Environment International 153 (2021) 106533

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Review article

Is there an association between hot weather and poor mental health outcomes? A systematic review and meta-analysis

Jingwen Liu [a], Blesson M. Varghese [a], Alana Hansen [a], Jianjun Xiang [a,b], Ying Zhang [c], Keith Dear [a], Michelle Gourley [d], Timothy Driscoll [c], Geoffrey Morgan [c], Anthony Capon [e], Peng Bi [a,*]

[a] School of Public Health, The University of Adelaide, Australia
[b] School of Public Health, Fujian Medical University, China
[c] Sydney School of Public Health, The University of Sydney, Australia
[d] Burden of Disease and Mortality Unit, Australian Institute of Health and Welfare, Australia
[e] Monash Sustainable Development Institute, Monash University, Australia

ARTICLE INFO

Handling Editor: Paul Whaley

Keywords:
High temperature
Heatwaves
Mental health
Systematic literature review
Meta-analysis

ABSTRACT

Background: Mental health is an important public health issue globally. A potential link between heat exposure and mental health outcomes has been recognised in the scientific literature; however, the associations between heat exposure (both high ambient temperatures and heatwaves) and mental health-related mortality and morbidity vary between studies and locations.

Objective: To fill gaps in knowledge, this systematic review aims to summarize the epidemiological evidence and investigate the quantitative effects of high ambient temperatures and heatwaves on mental health-related mortality and morbidity outcomes, while exploring sources of heterogeneity.

Methods: A systematic search of peer-reviewed epidemiological studies on heat exposure and mental health outcomes published between January 1990 and November 2020 was conducted using five databases (PubMed, Embase, Scopus, Web of Science and PsycINFO). We included studies that examined the association between high ambient temperatures and/or heatwaves and mental health-related mortality and morbidity (e.g. hospital admissions and emergency department visits) in the general population. A range of mental health conditions were defined using ICD-10 classifications. We performed random effects meta-analysis to summarize the relative risks (RRs) in mental health outcomes per 1 °C increase in temperature, and under different heatwaves definitions. We further evaluated whether variables such as age, sex, socioeconomic status, and climate zone may explain the observed heterogeneity.

Results: The keyword search yielded 4560 citations from which we identified 53 high temperatures/heatwaves studies that comprised over 1.7 million mental health-related mortality and 1.9 million morbidity cases in total. Our findings suggest associations between heat exposures and a range of mental health-related outcomes. Regarding high temperatures, our meta-analysis of study findings showed that for each 1 °C increase in temperature, the mental health-related mortality and morbidity increased with a RR of 1.022 (95%CI: 1.015–1.029) and 1.009 (95%CI: 1.007–1.015), respectively. The greatest mortality risk was attributed to substance-related mental disorders (RR, 1.046; 95%CI: 0.991–1.101), followed by organic mental disorders (RR, 1.033; 95%CI: 1.020–1.046). A 1 °C temperature rise was also associated with a significant increase in morbidity such as mood disorders, organic mental disorders, schizophrenia, neurotic and anxiety disorders. Findings suggest evidence of vulnerability for populations living in tropical and subtropical climate zones, and for people aged more than 65 years. There were significant moderate and high heterogeneities between effect estimates in overall mortality and morbidity categories, respectively. Lower heterogeneity was noted in some subgroups. The magnitude of the effect estimates for heatwaves varied depending on definitions used. The highest effect estimates for mental health-related morbidity was observed when heatwaves were defined as “mean temperature ≥90th percentile for ≥3 days” (RR, 1.753; 95%CI: 0.567–5.421), and a significant effect was also observed when the definition was “mean temperature ≥95th percentile for ≥3 days”, with a RR of 1.064 (95%CI: 1.006–1.123).

* Corresponding author at: School of Public Health, Faculty of Health and Medical Sciences, The University of Adelaide, South Australia 5005, Australia.
E-mail address: peng.bi@adelaide.edu.au (P. Bi).

https://doi.org/10.1016/j.envint.2021.106533
Received 21 November 2020; Received in revised form 12 March 2021; Accepted 16 March 2021
Available online 30 March 2021

Conclusions: Our findings support the hypothesis of a positive association between elevated ambient temperatures and/or heatwaves and adverse mental health outcomes. This problem will likely increase with a warming climate, especially in the context of climate change. Further high-quality studies are needed to identify modifying factors of heat impacts.

1. Introduction

As one of the greatest challenges in the 21st century, climate change has been reported to damage human health through multiple pathways (Patz et al., 2005). The associations between high temperatures, heatwaves and adverse health outcomes have been well studied for a number of diseases (Martiello and Giacchi, 2010; Åström et al., 2011). Mental health is being widely recognised as a public health challenge which can often be accompanied by associated socioeconomic consequences (James et al., 2018). The 2017 Global Burden of Disease (GBD) study estimated that more than one in ten people globally (792 million or 10.7% of the global population) lived with a mental health disorder which accounted for around 5% of the global disease burden (James et al., 2018). The importance of environmental risk factors on mental health outcomes has attracted some attention (HM Government, 2018), with growing evidence suggesting the negative impacts of extreme heat exposure on mental health (Berry et al., 2010; Page and Howard, 2010). However, when compared to other heat-related health outcomes (e.g., cardiovascular, cerebrovascular, and respiratory diseases), mental health disorders have received relatively little attention (Berry et al., 2010; Ye et al., 2012).

In existing heat-health literature, health outcomes on days of increased ambient temperatures are often compared to other days of minimal risk, and those during heatwaves (where consecutive days of high temperatures occur) compared to the health outcomes on non-heatwave days. Some epidemiological studies have associated risks of a range of mental health-related outcomes with high temperatures (Mullins and White, 2019); however, there are inconclusive findings on the effects. For example, studies have found that mental-health related hospital admissions and emergency department visits for conditions including affective disorders, anxiety, depressive disorders, schizophrenia, and organic mental disorders increased with high temperatures (Zhang et al., 2020; Basu et al., 2017; Zhang et al., 2020). A previous systematic review of 35 studies reported an increased risk of suicide and self-harm during high temperatures; however, there was mixed evidence for a link with mania and depression (Thompson et al., 2018). In addition to this, several individual or contextual subgroup characteristics leading to greater vulnerability have been documented in previous research, including age (elderly), sex, socioeconomic factors (national income), and temperature zones (Åström et al., 2011; Gao et al., 2019). It is therefore important to quantify the effects of heat exposures on mental health-related mortality and morbidity, and assess heterogeneity in the associations with respect to individual and contextual population characteristics, to fill the knowledge gaps. Hence, there is a need to review current findings and synthesise results, and comprehensively assessing the risk of bias, and the quality and strength of evidence (Thompson et al., 2018).

In this review and meta-analysis, the objectives were to (1) conduct a systematic and robust overview of epidemiological literature to summarize evidence and evaluate the quality of studies assessing the quantitative association between high temperatures, and/or heatwaves and mental health-related mortality and/or morbidity; (2) assess vulnerability of mental health-related mortality and morbidity during high temperatures and heatwaves with respect to contextual population characteristics, and (3) examine the sources of heterogeneity.

2. Methods

This systematic review and meta-analysis were conducted based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The protocol has been registered in the PROSPERO International prospective register of systematic reviews (http://www.crd.york.ac.uk/PROSPERO), CRD42020201511.

A summary of the Participants-Exposure-Comparisons-Outcome (PECO) framework (Morgan et al., 2018) is presented as follow:

- Participants: the general population
- Exposure: high ambient temperatures, and heatwave events as defined by the authors of the original studies
- Comparators: a comparable population unexposed to the same high temperature or heatwaves or the same population at a time when it was not exposed to the same high temperature or heatwaves
- Outcome: mental health-related mortality and morbidity, including 'mental and behavioural disorders (MBDs)', and 'suicide and self-harm'.
- Study design: ecological observational studies

2.1. Databases and study selection

A comprehensive search strategy (Supplementary I, Table S1) was used to search for studies in five electronic databases (PubMed, Embase, Scopus, Web of Science and PsycINFO). After consultation with the University librarian and considering both the sensitivity and specificity, medical subject headings (MeSH) terms with explosion were used, together with Text Words (TW) terms. The keywords were 'mental illness', or 'suicide' for mental health outcome terms, paired with climate terms: 'climate change', 'weather', 'temperature' or 'heat'. Studies published in English between 1 January 1990 and 20 May 2020 in peer-reviewed journals were identified. An update of the data search was performed in November 2020, in order to incorporate relevant studies that might have been published shortly before the finalization of the review. Epidemiological studies reporting quantitative associations between temperatures, heatwaves, and cause-specific, mortality and/or morbidity outcomes (i.e., hospitalisation, emergency presentation) were considered in this review. The references of all included articles were checked manually for additional relevant studies.

Retrieved articles were imported into the Endnote X8.2 reference management system (Clarivate Analytics, 2016), and duplicates were removed before being loaded into Rayyan QCRI (an application for systematic reviews) (Mourad et al., 2016). Titles, abstracts and full-texts were screened in duplicate (by J.L. and B.V.) for fit against the eligibility criteria (see Section 2.2). Selection decisions were made independently with disagreements (15%) resolved through discussions, and, when necessary, by consulting a third investigator (A.H.). Fig. 1 outlines the search strategy and selection procedure guided by the PRISMA (Moher et al., 2009).

2.2. Eligibility criteria and data extraction

Studies were included in the review if they explicitly assessed the quantitative effects of high ambient temperatures and/or heatwaves on mental health outcomes, and met the following criteria: (1) original and peer-reviewed literature with an independent study population; (2) exposure was outdoor high ambient temperatures, heatwaves or hot weather; (3) observational studies reporting comparative risks over different time periods or different exposures. Studies were excluded if: (1) examining only at seasonal effects without explicitly considering temperatures; (2) review and commentary research.

Details of each eligible study including author, publication year, location, study period, analytical methods, measures of exposures and study findings, were separately extracted into a customised spreadsheet by two investigators (J.L. and B.V.).

2.3. Quality and strength of evidence

Evidence provided by reviewed studies was assessed according to the Navigation Guide for systematic reviews of environmental exposures (Woodruff and Sutton, 2014; Johnson et al., 2014), which provides guidelines on the quality assessment of research, and systematic synthesis of evidence specifically for observational human studies in environmental health. Three stages of assessment were included: (1) risk of bias assessment in each individual study, (2) assessment of quality of evidence across studies, and (3) rating the strength, or certainty of evidence across studies. Further details on these assessments are provided in Sections 2.3.1 to 2.3.4. Briefly, studies were independently appraised by three investigators (J.L., B.V., and J.X.) to assess risk of bias and quality of evidence. Each component rating was discussed by the three investigators to reach an agreed rating. Where consensus could not be reached, there was consultation with A.H. and P.B. to determine final ratings.

2.3.1. Risk of bias assessment

The risk of bias rating tool used in this study was modified from the Office of Health Assessment and Translation (OHAT) approach under the National Institutes of Environmental Health Sciences-National Toxicology Program (OHAT, 2015), and the Navigation Guide Systematic Review Methodology (Woodruff and Sutton, 2014). Accordingly, the risk of bias of individual studies was assessed according to several key components: exposure assessment, outcome assessment, confounding bias, selection/recruitment bias, incomplete outcome data, selective reporting, conflict of interest, and other sources of bias. Each of these were evaluated as "low", "probably low", "probably high", or "high" risk based on a pre-defined criterion (Supplementary I, Table S2).

2.3.2. Synthesis of evidence

Two approaches were applied to synthesise evidence from the studies; quantitatively (n = 41) and qualitatively (n = 12). A meta-analysis was performed on studies that met our further restricted criteria (see Section 2.3.2.1) for quantitative synthesis. A narrative synthesis was conducted of the remaining studies to summarize the results.

2.3.2.1. Meta-analysis. Studies suitable to be included in the meta-analysis were those where: (1) daily outcomes were mortality or morbidity (emergency presentations or hospital admissions) for MBDs and/or suicides; defined using the International Classification of Diseases (ICD-9: 290–319, or ICD-10: F00-F99; ICD-9: E950-E959, ICD-10: X60-X84), or clinical diagnosis made by health professionals; (2) the exposure of interest were ambient temperatures (minimum, maximum or mean), and apparent temperatures (minimum, maximum or mean), due to their strong correlation and that on average, they have similar predictive ability (Barnett et al., 2010), or heat waves; (3) the effect estimates were reported as relative risk (RR), odds ratio (OR), or incidence rate ratio (IRR) or the estimates could be converted to RR; (4) studies could be categorized as time-series (T-S), case-crossover (C-C) or

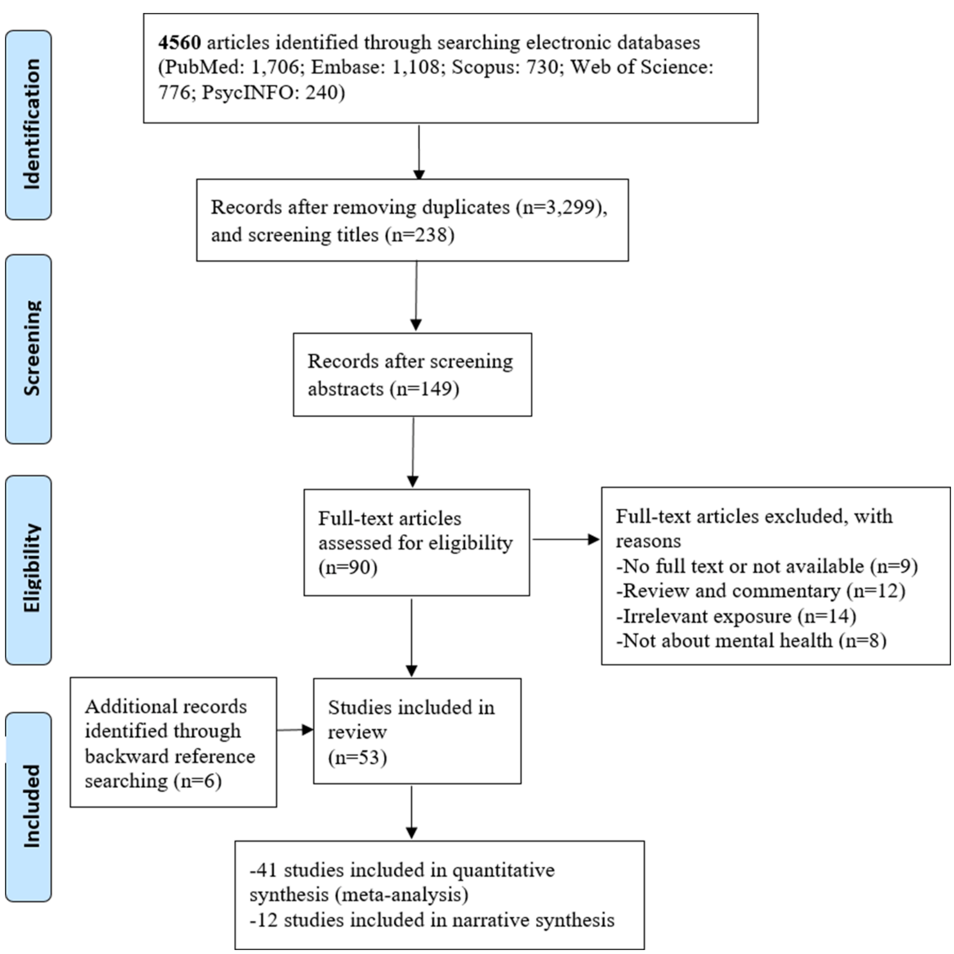

Fig. 1. PRISMA diagram outlining the procedure of study selection.

a case series design, given their comparable effect estimates for investigating temperature and mortality/morbidity associations (Lu and Zeger, 2007).

