J, Liu XF (2008) Urbanization effects on observed surface air temperature trends in North China. J Clim 21:1333–1350

von Storch H, Zwiers FW (2003) Statistical analysis in climate research. Cambridge University Press, New York, p 504

Wang Y, Liu XN, Ju XH (2007) Differences between automatic and manual observation. J Appl Meteorol Sci 18(6):849–855 (in Chinese)

Wei FY (2007) Diagnosis and forecasting methods of modern climatic statistics (version 2). China Meteorological, Beijing (in Chinese)

Yan ZW, Yang C, Jones PD (2001) Influence of inhomogeneity on the estimation of mean and extreme temperature trends in Beijing and Shanghai. Adv Atmos Sci 18(3):309–322

Yang X, Hou Y, Chen B (2011) Observed surface warming induced by urbanization in east China. J Geophys Res 116:D14113. doi:10.1029/2010JD015452

Zhai PM, Pan XH (2003) Trends in temperature extreme during 1951–1999 in China. Geophys Res Lett 30(17):1–4

Zhang AY, Ren GY, Zhou JX et al (2010) Urbanization effect on surface air temperature trends over mainland China. Acta Meteorol Sin 68(6):957–966 (in Chinese)

Zhang L, Ren GY, Liu J et al (2011) Urbanization effect on trends of extreme temperature indices at Beijing meteorological station. Chin J Geophys 54(5):1150–1159 (in Chinese)

Zhou YQ, Ren GY (2009) Urbanization effect on trends of maximum temperature, minimum temperature and diurnal temperature range in North China. Plateau Meteorol 28(5):1158–1166 (in Chinese)

Zhou YQ, Ren GY (2011) Change in extreme temperature events frequency over mainland China during 1961–2008. Clim Res 50(1–2): 125–139