Spatial Variability of Municipality-wise Heat and Cold Mortality in Japan with Respect to Temperature and Economic States

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Abstract A series of statistical analyses are made to find the dependence of heat and cold mortalities on the temperature and economic states of municipalities in Japan, using vital statistics data for 18 years, from 1999 to 2016. A partial correlation analysis for 1,207 municipalities over the country has indicated that heat and cold mortalities are positively and negatively correlated with summer and winter temperatures, respectively, while they are both negatively correlated with annual income and positively correlated with municipality population. These features are essentially common to genders, age groups, and regions, and indicate that heat and cold mortalities depend on both climatic and socioeconomic factors. An additional analysis of 151 wards in Tokyo and 12 other government-designated cities has also shown a correlation between heat/cold mortality and income; in particular, exceptionally high mortality is found in some wards which have areas with poor living conditions.

Key words heat stroke mortality, cold mortality, vital statistics, temperature, income

Introduction The Japanese climate is affected by the East Asian monsoon and is characterized by a relatively high annual temperature range even though it is surrounded by the ocean (Arakawa and Taga 1969; Japan Meteorological Agency 2019a). In Japan, there is growing interest in addressing heat strokes during summer due to the rapid increase of heat stroke deaths since the mid-1990s (Fujibe 2013) accompanied by frequent occurrences of extremely hot summers (Japan Meteorological Agency 2019b). According to the vital statistics based on the Tenth International Classification of Diseases (ICD-10), deaths from “exposure to excessive natural heat” with a code of X30 amount to several hundred to a thousand per year. Additionally, although it has received much less social attention, deaths from “exposure to excessive natural cold” (X31) also amount to about a thousand every year. Both heat and cold mortalities increase with age (Fujibe 2016; Fujibe et al. 2018a), so that the number of casualties in Japan increases with the increase of elderly people (Fujibe 2013, 2016; Fujibe et al. 2018a, 2019).

A number of studies have been conducted to understand the regional features of heat mortality in Japan using vital statistics data. Hoshi et al. (2010) showed that prefecture-averaged heat mortality was highest in Okinawa, the southernmost prefecture, and lowest in Hokkaido, the northernmost island, with a statistically significant correlation between mortality and highest annual temperature. Fujibe et al. (2018a) showed different dependencies of prefecture-averaged heat-stroke mortality on temperature for different age groups. The relationship between daily heat-stroke casualties and temperature was studied by Hoshi et al. (2016) and Fujibe et al. (2018b), who showed that heat mortality under a specified daily temperature tended to be higher in regions with cooler summer climates. Their findings indicate the effects of acclimatization, which could reduce the regional variability of heat mortality between different climate zones.

More localized features of heat stroke casualties have been investigated for many parts of the world with respect to urban-rural difference (Tan et al. 2010; Gabriel and Endlicher 2011; Li et al. 2017; Hu et al. 2019) and intra-city variations (Vaneckova et al. 2010; Chan et al. 2012; Honda et al. 2012; Harlan et al. 2013; Rosenthal et al. 2014; Madrigano et al. 2015; Kim and Kim 2017; Schinasi et al. 2018), although these studies target “heat-related mortality” defined by excessive mortality under high temperature rather than heat-stroke deaths in a nar-
row sense. While some of them paid attention to both climatic and social factors, such as economic state and education, the results are not sufficiently consistent to provide a unified view of the spatial variation of heat-related mortality. Local variations of heat stroke casualties have also been examined for some areas of Japan using data on ambulance transportation (Kurabayashi and Fukuda 2005; Samata et al. 2008; Akatsuka et al. 2016) and mortality (Fujibe et al. 2017). Fujibe et al. (2017) analyzed heat mortality for the Tokyo Ward Area in the summer of 2013 and found that mortality was high in its periphery, particularly in the inland area, where the daytime temperature tends to be high. In addition, they found a negative correlation between heat mortality and mean income of each ward. However, because these studies are limited in spatial and temporal coverage, analyses over a longer period and larger area are required to obtain a comprehensive understanding of local variations of heat mortality and their controlling factors.