We used the method of DerSimonian and Laird (1986) for the meta-analysis of study findings. This method which incorporates a random-effects model with inverse variance weighting, was used due to the heterogeneity in exposures and outcome definitions, study populations, and prevalence of mental health-related outcomes (Gao et al., 2019; Luo et al., 2019; Braithwaite et al., 2019). The meta-analysis was conducted using three steps: (1) the pooled estimates were calculated for temperature exposure using a random-effects model; (2) subgroup analysis was performed based on the classifications of MBDs, population characteristics, climate zone, and national income level of the study region (James et al., 2018); and (3) sensitivity analyses were conducted to test the extent to which study designs and assumptions could have influenced the association measures (Section 2.3.2.3).

For studies reporting percent changes (PCs), or ORs of health outcomes per unit increase in temperature, the effect estimates were converted to relative risks (RRs) using the equation: PC = (OR-1) × 100, and RR = OR/[(1-P0) + (P0 × OR)], where P0 = the incidence of the non-exposed group. We assumed RR = OR in this review (Moghadamnia et al., 2017). In order to convert estimates of increases in health outcomes corresponding to one-degree Celsius increase in temperature, or for studies reporting the effect of X degrees increase above a reference temperature point, the effect size was divided by X (Moghadamnia et al., 2017). For studies reporting percentile-based RR estimates, we recorded the estimates per absolute change in temperature and calculated the log-RR, assuming a log-linear relationship in the range of temperature percentiles (Ma et al., 2014).

Following the Cochrane Collaboration guidelines (Higgins and Green, 2011), where multiple estimates were reported in a study, the specified final model was selected; or, where a final model was not specified, the model with the highest number of relevant covariates was selected. When there was overlap in the study period and location, the longer study period (larger sample size) was selected. For studies that reported multiple estimates for different age- and sex- groups, percentile-based RR estimates, or outcomes (i.e. emergency department visits, hospital admissions), a meta-analysis was performed to yield one overall estimate using a fixed-effect model (Luo et al., 2019). However, if studies reported RRs that could not be assessed as being in the age groups <65 or ≥65, we did not include those estimates in the age-stratified meta-analysis. For studies reporting country and city-specific estimates, country-specific estimates were used to compute the pooled effect estimates separated by specific MBDs to maximise the included cases. Only the city/region-specific estimates were used to conduct the meta-analyses by climate zone considering the differences in geography and climate within country.

2.3.2.2. Heterogeneity. Heterogeneity was investigated using Cochrane Q (where $p < 0.10$ was deemed statistically significant); and Higgins I^2 statistics, where increasing values (ranging 0–100%) correspond to increasing heterogeneity (Higgins et al., 2003). The heterogeneity was categorized as low ($I^2 \leq 25\%$), moderate ($25\% < I^2 < 75\%$), or high ($I^2 \geq 75\%$). Meta-analyses were performed to investigate the heterogeneity one step further, with stratification by disease classification, sex and age, predominant climate of the study region (defined following the Köppen-Geiger climate classification (Peel et al., 2007), and income of the study region (classified according to the Socio-demographic Index used in the Global Burden of Disease Study (GBD, 2017) (James et al., 2018).

2.3.2.3. Publication bias and sensitivity analysis. Funnel plots and Egger's tests were used to assess the potential publication bias (Egger et al., 1997). The *Trim and Fill* method (a tool to detect and adjust for publication bias) was used to estimate and impute studies using high temperature as the exposure. We did not apply the *Trim and Fill* method to the heatwave studies due to the low number of studies and different heatwave definitions used.

In terms of sensitivity analysis, we conducted five analyses, i.e. analyses to pool the estimates based on different exposure metrics (mean temperature, maximum temperature, apparent temperature) (Duval and Tweedie, 2000; Duval and Tweedie, 2000); the inclusion of studies using weekly and monthly outcome variables; an analysis by study design (e.g., T-S, C-C); an analysis comparing studies rated "probably high risk of bias" versus studies rated "low" or "probably low risk of bias"; and leave-one-out analysis to assess robustness and variations in the pooled effect sizes when each study was excluded one at a time (Hedges et al., 2010). Statistical analyses were carried out using the Meta and Metafor package v. 2.4–0 in R statistical software, and metan in Stata (version 15.0).

2.3.3. Quality assessment of evidence across studies

We rated the overall quality of evidence across high temperature and heatwave studies separately as *high*, *moderate*, or *low* following the method of Johnson et al. (2014). Consistent with the Navigation Guide approach, we initially rated the body of evidence as *moderate* due to the risk of unmeasured confounding in observational studies, and then considered adjustments to downgrade or upgrade this rating. The quality of evidence was downgraded based on five factors: (1) risk of bias across studies (the study ratings from the step 1 of the assessment), (2) indirectness (evidence was not comparable to the question of interest regarding our prespecified PECO of systematic review), (3) inconsistency (effect estimates in similar populations were widely different), (4) imprecision (sample size too low to conduct an adequately powered study and with wide confidence intervals), (5) publication bias (results of published studies are systematically different from results of unpublished studies, which was detected by visual inspection of the funnel plot and confirmed using the Egger's test). The quality of evidence was upgraded based on three factors: (1) a large magnitude of effect (strength of the associations was unlikely to be explained by confounding factors alone and substantially larger than the anticipated effect of a significant unmeasured confounder), (2) evidence of a dose–response relationship (consistent between dose and response across studies), and (3) possibility of confounding minimizing effect (the pooled effect estimate was positive despite the consideration of all plausible residual confounders that would shift the results towards no effect).

Statistical tests were performed to assess for inconsistency (i.e., heterogeneity) and publication bias mentioned in Sections 2.3.2.2 and 2.3.2.3. Quality of evidence was rated by two investigators (J.L. and B. V.) independently, and then ratings were compared and any disagreement resolved by discussion with other authors. Possible ratings were 0 (no change from initial quality rating), −1 (1 level downgrade) or −2 (2 level downgrade); +1 (1 level upgrade) or +2 (2 level upgrade). The downgrading and upgrading were conservative only if there was a compelling evidence to process the rating.

2.3.4. Assessment of strength/certainty of evidence across studies

We assessed the strength of evidence according to the body of evidence provided in reviewed papers based on four domains involving: (1) quality of the body of evidence, rated from the previous stage of assessment (Section 2.3.3), (2) direction of effect estimates (i.e., consistency across studies on whether high temperatures and heatwaves exposure suggests increased or decreased risks of mental health-related mortality and morbidity), (3) confidence in effect estimates (i.e., the likelihood of new study with an effect estimate that would change the results of meta-analysis), and other compelling attributes of the data that may influence certainty (OHAT, 2015). According to the definitions specified in the Navigation Guide, these considerations are used to assign the overall strength rating evaluated as "sufficient evidence", "limited evidence", "inadequate evidence" or "lack of evidence" (Johnson et al., 2014).

3. Results

3.1. Study selection

There were 4560 records imported into Endnote during the initial search as shown in Fig. 1. After removing duplicates, screening titles and abstracts, and reading the full-texts, 53 original studies met the overall inclusion criteria.

3.2. Study characteristics

The characteristics of the included studies are presented in Table 1. Among the 53 studies (containing more than 1.7 million deaths and 1.9 million disease cases), 41 studies examined the effects of high ambient temperatures on mental health outcomes (Basu et al., 2017; Zhang et al., 2020; Grjibovski et al., 2013; Luan et al., 2019; Chan et al., 2018; Kim et al., 2011; Wang et al., 2014; Peng et al., 2017; Wang et al., 2018; Williams et al., 2012; Kim et al., 2015; Müller et al., 2011; Schneider et al., 2020; Lee et al., 2018; Vida et al., 2012; Page et al., 2007; Sung et al., 2011; Trang et al., 2016; Linares et al., 2017; Almendra et al., 2019; Kim et al., 2016; Page et al., 2012; Gasparrini et al., 2012; Ho and Wong, 2019; Fernández-Niño et al., 2018; Carlsen et al., 2019; Sung et al., 2013; Min et al., 2019; Kim et al., 2019; Liu et al., 2020; da Silva et al., 2020; Niu et al., 2020; Qi et al., 2015; Burke et al., 2018; Qi et al., 2014; Bando et al., 2017; Pan et al., 2019; Marion et al., 1999; Wei et al., 2019; Yi et al., 2019), 9 examined the effects of heatwaves (Hu et al., 2020; Khalaj et al., 2010; Wilson et al., 2013; Liu et al., 2019; Hansen et al., 2008; Xu et al., 2019; Vaneckova and Bambrick, 2013; Wang et al., 2012; Åström et al., 2015), and 3 examined both (Sherbakov et al., 2018; Rocklöv et al., 2014; Trang et al., 2016). Of the 26 mortality and 30 morbidity papers included in this review (4 studies focused on both mortality and morbidity). Those deemed suitable for the meta-analysis included 17 mortality (high ambient temperatures, n = 15; heatwaves, n = 3) and 26 morbidity (heatwaves, n = 8; high ambient temperatures, n = 21) studies. The study locations (Supplementary II, Fig. S1) varied widely from Asia, Oceania, Europe, North and South America, and included 106 city/region-specific estimates. The studies fell into four Köppen–Geiger climate zones: "A" and "B" climate- Tropical and Arid, "C" climate- Temperate climates (i.e., Mediterranean, Oceanic climate, and Subtropical climate), and "D" climate- Continental (Peel et al., 2007). Studies used various forms of ambient temperatures as the exposure, with the mean daily temperature being the most widely used heat metric (34 studies). Details of the contextual characteristics are listed in Supplementary I, Table S3.

3.3. Risk of bias assessment

The risk of bias and quality of the studies were appraised according to the key components of exposure, outcome, and confounding bias. Assessment summaries for each study are available in detail in Table S4 (Supplementary I).

The exposure parameter (i.e., temperature data) in all included studies was sourced from official weather data stations. The exposure monitoring was considered sufficiently consistent in this regard. However, as the studies were generally ecological in nature they often relied on exposure metrics from either one weather station or averaged from several local weather stations (Luo et al., 2019). According to the predefined criterion listed in Supplementary I, Table S2, the exposure bias of included studies ranged from "low risk" when satellite data was used to "probably high risk" when one weather station was used for high temperatures. For heatwaves studies, the risk of bias ranged from "probably low risk" to "probably high risk".

For outcome bias assessment, we focussed on diagnostic misclassification (Wang et al., 2014; Peng et al., 2017; Page et al., 2007). The comparability across the studies was judged sufficiently, given the majority of studies (41 out of 43 for high temperatures, 11 out of 12 for heatwaves) obtained mortality and morbidity data from healthcare surveillance systems. Additionally, the International Classification of Diseases and Health Problems (ICD) 9th revision and the ICD 10th revision codes were used to define specific causes of death and disease. Only one study that we included in the systematic review was assigned a "probably high risk" for outcome assessment because the disease classification was assessed by a local specialist (Müller et al., 2011).

For confounding bias, we assessed the methods used to adjust for confounders in the statistical models used. Among these studies, 58% (25 out of 43 for high temperatures, 7 out of 12 for heatwaves) adjusted for the important well studied confounding factors (i.e. seasonality, time trends, day of week and relative humidity (Basu et al., 2017; Ding et al., 2016) that are likely to change and introduce bias when examining short-term health effects of heat exposure (Bhaskaran et al., 2013). Air pollution, which may be a moderator of the association between high temperatures and mental health outcomes (Braithwaite et al., 2019; Wang et al., 2018; Pan et al., 2019), was accounted for in 49% of studies (n = 20 for high temperatures; n = 6 for heatwaves).

The results of the risk of bias assessment in individual studies are summarised in Fig. 2. When we synthesised the risk of bias among key components (i.e., exposure assessment, outcome assessment, confounding bias), the majority of studies was rated as "probably low risk" or "low risk" (n = 33 for high temperatures; n = 9 for heatwaves) (Fig. 3).

3.4. Synthesis of findings

3.4.1. Quantitative synthesis using meta-analysis

A random-effects meta-analysis was conducted on studies where the number of studies was equal or more than 2. Table 2 shows estimates for mental health-related mortality and morbidity outcomes for exposures of high ambient temperatures. The overall pooled results indicated that every 1 °C increase in temperature was significantly associated with a 2.2% increase in overall mental health-related mortality (RR = 1.022; 95%CI: 1.015–1.029) and 0.9% increase in morbidity (RR = 1.009; 95% CI: 1.007–1.015). Forest plots showing the overall and cause-specific pooled results of the meta-analysis are displayed in Fig. S2 and Fig. S3 (Supplementary II).

