Enhancing health resilience in Japan in a changing climate

Yoonhee Kim,[a,*] Kazutaka Oka,[b] Erin C. Kawazu,[c] Chris Fook Sheng Ng,[d] Xerxes Seposo,[e] Kayo Ueda,[e] Masahiro Hashizume,[d,f] and Yasushi Honda[b]

[a]Department of Global Environmental Health, Graduate School of Medicine, The University of Tokyo, Japan
[b]Center for Climate Change Adaptation, National Institute for Environmental Studies, Japan
[c]Institute for Global Environmental Strategies, Japan
[d]Department of Global Health Policy, Graduate School of Medicine, The University of Tokyo, Japan
[e]Graduate School of Medicine, Hokkaido University, Japan
[f]Department of Global Health, School of Tropical Medicine and Global Health, Nagasaki University, Japan

The Lancet Regional Health - Western Pacific 2023;40: 100970

Published Online 15 November 2023

https://doi.org/10.1016/j.lanwpc.2023.100970

Summary

Climate change poses significant threats to human health, propelling Japan to take decisive action through the Climate Change Adaptation Act of 2018. This Act has led to the implementation of climate change adaptation policies across various sectors, including healthcare. In this review, we synthesized existing scientific evidence on the impacts of climate change on health in Japan and outlined the adaptation strategies and measures implemented by the central and local governments. The country has prioritized tackling heat-related illness and mortality and undertaken various adaptation measures to mitigate these risks. However, it faces unique challenges due to its super-aged society. Ensuring effective and coordinated strategies to address the growing uncertainties in vulnerability to climate change and the complex intersectoral impacts of disasters remains a critical issue. To combat the additional health risks by climate change, a comprehensive approach embracing adaptation and mitigation policies in the health sector is crucial. Encouraging intersectoral communication and collaboration will be vital for developing coherent and effective strategies to safeguard public health in the face of climate change.

Keywords: Climate change; Health impacts; Adaptation measures; Heat; Japan

Introduction

Climate change poses a significant threat to public health. Japan, a country with a sizable aging population and a history of numerous natural disasters, recognizes the profound impact of climate change on all aspects of society, including the health sector. The Japanese government enacted the Climate Change Adaptation Act in 2018 and has developed the National Adaptation Plan (NAP) and the Local Climate Change Adaptation Plans (LCCAPs) to manage climate risks and reduce the impact of climate change. In addition, the Ministry of the Environment, Japan (MOEJ) has committed to publishing its Assessment Report on Climate Change Impacts in Japan every five years. The second assessment report was issued in 2020.[1]

The Intergovernmental Panel on Climate Change (IPCC) has described climate change adaptation options to mitigate the risks on human health (as one of the Representative Key Risks) in its Six Assessment Report Working Group II report, listing three adaptation options: availability of health infrastructure, access to health care, and disaster early warning.[2] Successful implementation of adaptation measures could reduce climate-related health risks. For example, urban greenspaces can reduce the urban heat island effect and improve physical and mental health.[3] Strengthening health infrastructure and access to health care improve the resilience of vulnerable populations.[4] Local cooling and early warning systems can minimize mortality, morbidity and potential future infectious disease outbreaks.[3,4]

To support adaptation planning and foster international cooperation, it is beneficial to share knowledge on current and future health vulnerabilities with respect to climate change, along with climate change adaptation and case studies from each country. This Series review aims to summarize the existing scientific evidence on observed impacts and future projections of climate change impacts on health in Japan and introduce climate change adaptation strategies and measures implemented in the country to enhance resilience.

Japan country profile

Climate and weather

Temperature

Japan is an island country with four distinct seasons (winter, spring, summer, and autumn) and a heterogeneous climate at the local level because of its elongated landmass and mountainous terrain. In terms of the Köppen–Geiger classification system, the north of the country is mostly of a "hot-summer humid continental climate" (Dfa), while the rest of the archipelago is

*Corresponding author. Department of Global Environmental Health, Graduate School of Medicine, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan.
E-mail address: yoonheekim@m.u-tokyo.ac.jp (Y. Kim).

mostly of a humid subtropical climate (Cwb, for example), with some spots of tropical rainforest climate (Af) and other local climates.[5] Fig. 1 demonstrates prefectural differences in temperature across the four seasons.[6]

The mean atmospheric temperature in Japan has generally risen from 1898 to 2019, at faster rates than the global average, according to the Japan Meteorological Agency (JMA).[1] Japan's temperature is projected to increase by 1.2–1.4 times the global average under both Representative Concentration Pathway (RCP) 2.6 (low-emission) and RCP8.5 (high-emission) scenarios.[1]

Rainfall

Precipitation tends to be higher in the summer, during the monsoon and typhoon seasons, and in the north-eastern part of the country (Supplementary Figure S1).[6]

In general, rainfall trends have become more extreme over time. Over the past century (from 1901 to 2019), the number of days with heavy rainfall has increased at a rate of 0.29 more days with 100 mm or more rainfall per century. However, the number of days with any rainfall (defined as 1.0 mm or more) has decreased during the same period, showing that rainfall trends are becoming more extreme.[1] Both days with heavy rainfall and dry days are projected to continue increasing going forward by the end of the century under the RCP8.5 scenario.[1]

Extreme weather events

Japan is highly exposed to climate hazards, including, but not limited to tropical storms, heavy rainfall and flooding.[7] The country experiences a greater number of typhoons than the global average.[7] Although Japan's capacity to mitigate and respond to meteorological hazards is considered to be high,[8] natural disasters in the recent past have caused significant impacts. For instance, Typhoon Faxai, a particularly strong typhoon making landfall in the Tokyo area in 2019, caused power outages in almost a million homes, forced 5000 people to evacuate, damaged buildings and vehicles, and interrupted transportation systems and businesses.[9]

No apparent long-term trends in the number of typhoons have been observed; however, some evidence has suggested a projected increase in the number of super-typhoons (upper category 4 and category 5 storms) in the western North Pacific region, including Japan, in the future due to global warming.[1,10]

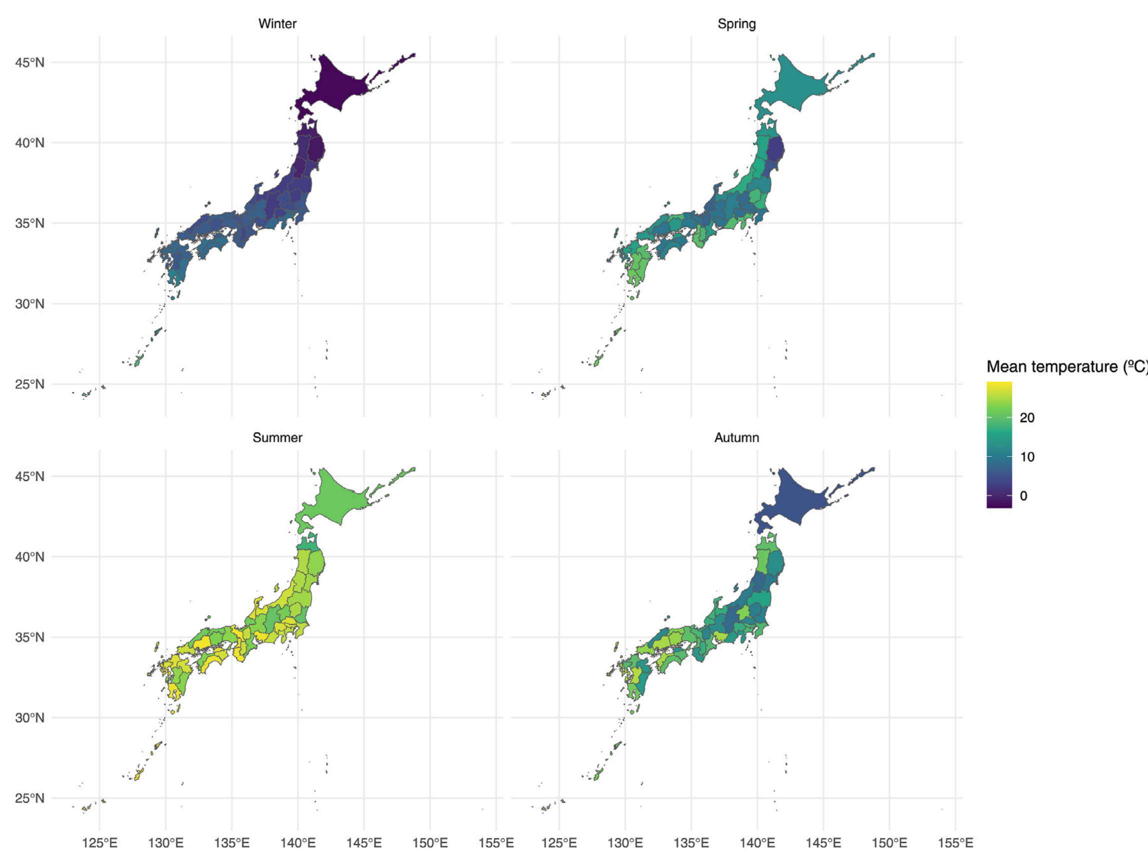

Fig. 1: Mean seasonal temperature by Japanese prefecture (1991–2020). The seasons were defined as follows: winter as December through February, spring as March through May, summer as June through August, and autumn as September through November. Source: authors based on national statistics.[6]

Demographics and health: the 'super-aged' society

The country is rapidly aging, with roughly a third estimated to be aged 65 years and over on average, as of October 2022.[11] Those under 15 years of age make up less than 12% of the total population,[11] reinforcing the inverted shape of the population pyramid. Japan has the longest life expectancy at birth in the world at 84 years, although the healthy life expectancy at birth is ten years shorter.[12,13]

Japan's aging demographic structure has become a major challenge to the social security system, including the national health insurance scheme. Between fiscal 2010 and fiscal 2019, medical expenditure per capita for beneficiaries of the Medical System for the Aged (i.e., the health insurance system for those above 75 years of age and those between 65 and 75 years of age with a government-recognized disability) increased from 904,795 Japanese yen to 954,369 Japanese yen.[6] The number of people insured under the Medical System for the Aged has steadily grown, and the proportion of the medical expenditures for this age group out of the total national medical expenditure has also grown from 34.0% (fiscal 2010) to 38.4% (fiscal 2019).[6]

Urbanization

In 2022, Japan's total population was estimated at approximately 124.9 million, decreasing for the 12th consecutive year.[11] Only the Tokyo Metropolitan Area saw an increase in population compared to 2021, at 0.2%; all other prefectures saw declines ranging from 0.01% to 1.59%.[11] 92% of the total population live in urban areas.[14] While most prefectures, on average, observed net out-migration in 2022, in-migration was concentrated to a comparatively few major cities—Tokyo being the most prominent, followed by Saitama, Osaka, Sapporo and Yokohama.[15]

Greenhouse gas emissions

Greenhouse gas concentrations in Japan have risen from pre-industrial levels.[16] Similar to global trends, carbon dioxide concentrations observed at Hateruma Island decreased in the first few months of the novel coronavirus disease (COVID-19) pandemic, mostly due to restrictions in China, but evidence suggests that global emissions have since rebounded.[17,18] In 2021, the annual mean concentration of atmospheric carbon dioxide at Japan's three observation stations ranged between 416.9 and 419.5 ppm.[16] Mean methane concentrations for the three stations in 2021 were the highest on record.[16]

Climate change and impact on health

In light of the country context described in the section, Japan country profile, section Climate change and impact on health presents a synthesis of scientific evidence that highlights observed impacts of climate change on health and projected future risks in Japan. The search strategy and selection criteria for the evidence update are described below.

