REVIEW ARTICLE

Projection of Heat-Related Health Effects Under Climate Change Scenarios in Asia: A Systematic Review

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ABSTRAK

Perubahan iklim merupakan cabaran utama yang sedang melanda seluruh dunia. Asia merupakan antara kawasan yang sangat terdedah kepada kejadian ekstrem akibat perubahan iklim termasuk haba dan kesan kesihatan yang berkaitan. Selain itu, kejadian haba melampau dijangka akan menjadi lebih kerap dan teruk. Walau bagaimanapun, ulasan mengenai kesan haba terhadap kesihatan di Asia adalah terhad. Kajian ini dijalankan untuk menyediakan tinjauan sistematik yang terkini dan menyeluruh mengenai haba dan kesannya terhadap kesihatan yang berkaitan di Asia. Kajian literasi telah dilakukan menggunakan pangkalan data Web of Science, SCOPUS, OVID MEDLINE (R) and PubMed, dengan menumpukan kepada artikel penyelidikan asal yang telah diterbitkan daripada Januari 2018 hingga Jun 2023. Kebanyakan kajian yang terlibat adalah daripada China, Iran, Filipina, Korea Selatan, Thailand, Türkiye dan Vietnam. Penemuan kajian ini menunjukkan kesan kesihatan yang membimbangkan iaitu trend unjuran yang semakin meningkat untuk kematian (semua punca, penyakit kardiovaskular dan penyakit pernafasan) dan morbiditi (penyakit berjangkit usus). Kajian ini menyediakan maklumat yang komprehensif dan terkini mengenai kesan kesihatan haba dan populasi yang terdedah di Asia. Ulasan ini boleh membantu dalam mengenalpasti dan melaksanakan strategi mitigasi dan penyesuaian yang berkesan untuk meningkatkan persediaan dan ketahanan terhadap kesan kesihatan haba yang teruk akibat perubahan iklim.

Kata kunci: Asia; haba; kesan kesihatan; perubahan iklim; unjuran

ABSTRACT

Climate change is a major challenge which currently affecting all nations. Asia is among the regions highly vulnerable to extreme events due to climate change, including heat and

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its related health effects. Furthermore, extreme heat events are projected to become more frequent and intense. However, reviews projecting the health impacts of heat in Asia are limited. This study was conducted to provide an updated and comprehensive systematic review assessing heat and the related health effects across Asia. A literature search was conducted using the Web of Science, SCOPUS, OVID MEDLINE (R) and PubMed databases, focused on original research articles published from January 2018 to June 2023. Most of the included studies were from China, Iran, the Philippines, South Korea, Thailand, Türkiye and Vietnam. This findings determined that the significant health effects were increased projection trend for mortality (all causes, cardiovascular diseases, respiratory diseases) and morbidity (intestinal infectious diseases). This review provides comprehensive, updated information on the heat health effects and vulnerable populations in Asia. The results can aid the identification and implementation of mitigation and adaptation plans to enhance preparation and resiliency against the adverse heat health effects of climate change.

Keywords: Asia; climate change; heat; health effects; projection

INTRODUCTION

It is widely acknowledged that prolonged heat exposure has harmful health effects, increasing mortality and morbidity cases in many parts of the world (Campbell et al. 2018; Mora et al. 2017). For example, a United States study reported that heat-related mortality in 1979-2018 generally ranged between 0.5 and 2 deaths per million people, with peaks in some years (US EPA 2021). Heat-related mortalities in 2000-2019 in Asia, Europe and Africa numbered 224,022, 178,712 and 25,549 per year, respectively.

Alongside increasing mortality, high temperatures are linked to increased Emergency Department (ED) visits (Ponjoan et al. 2017) and hospital admissions (Åström et al. 2013; Nhat et al. 2022). People with chronic diseases, especially cardiopulmonary diseases, are more susceptible to high temperatures (Yang et al. 2021). For example, a study in Vietnam reported increased cardiovascular hospital admission rates during hot temperatures (Nhat et al. 2022). This tropical country experienced increased hospitalisation risk during ambient temperatures >25.7°C. A Rhode Island study reported that increased maximum daily temperatures of 24-29°C were associated with 1.3% and 23.9% higher rates of all-cause and heat-related ED visits, respectively.

Advanced studies have addressed the projection of heat-related mortality and morbidity over the long-term (up to 2100), such as those conducted in China (Sun et al. 2021; Yang et al. 2021), Germany (Huber et al. 2020), South Korea (Kim et al. 2014) and the United States (Weinberger et al. 2017). These studies indicated that heat-related health effects increase when temperatures become higher. Rocque et al. (2021) and Campbell et al. (2018) conducted more comprehensive reviews globally. However, these reviews did not involve projections for future health effects. Huang et al. (2011) and Sanderson et al. (2017) conducted global reviews on heat-related mortality projections, but the study by Huang et al. (2011) was conducted a decade ago and both reviews did not include the morbidity effects from high temperatures.

Despite the studies on the health effects of high temperatures, systematic reviews of existing studies, particularly over the long-term in Asia, remain limited. Asia is the largest continent, covering approximately 30% of the Earth land area and is the world's most populous region, where approximately 60% of the total population resides (Boudreau et al. 2023). Additionally, global studies have reported that populations in tropical and subtropical regions, particularly Asia, are among the populations largely exposed to extreme heatwaves (Guo et al. 2018; Marcotullio et al. 2022). Hence, this study aimed to address the knowledge gap by systematically reviewing previous studies to enhance understanding of the long-term effects of heat-related mortality and morbidity linked to climate change events in Asia.

MATERIALS AND METHODS

The Review Protocol

This systematic review was guided by PRISMA Statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Page et al. 2021).

Research Question Formulation

This systematic literature review is an aetiology/risk type of review, that asseses the association between specific exposures/risk factors and health effects. The PEO (P, population; E, exposure; O, Outcome) concept was use to guide the research formulation (Moola et al. 2015). Based on these concepts, the authors have included three main aspects in the review namely (i) Asian population (population); (ii) high ambient temperature (exposure of interest); and (iii) projected mortality and morbidity cases (outcome) which then guide the authors to formulate its main research questions – What is the projection on heat-related mortality and morbidity under different climate change scenarios in Asia?

Systematic Searching Strategies

(i) Identification

The keywords were constructed referring to the research question and their identification required the online thesaurus, keywords from previous studies and keywords recommended by experts. The search string was created and generated using Boolean operators and keywords were search using Web of Science, SCOPUS, OVID MEDLINE R and PUBMED (Table S1).

(ii) Screening

Screening involved the authors (FA and NA) to manually examined each article to ensure their relevance based on objectives in the present study. This process was conducted by reading the title and abstract of the articles. Disagreements were resolved by discussion with a third author (RH) to reach consensus.

(iii) Inclusion and exclusion criteria

The inclusion criteria were: (i) publication within the 5-year span from 2018-2023;

(ii) full original article in a journal; (iii) published in English; (iv) heat related mortality and morbidity, (v) incorporated climate projection with or without climate change scenarios and (vi) conducted in Asian countries. The exclusion criterion is non-original articles such as conference proceedings, reports, systematic reviews, and meta-analyses.

Quality Assessment

The quality of eligible articles was assessed by FA and NA using a modified score checklist for ecological studies based on previous studies (Baharom et al. 2021; Dufault & Klar 2011). The quality evaluation consisted of 11 components, with a maximum total score of 15 points. The article quality was scored as low (≤5 points), medium (6-10 points), and high-relevance (≥11 points). The article's quality must be at least moderate to be included in the review.

Data Extraction and Synthesis

FA and NA extracted the data independently using a standardised data extraction form and presented it in a standard Microsoft Excel 365 spreadsheet. The extracted data and information include: (i) Authors; (ii) Year of publication; (iii) Location; (iv) Study period; (v) Temperature exposure; (vi) Heat-related mortality; (vii) Heat-related morbidity; (viii) Climate models; (ix) Climate change scenarios; (x) Statistical analysis; (xi) Demographic changes (population, adaptation and acclimatisation); and (xii) Health effects projection.