In terms of cold deaths in Japan, Fujibe et al. (2019) showed a negative correlation between X31 mortality and climatic-mean winter temperature, with a rate of about 12% in a prefecture where the temperature was 1°C lower. A number of studies in other countries have shown differences of cold mortality or cold-related mortality based on income and race as well as between urban and rural areas (Hajat et al. 2005; Thacker et al. 2008; Deschenes and Moretti 2009; Berko et al. 2014). Vuillermoz et al. (2016) showed high cold mortality among homeless people in France. These facts indicate the influences of social factors on cold-related deaths. However, public interest in deaths due to cold is low in Japan, and its statistical features have remained largely unclear.

The aim of the present study is to find the dependence of heat and cold mortality on temperature and economic states on a scale smaller than prefectures using municipality-wise data over Japan.

**Data and Procedure of Analysis**

**Local government system of Japan**

The largest unit of the local government in Japan is a prefecture. There are 47 prefectures, each named with one of the four words “to,” “do,” “fu,” and “ken.” The dis-
tinction among the four words is primarily derived from historical factors, with little practical difference\(^1\). Figure 1 shows the prefectures and their populations as per the 2015 National Census. In the present study, the 47 prefectures are divided into nine regions, A to I, for the reason explained in the “Procedure of analysis” section.

The lower unit of the local government is city (shi), town (machi, cho), and village (mura, son). They are denoted by the generic word “municipality” in this paper. The present study is based on the municipality division at the end of 2016. The first part of the study considered 1,207 municipalities having a population of 10,000 and over, with a total population of 124.7 million which accounts for 98.1% of the population of Japan (127.1 million). Table 1 shows the number of municipalities in each population range for each region based on the 2015 National Census.

Some larger cities are categorized as “government-designated cities” (GDCs) and are divided into wards (ku). There are 20 GDCs as of 2019. The eastern part of the Tokyo Metropolis is also divided into wards, which constitute the “Tokyo Ward Area” (TWA) having the appearance of a GDC\(^2\). The second part of the present study was made for the 151 wards of the TWA and the 12 GDCs that were designated by 1999. Figure 2 shows their locations and populations. The total population of the 151 wards is 30.3 million.

**Data**

The data on the heat- and cold-caused deaths were obtained from the vital statistics provided by the Ministry of Health, Labour and Welfare (MHLW) of Japan for 18 years, from 1999 to 2016. The data include the age, gender, date, and place of death of individuals who were determined to have died from X30 or X31. The place of death is specified as the municipality, including the wards of the TWA and GDCs. The total number of victims over the chosen period was 10,884 and 17,242 for X30 and X31, respectively; the analysis was performed for 10,799 and 16,573 cases, respectively, excluding those for which the place of death was outside Japan or unspecified.

The mortality rate was calculated for each year and

| City       | Pop. (×10^3) wards | No. of wards |
|------------|-------------------|--------------|
| Sapporo    | 1,963             | 10           |
| Sendai     | 1,086             | 5            |
| Chiba      | 975               | 6            |
| Tokyo (TWA)| 9,273             | 23           |
| Kawasaki   | 1,504             | 7            |
| Yokohama   | 3,733             | 18           |
| Nagoya     | 2,314             | 16           |
| Kyoto      | 1,472             | 11           |
| Osaka      | 2,713             | 24           |
| Kobe       | 1,332             | 9            |
| Hiroshima  | 1,199             | 8            |
| Kitakyushu | 951               | 7            |

**Figure 2.** Location of the Tokyo Ward Area and 12 government-designated cities in Japan studied here. Yellow and brown lines indicate the boundaries of prefectures and regions, respectively. The table on the upper left indicates the populations of the Tokyo Ward Area and the 12 cities in 2015.

