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Extreme Heat and Vulnerability in Japan
Demographic and Spatial Analyses of Heatstroke

Wataru Gima
The Graduate Center, City University of New York

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EXTREME HEAT AND VULNERABILITY IN JAPAN
DEMOGRAPHIC AND SPATIAL ANALYSES OF HEATSTROKE

by

WATARU GIMA

A master’s thesis submitted to the Graduate Faculty in Liberal Studies in partial fulfillment of
the requirements for the degree of Master of Arts, The City University of New York

2019
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Wataru Gima

This manuscript has been read and accepted for the Graduate Faculty in Liberal Studies in satisfaction of the thesis requirement for the degree of Master of Arts.

22 April 2019

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ABSTRACT

Extreme Heat and Vulnerability in Japan
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Advisor: Deborah Balk

This master’s thesis attempts to discover demographic and spatial disparities in heatstroke deaths in Japan. The first part of analyses was conducted by demographic methods, which utilizes heatstroke deaths data classified under the ICD-10 code from 1995 to 2017. I found that males had more deaths than females during the study period and that the elderly population of both genders had significantly higher number of deaths. In addition, the study examined the probability of surviving and life expectancy among the elderly population when eliminating heatstroke deaths, improvement in these two variables was observed however remained small, as the number of heatstroke deaths has been small, compared to other major diseases.

The second part of the study is spatial analyses of heatstroke deaths by prefecture and patients in 23 special wards as well as Osaka City. In this part, the study used prefectural heatstroke deaths data from 2013 to 2017, during which the total number of deaths was concentrated in prefectures with large populations such as Tokyo and Osaka Prefecture. However, the crude death rate (CDR) for both genders was higher in other prefectures; with
Okinawa Prefecture having the highest CDR among elderly males while Toyama Prefecture having the highest CDR among elderly females.

Through reviewing several researches on how different elderly males and females had experienced heatstroke, the study also identified spatial variations in heatstroke occurrence between males and females: males experiencing heatstroke the most in the bedroom while females experiencing it the most in the kitchen. This difference suggests that heatstroke may have occurred more on a particular gender depending on their traditional gender roles within households. Lastly, the vulnerability assessment on heatstroke risk in Tokyo Metropolitan area and Osaka City was conducted by using the several human factors of heatstroke such as the elderly population. The result was that several wards in both study areas had much higher vulnerability compared to other wards, which indicates the spatial disparities of heatstroke risks within the two major metropolitan areas of Japan.
ACKNOWLEDGMENTS

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Secondly, my families in Okinawa, Japan and in New York who have always been there for me throughout two years of my academic endeavor at the Graduate Center. Your continuous support has played a significant role in this chapter of my life.

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CHAPTER 1
1.1 INTRODUCTION

The earth is warming rapidly due to anthropogenic greenhouse gas emissions that have increased since the preindustrial era, driven by economic and population growth (IPCC AR5, 2014). As a result, a variety of socioeconomic impacts including an increase in extreme heat events, heavy precipitation events, and sea level rise have stemmed from global warming. In July 2018, the Japan Meteorological Agency (hereafter JMA) had declared heat waves as a natural disaster for the first time.\(^1\) According to the Fire and Disaster Management Agency of Japan, 92,710 people were hospitalized due to heatstroke between May and September in 2018, with an increase of 42,153 people from 2017 (FDMA, 2018). According to the JMA, extreme heat, also known as Mousho (猛暑) in Japanese, refers to the temperature of 35°C (=95°F) or above.\(^2\)

Record-breaking extreme heat events were also observed in the past. For instance, the JMA reported that the average temperature of Japan from June to August in 2010 was the hottest over the last 113 years since the government began collecting temperature data in 1898.\(^3\) Furthermore, the average summer temperature in 2010 was 1.64°C higher compared to the 30-year average from 1971 to 2000. As shown in the next chapter, the number of heatstroke deaths has also been increasing in Japan, with the elderly population being disproportionately more vulnerable.

---


Numerous research, backed with government actions, regarding the increasing risks of extreme heat events have emerged from all over the globe. Some researchers attempt to project heat-related mortality and trends of future extreme heat events that would cause high mortality in the United States (Anderson et al., 2016 and Petkova et al., 2013 and 2014) while others examine how temperature and humidity would increase heat-related mortality in the future (Barreca, 2010, Akihiko et al., 2014, and Fujibe, 2013) and disparities in heat-related deaths (Gronlund, 2014).

In Japan, however, researches on demographic characteristics of heatstroke deaths and spatial distribution of risks and disparities appear not to have been thoroughly conducted. It is important to capture demographic and spatial characteristics of heatstroke deaths in Japan, as threats of global warming have become severe and intertwined with other social issues such as rapid aging. Therefore, in this master’s thesis, I ask two questions: (1) using demographic methods, what patterns and disparities can be identified in heatstroke deaths from 1995-2017; and (2) how the number of heatstroke deaths vary across prefectures; and how heatstroke occurrences vary within the two major metropolitan areas of Japan: 23 special wards in Tokyo and Osaka City.

To answer the first question, I utilized heatstroke deaths data that is classified under the International Classification of Diseases 10 (ICD-10), and the period studied is from 1995 to 2017. Several datasets were used to answer the second question: heatstroke deaths by prefecture and reviews on research that
examined characteristics of heatstroke occurrence in a smaller scale of space such as inside the residential buildings. In addition, three variables of the human factors of heatstroke as well as the number of heatstroke patients in 2015 were used to conduct vulnerability assessment in the two study areas of Tokyo and Osaka.

1.2 LITERATURE REVIEW

I will begin the review of related literature by establishing a deeper understanding of heatstroke: what it is and how it occurs. Saito (2018) held a training session for the prevention of heatstroke at the workplace, and his PowerPoint slides are available on the website of the Ministry of Health, Labour and Welfare. Heatstroke occurs due to multiple factors such as intensive heat, imbalance of body water and salt. It can be categorized into three degrees of severity. Severity I causes dizziness, muscle pain, and numbness of legs and hands. Severity II causes nausea, headache, and fatigue. Severity III causes high body temperature, convulsion, and disturbance of consciousness. Thus, especially for Severity III, it is a must to call for an ambulance if you or people around you experience such symptoms. As we all know, the worst case scenario can be death.

Saito (2018) also discusses five factors that increase risks of heat stroke especially at the workplace: environment, work, clothing choice, time, and the human body. The human body factors include whether a person is obese, holds chronic diseases such as high blood pressure and diabetes, is elderly, and so on. Although this master’s thesis does not look at individual cases of heatstroke deaths or occurrence, these factors are important to consider in future field researches.

---

It is because certain factors may increase risks of getting heatstroke and may be more effective in terms of heatstroke prevention. For instance, proper clothing choice may provide a short-term response to reduce risks of heatstroke during hot days, while improving health conditions may have long-term effect for an individual. Understanding how these five factors of heatstroke influence each other will provide more precise and insightful information in order to establish mitigation methods during intense heat events.