RESULTS

Study Identification, Screening and Selection

Study identification, screening and selection were summarised in Figure 1. In total, 3832 articles were retrieved in the first stage of the systematic literature review process. Prior to screening, 2398 articles were excluded using automation tools and 610 duplicates were removed. Overall, a total of 3008 articles were excluded, the remaining 824 articles proceeded for the screening and eligibility process. As a result, a total of 722 articles were excluded and there were 102 remaining articles ready for retrieval and eligibility. This was done by reading the titles, abstracts of the articles, and the main contents of the retrieved articles to confirm they were aligned with objectives in the present study. As a result, a total of 71 articles were excluded because they focused on heat-independent effects (10), historical climate change scenarios (12), different study outcomes (17), method development (2), no climate projection (3) and non-Asian countries (27). Overall, there were 29 remaining articles ready to be analysed. This process had scored 12 articles as high, 16 medium and 1 low-relevance (Table S2). Hence, 28 articles were included for the review.

Geographical Distribution of the Included Articles

Figure 2 depicted the geographical distribution of the included articles in Asia. Subregional categorisation revealed that most of the studies were from East Asia (86%), followed by those from Southeast

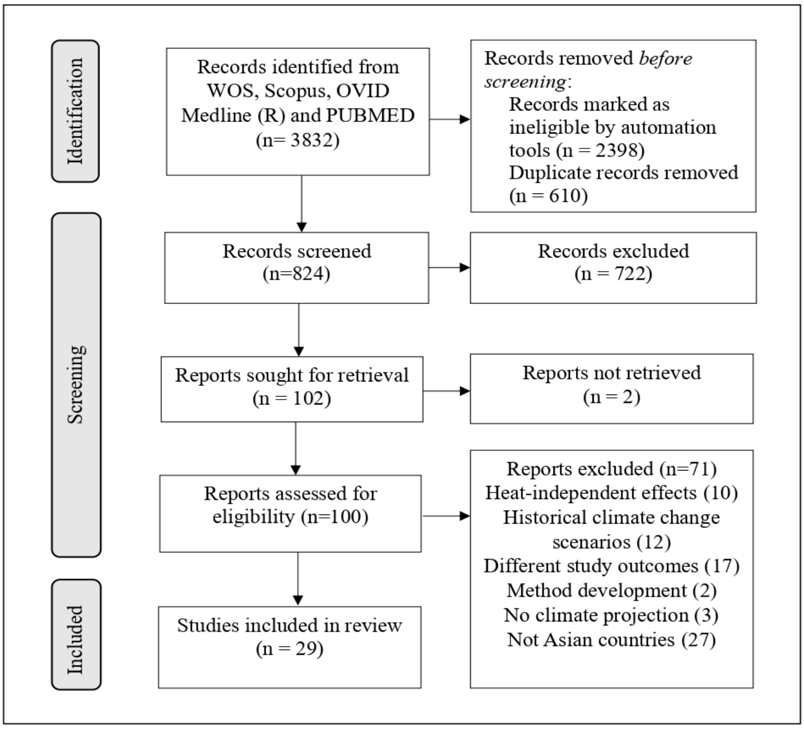

FIGURE 1: The PRISMA flow diagram

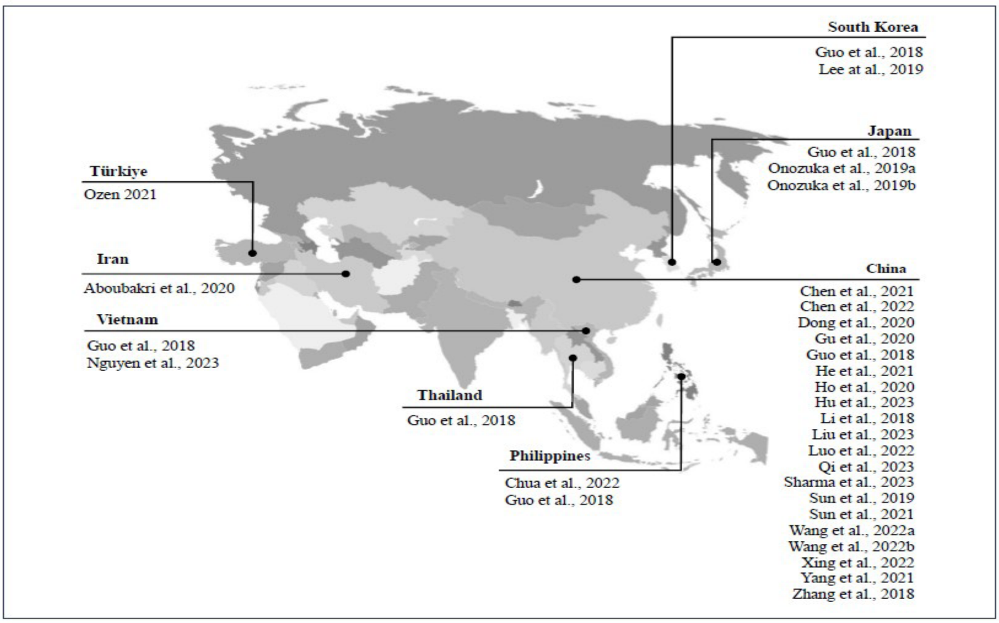

FIGURE 2: Studies location included in the review

Asia (7%) and West Asia (7%).

Basic Characteristics of the Eligible Studies

A few important characteristics of the included studies influenced the outcome for projecting heat-related health effects (Table S3). First, the selected study periods enabled forecasting of the future effects in the near-term (up to 2050) or long-term (up to 2100). The measures of temperature exposure in the included studies were daily maximum, mean and minimum temperatures; combination of minimum and maximum temperatures, diurnal temperature range (DTR), and modelled mean temperature of the warmest quarter. The daily mean and maximum temperatures were commonly used.

The included studies used various global climate models (GCMs), which ranged from one GCM (Ho et al. 2020; Özen 2021; Sun et al. 2019; Wang et al. 2022b) to 31 GCMs (Sun et al. 2019). The future climate projection was closely related to the climate change scenarios chosen. Climate projections involve representative concentration pathways (RCP) and shared socioeconomic pathways (SSP). Guo et al. (2018), Nguyen et al. (2023), Onozuka et al. (2019a) and Onozuka et al. (2019b) incorporated all four RCPs in their studies. Furthermore, Wang et al. (2022b) and Xing et al. (2022) incorporated both RCP and SSP scenarios.

Health Effects

Table 1 showed the projection of heat-related mortality and morbidity. Future climate would affect mortality, especially all-cause mortality (A00-Z99), all-cause non-external mortality/non-accidental death (A00-R99), cardiovascular disease (CVD)/circulatory system disease (I00-I99), coronary heart disease/ischemic heart disease (I20-I25), stroke (I60-I69), respiratory diseases (J00-J99), chronic lower respiratory disease (J40-J47), chronic obstructive pulmonary disease (COPD) (J41-J44), total injury (V00-Y99), road traffic injury (V00-V99), falls (W00-W19), drowning (W65-W74), suffocation (W75-W84), other unintentional injury (W20-W64, W85-W99, X00-X59), suicide (X60-X84) and assault (X85-Y09).

Morbidity related to extreme heat had also been investigated. The included studies focused on the projection of heat-related morbidity on intestinal infectious disease (IID) hospital admission, bacillary dysentery, out-of-hospital cardiac arrest (OHCA) and infectious gastroenteritis. Figure S1 highlighted that the most projected heat-related mortalities were related to: (i) all causes; (ii) CVD; and (iii) respiratory diseases. IID was the most projected heat-related morbidity.