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### Table 1. Number of Japanese municipalities with a population over 10,000 (according to the 2015 Census) for the nine regions defined in Figure 1 (center)

| Region name   | Number of prefectures (≥1,000,000) | Number of municipalities in each population range |
|---------------|-----------------------------------|-----------------------------------------------|
| A Hokkaido    | 1                                 | 1,1,1,13,35,57                               |
| B Tohoku      | 7                                 | 2,3,13,54,70,141                             |
| C Kanto       | 7                                 | 4,17,69,108,58,256                           |
| D Hokuriku and Ko-shin-etsu | 6 | 0,4,10,58,49,121 |
| E Tokai       | 4                                 | 1,9,25,65,38,138                             |
| F Kinki       | 6                                 | 3,12,28,70,43,156                            |
| G Chugoku and Shikoku | 9 | 1,6,20,53,63,143 |
| H Kyushu      | 6                                 | 1,7,14,73,77,172                             |
| I Okinawa     | 1                                 | 0,1,3,10,9,23                               |
| Total         | 47                                | 12,60,189,504,442,1,207                     |
| Population (10^3) | 127,095 29,621 28,438 30,791 27,715 8,122 | 124,686 |
municipality by dividing the number of deaths by population. For municipalities that underwent annexation, the area at the end of 2016 was used. In order to avoid the apparent difference of mortality arising from different age distributions based on years and municipalities, age adjustment was made on the basis of the population of the whole country in the 2015 National Census, in the same manner as done by Fujibe et al. (2018a). The present study is based on the 18-year average of the adjusted mortality. Hereafter, it is denoted $M_i$, where the suffix $i$ indicates municipality.

For the information on the climate of each municipality, gridded temperature compiled by the Japan Meteorological Agency (JMA) were obtained from the website of the Ministry of Land, Infrastructure and Transport (MLIT; http://niftp.mlit.go.jp/kj/index.html). The data provides 30-year means (1981 to 2010) of the daily average, maximum, and minimum temperatures each month, with a resolution of 30° in latitude and 45° in longitude over the land area of Japan3. The average temperature is used for the present study unless otherwise stated. In order to calculate the temperature representing the populated area of the municipality, a population-weighted average was calculated using gridded population data with the same resolution obtained from the Portal Site of Official Statistics of Japan (e-Stat; https://www.e-stat.go.jp/gis/statmap-search?page=1&toukei=00200521). Because 82% of heat-stroke deaths in Japan were found to occur in July and August (Fujibe et al. 2018a), and 78% of cold deaths from December to March, (Fujibe et al. 2019), analyses of heat and cold mortalities were based on average temperatures for these two and four months, respectively. The resulting temperature will be denoted by $T_i$, where $i$ indicates municipality.

As an index related to the socioeconomic state of the municipality, data on taxable income were obtained from a website of the Ministry of Internal Affairs and Communications (MIC; http://www.soumu.go.jp/iken/kessan_jokyo_2.html) for the fiscal year of 2015 (April 2015 to March 2016). The data are provided for each municipality except the wards in GDCs. Hereafter, the per capita taxable income for a municipality $i$ will be denoted by $S_i$. As another source of data on the economic state, the results of “2013 Housing and Land Survey” were obtained from e-Stat (https://www.e-stat.go.jp/en/stat-search/files?page=1&toukei=00200522&tstat=000001063455). The data provide information on the employment status and income of the primary household earners for all the municipalities including wards in GDCs, with the exception of towns and villages with populations below 15,000. In the present study, the percentage of primary household earners with an annual income under three million yen was used as an index of the degree of poverty, and it is denoted by “<3-million rate” with the symbol $s_i$. The percentage of primary household earners with an annual income of ten million yen or over (≥10-million rate), and those without jobs (no job rate) were also analyzed4. In addition, the percentage of people at the age of 60 or over (≥60 years old rate), and that of 80 or over (≥80 years old rate) were used on the basis of the results of the 2015 National Census.

**Procedure of analysis**

The analysis has two parts. One was made for the 1,207 municipalities in the country with populations over 10,000 for the purpose of finding general features of the dependence of heat and cold mortalities on temperature and annual income. The municipalities range over various locales, including core cities and rural areas. The TWA and GDCs were each treated as a single area in this analysis. Another part of the analysis was performed for the 151 wards of Tokyo and 12 GDCs, in order to examine sub-city scale variability of heat and cold mortality in urban areas.