Researches on the associations between extreme heat and mortality have been conducted in several ways. Akihiko et al. (2014) analyzed the correlation between heatstroke deaths and climate variability in the Kanto region of Japan, comparing two temperature indicators: the Wet Bulb Globe Temperature (WBGT) and the number of extremely hot days, days in which the daily maximum temperature exceeds 35°C (95°F). The WBGT index is an index developed in the United States in 1954 in order to prevent heatstroke. The index uses the unit of Celsius but incorporates temperature, humidity, wind speed, sun angle, and cloud cover (solar radiation) to represent how human body perceives temperature.

The authors found a higher correlation between the number of heatstroke deaths and the number of extremely hot days, compared to the WBGT. In addition, the authors examined the tropical climate variability such as El Nino/Southern Oscillation and the Indian Ocean Dipole (IOD) to find causes of the inter-annual variability in the number of extremely hot days. They found that the positive IOD tended to be more frequently associated with the excess number of extremely hot days. However, the correlation between these two variables was proven to be weak. Although this research will not look at the relationship between the number of extremely hot days and climate variability, their findings suggest that climate variability may also be a factor that needs to be considered in future research. Lastly, even though the authors have pointed out
that the number of extremely hot days might be a better index to be used in researches of heatstroke deaths, this research still incorporates the WBGT index.

Fujibe (2013) used the summer temperature of July and August to analyze long-term variations in heat mortality and summer temperature in Japan. Japan has conformed to the International Statistical Classification of Diseases and Related Health Problems (ICD) since 1899. The most recent ICD is ICD-10 that has been applied since 1995, and deaths due to heatstroke are classified under the code X30, defined as “exposure to excessive natural heat”. Using these data, Fujibe analyzed a long-term variation in summer temperature and heat mortality from 1909 to 2011. The results show that there is a correlation of 0.7 to 0.8 between summer temperature and heat-related deaths before the World War II and from 1960 to the beginning of 1990s. However, the correlation becomes weak after the end of 1990s, which suggests that there might be other factors other than temperature. The research shows that the elderly have the highest mortality rate. This implies that the recent rapid increase in the number of heat-related deaths among elderly is due to the change in population structure and increase in the elderly population. Furthermore, Fujibe did not find any prefectural deviation in heat-related mortality rate in Japan; however, Tokyo and Osaka Prefectures had a relatively higher increase in mortality rate compared to the surrounding prefectures. It is important to note that there might be an ostensible increase in heat mortality due to a shift from ICD-9 to ICD-10 (Hoshi et al., 2010). However, Fujibe states that such increase in heat mortality may not be as apparent as it had been discussed. This research focuses on heatstroke death from 1995 to 2017, during which the ICD-10 has been used to classify causes of deaths.

Fujibe et al. (2018) examined spatial and temporal features of heatstroke mortality in Japan from 1999 to 2014. They found that heatstroke mortality has different spatial patterns; for
instance, the mortality rate under age 60 is positively correlated with seasonal mean temperature and is higher in the southern parts of Japan. Also, the mortality rate of the age group 80 and over is positively correlated with summer peak temperature. Their findings provide an insightful contribution that this research should include several temperature variables besides extremely hot days and the WBGT index. Furthermore, their results suggest that vulnerability to extreme heat may also have different spatial patterns when taking several socioeconomic variables into analysis. Additionally, they state that the WBGT index may not be enough for damage prevention against extreme heat, as the index is only valid for outdoors while the elderly tend to suffer from a heat stroke indoors. However, high WBGT is expected to have influence, as it will increase indoor temperature when no air conditioning is present. This question should be asked in future research in order to examine how temperature itself and the WBGT index impact indoor temperature.

Hoshi et al. (2010) also looked at a regional difference in heat mortality in Japan. According to their results, mortality and age-adjusted mortality due to heat disorders tended to be higher in areas along the Sea of Japan and inland areas, and lower in areas along the Pacific Ocean in northern Japan. The prefecture-specific differences in heat mortality is attributable to differences in the summertime heat environment as well as the intensity of heat wave. Their findings are consistent with other researches that I mentioned above that summer temperature is one key factor that significantly influences heat mortality; thus, I will be using temperature data between May and September. Barreca (2010) examined the effects of temperature and humidity on mortality in the United States from 1968 to 2002. His findings indicate that temperature and humidity have a large impact on cardiovascular-related and influenza-related mortality and impact individuals over the age of 45. Furthermore, he projects that mortality rate is likely to
increase by 0.9 percent by the end of 21st century in the United States.

Racial and socioeconomic disparities in heat-related deaths have been observed in the United States. Gronlund (2014) provides a thorough overview of the mechanisms of racial and socioeconomic disparities in heat-related health effects. In the United States, blacks tend to have relatively higher vulnerability to heat-associated health effects, compared to whites and other ethnic groups. Being a racial and ethnic minority in the U.S. is often associated with lower income, poorer physical health, living in a vulnerable area, lower air conditioning ownership, and so on. Furthermore, she states that occupations such as construction workers, farm laborers, miners, first responders, and military personnel have higher exposure to heat; thus, people in these occupations have higher vulnerability to extreme heat events in general. We may not have enough data to analyze racial disparities in terms of heat mortality, as Japan is a homogeneous country; however, future researches should collect and incorporate other aspects of inequality.

Researches on extreme heat also include future projections using the Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs). The SSPs and RCPs were designed by an international team of climate scientists, economists, and energy systems modelers to explore “how global society, demographics and economics might change over the next century.” Anderson et al. (2016) have used two climate change scenarios (RCP 4.5 and 8.56), two scenarios of population change (SSP3 and 5), and three scenarios of community adaptation to heat (none, lagged, and on-pace) in order to project trends in high-mortality heat waves in 82 U.S. communities. High-mortality heat wave was defined as heat waves that

---


6 RCP 4.5 is a scenario wherein greenhouse gas emissions will be stabilized before 2100 because of employment of a range of technologies and strategies for reducing greenhouse gas emission. On the other hand, RCP 8.5 is a high emission scenario, wherein the global temperature rises by about 5-6°C by 2100.
increase mortality risk by $\geq 20$ percent. They found that more high-mortality heat waves, expect on-pace adaptation, and population exposure were expected; although such severe heat waves remain as 1 percent of all heat waves and its exposure under all scenarios. Despite projections of extreme heat events being beyond the scope in this study, applying their methods to Japan may bring insightful results, in future research.