A concise summary of the updated evidence is provided in Table 1. For the sake of consistency with the government's impact assessment report,[1] we adopted the same impact categories, such as non-optimal temperatures, air pollution, climate-sensitive infectious diseases, and placed airborne pollen and allergies as a main category. This alignment allows us to obtain a comprehensive picture, connecting our review with the government experts' evaluation, which takes into account significance, urgency, and confidence of the impacts, as indicated in Supplementary Table S1 and "methodology for climate change impact assessment" in the Supplementary Materials.

Additionally, we generated two new impact categories: natural disasters and extreme weather events, and unprecedented global health crises. Addressing these impact categories is critical, given the expected increase in the frequency and intensity of extreme weather events due to climate change in the future. Unprecedented global health crises are also likely to have a massive impact on the global economy and the vulnerability of current systems. Such external shocks can intensify the impacts of climate change on health (see the section Communication and policy recommendation).

Observed impacts

Non-optimal ambient temperature

The short-term effects of heat and cold stress are well-documented in Japan.[19,20,23] The effect of heat is acute, within one to two days, while that of cold conditions can be delayed for up to two weeks. Heat-related deaths and ambulance transportation for heatstroke are two widely reported health outcomes in Japan, with populations aged 65 and older accounting for most of the burden.[46–49] For heatstroke, there were two important observations: (i) heatstroke symptoms often began occurring at home; and (ii) aggravations were common in older adults.[50,51] In the 2018–2022 period, there were approximately 70,000 annual cases of ambulance transport due to heatstroke (Fig. 2).[52,53] While the majority of cases were observed between 2008 and 2022 occurred in July and August, in recent years, ambulance transport has been observed as early as May (Fig. 2). Multi-country studies that include Japan have reported an increased risk of mortality associated with heat and heatwaves.[19,54] The effect of heat was found to be higher in early summer than in late summer.[55] This effect was also found to be stronger in densely populated metropolitan areas[56] and differed regionally within Japan.[57] However, the overall mortality attributable to non-optimal ambient temperature was larger for exposure to cold stress. Cold spells have also been linked to mortality, especially episodes that are more intense, longer, or earlier in the cold season.[58]

Category	Observed impacts	Future prospects	Impact assessment[a]			Key references[b]
			Significance	Urgency	Confidence	
Heat-related illness	• Well documented evidence of **heat-related mortality** and ambulance transport for heatstroke, especially among **older adults** ✔ Ability to regulate body temperature declines with age ✔ High risk of heatstroke symptom onset at home ✔ Older adults with respiratory disease at risk of dyspnea when sleeping in hot settings • **Heat-related morbidity:** Sleep issues, fatigue, feverishness, headaches • Effect higher in early summer and densely populated areas • **Temporal changes in vulnerability:** population becoming less vulnerable to heat stress over the last four decades; threshold for heat-related mortality has shifted upward	• Heat-related excess mortality is expected to increase by the end of the 21st century. • Future mortality burden attributable to hot night excess in Japan is estimated to be higher than attributable to daily mean temperature. • Rising ambient temperatures are projected to lead to negative impacts on daytime with safely performed outdoor labor, work efficiency, and learning effectiveness.	●	●	●	19–22
Cold-related deaths	• Observed higher mortality than excess mortality from heat	• Expected to decrease by the 21st century as warming continues	◆	▲	▲	19,23,24
Water-borne and food-borne diseases	• Warming has led to the spread of bacteria causing diarrhea and skin disorders in the Kyushu region. • Rising temperatures increase the risk of heat-attributable infectious gastroenteritis and extend the epidemic period of rotavirus in Japan.	• Net heat- and cold-attributable diarrhea incidence rates are expected to decrease due to climate change.	◆	▲	▲	25–28
Vector-borne diseases	• Climate-sensitive diseases not endemic to Japan such as dengue fever have been detected and monitored. • Due to rising temperatures, the winter season in Japan now begins later, causing a shift or extension in the epidemic period.	• The distribution of *Aedes albopictus* mosquitoes may broaden by the end of the century; projection studies for health impacts of vector mosquito-borne diseases remain limited.	●	●	▲	29–31
Complex impacts of air pollution (O_3) and warming	• Short-term link between daily O_3 cardiorespiratory mortality has been found.	• Linkages with climate change are inconclusive to date.	◆	▲	▲	32–34
Pollen	• Airborne pollen from the Japanese cedar, cypress, and birch are common in the spring in Japan, causing seasonal allergies.	• Climate change and changes in land use can influence the concentration of pollen, leading to an increase in return visit rates for cedar allergy and medical expenses.	◆	▲	▲	35–38
Natural disasters and extreme weather events	• Flooding events are associated with an increase in prescription medication access, cardiovascular and cerebrovascular cases, and cognitive decline in older adults.	• Potential cascading events and complex disasters with exacerbating impacts of climate change • High degree of uncertainty regarding these exogenous shocks	●	●	●	39–41
Unprecedented global health crises	• The COVID-19 pandemic has impacted temperature-related health outcomes in Japan, potentially due to precautionary measures that have altered human behavior.		●	N/A	□	42–44

[a]The impact assessments regarding significance, urgency, and confidence for the first five categories—heat-related illness, cold-related deaths, water-borne and food-borne diseases, vector-borne diseases, and complex impacts of air pollution (O_3) and warming—were adapted from the government's Assessment Report on Climate Change impacts in Japan based on the evaluations by government experts. On the other hand, assessments for the last three categories—pollen, natural disasters and extreme weather events, and unprecedented global health crises—were determined by the authors of the present study. [b]The literature cited in the table is distinct from traditional methods employed in systematic reviews. The selected articles were chosen based on fundamental criteria: they were peer-reviewed, and their authors were known to have a proven track record relevant to the field. See also "Detailed methodology for evidence update" in the Supplementary Materials.

Legend

Significance	Urgency	Confidence
● Recognized as having particularly significant impacts	● High	● High
◆ Recognized as having impacts	▲ Medium	▲ Medium
— N/A[c]	□ Low	□ Low
	— N/A[c]	— N/A[c]

[c]N/A: Not applicable (currently cannot be assessed).

Table 1: **Observed trends and future prospects of health impacts of climate variability and change in Japan.**

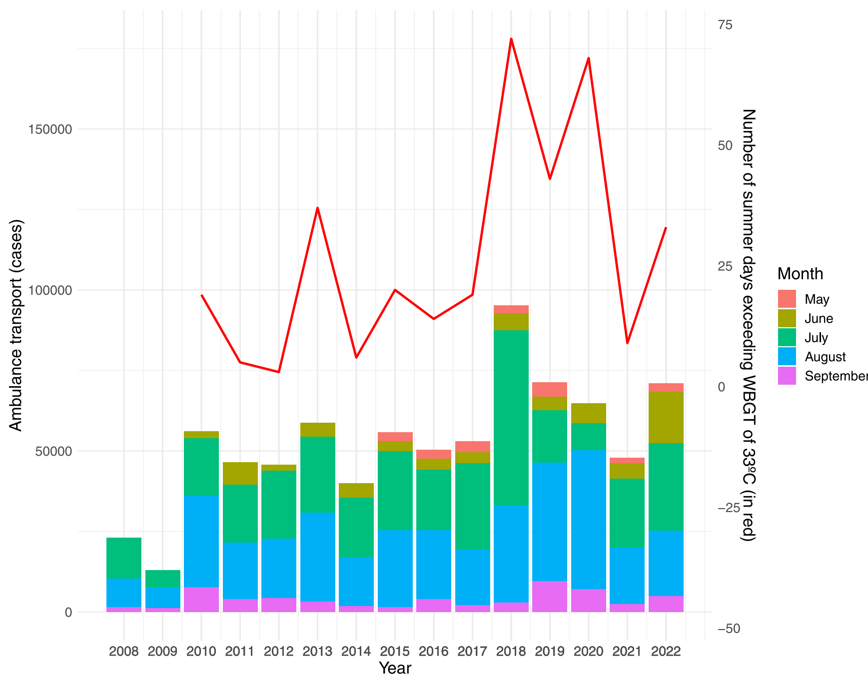

Fig. 2: Number of people transported by ambulance due to heatstroke, 2008–2022 (left axis) and the number of days exceeding a wet bulb globe temperature (WBGT) of 33 °C, which is the threshold triggering the Heat Stroke Alert in Japan (right axis). No ambulance transport data were available for June in 2008 and 2009, as well as for May in 2010–2014 and 2020, and no WBGT data were available for 2008 and 2009. Sources: Fire and Disaster Management Agency (FDMA), Japan[52] and MOEJ.[53]

The indirect health effects of heat, such as a decline in sleep quality, greater fatigue and tiredness, and feverishness, have been reported in Japan through a survey of approximately 600 subjects.[59] The “urban heat island effect” and “tropical nights” (when the ambient temperature does not go below 25 °C at nighttime) have been suggested to be associated with an increase in sleep disorder rates. A 1 °C increase in daily minimum nighttime temperature in the summer has been associated with a 2.3% increase in the prevalence of sleep disorders.[60] High temperatures have also been associated with emergency department visits for nighttime headaches among children.[61] In terms of labor productivity, some have suggested a worldwide decline due to high temperatures; however, the evidence remains limited.[62]

Other health outcomes have also been examined in Japan. Associations between higher ambient temperature and increased rates of suicides have been reported.[63–65] In addition, high temperatures have also been associated with traumatic injuries due to traffic accidents, self-harm and assault based on ambulance transport records in past studies.[66,67] Both high and low temperatures have also been associated with increased risk of death by falls and drowning, with evidence of sex and age group differences.[68] A nationwide database study has also suggested that heat is associated with daily hospitalizations for diabetic complications such as hyperglycemia and hypoglycemia.[69]

According to a global study involving 43 countries, the proportion of heat-related mortality attributable to human-induced climate change in Japan (compared to total mortality) surpassed that of South Korea and China and was comparable with figures observed in Australia, North America, and Northern Europe.[21] Another study indicated a substantial rise in heatwave exposure, particularly among vulnerable populations aged 65 and above, with Japan representing a major portion of the concerning trend.[70] Despite this, Japan’s mortality burden attributable to heat has remained relatively stable over time in contrast to the global average, which has increased (Supplementary Figure S2).