For heatwave exposures, the definitions varied by temperature metrics (i.e., maximum and mean temperatures), threshold temperatures, and duration. Hence, the random-effects meta-analyses were performed where there were more than two studies using the same heatwave definition. The pooled estimates show increases in the risk of mental-health related morbidity during heatwaves. Where heatwaves were defined as 3 or more consecutive days when daily mean temperature reached or exceeded 95th percentiles of mean temperature the results were statistically significant (RR = 1.064; 95%CI:1.006–1.123). Information specific to the heatwave definitions used in the studies is summarised in Table 3.

3.4.1.1. Mental diseases' classifications. Pooled RRs for cause-specific MBDs and suicide in mortality and morbidity were computed for every 1-degree Celsius increase in temperature. The strongest effects for mortality were attributable to substance-related mental disorders (RR = 1.046, 95%CI: 0.991–1.101); however, this is not at the level of statistically significant. Statistically significant positive associations were found for organic mental disorders (i.e., conditions caused by the gradual decrease in the functioning of the brain) (RR = 1.033, 95%CI: 1.020–1.046), and suicides and self-harm (RR = 1.012, 95%CI: 1.003–1.021). For morbidity outcomes, the greatest effects were observed for mood disorders (RR = 1.011, 95%CI: 1.003–1.018), followed by organic mental disorders (RR = 1.008, 95%CI: 1.001–1.015), schizophrenia (RR = 1.007, 95%CI: 1.002–1.011), and neurotic and anxiety disorders (RR = 1.007, 95%CI: 1.001–1.013) (Table 2).

Table 1
Characteristics of included studies.

Author, year	ID	Location	Study period	Study design	Exposure	Resolution	Mortality/ morbidity	Outcomes (ICD code[a]); and ages	Income group
***Studies included in random effect* meta-analysis**									
Grjibovski et al. 2013 (Grjibovski et al., 2013)	1	Astana, Kazakhstan	2005–2010	T-S	Tmean	Daily	Mortality	Suicides (X60-X84); All ages	High-Middle
Luan et al. 2019 (Luan et al., 2019)	2	31 cities, China	2008–2013	T-S	Tmean	Daily	Mortality	Suicides (X60-X84); All ages	High-Middle
Chan et al. 2018 (Chan et al., 2018)	3	Hong Kong, China	2002–2011	T-S	Tmean	Daily	Morbidity	Mental disorders (290–319); All ages	High
Kim et al. 2011 (Kim et al., 2011)	4	South Korea	2001–2005	T-S	Tmean	Daily	Mortality	Suicides (X60-X84); All ages	High
Wang et al. 2014 (Wang et al., 2014)	5	Toronto, Canada	2002–2010	T-S	Tmean	Daily	Morbidity	Mental disorders (F00-F99); All ages	High
Sherbakov et al. 2018 (Sherbakov et al., 2018)	6	California	1999–2009	T-S	Heatwave/ Tmean	Daily	Morbidity	Mental disorders (290–319); All ages	High
Peng et al. 2017 (Peng et al., 2017)	7	Shanghai, China	2008–2015	T-S	Tmean	Daily	Morbidity	Mental disorders (F00-F99); All ages	High-Middle
Wang et al. 2018 (Wang et al., 2018)	8	Hefei, China	2005–2014	T-S	Tmean	Daily	Morbidity	Schizophrenia (F00-F29); All ages	High-Middle
Williams et al. 2012 (Williams et al., 2012)	9	Adelaide, Australia	1993–2009	T-S	Tmax	Daily	Morbidity	Mental disorders (F00-F99); All ages	High
Kim et al. 2015 (Kim et al., 2015)	10	Seoul, South Korea	1992–2009	T-S	Tmax	Daily	Mortality	Mental disorders (F00-F99); All ages	High
Muller et al. 2011 (Müller et al., 2011)	11	Mittelfranken, Germany	1998–2005	T-S	Tmean	Daily	Mortality	Suicides (X60-X84); All ages	High
Schneider et al. 2020 (Schneider et al., 2020)	12	Southern Germany	1990–2006	C-C	Tmean	Daily	Mortality	Suicides (X60-X84); All ages	High
Lee et al. 2018 (Lee et al., 2018)	13	South Korea	2003–2013	T-S	Tmean	Daily	Morbidity	Mental disorders (F00-F99); All ages	High
Vida et al. 2012 (Vida et al., 2012)	14	3 regions, Canada	1995–2008	T-S	Tmean	Daily	Morbidity	Mental and psychosocial diseases; 15–64, ≥65	High
Page et al. 2007 (Page et al., 2007)	15	England and Wales	1993–2003	T-S	Tmean	Daily	Mortality	Suicides (X60–X84, Y10–Y34 (excluding Y33.9); All ages	High
Sung et al. 2011 (Sung et al., 2011)	16	Taiwan	1996–2007	T-S	Tmean	Daily	Morbidity	Schizophrenia (295); All ages	High
Trang et al. 2016a (Trang et al., 2016)	17	Hanoi, Vietnam	2008–2012	T-S	Tmean	Daily	Morbidity	Mental disorders (F00-F99); All ages	Middle
Linares et al. 2017 (Linares et al., 2017)	18	Madrid, Spain	2001–2009	T-S	Tmax	Daily	Morbidity	Dementia (290–294); All ages	High
Almendra et al. 2019 (Almendra et al., 2019)	19	Lisbon, Portugal	2008–2014	T-S	Tmean	Daily	Morbidity	Mental disorders (291–293, 295–298, 300, 307.1, 307.4, 307.5, 307.8, 303–305, 308–309, 311, 316) (E95); All ages	High-Middle
Rocklov et al. 2014 (Rocklöv et al., 2014)	20	Sweden	1990–2002	C-C	Heatwave/ Tmax	Daily	Mortality	Mental disorders (290–319); All ages	High
Kim et al. 2016 (Kim et al., 2016)	21	6 cities, South Korea; 6 cities, Japan; 2 cities, China	1992–2010; 1972–2010; 1994–2007	C-C	Tmean	Daily	Mortality	Suicides (X60-X84); All ages	High
Page et al. 2012 (Page et al., 2012)	22	9 regions, England	1998–2007	T-S	Tmean	Daily	Mortality	Psychosis, dementia and substance misuse; All ages	High
Gasparrini et al. 2012 (	23	England and Wales	1993–2006	T-S	Tmax	Daily	Mortality	Mental disorders (F00-F99); All ages	High

(*continued on next page*)

Table 1 (*continued*)

Author, year	ID	Location	Study period	Study design	Exposure	Resolution	Mortality/ morbidity	Outcomes (ICD code[a]); and ages	Income group
Gasparrini et al., 2012)									
Ho & Wong 2019 (Ho and Wong, 2019)	24	Hong Kong, China	2007–2014	T-S	Tmean	Daily	Mortality	Mental disorders (F00-F99); All ages	High
Fernandez-Nino et al. 2018 (Fernández-Niño et al., 2018)	25	Colombia	2005–2015	T-S	Tmean	Daily	Mortality	Suicides (X60-X84); All ages	Middle
Carlsen et al. 2019 (Carlsen et al., 2019)	26	Sweden	2012–2017	C-C	Tmean	Daily	Morbidity	Psychiatric emergencies visits; All ages	High
Sung et al. 2013 (Sung et al., 2013)	27	Taiwan	1996–2007	T-S	Tmean	Daily	Morbidity	Bipolar disorder (296.0, 296.1, 296.4–296.8); All ages	High
Min et al. 2019 (Min et al., 2019)	28	Yancheng, China	2014–2017	T-S	Tapparent	Daily	Morbidity	Mental disorders (F00-F99); All ages	High-Middle
Basu et al. 2017 (Basu et al., 2017)	29	California	2005–2013	T-S	Tapparent	Daily	Morbidity	Mental disorders (290–319); All ages	High
Kim et al. 2019 (Kim et al., 2019)	30	12 countries	Different periods between 1973 and 2013	C-C	Tmean	Daily	Mortality	Suicides (X60-X84); All ages	Middle/ High
Liu et al. 2020 (Liu et al., 2020)	31	Hong Kong, China	2006–2016	T-S	Tmean	Daily	Mortality	Mental disorders (F00-F99); All ages	High
Zhang et al. 2020 (Zhang et al., 2020)	32	3 cities, China	2013–2018	C-C	Tmean	Daily	Morbidity	Depressive disorders (F32-F33), organic mental disorders (F00-F09), anxiety (F40-F41), affective disorders F30-F31, F34-F39), and schizophrenia (F20-F29); All ages	High-Middle
Da Silva et al. 2020 (da Silva et al., 2020)	33	Curitiba, Brazil	2010–2016	T-S	Tmean	Daily	Morbidity	Mental disorders (F00-F99); All ages	Middle
Niu et al. 2020 (Niu et al., 2020)	34	Beijing, China	2016–2018	T-S	Tapparent	Daily	Morbidity	Mental disorders (F00-F99); All ages	High
Trang et al. 2016b (Trang et al., 2016)	35	Northern Vietnam	2008–2012	T-S	Heatwave/ Tmean	Daily	Morbidity	Mental disorders (F00-F99); All ages	Middle
Hu et al. 2020 (Hu et al., 2020)	36	Shenzhen, China	2013–2017	T-S	Heatwave	Daily	Morbidity	Suicides (X60-X84); All ages	High-Middle
Khalaj et al. 2010 (Khalaj et al., 2010)	37	New South Wales, Australia	1998–2006	C-S	Heatwave	Daily	Morbidity	Mental disorders (F00-F99); All ages	High
Wilson et al. 2013 (Wilson et al., 2013)	38	Greater Metropolitan Sydney Region, Australia	1997–2007; 1997–2010	C-C	Heatwave	Daily	Both	Mental disorders (F00-F99); All ages	High
Liu et al. 2019 (Liu et al., 2019)	39	Jinan, China	June-July 2010	C-C	Heatwave	Daily	Morbidity	Mental disorders (F00-F99); All ages	High-Middle
Hansen et al. 2008 (Hansen et al., 2008)	40	Adelaide, Australia	1993–2006	T-S	Heatwave	Daily	Both	Mental disorders (F00-F99); All ages	High
Xu et al. 2019 (Xu et al., 2019)	41	Queensland, Australia	2013–2015	T-S	Heatwave	Daily	Morbidity	Mental disorders (F00-F99); All ages	High
***Studies excluded from random effect* meta-analysis**									
Qi et al. 2015 (Qi et al., 2015)	42[b]	8 cities, Australia	1985–2005	T-S	Tmean	Monthly	Mortality	Suicides (X60-X84); All ages	High
Burker et al. 2018 (Burke et al., 2018)	43[b]	US; Mexico	1968–2004; 1990–2010	T-S	Tmean	Monthly	Mortality	Suicides (X60-X84); All ages	High; Middle
Qi et al. 2014 (Qi et al., 2014)	44[b]	Australia	1996–2005	T-S	Tmean	Monthly	Mortality	Suicides (X60-X84); All ages	High
Bando et al. 2017 (Bando et al., 2017)	45[b]	São Paulo, Brazil	1996–2007	T-S	Tmin	Weekly	Mortality	Suicides (X60-X84); All ages	High-Middle
Mullins et al. 2019 (Mullins and White, 2019)	46[b]	The United States	1960–2016	T-S	Tmean	Monthly	Both	Mental disorders (F00-F99), Suicides (X60-X84); All ages	High
Pan et al. 2019 (Pan et al., 2019)	47	Hefei, China	2005–2014	T-S	Tmean	Daily	Morbidity	Schizophrenia (F20); All ages	High-Middle

(*continued on next page*)

Table 1 (*continued*)

Author, year	ID	Location	Study period	Study design	Exposure	Resolution	Mortality/ morbidity	Outcomes (ICD code[a]); and ages	Income group
Marion et al. 1999 (Marion et al., 1999)	48	British Columbia	1981–1991	T-S	Tmean	Monthly	Mortality	Suicides (X60-X84); All ages	High
Wei et al. 2019 (Wei et al., 2019)	49	New England	2001–2011	S-A	Tmean	Daily	Morbidity	Dementia (290); ≥65	High
Yi et al. 2019 (Yi et al., 2019)	50	Hefei, China	2005–2014	T-S	Tapparent	Daily	Morbidity	Schizophrenia (F00-F29); All ages	High-Middle
Vaneckova 2013 (Vaneckova and Bambrick, 2013)	51	Sydney, Australia	1991–2009	C-C	Heatwave	Daily	Morbidity	Mental disorders (290–319); All ages	High
Wang et al. 2012 (Wang et al., 2012)	52	Brisbane, Australia	1996–2005	C-C	Heatwave	Daily	Both	Mental disorders (F00-F99); All ages	High
Astrom et al. 2015 (Åström et al., 2015)	53	Rome, Italy and Stockholm, Sweden	2000–2008	T-S	Heatwave	Daily	Mortality	Psychiatric disorders (F20-F22, F31, F32, F34, F43) (291–299, 300.4, 301.1, 309.0, 309.1, 311); ≥50	High

[a] ICD code refers to ICD-9 and ICD-10. T-S, time series. C-C, case-crossover. C-S, case-series. S-A, survival analysis.
[b] Studies included in sensitive analysis.