It is to be noted that heat and cold mortalities are less than $10^{-5}$ on a national average. This indicates that the number of deaths in a city with a population of 100,000 is of the order of ten in the analysis period (18 years). As a result, the statistical uncertainty is so large that it is impossible to make a detailed analysis for each municipality. For this reason, the present study is based on a correlation analysis that covers a sufficient number of municipalities.

Figure 3a shows a scatter diagram of cold mortality and annual income for municipalities with populations above 100,000, with different symbols according to regions. There is an overall negative correlation of $-0.24$. However, there are regional differences, such as high income in Region C (the metropolitan area centered at Tokyo) and low income in Regions H and I. As the target of the present study was the mortality variations on a scale smaller than prefectures, because regional-scale variability had been examined in previous studies (e.g., Fujibe et al. 2018a, b, 2019), the analysis was performed on normalized values defined by the deviation of each variable from its average over each region, namely,
where the symbol “< >” indicates the population-weighted average among municipalities with populations over 10,000 in each region. Note that the temperature is defined for different seasons for heat and cold mortalities. Figure 3b shows a scatter diagram of normalized cold mortality and income, namely, $\delta M_i$ and $\delta S_i$. It can be observed that regional differences almost disappear, although municipalities in Region C tend to have low relative incomes because of the distinctively high relative income in Tokyo, resulting in a high average value for the region. For the sake of comparison, an additional analysis was performed using the deviation from the average income in each prefecture. Analyses based on unnormalized values of mortality and income (namely, $M_i$ and $S_i$) were also performed.

The relationship between $\delta M_i$, $\Delta T_i$, $\delta S_i$, and population ($P_i$) was assessed using a partial correlation analysis after transforming them into $\delta M_i^{1/4}$, $\ln \delta S_i$, and $\ln P_i$. The reason for using the logarithm of $\delta S_i$ and $P_i$ is their skewed distributions, which are often regarded as close to the log-normal distribution (Limpert et al. 2001; Luckstead and Devadoss 2017). The mortality has also been considered in logarithm in many previous studies. In the present study, however, some municipalities have a null fatality; therefore, that logarithm of mortality cannot be used. The number of such municipalities is 107 in terms of heat deaths and 45 in terms of cold deaths. Thus $\delta M_i^{1/4}$ was used instead. For the sake of comparison, analyses based on $\delta M_i^{1/2}$ and $\delta M_i$ were performed, and an analysis using $\ln \delta M_i$ was also attempted by omitting municipalities that had no fatalities. Additionally, analysis for the $<3$-million rate was performed for comparison, using data of 1,090 municipalities available from the “2013 Housing and Land Survey”, excluding three cities with a population below 10,000.

The analysis for wards in the TW A and GDCs was performed in the same way as described above, except that the mortality was used in the logarithmic form, population was not considered, the $<3$-million rate ($s$) was used instead of annual income, and normalization of variables was based on their averages over each city. For comparison, analyses using the $\geq 10$-million rate, no job rate, $\geq 60$ years old rate, and $\geq 80$ years old rate instead of $<3$-million rate were performed as well.

### Results

**Analysis of municipalities in the entire country**

Figure 4 shows the results of correlation analysis for $\delta M_i^{1/4}$, $\Delta T_i$, $\ln \delta S_i$, and $\ln P_i$. The partial correlation between $\delta M_i^{1/4}$ and $\Delta T_i$ is 0.17 for heat mortality and $-0.16$ for cold mortality. Both are statistically significant at the 1% level. Thus, heat/cold mortality tends to be higher in municipalities with higher summer/lower winter temperatures. The partial correlation between $\delta M_i^{1/4}$ and $\ln \delta S_i$ is $-0.20$ and $-0.22$, respectively, and that between $\delta M_i^{1/4}$ and $\ln P_i$ is 0.20 for both. These facts
indicate that heat and cold mortalities tend to be higher in municipalities with lower incomes and larger populations.