1.3 DATA AND METHODOLOGY

1.3.1 DATA

This study incorporates spatial and non-spatial data. The number of deaths due to heatstroke by gender was obtained from e-Stat, the Japanese government’s statistical website. As I mentioned above, my analysis focuses on heat mortality under the ICD-10 classification, which is from 1995 to 2017. (2018 data is not included in this study because the data is not available yet.) The ICD-10 code for heatstroke deaths is X30, which is available for both male and female and in age groups. Age groups are 0, 1-4, 5-9...90-94, 95-99, and 100+. Population data was also obtained from the same website and is available in one year intervals, which is summarized in 5-year age groups for all ages above 1, and the very old. It is important to note that Japan has conducted a national census every five years since 1920; thus, population data for the same duration of time as of heatstroke deaths, 1995, 2000, 2005, 2010, and 2015, has detailed numbers. For the rest of the years, population is shown per 1,000, thus this research experiences a limitation in population data. Furthermore, open age interval of population data from 1996 to 1999 as well as from 2001 to 2004 is aggregated at age 90+. To overcome this limitation, I have conducted the following procedures to estimate population for the age groups of 90-94, 95-99, and 100+ for the respective years mentioned above. Firstly, I divided the period from 1995 to 2005 into two, 1995-2000 and 2000-2005, and calculated the mean annualized growth rate for
each age group during the two periods. To do this, the following formula was used:

\[ r^{90-94} [1995, 2000] = \frac{\ln\left(\frac{N(2000)}{N(1995)}\right)}{5}, \]

where \( r \) is an annualized growth rate, and \( N \) is the population data of the respective age groups and years. The table below is the respective growth rate. Figures 1.1 and 1.2 show the interpolated population of these age groups for males and females.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>90-94</td>
<td>0.0797</td>
<td>0.0688</td>
<td>0.0906</td>
<td>0.0807</td>
</tr>
<tr>
<td>95-99</td>
<td>0.0935</td>
<td>0.1004</td>
<td>0.1125</td>
<td>0.1195</td>
</tr>
<tr>
<td>100+</td>
<td>0.1040</td>
<td>0.1236</td>
<td>0.1443</td>
<td>0.1494</td>
</tr>
</tbody>
</table>

Figure 1.1 | The mean annualized growth rate for age groups of 90-94, 95-99, and 100+ 1995-2000 and 2000-2005

Using these growth rates, I applied the following equation to interpolate the population of the respective age groups:

\[ N(T) = N(0) \cdot e^{Tr}, \]

where \( T \) is the year, and \( r \) is the growth rate. For instance, estimating population for the age group of 90-94 in 1996 when there are 100,219 people in the same age group in 1995 is:

\[ N(1) = N(0) \cdot e^{1 \cdot 0.0797} = 100,219 \cdot e^{0.0797} = 108,535 \]

In this example, \( T \) is 1 because 1996 is just a year after 1995. For the second period from 2000 to 2005, \( N(0) \) is 2000.

---

7 The formula is an example for the age group 90-94 from 1995 to 2000.
Based on the results, the growth of the eldest population is the most noticeable among the

---

8 Each dot in 1995, 2000, and 2005 in each solid line is the actual data from the national census. The same goes for Figure 3.3 as well.
age group of 90-94 for both males and females. However, the growth is larger among females from 1995 to 2005. Furthermore, the population growth of the other two age groups is also larger among females.

Chapter 3 utilizes different datasets: heatstroke deaths by prefecture and gender as well as heatstroke patients in Tokyo Metropolitan area and Osaka City. The first dataset on prefectural heatstroke deaths from 2013 to 2017 was obtained from the Ministry of Health, Labour and Welfare of Japan. The second dataset on heatstroke patients by gender in Tokyo Metropolitan area and Osaka City from 2011 to 2015 was obtained from the National Institute for Environmental Studies, which is associated with two temperature variables.

Temperature data includes two variables: the number of days that exceeded 35°C (95°F) (= extremely hot days) and the Wet Bulb Globe Temperature above 28°C. The WBGT uses the unit of Celsius however it does not equal to the actual temperature. According to the Ministry of the Environment, the WBGT of 21°C or less is 24°C or less than the actual temperature; the WBGT of 28-31°C is equal to 31-35°C in the actual temperature. Although I use 35°C or above for the temperature variable as hot days, I use 28°C for the WBGT variable, 31°C of the actual temperature. The reason being, when the WBGT exceeds 28°C, the number of heatstroke patients drastically increases.\(^9\) Data on extremely hot days was obtained from the Japan Meteorological Agency, and the WBGT data was obtained from the Ministry of Environment. Although previous researches incorporated months other than summer, this research focuses on summer temperature; thus, months from May to September were used in the analyses. It is important to note that the WBGT


\(^{10}\) Same as above.
data from 2011 to 2013 does not include the month of May although data on heatstroke patients was collected from May to September each year. This might influence the result however it could be a minimum influence, as the majority of hot days is concentrated in July and August.

1.3.2 METHODOLOGY

Chapter 2 examines the demographic characteristics of heatstroke deaths in Japan. It begins with crude death rates of heatstroke deaths by year, gender, and age group in order to examine disparities in heatstroke deaths from 1995 to 2017. In addition, a life table analysis method is used to study how extreme heat has affected society over time. This method helps us examine improvements in life expectancy and probability of surviving and dying when eliminating heatstroke deaths, as well as proportion of population at respective age groups that will die due to heatstroke. As mentioned previously, future projection of extreme heat events or heatstroke deaths is out of scope. However, past trends may provide us with insightful suggestions as to how extreme heat would influence society.

Chapter 3 focuses on spatial aspects of heatstroke deaths and patients to examine how the characteristics of heatstroke vary or are concentrated on certain areas of Japan. Furthermore, I intend on conducting a vulnerability assessment of heatstroke risks in 23 special wards in Tokyo and Osaka City. This assessment takes the number of heatstroke patients and the other human factors of heatstroke such as the number of the elderly population as well as the elderly population who are living alone. I took the proportion of each variables, and the vulnerability level was calculated by summing each variable.
1.3.3 LIMITATIONS

This research encountered several limitations. First, the demographic data while of fine quality, are somewhat limited for use in this analysis. As mentioned above, only years during which a national census was conducted have detailed population data. Because of this, demographic analyses using life tables only use population data from 1995, 2000, 2005, 2010, and 2015 in order to deliver meaningful results. Another issue with population data is that I have annually interpolated population for the age groups of 90-94, 95-99, and 100+ for the years from 1996 to 1999 and from 2001 to 2004, as mentioned in DATA and METHODOLOGY. The interpolated population may not be accurate as it would ignore cohort or period-specific variability that may be real in between the observations, but the research moves forward with this limitation in order to create age groups throughout the study period.

Secondly, the first part of the analysis focuses on the elderly population, as they are disproportionately more vulnerable to extreme heat events and have much higher age-specific mortality rate. For this reason, I have selected age groups from 60-64 to 95-99, excluding the open age interval of 100+. It is important to note that this research still recognizes the necessity of studying relationships between extreme heat events and younger generations both to understand the impact on those age groups (though perhaps it would be observed through other disease outcomes) and as a comparison of the relationship between extreme heat and mortality of younger age groups to the elderly.

Thirdly, data on prefectural heatstroke deaths used in Chapter 3 is not available in age groups. Thus, the analysis that looked at the deaths among elderlies assumed the same distribution of deaths among elderlies that was found in Chapter 2. More detailed discussion on this is provided in the chapter.
Fourthly, similar to the third limitation, data on heatstroke patients that I obtained from the National Institute for Environmental Studies is provided by gender but not in age groups. As most of heatstroke deaths are concentrated among elderlies, we may also assume that there would be higher proportion of heatstroke patients. However, it is worth noting that applying such assumption on the dataset of heatstroke patients may not yield accurate results, and this research should re-analyze once the proper data is available.

Fifthly, temperature variables that I utilize in Chapter 3 are the number of days that the maximum temperature exceeded 35°C and the number of days that the daily maximum WBGT exceeded 28°C. As I discuss in detail in Chapter 3, there are several other ways to incorporate temperature variables in examining relationships between temperature and heatstroke deaths/occurrence. For instance, one can look at how long in a day high temperature are consecutively observed. Or, one can also look at the deviation of temperatures of days when there were relatively more heatstroke deaths/patients in comparison to the 30-year average temperature.