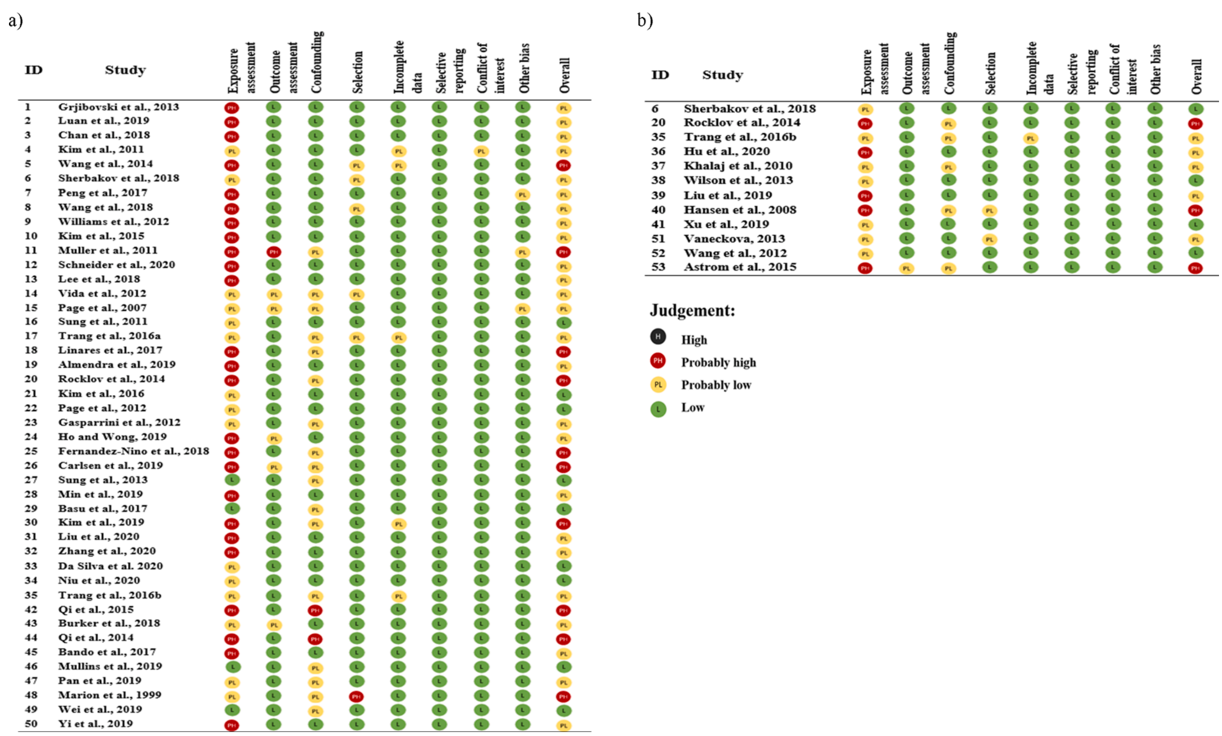

Fig. 2. Summary of the results of the risk of bias assessment in individual studies a) high temperatures, and b) heatwaves studies. * Refer to Table 1 for details.

3.4.1.2. Sex and age. In the subgroup analysis by sex and age, the male group showed statistically significant positive associations in both mental health-related mortality (RR = 1.020, 95%CI: 1.002–1.038) and morbidity (RR = 1.007, 95%CI: 1.003–1.011). Slightly lower risk was observed in females (RR = 1.006, 95%CI: 1.004–1.008) than males in morbidity outcomes. Moderate heterogeneity in studies was observed for both sex in mortality and morbidity outcomes.

Additionally, people aged 65 and over (mortality: RR = 1.025, 95% CI: 1.015–1.035; morbidity: RR = 1.010, 95%CI: 1.005–1.008) were more vulnerable to increased temperatures than people aged < 65 (mortality: RR = 1.017, 1.005–1.028; morbidity: RR = 1.005, 95%CI: 1.003–1.006).

3.4.1.3. Climate zone and national income level. Regarding the analyses of climate zone on city/region-specific estimates, there was an observed variation of effects per one-degree increase in temperature across climate zones. The highest significant pooled RR was found in the tropical climate zone for mental health-related mortality (RR = 1.037, 95%CI: 1.013–1.060), while no study was found in this climate zone for morbidity outcomes. Nevertheless, relatively high pooled RRs were observed in the subtropical climate zone for both mortality (RR = 1.028, 95%CI: 1.014–1.042) and morbidity (RR = 1.012, 95%CI: 1.006–1.018) outcomes. The lowest significant pooled RRs (number of studies >2) were found in the continental zone for mental health-related mortality (RR = 1.023, 95%CI: 1.009–1.038) and morbidity (RR = 1.008, 95%CI: 1.002–1.014). In addition to this, using study estimates from the northern-hemisphere, we observed higher minimum mortality

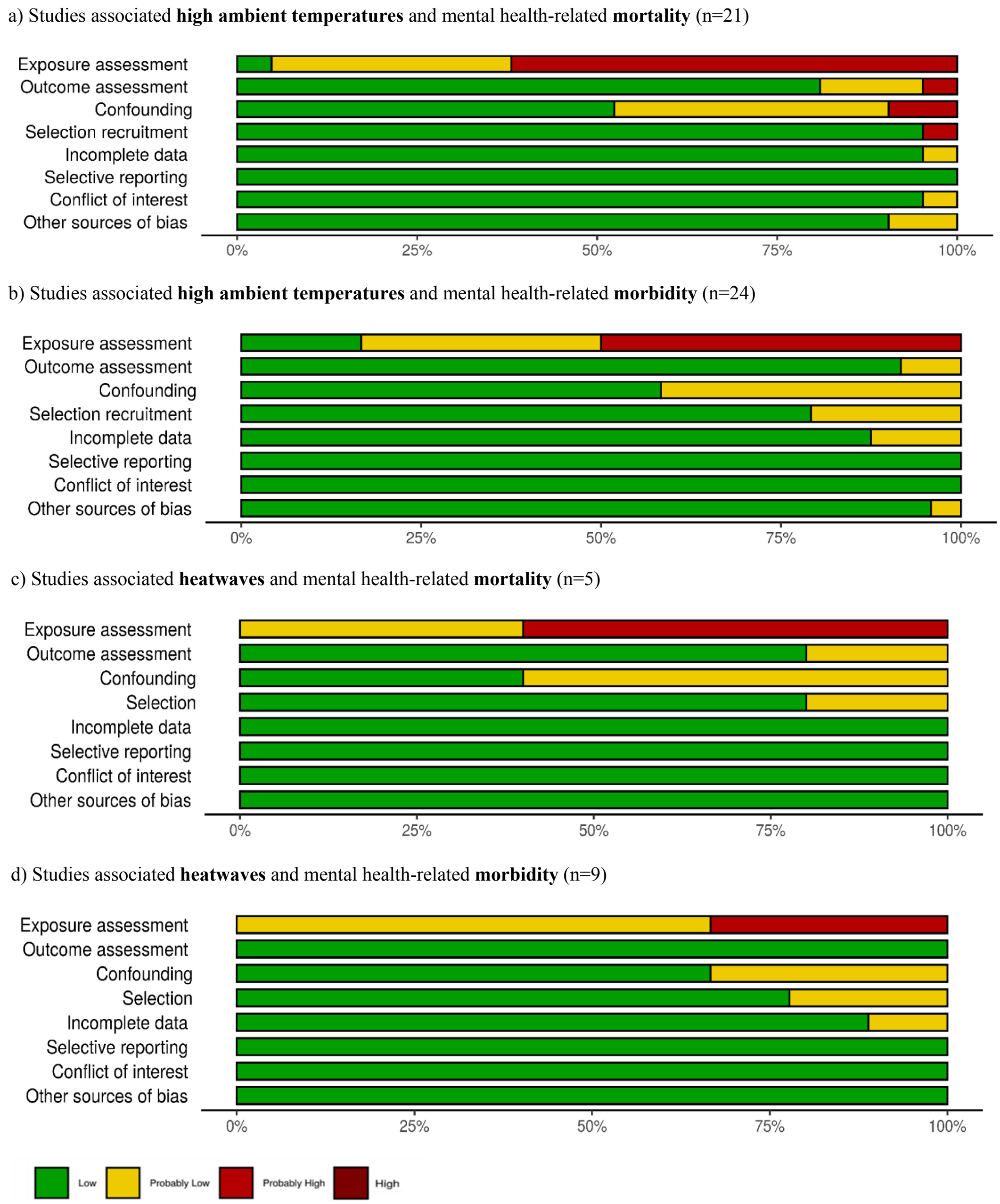

Fig. 3. Synthesis of the risk of bias assessment across studies in review, including a) high ambient temperatures and mental health-related mortality, b) high ambient temperatures and mental health-related morbidity, c) heatwaves and mental health-related mortality, and d) heatwaves and mental health-related morbidity. * The traffic-light plots were created using the Risk of Bias Visualisation (ROBVIS) tool (McGuinness and Higgins, 2020).

temperatures (MMTs) in populations living in lower latitudes (Fig. 4).

Regarding national income level, the majority of studies were conducted in countries categorized as high and high-middle income level. The increased in pooled RR estimates was observed in mortality outcomes with the lowest pooled RR in countries of high national income level (RR = 1.015, 95%CI: 1.008–1.022), and the highest pooled RR in countries with middle national income (RR = 1.032, 95%CI: 1.018–1.046) (Table 2).

3.4.1.4. Publication bias and sensitivity analysis. Asymmetric funnel plots were observed for both mental health related mortality (MBDs, Egger test p-value = 0.007; Suicides and self-harm, Egger test p-value = 0.9743) and morbidity (MBDs, Egger test p-value = 0.002) of high temperature effects (Supplementary II, Fig. S4). The *Trim and Fill* results show that the funnel plots were symmetric about the effect size, after four and seven mental health-related mortality and morbidity study estimates were imputed, respectively. The funnel plots with imputed studies are displayed in Fig. S5 (Supplementary II). The imputed pooled RR estimates for every 1 °C increase in temperature were 1.016 (95%CI: 1.009–1.023) for mental health-related mortality and 1.007 (95%CI: 1.005–1.009) for morbidity. After accounting for the potential publication bias, the 'adjusted' pooled RR estimates suggested a lower RR than the original pooled RR estimates, while still indicated a positive association between increases in temperature and the mental health-related mortality (MBDs: adjusted RR = 1.016, 1.000–1.010; Suicides and self-harm: adjusted RR = 1.014, 1.011–1.017) and morbidity (MBDs: adjusted RR = 1.007, 1.004–1.010).

The sensitivity analysis (i.e., restriction of studies using mean temperature metric, studies rated as "low" and "probably low" risk of bias, studies using time-series design, and inclusion of studies in weekly and

Table 2
Random-effects meta-analyses on the relationships between **high temperatures** and mental health morbidity and mortality outcomes in different groups.

	Morbidity			Mortality		
	Est.	**RR (95%CI);**	**Heterogeneity(I^2, *p*-value)**	**Est.**	**RR (95%CI);**	**Heterogeneity(I^2, *p*-value)**
Overall	18	**1.009 (1.007–1.012)**	87.1%, $p = 0.000$	12	**1.022 (1.015–1.029)**	73.3%, $p = 0.000$
Cause specific						
Mental and behavioural disorders (F00-F99)	12	**1.007 (1.005–1.009)**	81.5%, $p = 0.000$	5	**1.031 (1.011–1.052)**	71.5%, $p = 0.007$
Schizophrenia (F20-F29)	7	**1.007 (1.002–1.011)**	80.3%, $p = 0.000$	2	1.008 (0.968–1.048)	0.0%, $p = 0.907$
Organic mental disorders (F00-F09)	5	**1.008 (1.001–1.015)**	79.8%, $p = 0.001$	3	**1.033 (1.020–1.046)**	0.0%, $p = 0.913$
Substance related mental-disorders (F10-F19)	3	1.008 (0.996–1.021)	69.9%, $p = 0.036$	4	1.046 (0.991–1.101)	88.0%, $p = 0.000$
Mood disorders (F30-F39)	6	**1.011 (1.003–1.018)**	87.3%, $p = 0.000$	–	–	–
Neurotic and anxiety disorders (F40-F48)	6	**1.007 (1.001–1.013)**	79.7%, $p = 0.000$	–	–	–
Other non-specified mental outcomes	3	**1.005 (1.001–1.009)**	17.6%, $p = 0.297$	1	**1.050 (1.020–1.080)**	–
Suicides and self-harm (X60-X84)	1	**1.010 (1.008–1.012)**	–	7	**1.012 (1.003–1.021)**	79.9%, $p = 0.000$
Sex						
Male	7	**1.007 (1.003–1.011)**	73.0%, $p = 0.001$	3	**1.020 (1.002–1.038)**	72.8%, $p = 0.025$
Female	7	**1.006 (1.004–1.008)**	39.0%, $p = 0.132$	3	1.022 (0.998–1.046)	73.4%, $p = 0.023$
Age (years)						
<65	9	**1.005 (1.003–1.006)**	53.6%, $p = 0.028$	6	**1.017 (1.005–1.028)**	79.9%, $p = 0.000$
≥65	5	**1.010 (1.005–1.008)**	66.6%, $p = 0.018$	6	**1.025 (1.015–1.035)**	76.1%, $p = 0.001$
Climate zone (Köppen classification)						
Group A-Tropical	–	–	–	2	**1.037 (1.013–1.060)**	33.4%, $p = 0.221$
Group B- Dry	–	–	–	1	1.017 (0.990–1.045)	–
Group C- Mediterranean	5	**1.010 (1.004–1.017)**	90.2%, $p = 0.000$	–	**–**	–
Group C- Oceanic	1	**1.003 (1.002–1.004)**	–	5	**1.026 (1.013–1.040)**	66.2%, $p = 0.019$
Group C- Subtropical	8	**1.012 (1.006–1.018)**	91.4%, $p = 0.000$	5	**1.028 (1.014–1.042)**	82.4%, $p = 0.000$
Group D- Continental	4	**1.008 (1.002–1.014)**	79.4%, $p = 0.002$	4	**1.023 (1.009–1.038)**	74.2%, $p = 0.009$
National income level*						
High	12	**1.010 (1.007–1.012)**	90.8%, $p = 0.000$	9	**1.015 (1.008–1.022)**	65.4%, $p = 0.003$
High-middle	5	**1.007 (1.002–1.012)**	82.1%, $p = 0.001$	2	**1.023 (1.007–1.039)**	66.6%, $p = 0.084$
Middle	2	1.010 (0.993–1.027)	75.6%, $p = 0.043$	2	**1.032 (1.018–1.046)**	0.0%, $p = 0.462$

Note: Sex differences in mortality only included cause of suicides. Est., number of specific risk estimates.

monthly time resolution), showed relatively stable changes in the pooled RRs among overall mortality and morbidity, as well as by subcategory (Supplementary II, Table S1). In addition, the pooled RRs remained consistent by repeatedly fitting the model (18 times for mortality, 12 times for morbidity), leaving out one study at a time (mortality: RR, 1.019–1.025; morbidity: RR, 1.008–1.010).