Air pollution

Rising ambient temperatures can accelerate the formation of secondary air pollutants such as tropospheric ozone (O_3). Many studies have reported yearly increases in concentrations of photochemical oxidants (O_x), which are mainly O_3.[71] It was suggested that warming may have contributed to these increases. In Japan, short-term associations between daily O_3 and cardiorespiratory mortality have been reported.[32] A study involving 20 countries found that Japan’s mortality burden attributable to daily ozone exposure was comparable to the global average.[72]

Reports from outside Japan have suggested that the rising O_3 concentration levels in tandem with warmer temperatures may exacerbate O_3-related deaths in the future.[71] Some studies have suggested the synergistic effects between air pollution and heat.[33,34] However, the current evidence linking air pollution-related mortality to climate change is inconsistent and inconclusive.[73]

Pollen and allergy

Concentrations of airborne pollen have increased over time in Japan.[35,74] Pollen from the Japanese cedar, cypress, and birch are common during springtime, and their concentrations are positively correlated with the previous-year mean summer temperature.[36] Climate change and changes in land use are two commonly cited factors that can influence the concentrations. In prefectures with high Japanese cedar (*Cryptomeria*) pollen dispersal, a high prevalence of cedar allergy has been observed.[75] Some medical centers have reported an increase in return visit rates for cedar allergy and an increase in the number of days needed to administer antiallergenic agents. These changes have also major implications on medical expenses.[37]

Climate-sensitive infectious diseases

Water-borne and food-borne diseases. In recent years, warming has been instrumental in the spread of *Vibrio vulnificus*, a g-proteobacterium found in highly enclosed brackish water zones, and many cases of these infections have been reported in the Kyushu region of Japan. This bacterium causes diarrhea, abdominal pain, and skin disorders. Similarly, reports from throughout Japan have indicated that an increase of sea surface temperature also caused increases in the number of *Vibrio parahaemolyticus*, a parasitic g-proteobacterium in fish and shellfish during the summer season.[25,76,77]

Studies have also shown a positive correlation between ambient temperature and risk of infectious gastroenteritis caused by water-borne and food-borne bacteria.[26,78] Studies have confirmed that rising ambient temperatures extended the epidemic period of the rotavirus in all regions of Japan,[79] whereas studies in Japan, Hong Kong, and Taiwan showed that lower temperatures increased acute diarrhea rates and these rates were highest at 11 °C.[80]

Vector-borne diseases. Temperature variations due to a changing climate have been observed, in many cases, to create suitable conditions for vector and viral viability. Non-endemic vector-borne diseases (e.g., dengue fever) have been observed in recent years in Japan,[81] which may be attributable to meteorological changes favoring vector viability.[82] For example, *Aedes albopictus*, a vector of the dengue, can survive in annual average temperature of 11 °C and has expanded its distribution northwards. In the 1950s, the distribution was limited to Tochigi prefecture; however, by the 2000s, it had spread to the northern Tohoku region.[83] Ticks can also be vectors of infections such as Japanese spotted fever, which is showing an increasing trend nationwide. Although the numbers of patients with *tsutsugamushi* disease (scrub typhus) have been declining in recent years, the numbers are still high.[84] Because the winter season in Japan now begins later due to temperature rise, the epidemic period for Japanese spotted fever has shifted to the end of the year,[29] and a positive correlation has been reported between the number of cases of *tsutsugamushi* disease and the previous fiscal year's average temperature, rainfall, snowfall, and amount of accumulated snow.[85] In January 2013, there was a severe febrile thrombocytopenia syndrome (SFTS) outbreak, another tick-borne infection, in western Japan.[86] Although the relationship between SFTS and climate change is still not clear, the number of reported patients with SFTS has been increasing annually, with 2019 marking a record high of over 100 cases.[86]

Natural disasters, extreme weather events, and unprecedented global health crises

Natural disasters and other extreme events batter Japan throughout the year. Impacts on health outcomes and health-seeking behavior are among the few extreme event-related effects that have been commonly documented in recent literature.[39–41,87–89] A case in point is the July 2018 floods, characterized by torrential rains. After the July 2018 floods, access to prescription medications such as benzodiazepine,[88] those for migraines,[89] irritable bowel syndrome,[39] and antidementia[87] have increased dramatically. Several studies have also documented the rise in cardiovascular and cerebrovascular morbidity[40] and cognitive decline[41] as a result of these extreme weather events.

Similarly, unprecedented global health crises, such as the COVID-19 pandemic, have also modified temperature-related effects on health. Recent literature suggests the potential effect measure modification of the pandemic on the relationship between temperature and health in Japan.[42–44,90] These investigations noted overall reductions in temperature-related health outcomes themselves such as heatstroke, as well as the strength of associations between temperature and health outcomes, which were potentially linked to the COVID-19 precautionary measures that have altered human behavior and subsequently affected individual exposure.

Projected future risks

The Japanese government recognized the "climate crisis" as a threat to the basis of human survival in a white paper,[91] extrapolating a threshold beyond which there could be catastrophic changes in the state of human survival and society. However, such a threshold carries limited interpretation in public health because, if the rise in temperature exceeds the physiological capacity of a human body, individuals who have the means to do so may adapt to such environmental change through shifts in lifestyle and social systems.

Non-optimal ambient temperature

Future projections of changes in heat- and cold-related excess mortality have been estimated based on several scenarios. A multi-country study reported that heat-related excess mortality in Japan is expected to increase from 0.3% (0.1–0.5) to 1.0% (0.3–1.8), while cold-related excess mortality is expected to decrease from 8.3% (5.5–10.8) to 6.9% (4.3–9.4) in 2090–2099 compared to 2010–2019 under RCP4.5. The net excess mortality, based on changes in heat- and cold-related excess mortality, was estimated at –0.7% (–1.4 to –0.2).[24] Another study based on the Model for Interdisciplinary Research on Climate (MIROC) dataset focusing on heat-related mortality risk projected a 2.5-fold increase and 7.3-fold increase in risk, on average, under the RCP2.6 and RCP8.5 scenarios, respectively (Fig. 3).[92] Moreover, a study in East Asia projected the future attributable fraction of mortality related to hot night excess (HNE), representing the intensity of nighttime heat, and reported that HNE in Japan was projected to present a greater mortality risk than daily mean temperature under both the updated RCP2.6 based on shared socioeconomic pathways 1 (SSP126) and the updated RCP4.5 based on SSP 2 (SSP245).[93]

A projection based on the Special Report on Emissions Scenarios (SRES) A1B scenario predicted that, by the 2090s, outdoor labor that can be safely performed in the daytime would be reduced by 30%–40% based on the wet bulb globe temperature (WBGT) index in August.[94] A projection based on RCP4.5 predicted that, by the end of the 21st century, the minimum WBGT would rise in every region of Japan, and there would be no days during the hottest month of August with WBGT below 21 °C in western Tokyo. The WBGT of 21 °C is stipulated as a the "almost safe" level under Japan Sports Association's "Guidelines to how much exercise can be safely performed".[95] The number of ambulance-transported cases of heatstroke is projected to increase, on average, by 1.8 times under RCP2.6 and 4.5 times under RCP8.5 by mid-21st century (Fig. 3).

Rising ambient temperatures are expected to lead to negative impacts on work efficiency, education, and learning effectiveness. In addition, a study in the Tokyo Metropolitan Area that projected willingness to pay (WTP) to avoid heat-related fatigue and sleep disorders in August in the 2070s (using the SRES A2 scenario) found total WTP figures of 21.4 million USD and 36.0 million USD to avoid fatigue and sleep disorders, respectively.[96] Another projection study showed that the WTP amounts to avoid sleep disorders are approximately two times higher than those for heatstroke.[97]

Air pollution

Projections of future O_3 concentrations and health effects in the 21st century have been reported in East Asia, including Japan. Based on multiple SRES scenarios, O_3

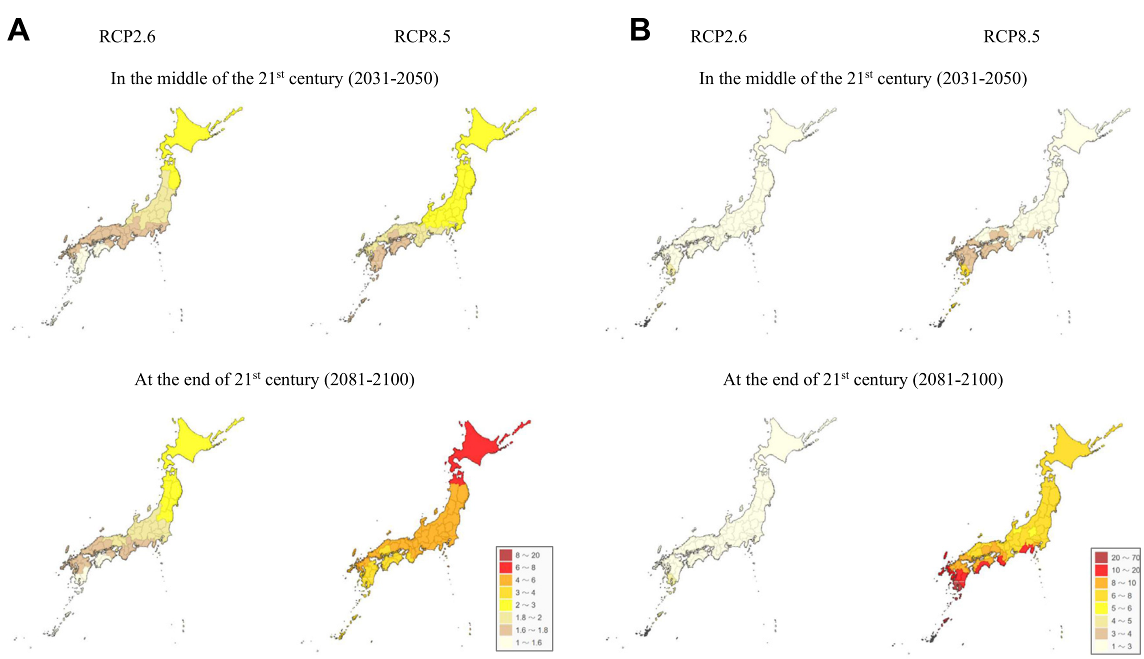

Fig. 3: Projected fold change in risk of (A) ambulance transport due to heatstroke and (B) heat-related mortality in the mid-century (2031–2050) and at the end of the 21st century (2081–2100), compared to the reference period (1981–2000), under low-emission (RCP2.6) and high-emission (RCP8.5) scenarios based on the MIROC dataset. RCP: Representative Concentration Pathway; MIROC: Model for Interdisciplinary Research on Climate. Source: Climate Change Adaptation Information Platform (A-PLAT): Climate change future projection WebGIS (https://adaptation-platform.nies.go.jp/webgis).[92]

concentrations in the summer were projected to peak in the 2020s except under the SRES-A2 scenario.[98] Future mortality rates attributable to O_3 in East Asia would peak in the 2050s under the RCP6.0 scenario.[99] Another study in Japan estimated a continual increase in premature mortality rates due to O_3 from 2000 to 2020.[100]

Climate-sensitive infectious diseases

Water-borne and food-borne diseases. Projection studies reported that diarrhea incidence rates due to temperature rise are expected to decrease in Japan, while diarrhea cases are expected to increase in Africa and Asia, except in high-income regions.[27,101] A recent study observed a potential reduction in infectious gastroenteritis cases in the country by 0.8%–9.1% in 2090–2099 compared to 2010–2019.[102] A similar projection study also highlights reductions in viral gastroenteritis in East Asia, taking note of the potential role of reduced viral viability in high temperatures,[28] which may lead to a reduction in future cases with rising temperature.

Vector-borne diseases. Although quantitative assessments on vector mosquito distribution have been reported, projections for likely patients vulnerable to vector-borne diseases are still limited. A projection of *A. albopictus* distribution showed that, although this mosquito species is currently found in about 40% of the Japanese territory, the geographical distribution of this mosquito species may broaden, reaching 75%–96% of the territory by the end of the century under the RCP8.5 scenario.[30,92] Another study indicated that a rise in ambient temperature would bring the start of hematophagy forward to earlier in the spring.[31]

Unique features in Japan

Aging society

Elderly people are highly vulnerable to heat stress. Sunstroke or heatstroke symptoms can quickly worsen in such vulnerable individuals. With increased age, the ability to properly regulate body temperature is compromised, meaning that there can be a delay before older individuals are aware of their experience of heat stress.[103] A high proportion of elderly patients are transported by ambulances for heatstroke in Japan.[51] Environments with prolonged extreme heat have been linked to the increasing trend in the number of heatstroke cases among older adults,[44,48,57,104,105] with a high risk of symptom onset at home, including bedrooms.[50] A rise in ambient temperature has also been reported to increase the risk of out-of-hospital cardiac arrest.[46] Among older adults with respiratory disease, sleeping in hot settings was found to be linked to dyspnea and a deterioration of their physical condition.[106] Elderly populations experience a high level of risk during extreme events: a recent study noted an increase in cognitive decline among older adults after the July 2018 floods.[41]

Temporal changes in heat-related mortality

Populations in Japan have become less vulnerable to heat stress over the last four decades.[22,107,108] Studies that examined the temperature-mortality association over time from 1972 to 2012 have reported an upward shift in the temperature threshold for heat-related mortality. Heat-related mortality risk (relative risk for the 99th percentile of temperature against the threshold temperature) has decreased from 1.18 to 1.01.[22] A previous study reported that the attenuation of heat-related mortality risk is linked to the use of air conditioning. The study estimated that air conditioning accounted for 20% of the observed attenuation of heat-related mortality during the summer in Japan, implying that the technology was an effective adaptation measure.[109]

Climate change adaptation measures

Climate change adaptation aims to reduce vulnerability to and impacts of climate change and build adaptive capacity. The IPCC in the Fifth Assessment Report suggested three general categories of adaptation options: structural/physical, social, and institutional.[110] Structural/physical options include interventions on the engineered and built environment, as well as technological, ecosystem-based, and service-based interventions. Social options include educational, informational, and behavioral aspects. Institutional options include economic, laws and regulations, government policies and programs. Adaptation options are interrelated and could cut across categories. Thus, different approaches to categorization exist. The European Climate Adaptation Platform (Climate-ADAPT) has another way in gray, green, and soft measures.[111] Gray adaptation options represent technological and engineering solutions, while green options represent ecosystem-based, services by natural ecosystems. Soft measures have policy, legal, social, management and financial aspects.