Lastly, datasets I utilized in this master’s thesis are particular for certain years; thus, using datasets from different years may yield different results. However, I believe all the analyses I conducted in Chapter 2 and 3 are unique and valuable in order to better understand the important characteristics of heatstroke in Japan.

CHAPTER 2

2.1 DEMOGRAPHIC ANALYSES OF EXTREME HEAT

In this chapter, I used three datasets, population, the total number of deaths, and heatstroke deaths (ICD-10: X30), to conduct demographic analyses. As mentioned above, the period of time studied is from 1995 to 2017, during which the ICD-10 has been applied to
classify causes of deaths. Figure 2.1 shows the increasing number of heatstroke deaths in Japan for both males and females. The drastic increase in the number of deaths in 2010 was due to record-breaking heat waves. According to the report created by the Japan Meteorological Agency, the average temperature from June to August in 2010 was the hottest over the last 113 years since the government began measuring temperature in 1898. Comparing the summer temperature in 2010 to the average temperature from 1971 to 2000, the temperature in 2010 increased by 1.64°C. For the most part of the study period, we can observe that there are more deaths for males than females. Although we cannot provide any conclusion at this stage of analyses, the figure indicates that males might have relatively higher exposure to the risks of extreme heat in Japan. Several possible explanations regarding this characteristic include the followings; 1) There are more males than females who engage in occupations such as construction, mining, fishery, and farming which are known to have higher exposure to heat; 2) Females in general have office work, thus have less exposure to heat or are in an environment with adaptation measures to heat such as air conditioning.

Figure 2.1 | The total number of heatstroke deaths, 1995-2017
It is necessary to decompose the total number of heatstroke deaths by age groups in order for us to further understand the demographic characteristics of heatstroke deaths in Japan. Figure 2.2 is the summary of the total number of heatstroke deaths by age group from 1995 to 2017. It is clearly shown that males have more deaths until the age group of 75-79; while females surpass after the age group of 80-84. This may be because there has been more elderly female population compared to males, which indicates that females at older ages fundamentally have higher exposure to extreme heat in general. Furthermore, the result imposes significant pressure on Japan’s aging society that global warming is expected to have additional health impacts, especially on the elderly.

![Figure 2.2 | The total number of heatstroke deaths by age groups, 1995-2017](image)

Figure 2.3 shows the CDR of the total number of heatstroke deaths of each gender per 1,000,000 people. The CDR was calculated as follows:

\[
\text{CDR}^{\text{male}} = \frac{\text{Total number of heatstroke deaths at time } T}{\text{Total number of male population at time } T} \cdot 1,000,000
\]
Interestingly, the figure resembles a similar path as Figure 2.1. It is important to note that including the total number of population might be a conservative denominator, as the entire population may not have been exposed to extreme heat. However, the CDR of the total number of heatstroke deaths also suggests that historically, males tend to have higher exposure and risks to extreme heat than females in Japan. Now, let’s examine how the CDR by age group looks like. Figure 2.4 shows the age specific CDR for males and females. Unlike Figure 4.2, the crude death rate of males’ heatstroke deaths for elderlies from 1995 to 2017 is much higher compared to females. The CDR is helpful to understand the overall characteristics of heatstroke deaths; however, the result depends on the denominator that is the male and female population in this study. The reason being, there are more females at older ages, compared to males, which makes the female CDR lower than males. To test what is attributable to the difference in the CDR, the Kitagawa decomposition method can be used.

---

The Kitagawa Decomposition is a method to decompose the difference between rates in A and B. In this master’s thesis, the rate is death rate, and I examined what was more attributable to the difference in the crude death rate of heatstroke deaths between males and females, differences in age compositions or
Before conducting the Kitagawa Decomposition, it is also important to see how the CDR among the elderly population has shifted over time. The graph below examines the changes in the standardized age specific crude death rate for age groups from 60-64 to 85-89 over time. I used the 2017 population for each gender as the base population in order to compare the changes without the results being influenced by neither population growth nor decline. Both graphs have a similar trend as Figure 2.1 and 2.3. Among the selected age groups, the standardized age-specific mortality rate of the age groups between 60 and 74 has not increased as much as the ones of the older age groups. One significant difference that draws attention is the gender difference in age groups which have relatively higher standardized age-specific CDRs. For males, the age group of 85-89 has experienced the largest increase while females in age groups of 80-84 had the largest increase. In addition, males at 85-89 have had the highest standardized age-specific CDR since 1995 except 1997. Especially in 2010 when there were severe extreme heat events, males in the eldest age group had the mortality rate of 264 heatstroke deaths per differences in age-specific death rate.
1,000,000 people that spans far beyond the mortality rates of other age groups. On the other hand, females in two age groups, 80-84 and 85-89, have had a similar pattern over the study period with some variations.

With these results, it is more likely that the eldest males will have much higher death rates, especially when extreme heat events occur in the future. Although this trend may not be necessarily applied to females based on the results, females at age above 80 will have equally high mortality rates compared to younger age groups. Overall, the standardized age-specific CDR among elderlies is most likely to increase in the future. These results should draw the attention of the public, as well as the government to prepare mitigation and adaptation strategies against extreme heat, as rapid aging in Japan is expected to worsen the situation.

Figure 2.5 | Changes in the age-specific CDR of males from 60-64 to 85-89, 1995-2017
As the study continues with demographic analyses of heatstroke deaths in Japan, I used the Kitagawa Decomposition method in order to examine what is causing the differences in mortality rates between males and females. For this analysis, I used population data from years when the national census was conducted: 1995, 2000, 2005, 2010, and 2015. The Kitagawa Decomposition was conducted as follows. Firstly, I took the age composition as well as age-specific mortality rate of each age group for both males and females. Secondly, I used the next two equations in order to identify contributions of age composition and age-specific mortality rates to the differences in the CDR:

\[
\text{Contribution of age composition} = \left( C_i^m - C_i^f \right) \cdot \frac{M_i^m + M_i^f}{2},
\]

\[
\text{Contribution of age-specific mortality rate} = (M_i^m - M_i^f) \cdot \frac{C_i^m + C_i^f}{2},
\]

where \( C \) is the population proportion of age group \( i \), and \( M \) is the age specific mortality rate of age group \( i \). Thirdly, each age specific contribution was summed and divided by the original difference in the CDR of males and females. Figure 2.7 shows the result.
The result clearly shows that the differences in the CDR were attributable to differences in age-specific mortality rates for every single year. Furthermore, the weight of age-specific mortality rates has been increasing, which is consistent with the previous results that age-specific mortality rates have increased since the beginning of the study period.