(i) Projection of heat-related mortality

Generally, the projections under all climate change scenarios (RCP2.6, RCP4.5, RCP6.0, RCP8.5) indicated an increase in heat-related mortality until the mid-century (Aboubakri et al. 2020; Chen et al. 2021; Chen et al. 2022; Guo et al. 2018). Aboubakri et al. (2020) reported that under all scenarios, the mean temperature will increase by approximately 1°C by 2050. Without adaptation, more than 3000 heat-related mortalities are expected each decade (2020s, 2030s, 2040s) in Kerman, Iran. Similarly, Guo et al. (2018), reported that heat-related

TABLE 1: Projection of heat-related mortality and morbidity

Authors, year	Mortality	Morbidity	Projection results
		EASTERN ASIA	
Hu et al. (2023)	Total injury (V00-Y98), unintentional injury (V00-X59), intentional injury (X60-Y09), other injury (Y10-Y98) by intention: Injury by mechanism: - transport injury (V00-V99), fall (W00-W19), mechanical force (W20-W64), drowning (W65-W74), suffocation (W75-W84), poisoning (X40-X49), other unintentional injury (W85-W99, X50-X59), suicide (X60-X84), assault (X85-Y09)	-	- Heat-related total injury mortality was projected to increase from 61,348 (4.41/100000) in the 2060s to 67,895 (4.88/100000) in the 2090s under RCP4.5 scenario whereas for RCP8.5, from 91,480 (6.58/100 000) to 156,586 (11.26/100 000) respectively. - Heat-related mortality for unintentional injury was much higher than intentional injury. - Most mechanism specific injury types were projected to increase with top three were drowning, transport accidents and suicide, whilst poisoning and suffocation projected to decrease. - Male, population 15–69 years old, and people living in Western China were more vulnerable to injury mortality from increased temperature.
Liu et al. (2023)	All causes (A00-Z99)	-	- Heatwave-related excess mortality consistently increased among various heatwave definitions, with more significant increase under SSP5-8.5, when no adaptation. - Heatwave-related excess mortality showed no discernible difference between SSP2-4.5 and SSP5-8.5 under adaptation scenarios. - Projection heatwave-related mortality will be greater under SSP5-8.5 than under SSP2-4.5, 2-8 times higher.
Qi et al. 2023	Non-accidental causes (A00 R99), cardiovascular disease (I00–I99), coronary heart disease (I20–I25), stroke (I60–I69), respiratory diseases (J00–J98), COPD (J41–J44).	-	- The highest mortality rate among the five disease groups of interest was CVD-related - Every 10 C increase in the DTR would result in a 3.3 % excess risk of non-accidental mortality. - SSP1-2.6, DTR-associated mortality decreased from 2017 (233,154 deaths), 2050s (221,860), 2090s (132,305), attributing to reduction in the population. - Population migration will alter the DTR associated mortality in most areas in future.

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Sharma et al. (2023)	All-causes, circulatory (ICD9-390-459) and respiratory diseases (ICD9-460-519)	-	- Significant increase in projection of heat-related mortalities under different RCP scenarios. - Heat-attributable mortalities would account for almost 170,360 (all-cause), 36,557 (circulatory diseases) and 29,386 (respiratory diseases) additional annual mortality among the elderly, under the RCP8.5 scenario by 2090-2099 - Heat-attributable all-cause mortalities would rise by 3% (RCP2.6), 11% (RCP6.0) and 30% (RCP8.5) by 2090-2099, among the elderly.
Chen et al. (2022)	Non-accidental mortality (A00-R99)	-	- Mortality burden continue to rise under all RCPs, but RCP2.6 and RCP4.5, it will increase until 2040-2060, then decrease. - The decrease of attributable mortality during in RCP2.6 is caused by the direct effects of reduced heatwave frequency and total population. - Under RCP4.5, mortality was relatively steady as the climate and population effects maintain a balance. Under RCP8.5, the decline in population size cannot offset the losses caused by elevated heatwave frequency (explaining 95.6% of the growth in attributable deaths) and an aging population (explaining 4.4% of the growth in attributable mortality - Half (47.4-51.7%) of all mortality concentrated in east and central China under any scenario, covering China's developed urban agglomerations.
Luo et al. (2022)	Total injury (V00-Y99), unintentional injury (V00-X59), road traffic injury (V00-V99), falls (W00-W19), drowning (W65-W74), suffocation (W75-W84), other unintentional injury (W20-W64, W85-W99, X00-X59), intentional injury (X60-Y09), suicide (X60-X84), assault (X85-Y09), other injury (Y10-Y99).	-	- Compound heat index (CHE) was projected to increase of 3.25 times (RCP4.5) and increase 7.37 times (RCP8.5), but a decreasing trend was observed under RCP2.6, by end of century. - Assuming constant population, increasing trends of injury mortality burden attributable to CHEs were observed under RCP4.5 and RCP8.5. - CHEs strongly associated with increased injury mortality risk (RR= 1.14, 95%CI: 1.09–1.19), unintentional injuries (RR = 1.16, 95%CI:1.11,1.22) and intentional injuries (RR = 1.11, 95% CI:0.99,1.25). - Female and elderly were more susceptible to CHEs. - By end of 21st century, the frequency and CHEs injury mortality burden projected to increase under RCP8.5 scenario, by 7.37-fold and 8.22-fold respectively, particularly in southern, eastern, central and northwestern China.

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Wang et al. (2022a)	All known deaths excluding deaths from external causes (S00–T98) and cancer (C00–D48)	-	- Age-standardised mortality rates (ASMR) due to hot days, projected to increase over time especially after 2050s. - Under RCP2.6, the ASMR was projected to decrease after 2050s, while under RCP8.5 ASMR to increase steeply until 2090s. - Under RCP4.5, 6.0, and 8.5, population age 75 and older was projected twice fold increase in ASMR than twice 74 and younger attributable to hot weather. - Cardiovascular ASMR was projected to increase 135.99%, more than respiratory ASMR (113.85%) under all scenarios, particularly during 2090s. - Notable increase of projected ASMR under RCP8.5, with all adaptation scenarios.
Wang et al. (2022b)	All circulatory system diseases (I00-I99), respiratory system diseases (J00-J99)	-	- In Nanjing, high temperature caused increase in mortality from CSD especially among elderly (>65 years), with female has higher mortality. - In Suzhou, RSD had higher mortality particularly among younger population (0-64 years). - In Yancheng, mortality from RSD was slightly higher than in other cities, with the elderly having the greatest threat.
Xing et al. (2022)	Cardiovascular disease (I00-I99)	-	- Elderly was more susceptible to temperature than younger individuals. - In 2080–2099, SSP1-2.6 had the lowest and SSP5-8.5 had the greatest temperature-related cardiovascular mortality ratio (MR). Improving urbanisation level could reduce cardiovascular MR by 1.0-4.5% (2020-2039), 2.5-6.1% (2050-2069), and 3.7-12.5% (2080-2099) opposed to fixed urbanisation level. - Under SSP5-8.5 scenario, cardiovascular MR could increase by 161.1% (2050-2069) and 268.4%, (2080-2099), opposed to fixed ageing level.
Chen et al. (2021)	All-causes (non accidental) mortality	-	- Projected heat-mortality due (≥30°) increased drastically in New Taipei, Tainan, and Kaohsiung from 100-200 (2021) to 500-800 (2060) under RCP8.5. - Population change Elderly population increased, heat-related mortality increased up to 10-fold than general population (i.e. Taichung, Tainan, and Kaohsiung) Population size decreased, attributable mortality/100 000 was projected to have more than 10-fold increase in Taichung, Tainan and Kaohsiung

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He et al. (2021)	Non-accidental causes (A00-R99), cardiovascular disease (I00-I99), cerebrovascular disease (I60-I69), respiratory disease (J00-J98)	-	- Under RCP4.5, compound hot extreme (CHE)- related mortality increased significantly to 290% (2030s), 618% (2060s), and 692% (2090s) compared to 1990s. - Under RCP8.5, steady increase projected (384%, 1029%, and 1832%, respectively). - Under RCP2.6, CHE-related mortality increased until middle of 21st century (253 deaths in 2030s, 287 deaths in 2060s) and decreased in 2090s (245 deaths). - Increase mortality risk for females, elderly and population living in north China.
Sun et al. (2021)	Non-accidental (A00-R99)	-	The excess mortality from heat was projected to increase by 62.7% (2050s) and 138.0% (2080s).
Yang et al. (2021)	Non-accidental causes (A00-R99), cardiovascular disease (I00–I99), stroke (I60–I69), ischemic heart disease (I20–I25), respiratory ailments (J00–J99), and COPD (J40–J47).	-	- Heat-related excess mortality was projected to increase from 1.9% (2010s) to 2.4% (2030s) and 5.5% (2090s) under RCP8.5 - Vulnerable group were people with cardiorespiratory diseases, females, elderly and those with low educational. - Under various SSPs, population ageing increased future heat-related excess mortality by 2.3 - 5.8 times, especially in the northeast.
Dong et al. (2020)	Respiration disease (R00-R99)	-	- Projected additional heat-related mortality, increased from 2030s-2070s under all scenarios, except in 2070s under RCP4.5+ SSP2 scenario with adaptation. - The largest increase was in 2070s without adaptation under RCP8.5+constant scenario, 148.8% . - Additional heat-related mortality became smaller when adaptation was conducted. - Under two constant population scenarios, heat-related mortality rose significantly, and mortality under RCP8.5 was higher than RCP4.5, particularly in June 2070s.