It is interesting to note, as shown in Figure 4, that temperature exhibits positive correlation with population and annual income, with a coefficient over 0.5, indicating high correlation. This situation can explain some differences of partial correlation and single correlation between $\delta M_i^{1/4}$ and the three other quantities, although they are mostly close to each other. The single correlation between $\delta M_i^{1/4}$ for heat mortality and income is small (0.01) despite the negative partial correlation, possibly because of the inverse dependence of mortality on population and income that are positively correlated. A similar explanation applies to the small single correlation between cold mortality and population.

Figure 5 shows the values of partial correlation between mortality and the three other quantities obtained for different options in the analysis. For both heat and cold mortalities, the results for the control case (No. 1 in each panel) are basically common to genders and age groups (Nos. 2 to 5), although the age group under 60 years old shows a higher correlation with population and lower correlation with temperature. The results do not change greatly if daily maximum or minimum temperatures are used instead of daily average temperatures (Nos. 6 and 7); the results also do not change significantly if Hokkaido and Okinawa are excluded from the statistics (No. 8). If cities with populations above one million are excluded (No. 9), the dependence on population decreases, especially for cold mortality. This fact implies that the dependence of mortality on population is influenced by high mortality in large cities. An analysis based on normalization with respect to average values in each prefecture (No. 10) does not show the result to be altered greatly, except for low correlation between cold mortality and temperature. Analyses using $\delta M_i^{1/2}$, $\delta M_i$, and $\ln \delta M_i$ instead of $\delta M_i^{1/4}$ (Nos. 11 to 13) tend to show lower correlation with population, especially for heat mortality based on $\delta M_i$ and $\ln \delta M_i$, although correlations with tem-
Temperature and income are hardly affected. The results are also insensitive to the use of the <3-million rate instead of income (No. 14), and absolute (namely, unnormalized) income instead of normalized income (No. 15), whereas the use of absolute mortality (No. 16) results in lower correlation for heat mortality. To summarize, the results are mostly insensitive to the options in the analysis except for some points described above.

According to a multiregression analysis using $\ln \delta M_i$, corresponding to the option No. 13, the regression coefficient of $\ln \delta M_i$ to $\Delta T_i$ is $0.17 \, \text{K}^{-1}$ for heat mortality and $-0.08 \, \text{K}^{-1}$ for cold mortality. Thus, heat mortality changes by about 17% for a 1°C difference in summer temperature in the municipality, while cold mortality changes by about 8% for a 1°C difference in winter temperature. The regression coefficient of $\ln \delta M_i$ to $\ln \delta S_i$ is $-0.75$ for heat mortality and $-0.88$ for cold mortality, indicating an increase in mortality by a factor of two or more for a municipality of half income.

Figure 6 shows the values of partial correlation for each region; the variability among the regions is not evident. Thus, correlations between heat/cold mortality and other parameters are a nationwide feature, although confidence ranges in Figure 6 are too large to enable recognition of detailed regional differences.

Analysis for wards in TWA and 12 GDCs

Figure 7 shows the correlation analysis results for $\ln \delta M_i$, $\Delta T_i$, and $\delta S_i$ for 151 wards in the TWA and 12 GDCs. The partial correlation between $\ln \delta M_i$ and $\Delta T_i$ is 0.27 for heat mortality, and 0.21 for cold mortality and between $\ln \delta M_i$ and $\delta S_i$, it is 0.32 and 0.40, respectively. The positive correlation between cold mortality and temperature is an unexpected feature, contradictory to the result for the whole country shown in the previous section. The positive correlation between mortality and the <3-million rate is consistent with the negative correlation between mortality and income for municipalities in the country.