Life table analysis is a fundamental analytical method of demography. With information on deaths and age, the life table enables us to understand life expectancy at birth, and the probability of surviving and dying of a certain age or age groups. Furthermore, we can choose the cause(s) of deaths and create multiple decrement and/or associated single decrement life tables in order to examine how much life expectancy or other functions would improve when eliminating causes of deaths. For instance, the male life expectancy at birth was 76.53 years in 1995 and 80.75 years in 2015. When eliminating deaths due to heatstroke, it becomes 76.54 years in 1995 and 80.76 years in 2015. In this case, the increase is a small amount because of the relatively small number of heatstroke deaths compared to other major diseases such as malignant
neoplasm. Using this life table method, the next analysis looks at several demographic characteristics of heatstroke deaths in depth. It is important to mention that I found a significant difference in the number of population of the census years and years in between each census. Therefore, I only selected years of the census, being 1995, 2000, 2005, 2010, and 2015, in order to deliver results as accurate and meaningful as possible.

Figures 2.8 and 2.9 are the results of the first life table analysis: proportion of males and females at older ages who will die from heatstroke based on the age-specific mortality rate of the respective years. The proportion was calculated by using two life table functions: \( l_x \) and \( l_x^i \). The function \( l_x \) is the number of life table population who is alive to respective age groups, and \( i \) means \( l_x \) when eliminating heatstroke deaths. The proportion was calculated as follows:

\[
\text{The proportion} = \frac{l_x^{i}}{l_x} \times 100
\]

The age groups that were selected were from 60-64 to 90-94 for both genders. As the number of heatstroke deaths is still small compared to other major causes of deaths, the proportion is also small. However, it is evident that the proportion has been increasing for both males and females. The result is consistent with the severe extreme heat which occurred in 2010 and increased the proportion drastically. Additionally, we can also expect it to increase in 2018 as Japan experienced another extreme heat event. It is interesting that we can observe similar lines of proportions for males and females of age groups from 60-64 to 75-79; however, the proportion of age groups from 85-89 to 90-94 is lower for females than males. This result suggests that males are expected to face a higher risk of heatstroke deaths at older ages compared to females who are in the same age groups.
Figure 2.8 | Proportion of those survived to respective age groups who will die from heatstroke male 1995, 2000, 2005, 2010, and 2015

Figure 2.9 | Proportion of those survived to respective age groups who will die from heatstroke female 1995, 2000, 2005, 2010, and 2015

The increase in the proportion from 1995 to 2015 was the highest for the age group of 60-64 for both males and females; 0.039 percent for males and 0.031 percent for females. This may be due to an increase in the number of population in the age group and suggests that the size of a vulnerable population will continue becoming larger and larger, as aging proceeds further in Japan.
In this next life table analysis, I looked at how the probability of surviving would improve when eliminating heatstroke deaths. Figures 2.10 and 2.11 show the difference between the probability of surviving with and without eliminating heatstroke deaths. For both males and females, the older the age group is, the higher improvement in probability of surviving, which is the result of elderlies being more vulnerable to extreme heat. Among males, the eldest age groups of 85-89 and 90-94 have had the highest improvement throughout the study period. However, the probability went down to the level of 1995. On the other hand, males in the age groups from 60 to 74 have had the lowest probability although the probability has been increasing as well. Females have shown similar trends as males – that the older age groups have had the highest improvement in probability, while the younger age groups have had the lowest. In addition, some differences can be observed between males and females. Firstly, there is a wider gap between the probabilities of the younger age groups from 60-79 among females. Although the probability of surviving is shown in percentage and is seemingly very small, its difference between the age group of 60-64 and 70-74 in 2010 is 55 people per 1,000,000 for females while it is 39 people per 1,000,000 for males.

![Figure 2.10](image)

**Figure 2.10** | Improvement in the probability of surviving when eliminating heatstroke deaths
In this chapter, I have utilized several demographic methods to analyze the characteristics of heatstroke deaths in Japan from 1995 to 2015 and have shown the following findings. Firstly, the total number of heatstroke deaths for both genders has been increasing since the beginning of the study period, and males have had more deaths compared to females throughout the period. Secondly, when decomposing the total number of deaths into age groups, elderlies in age groups from 60-64 to 95-99 have had more deaths, compared to younger age groups. When all the deaths by age group are combined from 1995 to 2017, it has shown that there were more deaths among females than males. This result might be because there are more women at older ages than men.

To better understand the demographic characteristics of heatstroke deaths, I looked at the crude death rate in several ways. The CDR of the total number of heatstroke deaths showed a similar path as Figure 2.1: the total number of heatstroke deaths. However, the age-specific CDR per 1,000,000 people revealed that males at older age groups have had much higher CDRs over females’. Furthermore, the age-specific CDR for males and females became higher towards older
age groups, except males in the open age interval had a lower CDR compared to the age groups of 95-99.

As elderlies of both genders are statistically more susceptible to heat, the study focused on age groups of 60-64 above, in order to further analyze how demographic characteristics of extreme heat, are similar or different between males and females and among each gender. The age-specific CDR in this analysis was standardized by using the 2017 population as a base population in order to examine the mortality rates without being influenced by population growth or decline during the study period. Among males, the eldest age group has had the largest standardized age specific CDR; while females have had gaps between each age group. To examine what is causing the differences in the crude death rate between males and females, I conducted the Kitagawa Decomposition. The result showed that differences in age-specific mortality rates among males and females have a much larger influence in the differences in the CDR of heatstroke deaths.

Using several life table analyses, I have discovered the trend of increase in the proportion of elderlies who will die of heatstroke. This trend has the heaviest effect among males in the eldest age groups. Furthermore, the analysis on probability of surviving showed that the eldest age groups of males and females had a larger improvement in survival probability when eliminating heatstroke deaths. Although the proportion of heatstroke deaths among the elderly population resulted in a small number, the proportion may increase, as prevention and cure of major causes of deaths become more available and accessible, which would require more attention than ever from public health agencies.
CHAPTER 3
3.1 SPATIAL ANALYSES OF HEATSTROKE DEATHS

In the previous chapter, I examined the disparities in the demographic characteristics of heatstroke deaths, especially among the elderly population in Japan. The main objective of this chapter is to look at spatial disparities of heatstroke deaths across Japan and of heatstroke patients in 23 special wards in Tokyo and Osaka City. Space is an important factor to be considered since intensity of extreme heat may differ depending on where people live or stay during extreme heat events. As Japan “consists of a great string of islands in a northeast-southwest arc that stretches for approximately 1,500 miles (2,400 km) through the western North Pacific Ocean,”\(^\text{12}\) there are most likely regional differences within the country.

This chapter uses a different dataset for heatstroke deaths, as the data (ICD-10) does not contain spatial information. The vital statistics of Japan provides the number of heatstroke deaths by prefecture and gender from 2013 to 2017, which is available on the website of the Ministry of Health, Labor and Welfare. Data is also available for 2010; however, I have excluded it from the analysis. The reason being, 2010 was an exceptionally hot year with numerous heatstroke deaths in Japan. It is also because data for years before and after 2010 is not available on the website.

There are 47 prefectures in Japan, and the figure below shows the total number of heatstroke deaths by prefecture and gender. Based on data between 2013 and 2017, Tokyo Prefecture had the highest number of heatstroke deaths, followed by Osaka and Hyogo Prefecture. Seemingly, the number of deaths is concentrated in the more populated prefectures; the proportion of population in these prefectures in 2017 is 10.96 percent (males) and 10.7 percent (females) in Tokyo, 6.88 percent (males) and 7.04 percent (females) in Osaka, and 4.26 percent (males) and 4.43 percent (females) in Hyogo Prefecture. Although there are prefectures

with a higher proportion of population with less heat stroke deaths, and vice versa, a correlation between the total number of heatstroke deaths and population during these five years shows a strong correlation: 0.892 for males and 0.88 for females.