In this review focusing on health sector, we have organized adaptation options into two categories: soft and hard measures. As the Assessment Report on Climate Change Impacts in Japan[1] evaluated heat-related impacts as an especially high priority, given the “significance”, “urgency”, and “confidence” of their impacts on health (see Supplementary Table S1), this section accordingly focuses on climate change adaptation measures to mitigate heat-related illness.

In Japan, various adaptation plans and measures with health co-benefits against extreme heat have been implemented, such as local cooling, urban greenspaces, and enhanced awareness.[4] These efforts have been reinforced since the enactment of the Climate Change Adaptation Act in 2018.[112] In this section, we describe climate change adaptation strategies and plans addressing extreme heat-related risks in Japan, categorized as soft and hard measures. We also introduce some case studies and discuss the effectiveness of the adaptation measures and challenges to their implementation. The soft and hard measures at the national and local levels highlighted here are summarized in Table 2.

Beyond the Climate Change Adaptation Act

National Adaptation Plan

In response to the various climate impacts already felt in Japan, the Climate Change Adaptation Act was enacted in December 2018.[112] In accordance with the Act, the Japanese Cabinet approved its National Adaptation Plan in 2021.[114] This plan identifies the impacts of heat, infectious diseases (e.g., vector-borne, water-borne, and food-borne infectious diseases), and air pollution on health and provides direction for the government's adaptation measures to address these impacts. This plan mainly organizes the initiatives to be undertaken by the government.

LCCAPs

Local governments are obligated to make efforts to formulate local climate change adaptation plans (LCCAPs) in accordance with the Climate Change Adaptation Act.[112] At the prefectural level, 46 out of all 47 prefectures have formulated LCCAPs (as of February 2023).[116] LCCAPs describe adaptation strategies including those against heat-related impacts and infectious diseases (e.g., vector-borne diseases). These LCCAPs mainly set the direction for initiatives to be undertaken by local governments.

Action Plan for Heatstroke Prevention

In response to the high risk of heatstroke, the Japanese government formulated the "Action Plan for Heatstroke Prevention" in March 2021.[117] This plan outlines the priority measures against heatstroke such as measures for the elderly, for which mortality is particularly high, and the strengthening of cooperation with local communities and industry. In March 2022, this plan was revised to strengthen measures to prepare for extreme heat events.[118] Revisions to the Climate Change Adaptation Act have upgraded this plan to a cabinet plan.[115] The mid-term goal of this plan is to halve the number of deaths due to heatstroke from current levels (approximate five-year moving average of 1295 deaths as of 2022).[115]

Level	Goals	Soft measures	Hard measures	Source
National	To mitigate health impacts	• Gathering scientific information about risk • Alerting the risk of heatstroke to the public (e.g., **Heatstroke Warning System—"Heat Stroke Alert"**) • Spreading awareness of prevention and countermeasure methods (e.g., **A-PLAT**[113]) • Cooperating with local governments/ industry (e.g., raising awareness of the risk of heatstroke) • Promoting surveys and research on heatstroke countermeasures	• Developing automation technology for outdoor agricultural work • Promoting the spread and expansion of ZEH/ZEB and thermal insulation reforms • Promoting proper use of air conditioners (e.g., **Subscription service for air conditioners**) • Supporting the installation of air conditioning and emergency power supply in schools, and social and sports facilities • Cooperating with industry to develop products to counter heatstroke	National Adaptation Plan[114] Action Plan for Heatstroke Prevention[115]
	To mitigate urban temperature	• Improving lifestyles • Promoting adaptation measures to reduce impact on human health (e.g., **A-PLAT**[113])	• Mitigating anthropogenic heat from human activities • Improving land surfaces through greening and use of water • Addressing the complexity of urban built environments (e.g., wind paths from water surfaces) • Strengthening observation and monitoring systems and promoting research and studies	
Regional/local	To mitigate health impacts	• Raising awareness of prevention and countermeasure methods (e.g., **Heatstroke Prevention Notification Post cards**)	• Preparing cooling centers for citizens (e.g., **the "Cool Oasis" campaign**) • Supporting the introduction of work clothes that reduce heat (**clothing with fans**, etc.)	Local climate change adaptation plans (LCCAPs)[116]
	To mitigate urban temperature	• Making plans to mitigate the urban heat island effect (e.g., **Urban Heat Island Countermeasures Policy of Tokyo** (Box 1))	• Improving land surfaces through greening and the use of water (e.g., **Social implementation: Saitama Prefecture's stadium** (Box 2))	

Table 2: **Climate change adaptation strategies/plans covered in this study to address extreme heat-related risks.**

Implemented adaptation measures

With the aforementioned policy foundations for adaptation to the heat-related impacts of climate change, specific actions are already being taken in the country. We have organized adaptation measures into two categories: soft and hard measures. Soft measures involve approaches such as raising awareness, improving lifestyles, and making plans to mitigate health impact, and are generally easier to implement than hard measures in terms of cost or time. On the other hand, hard measures include the installation or use of technology and infrastructure beneficial to preventing heatstroke, such as air conditioners, fans, and measures to mitigate urban temperatures. We describe some examples of soft and hard measures below. Table 2 summarizes the measures at the national and regional/local levels.

Soft measures

Soft measures are relatively easy to implement without much cost or time and involve approaches such as raising awareness. The "Heat Stroke Alert",[119] a type of heatstroke warning system, is one example, as it warns the public of potential heat exposure. In addition, many local governments have promoted heatstroke prevention through the distribution of videos, creation and distribution of leaflets, and hosting of events.

Heatstroke warning system: Heat Stroke Alert. For the purpose of encouraging people to prepare against heatstroke, JMA began "High-Temperature Warnings" from 2011, where warnings were issued when the daily maximum temperature was predicted to reach or exceed 35 °C.[120] The revamped "Heat Stroke Alert" launched in 2020 by JMA and MOEJ is a system in which an alert is issued when the WBGT is predicted to reach or exceed 33 °C (Fig. 4).[119] Supplementary Figure S3 shows the flow of information dissemination for the Heat Stroke Alert. The Heat Stroke Alert is identified as one of the most important measures against heatstroke in the National Adaptation Plan and the Action Plan for Heatstroke Prevention (Table 2). Climate change has exacerbated the risk of extreme high temperatures and, as a result, serious cases of heatstroke. In order to reduce the risk of such severe cases, the establishment of an additional alert level above the current criteria (i.e., WBGT of 33 °C) is currently under consideration by the Japanese government.[115]

A-PLAT. The National Institute for Environmental Studies, Japan (NIES) is required to disseminate information related to sectoral impacts and adaptation and to support the formulation of adaptation plans by local authorities and others through the cooperation with relevant ministries and agencies,[113] in accordance with the Climate Change Adaptation Act. To meet this requirement, NIES launched the Climate Change Adaptation Information Platform (A-PLAT). A-PLAT shares the information on existing adaptation initiatives conducted by the national government, local authorities, and private companies. A-PLAT includes many existing adaptation actions related to the health sector such as raising awareness of the "heat index" (i.e., WBGT) and promoting the use of parasols.

Heatstroke Prevention Notification Postcards. To spread awareness of the risk of heatstroke and prevention against heatstroke, the City of Yokohama has collaborated with entities (e.g., post office, fire department) to deliver "Heatstroke Prevention Notification Postcards" to citizens.[121]

Hard measures

Hard measures mainly include the use of technology or infrastructure beneficial to preventing heatstroke, such as air conditioners and fans. We illustrate some examples of relevant initiatives below.

Subscription service for air conditioners. The MOEJ implemented a pilot project that offered a subscription service to promote the installation of air conditioners. The vulnerable population, particularly older adults, tends not to use air conditioning, thereby increasing the risk of heatstroke.[50] In Tokyo, among those who died indoors due to heatstroke, approximately 90% did not use air conditioning and 35.9% had not installed air conditioning as of 2018.[122] Living without air conditioning has also been linked to low socioeconomic status.[123] The high cost of installation and electricity may prevent the underserved from installing and using this technology. Because of this, the MOEJ implemented a pilot project that offered a subscription service for air conditioners in 2022.[124] The project aimed to establish a business promoting the installation of air conditioners for heatstroke prevention. Local authorities and private sector actors installed air conditioners in households and public facilities and collected data to evaluate the economic efficiency and effectiveness of this subscription model, such as air conditioner operating status, monthly energy use and electricity bills. A questionnaire on attitudes towards the use of air conditioning was also conducted. Although the effectiveness of the project has yet to be verified, it is expected to be a leading heatstroke countermeasure.

The "Cool Oasis" campaign. To serve as cooling centers for people to stop by to reduce heat stress, Saitama Prefecture operates the "Cool Oasis" campaign.[125] Not only public facilities, but also companies in the prefecture participate in this campaign. In 2023, about 9000 facilities, including convenience stores, drugstores, post offices, and car dealerships are cooperating on this initiative.

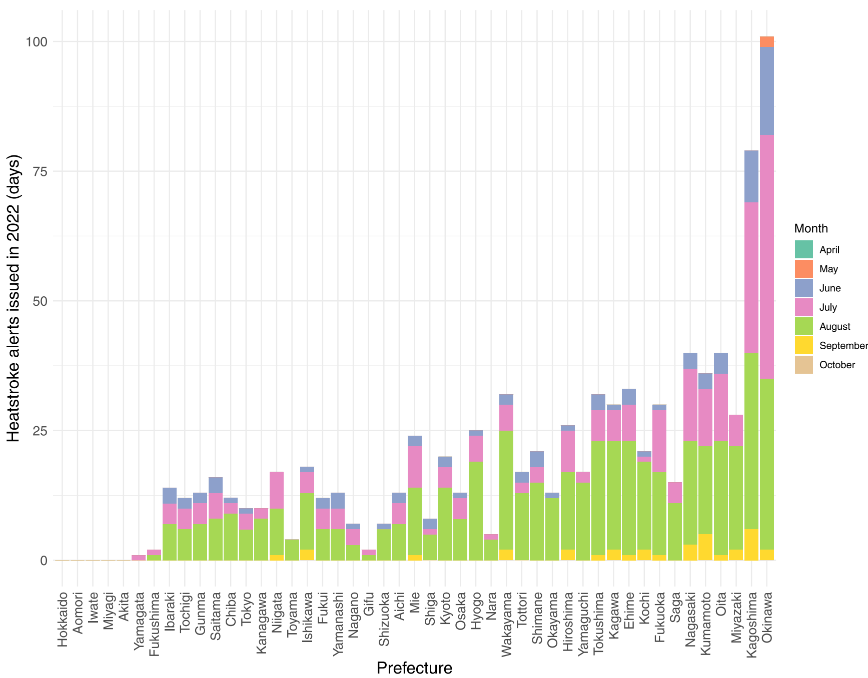

Fig. 4: Number of heatstroke alerts issued by prefecture in the warm months of 2022 in Japan. Source: Heat Stroke Alert (JMA and MOEJ, https://www.wbgt.env.go.jp/alert_record.php).[119]

Clothing with fans. At the individual level, the innovation of clothing with fans for outdoor workers or factory workers is gaining traction.[126] These clothing items protect individuals by cooling the air to which users are directly exposed (i.e., between the body and clothing).