Figure 8 shows the values of partial correlation between $\ln \delta M_i$, and two other parameters for different options in the analysis. The positive correlation between cold mortality and $\Delta T_i$ is nearly non-existent if Tokyo and Osaka are excluded (No. 2), whereas Tokyo and Osaka show high correlation, about 0.5, between cold mortality and $\Delta T_i$, as well as positive correlation between both heat and cold mortalities and $\delta S_i$ (Nos. 3 and 4). The result of the control case hardly changes if $\delta M_i^{1/4}$ is used instead of $\ln \delta M_i$ (No. 5). For analyses using social indices other than <3-million rate (Nos. 6 to 9), the correlation between mortalities and $\geq$10-million rate is slightly weaker than in the control analysis (No. 6), whereas that between mortalities and no job rate is statistically significant only for heat mortality (No. 7), and no correlation is found for $\geq$60 years old rate nor $\geq$80 years old rate (Nos. 8 and 9). In addition, correlations between absolute values of <3-million rate (No. 10) are statistically significant but weaker than the control case. There is no correlation between absolute heat mortality and absolute <3-million
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rate (No. 10), although significant positive correlation is seen for cold mortality.

Figure 9 shows the relationship between $M_i$ and $s_i$, and $\delta M_i$ and $\delta s_i$ for cold mortality for the 151 wards. Apart from TWA, Yokohama, and Osaka, wards in Sapporo and Sendai are shown in a symbol different from other GDCs because these two cities are in northern Japan, where cold mortality tends to be higher compared to eastern and western Japan (Fujibe et al., 2019). The unnormalized values $M_i$ and $s_i$ have a positive correlation, but the axes of distribution differ among cities, as seen clearly for Tokyo and Osaka. For normalized values of $\delta M_i$ and $\delta s_i$, deviation among cities is largely reduced. However, several wards have exceptionally high mortality, such as Nishinari and Naniwa Wards of Osaka, Naka Ward of Yokohama, and Taito Ward in Tokyo.

Figure 10 shows the distribution of heat and cold mortality in wards in the area from the TWA through Kawasaki City to Yokohama City, and Osaka City. It can be seen that the above-mentioned wards have much higher values of cold mortality compared to the surrounding wards. Nishinari Ward of Osaka and Naka Ward of Yokohama also have high heat mortality. In contrast, Chiyoda Ward of Tokyo and Chuo Ward of Osaka have lower heat mortality than others. These wards are in the central business area and are characterized by low $<3$-million rates.

Figure 11 shows the mortality for each gender and ten-year age group in the Taito, Naka, and Nishinari Wards, each relative to the average over the TWA, Yokohama, and Osaka Cities, respectively. The results are somewhat complicated, but it can be seen that high mortality in
these wards (except for heat mortality in Taito Ward) are higher for men than for women, as well as higher for individuals below 80 years old. These features are more evident for cold mortality than for heat mortality.

Summary and Remarks

The results of the study are summarized as follows.

(1) For 1,207 municipalities in Japan with populations above 10,000, heat and cold mortalities are positively and negatively correlated to summer and winter temperature, respectively, and both are correlated positively with annual income. These features are found to be in common with different genders, age groups, and regions.

(2) Another analysis for 151 wards in Tokyo and 12 GDCs has confirmed the dependence of heat and cold mortalities on income, although cold mortalities in wards of Tokyo and Osaka are found to correlate positively with temperature.

(3) Exceptionally high values of cold mortality are found in the Nishinari Ward of Osaka, Naka Ward of Yokohama, and Taito Ward in Tokyo. The first two wards have high values of heat mortality also. The excessive mortality in these wards are largely attributable to the high mortality of men of ages below 80 years.

Figure 10. Distribution of (a) heat mortality and (b) cold mortality in the area from the Tokyo Ward Area (T) through Kawasaki City (K) to Yokohama City (Y), and Osaka City (upper right). Cy: Chiyoda Ward (Tokyo), Ta: Taito Ward (Tokyo), Nk: Naka Ward (Yokohama), Co: Chuo Ward (Osaka), Nw: Naniwa Ward (Osaka), Ni: Nishinari Ward (Osaka). City boundaries are shown in red lines, and ward boundaries are shown in thin black lines. Orange lines indicate prefecture boundaries outside cities shown here.