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Gu et al. (2020)	All causes (A00-Z99), Circulatory system (I00-I99), Respiratory system (J00-J99), Digestive system (K00-K93), Nervous system (G00-G99), Mental disorders (F00-F99), Urinary system (N00-N39), Endocrine disease (E00-E35), External causes (V01-Y98), Ischemic heart disease (I20-I25), Cerebrovascular disease (I60-I69), Other heart disease (I00-I19), Respiratory infections (J00-J22), Chronic lower respiratory disease (J40-J47), Diabetes (E10-E14), Accidents (V01-X59)	-	Heat-related excess mortality was projected to increase between 2.90% (cerebrovascular disease) to 8.04% (nervous system disease) by the end of the 21st century under RCP8.5.
Ho et al. (2020)	All-cause mortality	-	- 1.7 more deaths per a summer day - Higher mortality was projected in 2050 than 2011 to 2014. - Increase in daytime temperature in rural areas contributed to higher mortality risk yet no significant increase in urbanised areas (human adaptation).
Liu et al. (2020)		Bacillary dysentery (BD	- Most parts of China, BD cases projected to increase as average temperature increase, particularly under RCP 8.5. - The associations between temperature and BD were similar for both gender and for children 0–5 y old and those ≥6 y old
Lee at al. (2019)	Non-accidental mortality (A00-R99)	-	- Temperature-related mortality in during summer in the 2090s was projected to increase 5.1 times (RCP 4.5) and 12.9 times (RCP 8.5) due to climate and population changes. - Under RCP 4.5, mortality ratio peaks in or around the 2060s and slightly declines to 5.1 in the 2090s because of the projected population decrease. - Under RCP 8.5, MR increased to 12.9 in the 2090s because of the increase in MR associated with climate change cancelled the decrease in MR associated with population change. - Compared to the reference mortality ratio of 12.9, climatic models had the greatest influence on mortality rate variations in the 2090s (+44% to -55%), followed by adaptation (-80%), climate (-60%), and population scenarios (+12% to -11%).

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Onozuka et al. (2019b)	-	Out-of-hospital cardiac arrest (OHCA)	- Projected increase OCHA heat-related morbidity across the scenarios with steeper slope under RCP8.5 - Heat-related excess morbidity was projected to rise from 0.4% to 2.4% across the same period and conditions. - Most of the excess morbidity was attributable to low temperatures, heat was only associated with a small fraction of excess morbidity (continuous increase with highest at the end of century under RCP8.5).
Onuzuka et al. (2019a)	-	Infectious gastroenteritis	- Projected increase excess heat-related morbidity across the scenarios with steeper slope under RCP8.5 - The diarrhoea heat-related excess morbidity was projected to rise from 5.7% to 9.7% under RCP8.5 across the same period, whereas the gradient gradually increased under RCP2.6, ranged from 5.8% (2010–2019) to 6.3% (2090–2099).
Sun et al. (2019)	Non-accidental mortality (A00-R99)	-	- The annual heat-related mortality in RCP4.5 and RCP8.5 will increase for under all population scenarios. - Heat-related mortality under climate scenario RCP8.5 increased dramatically compared to RCP4.5 scenario. - The median estimates of heat-related mortalities increased by approximately 127%, 221%, and 202%, respectively, under RCP4.5/SSP2 scenario, and increased by approximately 137%, 325%, and 443%, under RCP8.5/SSP5 scenario.
Guo et al. (2018)	Non-accidental mortality (A00–R99)	-	- Under no adaptation scenario, heatwave-related excess mortality was projected to increase. - Heatwave-related excess mortality increased when population variant and the greenhouse gas emissions became higher. - The heatwave-related excess mortality was projected to increase across all the countries /regions (except Japan), if under hypothetical adaptation, high-variant population and all scenarios of greenhouse gas emissions. - The increases under hypothetical adaptation were much lower than those without adaptation. - The decreases in heatwave-related excess mortality in Japan was attributable to the population decrease in the future.

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Li et al. (2018)	All-causes	-	In the middle and late 21st century (2041–2060), there were increase in annual incidence of excess heat-related mortality under all climate change scenarios. Adaptation assumption resulted in a decrease of 11% (2050s) and 36% (2070s) in projected heat mortality.
Zhang et al. (2018)	Cardiovascular disease (I00-I99)	-	- Assuming no population change, before 2050, the annual number of temperature-related CVD mortality showed increasing trend under RCP2.6, RCP4.5, and RCP8.5. - For 2050s-2070s, temperature-related CVD mortality was projected to increase under the RCP4.5 and RCP8.5 scenarios. Under 2.5 scenario, mortality was projected to remain constant or decrease slightly. - Assuming population change, the annual rise in temperature-related CVD mortality was up to five times greater compared to constant population.
		SOUTHEAST ASIA	
Chua et al. (2022)	Intestinal infectious diseases (A00–A09)	Intestinal infectious diseases hospital admission	- Future excess mortality was projected to increase considerably under RCP 4.5, 6.0, and 8.5 without population change or high population growth. - Projection of temperature-related excess hospital admissions may increase only moderately because some regional risks were greater with lower temperatures
Nguyen et al. (2023)	All-causes	-	- Mortality count caused by heatwaves will increase in the future. - Elderly (> 80 years old), female, people in South and North of Vietnam more likely affected by heatwaves. - A 1°C increase in the annual average temperature was associated with a 2.73% increase in the monthly mortality rate
		WESTERN ASIA	
Aboubakri et al. (2020)	All-causes	-	No adaptation -Under all scenarios, the temperature mean will rise about 1°C by 2050. Without adaptation, more than 3000 heat-related mortality in each decade (2020s, 2030s and 2040s). -Attributable number was highest in 2050 based on the worst climate scenario (RCP8.5) Adaptation - The contribution of heat to the attributable fraction slightly declined as MMT increases.

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Özen (2021)	All natural causes (ICD-9: 1–799)	-	- Mortality was projected to increase with extreme temperature events and overall increases in temperature variation. - Increases in mortality as expected had been found not only to be correlated with extreme temperature events (supporting the threshold hypothesis in the case of Turkey) but also to show a relationship between overall increases in temperature variation and an increase in the underlying mortality rate. - Elderly mortality and temperature change will be further strengthened as the size of the vulnerable population grows and the extreme heat events becames increasingly commonplace. - Central Anatolian region and the inner Mediterranean regions will become especially high-risk areas, with very high levels of temperature increases, high levels ofold age/adult age populations, and lower relative MMTs

CVD: Cardiovascular disease; DTR: Diurnal temperature range; RSD: Respiratory system diseases; BD: Bacillary dysentery; OHCA: Out-of-hospital cardiac arrest; MMT: Minimum mortality

excess mortality is projected to increase under a no-adaptation scenario. A study in China reported that the decreased mortality burden after 2060 was related to the direct effects of reduced heatwave frequency and total population. Chen et al. (2021) included population change and the expanding elderly population and reported increased heat-related mortality by up to 10-fold than the general population in Taichung, Tainan, and Kaohsiung, China.