Measures to mitigate urban temperatures and social implementation case. Measures to mitigate urban temperatures (i.e., the urban heat island effect) can include measures to mitigate anthropogenic heat, to improve land surfaces, and to address the complexity of urban built environments.[127] Some local governments have formulated comprehensive plans to mitigate urban temperatures (see Box 1).

Anthropogenic heat is the waste heat generated from air conditioning of buildings, automobile use, and other activities that warm the atmosphere. Measures to reduce anthropogenic heat include improving the efficiency of energy-consuming equipment (reducing energy consumption) and effective use of anthropogenic heat (cascading the use of energy).[130]

In urban and urbanizing areas, land surface is modified, resulting in greater coverage of asphalt or concrete instead of green or natural space. Green or natural ground surfaces contain water, which prevents them from becoming hotter when exposed to solar radiation because of evapotranspiration. On the other hand, asphalt or concrete surfaces become hotter when exposed to solar radiation and release heat into the atmosphere at night. Measures to improve land surfaces include greening ground surfaces, building rooftops, and walls, as well as making building surfaces highly reflective (see Box 2 as a case study on urban greening).

Moreover, increasingly complex buildings being developed in the city pose structural barriers for wind to effectively pass through the environment.[130] As a result, heat remains trapped in the city, elevating local air temperature. To address this, during urban redevelopment, the structure and layout of buildings can be modified to promote the passage of air.

Evaluation of the effectiveness of measures

Although various soft measures, such as raising public awareness about the risk of heatstroke, have been implemented under each adaptation strategy/plan in Japan, it remains unclear to what extent each of these measures, including the Heat Stroke Alert, has contributed to the reduction of health impacts. Further research is needed to quantify the effectiveness of soft measures, taking into account the evidence on economic assessment of heat early warning systems and how to bridge the gap between climate and health professionals.[133]

Regarding hard measures, while no studies have evaluated the health benefits of their implementation in Japan, a few simulation studies have attempted to evaluate the effectiveness of these measures in terms of their health benefits, and the health benefits varied from

Box 1.

Mitigation plan for the urban heat island effect.

Urban Heat Island Countermeasures Policy of Tokyo

The urban heat island effect has led to disproportionately warm temperatures in urban areas.[128] Local governments have formulated plans to mitigate the urban heat island effect and implemented various measures. For example, the Tokyo Metropolitan Government (TMG) formulated the "Urban Heat Island Countermeasures Policy" in 2003, which outlines the countermeasures from three perspectives: promotion of countermeasures initiated by TMG; promotion of countermeasures in cooperation with the private sector; and promotion of research and studies related to countermeasures.[129]

measure to measure. For example, a simulation study in the 23 wards of Tokyo used heat island mitigation scenarios to understand how measures such as building greening, high-albedo coating, and air conditioning (as modeled by roof-level emissions of all anthropogenic heat by air conditioning), could impact WBGT and heat disorder risk (HDR).[134] Contrary to expectations, none of the measures effectively lowered the outdoor WBGT and HDR. Another study conducted in the 23 wards of Tokyo estimated the effectiveness of measures to mitigate urban temperatures, including ground greening, electric vehicle, and atmospheric heat source heat pump water heater, on temperature reduction and heat-related mortality.[135] This study found no significant difference among the measures in reducing heat-related mortality, with reductions ranging from 0% to 16%, which also varied geographically. One recent study estimating the effectiveness of air conditioning use in six cities in Japan demonstrated that air conditioning can reduce heat-related deaths significantly, resulting in approximately a 50% reduction in heat-related deaths compared to a scenario with no air conditioning use.[136] However, the study also highlighted the negative impacts of air conditioning use, indicating that anthropogenic heat generated by air conditioning systems can accelerate rising temperatures, contributing to unavoidable heat-related excess deaths. These contributions provide useful information for planning adaptation measures.

Box 2.

Social implementation case to mitigate urban temperatures.

Saitama Prefecture's stadium

Saitama Prefecture is prone to high temperatures. With rising temperatures, there has been an increase in the number of patients with heatstroke transported by ambulance. Efforts to ameliorate the heat environment are therefore crucial. In response to this situation, the Center for Environmental Science in Saitama (CESS), a prefectural research institute for environmental science, conducted a study to understand the effectiveness of measures to ameliorate the heat environment planned by Saitama Prefecture for the Kumagaya Sports Culture Park, one of the venues for the 2019 Rugby World Cup.[131] In collaboration with national research institute (namely, Japan Agency for Marine-Earth Science and Technology), CESS evaluated the effectiveness of measures such as tree planting, greenspace development, and highly reflective pavement before the completion of the park by numerical simulations using a supercomputer and evaluated the optimal placement for trees. Based on these simulated results, trees were planted in the park, leading to an observed reduction in heat stress.[132] This is a rare and leading example of a municipality optimizing measures based on numerical simulations.

Conveying the urgency of the challenges: tackling barriers to implementation

Promoting the use of air conditioners

In the 23 wards of Tokyo, 90% of all heat-related deaths are among older adults. Furthermore, 93% of all deaths occurred indoors, while 40% of ambulance transport cases due to heatstroke occurred indoors.[137] Of those who died indoors, 90% were not using air conditioning, even though 55% of those who died indoors had air conditioning available (see also "*Subscription service for air conditioners initiated by MOEJ*" described in the section Hard measures).[138] In light of the country's super-aged population, a critical priority is the promotion of the appropriate use of air conditioners among the older adults and persons with underlying health conditions to reduce heatstroke risk (see Supplementary Table S1).

Limitations of measures for mitigating urban temperatures

Implementation of hard measures to mitigate urban temperatures usually takes a long time. In addition, implementation of hard measures is usually at the level of individual buildings or city blocks, and extensive areal implementation is difficult. Therefore, practically speaking, the extent to which health outcomes may improve by introducing these measures may be limited.

Communication and policy recommendation

Japan has been classified as a 'super-aged' society with more than 90% of residents living in urban areas. These factors accentuate Japan's vulnerability to climate change-related health risks, particularly for extreme heat. Therefore, mitigating heat stress to protect public health has been recognized as a high national priority by the Japanese government and in national assessments of climate change impacts.[1] Both central and local governments have accordingly implemented adaptation measures for extreme heat. However, little is known about their effectiveness and potential health co-benefits. A systematic assessment on the implemented adaptation measures is needed to monitor and maximize their effectiveness.

Furthermore, continuous efforts to comprehensively understand both direct and indirect health impacts of climate change should be made, despite the complexity of causal pathways.[139] To date, the evidence has disproportionately addressed more direct health impacts, such as mortality from heat and floods, while there have been few quantitative assessment studies of indirect impacts. Further research is warranted on such indirect impacts as vector- and water-borne infections, allergic diseases due to increased allergens (e.g., pollen and mold spores), air pollution-related health effects (e.g., O_3), and mental health (see the section Climate change and impact on health).

Challenges in climate change and health in Japan

Uncertainty in vulnerability

Policymaking should consider vulnerability to the health impacts of climate change. Although it is widely recognized that older people are vulnerable to heat stress, few studies in Japan have focused on the impact of socioeconomic status on the health effects of climate change, despite increasing awareness of health disparities and climate justice.

In addition to its health impacts, the COVID-19 pandemic has had a massive impact on the global economy, revealing the vulnerability of current systems (see the section Climate change and impact on health, COVID-19). While Japan has implemented measures to prevent heat-related deaths and heatstroke, the effectiveness of these measures may be affected by unpredictable external factors such as pandemics or large-scale natural disasters. Even if policies are in place to mitigate the effects of heat and cold stress, these issues may resurface due to such external shocks. In such cases, populations may temporarily lose their ability to adapt to non-optimal temperatures, and the damage caused by this disruption may be greater for more vulnerable groups.

To better prepare society for such uncertainties and manage associated health risks, substantial efforts are needed to improve health infrastructure, emergency response systems, and public health campaigns. The initial steps to move forward include assessing the potential extent of uncertainties to facilitate science-based policymaking and initiate a discourse on the appropriate roles and capacities in each sector, and exploring ways to complement efforts across different sectors to utilize limited resources more effectively.

Development of a coherent strategy across multiple sectors

Recurrent natural disasters in Japan, including typhoons with heavy rain, floods, and earthquakes, have prompted the government and academic society to reconsider current strategies for preparing for multifactorial health impacts. The latest report on assessment of climate change impacts in Japan has introduced a new assessment category: complex disasters, which refer to compounding or cascading events.[1] Climate change-driven extreme weather increases the risk of simultaneous disasters, such as sediment disasters, flooding, and storm surges, which can have more pronounced impacts than a single event. These disasters also cause infrastructure and disruption in lifelines, leading to additional cross-domain impacts.[1,140] For instance, in the summer of 2019, a typhoon with heavy rain struck the Tokyo Metropolitan Area, leading to widespread power outages. People on the following day were exposed to high temperatures without air conditioning, resulting in a substantial increase in ambulance transport.[141] The academic society has released recommendations and research needs for disaster management, particularly in the field of civil engineering, to address the emerging issues. However, there is limited evidence on the health impacts and any related adaptation measures for such complex disasters, as well as their prediction and economic impacts. Further interdisciplinary research and subsequent multistakeholder cooperation are critical to devise a whole-of-society approach to the myriad risks that complex disasters pose.

Comprehensive approaches to adaptation measures considering mitigation policies

Air conditioning has traditionally been the most effective means of safeguarding health against extreme heat. However, relying on air conditioning is, at present, an environmentally unsustainable approach due to its heavy reliance on electricity, a significant portion of which is currently generated from fossil fuels, accounting for 88% of total primary energy supply in 2019 in Japan.[142] The operation of air conditioning also generates excess anthropogenic heat, increases high temperatures in densely populated urban areas, and thus intensifies the urban heat island effect.[143] In addition to accelerating progress on lowering emissions in the power sector, it is essential to explore more effective approaches that combine air conditioning with other cooling strategies, such as electric fans, ice towels, or cold water.[144] Finding the right balance in the use of air conditioning can contribute to mitigating greenhouse gas emissions and promoting sustainable cooling practices.

Furthermore, the healthcare sector in Japan has substantially contributed to greenhouse gas emissions, accounting for 4.6%–6.4% of total domestic greenhouse gas emissions in the 2010s.[145,146] In addition to effective adaptation measures, the healthcare sector has ample opportunity to reduce its own emissions to contribute to the achievement of the netzero emissions goal. These careful considerations would help prevent additional health risks attributable to human-induced climate change and mitigate unnecessary emissions of greenhouse gases that may exacerbate the potential hazards of climate change.