Figure 11. Relative heat and cold mortalities for each gender and age group for Taito Ward (Tokyo; a, e), Naka Ward (Yokohama; b, f), Nishinari Ward (Osaka; c, g), and population-weighted averages for the three wards (d, h). Values for those aged 50−59, 60−69, 70−79, 80−89, ≥90 years old are plotted at 55, 65, 75, 85, 95 years old on the x-axis. Vertical bars for the age-averaged statistics indicate the 95% confidence ranges.
The result for municipalities indicates that heat and cold mortalities are correlated with both temperature and income, namely, climatic and socioeconomic factors. The rate of change of heat and cold mortalities according to municipality temperature was estimated to be $0.17 \, K^{-1}$ and $-0.08 \, K^{-1}$, respectively, according to the statistics for municipalities in the country. These values are roughly of the same order as the dependence on prefecture-wise temperature variation (Fujibe et al., 2018a, 2019), indicating that heat and cold mortality are influenced by both regional scale and municipality scale climates. However, a positive dependence of heat mortality on municipality temperature is commonly found for the age group of under 60 years old and that of 80 years and over, in contrast to the opposite dependences of the two age groups on prefecture-wise temperature (Fujibe et al., 2018a). This implies different relationships of heat mortality and climate according to spatial scales. As discussed by Fujibe et al. (2018a), a higher day-to-day variability of summer temperature in central and northern Japan can lead to higher mortality rates in elderly people, who are more vulnerable to sporadic hotness, than in southern Japan. In comparison, spatial difference in temperature variability is likely to be small within a prefecture, resulting in a small difference of mortality-temperature relationship according to age.

Heat and cold mortalities are also related to the economic states of wards in GDCs. However, the relationship between mortality and temperature for these wards differs from that of municipalities in the country with respect to the positive correlation between cold mortality and temperature, especially for wards of Tokyo and Osaka. This positive correlation is an unexpected result and implies that temperature is not a leading factor controlling the distribution of mortality within large cities, although it may be partly due to inaccurate representation of ward-scale temperature distribution in the gridded data. Analysis using data based on a denser observation network is required to evaluate the relationship between heat/cold mortality and temperature.

Human perceptions of temperature were not used for this study for two reasons. The first is that data needed to calculate them, such as humidity, wind speed, and radiation, were unavailable at a spatial resolution appropriate for the purpose of the study. The second is that the motive of the study was to evaluate the dependence of heat and cold mortality on local temperature from a climatological viewpoint rather than for a practical purpose. Determining the relationship between heat/cold mortality and human-perceived temperature indices such as wet bulb globe temperature (WBGRT) on a local scale will be the subject of a future study.

The dependence of mortality on income and the <3 million rate indicates the influence of economic state on deaths from heat and cold and implies the possibility of reducing casualties by improving living conditions. The wards that showed exceptionally high mortality had “doya” (flopshouses) areas—namely, San’ya in Taito Ward, Airin-chiku in Nishinari Ward, and Kotobuki-cho in Naka Ward—for day laborers. It is likely that the poor living conditions in these areas is one cause of high mortality. Tanaka et al. (1988) surveyed cold deaths in Tokyo around 1980 and found that many of them occurred outdoors among people they described as “inebriate and/or vagabond.” However, recent heat and cold deaths are more frequent in elderly people living indoors, indicating the change of damage patterns during the last few decades. A detailed analysis of the processes leading to heat and cold deaths must be made to take effective measures towards casualty reduction.

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Notes

1. The official English name of Tokyo-to is “Tokyo Metropolis” and not “Tokyo Prefecture”; but this distinction is omitted in this paper for the sake of convenience.
2. Wards in GDCs do not have a governing system, whereas those in the TWA have a municipal status equivalent to cities. Apart from this difference, the TWA has an appearance of a GDC.
3. The gridded temperature data were constructed from the observed values of the JMA’s Automated Meteorological Data Acquisition System (AMeDAS), which has a horizontal resolution of ~20km, so that the gridded data do not represent actual temperature variability on a scale smaller than 10km, although topographical and urban factors have been taken into account on the basis of empirical relationship (https://www.data.jma.go.jp/obd/stats/etrn/view/ atlas_manual_new.html).
4. No job rate is different from unemployment rate in that it includes all kinds of jobless people such as pensioners; students are not included. Some respondents (10–20%) did not answer the “2013 Housing and Land Survey.”
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