(ii) Projection of heat-related morbidity

A study in the Philippines projected a moderate increase in IID hospital admissions as some regional risks were higher at lower temperatures (Chua et al. 2022). In most parts of China, bacillary dysentery cases were projected to increase as average temperatures increase, particularly under RCP8.5 (Liu et al. 2020). Onozuka et al. (2019b) reported that diarrhea heat-related excess morbidity was projected to increase from 5.7% to 9.7% under RCP8.5 across the same period, whereas the gradient gradually increased under RCP2.6 and ranged from 5.8% (2010-2019) to 6.3% (2090-2099).

DISCUSSION

Asia has the largest land mass, extends to the Arctic, and is warming faster than the world average. Kirtman & Power (2013) stated that the global temperature is projected to increase by 2˚C under RCP8.5 in 2050 as opposed to 1˚C under RCP4.5 above the pre-industrial level. Asia is projected to experience average temperature increases of >2˚C by 2050 under RCP8.5, with the magnitude and pace of warming varying across locations (Woetzel et al. 2020). Concurrently, the future warming climate is an alarming risk to human health worldwide, particularly in Asia, which houses approximately 60% of the world population (UNDESA 2017). The variations in heat-related mortality and morbidity are associated with variations in projected climate change, adaptation, and population change (Lee et al. 2019).

Health Effects of Heat on All-cause Mortality

The relationship between future heat and all-cause/non-accidental mortality was assessed in all sub-regions reviewed. Assuming constant populations and no adaptation, the heat-related burden was projected to increase from near-century to end-century under RCP8.5 (Liu et al. 2023; Yang et al. 2021). A 2021 report stated that under RCP8.5, heat-related mortality in China is expected to increase from 1.9% in the 2010s to 2.4% in the 2030s and 5.5% in the 2090s (Yang et al. 2021). These observations agreed with the results of Gu et al. (2020), which documented that the anticipated mortality rate from heat-related causes would increase from 0.75% in the 2010s to 4.1% in the 2090s. Notably, research conducted under RCP8.5 in Türkiye and Vietnam also revealed an increased trend in mortality and rising temperatures (Nguyen et al. 2023; Özen 2021)

The reviewed studies in Asia demonstrated a strong and consistent link with studies in other warm climates, such as the Middle East and North Africa (MENA) region. Under a high-emissions scenario (SSP5-8.5), MENA is projected to experience a 98% increase in annual heat-related mortality by 2100 (Hajat et al. 2023). A review by Gasparrini et al. (2017) identified a similar elevated trend of heat-related mortality in South America, Southern Europe, Central America, Central Europe and Southeast Asia under RCP8.5. These results indicate that the rising trend in mortality can generally be related to the warm climate resulting from the business-as-usual scenario, with the highest eenhouse gas (GHG) emissions and no strict climate mitigation measures. Contrastingly, if adaptation or population growth are assumed, heat-related mortality will decline, but the related mortality cannot compensate for the losses due to the increased frequency of heatwaves (Chen et al. 2022; Lee et al. 2019).

Health Effect of Heat on CVD Mortality

CVD are among the most common causes of non-accidental mortality. An estimated half a billion people worldwide have CVD. Meta-analyses have demonstrated that CVD is the leading cause of mortality during heatwaves (Ebi et al. 2021). A study in China by Qi et al. (2023) demonstrated that CVD mortality accounted for the highest percentage of total mortality (approximately 52%) from five disease groups of interest. Additionally, provinces with high populations and elderly people present a higher CVD-related mortality risk. Focusing on the effects of heat exposure on elderly people, Sharma et al. (2023) focused on weather variables and mortalities among the elderly population (aged >65 years). The authors reported increasing trends of heat-related mortality in 2030-2099 under RCP6.0 and RCP8.5. Under RCP8.5 (2090-2099) and assuming constant population growth, heat-related mortality would be responsible for 36,557 additional mortalities per year among elderly people. The possible reason for this trend is that extreme heat strains elderly people's hearts, making it more challenging for elderly people to manage, frequently leading to fatal heart-related issues during heatwaves (Kenney et al. 2014). Wang et al. (2022a) reported similar results, where they projected that cardiovascular age-standardised mortality rates would increase by 136% under all scenarios, with the 2090s being the most affected.

Contrastingly, a study in Japan by Onozuka et al. (2019a) reported the opposite finding. Onozuka et al. (2019a), stated that there would be a significant net decrease in temperature-related out-of-hospital cardiac arrest (OCHA) in higher-emission scenarios. Low temperatures were the main factor contributing to the excess morbidity, with heat being associated with only a minor portion of it. The direction and magnitude of the effects on mortality and morbidity might be inconsistent due to climate change. These inconsistent findings correlated to a review by Amegah et al. (2016) in Sub-Saharan Africa. Conclusively, positive or negative temperature variations are linked to CVD mortality and morbidity. Specifically, warmer temperatures are associated with higher risks of cardiovascular events, although lower temperatures may also be associated with these effects, which may differ depending on the conditions and geographic areas.

Health Effects of Heat on Respiratory Diseases Mortality

Climate change presents a serious threat to respiratory health by promoting or aggravating respiratory diseases or indirectly by increasing exposure to risk factors for respiratory diseases (D'Amato et al. 2014). Sharma et al. (2023) stated that future heat-related respiratory mortality is projected to increase more than CVD, particularly between 2060 and 2069, under RCP8.5. Under RCP8.5, the frequency of hot temperature extremes would increase by 6% and 15% in the 2030s and 2060s, respectively. Nevertheless, the long-term changes would be more pronounced, with an increased frequency of days with temperatures of 32-33°C in the 2090s, increasing the respiratory mortality risk in Taiwan. Overall, the RCP8.5 scenarios demonstrated the largest projected increases in temperature and mortality, with more significant long-term (2090-2099) effects. The reasons for this trend include a decline in the number of days with low temperatures and increased emission and pollutant levels associated with different RCP scenarios. Similarly, a review presented higher effects of future temperature change on respiratory rather than circulatory diseases.

This review focused on studies in the United Kingdom that reported that respiratory disease mortality is more susceptible to heat than CVD mortality despite the higher absolute burden of CVD mortality (Arbuthnott & Hajat 2017). Dong et al. (2020) exclusively examined mortality related to respiratory diseases. Respiratory heat-related mortalities were projected to increase from the 2030s to the 2070s under all four combination scenarios except for adaptation scenarios in the 2070s under the RCP4.5+SSP2 scenario. The largest increase in heat-related mortalities is 148.8% (85.5~226.1%), which occurs in the 2070s without adaptation under the RCP8.5+constant scenario. These studies demonstrated significant and consistent results with the study by Yang et al. (2021). Yang et al. (2021) projected that the excess cause-, age-, region-, and education-specific mortality in 161 Chinese districts/counties will be related to future high temperatures under RCP4.5 and RCP8.5. The key finding of cause-specific mortality includes populations with cardiorespiratory diseases, with the estimated heat-related attributable fractions in the 2090s under RCP8.5 being 6.3% (95% empirical confidence interval [eCI]: 2.3–10.2) for cardiovascular mortality and 7.7% (95% eCI: 1.6 to 14.7) for respiratory mortality.

Health Effects of Heat on Morbidity

Climate change significantly affects heat-related IID morbidity (Chua et al. 2022; Liu et al. 2020; Onozuka et al. 2019b). IID, or gastroenteritis, is an inflammation of the stomach and small and large intestines caused by bacterial, viral, or parasitic infections (Centers for Disease Control and Prevention 2018). Liu et al. (2020) corroborated that bacillary dysentery cases are projected to increase with rising average temperatures, especially under RCP8.5, in most of China. Both sexes and children aged 0-5 years and 6 years, demonstrated similar relationships between temperature and bacillary dysentery. Onozuka et al. (2019b) examined projections of temperature-related excess morbidity due to infectious gastroenteritis in Japan and reported similar findings.