3.4.2. Narrative synthesis

We conducted a narrative synthesis of 12 studies that were excluded from the meta-analysis (Table 1). Among the 12 studies, nine described the relationship between high temperature and different mental health outcomes. A positive association was reported between increasing temperature and suicides (Mullins and White, 2019; Marion et al., 1999; Qi et al., 2015; Burke et al., 2018; Qi et al., 2014; Bando et al., 2017), and mental health emergency department visits (Marion et al., 1999). Two studies focused on temperature impacts on hospitalizations for schizophrenia reported the acute effects of high AT, especially in males and those over 40 years old (Pan et al., 2019; Yi et al., 2019). A study which was conducted in New England reported a greater risk of dementia-associated hospital admissions during cooler-than average temperatures and higher temperatures variability (Wei et al., 2019). For studies examining the effects of heatwaves on mental health outcomes (n = 3), a positive association was observed in two studies with greater effects reported for psychoses admission (Vaneckova and Bambrick, 2013), and higher vulnerability during extreme heat among people with underlying mental and behavioural disorders (Åström et al., 2015). On the other hand, no statistically significant effects were found in a study in Brisbane (Wang et al., 2012) using emergency hospital admission and mortality data.

3.5. Quality of the evidence

The assessment of the overall quality of evidence on heat exposures (high temperature, and heatwaves) as a risk factor for mental health-related mortality and morbidity was summarised in Table 4. As recommended elsewhere regarding the strength of evidence sourced from observational studies (Johnson et al., 2014), we began with a baseline of *moderate* for the quality of body of evidence. For the risk of bias domain, since the majority of studies had "low" and "probably low" risk of bias (as mentioned in Section 3.3), and we considered that there was no indication of substantial difference between studies with "low"/ "probably low" versus "high" risk of bias; we did not downgrade the evidence for this factor in each exposure-outcome combination. Regarding associations between high temperatures and mental health-related mortality (MBDs and suicides) and morbidity (MBDs), we downgraded the overall quality of the evidence due to the criteria of inconsistency, given moderate to high heterogeneities were observed in mortality (MBDs, $I^2 = 71.5\%, p = 0.007$; Suicides, $I^2 = 79.9\%, p = 0.000$) and morbidity (MBDs, $I^2 = 78.4\%$, $p = 0.000$) studies, respectively; while we upgraded for dose response categories as most of the studies suggested an exposure response gradient. Statistical analysis was able to be conducted to assess the potential publication bias using evidence in these studies. Funnel plots and Egger's tests suggest potential publication bias for both MBDs mortality and morbidity. The *Trim and Fill* results showed lower but positive pooled effect estimates after adjusted for small study bias (as concluded in Section 3.4.1.4); therefore, we did not downgrade the quality of evidence for potential risk of publication bias.

For studies examining the effects of heatwave exposures, we did not downgrade or upgrade factors for each of the domains to change the initial rating for reasons listed in Table 4. Due to the limited number of heatwaves studies, we were not able to utilize the statistical methods (i.e., funnel plot and Eggers' test) to assess publication bias, and no trimming was performed for these studies. In summary, the resulting rating of the overall quality of evidence across studies of high temperatures and/or heatwaves as a risk factor for mental health-related mortality and morbidity outcomes was *moderate* (based on criteria in Section 2.3.3).

3.6. Strength of the evidence

We summarised the rating of the strength of the overall body of evidence regarding the impacts of high temperatures on MBDs or

Table 3
Relationships between **heatwaves** and mental health-related morbidity and mortality based on different heatwave definitions. Random-effects meta-analysis was conducted when k (number of specific risk estimates) ≥ 2 under the same heatwave definitions.

Duration (days)	Heatwave criteria	Study (ID*)	Relative risks (95%CI)
Heatwave definitions used in the existing literature (Morbidity)			
1	Maximum temperatures ≥ 95th percentile	38	1.01 (0.98–1.04)
1	Maximum temperatures ≥ 99th percentile	37 38	**37:** 1.04 (0.99–1.10) **38:** 1.08 (0.97–1.20) ***Pooled (Random-effect): 1.048 (0.999–1.098); I^2 = 0.0%; p = 0.533***
2	Maximum temperatures ≥ 37 °C for ≥ 2 days	52	0.86 (0.70–1.07)
3	Maximum temperatures ≥ 35 °C for ≥ 3 days	39 40	**39:** 1st: 2.23 (1.44–3.47) 2nd: 2.84 (1.78–4.53) 3rd: 3.18 (2.00–5.06) 4th: 2.99 (2.16–4.14) Pooled (fixed-effect): 2.81 (2.29–3.45) **40:** 1.07 (1.02–1.13) ***Pooled (Random-effect): 1.727 (0.672–4.437); I^2 = 98.7%; p < 0.001***
3	Maximum temperatures ≥ 99th percentile for ≥ 3 days	37	1.07 (1.00–1.15)
1	Mean temperatures ≥ 95th percentile	51	1.02 (1.00–1.03)
1	Mean temperatures ≥ 95th percentile	51	1.01 (0.98–0.92)
2	Mean temperatures ≥ 95th percentile for ≥ 2 days	6	**6:** 0.98 (0.92–1.04)
3	Mean temperatures ≥ 90th percentile for ≥ 3 days	35 36	**35:** 1.15 (1.01–1.31) **36:** 3.85 (1.04–14.23) ***Pooled (Random-effect): 1.753 (0.567–5.421); I^2 = 69.2%; p = 0.072***
3	Mean temperatures ≥ 95th percentile for ≥ 3 days	41 35	**41:** 1.06 (1.00–1.12) **35:** 1.13 (0.92–1.38) ***Pooled (Random-effect): 1.064 (1.006–1.123); 0.0%; p = 0.564***
3	Mean temperatures ≥ 99th percentile for ≥ 3 days	35	0.84 (0.53–1.35)
Heatwave definitions used in the existing literature (Mortality)			
1	Minimum temperatures ≥ 17.4 °C of the warm season	20	<65 years of age: 1.05 (0.90–1.23) ≥65 years of age: 1.10 (1.03–1.18) Pooled (fixed-effect): 1.09 (1.03–1.16)
1	Maximum temperatures ≥ 95th percentile	38	1.10 (0.95–1.27)
1	Maximum temperatures ≥ 99th percentile	38	0.88 (0.64–1.20)
2	Maximum temperatures ≥ 37 °C for ≥ 2 days	52	0.82 (0.22–3.06)
3	Maximum temperatures ≥ 35 °C for ≥ 3 days	40	2.08 (1.05–4.14)
2	Maximum apparent temperature ≥ 95th percentile for ≥ 2 days	53	Rome: ≥50 years of age: 1.21 (1.06–1.38) 50–74 years of age: 1.17 (0.90–1.52) ≥75 years of age: 1.23 (1.05–1.42) Stockholm: ≥50 years of age: 1.33 (1.10–1.61) 50–74 years of age: 1.25 (0.99–1.58) ≥75 years of age: 1.52 (1.06–2.16) Pooled (fixed-effect): ≥50 years of age: 1.25 (1.12–1.39) 50–74 years of age: 1.21 (1.02–1.45) ≥75 years of age: 1.27 (1.11–1.46)

* Refer to Table 1 for details.

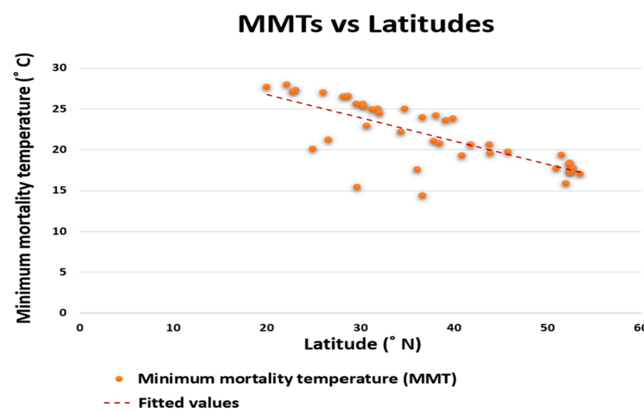

Fig. 4. Mental health-related minimum mortality temperature (MMT) against latitude*. * Values derived from studies using mental health-related MMT as threshold reference. All studies were conducted in the northern hemisphere.

suicides mortality, and MBDs morbidity, as well as the effects of heatwave exposures on mental health-related mortality and morbidity. The following considerations were made for the strength of the evidence. The quality of the body of evidence was moderate for studies on each exposure-outcome combination as concluded above (Section 3.5). The direction of effect estimates indicated that the risk of mental health-related mortality and morbidity increased with higher temperatures, and with more intense or frequent heatwave episodes. In addition, for high temperatures studies, sensitivity analysis showed subtle changes in the pooled effect estimates among overall mortality and morbidity, and in subcategories separated by MBDs and suicides; thus, we considered that future studies are less likely to have effect estimates that would shift the effects to null. However, for heatwaves studies, the interpretation of and comparison of effect estimates between studies can be hampered by differences in heatwave definitions and contexts, and more studies are needed to conduct sensitivity analyses. Other compelling attributes of the data that may influence certainty including heat event characteristics (differences in definitions of threshold temperatures and heatwaves), population vulnerability, and heat response may make the interpretation less certain.

We concluded that there was sufficient strength in the body evidence for studies on high temperatures included in this review, and limited strength in the body evidence for studies on heatwave exposures as risk factors for adverse mental health outcomes. The descriptions associated with this analysis, together with explanations of the rationale behind the judgements made can be seen in Table 5.

4. Discussion

4.1. Key findings

To the best of our knowledge, this is the first systematic literature

Table 4
Quality of evidence in studies investigating the association between heat exposure (i.e. high temperatures, and heatwaves) and mental health-related outcomes (mortality and morbidity), for each exposure-outcome pair.

Exposure-Outcome	Risk of bias across studies	Indirectness	Inconsistency	Imprecision	Publication bias	Large magnitude of effect	Dose-response	Confounding minimises effect	Overall quality of evidence
Initial rating: Moderate	Downgrade considerations					Upgrade considerations			
High temperature									
Mortality									
-MBDs	(0) We have found majority of the studies (5/6) have low or probably low risk of bias, with one study rated as high risk of bias in overall domain. We judged there is no substantial risk of bias across most studies.	(0) Mental health-related deaths were identified under standard definitions in most studies, with direct measures of exposure.	(−1) Moderate heterogeneity was found across the studies $I^2 = 71.5\%$, with the heterogeneity ranged from low to high in the subgroup analysis.	(0) Most studies are representative of appropriate proportion of population of interest across different years of time. We judged the 95% CIs of the meta-analysis are sufficiently narrow.	(0) Although funnel pots and egger's tests suggest potential publication bias, the pooled RR adjusted for small study bias using the *Trim and Fill* method showed little change in effect estimate (RR, 1.02; 95% CI: 1.00–1.03). Therefore, we did not downgrade the quality of evidence for potential risk of publication bias.	(0) We did not consider the estimated effects large, as overall effect magnitude (pooled RR) was below 2.	(+1) Most of the studies showed evidence of a dose-response relationship, with statistically significant increase risk of MBDs mortality with the rise in high temperatures within certain range.	(0) Time series study control the potential confounders by statistical modelling, while case-crossover by study design. We identified and acknowledged that some studies might have residual confounding because they did not adjust for all important well studied confounders. However, we did not expect that omission of any of these confounders would have led to underestimating our pooled estimate.	***Moderate*** Downgrading/upgrading kept the overall quality of body of evidence to moderate.
-Suicides	(0) Half of the studies (6/12) have low or probably low risk of bias, with no study rated as high risk of bias in overall domain. We judged there is no substantial risk of bias across most studies.	(0) Mental health-related deaths were identified under standard definitions in most studies, with direct measures of exposure.	(−1) High heterogeneity was found across the studies $I^2 = 79.9\%$.	(0) Most studies are representative of appropriate proportion of population of interest across different years of time. We judged the 95% CIs of the meta-analysis are sufficiently narrow.	(0) Funnel plot and egger's test ($p = 0.9743$) suggest no potential publication bias.	(0) We did not consider the estimated effects large, as overall effect magnitude (pooled RR) was below 2.	(+1) Most of the studies showed evidence of a dose-response relationship, with statistically significant increase risk of suicides with the rise in high temperatures within certain range.	(0) Time series study control the potential confounders by statistical modelling, while case-crossover by study design. We identified and acknowledged that some studies might have residual confounding because they did not adjust for all important well studied confounders. However, we did not expect that omission of any of these confounders would have led to underestimating our pooled estimate.	***Moderate*** Downgrading/upgrading kept the overall quality of body of evidence to moderate.
Morbidity									
-MBDs	(0) We have found majority of the studies (18/21) have	(0) Mental health-related diseases were identified	(−1) High heterogeneity was found across the studies	(0) Most studies are representative of appropriate proportion of	(0) Although funnel pots and egger's tests suggest potential	(0) We did not consider the estimated effects large, as overall	(+1) Most of the studies showed evidence of a dose-response	(0) We identified and acknowledged that some studies might have residual	***Moderate*** Downgrading/upgrading kept the overall quality of body of

(*continued on next page*)

Table 4 (*continued*)