Conclusions

Science-based policymaking is crucial for climate change adaptation. More quantitative scientific evidence is needed to holistically understand both direct and indirect health impacts of climate change. This evidence will then need to be translated into policy and practice. This will require collaboration and communication among multiple stakeholders, including researchers across different fields, policymakers, and society. This would help Japanese society enhance understanding of

Search strategy and selection criteria

To update the evidence, we began by extracting references from two extensive reports[1,45] on climate change and human health in Japan. The two reports, from the Association of Academies and Societies of Sciences in Asia (AASSA) and the Ministry of the Environment, Japan (MOEJ) respectively, provide a comprehensive examination and documentation of the effects of climate change on human health in Japan. The combined relevant references (n = 97) provide over two decades of scientific evidence, up to 2019. Among the 97, 48 references were excluded because of any of the following reasons: the full text was unavailable, the abstract was unavailable, the evidence was not focused on Japan, and/or the reference was gray literature. To identify new references beyond this period and to emulate the search strategy utilized in the two reports, we text-mined the abstracts of the remaining references (n = 49) to create a set of keywords to be used for the Boolean search on PubMed. There were 189 keywords generated by this method, but many keywords were loosely related and could be clustered into more general concepts, which enabled us to isolate three: "climate", "health", and "Japan". We added an important keyword "extreme weather event" not captured in previous reports. Then, we implemented a Boolean search strategy on PubMed using the keywords to identify new publications from 2020. Through extensive expert discussions, we assessed each study's originality, scientific soundness, and relevance to the broad scope of climate change and health, and selected eligible studies (n = 43). More detailed information on the process is described in the Supplementary Materials and summarized in Supplementary Figures S4.

the complex relationships between climate change and health, develop innovations and effective measures against the impacts of climate change, and enable urgent actions. To respond effectively to a range of climate-related and other health emergencies, it is necessary to adopt a comprehensive, all-hazards approach to health crisis management. This approach can contribute to a more sustainable and resilient health system and society as a whole.

Contributors

YK, KO, MH, and YH conceptualized the Series and contributed to outlining the approach. YK and ECK were the overall editors. ECK drafted the section Japan country profile. YK, CFSN, and XS synthesized elements of Section Climate change and impact on health and drafted Section Climate change and impact on health. KO, KU, and YH synthesized elements of Section Climate change adaptation measures. KO drafted Section Climate change adaptation measures, and KU contributed to editing. YK drafted Section Communication and policy recommendation and the rest of the paper. KU, MH, and YH advised on all sections. All authors reviewed and contributed to editing. All authors approved the final version submitted for publication.

Data sharing statement

All data presented in this review are included in the references and the Supplementary Materials.

Editor note

The Lancet Group takes a neutral position with respect to territorial claims in published maps and institutional affiliations.

Declaration of interests

KO received the Environment Research and Technology Development Fund of the Environmental Restoration and Conservation Agency. YK was supported by the University of Tokyo Excellent Young Researcher award.

Acknowledgments

This research was supported by the Environment Research and Technology Development Fund (JPMEERF20231007) of the Environmental Restoration and Conservation Agency provided by Ministry of the Environment of Japan.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanwpc.2023.100970.

References

1 Ministry of the Environment, Japan (MOEJ). Assessment report on climate change impacts in Japan. *MOEJ*; 2020. https://www.env.go.jp/content/000047546.pdf.
2 New M, Reckien D, Viner D, et al. Decision-making options for managing risk. In: Pörtner H-O, Roberts DC, Tignor M, et al., eds. *Climate change 2022: impacts, adaptation and vulnerability contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change*. Cambridge, UK and New York, NY, USA: Cambridge University Press; 2022.
3 Romanello M, Di Napoli C, Drummond P, et al. The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels. *Lancet*. 2022;400(10363):1619–1654.
4 Sharifi A, Pathak M, Joshi C, He B-J. A systematic review of the health co-benefits of urban climate change adaptation. *Sustain Cities Soc*. 2021;74:103190.
5 World Bank Group. Japan; 2021. https://climateknowledgeportal.worldbank.org/country/japan. Accessed October 17, 2023.
6 Statistics Bureau; Ministry of Internal Affairs and Communications, Japan. *Japan statistical yearbook 2023*; 2023. https://www.stat.go.jp/english/data/nenkan/72nenkan/zenbun/en72/book/index.html. Accessed May 1, 2023.
7 The International Energy Agency (IEA). *Japan climate resilience policy indicator*; 2021. https://www.iea.org/articles/japan-climate-resilience-policy-indicator. Accessed May 19, 2023.
8 Disaster Risk Management Knowledge Centre, European Commission. *INFORM risk country profile - Japan*; 2023. https://drmkc.jrc.ec.europa.eu/inform-index/INFORM-Risk/Country-Risk-Profile. Accessed May 19, 2023.
9 McCurry J. *Typhoon Faxai batters Tokyo, causing evacuations, blackouts and transport chaos*. The Guardian; 2019. https://www.theguardian.com/world/2019/sep/09/typhoon-faxai-batters-tokyo-causing-evacuations-blackouts-and-transport-chaos. Accessed November 9, 2023.
10 Tsuboki K, Yoshioka MK, Shinoda T, Kato M, Kanada S, Kitoh A. Future increase of supertyphoon intensity associated with climate change: increase of super-typhoon intensity. *Geophys Res Lett*. 2015;42(2):646–652.
11 Statistics Bureau, Ministry of Internal Affairs and Communications, Japan. *Current population estimates as of October 1, 2022*; 2022. https://www.stat.go.jp/english/data/jinsui/2022np/index.html. Accessed May 1, 2023.
12 World Health Organization (WHO). *Healthy life expectancy (HALE) at birth (years)*; 2019. https://www.who.int/data/gho/data/indicators/indicator-details/GHO/gho-ghe-hale-healthy-life-expectancy-at-birth. Accessed May 1, 2023.
13 World Health Organization (WHO). *Life expectancy at birth (years)*; 2023. https://www.who.int/data/gho/data/indicators/indicator-details/GHO/life-expectancy-at-birth-(years. Accessed May 1, 2023.
14 Central Intelligence Agency (CIA). Japan; 2023. https://www.cia.gov/the-world-factbook/countries/japan/. Accessed May 1, 2023.
15 Statistics Bureau, Ministry of Internal Affairs and Communications, Japan. *Report on internal migration in Japan/annual report (Real number) 2020*; 2023. https://www.e-stat.go.jp/en/stat-search/files?fpage=1%26layout=datalist%26toukei=00200523%26tstat=000000070001%26cycle=7%26year=20220%26month=0%26tclass1=000001148746. Accessed May 1, 2023.
16 Japan Meteorological Agency (JMA). *Climate change monitoring report 2021*; 2022. https://www.jma.go.jp/jma/en/NMHS/ccmr/ccmr2021.pdf. Accessed May 17, 2023.
17 Tohjima Y, Patra PK, Niwa Y, Mukai H, Sasakawa M, Machida T. Detection of fossil-fuel CO2 plummet in China due to COVID-19 by observation at Hateruma. *Sci Rep*. 2020;10(1):18688.
18 Friedlingstein P, Jones MW, O'Sullivan M, et al. Global carbon budget 2021. *Earth Syst Sci Data*. 2022;14(4):1917–2005.

19 Gasparrini A, Guo Y, Hashizume M, et al. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *Lancet*. 2015;386(9991):369–375.
20 Ng CF, Ueda K, Ono M, Nitta H, Takami A. Characterizing the effect of summer temperature on heatstroke-related emergency ambulance dispatches in the Kanto area of Japan. *Int J Biometeorol*. 2014;58(5):941–948.
21 Vicedo-Cabrera AM, Scovronick N, Sera F, et al. The burden of heat-related mortality attributable to recent human-induced climate change. *Nat Clim Change*. 2021;11(6):492–500.
22 Chung Y, Yang D, Gasparrini A, et al. Changing susceptibility to non-optimum temperatures in Japan, 1972-2012: the role of climate, demographic, and socioeconomic factors. *Environ Health Perspect*. 2018;126(5):057002.
23 Ng CF, Ueda K, Takeuchi A, et al. Sociogeographic variation in the effects of heat and cold on daily mortality in Japan. *J Epidemiol*. 2014;24(1):15–24.
24 Gasparrini A, Guo Y, Sera F, et al. Projections of temperature-related excess mortality under climate change scenarios. *Lancet Planet Health*. 2017;1(9):e360–e367.
25 Kanatani J-I, Isobe J, Kimata K, Shimizu M, Sata T, Watahiki M. Correlation between levels of *Vibrio parahaemolyticus* detected in seawater from fishing ports and in fishes on the market and the number of cases of foodborne outbreak in Toyama prefecture during 1979−1995 and 2008−2012 [in Japanese]. *Jpn J Food Microbiol*. 2014;31(2):93–99.
26 Onozuka D, Hashizume M. Weather variability and paediatric infectious gastroenteritis. *Epidemiol Infect*. 2011;139(9):1369–1378.
27 World Health Organization (WHO). *Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s*. Geneva, Switzerland: WHO; 2014. https://www.who.int/publications/i/item/9789241507691. Accessed November 9, 2023.
28 Chua PLC, Huber V, Ng CFS, et al. Global projections of temperature-attributable mortality due to enteric infections: a modelling study. *Lancet Planet Health*. 2021;5(7):e436–e445.
29 Yoshikura H. Geographical distribution of Japanese spotted fever and tsutsugamushi disease in Japan - possible effect of environmental temperature. *Jpn J Infect Dis*. 2017;70(3):349–351.
30 Kobayashi M. Mosquito-borne infection [in Japanese]. *Public Health*. 2015;79(7):449–453.
31 Komagata O, Higa Y, Muto A, et al. Predicting the start of the *Aedes albopictus* (Diptera: Culicidae) female adult biting season using the spring temperature in Japan. *J Med Entomol*. 2017;54(6):1519–1524.
32 Ng CF, Ueda K, Nitta H, Takeuchi A. Seasonal variation in the acute effects of ozone on premature mortality among elderly Japanese. *Environ Monit Assess*. 2013;185(10):8767–8776.
33 Lee W, Choi HM, Kim D, Honda Y, Leon Guo Y-L, Kim H. Synergic effect between high temperature and air pollution on mortality in Northeast Asia. *Environ Res*. 2019;178:108735.
34 Kim SE, Lim Y-H, Kim H. Temperature modifies the association between particulate air pollution and mortality: a multi-city study in South Korea. *Sci Total Environ*. 2015;524–525:376–383.
35 Gotou M. A survey of airborne Japanese cedar pollen in the Kansai Region: 10-year survey results from Hyogo prefecture [in Japanese]. *Seikatsu Eisei*. 2010;54(1):3–12.
36 Kishikawa R, Koto E. Effect of climate change on allergenic airborne pollen in Japan. *Immunol Allergy Clin*. 2021;41(1):111–125.
37 Ito Y. Clustering Sugi-pollen dispersal patterns for the past 26 years [in Japanese]. *Nihon Jibiinkoka Gakkai Kaiho*. 2014;117(5):681–687.
38 Kondo M, Shono A, Honda Y. Global warming, cedar pollinosis, and health care budget impact. *Glob Environ Res*. 2007;11(1):73–78.
39 Okazaki Y, Yoshida S, Kashima S, Miyamori D, Matsumoto M. Increased prescriptions for irritable bowel syndrome after the 2018 Japan floods: a longitudinal analysis based on the Japanese National Database of Health Insurance Claims and specific health checkups. *BMC Gastroenterol*. 2022;22(1):263.
40 Sunohara D, Miura T, Komatsu T, et al. Relationship between the flood disaster caused by the Reiwa first year east Japan typhoon and cardiovascular and cerebrovascular events in Nagano city: the SAVE trial. *J Cardiol*. 2021;78(5):447–455.
41 Yoshida S, Kashima S, Matsumoto M. The effect of the 2018 Japan floods on cognitive decline among long-term care insurance users in Japan: a retrospective cohort study. *Environ Health Prev Med*. 2021;26(1):113.
42 Ohashi Y, Takane Y, Nakajima K. Impact of the COVID-19 pandemic on changes in temperature-sensitive cardiovascular and respiratory disease mortality in Japan. *PLoS One*. 2022;17(10):e0275935.
43 Seposo X, Madaniyazi L, Ng CFS, Hashizume M, Honda Y. COVID-19 pandemic modifies temperature and heat-related illness ambulance transport association in Japan: a nationwide observational study. *Environ Health*. 2021;20(1):122.
44 Uryu S, Tanoue Y, Nomura S, et al. Trends in emergency transportation due to heat illness under the new normal lifestyle in the COVID-19 era, in Japan and 47 prefectures. *Sci Total Environ*. 2021;768:144723.
45 Association of Academies and Societies of Sciences in Asia (AASSA). *The imperative of climate action to promote and protect health in Asia*. AASSA; 2021. https://www.interacademies.org/publication/imperative-climate-action-promote-and-protect-health-asia. Accessed November 9, 2023.
46 Yamazaki S, Michikawa T. Association between high and low ambient temperature and out-of-hospital cardiac arrest with cardiac etiology in Japan: a case-crossover study. *Environ Health Prev Med*. 2017;22(1):60.
47 Lim YH, Reid CE, Honda Y, Kim H. Temperature deviation index and elderly mortality in Japan. *Int J Biometeorol*. 2016;60(7):991–998.
48 Fujibe F, Matsumoto J, Suzuki H. Spatial and temporal features of heat stroke mortality in Japan and their relation to temperature variations, 1999-2014 (vol 91, pg 17, 2018). *Geogr Rev Jpn Ser B*. 2019;92(1):50.
49 Chung Y, Lim YH, Honda Y, et al. Mortality related to extreme temperature for 15 cities in northeast Asia. *Epidemiology*. 2015;26(2):255–262.
50 Kondo M, Ono M, Nakazawa K, et al. Population at high-risk of indoor heatstroke: the usage of cooling appliances among urban elderlies in Japan. *Environ Health Prev Med*. 2013;18(3):251–257.
51 Fire and Disaster Management Agency (FDMA). *Japan Status report of emergency transport due to heatstroke during May and September in 2018 [in Japanese]*. Japan: Ministry of Internal Affairs and Communications; 2018. https://www.fdma.go.jp/disaster/heatstroke/item/heatstroke003_houdou01.pdf. Accessed November 9, 2023.
52 Fire and Disaster Management Agency (FDMA), Japan. *Heatstroke information* 2023.
53 Ministry of the Environment, Japan (MOEJ). *Heat stress index: WBGT* 2023.
54 Guo Y, Gasparrini A, Armstrong BG, et al. Heat wave and mortality: a multicountry, multicommunity study. *Environ Health Perspect*. 2017;125(8):087006.
55 Gasparrini A, Guo Y, Hashizume M, et al. Changes in susceptibility to heat during the summer: a multicountry analysis. *Am J Epidemiol*. 2016;183(11):1027–1036.
56 Lee W, Ebi KL, Kim Y, et al. Heat-mortality risk and the population concentration of metropolitan areas in Japan: a nationwide time-series study. *Int J Epidemiol*. 2021;50(2):602–612.
57 Ueno S, Hayano D, Noguchi E, Aruga T. Investigating age and regional effects on the relation between the incidence of heat-related ambulance transport and daily maximum temperature or WBGT. *Environ Health Prev Med*. 2021;26(1):116.
58 Ma C, Yang J, Nakayama SF, et al. Cold spells and cause-specific mortality in 47 Japanese prefectures: a systematic evaluation. *Environ Health Perspect*. 2021;129(6):67001.
59 Narumi D, Ihara T, Fukuda S. Study on the impact for fatigue due to changing urban outdoor temperature [in Japanese]. *AIJ J Technol Des*. 2017;23(54):563–566.
60 Ohashi Y, Ihara T, Genchi Y. Relationship between sleep disorder and nighttime outdoor thermal environment in the 23 wards of Tokyo [in Japanese]. *J Environ Inf Sci*. 2014;28:367–372.
61 Yamaguchi H, Nozu K, Ishiko S, et al. Multivariate analysis of the impact of weather and air pollution on emergency department visits for night-time headaches among children: retrospective, clinical observational study. *BMJ Open*. 2021;11(4):e046520.
62 Bennett CM, McMichael AJ. Non-heat related impacts of climate change on working populations. *Glob Health Action*. 2010;3(1):5640.
63 Likhvar V, Honda Y, Ono M. Relation between temperature and suicide mortality in Japan in the presence of other confounding factors using time-series analysis with a semiparametric approach. *Environ Health Prev Med*. 2011;16(1):36–43.
64 Kim Y, Kim H, Honda Y, et al. Suicide and ambient temperature in East Asian countries: a time-stratified case-crossover analysis. *Environ Health Perspect*. 2016;124(1):75–80.
65 Kim Y, Kim H, Gasparrini A, et al. Suicide and ambient temperature: a multi-country multi-city study. *Environ Health Perspect*. 2019;127(11):117007.
66 Kubo R, Ueda K, Seposo X, Honda A, Takano H. Association between ambient temperature and intentional injuries: a case-