Excess heat-related morbidity was projected to increase with a steeper slope under RCP8.5 in all scenarios (Onozuka et al. 2019b). Under RCP8.5, the diarrhea heat-related excess morbidity was projected to increase from 5.7% to 9.7% during the same period, while under RCP2.6, the gradient would progressively increase from 5.8% (2010-2019) to 6.3% (2090-2099). Furthermore, Chua et al. (2022) reported that the projection for temperature-related hospitalisations due to IID had increased, suggesting higher hospitalisations in 2090-2099 due to high population growth. This increasing trend was supported by the review by Ghazani et al. (2018). The review concluded that infectious gastroenteritis risk would increase in response to rising temperatures and more frequent and intense heat waves attributed to climate change. Higher temperatures tend to exacerbate bacterial conditions (Ghazani et al. 2018).

Strengths and Limitations of the Reviews

This review revealed current public health issues on heat-related health effects in Asian countries. All studies eligible in this review were subjected to systematic critical appraisal using the modified quality assessment checklist. The quality assessment checklist was specifically designed and adapted for ecological study, based on assessment tool reported in other ecological reviews by Baharom et al. (2021) and Dufault & Klar (2011). The scores of included studies ranged from moderate and high relevance, with low relevance studies being excluded.

This review has a couple of limitations worth noting. Firstly, it lacks registration. While not mandatory, having a pre-registered protocol would be advantageous. We acknowledged that a systematic review registry might alleviate publication bias, improve transparency and prevent redundant work (Straus & Moher 2010). Second limitation of this review is the lack of available research on heat-related morbidity in Asia. Thus, caution should be exercised as there could be more morbidity cases arise in future extend beyond IID. Furthermore, a significant proportion of included studies were reported in China. This may suggest that the country has a particular interest and emphasis this topic possibly influenced by the significant effects of heatwaves in addition to the large size and population of the country along with the concentration of research institutes. It is important to acknowledge potential of bias in the results for many other lower- and middle-income countries (LMICs). As these LMICs may differ greatly from China in terms of geographical and culture.

CONCLUSION

This review provides robust evidence for the association between heat and mortality as well as morbidity in the future in Asia. Temperatures will continue to rise, as will heat-related mortality or morbidity. The trend might vary depending on projected climate change scenarios, population changes and adaptation. Heat-related cardiovascular and respiratory mortality and IID are also projected to increase. This review improves projection realism and serves as a platform for scholars and policymaker consensus on provisions to mitigate future heat-related health effects. Future studies should focus on subcontinents or countries with limited studies as the effects vary with demographic factors.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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TABLE S1: The search strings

Database	Search string
Web of Science	TS= ((project* OR future) AND ("heat-related" OR "high temperature" OR "hot temperature" OR "extreme temperature" OR "extreme heat" OR "heat wave*") AND (mortality OR death OR morbidity OR disease OR illness) AND ("climat* change*" OR "global warming" OR "environmental change*" OR "greenhouse effect*" OR "climat* variability" OR "extreme weather event*"))
SCOPUS	TITLE-ABS-KEY ((project* OR future) AND ("heat-related" OR "high temperature" OR "hot temperature" OR "extreme temperature" OR "extreme heat" OR "heat wave*") AND (mortality OR death OR morbidity OR disease OR illness) AND ("climat* change*" OR "global warming" OR "environmental change*" OR "greenhouse effect*" OR "climat* variability" OR "extreme weather event*"))
OVID MEDLINE (R)	(project*.mp. OR future.mp. or *Forecasting/) AND (*Hot Temperature/ or "heat-related".mp. OR *Hot Temperature/ or "high temperature".mp. OR "hot temperature".mp. or *Hot Temperature/ OR *Hot Temperature/ or "extreme temperature".mp. OR "extreme heat".mp. or *Hot Temperature/ or *Extreme Heat/ or *Hot Temperature/ or "heat wave*".mp. or *Extreme Heat/) AND (morbidity.mp. or *Morbidity/ OR illness.mp OR disease.mp. or *Disease/ OR mortality.mp. or *Mortality/ OR death.mp. or *Death/) AND (*climate change/ or *greenhouse effect/ OR "global warming".mp. or *Greenhouse Effect/ or *Global Warming/ OR *Climate Change/ or "environmental change*".mp. OR *Greenhouse Effect/ or "greenhouse effect*".mp. OR *Climate Change/ or "climate* variability".mp. or *Greenhouse Effect/ OR *extreme weather/ or *temperature/)
PUBMED	(project*[Title/Abstract] OR future[Title/Abstract]) AND ("heat-related"[Title/Abstract] OR "high temperature"[Title/Abstract] OR "hot temperature"[Title/Abstract] OR "extreme temperature"[Title/Abstract] OR "extreme heat"[Title/Abstract] OR "heat wave*"[Title/Abstract]) AND (mortality[Title/Abstract] OR death[Title/Abstract] OR morbidity[Title/Abstract] OR disease[Title/Abstract] OR illness[Title/Abstract]) AND ("climate change*"[Title/Abstract] OR "climatic change*"[Title/Abstract] OR "global warming"[Title/Abstract] OR "environmental change*"[Title/Abstract] OR "greenhouse effect*"[Title/Abstract] OR "climate variability"[Title/Abstract] OR "climatic variability"[Title/Abstract] OR "extreme weather event*"[Title/Abstract])

TABLE S2: Critical appraisal of selected studies

No.	Author, Year	Sample size	Level of data aggregation	Level of inference	Pre-specification of ecological units	Analytic methodology	Validity of statistical inferences	Use of covariates	Proper adjustment for covariates	Statement of study design	Justification of study design	Discussion of cross-level bias and limitations	Total marks
						EASTERN ASIA							
1	Hu et al. (2023)	1	1	1	1	2	0	1	1	1	0	1	10
2	Liu et al. (2023)	0	1	1	1	2	0	1	1	1	0	1	9
3	Qi et al. (2023)	1	1	1	1	2	1	0	1	0	0	1	9
4	Sharma et al. (2023)	0	2	1	1	2	1	1	1	1	1	1	12
5	Chen et al. (2022)	1	2	1	1	2	1	1	1	1	0	1	11
6	Luo et al. (2022)	1	1	1	1	2	0	1	1	1	0	1	10
7	Wang et al. (2022a)	0	2	1	1	2	0	0	1	1	0	1	9
8	Wang et al. (2022b)	0	1	1	1	2	0	1	1	1	0	1	9
9	Xing et al. (2022)	0	1	1	1	2	1	1	1	1	0	0	9
10	Chen et al. (2021)	2	1	1	1	2	0	1	1	1	0	1	11
11	He et al. (2021)	0	1	1	1	2	1	1	1	1	1	1	11
12	Sun et al. (2021)	0	1	1	1	2	1	0	0	1	0	1	8
13	Yang et al. (2021)	0	1	1	1	2	1	0	1	1	0	1	9
14	Dong et al. (2020)	0	1	1	1	2	0	1	1	1	0	0	8
15	Gu et al. (2020)	0	1	1	1	2	0	1	1	1	0	1	9
16	Ho et al. (2020)	1	2	1	1	2	1	1	1	0	0	1	11
17	Liu et al. (2020)	1	1	1	1	2	1	1	1	1	0	1	11
18	Lee at al. (2019)	1	1	1	1	2	0	0	1	0	0	0	7
19	Onozuka et al. (2019b)	1	2	1	1	2	1	0	1	1	0	1	11

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20	Onuzuka et al. (2019a)	1	2	1	1	2	1	1	1	1	0	1	12
21	Sun et al. (2019)	0	1	1	1	2	0	1	1	1	0	1	9
22	Guo et al. (2018)	1	2	1	1	2	1	1	1	1	0	1	12
23	Li et al. (2018)	1	1	1	1	2	1	0	1	0	0	1	9
24	Zhang et al. (2018)	0	1	1	1	2	1	1	1	1	1	1	11
						SOUTHEAST ASIA							
1	Chua et al. (2022)	1	3	1	1	2	1	1	1	1	0	1	13
2	Nguyen et al. (2023)	1	3	1	1	2	1	1	1	0	0	0	11
						WESTERN ASIA							
1	Aboubakri et al. (2020)	0	2	1	1	2	0	0	0	1	1	1	8
2	Ozen (2021)	1	1	1	1	2	1	0	0	0	0	1	8