Exposure-Outcome	**Risk of bias across studies**	**Indirectness**	**Inconsistency**	**Imprecision**	**Publication bias**	**Large magnitude of effect**	**Dose-response**	**Confounding minimises effect**	**Overall quality of evidence**
Initial rating: Moderate	Downgrade considerations					Upgrade considerations			
	low or probably low risk of bias, with no study rated as high risk of bias in overall domain. We judged there is no substantial risk of bias across most studies.	under standard definitions in most studies, with direct measures of exposure.	$I^2 = 78.4\%$, with the heterogeneity ranged from low to high in the subgroup analysis.	population of interest across different years of time. We judged the 95% CIs of the meta-analysis are sufficiently narrow.	publication bias, the pooled RR adjusted for small study bias using the *Trim and Fill* method showed little change in effect estimates (RR, 1.006; 95%CI: 1.004–1.008). Therefore, we did not downgrade the quality of evidence for potential risk of publication bias.	effect magnitude (pooled RR) was below 2.	relationship, with statistically significant increase risk of MBDs morbidity with the rise in high temperatures within certain range.	confounding because they did not adjust for all important well studied confounders. However, we did not expect that omission of any of these confounders would have led to underestimating our pooled estimate.	evidence to moderate.
Heatwave									
Mortality (n = 5)									
	(0) We have found "probably high risk of bias" rather than high risk of bias in 60% of studies in overall domain; therefore, we have not downgraded the rating based on risk of bias assessment.	(0) Mental health-related deaths were identified under standard definitions in most studies, with direct measures of exposure.	(0) Effect estimates varied under different heatwave definitions, with I^2 ranged from low to high heterogeneity where meta-analysis was warranted. However, variations likely because of differing contexts.	(0) Most studies are representative of appropriate proportion of population of interest across different time. Wide confidence interval was found in some studies and results of meta-analysis, but based on comparison between few settings.	(0) Number of studies included in the systematic review and meta-analysis were insufficient for a statistical evaluation of potential publication bias.	(0) Effect magnitude over 2 times increase in the outcome prevalence was shown in one study (ID 40). However, evidence was not sufficient enough to upgrade the quality of evidence for large magnitude of effect.	(0) Dose-response relationship is difficult to compare across studies due to differences in contexts and heatwave definitions.	(0) We identified and acknowledged that some studies might have residual confounding because they did not adjust for all important well studied confounders. However, we found no evidence to suggest that possible residual confounders would shift the effect to null.	***Moderate*** There were no upgraded or downgraded to change quality from the initial rating.
Morbidity (n = 10)									
	(0) Only one study was rated "probably high risk of bias" in overall domain. We judged there is no substantial risk of bias across most studies	(0) Mental health-related diseases were identified under standard definitions in most studies, with direct measures of exposure.	(0) Effect estimates varied under different heatwave definitions, study settings and sub-populations.	(0) Most studies are representative of appropriate proportion of population of interest across different time. Wide confidence interval was found in some studies, but based on comparison between few settings.	(0) Number of studies included in the review were insufficient for an evaluation of potential publication bias.	(0) Effect magnitude over 2 times increase in the outcome prevalence was shown in two study (ID 36 and 39). However, evidence was not sufficient enough to upgrade the quality of evidence for large magnitude of effect.	(0 Dose-response relationship is difficult to compare across studies due to differences in contexts and heatwave definitions.	(0) We identified and acknowledged that some studies might have residual confounding because they did not adjust for all important well studied confounders. However, we found no evidence to suggest that possible residual confounders would shift the effect to null.	***Moderate*** There were no upgraded or downgraded to change quality from the initial rating.

*MBDs, Mental and behavioural disorders.

review to investigate the effect of high ambient temperatures and heatwaves on mental health-related mortality and morbidity incorporating a meta-analysis to quantify the effect sizes. The findings from the 53 studies (comprising over 1.7 million mental health-related mortality and 1.9 million morbidity cases) published between January 1990 and November 2020, showed evidence of a positive association between elevated ambient temperatures (and heatwaves) and adverse mental health outcomes. The meta-analysis found that for every 1 °C increase in temperature there is an associated 2.2% (RR = 1.022, 95%CI: 1.015–1.029) increase in mental health-related mortality and 0.9% (RR = 1.009, 95%CI: 1.007–1.015) increase in morbidity. High ambient temperature is associated with an increase in the risk across most cause-specific mental health related morbidity outcomes and some mortality outcomes. Regarding heatwave exposure, most studies reported a significant increase in mental health-related mortality and morbidity during heatwave days despite differences in heatwave definitions. However, "low" to "high" heterogeneity among the heatwave studies was detected during the meta-analysis. A significant increase in risk was observed in mental-health related morbidity in studies where heatwaves were defined as ≥3 days with a mean temperature ≥95th percentile for the study location.

A previous systematic review of mental health impacts associated with high ambient temperatures and heatwaves by Thompson et al. (2018), commented on quality and variation of prior studies on this topic, as well as the importance of incorporating temperature thresholds (i.e., the point at which the risk of mental health outcome of interest increased) into hot weather-warning systems for public health action (Basu et al., 2017). Our study offers an updated search of the literature to fill emerging gaps in knowledge about the quantitative estimates of the association between temperature and mental health-related mortality and morbidity via meta-analysis. Our review also provides a comprehensive systematic assessment of the risk of bias in individual studies, as well as a summary of the quality, strength, and certainty of the evidence across studies. Additionally, we identified a relationship between latitude and temperature thresholds for mental health-related mortality, with lower minimum mortality temperatures observed in higher latitudes, suggesting possible physiological adaptation in high temperature regions (Yin et al., 2019).

We found significantly moderate and high between-study heterogeneity in the pooled results for overall mental health-related mortality ($I^2 = 73.3\%$, $p = 0.000$) and morbidity ($I^2 = 87.1\%$, $p = 0.000$) (Table 2). Although I^2 over 75% indicates considerable heterogeneity, this reference point is considered more suited to study designs of experimental epidemiology rather than observational studies in population health (Åström et al., 2011). Furthermore, previous meta-analyses of temperature-health relationships have generally reported moderate to high between-study heterogeneity (Gao et al., 2019; Moghadamnia et al., 2017; Bunker et al., 2016).

4.2. Subgroup analyses

In the subgroup analysis of disease categories, the highest RR of statistically significant was found for organic mental disorders and mood disorders for mental health-related mortality and morbidity, respectively. In terms of organic mental syndrome (i.e., conditions related to gradual decrease in the functioning of the brain), heat exposure can cause an increase in central body and brain temperature, which can link to changes in the brain's processing capacity or sensation of environmental factors (Mullins and White, 2019). Demented patients and/or elderly with diminished cognitive function, coping ability, and lower stress threshold, may have greater difficulties in managing stressful environmental situations, which in turn can exacerbate mental health conditions, and hence increase risk of premature mortality (Cornali et al., 2004). Some studies have also reported the influence of changes in the environment and temperatures on emotional state, and regulation of emotion and behaviours (Mullins and White, 2019; Hansen et al., 2008). A meta-analysis of observational studies has shown that a pre-existing psychiatric illness tripled the mortality risk when compared to other pre-existing conditions during heatwaves (Bouchama et al., 2007). A similar notion may be applicable for the increased risk in other mental conditions such as psychological disorders including schizophrenia. Failure to gain relief from the heat may also exacerbate mental stress and depression; and may trigger risk behaviours such as alcohol and/or substance consumption, intentional self-harm including suicides (Page et al., 2007).

Indeed, previous literature has provided convincing evidence in terms of the high temperature effects on suicide (Gao et al., 2019). Studies generally suggested an elevated risk of suicide in men compared with women perhaps because of greater exposure to high temperatures (i.e., outdoor workers) (Thompson et al., 2018; Gao et al., 2019). However, given mixed results have been observed in studies describing risk by sex (the RRs was higher in males in four of the eight cities in Australia (Study ID 42) (Qi et al., 2015), and 12 of the 31 cities in China (Study ID 2) (Luan et al., 2019), more studies should be carried out based on the context of local characteristics, such as the difference in education levels between males and females (Mullins and White, 2019; Kim et al., 2011).

Further subgroup analyses for high temperature exposure identified that people aged 65 years and over were more vulnerable to increased temperatures than younger people (aged < 65 years). The strongest significant effect was observed in populations living in the tropical climate zone and the subtropical climate zone for mental health-related mortality and morbidity outcomes, respectively. In addition, an exposure–response gradient was observed in the mortality outcomes by countries of different national income level, with the lower the national income level having a higher pooled risk estimate per 1 °C increase in temperature. The possible reason is those who live in poor countries often lack access to cooling equipment (i.e., air conditioning) to reduce heat stress. However, there was significant between-study heterogeneity in high income group studies and few studies from low- and middle-income countries, further research is required to better understand how the health risks vary for such groups.

4.3. Potential biological mechanisms

The negative impacts of heat exposure on mental health are evident from our findings, however the underlying physiological mechanisms are complex. The plausible etiological pathways may be explained in part by the pathophysiological effects on the neurological system. High temperature has been reported to affect the levels and balance of the neuro-transmitters serotonin and dopamine in the brain that have roles in mood, cognitive function, and complex task performance (Mullins and White, 2019; Taylor et al., 2016; Pilcher et al., 2002; Sarrias et al., 1989). Also, when high temperatures are sustained for several days or weeks, individuals' physiological and behavioural adaptation strategies can be challenged (Ye et al., 2012; Taylor et al., 2016), and irritability and psychological distress (including risky behaviours such as substance abuse and alcohol consumption), aggression, violence, and suicides are more common (Basu et al., 2017; Page et al., 2007). Evidence from human experimental studies have shown that high temperature exposure has a profound adverse impact on cognitive function, mood state, and mental performance (Cian et al., 2001; McMorris et al., 2006; Hämäläinen et al., 2012), which may explain reported increases in hospitalizations for dementia during heatwaves (Linares et al., 2017; Hansen et al., 2008).

In addition, neuro-inflammation which can occur because of heat stress, may play a role in mental disorders such as depression, psychosis and cognitive impairment (including poor retention in memory tasks) (Liu et al., 2012; Barron et al., 2017; Yirmiya and Goshen, 2011). In animal studies, Lee et al. (2015) reported significant neuro-inflammatory responses and neuronal cell death in the hippocampus in the brain because of heat exposure (Lee et al., 2015). Similarly, neuro-

Table 5
Summary of findings and strength of evidence in studies investigating the association between heat exposure (i.e. high temperatures, and heatwaves) and mental health-related outcomes (mortality and morbidity), for each exposure-outcome pair.

Exposure-Outcome ***Quality of evidence: Moderate***	**Direction of effect estimate**	**Confidence in effect estimate**	**Other compelling aspects**	**Overall strength of evidence**
High temperature				
Mortality				
-MBDs	MBDs-related deaths increased with increasing exposure to high temperatures.	No substantial changes were observed in sensitivity analysis; thus, an effect estimate from a new study is less likely to shift the pooled effect estimate to null.	Variation in threshold temperatures, contextual factors, including population vulnerability, and exposure level, any intervention or preventative response vary across studies may make interpretation less certain, as well as the residual confounding factors.	***Sufficient*** We found that there is a positive association between high temperatures, and MBDs related mortality. The available evidence includes results from large proportion of studies in well-designed and well-conducted; therefore, we believe that our conclusion is less likely to be strongly affected by the results of future studies.
-Suicides	Mortality due to suicides increased with increasing exposure to high temperatures.	No substantial changes were observed in sensitivity analysis; thus, an effect estimate from a new study is less likely to shift the pooled effect estimate to null.	Variation in threshold temperatures, contextual factors, including population vulnerability, and exposure level, any intervention or preventative response vary across studies may make interpretation less certain, as well as the residual confounding factors.	***Sufficient*** We found that there is a positive association between high temperatures, and mortality due to suicides. The available evidence includes results from one or more studies of well-designed and well-conducted; therefore, we believe that our conclusion is less likely to be strongly affected by the results of future studies.
Morbidity				
-MBDs	MBDs-related mortality increased with increasing exposure to high temperatures.	No substantial changes were observed in sensitivity analysis; thus, an effect estimate from a new study is less likely to shift the pooled effect estimate to null.	Variation in threshold temperatures, contextual factors, including population vulnerability, and exposure level, any intervention or preventative response vary across studies may make interpretation less certain, as well as the residual confounding factors.	***Sufficient*** We found that there is a positive association between high temperatures, and mortality due to MBDs. The available evidence includes results from large proportion of studies in well-designed and well-conducted; therefore, we believe that our conclusion is less likely to be strongly affected by the results of future studies.
Heatwave				
Mortality	Mental health-related mortality increased with increasing during heatwave.	Effect estimate relate to varying contexts, intensity and duration of heatwave. New studies might show different estimates with different heatwave definitions.	Heat event characteristics (heatwave definitions), contextual factors, including population vulnerability, and exposure level, any intervention or preventative response vary across studies may make interpretation less certain, as well as the residual confounding factors.	***Limited*** Based on our analysis and interpretation of the evidence, we concluded that increased risk of mental health-related mortality during heatwave exposure is likely. However, evidence is limited because of the insufficient number of studies to facilitate comparison across studies in different heatwave definitions.
Morbidity	Mental health-related morbidity increased with increasing during heatwave.	Effect estimate relate to varying contexts, intensity and duration of heatwave. New studies might show different estimates with different heatwave definitions.	Heat event characteristics (heatwave definitions), contextual factors, including population vulnerability, and exposure level, any intervention or preventative response vary across studies may make interpretation less certain, as well as the residual confounding factors.	***Limited*** Based on our analysis and interpretation of the evidence, we concluded that increased risk of mental health-related morbidity during heatwave exposure is likely. However, evidence is limited because of the insufficient number of studies to facilitate comparison across studies in different heatwave definitions.

*MBDs, Mental and behavioural disorders.

inflammation has also been shown to occur in the hypothalamus region of the brain (which is involved in, among other things, body temperature regulation) in heat-exposed rats (Chauhan et al., 2017). Studies have suggested that a single episode of hyperthermia can lead to short-term neurological dysfunction which in some cases may have prolonged effects in attention, memory, or personality (Walter and Carraretto, 2016). These inherent changes in the brain may reduce people's cognitive awareness of the environment, and their ability to undertake adaptive behaviours (i.e., appropriate wearing of clothing and fluid intake), which in turn contributes to their increased vulnerability to heat stress. Hence, those with mental illness or neurological diseases such as Alzheimer's disease (although not included in this review) may be susceptible to the effects of high temperatures (Lee et al., 2018; Hansen et al., 2008).