Figure 3.1 | The total number of heatstroke deaths by prefecture, 2013-2017

Figure 3.2 shows the crude death rate of heatstroke by prefecture and gender. It is to my surprise that the CDR for males is the highest in Okinawa Prefecture, followed by Kagoshima and Kochi Prefecture. In Okinawa, the CDR is 19.3 people per 1,000,000 while the smallest CDR was observed in Hokkaido Prefecture: 2.4 people per 1,000,000. Among females, Toyama Prefecture had the highest CDR, followed by Kagoshima and Kagawa Prefecture. The CDR of females in Toyama Prefecture is 13.4 per 1,000,000 people; while Hokkaido Prefecture has the smallest CDR for females. For Hokkaido Prefecture, it may simply be because it is the northernmost prefecture, the majority of which is under the subarctic climate. Furthermore, there
are few days in the summer that the maximum temperature exceeds 30°C. Therefore, it is most likely that Hokkaido Prefecture has the lowest exposure as well as vulnerability to risks of extreme heat events in Japan, as intense heat is one of the major factors of heatstroke deaths. In addition, for the total number of heatstroke deaths, Tokyo Prefecture had the largest number. However, Osaka and Hyogo Prefecture had more heatstroke deaths per 1,000,000.

![The CDR of heatstroke deaths by prefecture per 1,000,000 | 2013-2017](image)

Figure 3.2 | The CDR of heatstroke deaths by prefecture per 1,000,000 | 2013-2017

Several limitations are likely to have influenced the results above. Firstly, I included all the population. However, the elderly population is more vulnerable to heat, as I examined in Chapter 2. Thus, I re-analyzed the mortality rate using the 2015 elderly population from age 60 to 99. The reason why I only used the 2015 population data is because the other years’ data on population in these age groups is not available on the government statistical website. For the heatstroke deaths, I took the ratio of deaths among the age groups of 60-99 from 2015 ICD-10

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data that I used in the previous chapter, with the assumption that the ratio of elderly’s heatstroke deaths is the same in each prefecture. The ratio of the heatstroke deaths among males at age 60-99 in 2015 was 81.4 percent while females’ was 93.13 percent.

As expected, elderlies at the ages between 60 and 99 in Hokkaido Prefecture had the lowest mortality rate for both males and females. Based on 2015 data, the highest CDR for males was Okinawa Prefecture with 321.8 per 1,000,000, followed by Osaka (163.8) and Kagoshima (160.2). The CDR of males in Okinawa was almost twice as high as the other two prefectures, which suggests that males in Okinawa may have more exposure and vulnerability to heat in general. On the other hand, the CDR of females in Okinawa is much lower to the males’; while the gap between other prefectures’ CDR of males and females is not as wide, compared to the case of Okinawa Prefecture.

The characteristics of heatstroke deaths also vary in space in a smaller scale. According to the report created by the Ministry of the Environment, heatstroke among students and working
adults in government-designated cities including Tokyo Prefecture mostly occurs during exercises and at the workplace in 2013, respectively (Ministry of the Environment, n.d., p.6). On the other hand, heatstroke among the elderly population above age 65 occurred the most inside residential buildings. According to the vital statistics in 2016, 38.8 percent of heatstroke deaths among elderlies occurred at home (Ministry of the Environment n.d., p.7).

Shibata el al. (2010) had conducted research on how much elderlies recognized risks of heatstroke inside the house and its actual condition of preventive measures. The result was that 89.7 percent of elderlies recognized heat stroke and its meaning; however, the percentage went down to 65.7 percent for the recognition of heat stroke risks inside residential buildings. In addition, 38.8 percent of males did not know about occurrence of in-residential heat stroke, while 21.5 percent of females did not know about it.

Shibata et al. (2010) also examined where in the house the study subjects experienced heatstroke. The place where males experienced heatstroke the most was in the bedroom, which almost reached 40 percent of males. On the other hand, 40 percent of females had experienced heatstroke in the kitchen. Spatial characteristics of heatstroke occurrence in residential buildings vary among gender. Their findings suggest that there is relatively high risk of getting heat stroke in places in the house where people, especially elderlies relax; also, its risk can be influenced by traditional gender roles within the house.

Inoue et al. (2016) had examined the thermal environment of elderly people, 70s, in daily life in summer, comparing with young adults, 20s. They found that the length of elderlies using air conditioning inside the house is twice as less as the young adults. Furthermore, elderlies’ thermal environment in the house is two degrees Celsius higher and more humid than of young adults, which implies that elderlies might be in an environment with higher risks of heatstroke on
a daily basis. This also urges that awareness programs on heat stroke should not only focus on outdoor risks of heat stroke but indoor risks as well.

As the number of heatstroke deaths is concentrated in prefectures with high population, the last spatial analysis of this study intends on examining spatial disparities of heatstroke occurrence in Tokyo and Osaka Prefecture, more specifically Tokyo Metropolitan area and Osaka City. There are 23 special wards in Tokyo Metropolitan area and 24 wards in Osaka City. For this analysis, I used data on heatstroke patients by gender at ward level from the National Institute for Environmental Studies. The duration of time studied is from 2011 to 2015, where data by gender is available. However, the data is not provided in age groups. Along with two temperature variables, I also looked at the correlation between the number of patients and the two temperature variables in respective years. In addition to this, I conducted a vulnerability assessment of these two cities using 2015 data.

I began with analyzing how temperature, the WBGT index, and the number of heatstroke patients relate to each other. There is one weather station within each city, from which I have obtained temperature data as well as the WBGT index for the same duration of time, 2011-2015. As for temperature data, the number of days that the daily temperature exceeded 35°C from May to September was used. On the other hand, the number of days that the daily WBGT index exceeded 28°C was selected for the WBGT index because it is a threshold of high chance of getting heatstroke. For both Osaka and Tokyo, the index was only available from June to September between 2011 and 2013. Although this limitation might influence the result, it might be the minimum since the majority of days that exceed 28°C WBGT temperature is concentrated in July and August.

In the Tokyo Metropolitan area, there were a total of 38 days that the daily maximum temperature exceeded 35°C from 2011 to 2015: four days in 2011, six days in 2012, 12 days in 2013, five days in 2014, and 11 days in 2015. The days wherein the daily maximum WBGT exceeded 28°C were 45 days in 2011, 57 days in 2012, 48 days in 2013, 35 days in 2014, and 44 days in 2015. In the meantime, the total number of extremely hot days in Osaka City from 2011 to 2015 was 58 days: seven days in 2011, 12 days in 2012, 23 days in 2013, five days in 2014, and 11 days in 2015. Regarding the WBGT index, there were a total of 282 days that exceeded 28°C in the WBGT in Osaka City: 70 days, 67 days, 55 days, 46 days, and 44 days, respectively from 2011 to 2015. Overall, Osaka City had more hot days in both temperature variables. However, the Tokyo Metropolitan area had 13,692 heat stroke patients in those five years while Osaka City had 4,276 heat stroke patients.