TABLE S3: Basic characteristics of the eligible studies

Authors, year	Location	Study period Historical/ Projection	Temperature exposure	Climate models	Climate change scenarios	Statistical analysis	Population change, adaptation and acclimatization
EASTERN ASIA							
Hu et al. (2023)	China	2010-2019/ 2060-2099	Daily average temperature	GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M	RCP 4.5 & RCP 8.5	Conditional logistic regression, multivariate meta-analysis, stratified analyses	Population change (SSP1-SSP5)
Liu et al. (2023)	China	2010-2019/ 2030-2099	Daily maximum temperature	ACCESS-CM2, ACCESS-ESM1-5 BCC-CSM2-MR, CanESM5, CanESM5-CanOE, CIESM, CMCC-CM2-SR5, CNRM-CM6-1, CNRM-CM6-1-HR, CNRM-ESM2-1, EC-Earth3, EC-Earth3-Veg, FGOALS-g3, GFDL-CM4, GFDL-ESM4, GISS-E2-1-G, HadGEM3-GC31-LL, INM-CM4-8, INM-CM5-0, IPSL-CM6A-LR MIROC6, MIROC-ES2L, MPI-ESM1-2-HR, MPI-ESM1-2-LR, MRI-ESM2-0, NESM3, UKESM1-0-LL	SSP2-4.5, SSP5-8.5	Quasi-Poisson models	Population changes (low, medium, and high variants)
Qi et al. (2023)	China	2013-2017/ 2050-2099	Daily DTR (daily maximum - daily minimum temperature)	ACCESS-CM2, ACCESS-ESM1–5, AWI-CM-1-1-MR, BCC-CSM2-MR, CanESM5, EC-Earth3-Veg, FGOALS-g3, FIO-ESM-2-0, IPSL-CM6A-LR, MPI-ESM1–2-LR, NESM3, and MIROC6	SSP1–2.6	Time-series regression, meta-analysis	Population changes
Sharma et al. (2023)	China	2005-2018/ 2030-2099	Daily average temperature	HadGEM2-AO, NorESM1-M, CSIRO-Mk3-6-0, CCSM4, bcc-csm1-1-m, MIROC5, CCSM4, HadGEM2-AO, CESM1-CAM5, MRI-CGCM3, MIROC5, GISS-E2-R, CCSM4, CSIRO-Mk3-6-0 HadGEM2-AO, CESM1-CAM5, GISS-E2-R, CCSM4, bcc-csm1-1, CSIRO-Mk3-6-0	RCP2.6, RCP6.0, RCP8.5	DLNM, random effect meta-analyses	Population changes -increase in elderly population 30% (2030s), 40% (2060s) and 50% (2090s)

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Chen et al. (2022)	China	1986 2005/ 2006 2100	Daily maximum temperature	HadGEM2-ES, MPI-ESM-MR, and NorESM1-M	RCP2.6, RCP4.5 & RCP8.5	Poisson GLM, meta-analysis	Population change (SSP2)
Luo et al. (2022)	China	2010-2019/ 2030-2099	Daily max and min temperature	GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESMCHEM and NorESM1-M	RCP2.6, RCP4.5, RCP8.5	Conditional logistic regression mode, DLNM, multivariate meta-analytical model	Population changes (SSP1-SSP5)
Wang et al. (2022a)	China	1976-2018/ 2030-2099	Daily mean temperature	24 GCMs	RCP4.5, RCP6.0 & RCP8.5	Pearson's correlation test, quasi-Poisson generalized additive models	Adaptation (No adaptation, Has adaptation)
Wang et al. (2022b)	China	2007-2015/ 2020-2100	Maximum temperature	CMIP 6: NorESM-MM	SSP126, SSP245, SSP370 & SSP585	DLNM, quasi-poisson models	
Xing et al. (2022)	China	2006-2011/ 2020-2099	Daily average temperature	CMIP 6: ACCESS-CM2, ACCESS-ESM-1-5, BCC-CSM2-MR, CCCma-CanESM5, CNRM-CM6-1, CNRM-ESM2-1, HadGEM3-GC31-LL, INM-CM4-8, INM-CM5-0, IPSL-CM6A-LR, MIROC6, MPI-ESM1-2-HR, MRI-ESM2-0	SSP1-2.6, SSP2-4.5, SSP3-7.0 & SSP5-8.5.	DLNM with generalized additive model (GAM)	Population changes (SSP1, SSP2, SSP3, and SSP5)
Chen et al. (2021)	China	2006-2017/ 2021-2060	Daily mean temperature	bcc-csm1-1 m, CCSM4, CESM1-BGC, CESM1-CAM5, CMCC-CM, EC-EARTH, MRI-CGCM3, and MRI-ESM1	RCP2.6, RCP4.5 & RCP8.5	Statistical modelling	Population changes
He et al. (2021)	China	1990-1999/ 2030-2099	Daily max and min temperature	GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M	RCP2.6, RCP4.5, RCP8.5	GLM, DLNM, quasi-Poisson distribution, multivariate meta-regression	Adaptation and population constant
Sun et al. (2021)	China	2013-2017/ 2041-2099	Average temperature	GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M	RCP4.5, RCP8.5, SSP1, SSP2, SSP3, SSP4	DLNM, multivariate meta-regression.	Population changes

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Yang et al. (2021)	China	1960-2005/ 2006-2099	Average temperature	BCC-CSM1-1, BCC-CSM1-1-M, BNU-ESM, CanESM2, CCSM4, CESM1-CAM5, CMCC-CM, CMCC-CMs, CSIRO-Mk3-6-0, EC-EARTH, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H-CC, GISS-E2-H-R, HadGEM2-AO, INMCM4, IPSL-CM5A-MR, IPSL-CM5B-LR, MIROC5, MIROC-ESM, MIROC-ESM-CHEM, MPI-ESM-LR, MPI-ESM-MR, MRI-CGCM3, NorESM1-M, NorESM1-ME	RCP4.5 & RCP8.5	quasi-Poisson regression with DLNM, meta-analyses	Population changes (constant from 2010 to 2099, and SSPs 1-5.
Dong et al. (2020)	China	2011-2020/ 2030-2080	Daily mean temperature	BCC-csm1-1, CNRM-CM5, CSIRO-Mk3-6-0, EC-EARTH, GFDL-ESM2M, HadGEM2-ES, MIROC5, MIROC-ESM-CHEM, MPI-ESM-MR, NorESM1-M	RCP4.5, RCP8.5	Spearman's correlation, DLNM, quasi-Poisson distribution regression	Population changes (Constant, SSP2 & SSP5) No adaptation and adaptation is conducted
Gu et al. (2020)	China	2009-2018/ 2010-2099	Daily mean temperature	BCC-CSM1-1, BCC-CSM1-1-M, BNU-ESM, CanESM2, CCSM4, CESM1-CAM5, CMCC-CM, CMCC-CMs, CSIRO-Mk3-6-0, EC-EARTH, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H-CC, GISS-E2-H-R, HadGEM2-AO, INMCM4, IPSL-CM5A-MR, IPSL-CM5B-LR, MIROC5, MIROC-ESM, MIROC-ESM-CHEM, MPI-ESM-LR, MPI-ESM-MR, MRI-CGCM3, NorESM1-M, NorESM1-ME (28 GCMs)	RCP4.5, RCP8.5	quasi-Poisson regression, DLNM	Population constant
Ho et al. (2020)	China	2001-2014/ 2050	Daily max and min temperature	WRF- CESMI 1	RCP8.5	Multivariate linear regression, Poisson generalized linear regression (time-stratified analysis)	Population change (year of the summer date was used as a control variable)
Liu et al. (2020)	China	2014-2016/ 2030-2090	Daily mean temperature	GFDL-ESM2M HasGEM2-ES Met Office IPSL-CM5A-LR MIROC-ESM-CHEM NorESM1-M	RCP 2.6, RCP 4.5, RCP 8.5	GLM combined with DLNM, quasi-Poisson distribution, multivariate meta analysis	Population constant