From the perspectives of heat induced sleep disruptions, evidence suggests that sleeping problems are associated with nearly all mental illness or psychiatric disorders (i.e., dementia, affective disorders, addictions, schizophrenia etc.) (Lõhmus, 2018). Several studies have reported that high night temperatures can be associated with sleep disturbances and sleep deprivation, particularly among the elderly (Okamoto-Mizuno and Mizuno, 2012; Buguet, 2007). In addition, sleep loss has also been associated with increased irritability, frustration, and negative emotions (Scott et al., 2017). This may explain the exacerbation of the mental health-related conditions during heatwaves, with consecutive hot day- and night-time temperatures. Overall, there is evidence for the bio-plausibility of the temperature-mental health relationship that can aid in the understanding and interpretation of the study findings.

4.4. Strengths and limitations

A key strength of this review is that it is the first systematic review of the literature investigating the association between increases in temperature, (and heatwaves), and mental health-related mortality and morbidity, that also includes a meta-analysis to quantify the association. We also assessed some possible sources of heterogeneity, and identified vulnerable subgroups, which may be useful for health authorities and relevant stakeholders in informing effective prevention measures. We adhered to an *a priori* protocol (PRISMA and PROSPERO) and framework (the Navigation Guide) to ensure the quality and robustness of this review. The sources of evidence were reliable according to our assessment of underlying risk of bias, as the mental health data used in the studies were from the official health departments or the national jurisdictional statistics departments. For the meta-analysis, we restricted studies to those using daily data (Thompson et al., 2018; Gao et al., 2019), and calculated RRs associated with a one-degree increase above the reference temperature points used, which allowed comparison and reduced heterogeneity between studies (Luo et al., 2019). Furthermore, sensitivity analysis indicated little changes to the pooled RRs reported in this review, adding to the reliability of the results.

Nevertheless, some limitations must be noted. First, grey literature and publications in languages other than English were not included, although our summary results would not be substantially affected as mentioned above. Second, the higher pooled RR found in middle-income countries need to be interpreted carefully given the limited number of studies in such countries. A call has been made by the Lancet series to close gaps in the low- and middle-income countries for mental health-related research and programmes given the higher burden of mental-health conditions (World Health Organization, 2001; Barbui et al., 2017). Additionally, the studies reviewed may not be an indication of the true prevalence of clinically significant mental disorders which may be underestimated worldwide due to the constraints of current diagnostic criteria (Kessler et al., 2009), and the under-investigated complex aetiology of mental health problems (Page and Howard, 2010; Vigo et al., 2016). Third, although there were consistent sources of temperature exposure across studies, concerns should not be ruled out that some exposure estimates were assigned from adjacent weather stations or interpolated with geographic information techniques leading to the underestimate of spatial differences in temperature. Hence, the exposure measurements cannot be used to accurately gauge the temperature exposure at an individual level and the link to high indoor temperatures (Thompson et al., 2018). Finally, while the scope of this review was to investigate the relationship between hot weather and mental health outcomes, it should be acknowledged that other unaccounted for environmental exposures correlated with high temperatures (such as solar radiation and high ozone concentrations) may adversely affect mental health (Thompson et al., 2018; Qi et al., 2015; Bernardini et al., 2019). Therefore, we could not exclude other potential unlisted confounding factors that might be associated with both high temperatures and mental health outcomes.

4.5. Implications for future research

Although previous studies have assessed the impacts of heatwaves on population health (Gasparrini and Armstrong, 2011; Campbell et al., 2018), knowledge gaps still exist in relation to effects of heatwave on mental health. Future research needs to be conducted as heatwave definitions can vary in terms of temperature thresholds, the use of different temperature metrics, and the duration of heatwaves. The exposure–response relationship between temperature and the risk of mental health-related outcomes, could also be researched further in different geographical regions and latitudes, with threshold temperatures detected so tailored interventions could be developed (Luo et al., 2019).

In addition, although most studies controlled for relevant confounders, more covariates could be considered in the future. Future studies may wish to incorporate factors that may be an effect modifier in the relationship assessment, these could include but not be limited to solar radiation, precipitation, greenspace, and air pollution. There should also be consideration of the regional contextual and socio-demographic characters (ethnicity, religion, socioeconomic status, and pre-existing health conditions) (Misra et al., 2019; Cianconi et al., 2020).

5. Conclusions

The findings of this systematic review and meta-analysis showed evidence of a positive association between elevated ambient temperatures and heatwaves, and adverse mental health outcomes. The association between high temperature and mental health-related mortality and morbidity were proved to be stable through a number of sensitivity analyses, which enhance the validity of the conclusions presented here. Although the needed fundamental evidence on vulnerable subgroups remains incomplete, this study observed that populations living in tropical and subtropical climate zones, and people aged 65 and over may be particularly vulnerable to temperature increase. It is therefore important to design relevant public health actions. In the context of global warming, it would be useful for local health authorities and service providers to incorporate mental health impacts into their heatwave warning systems, and to have public health policies and guidelines addressing preventable heat-related mental health mortality and morbidity (Kay et al., 2000).

Funding

J.L is supported by the Adelaide University China Fee Scholarships (China Scholarship Council), and this project is part of an Australian Research Council Discovery Program (DP200102571).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2021.106533.

References

Almendra, R., Loureiro, A., Silva, G., et al., 2019. Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon. Sci. Total Environ. 647, 127–133.

Åström, D.O., Bertil, F., Joacim, R., 2011. Heat wave impact on morbidity and mortality in the elderly population: a review of recent studies. Maturitas 69, 99–105.

Åström, D.O., Schifano, P., Asta, F., et al., 2015. The effect of heat waves on mortality in susceptible groups: a cohort study of a mediterranean and a northern European City. Environ. Health. 14, 30.

Bando, D.H., Teng, C.T., Volpe, F.M., et al., 2017. Suicide and meteorological factors in Sao Paulo, Brazil, 1996–2011: a time series analysis. Braz. J. Psychiatry. 39, 220–227.

Barbui, C., Purgato, M., Churchill, R., et al., 2017. Cochrane for global mental health. Lancet Psychiatry. 4, e6.

Barnett, A.G., Tong, S., Clements, A.C., 2010. What measure of temperature is the best predictor of mortality? Environ. Res. 110 (6), 604–611.

Barron, H., Hafizi, S., Andreazza, A.C., et al., 2017. Neuroinflammation and oxidative stress in psychosis and psychosis risk. Int. J. Mol. Sci. 18, 651.

Basu, R., Gavin, L., Pearson, D., et al., 2017. Examining the association between apparent temperature and mental health-related emergency room visits in California. Am. J. Epidemiol. 187, 726–735.

Bernardini, F., Attademo, L., Trezzi, R., 2019. Air pollutants and daily number of admissions to psychiatric emergency services: evidence for detrimental mental health effects of ozone. Epidemiol. Psychiatr. Sci. 29, e66.

Berry, H.L., Bowen, K., Kjellstrom, T., 2010. Climate change and mental health: a causal pathways framework. Int. J. Public Health. 55, 123–132.

Bhaskaran, K., Gasparrini, A., Hajat, S., et al., 2013. Time series regression studies in environmental epidemiology. Int. J. Epidemiol. 42 (4), 1187–1195.

Bouchama, A., Dehbi, M., Mohamed, G., et al., 2007. Prognostic factors in heat wave related deaths: a meta-analysis. Arch. Intern. Med. 167, 2170–2176.

Braithwaite, I., Zhang, S., Kirkbride, J.B., et al., 2019. Air pollution (particulate matter) exposure and associations with depression, anxiety, bipolar, psychosis and suicide risk: a systematic review and meta-analysis. Environ. Health Perspect. 127, 126002.

Buguet, A., 2007. Sleep under extreme environments: effects of heat and cold exposure, altitude, hyperbaric pressure and microgravity in space. J. Neurol. Sci. 262, 145–152.

Bunker, A., Wildenhain, J., Vandenbergh, A., et al., 2016. Effects of air temperature on climate-sensitive mortality and morbidity outcomes in the elderly; a systematic review and meta-analysis of epidemiological evidence. EBioMedicine. 6, 258–268.

Burke, M., González, F., Baylis, P., et al., 2018. Higher temperatures increase suicide rates in the United States and Mexico. Nat. Clim. Change 8, 723–729.

Campbell, S., Remenyi, T.A., White, C.J., et al., 2018. Heatwave and health impact research: a global review. Health Place. 53, 210–218.

Carlsen, H.K., Oudin, A., Steingrimsson, S., et al., 2019. Ambient temperature and associations with daily visits to a psychiatric emergency unit in Sweden. Int. Environ. Res. Public Health. 16, 286.

Chan, E.Y., Lam, H.C., So, S.H., et al., 2018. Association between ambient temperatures and mental disorder hospitalizations in a subtropical city: a time-series study of Hong Kong special administrative region. Int. J. Environ. Res. 15, 754.

Chauhan, N.R., Kapoor, M., Singh, L.P., et al., 2017. Heat stress-induced neuro-inflammation and aberration in monoamine levels in hypothalamus are associated with temperature dysregulation. Neuroscience 358, 79–92.

Cian, C., Barraud, P.A., Melin, B., et al., 2001. Effects of fluid ingestion on cognitive function after heat stress or exercise-induced dehydration. Int. J. Psychophysiol. 42, 243–251.

Cianconi, P., Betrò, S., Janiri, L., 2020. The impact of climate change on mental health: a systematic descriptive review. Front. Psychiatry 11.

Clarivate Analytics, 20EndNote X8 .2 (Bld 13302). Web of Science Group. http://download.endnote.com/updates/18.0/EndNoteX82UpdateInstaller.zip.

Cornali, C., Franzoni, S., Riello, R., et al., 2004. Effect of high climate temperature on the behavioral and psychological symptoms of dementia. J. Am. Med. Dir. Assoc. 5, 161–166.

da Silva, I., de Almeida, D.S., Hashimoto, E.M., Martins, L.D., 2020. Risk assessment of temperature and air pollutants on hospitalizations for mental and behavioral disorders in Curitiba, Brazil. Environ. Health. 19 (1), 79.

DerSimonian, R., Laird, N., 1986. Meta-analysis in clinical trials. Control. Clin. Trials 7, 177–188.

Ding, N., Berry, H.L., Bennett, C.M., 2016. The importance of humidity in the relationship between heat and population mental health: evidence from Australia. PLoS ONE 11, e0164190.

Duval, S., Tweedie, R., 2000. Trim and fill: a simple funnel-plot–based method of testing and adjusting for publication bias in meta-analysis. Biometrics 56, 455–463.

Duval, S., Tweedie, R., 2000. A nonparametric "trim and fill" method of accounting for publication bias in meta-analysis. J. Am. Stat. Assoc. 95, 89–98.

Egger, M., Smith, G.D., Schneider, M., et al., 1997. Bias in meta-analysis detected by a simple, graphical test. BMJ 315, 629–634.

Fernández-Niño, J.A., Flórez-García, V.A., Astudillo-García, C.I., et al., 2018. Weather and suicide: a decade analysis in the five largest capital cities of Colombia. Int. J. Environ. Res. Public Health 15, 1313.

Gao, J., Cheng, Q., Duan, J., et al., 2019. Ambient temperature, sunlight duration, and suicide: a systematic review and meta-analysis. Sci. Total Environ. 646, 1021–1029.

Gasparrini, A., Armstrong, B., 2011. The impact of heat waves on mortality. Epidemiology. 22, 68–73.

Gasparrini, A., Armstrong, B., Kovats, S., et al., 2012. The effect of high temperatures on cause-specific mortality in England and Wales. J. Occup. Environ. Med. 69, 56–61.

Grjibovski, A.M., Kozhakhmetova, G., Kosbayeva, A., et al., 2013. Associations between air temperature and daily suicide counts in Astana, Kazakhstan. Medicina. 49, 59.

Hämäläinen, P., Ikonen, A., Romberg, A., et al., 2012. The effects of heat stress on cognition in persons with multiple sclerosis. Mult. Scler. J. 18, 489–497.

Hansen, A., Bi, P., Nitschke, M., et al., 2008. The effect of heat waves on mental health in a temperate Australian city. Environ. Health Perspect. 116, 1369–1375.

Hedges, L.V., Tipton, E., Johnson, M.C., 2010. Robust variance estimation in meta-regression with dependent effect size estimates. Res. Synth. Methods. 1, 39–65.

Higgins, J.P., Green, S., 2011. Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0. (Eds.), London, Cochrane.

Higgins, J.P., Thompson, S.G., Deeks, J.J., et al., 2003. Measuring inconsistency in meta-analyses. BMJ 327, 557–560.

HM Government, 2018. A green future: our 25 year plan to improve the environment. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf (accessed 16 August 2020).

Ho, H.C., Wong, M.S., 2019. Urban environmental influences on the temperature–mortality relationship associated mental disorders and cardiorespiratory diseases during normal summer days in a subtropical city. Environ. Sci. Pollut. Res. 26, 24272–24285.

Hu, J., Wen, Y., Duan, Y., et al., 2020. The impact of extreme heat and heat waves on emergency ambulance dispatches due to external cause in Shenzhen, China. Environ. Pollut. 261, 114156.

James, S.L., Abate, D., Abate, K.H., et al., 2018. Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet 392, 1789–1858.

Johnson, P.I., Sutton, P., Atchley, D.S., et al., 2014. The navigation guide evidence-based medicine meets environmental health: systematic review of human evidence for PFOA effects on fetal growth. Environ. Health Perspect. 122, 1028–1039.

Kay, D., Prüss, A., Corvalan, C., 2000. Methodology for Assessment of Environmental Burden of Disease: Report on the ISEE Session on Environmental Burden of Disease. https://www.who.int/quantifying_ehimpacts/publications/methodoly/en/ (accessed 17 August 2020).

Kessler, R.C., Aguilar-Gaxiola, S., Alonso, J., et al., 2009. The global burden of mental disorders: an update from the WHO World Mental Health (WMH) surveys. Epidemiol. Psichiatr. Soc. 18, 23.