As there are only a few variables for both temperature and heat stroke patients, I used Microsoft Excel’s trend line function in order to briefly look at the correlation between the number of heatstroke patients in each year and two temperature variables. The correlation was strong and positive between the number of heatstroke patients and extremely hot days: 0.6665 for Tokyo Metropolitan area and 0.64043 for Osaka City. On the other hand, the correlation between the number of heatstroke patients and the WBGT index was negative. This result may not determine the correlation between these variables, as the number of years studied is only five years. However, it indicates the necessity to pay close attention to extremely hot days.

For both actual temperature and the WBGT index, Osaka City had more days that exceeded the threshold of each variable. However, 23 special wards in Tokyo Metropolitan area had thrice as much heat stroke patients than Osaka City almost each year. Based on the 2015 national census, the elderly population above the age of 65 in the Tokyo Metropolitan area
amounts to 1,997,870 people, while in Osaka City 668,698 people. In addition, the number of heatstroke patients was higher in Tokyo Metropolitan area (3,298 people in 2015); there were 1,146 heatstroke patients in Osaka City in 2015. When looking at the rate with an assumption that the majority of the heatstroke patients in 2015 was also elderlies, Osaka City had 171.4 patients per 100,000 people while Tokyo Metropolitan area had 165.1 patients in 2015; thus, Osaka City had relatively more hot days as well as heat stroke patients, compared to Tokyo Metropolitan area. This comparison of heat stroke patients may suggest that hotter places would have a higher proportion of heat stroke patients per population even if places with larger elderly population would have larger exposure to risks of intense heat, resulting in more heat stroke patients in the absolute number.

A space-inclined vulnerability assessment of plausible heatstroke risks at a local level is another important field in regards to developing mitigation and adaptation measures against increasing risks of heatstroke. In my last analysis, I have conducted a case study of the vulnerability assessment in 23 special wards in Tokyo and 24 wards in Osaka City, using four variables from 2015 data that are summarized per ward: the proportion of heatstroke patients (V1), the proportion of the elderly population above age 65+ (V2), the proportion of households that only consists of elderlies above age 65+ (V3), and the proportion of the elderly population age above 65+ who live alone (V4). By summing the proportion of each variable per ward, I have calculated the vulnerability level of each ward in the two study locations. The equation remains simple but can be revised as other variables are included into the assessment. Weight on certain variables may also be added if such variables would increase vulnerability more than the other variables:

\[
\text{Vulnerability Level} = V1^i + V2^i + V3^i + V4^i,
\]
where $i$ indicates a ward.

Although there is room for improvement in this method, I have obtained several interesting results. Firstly, the vulnerability level of the wards significantly varies in each location. In Tokyo, the maximum possible and minimum possible levels are 37.84 and 2.86, respectively. Setagaya Ward in Tokyo had the maximum vulnerability level of 35.12 while Chiyoda Ward had only 3.38. The median level was 15.25, and the average was 17.39, which implies that the risks are more concentrated among the minority of the wards, as the median level is less than the average. In 2015, there were 9 special wards out of 23 wards that had the higher vulnerability level than the average. The top five special wards with the highest vulnerability level were Setagaya Ward (35.12), Adachi Ward (33.65), Oota Ward (31.06), Nerima Ward (30.41), and Edogawa Ward (25.39). The difference between the highest vulnerability level and the lowest vulnerability level was 31.28, which implies the significant disparity of heatstroke risks within 23 special wards of Tokyo Prefecture.

In the case of Osaka City, the maximum possible and minimum possible levels are 36.18 and 6.47, respectively. The median level was 14.27 while the average level was 16.67 in 2015, which is the same case for Tokyo. There were 9 wards out of 24 that had the higher vulnerability level than the average. The maximum level was observed in Hirano Ward, and the minimum was in Fukushima Ward. The top five special wards with the highest vulnerability level were Hirano Ward (33.17), Nishinari Ward (28.87), Sumiyoshi Ward (24.77), Higashiyodogawa Ward (24.02), and Yodogawa Ward (23.71). The difference between the highest vulnerability level and the lowest vulnerability level was 25.65.

The second interesting finding when comparing the top five wards with the highest vulnerability level in Tokyo and Osaka is that the relatively more variation in VL within the top
five wards was observed in Osaka City while the variation in the top five wards with the highest VL in Tokyo remained relatively small. This implies that heatstroke risks in Osaka City may be highly concentrated in one ward, and there are several wards that approximately share the same degree of risks in 23 special wards in Tokyo.

Third, the number of units I obtained from two study locations resulted in 47 wards, which can be compared by adding temperature variables as weight. By incorporating temperature variables, the assessment can be expanded to compare the vulnerability level among wards, cities, and prefectures. Furthermore, other variables such as the population in occupations with high exposure to heat such as mining and constructions can be added to make the assessment even more meaningful.

Along with other variables that have spatial information such as hospitals and evacuation facilities from intense heat during the summer, local governments can utilize results of this assessment by using geographic information systems in order to effectively allocate limited resources and to provide awareness programs to their citizens. For instance, local governments can establish temporal intense-heat evacuation centers more in places with the higher vulnerability level. Also, governments can collect data on heatstroke patients with spatial information such as GPS and examine if heatstroke occurrences are concentrated in places with high vulnerability level in order to validate this vulnerability assessment method.

It is important to note that there are several other ways to treat temperature data as well as the WBGT index. Firstly, one can use the number of hours within a day that exceeded 35℃ and how long it continued. Such data can be combined with a weekly report on prefectural heat stroke patients provided by the Fire and Disaster Management Agency from May to September to examine a close relationship between severe heat and heat stroke occurrence. Secondly, using
a deviation of a daily maximum temperature compared to the 30-year average temperature can also be used to analyze relationships between days that are relatively hotter than the past and heat stroke occurrence.

In this chapter, I first examined how the total number of heatstroke deaths from 2013 to 2017 varied across prefectures. With a strong correlation, I found that the number of heatstroke deaths was concentrated in prefectures with large population. However, the results of the CDRs showed that Okinawa Prefecture had the highest CDR per 1,000,000 people for the male population while Toyama Prefecture had the highest CDR for the female population. Through reviewing how heatstroke experiences vary between males and females within a smaller scale of space, the study encountered to an interesting question that future research can be conducted: how do cultural factors influence heatstroke occurrence in society? This research question is important to be asked because several research found that females experienced heatstroke in the kitchen the most while it was the bedroom for males. As Saito (2018) discusses the five factors that may increase risks of heatstroke, this cultural aspect can be the sixth factor to be considered in future studies of heatstroke.

Lastly, the vulnerability assessment I conducted may not be in the best shape yet but was helpful to further understand how much risks of heatstroke differ within 23 special wards in Tokyo and Osaka City. By incorporating more socioeconomic variables that may increase risks of heatstroke and temperature variables, the assessment can be more effectively used to identify vulnerable census tracts, wards, cities and prefectures and can be used to compare several study locations that are spread across space. This assessment method, once it becomes more sophisticated, can be a helpful tool for governments to efficiently and effectively allocate limited resources into necessary places during intense heat events.
CHAPTER 4
4.1 CONCLUSION

In this master’s thesis, I used demographic and spatial analysis methods in order to examine characteristics of heatstroke deaths in Japan. In Chapter 2, I found that males had a higher CDR compared to females during the study period from 1995 to 2017. It is especially clear that the elderly population had higher vulnerability to risks of heatstroke deaths, which also implies higher vulnerability to heat every year. The difference in the CDR of heatstroke deaths among males and females was more attributable to the differences in age-specific mortality rates, in which its weight has been increasing. In addition, the elderly population for both males and females turned out to be much more vulnerable, as the age-specific CDR became higher towards the older age groups.