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Lee at al. (2019)	South Korea	1991-2005/ 2090	Daily maximum temperature	BCC-CSM1.1, BCC-CSM1.1-M, CanESM2, CCSM4, CESM1-BGC, CESM1-CAM5, CMCC-CM, CNRM-CM5, FGOALS-s2, GFDL-ESM2G NOAA, GFDL-ESM2M HadGEM2-AO, HadGEM2-CC, HadGEM2-ES, INM-CM4, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR, MIROC-ESM, MIROC-ESM-CHEM, MIROC5, MPI-ESM-LR, MPI-ESM-MR, MRI-CGCM3, NorESM1-M	RCP4.5, RCP8.5	DLNM, quasi-Poisson distribution	Population change (high, medium and low variants) Adaptation is conducted (absolute threshold shift, slope reduction in the temperature-mortality relationship, a combination of slope reduction and threshold shift, and a sigmoid function based on the historical trend)
Onozuka et al. (2019b)	Japan	2010-2019/ 2090-2099	Daily mean temperature	GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESMI-M	RCP2.6, RCP4.5, RCP6.0, RCP8.5	Time-series quasi-Poisson regression model combined with DLNM, multivariate meta-regression models	Constant
Onuzuka et al. (2019a)	Japan	1960-2005/ 2006–2099	Daily average temperature	GFDL-ESM2M, HadGEM2ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M	RCP2.6, RCP4.5, RCP6.0, RCP8.5	quasi-Poisson regression, DLNMs, multivariate meta-regression models	Constant
Sun et al. (2019)	China	2007-2012/ 2010-2099	Daily mean temperature	31 GCMs	RCP4.5, RCP8.5,	Poisson regression model (GLM), DLNM	Population changes (constant, SSP2 & SSP5)
Guo et al. (2018)	China, Taiwan, South Korea, Japan, Philippines, Thailand & Vietnam	1971-2020/ 2031-2080	Daily mean temperature	GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M.15	RCP2.6, RCP4.5, RCP6.0 & RCP8.5	Time series Poisson regression, meta-regression	Adaptation is conducted (no adaptation and hypothetical adaptation) Population changes (high variant, median variant, and low variant)

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Li et al. (2018)	China	1970-2000 /2041-2080	Modeled mean temperature of the warmest quarter	ACCESS1-0, BCC-CSM1-1, CCSM4, CESM1-CAM5-1-FV2, CNRM-CM5, GFDL-CM3, GFDL-ESM2G, GISS-E2-R, HadGEM2-AO, HadGEM2-CC, HadGEM2-ES, INMCM4, IPSL-CM5A-LR, MIROC-ESM-CHEM, MIROC-ESM, MIROC5, MPI-ESM-LR, MRI-CGCM3, and NorESM1-M.	RCP8.5, RCP4.5, RCP2.6	Damage function approach (Statistical modelling)	Population changes, Adaptation (no adaptation, has adaptation)
Zhang et al. (2018)	China	2007-2009/ 2050-2070	Maximum temperature	19 GCMs	RCP2.6, RCP4.5, RCP8.5, SSP1, SSP2 & SSP3	Generalized linear models, DLNMs	Population changes (SSP1-3) Adaptation conducted
SOUTHEAST ASIA							
Chua et al. (2022)	Philippines	2010-2019/ 2090-2099	Daily mean temperature	GFDL-ESM2M, HadGEM2-ES, (PSL-CM5A-LR, and MIROC5.	RCP2.6, RCP4.5, RCP6.0, RCP8.5	quasi-Poisson GLM, DLNM, meta-regression model	Population changes (SSP1, SSP2, SSP3, SSP4, & SSP5), No adaptation
Nguyen et al. (2023)	Vietnam	2000–2018 /2020-2070	Daily mean temperature	-	RCP2.6, RCP4.5, RCP6.0, RCP8.5	Regression model	Constant
WESTERN ASIA							
Aboubakri et al. (2020)	Iran	2010-2019/ 2030, 2040, 2050	Daily mean temperature	NCEP, CanESM2	RCP2.6, RCP4.5, RCP8.5	quasi-Poisson time-series regression analysis, Distributed Lag Non-linear Models (DLNM)	Adaptation is conducted
Ozen (2021)	Turkiye	2009-2016/ 2017-2100	Maximum temperature	GFDL-ESM2M	RCP 2.6, RCP 6.0	Regression model	Population constant

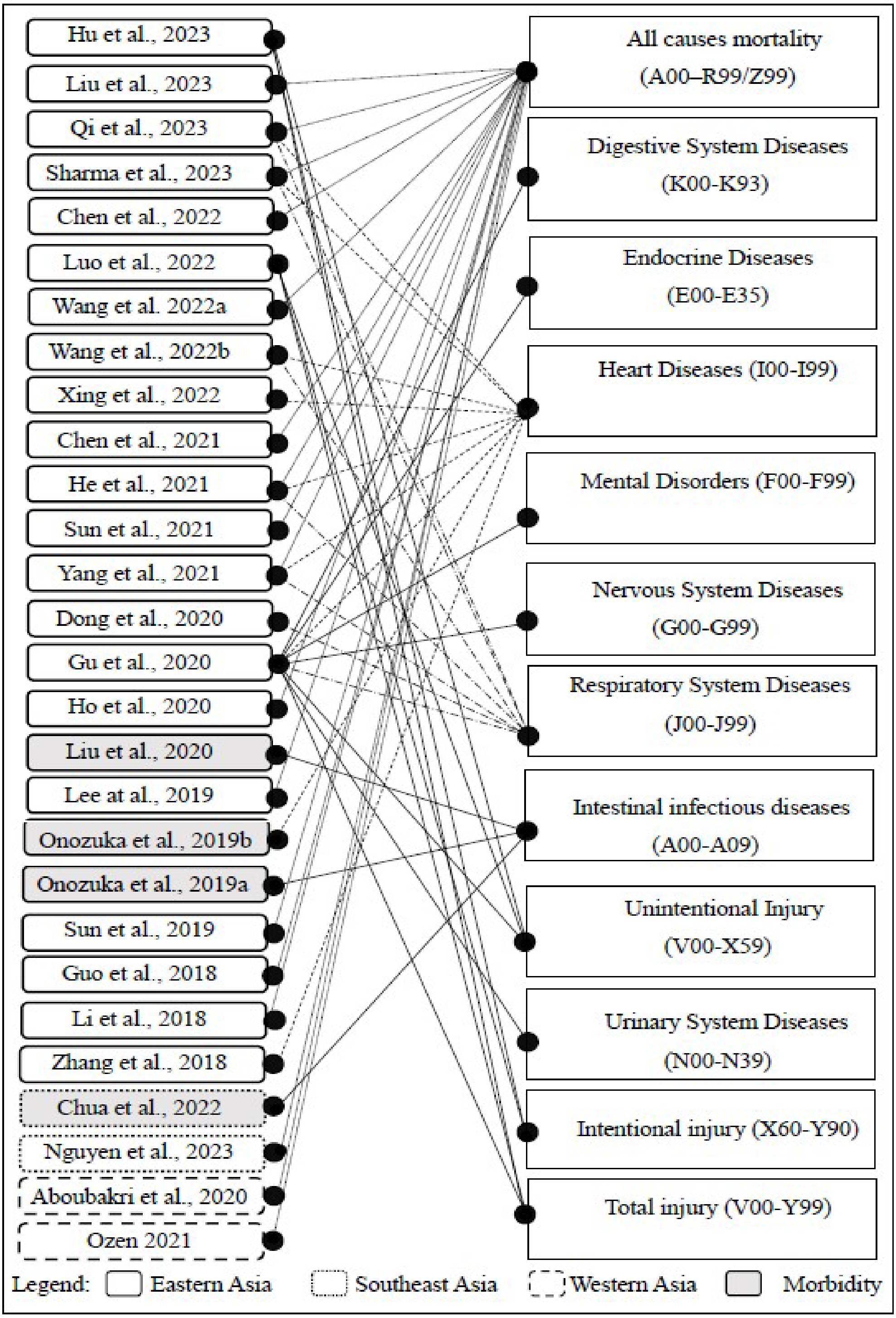

FIGURE S1: Studies and their respective heat-related mortality and morbidity