Khalaj, B., Lloyd, G., Sheppeard, V., et al., 2010. The health impacts of heat waves in five regions of New South Wales, Australia: a case-only analysis. Int. Arch. Occup. Environ. Health 83, 833–842.

Kim, Y., Kim, H., Kim, D.S., 2011. Association between daily environmental temperature and suicide mortality in Korea (2001–2005). Psychiatry Res. 186, 390–396.

Kim, Y., Kim, H., Honda, Y., et al., 2016. Suicide and ambient temperature in East Asian countries: a time-stratified case-crossover analysis. Environ. Health Perspect. 124, 75–80.

Kim, Y., Kim, H., Gasparrini, A., et al., 2019. Suicide and ambient temperature: a multi-country multi-city study. Environ. Health Perspect. 127, 117007.

Kim, C.T., Lim, Y.H., Woodward, A., et al., 2015. Heat-attributable deaths between 1992 and 2009 in Seoul, South Korea. PLoS One. 10, e0118577.

Lee, S., Lee, H., Myung, W., et al., 2018. Mental disease-related emergency admissions attributable to hot temperatures. Sci. Total Environ. 616, 688–694.

Lee, W., Moon, M., Kim, H.G., et al., 2015. Heat stress-induced memory impairment is associated with neuroinflammation in mice. J. Neuroinflammation. 12, 1–13.

Linares, C., Culqui, D., Carmona, R., et al., 2017. Short-term association between environmental factors and hospital admissions due to dementia in Madrid. Environ. Res. 152, 214–220.

Liu, J., Hansen, A., Varghese, B., et al., 2020. Cause-specific mortality attributable to cold and hot ambient temperatures in Hong Kong: a time-series study, 2006–2016. Sustain. Cities Soc. 102131.

Liu, Y., Ho, R.C.M., Mak, A., 2012. Interleukin (IL)-6, tumour necrosis factor alpha (TNF-α) and soluble interleukin-2 receptors (sIL-2R) are elevated in patients with major depressive disorder: a meta-analysis and meta-regression. J. Affect. Disord. 139, 230–239.

Liu, X., Liu, H., Fan, H., et al., 2019. Influence of heat waves on daily hospital visits for mental illness in Jinan, China - a case-crossover study. Int. J. Environ. Res. Public Health 16, 87.

Lõhmus, M., 2018. Possible biological mechanisms linking mental health and heat—a contemplative review. Int. J. Environ. Res. Public Health 15, 1515.

Lu, Y., Zeger, S.L., 2007. On the equivalence of case-crossover and time series methods in environmental epidemiology. Biostatistics. 8, 337–344.

Luan, G., Yin, P., Wang, L., et al., 2019. Associations between ambient high temperatures and suicide mortality: a multi-city time-series study in China. Environ. Sci. Pollut. Res. 26, 20377–20385.

Luo, Q., Li, S., Guo, Y., et al., 2019. A systematic review and meta-analysis of the association between daily mean temperature and mortality in China. Environ. Res. 173, 281–299.
Ma, W., Chen, R., Kan, H., 2014. Temperature-related mortality in 17 large Chinese cities: how heat and cold affect mortality in China. Environ. Res. 134, 127–133.
Marion, S.A., Agbayewa, M.O., Wiggins, S., et al., 1999. The effect of season and weather on suicide rates in the elderly in British Columbia. Can. J. Public Health 90, 418–422.
Martiello, M.A., Giacchi, M.V., 2010. High temperatures and health outcomes: a review of the literature. Scand J. Public Health. 38, 826–837.
McGuinness, L.A., Higgins, J.P.T., 2020. Risk-of-bias VISualization (robvis): An R package and Shiny web app for visualizing risk-of-bias assessments. Res Syn Meth. 1–7 https://doi.org/10.1002/jrsm.1411.
McMorris, T., Swain, J., Smith, M., et al., 2006. Heat stress, plasma concentrations of adrenaline, noradrenaline, 5-hydroxytryptamine and cortisol, mood state and cognitive performance. Int. J. Psychophysiol. 61, 204–215.
Min, M., Shi, T., Ye, P., et al., 2019. Effect of apparent temperature on daily emergency admissions for mental and behavioral disorders in Yancheng, China: a time-series study. Environ. Health. 18, 98.
Misra, S., Stevenson, A., Haroz, E.E., et al., 2019. 'Global mental health': systematic review of the term and its implicit priorities. BJPsych. Open. 5.
Moghadamnia, M.T., Ardalan, A., Mesdaghinia, A., et al., 2017. Ambient temperature and cardiovascular mortality: a systematic review and meta-analysis. PeerJ 5, e3574.
Moher, D., Liberati, A., Tetzlaff, J., et al., 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 6, e1000097.
Morgan, R.L., Whaley, P., Thayer, K.A., Schünemann, H.J., 2018. Identifying the PECO: a framework for formulating good questions to explore the association of environmental and other exposures with health outcomes. Environ. Int. 121(Pt 1): 1027–1031, PMID: 30166065, https://doi.org/10.1016/j.envint.2018.07.015.
Mourad, O., Hossam, H., Zbys, F., et al., 2016. Rayyan — a web and mobile app for systematic reviews. Syst. Rev. 5, 210. https://doi.org/10.1186/s13643-016-0384-4.
Müller, H., Biermann, T., Renk, S., et al., 2011. Higher environmental temperature and global radiation are correlated with increasing suicidality—a localized data analysis. Chronobiol. Int. 28, 949–957.
Mullins, J.T., White, C., 2019. Temperature and mental health: evidence from the spectrum of mental health outcomes. J. Health Econ. 68, 102240.
Niu, Y., Gao, Y., Yang, J., et al., 2020. Short-term effect of apparent temperature on daily emergency visits for mental and behavioral disorders in Beijing, China: a time-series study. Sci. Total Environ. 733, 139040.
OHAT (Office of Health Assessment and Translation). Division of the National Toxicology Program. National Institute of Environmental Health Sciences, 2015. Handbook for conducting a literature-based health assessment using OHAT approach for systematic review and evidence integration. https://ntp.niehs.nih.gov/ntp/ohat/pubs/handbookmarch2019_508.pdf (accessed 16 August 2020).
Okamoto-Mizuno, K., Mizuno, K., 2012. Effects of thermal environment on sleep and circadian rhythm. J. Physiol. Anthropol. 31, 14.
Page, L.A., Hajat, S., Kovats, R.S., et al., 2012. Temperature-related deaths in people with psychosis, dementia and substance misuse. Br. J. Psychiatry 200, 485–490.
Page, L.A., Howard, L.M., 2010. The impact of climate change on mental health (but will mental health be discussed at Copenhagen?). Psychol. Med. 40, 177–180.
Page, L.A., Hajat, S., Kovats, R.S., 2007. Relationship between daily suicide counts and temperature in England and Wales. Br. J. Psychiatry 191, 106–112.
Pan, R., Zhang, X., Gao, J., et al., 2019. Impacts of heat and cold on hospitalizations for schizophrenia in Hefei, China: an assessment of disease burden. Sci. Total Environ. 694, 133582.
Patz, J.A., Campbell-Lendrum, D., Holloway, T., et al., 2005. Impact of regional climate change on human health. Nature 438, 310–317.
Peel, M.C., Finlayson, B.L., McMahon, T.A., 2007. Updated world map of the Köppen-Geiger climate classification. Hydrol. Earth Syst. Sci. 11, 1633–1644.
Peng, Z., Wang, Q., Kan, H., Chen, R., et al., 2017. Effects of ambient temperature on daily hospital admissions for mental disorders in Shanghai, China: a time-series analysis. Sci. Total Environ. 590, 281–286.
Pilcher, J.J., Nadler, E., Busch, C., 2002. Effects of hot and cold temperature exposure on performance: a meta-analytic review. Ergonomics 45, 682–698.
Qi, X., Hu, W., Mengersen, K., et al., 2014. Socio-environmental drivers and suicide in Australia: Bayesian spatial analysis. BMC Public Health. 14, 1–10.
Qi, X., Hu, W., Page, A., et al., 2015. Associations between climate variability, unemployment and suicide in Australia: a multicity study. BMC Psychiatry. 15, 114.
Rocklöv, J., Forsberg, B., Ebi, K., et al., 2014. Susceptibility to mortality related to temperature and heat and cold wave duration in the population of Stockholm County, Sweden. Glob. Health Action. 7, 22737.
Sarrias, M.J., Artigas, F., Martínez, E., et al., 1989. Seasonal changes of plasma serotonin and related parameters: correlation with environmental measures. Biol. Psychiatry 26, 695–706.
Schneider, A., Hampel, R., Ladwig, K.H., et al., 2020. Impact of meteorological parameters on suicide mortality rates: a case-crossover analysis in Southern Germany (1990–2006). Sci. Total Environ. 707, 136053.
Scott, A.J., Webb, T.L., Rowse, G., 2017. Does improving sleep lead to better mental health? A protocol for a meta-analytic review of randomised controlled trials. BMJ Open. 7, e016873.
Sherbakov, T., Malig, B., Guirguis, K., et al., 2018. Ambient temperature and added heat wave effects on hospitalizations in California from 1999 to 2009. Environ. Res. 160, 83–90.
Sung, T.I., Chen, M.J., Lin, C.Y., et al., 2011. Relationship between mean daily ambient temperature range and hospital admissions for schizophrenia: results from a national cohort of psychiatric inpatients. Sci. Total Environ. 410, 41–46.
Sung, T.I., Chen, M.J., Su, H.J., 2013. A positive relationship between ambient temperature and bipolar disorder identified using a national cohort of psychiatric inpatients. Soc. Psychiatry Psychiatr. Epidemiol. 48, 295–302.
Taylor, L., Watkins, S.L., Marshall, H., et al., 2016. The impact of different environmental conditions on cognitive function: a focused review. Front. Physiol. 6, 372.
Thompson, R., Hornigold, R., Page, L., et al., 2018. Associations between high ambient temperatures and heat waves with mental health outcomes: a systematic review. Public Health. 161, 171–191.
Trang, P.M., Rocklöv, J., Giang, K.B., et al., 2016. Heatwaves and hospital admissions for mental disorders in northern Vietnam. PLoS ONE 11, e0155609.
Trang, P.M., Rocklöv, J., Giang, K.B., et al., 2016. Seasonality of hospital admissions for mental disorders in Hanoi. Vietnam. Glob. Health Action. 9, 32116.
Vaneckova, P., Bambrick, H., 2013. Cause-specific hospital admissions on hot days in Sydney, Australia. PLoS One. 8, e55459.
Vida, S., Durocher, M., Ouarda, T.B., et al., 2012. Relationship between ambient temperature and humidity and visits to mental health emergency departments in Québec. Psychiatr. Serv. 63, 1150–1153.
Vigo, D., Thornicroft, G., Atun, R., 2016. Estimating the true global burden of mental illness. Lancet Psychiatry. 3, 171–178.
Walter, E.J., Carraretto, M., 2016. The neurological and cognitive consequences of hyperthermia. Crit. Care 20, 1–8.
Wang, X.Y., Barnett, A.G., Yu, W., et al., 2012. The impact of heatwaves on mortality and emergency hospital admissions from non-external causes in Brisbane, Australia. J. Occup. Environ. Med. 69, 163–169.
Wang, X., Lavigne, E., Ouellette-kuntz, H., et al., 2014. Acute impacts of extreme temperature exposure on emergency room admissions related to mental and behavior disorders in Toronto, Canada. J. Affect. Disord. 155, 154–161.
Wang, S., Zhang, X., Xie, M., et al., 2018. Effect of increasing temperature on daily hospital admissions for schizophrenia in Hefei, China: a time-series analysis. Public Health. 159, 70–77.
Wei, Y., Wang, Y., Lin, C.K., et al., 2019. Associations between seasonal temperature and dementia-associated hospitalizations in New England. Environ. Int. 126, 228–233.
Williams, S., Nitschke, M., Sullivan, T., et al., 2012. Heat and health in Adelaide, South Australia: assessment of heat thresholds and temperature relationships. Sci. Total Environ. 414, 126–133.
Wilson, L.A., Morgan, G.G., Hanigan, I.C., et al., 2013. The impact of heat on mortality and morbidity in the Greater Metropolitan Sydney Region: a case crossover analysis. Environ. Health. 12, 98.
Woodruff, T.J., Sutton, P., 2014. The Navigation Guide systematic review methodology: a rigorous and transparent method for translating environmental health science into better health outcomes. Environ. Health Perspect. 122, 1007–1014.
World Health Organization, 2001. Mental disorders affect one in four people. NMH Communications. https://www.who.int/whr/2001/media_centre/press_release/en/ (accessed 17 August 2020).
Xu, Z., FitzGerald, G., Guo, Y., et al., 2019. Assessing heatwave impacts on cause-specific emergency department visits in urban and rural communities of Queensland, Australia. Environ. Res. 168, 414–419.
Ye, X., Wolff, R., Yu, W., et al., 2012. Ambient temperature and morbidity: a review of epidemiological evidence. Environ. Health Perspect. 120, 19–28.
Yi, W., Zhang, X., Gao, J., et al., 2019. Examining the association between apparent temperature and admissions for schizophrenia in Hefei, China, 2005–2014: a time-series analysis. Sci. Total Environ. 672, 1–6.
Yin, Q., Wang, J., Ren, Z., et al., 2019. Mapping the increased minimum mortality temperatures in the context of global climate change. Nat. Commun. 10, 1–8.
Yirmiya, R., Goshen, I., 2011. Immune modulation of learning, memory, neural plasticity and neurogenesis. Brain Behav. Immun. 25, 181–213.
Zhang, S., Yang, Y., Xie, X., et al., 2020. The effect of temperature on cause-specific mental disorders in three subtropical cities: a case-crossover study in China. Environ. Int. 143, 105938.
Zhang, S., Li, H., Qian, Z.M., et al., 2020. Short-term effects of air pollution on cause-specific mental disorders in three subtropical Chinese cities. Environ. Res. 191, 110214.