The proportion of heatstroke deaths was small, which resulted in a small improvement in the probability of surviving and life expectancy at birth when eliminating heatstroke deaths as a cause of death. Even so, the proportion is expected to increase, as the proportion of other causes of deaths decrease due to advancement in medical treatments of such diseases. The results of the demographic analyses also indicate that risks of heatstroke deaths may increase more and more because rapid aging produces more elderly population. Although this study did not strongly discuss how the elderly population should be defined, future studies may be required to do so since people live longer and the age groups that are considered “elderly” may also shift to older age groups, which may exclude age groups of 60s.

In Chapter 3, I conducted spatial analysis of heat stroke deaths in Japan and of heat stroke occurrence in Tokyo Prefecture. As expected, the total number of heat stroke deaths from 2013 to 2017 in the northern prefectures was much smaller compared to other prefectures. Also, the total number of heatstroke deaths was concentrated in prefectures with large populations like
Tokyo and Osaka for both males and females. The death rate for males, however, was much higher in Okinawa Prefecture and the death rate for females was the highest in Toyama Prefecture. I have also examined the mortality rate of heat stroke deaths among elderlies above age 60 with several assumptions as mentioned above. Gender disparity was observed most clearly in Okinawa Prefecture, where the CDR of elderly males in 2015 was 322 per 1,000,000 people while the CDR of elderly females was 119 per 1,000,000. This result urges to further analyze heatstroke characteristics within Okinawa Prefecture in order to identify what factors may cause the difference in the CDR.

I have also reviewed several researches in order to examine how heatstroke characteristics vary in a much smaller scale of space such as inside residential buildings. Based on the studies I have reviewed in Chapter 3, the place where elderly females experienced heatstroke the most was the kitchen. On the other hand, the place where elderly males experienced heatstroke the most was the bedroom. These results suggest that heatstroke might have occurred more disproportionately for both males and females in situations with the traditional gender roles within households. From this result, it may be necessary to consider cultural factors into the five factors of heatstroke such as the environment and the human body that can increase risks of heatstroke. Using these factors, future research can design case studies of individual heatstroke experiences to further develop the relationships between heatstroke and our society.

The number of heatstroke deaths has been concentrated in prefectures with a large population, and certain areas with a high proportion of the elderly population may hold potential risks of heatstroke. As the number of intense heat events increased annually due to global warming, high heat events are also expected to be widespread throughout Japan, resulting in
prefectures with low summer temperature experiencing more heat stroke occurrences. In order to understand spatial changes in heatstroke deaths and occurrences in Japan, future research should focus on where it occurred and how heat events are related to such places. Furthermore, as I have examined demographic and spatial characteristics of heatstroke deaths and patients, I have encountered several data limitations that would expand possibilities of future research upon overcoming such limitations. First, raw data on heatstroke deaths or patients should contain spatial and time information such as its location and what time in a day it occurred. Locational information can be aggregated at census tract level, as there may be an issue regarding persons’ privacy. Second, when there are heat stroke patients or deaths, medical personnel should record temperature and WBGT at the place. This will give more precise data on developing the association between environmental factors and human factors of heatstroke.

In addition, the vulnerability assessment I conducted in Chapter 3 can be more sophisticated by incorporating more variables such as occupation to effectively analyze spatial disparities of heatstroke risks. The accuracy of the analysis increases, as more data become available at a finer scale of space such as census tracts. I believe the development of this assessment will be a useful tool for local governments to allocate limited resources to the most vulnerable locations that may hold high risks of heat stroke occurrence. Although this study was not able to analyze exposure to heat at the individual level due to data constraints, this finding strongly urges the government and public to pay attention to increasing heat events. Japan is a developed country experiencing rapid aging, which suggests an increase in vulnerability to extreme heat events, as the ratio of elderlies has been increasing.

Heatstroke death is preventable with proper knowledge and countermeasures such as drinking water often, having a balanced diet, consuming an appropriate amount of salt, checking
The government ministries of Japan have also implemented several policies nationwide in order to prevent heat stroke deaths and equip citizens with proper preventive knowledge. For instance, the Japan Meteorological Agency provides a heat alert system that helps citizens prepare for intense heat. Furthermore, several ministries including the Fire and Disaster Management Agency and Ministry of Education, Culture, Sports, Science and Technology set July as “Heatstroke Prevention Awareness Month” since 2013 through social media, posters, and leaflets in order to enhance citizens’ awareness regarding prevention and countermeasures of heatstroke.

In addition to these actions, Ministry of the Environment as well as Ministry of Health, Labor and Welfare provide leaflets regarding heat stroke prevention for elderlies and gather local governments’ actions on heatstroke prevention targeting elderlies. For example, the Minato District in Tokyo provides heat stroke prevent leaflets to elderlies who are above age 70 and are living alone and to households which are consist of elderlies above age 75 who do not utilize neither nursing insurance nor the District’s eldercare service.

Ministry of the Environment promotes researches on relationships between global warming and heat stroke/heat stress and its future trends through “competitive funds.” As I have discussed, overall vulnerability and exposure to extreme heat and its risks are expected to increase in Japan, especially among the elderly population. In 2018, the elderly population, aged above 65, consisted 28.1 percent of the total population, which is expected to reach 35.3 percent

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by 2040.\textsuperscript{17} Future studies of extreme heat and heat stroke, therefore, should also include demographic changes within the country. Although this master’s thesis faced several limitations, I hope the findings will help us better understand risks and vulnerability of extreme heat events and be utilized for extreme heat prevention.

REFERENCES


DATA

- Heatstroke deaths from 1995 to 2017 by gender and age group (ICD-10 X30 | e-Stat)
  https://www.e Stat.go.jp/stat-search/files?page=1&layout=datalist&toukei=00450011&bunya_l=02&tstat=000001028897&cycle=7&tc lass1=000001053058&tc lass2=000001053061&tc lass3=000001053065&result_page=1&second2=1
- Heatstroke patients from 2011 to 2015 in 23 special wards in Tokyo and Osaka City
- The elderly population above age 65+ in 23 special wards in Tokyo and Osaka
- The elderly population above age 65+ who are living alone in 23 special wards in Tokyo and Osaka
- The number of days that the daily maximum temperature exceeded 35°C
- The number of days that the WBGT Index exceeded 28°C
  http://www.wbgt.env.go.jp/record_data.php
• The number of households that consists of elderlies age 65+

• Total Deaths from 1995 to 2017 by gender and age group
https://www.e-stat.go.jp/stat-
search/files?page=1&layout=datalist&toukei=00450011&bunya_1=02&tstat=000001028897&cyc
e=7&tcass1=000001053058&tcass2=000001053061&tcass3=000001053065&result_page=1&second2=1