crossover analysis using ambulance transport records in Japan. *Sci Total Environ*. 2021;774:145511.
67 Abe T, Tokuda Y, Ohde S, Ishimatsu S, Nakamura T, Birrer RB. The influence of meteorological factors on the occurrence of trauma and motor vehicle collisions in Tokyo. *Emerg Med J*. 2008;25(11):769–772.
68 Pan R, Honda Y, Minakuchi E, Kim SE, Hashizume M, Kim Y. Ambient temperature and external causes of death in Japan from 1979 to 2015: a time-stratified case-crossover analysis. *Environ Health Perspect*. 2022;130(4):47004.
69 Miyamura K, Nawa N, Nishimura H, Fushimi K, Fujiwara T. Association between heat exposure and hospitalization for diabetic ketoacidosis, hyperosmolar hyperglycemic state, and hypoglycemia in Japan. *Environ Int*. 2022;167:107410.
70 Romanello M, McGushin A, Di Napoli C, et al. The 2021 report of the Lancet Countdown on health and climate change: code red for a healthy future. *Lancet*. 2021;398(10311):1619–1662.
71 Fleming ZL, Doherty RM, von Schneidemesser E, et al. Tropospheric Ozone Assessment Report: present-day ozone distribution and trends relevant to human health. *Elementa Sci Anthrop*. 2018;6:12.
72 Vicedo-Cabrera AM, Sera F, Liu C, et al. Short term association between ozone and mortality: global two stage time series study in 406 locations in 20 countries. *BMJ*. 2020;368:m108.
73 Orru H, Ebi KL, Forsberg B. The interplay of climate change and air pollution on health. *Curr Environ Health Rep*. 2017;4(4):504–513.
74 Kobayashi S, Takeuchi S, Yasaka M. Trends in annual counts of Betula pollen from six cities in Hokkaido [in Japanese]. *Jpn J Palynol*. 2013;59:59–67.
75 Suzuki M. Allergic rhinitis and lifestyle [in Japanese]. *Arerugi*. 2015;64(7):911–917.
76 Arizuka M, Seki K, Miyamoto T, Uchida J, Ikemoto R. *Prevalence survey of* Vibrio parahaemolyticus *in Kagawa prefecture [in Japanese]*; 2013. http://id.ndl.go.jp/bib/025172808. Accessed October 4, 2023.
77 Goto I, Nakai M, Miyazaki M, et al. Investigation of *Vibrio parahaemolyticus* and Salmonella detected in food poisoning or gastroenteritis [in Japanese]. *Ann Rep Miyagi Health Environ Center*. 2011;29:33–36.
78 Onozuka D, Hagihara A. Nationwide variation in the effects of temperature on infectious gastroenteritis incidence in Japan. *Sci Rep*. 2015;5:12932.
79 Dey SK, Ushijima H, Phathammavong O, et al. Seasonal trend and serotype distribution of rotavirus infection in Japan, 1981-2008. *Pediatr Infect Dis J*. 2010;29(2):166–167.
80 Chen C-C, Lin B-C, Yap L, Chiang P-H, Chan T-C. The association between ambient temperature and acute diarrhea incidence in Hong Kong, Taiwan, and Japan. *Sustainability*. 2018;10(5):1417.
81 Ministry of Health, Labour and Welfare (MHLW), Japan. *Outbreak of domestic cases of dengue fever [in Japanese]*; 2019. https://www.mhlw.go.jp/content/000549790.pdf. Accessed July 4, 2023.
82 Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan Meteorological Agency (JMA), Ministry of the Environment, Japan (MOEJ). *Integrated report on observation, prediction and impact assessment for climate change in 2012 [in Japanese]*; 2013. https://www.env.go.jp/earth/ondanka/rep130412/report_full.pdf. Accessed October 4, 2023.
83 Kobayashi M, Komagata O, Nihei N. Global warming and vector-borne infectious diseases. *J Disaster Res*. 2008;3(2):105–112.
84 Yoshizumi M, Koike M, Takahashi N, et al. Epidemiological study of the features of tsutsugamushi disease in Gunma prefecture and Tone-Numata Health and Medical Service Area. *Kitakanto Med J*. 2017;67(1):23–31.
85 Seto J, Suzuki Y, Nakao R, Otani K, Yahagi K, Mizuta K. Meteorological factors affecting scrub typhus occurrence: a retrospective study of Yamagata prefecture, Japan, 1984–2014. *Epidemiol Infect*. 2017;145(3):462–470.
86 National Institute of Infectious Diseases (NIID). Severe fever with thrombocytopenia syndrome (SFTS) in Japan, as of June 2019. *Infect Agents Surveill Rep*. 2019;40(7):111–112.
87 Kashima S, Yoshida S, Okazaki Y, Ishii S, Koike S, Matsumoto M. The 2018 Japan floods increased prescriptions of antidementia drugs among disaster victims. *J Am Med Dir Assoc*. 2022;23(6):1045–1051.
88 Okazaki Y, Yoshida S, Kashima S, Ishii S, Koike S, Matsumoto M. Impact of the 2018 Japan floods on benzodiazepine use: a longitudinal analysis based on the National Database of Health Insurance Claims. *Soc Psychiatry Psychiatr Epidemiol*. 2022;57(12):2411–2421.
89 Okazaki Y, Yoshida S, Kashima S, Koike S, Matsumoto M. Impact of the 2018 Japan floods on prescriptions for migraine: a longitudinal analysis using the National Database of Health Insurance Claims. *Headache*. 2022;62(6):657–667.
90 Hatakeyama K, Ota J, Takahashi Y, Kawamitsu S, Seposo X. Effect of the COVID-19 pandemic on heatstroke-related ambulance dispatch in the 47 prefectures of Japan. *Sci Total Environ*. 2021;768:145176.
91 Ministry of the Environment, Japan (MOEJ). *Annual report on the environment, the sound material-cycle society and biodiversity in Japan 2020 [in Japanese]*. MOEJ; 2020. https://www.env.go.jp/policy/hakusyo/r02/pdf/full.pdf. Accessed November 9, 2023.
92 S-8 Climate Change Impact and Adaptation Research Project Team. *Climate change "Impacts on Japan": comprehensive impact assessment and adaptation measures based on new scenarios*. Ibaraki, Japan; 2014. https://www.nies.go.jp/s8_project/symposium/20141110_s8english.pdf. Accessed July 4, 2023.
93 He C, Kim H, Hashizume M, et al. The effects of night-time warming on mortality burden under future climate change scenarios: a modelling study. *Lancet Planet Health*. 2022;6(8):e648–e657.
94 Suzuki-Parker A, Kusaka H. Future projections of labor hours based on WBGT for Tokyo and Osaka, Japan, using multi-period ensemble dynamical downscale simulations. *Int J Biometeorol*. 2016;60(2):307–310.
95 Suzuki-Parker A, Kusaka H. Future projection of thermal environment in Japan using WBGT [in Japanese]. *Jpn J Biometeorol*. 2015;52(1):59–72.
96 Ihara T, Kusaka H, Hara M, Matsuhashi R, Yoshida Y. Estimation of mild health disorder caused by urban air temperature increase with midpoint-type impact assessment methodology [in Japanese]. *J Environ Eng*. 2011;76:459–467.
97 Kusaka H, Iijima N, Ihara T, Hara M, Takane Y, Iizuka S. Future projection of heat stroke and sleep disturbance for 2070's August in Tokyo, Nagoya, and Osaka [in Japanese]. *J Environ Eng*. 2013;78:873–881.
98 Lee J-B, Cha J-S, Hong S-C, et al. Projections of summertime ozone concentration over East Asia under multiple IPCC SRES emission scenarios. *Atmos Environ*. 2015;106:335–346.
99 Silva RA, West JJ, Lamarque JF, et al. The effect of future ambient air pollution on human premature mortality to 2100 using output from the ACCMIP model ensemble. *Atmos Chem Phys*. 2016;16(15):9847–9862.
100 Yamashita K, Honda Y. In: Akhtar R, Palagiano C, eds. *Climate change and air pollution in East Asia: taking transboundary air pollution into account*. Cham: Springer; 2018:309–326.
101 Tang L, Itsubo N. Estimation of human health damage factor on waterborne disease caused by global warming [in Japanese]. *J Life Cycle Assess Jpn*. 2011;7:242–256.
102 Onozuka D, Gasparrini A, Sera F, Hashizume M, Honda Y. Modeling future projections of temperature-related excess morbidity due to infectious gastroenteritis under climate change conditions in Japan. *Environ Health Perspect*. 2019;127(7):077006.
103 Kuzuya M. Heatstroke in older adults. *Jpn Med Assoc J*. 2013;56:193–198.
104 Otani S, Funaki Ishizu S, Masumoto T, Amano H, Kurozawa Y. The effect of minimum and maximum air temperatures in the summer on heat stroke in Japan: a time-stratified case-crossover study. *Int J Environ Res Public Health*. 2021;18(4).
105 Toosty NT, Hagishima A, Tanaka KI. Heat health risk assessment analysing heatstroke patients in Fukuoka city, Japan. *PLoS One*. 2021;16(6):e0253011.
106 Kaido T, Suzuki Y, Honda Y, Honjo A, Maekura R. Association between bedroom thermal environment and complaints of dyspnea in patient with chronic obstructive pulmonary disease [in Japanese]. *Jpn J Health Hum Ecol*. 2017;83(3):85–93.
107 Onozuka D, Hagihara A. Variation in vulnerability to extreme-temperature-related mortality in Japan: a 40-year time-series analysis. *Environ Res*. 2015;140:177–184.
108 Ng CFS, Boeckmann M, Ueda K, et al. Heat-related mortality: effect modification and adaptation in Japan from 1972 to 2010. *Glob Environ Change*. 2016;39:234–243.
109 Sera F, Hashizume M, Honda Y, et al. Air conditioning and heat-related mortality: a multi-country longitudinal study. *Epidemiology*. 2020;31(6):779–787.
110 Noble IR, Huq S, Anokhin YA, et al. Adaptation needs and options. In: Field CB, Barros VR, Dokken DJ, et al., eds. *Climate change 2014: impacts, adaptation, and vulnerability part A: global and sectoral aspects*

contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2014.

111 European Commission, European Environment Agency. *Adaptation options*; 2023. https://climate-adapt.eea.europa.eu/en/knowledge/adaptation-information/adaptation-options. Accessed October 10, 2023.

112 Ministry of the Environment, Japan (MOEJ). *Cabinet approval of the Climate Change Adaptation Act [in Japanese]*; 2018. https://www.env.go.jp/press/105165.html. Accessed March 2, 2023.

113 National Institute for Environmental Studies (NIES). *Climate change adaptation information platform (A-PLAT)*; 2023. https://adaptation-platform.nies.go.jp/en/. Accessed July 4, 2023.

114 Cabinet Office. *National adaptation plan [in Japanese]*; 2021. https://www.env.go.jp/content/000138042.pdf. Accessed May 5, 2023.

115 Ministry of the Environment, Japan (MOEJ). *Cabinet decision regarding the Heatstroke countermeasure implementation plan and climate change adaptation plan (partially revised) [in Japanese]*; 2023. https://www.env.go.jp/press/press_01675.html. Accessed July 4, 2023.

116 National Institute for Environmental Studies (NIES). *List of local climate change adaptation plans [in Japanese]*; 2023. https://adaptation-platform.nies.go.jp/local/plan/list.html. Accessed July 4, 2023.

117 Government of Japan. *Action plan for heatstroke prevention [in Japanese]*; 2021. https://www.env.go.jp/content/900517263.pdf. Accessed May 17, 2023.

118 Government of Japan. *Action plan for heatstroke prevention [in Japanese]*; 2022. https://www.env.go.jp/content/900502212.pdf. Accessed May 17, 2023.

119 Ministry of the Environment, Japan (MOEJ). *Heatstroke alert [in Japanese]*; 2023. https://www.wbgt.env.go.jp/about_alert.php. Accessed July 4, 2023.

120 Japan Meteorological Agency (JMA). *Heat watch information [in Japanese]*; 2023. https://www.data.jma.go.jp/add/suishin/cgi-bin/catalogue/make_product_page.cgi?id=Ko-on. Accessed July 4, 2023.

121 City of Yokohama. *Heatstroke prevention notification postcards [in Japanese]: city of Yokohama*; 2018. https://www.city.yokohama.lg.jp/city-info/koho-kocho/press/shobo/2018/20180702-019-27696.files/phpYlG18A.pdf. Accessed March 2, 2023.

122 Tokyo Metropolitan Government (TMG). Heatstroke fatalities in the summer of 2020 [the 23 wards of Tokyo (confirmed counts)/[reference] Tama area (confirmed counts)] [in Japanese]. https://www.hokeniryo.metro.tokyo.lg.jp/kansatsu/oshirase/R02-heatstroke.html. Accessed July 4, 2023.

123 Kayaba M, Kondo M, Honda Y. Characteristics of elderly people living in non-air-conditioned homes. *Environ Health Prev Med*. 2015;20(1):68–71.

124 Ministry of the Environment, Japan (MOEJ). *Results of bid for entities to implement a subscription-based pilot business to spread the use of air conditioning [in Japanese]*; 2022. https://www.env.go.jp/press/110842.html. Accessed July 4, 2023.

125 Saitama Prefecture. *"Cool Oasis" to prevent heatstroke [in Japanese]*; 2022. https://www.pref.saitama.lg.jp/a0704/netsuchusyo/cool-oasis.html. Accessed March 2, 2023.

126 Wariishi H, Tsujimi S, Tanaka T. Actual usage of air-conditioned wear in building facilities construction sites. *Trans Soc Heat Aircondition Sanit Eng Jpn*. 2021;46(297):39–46.

127 SHASEJ. *Heat island countermeasures*. Tokyo: Ohmsha Co.; 2009.

128 Oke TR, Mills G, Christen A, Voogt JA. *Urban climates*. Cambridge: Cambridge Univ. Press; 2017.

129 Tokyo Metropolitan Government (TMG). *Urban heat island countermeasures policy [in Japanese]*. TMG; 2003. https://www.kankyo.metro.tokyo.lg.jp/climate/heat_island/regulation.files/heathousin.pdf. Accessed November 9, 2023.

130 Ministry of the Environment, Japan (MOEJ). *Chapter 4: Heat island countermeasures [in Japanese]. FY1999 report on countermeasure methods to inhibit the heat island effect* 2000.

131 Ministry of Education, Culture, Sports, Science and Technology (MEXT). *Social implementation program on climate change adaptation technology (SI-CAT) [in Japanese]*; 2020. https://www.restec.or.jp/si-cat/_public/202003/SI-CAT%E6%88%90%E6%9E%9C%E9%9B%86%E5%8E%9F%E7%A8%BF%E9%9B%86_%E3%83%95%E3%83%AB_20200302.pdf. Accessed June 30, 2023.

132 Local Climate Change Adaptation Center in Saitama. Heat stress countermeasures in Kumagaya Sports Culture Park and their effectiveness [in Japanese]. https://saiplat.pref.saitama.lg.jp/adaption_case/kumagaya-sports-culture-park. Accessed July 24, 2023.

133 Rao-Skirbekk S, Budin-Ljøsne I, Chaudhary P, Sitoula S, Chersich M. Costs and benefits of climate services for heat-health adaptation in Europe. *Eur J Public Health*. 2023;33(Supplement_2):ckad160.371.

134 Ohashi Y, Ihara T, Kikegawa Y, Sugiyama N. Numerical simulations of influence of heat island countermeasures on outdoor human heat stress in the 23 wards of Tokyo, Japan. *Energy Build*. 2016;114:104–111.

135 Yamaguchi K, Umeno R, Takane Y, Ihara T. Evaluation of mortality risk reduction effect of heat adaptation measures considering time-of-day temperature effects [in Japanese]. *Jpn J Biometeorol*. 2022;2022:S36.

136 Chua PL, Takane Y, Ng CF, Oka K, Honda Y, Hashizume M. *Heat-related excess mortality due to climate change: effect of adding positive feedback from anthropogenic heat from air conditioning [in Japanese]*. Japan: The Meteorological Society of Japan; 2022:156.

137 Fire and Disaster Management Agency (FDMA), Japan. *Ambulance transport for patients with heatstroke in 2022 (May to September) [in Japanese]*; 2022. https://www.fdma.go.jp/disaster/heatstroke/items/r4/heatstroke_geppou_202205-09.pdf. Accessed May 17, 2023.

138 Tokyo Medical Examiner's Office (TMEO). Heatstroke fatalities in the summer of 2020. https://www.fukushihoken.metro.tokyo.lg.jp/kansatsu/oshirase/R02-heatstroke-sokuhou.html. Accessed March 2, 2023.

139 World Health Organization (WHO). *Climate change and human health: risks and responses*. Geneva: World Health Organization; 2003. https://apps.who.int/iris/handle/10665/42742. Accessed November 9, 2023.

140 Cabinet Office. *White paper: disaster management in Japan*. Cabinet Office; 2018. https://www.bousai.go.jp/kaigirep/hakusho/pdf/H30_hakusho_english.pdf. Accessed November 9, 2023.

141 Yamasaki L, Kamada T, Ng C, et al. *Heat-related deaths and ambulance transports after typhoon-triggered power outages: a quasi-experimental study in the metropolitan areas of Japan. Abstract. International Society for Environmental Epidemiology (ISEE)*; 2022. https://ehp.niehs.nih.gov/doi/abs/10.1289/isee.2022.O-OP-263. Accessed November 4, 2023.

142 The International Energy Agency (IEA). *Japan 2021: energy policy review*. Paris; 2021. https://www.iea.org/reports/japan-2021. Accessed May 19, 2023.

143 de Munck C, Pigeon G, Masson V, et al. How much can air conditioning increase air temperatures for a city like Paris, France? *Int J Climatol*. 2013;33(1):210–227.

144 Jay O, Capon A, Berry P, et al. Reducing the health effects of hot weather and heat extremes: from personal cooling strategies to green cities. *Lancet*. 2021;398(10301):709–724.

145 Nansai K, Fry J, Malik A, Takayanagi W, Kondo N. Carbon footprint of Japanese health care services from 2011 to 2015. *Resour Conserv Recycl*. 2020;152:104525.

146 Health Care Without Harm, ARUP. *Health care's climate footprint: how the health sector contributes to the global climate crisis and opportunities for action*; 2019. https://noharm-global.org/sites/default/files/documents-files/5961/HealthCaresClimateFootprint_092319.pdf. Accessed June 11, 2023.